TRANSBUS DOCUMENT TR 76-003

ENERGY ABSORBING BUMPERS FOR TRANSIT BUSES

TRANSBUS PROGRAM

BOOZ ALLEN APPLIED RESEARCH

DEPARTMENT OF TRANSPORTATION
URBAN MASS TRANSPORTATION ADMINISTRATION
WASHINGTON, D.C.

NOTICE

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTA-IT-06-0025-77-4	PB 269-405	

4. Title and Subtitle	5. Report Date
ENERGY ABSORBING BUMPERS FOR TRANSIT BUSES Transbus Program	May 1976
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No. TR 76-003
9. Performing Organization Name and Address Booz, Allen Applied Research 4733 Bethesda Avenue Bethesda, Maryland 20014	10. Work Unit No. (TRAIS) IT-06-0025 11. Contract or Grant No. DOT-UT-10008
12. Sponsoring Agency Name and Address U. S. Department of Transportation Urban Mass Transportation Administration 400 Seventh Street, S. W. Washington, D. C. 20590	13. Type of Report and Period Covered Technical Report Sept. 1973-Nov. 1976 14. Sponsoring Agency Code

15. Supplementary Notes

The findings of this report are based, in part, on detailed controlled tests conducted at the Ultrasystems test facility, Phoenix, Arizona, and at CALSPAN Corporation, Buffalo, New York.

16. Abstract

This report describes the results of a program to test and evaluate the potential benefits of energy absorbing bumpers for transit buses. The objective of the program is to determine, through controlled tests, the capabilities/limitations of six new design energy absorbing bumper systems. Principal emphasis is placed upon the bumper system performance under simulated in-service tests with respect to its effectiveness in protecting the bus from minor accident hazards encountered during revenue service.

The economic benefits of energy absorbing bumpers are discussed with respect to life-cycle accident costs. The test facilities, each type of bumper system tested, and the test procedure is described in detail, in terms of the objectives of the tests, equipment and methodology used for testing, and functional descriptions of each bumper system. The detailed test results for each bumper system are presented in table format, indicating energy absorbing performance at various impact velocities, maximum impact capability, and other attendant characteristics.

Conclusions concerning the results of the tests including projected benefits of energy absorbing bumpers are delineated. Significant factors relating to bumper weight, cost, durability, etc., are summarized. Recommendations for the physical and performance properties of an energy absorbing bumper system for transit are also stated. Product improvements of bumper systems are discussed.

17. Key Words	18. Distribution Statement
Bus, Design Bumper Testing Crash Energy Absorption Mass Transit Prototype Bus Bumper Development	Available to the Public through the National Technical Information Service Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	48	A03/4.00

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TECHNICAL REPORT STANDARD TITLE PAGE

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Bus Design
Prototype Bus Bumper Development
Bumper Testing
Crash Energy Absorption

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Unclassified	Unclassified	40	

Form DOT F 1700.7 (8-69)

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1. INTRODUCTION. This report discusses the results of a series of controlled tests of energy absorbing bumpers and the life-cycle cost evaluations related to accident claims and bus repair costs.

a. Report Objectives. This report has three objectives:

- Quantify the potential economic benefits of energy absorbing bumpers for transit buses

- Provide reference information for evaluation of the physical and performance properties of energy absorbing bumper systems designed for transit bus application

- Provide information on the performance of innovative energy absorbing bumper systems in simulated 4,000-pound automobile crash situations as inputs to the development of a performance specification for future transit buses.

b. Economic Benefits. Based on a previous field investigation into the potential benefits of energy absorbing bumpers,[(1)*] which used the 1969-to-1970 time period as a baseline, estimated life-cycle accident costs involving the front bumper area of urban buses were:

- $ 800 in bus damage (front and front corners)

- $1,600 in direct claims payments to other vehicle owners (bus hits rear of automobile)

* Refer to the reference list at the end of this report.

- $1,200 overhead expenses prorated at 50 percent for staff, special insurance coverage, etc.

- $3,600 total cost to the bus property of accidents involving the front end of a typical bus within the life-time of the bus.

This total life-time cost for bus-striking-the-rear-of-the-automobile-type accident category accounted for 26 percent of all traffic accident costs. Based on these background statistics, the use of energy absorbing bumpers seems to have major safety and economic benefits. This is especially true in light of the fact that overall safety and insurance costs have increased by 62 percent since the 1969-to-1970 period. Also, the analysis in reference (1) used very conservative assumptions. Thus, if cost statistics are updated to reflect the 1975 cost index, the total life-cycle costs involved in bus-strikes-car accidents may be as great as $7,200.

The previous investigation found that no damage occurs to automobiles struck by transit buses at speeds below 2.16 mph.[(1)] The study indicated that a transit bus, fitted with energy absorbing bumpers designed to eliminate all damage to an automobile at an 8-mph impact speed, would experience at least a $930 reduction in accident claims costs (1969-to-1970 baseline) during its life cycle. Under current conditions, similar bumper performance would yield cost savings in excess of $2,000 in the life of a single bus by eliminating car damage in impacts below 8 mph. Accident damage/claim cost reductions for the automobile in higher-speed crashes (above 8 mph) should add an additional $1,000. Thus, total claims cost savings may exceed $3,000 in the life of a single bus or the equivalent of 0.6 cents-per-mile.

Figure 1 shows the result of an in-depth analysis of the 1969-to-1970 accident files of two major bus properties.[(1)] It displays the accumulation of other vehicle damage claims costs in the life of the transit bus for rear-end accidents only (bus strikes rear of car). The figure indicates that 50 percent of the accidents in which the bus strikes the rear of an automobile account for only $400 in direct

claims costs. These are the low speed, low cost, accidents. The remaining 50 percent of the rear-end accidents account for $1,260 in claims costs over the life of the bus. Current claims costs are estimated to be about double those shown in Figure 1.

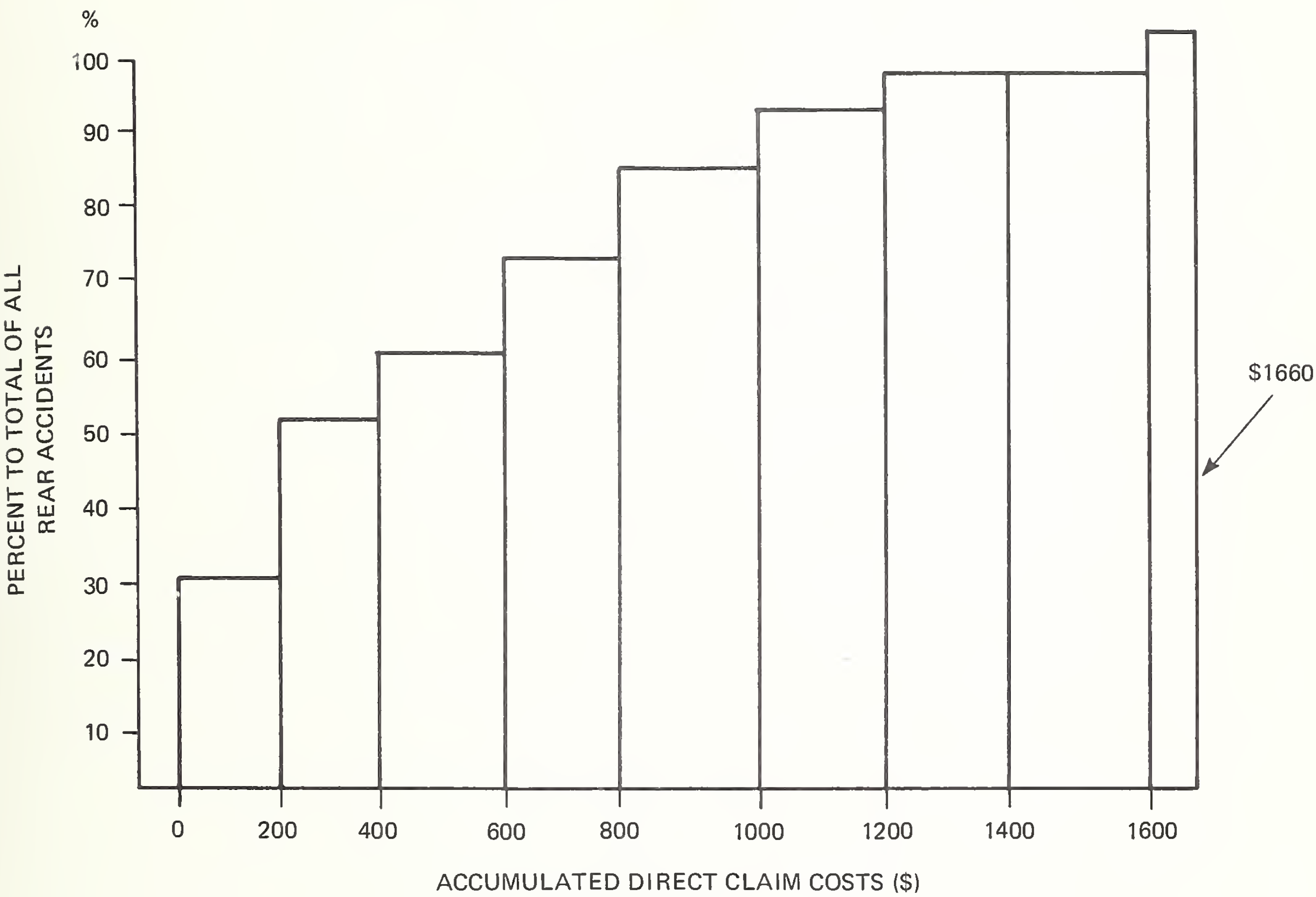

FIGURE 1. EXAMPLE OF DIRECT CLAIM COSTS— BUS STRIKES CAR ACCIDENTS

Reports of specific accident cases indicate that water bumpers, such as those manufactured by Energy Absorption Systems, Inc. (EAS)[2] of Chicago, Illinois, are effective in reducing accident claims costs in low-speed (5 to 10 mph) bus/auto crashes. An informal study, conducted by the claims manager of a major West Coast bus property supplied by EAS, indicates that water-bumper-equipped

buses have traffic accident claims costs that may be as much as 35 percent less than a comparable bus without water bumpers. The statistical validity of the precise claims reduction quoted is subject to question because of the limited sample size. The fact that water bumpers will reduce accident claims is established, but the cost of repair to buses (including the bumpers) could increase under certain situations such as when the bumpers receive significant damage in accidents. Also, the water bumper requires periodic maintenance (checking and refilling water bags).

c. Energy Absorbing Bumper Systems. The evidence related to the benefits of energy absorbing bumpers, however, was sufficient to justify a research and development effort in the bumper area on the Transbus program. Three innovative bumper systems were installed on the Transbus prototypes, Figure 2, as follows:

- AM General Transbus. A pneumatic energy absorbing bumper cast from an elastomeric compound developed by the Firestone Tire and Rubber Company[3]

- General Motors Truck and Coach Division Transbus. An aluminum bumper covered by an elastomer and spring-mounted to the vehicle structure[4]

- Rohr Industries. A steel bumper covered with an elastomer and mounted to the vehicle structure with shock absorbing cylinders supplied by the Menasco Manufacturing Company.[5]

In addition, two new energy absorbing bumpers, TRANSAFE and HELP, have been developed since the Transbus prototype designs were completed and are, therefore, also discussed in this report. These new bumpers are designed as follows.

- The TRANSAFE Bumper. This bumper recently developed by EAS[6] is a foam-type energy absorbing bumper cast from a polyurethane composition. Three energy absorbing

AM GENERAL TRANSBUS

GENERAL MOTORS TRANSBUS

ROHR TRANSBUS

FIGURE 2. TRANSBUS PROTOTYPE COACHES

modules are mechanically attached to a high-strength fiberglass-reinforced plastic backup beam to form a complete bumper configuration for use on various types of vehicles.

- HELP Bumpers (Pneumatic and Semi-Pneumatic). These two High Energy Level Pneumatic (HELP) bumpers recently developed by Firestone Tire and Rubber Company(7) are an improved design of the pneumatic bumper used on the AMG Transbus. In external appearance, the new design bumpers resemble, to some extent, the AMG Transbus bumper; however, the semi-pneumatic version functions at ambient air pressure and does not require attachments to the pressurized air system of the vehicle. Three energy absorbing modules are mechanically attached to a backup structure of high-yield-strength steel and extruded aluminum.

The bumper systems developed for Transbus, the currently available water bumper, and the new bumpers (foam, pneumatic, and semi-pneumatic) have different performance and maintenance characteristics. This report is based on the results of a test and evaluation program which included:

- Performance testing of the three Transbus bumper systems, the water and foam bumper systems, and a standard current coach bumper employing test procedures similar to those of Federal Motor Vehicle Safety Standard 215 (FMVSS-215) for automotive bumpers*

- In-service evaluations of the maintenance characteristics of the Transbus bumpers by maintenance personnel of four United States transit operations under demonstration grants from the Urban Mass Transportation Administration (UMTA) as part of the Transbus public demonstration program

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* Tests of foam bumper (TRANSAFE) and pneumatic bumpers (HELP) conducted by CALSPAN for EAS and Firestone were not part of the Transbus program test; however, these tests were similar and were observed by Booz, Allen.

- A detailed analysis of the life-cycle cost benefits and safety benefits of each Transbus bumper system and other new design bumpers.

The findings of this report are based, in part, on detailed controlled tests conducted at the Ultrasystems test facility, Phoenix, Arizona, and at CALSPAN Corporation, Buffalo, New York.

d. Energy Absorbing Bumper Systems Progress. During the Transbus program (June 1971 to date), significant improvements in bumper technology were witnessed. The presence of the Transbus program and the bumper testing effort may have contributed in stimulating these improvements. Both major manufacturers, Firestone and EAS, have made and continue to make improvements in their bumper designs.

2. TEST DESCRIPTION. The Dynamic Science Division of Ultrasystems, Inc. conducted a series of bumper tests, in accordance with the requirements specified in FMVSS-215, at their Pendulum test facility. These tests were performed under subcontract to Booz, Allen Applied Research, the Transbus Prime Contractor for UMTA.

a. Test Objectives. The specific objectives of the bumper tests were to:

- Determine for comparative purposes the ruggedness, resilience, impact-absorbing capability, and the impact-load transmissibility to the bus structure and to the impacted vehicle of various designed bumpers, when subjected to a simulated impact by a 4,000-pound automobile, moving at varying low speeds

- Obtain performance data concerning energy absorption characteristics including limits of absorption capabilities in longitudinal and corner impacts under simulated in-service accidents

- Obtain data required to analytically relate bumper performance to transit coach life-cycle costs

- Obtain detailed data required to determine performance requirements for Transbus production series bumper specifications and to establish areas for product improvement.

b. Test Facility. The pendulum used at Dynamic Science, Figure 3, consisted of a striker mass assembly suspended by four 13-foot support arms. The front and rear arm pairs were structurally triangulated to provide torsional rigidity from asymmetrical impact loading. The pendulum (striker assembly and support arms) was mounted on a platform which was supported by a structural tower. Incorporated between the structural tower and platform, an electrically-operated screw-jack system allowed vertical positioning of the pendulum assembly.

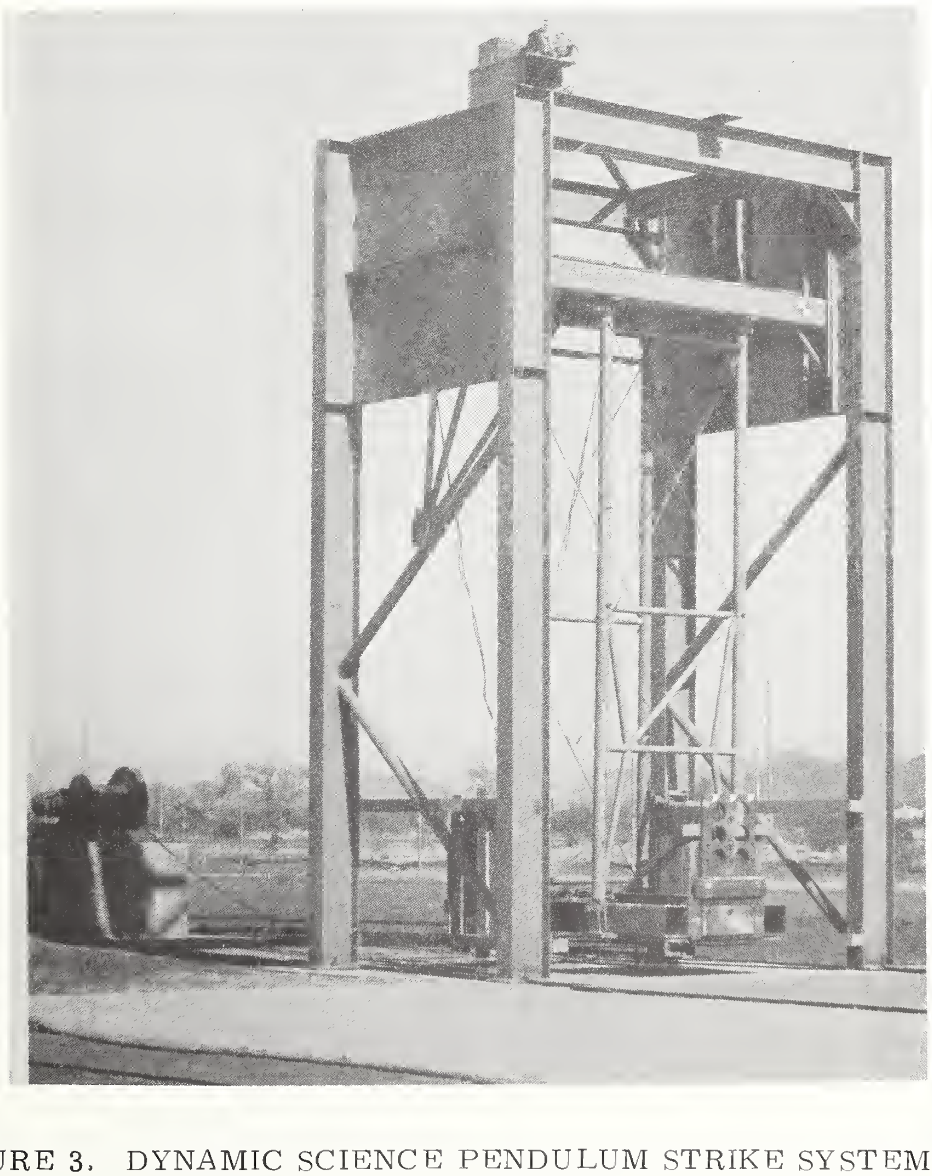

FIGURE 3. DYNAMIC SCIENCE PENDULUM STRIKE SYSTEMS

The striker assembly employed a 4,000-pound mass with a faceplate attached to the front of the assembly which included the impact head specified in FMVSS-215 for the conduct of the bus bumper tests. The test area was designed to accommodate the mounting of a rigid barrier to support the test bumper.

For testing, the pendulum was pulled back to its pretest position by a cable and an electrically driven winch. Release of the pendulum was accomplished by an electrically-operated quick-disconnect mechanism. A rebound stop mechanism prevented a secondary impact.

The test instrumentation included a "break-wire" speed trap, transducers to measure the impact velocity/forces, and bumper displacements at the longitudinal and 30-degree corner impacts. The impact events were recorded by high-speed cameras mounted on the pendulum tower directly above the bumper.

The Calspan Corporation subsequently conducted a series of controlled tests on new design energy absorbing bumpers provided by EAS and the Firestone Tire and Rubber Company. These tests were witnessed by Booz, Allen.

Calspan's impact pendulum, Figure 4, is designed to test bumper systems in accordance with requirements specified in FMVSS-215.

The Calspan pendulum is a compound pendulum consisting of an impact head mounted on a heavy platform, suspended by four 11-foot, lightweight, rigid hangers from a steel framework.

The test instrumentation included a "light-beam" speed trap, transducers to measure the impact velocity and forces, and bumper displacements at the longitudinal and 30-degree corner impacts. The impact events were recorded by high-speed cameras mounted on the pendulum tower directly above the bumper.

The striker assembly employed a 4,000-pound mass with a faceplate attached to the front assembly which included the

impact head specified in FMVSS-215 for the conduct of the TRANSAFE and HELP bumpers tests.

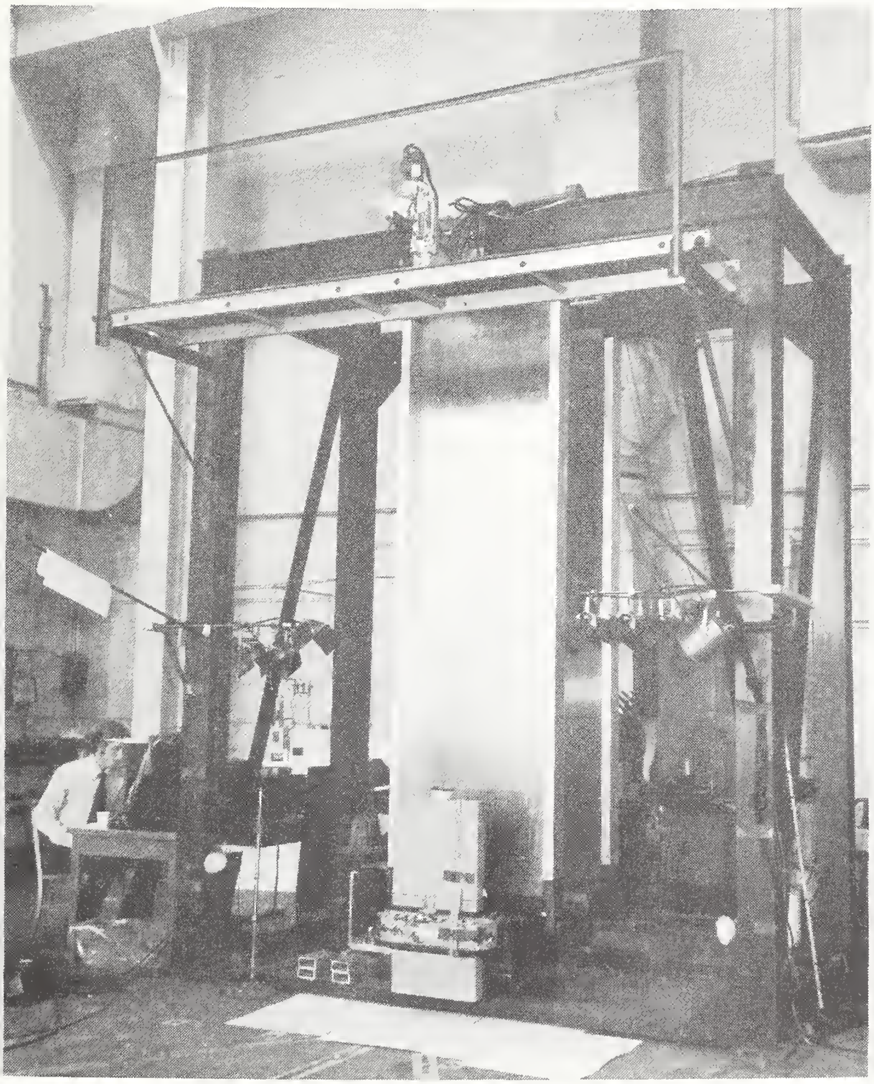

FIGURE 4. CALSPAN VEHICLE IMPACT PENDULUM

c. Test Articles. The test articles included one front bumper assembly complete with supporting and mounting components from each of the three Transbus prototype coaches (as developed by AM General Corporation, GMC Truck and Coach Division, and Rohr Industries), a current production coach bumper and an EAS passenger coach water bumper.

(1) AMG Transbus Bumper. The AMG Transbus bumper is a high-energy-level pneumatic bumper system and consists essentially of a hermetically-sealed package comprising an inflated flexible front section, attached to a rigid back, into which a relief valve is incorporated. For testing, the system was inflated to a positive static pressure in the order of 15 psi. Each compartment contains a relief valve for venting air during impact, when the compartment pressure exceeds the relief valve setting. Figure 5 is a typical overhead view of the AMG Transbus bumper undergoing testing. Figure 6 shows a front-end view of the AMG bumper installed on the AMG Transbus.

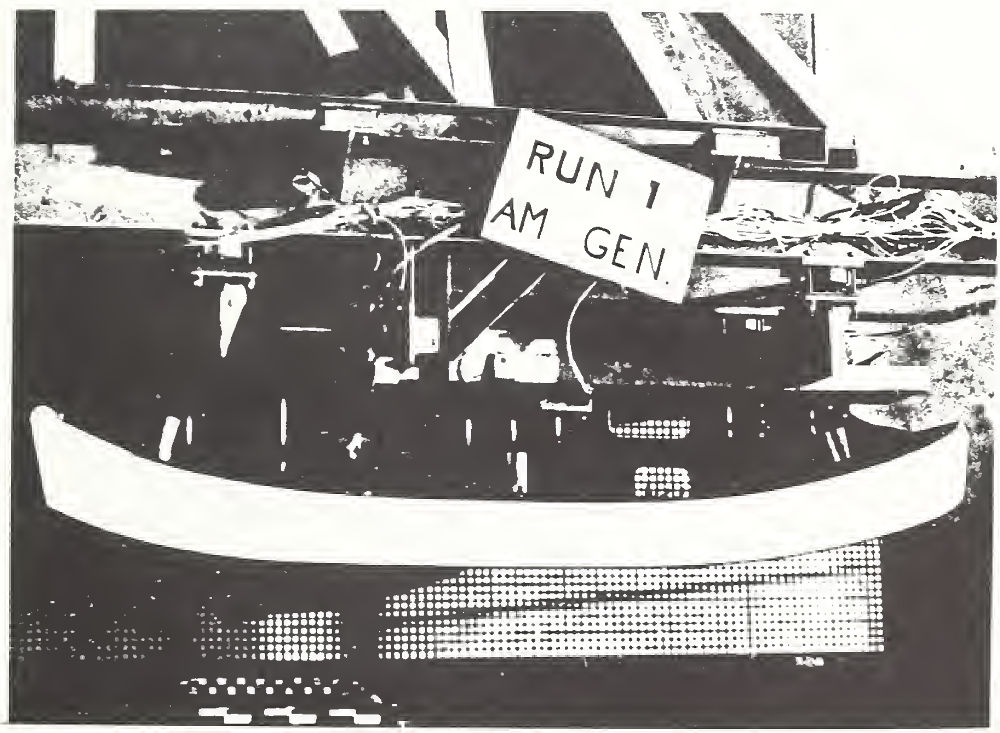

FIGURE 5. AMG TRANSBUS BUMPER—TYPICAL LONGITUDINAL TEST CONFIGURATION

FIGURE 6. AMG TRANSBUS BUMPER INSTALLATION

(2) GMC Transbus Bumper. The GMC Transbus bumper consists of an aluminum alloy faceplate supported by four steel springs. Unlike the typical current production bus bumper, the energy absorbing springs are unique in that they are not attached to the faceplate in a fixed position, but instead have a lateral freedom of movement when experiencing an impact. Figure 7 is a typical overhead view of the GMC Transbus bumper undergoing testing. Figure 8 shows a front-end view of the GMC bumper installed on the GMC Transbus.

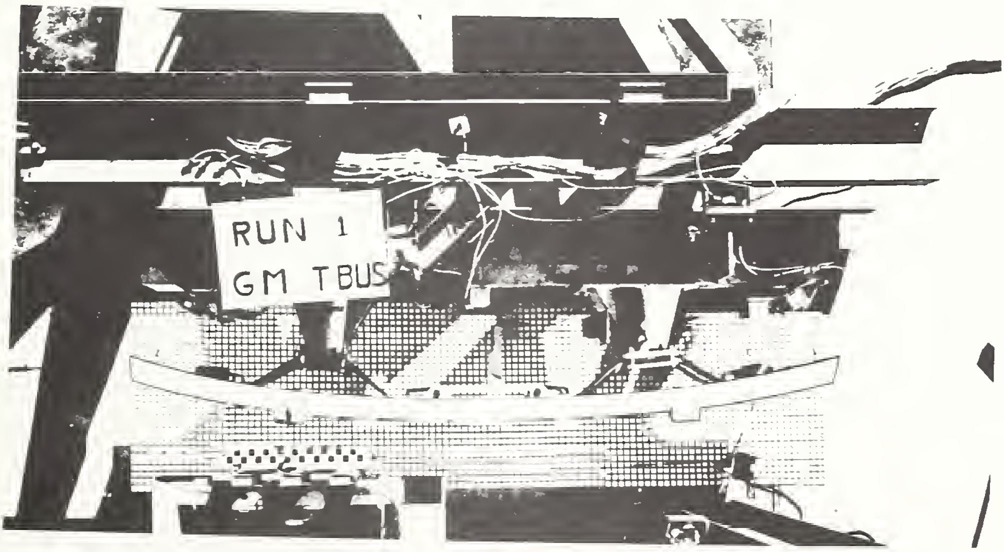

FIGURE 7. GMC TRANSBUS BUMPER—TYPICAL TOP VIEW OF LONGITUDINAL IMPACT CONFIGURATION

FIGURE 8. GMC TRANSBUS BUMPER INSTALLATION

(3) Rohr Transbus Bumper. The Rohr Industries Transbus bumper consists of a steel faceplate covered with an elastomer and four silicone-elastomer-filled shock isolators supplied by the Menasco Manufacturing Company. The shock isolator output characteristics are composed of two principal components: a spring or energy storing function, and a damping function.

The spring function is obtained by the stroking of a piston rod into a pressure vessel containing pressurized elastomer. This results in a reduction in elastomer volume which, in turn, causes its pressure to rise as a function of the piston rod stroke. The elastomer pressure reacts against the piston-rod-projected area to produce a typical spring-characteristic curve. After the piston has compressed the elastomer, it will return to its extended position by the stored energy in the spring function, thus forcing the elastomer back to its original position through orifices. Figure 9 is a typical overhead view of the Rohr Industries Transbus bumper undergoing

testing. Figure 10 shows a front-end view of the bumper installed on the Rohr Transbus. The elastomeric cover was not installed during testing, as it was not available from Rohr at that time.

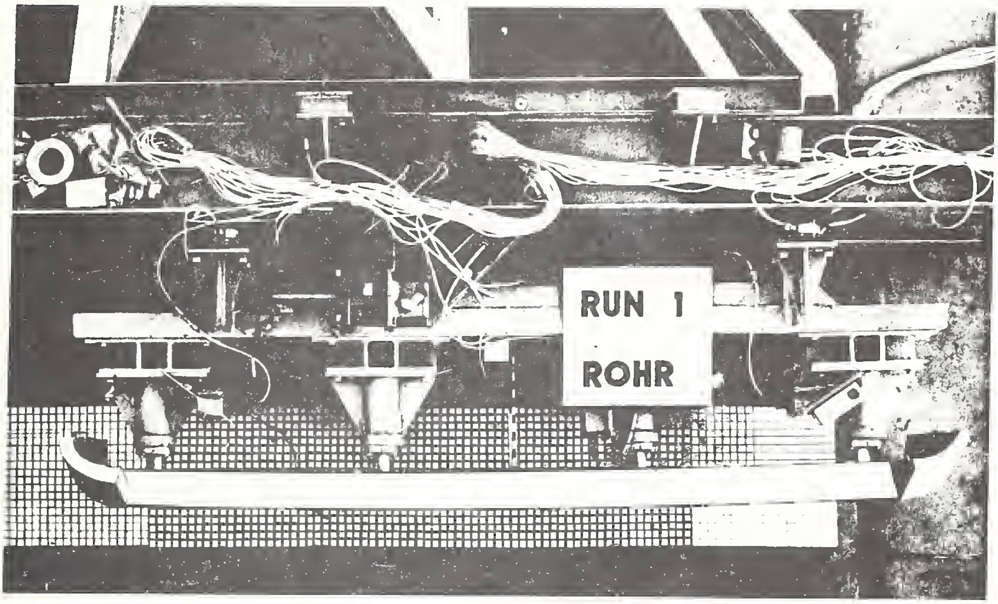

FIGURE 9. ROHR TRANSBUS BUMPER—TYPICAL LONGITUDINAL IMPACT CONFIGURATION

FIGURE 10. ROHR TRANSBUS BUMPER INSTALLATION

(4) GMC Production Bumper. The GMC production bumper is a standard rigid bumper, consisting of a steel faceplate supported by two leaf springs. Figure 11 is a typical overhead view of the GMC production bumper undergoing testing.

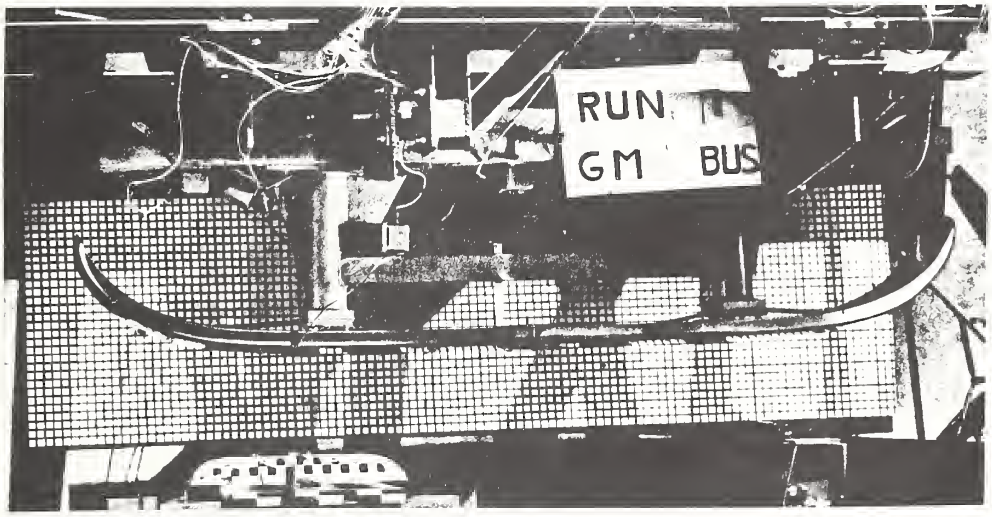

FIGURE 11. GMC PRODUCTION BUMPER—TYPICAL LONGITUDINAL IMPACT CONFIGURATION

(5) EAS Water Bumper. The EAS water bumper is an impact-cushioning bumper and consists of seven specially designed water-filled vinyl modules with four (each) plastic release plugs, mounted on a solid flex beam. During impact, the plastic release plugs pop up, allowing water to escape through pressure-regulating orifices. This action absorbs a significant amount of the impact energy, considerably lessening the severity of the crash. Figure 12 is a typical overhead view of the EAS water bumper undergoing testing.

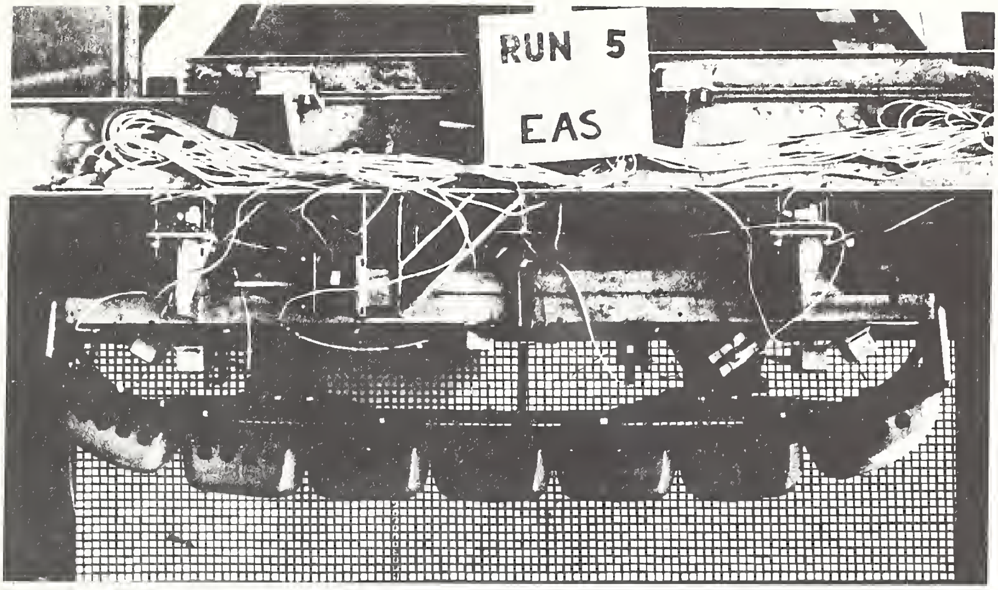

FIGURE 12. EAS WATER BUMPER—TYPICAL LONGITUDINAL IMPACT CONFIGURATION

(6) EAS TRANSAFE Bumper. The EAS TRANSAFE bumper, tested at Calspan, consists of three components: modules, backup beam, and mounting brackets. The modules consist of a PVC shell filled with a polyurethane foam. The modules slide onto, and are mechanically attached to, the backup beam. The backup beam is a high-strength fiberglass-reinforced plastic beam. The entire setup is then attached to rigid mounting brackets which, in turn, are attached to the bus. The bumper is adapted to mount to either the front or rear of the vehicle. The bumper weight, as tested, was approximately 170 pounds.

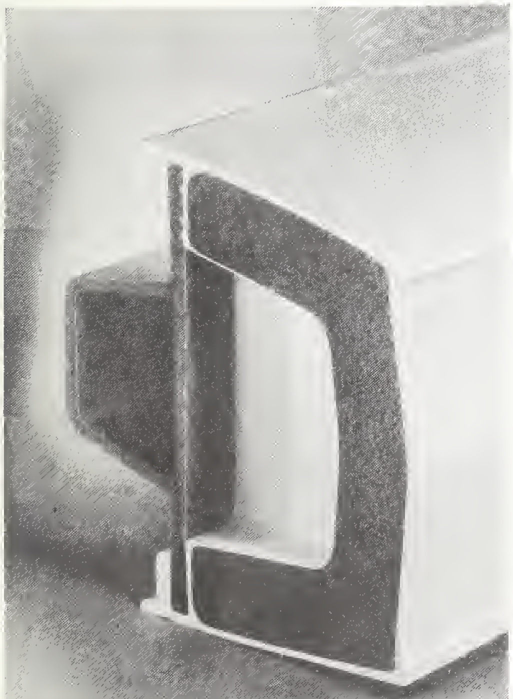

FIGURE 13. EAS TRANSAFE BUMPER—CUT-AWAY VIEW

Figure 13, a cut-away view, shows the interior construction of the TRANSAFE bumper. The Calspan Corporation performed a series of tests on the TRANSAFE bumper on June 17, 1975, employing procedures similar to those used for testing Transbus bumpers. Booz, Allen witnessed this test series. Figure 14 is a typical overhead view of the 102-inch bumper undergoing testing. Figure 15 shows a front-end view of the bumper mounted on a current production coach.

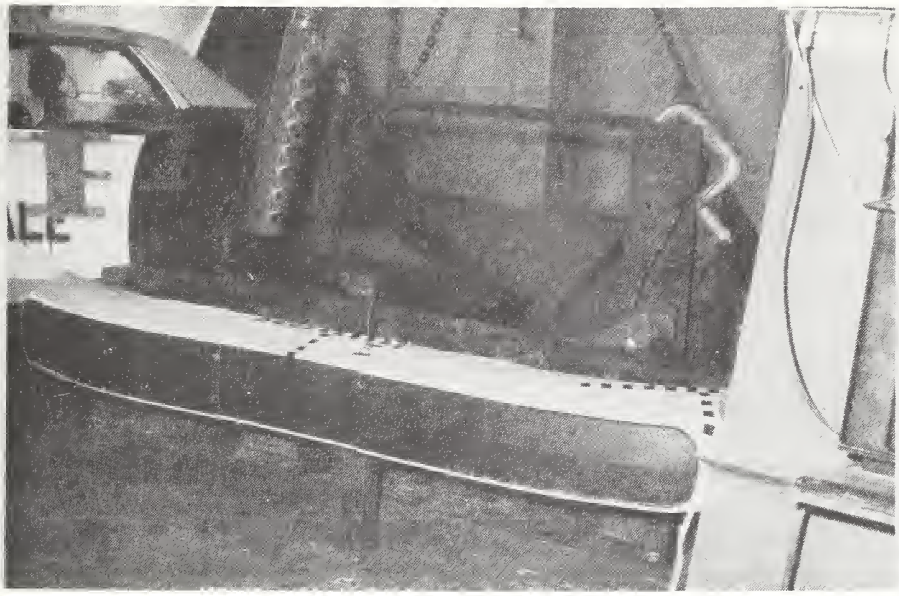

FIGURE 14. EAS TRANSAFE BUMPER—TYPICAL LONGITUDINAL IMPACT CONFIGURATION

FIGURE 15. EAS TRANSAFE BUS BUMPER INSTALLATION

(7) Firestone HELP Bumpers. The Firestone new design HELP bumpers, also tested at Calspan, consist of three hermetically-sealed modules manufactured from nonreinforced elastomeric materials. These are mounted to a high-strength steel backup structure. The structure is designed for mounting on the vehicle frame with special brackets.

Two types of HELP bumpers were tested: pneumatic and semi-pneumatic. The pneumatic bumper, Figure 16, is designed for direct connection through a pressure regulator to the vehicle's compressed air system. Upon impact, the air in the module is dissipated through high-volume relief valves. The semi-pneumatic bumper, Figure 17, is identical in external appearance to the pneumatic bumper. However, it does not require attachment to a compressed air system. Special valves provide ambient air pressure to the modules. These valves are rubber hemispheres (Figure 17) slit in two directions, so that they open like the petals of a flower when the bumper is impacted. After impact, there is a momentary vacuum in the module, thus decreasing rebound. Figure 18 is a typical overhead view of the HELP 96-inch bumper undergoing testing. Figure 19 shows a front-end view of the pneumatic bumper mounted on a current production coach.

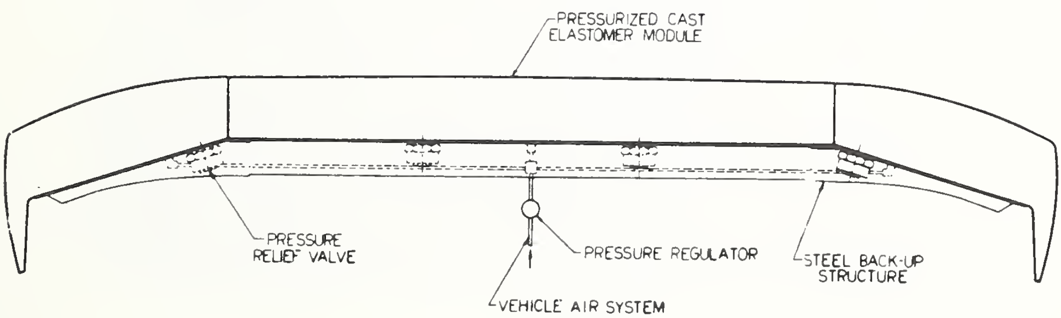

FIGURE 16. FIRESTONE HELP BUMPER—PNEUMATIC SYSTEM

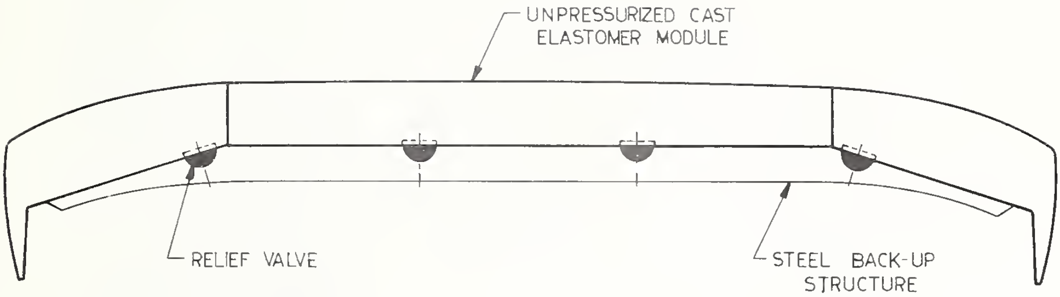

FIGURE 17. FIRESTONE HELP BUMPER—SEMI-PNEUMATIC SYSTEM

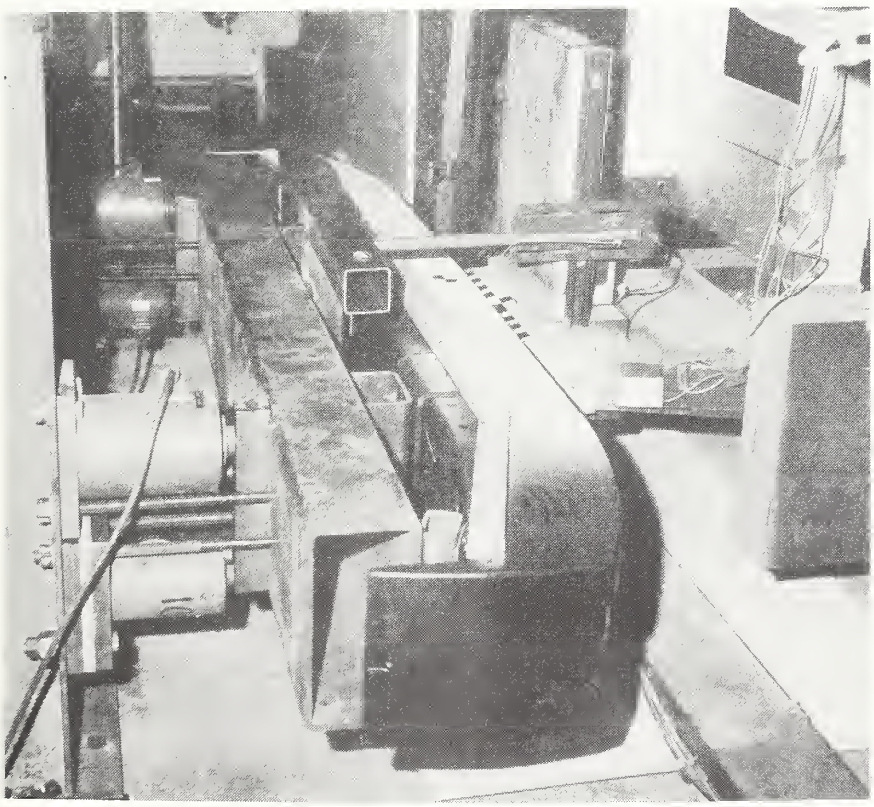

FIGURE 18. FIRESTONE HELP BUMPER—TYPICAL LONGITUDINAL IMPACT CONFIGURATION

FIGURE 19. FIRESTONE HELP BUS BUMPER INSTALLATION

d. Test Procedures. Initial bumper impact tests were conducted outside at the test facility of Dynamic Science, a division of Ultrasystems, Inc., Phoenix, Arizona, during the fall of 1973. The intent of the Transbus bumper test program was to conduct a series of tests which closely simulated the environment to which bumpers are subjected in actual revenue service. The following criteria were selected:

- Striker weight of 4,000 pounds
- Pendulum designed to strike with a force that simulated a passenger car mass
- Impact velocity progressively increasing from 1.0 mph, in 0.5 mph increments, to a point when the bumper undergoing testing "bottomed out" on the hard surface of the bumper-mounting fixture or on the bumper system's own mounting/backing plate

- Impact areas on the bumpers consisted of ten impact zones for longitudinal impacts and six impact zones for angle impacts. (See Figure 20 for zone location and impact sequence schedules for each bumper.)

Four basic tests were conducted on each of the AMG, GMC and Rohr Transbus bumpers, GMC current production bus bumpers and EAS water bumpers.

- Longitudinal Impacts. This test commenced with an initial impact in Zone No. 1 at 1.0 mph (1.45 fps) and progressed, in 0.5 mph (0.73 fps) increments, in accordance with sequence schedule shown in Figure 19, until the resilient members of the bumper system reached approximately 90 percent of maximum travel capability.

- 30-Degree Corner Impacts. This test commenced with an initial impact in Zone No. 1 (right corner) at 1.0 mph (1.45 fps) and progressed, in 0.5 mph (0.73 fps) increments, in accordance with sequence schedule shown in Figure 20, until the resilient members of the bumper system reached approximately 90 percent of maximum travel capability.

- Final Longitudinal Impacts. This test commenced with an initial impact at 0.5 mph (0.73 fps) above the last impact velocity of Test No. 1 in the next sequential zone number, and progressed, in 0.5 mph (0.73 fps) increments, until the resilient members of the bumper system "bottomed out."

- Final 30-Degree Impacts. This test commenced with an initial impact at 0.5 mph (0.73 fps) above the last impact velocity of Test No. 2 in Zone No. 1 (left corner), and progressed, in 0.5 mph (0.73 fps) increments, until the resilient members of the bumper "bottomed out."

The Calspan Corporation performed a series of impact tests on the TRANSAFE and HELP bumpers during June through August 1975. Booz, Allen witnessed this test program. Two basic tests were conducted on the EAS (TRANSAFE) and Firestone (HELP) bumpers at Calspan.

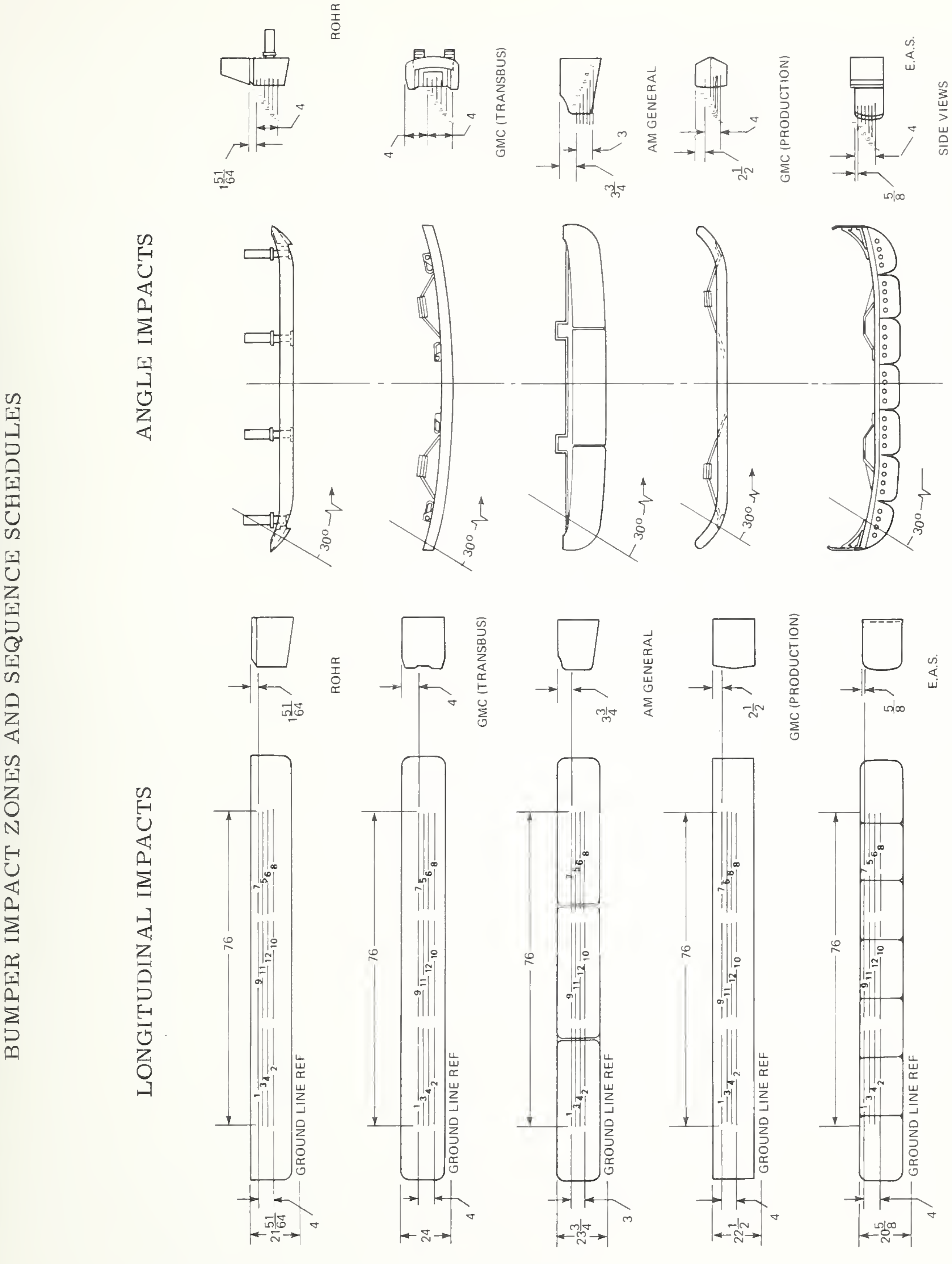

FIGURE 20. BUMPER IMPACT ZONES AND SEQUENCE SCHEDULES

These tests were similar to the more detailed Transbus bumper test series which was described earlier in this report. The Calspan tests were as follows.

- TRANSAFE Bumper (EAS)
  - Longitudinal Impacts (Center). This test consisted of five impacts on the center module, commencing at 3-mph impact, and progressing to a maximum impact of 7.0 mph.
  - Corner Impacts. This test consisted of three impacts on the left corner (30 degrees) module, commencing at 2.67-mph impact, and progressing to a maximum impact of 3.97 mph.
- HELP Bumper (Firestone) - Pneumatic Bumper
  - Longitudinal Impacts (Front). This test consisted of four impacts at varying heights on the center module, commencing at 1.96-mph impact, and progressing to a maximum impact of 7.1 mph.
  - Corner Impacts. This test consisted of four impacts on the left corner (30 degrees) and one impact on the right corner (30 degrees) of the bumper, commencing at 1.96-mph impact, and progressing to a maximum impact of 5.03 mph.
- Semi-Pneumatic
  - Longitudinal Impacts (Front). This test consisted of five impacts at varying heights on the center module, commencing at 2.0-mph impact and progressing to a maximum impact of 6.56 mph.
  - Corner Impacts. This test consisted of eight impacts on the left corner (30 degrees) of the bumper, commencing at 1.97-mph impact, and progressing to a maximum impact of 7.59 mph.

3. TEST RESULTS. Tables 1 through 8 show the results of impact tests conducted on each type bumper. Each table indicates the maximum load (lbf) experienced by the bumper undergoing testing for a specific impact velocity (mph). Also indicated is the approximate rebound velocity (mph), approximate percent of kinetic energy (KE) attenuated, and the maximum deflection (inches) by the bumper.

Since the bumpers were mounted on a rigid barrier, all "g" loads and deflections were higher than those that would be encountered if mounted on an urban bus.

The values in Tables 1 through 7 were either taken by direct measurements at the test facility, or computed from the high-speed films (rebound velocity). As a check, the area under the acceleration-time curve was planimetered to assure that the impact velocity was equal to the total velocity change.

The percent of initial kinetic energy absorbed by each bumper, averaged over all the tests, was as follows:

AMG (pneumatic bumper)	- 68.3 percent	HELP (pneumatic)	- 68.6 percent
GMC (free spring bumper)	- 68.3 percent	(semi-pneumatic)	- 73.8 percent
ROHR (elastomer shock isolater bumper)	- 93.3 percent	TRANSAFE (foam)	- 76.8 percent
EAS (water bumper)	- 82.6 percent	GMC Current Production	- 47.4 percent.

Since such an average includes all impact speeds, it is only a rough measure of performance. Detailed data on energy absorption performance is given in Tables 1 through 7. The inconsistency of the data, in some areas of the tables, is primarily due to the difficulties experienced in accurately reading rebound velocity off the test films, not characteristics of the bumpers themselves.

The maximum impact (mph) capability and other attendant characteristics for each type bumper system is summarized in Table 8.

TABLE 1. AMG TRANSBUS BUMPER TEST RESULTS

Test No.	Test Type	Impact mph	Load Cell lbf (max)	Rebound mph	Attn. % KE	Defl. in. (max)
1	Longitudinal	1.04	4,000	0.55	72	1.75
2	Longitudinal	1.57	7,600	0.85	71	1.5
3	Longitudinal	2.06	11,000	1.13	70	3.0
4	Longitudinal	2.57	14,500	1.49	67	3.1
5	Longitudinal	3.08	16,250	1.52	75	4.1
6	Longitudinal	3.57	19,000	1.96	70	3.7
7	Longitudinal	3.87	19,000	2.17	69	2.6
8	Longitudinal	4.50		2.07	78	
9	Longitudinal	4.49		2.78	62	
10	Right Corner	1.04	5,000	0.47	80	0.75
11	Right Corner	1.57	6,000	0.82	70	2.40
12	Right Corner	2.08	7,600	1.66	36	2.3
13	Right Corner	2.56	9,500	1.38	71	2.3
14	Right Corner	3.09	11,500	1.45	78	2.9
15	Right Corner	3.58	11,000	1.97	69	2.8
16	Right Corner	4.05	13,000	2.51	62	2.6
17	Right Corner	4.55	14,000	2.55	68	4.4
18	Right Corner	5.01	16,000	3.26	57	4.6
19	Longitudinal	5.07	17,500	3.14	62	5.0
20	Longitudinal	5.51	20,000	2.87	73	5.0
21	Longitudinal	6.03	21,500	3.62	65	6.2
22	Longitudinal	6.57	25,000	4.73	48	6.4
23	Longitudinal	7.02	32,000	3.65	73	6.2
24	Left Corner	5.53	19,000	2.27	83	6.2
25	Left Corner	6.06	20,000	2.85	79	7.0

TABLE 2. GMC TRANSBUS BUMPER TEST RESULTS

Test No.	Test Type	Impact mph	Load Cell lbf (max)	Rebound mph	Attn. % KE	Defl. in. (max)
1	Longitudinal	1.00	4,500	0.88	22	0.30
2	Longitudinal	1.54	5,400	0.75	76	0.25
3	Longitudinal	2.04	7,700	1.10	71	0.40
4	Longitudinal	2.54	10,000	1.14	79	0.45
5	Longitudinal	3.07	12,500	1.41	79	0.60
6	Longitudinal	3.54	17,000	1.84	73	0.75
7	Longitudinal	3.55	23,000	2.13	64	1.25
8	Right Corner	1.02	12,000	0.95	16	1.00
9	Right Corner	1.53	2,550	0.83	71	1.50
10	Right Corner	2.02	3,500	0.89	81	2.20
11	Longitudinal	4.04	18,000	2.50	62	0.80
12	Longitudinal	4.53	30,000	2.67	65	0.50
13	Longitudinal	5.08	25,000	2.95	66	2.80
14	Longitudinal	5.55	36,000	3.50	61	2.50
15	Longitudinal	6.05	34,000	3.63	64	3.20
16	Longitudinal	6.56	41,500	2.56	85	4.00
17	Longitudinal	7.19	29,000	3.02	83	0.25
18	Longitudinal	7.59	39,000	2.6	88	1.00
19	Left Corner	2.54	14,500	1.47	66	2.75
20	Left Corner	3.06	5,000	1.84	64	3.30
21	Left Corner	3.55	5,000	1.78	75	4.00
22	Left Corner	4.05	7,500	1.86	79	4.25
23	Left Corner	4.57	16,000	1.97		3.50
24	Left Corner		15,000			1.50

TABLE 3. GMC CURRENT PRODUCTION BUMPER TEST RESULTS

Test No.	Test Type	Impact mph	Load Cell lbf (max)	Rebound mph	Attn. % KE	Defl. in. (max)
1	Longitudinal	1.02	2,500	1.47		1.40
2	Longitudinal	1.57	2,700	0.88	68	2.00
3	Longitudinal	1.56	4,000	0.75	00	1.25
4	Right Corner	1.05	700	0.76	42	1.75
5	Right Corner	1.57	1,500	0.75	78	3.00
6	Longitudinal	2.04	28,500	1.18	67	1.75
7	Longitudinal	2.58	7,500			2.5
8	Left Corner	2.58	250	2.76	00	5.0

TABLE 4. ROHR INDUSTRIES TRANSBUS BUMPER TEST RESULTS

Test No.	Test Type	Impact mph	Load Cell lbf (max)	Rebound mph	Attn. %KE	Defl. in. (max)
1	Longitudinal	1.02	7,200	—	—	0.25
2	Longitudinal	1.51	8,700	—	—	0.4
3	Longitudinal	2.01	10,000	—	—	0.75
4	Longitudinal	2.51	10,000	0.60	94	1.4
5	Longitudinal	3.05	12,000	0.56	97	1.75
6	Longitudinal	3.53	10,500	—	—	2.25
7	Longitudinal	4.07	13,000	0.63	97	2.5
8	Longitudinal	4.53	13,500	0.72	98	3.25
9	Longitudinal	4.53	19,500	0.69	98	2.00
10	Longitudinal	5.03	—	1.20	94	2.25
11	Longitudinal	5.52	22,000	1.14	94	2.8
12	Longitudinal	6.0	23,000	1.66	92	3.5
13	Right Corner	1.01	2,700	0.84	92	0.4
14	Right Corner	1.53	5,000	—	—	0.75
15	Right Corner	2.02	6,000	0.60	91	1.2
16	Right Corner	2.51	6,500	0.72	92	1.5
17	Right Corner	3.05	7,000	0.80	93	2.2
18	Right Corner	3.52	8,000	0.92	93	2.75
19	Right Corner	4.03	8,500	1.11	92	3.2
20	Longitudinal	6.5	38,000	1.61	94	3.75
21	Left Corner	5.06	12,000	1.66	89	4.2
22	Left Corner	5.5	16,500	0.93	97	4.5
23	Left Corner	5.54	21,000	1.89	90	4.1
24	Left Corner	6.08	19,000	2.31	86	3.9

TABLE 5. EAS TRANSAFE BUMPER TEST RESULTS

Test No.	Test Type	Impact mph	Load Cell lbf (max)	Rebound mph	Attn. %KE	Defl. in. (max)
1	Longitudinal	2.99	7,300	1.48	74	3.85
2	Longitudinal	4.99	22,000	2.04	79	5.10
3	Longitudinal	5.49	28,000	2.75	74	5.72
4	Longitudinal	6.01	33,000	2.88	76	6.15
*5	Right Corner	2.67	10,400	1.04	71	5.25
*6	Right Corner	3.48	19,100	1.19	83	5.77
*7	Right Corner	3.97	31,000	1.58	75	5.95
8	Longitudinal	7.00	39,000	2.78	82	6.65

* The values determined for Tests No. 5, 6, and 7 measured only that component of force which was imparted to the load cell behind the large structural tubing. Some of the force undoubtedly was transmitted laterally and, thus, was not included in the force-versus-deflection curves which were used in computing rebound velocity and energy absorbed.

TABLE 6. EAS WATER BUMPER TEST RESULTS

Test No.	Test Type	Impact mph	Load Cell lbf (max)	Rebound mph	Attn. % KE	Defl. in. (max)
1	Longitudinal	1.01	2,000	0.65	59	1.75
2	Longitudinal	1.53	3,000	1.30	27	3.5
3	Longitudinal	2.02	5,000	0.60	91	3.5
4	Longitudinal	2.54	7,000	0.86	89	4.25
5	Longitudinal	3.06	8,750	0.52	97	4.5
6	Longitudinal	3.54	12,500	0.70	96	4.75
7	Longitudinal	4.02	16,000	1.09	93	6.0
8	Longitudinal	4.53	17,000	0.49	99	6.25
9	Longitudinal	5.06	18,000	1.92	86	6.0
10	Longitudinal	5.03	27,500	1.46	91	6.8
11	Right Corner	1.02	2,000	0.71	51	2.2
12	Right Corner	1.54	4,000	0.90	65	3.2
13	Right Corner	2.04	5,000	1.00	76	3.9
14	Right Corner	2.54	6,000	1.20	78	4.0
15	Right Corner	3.06	8,000	0.58	96	4.6
16	Right Corner	3.51	9,000	0.53	98	4.7
17	Longitudinal	5.58	20,500	1.17	96	6.5
18	Longitudinal	6.07	24,000	1.27	96	7.5
19	Left Corner	4.05	10,500	1.54	86	6.7

TABLE 7. FIRESTONE HELP BUMPER TEST RESULTS

Firestone HELP (Semi-Pneumatic) Bumper Test Results							
Impact Secq. No.	Test No.	Test Type	Impact (mph)	Load Cell (lbf max)	Rebound (mph)	Attn. % KE	Defl. (in max)
4	1	Longitudinal	2.02	3,800	1.40	58.7	1.6
1	2	Longitudinal	5.06	18,000	2.89	76.5	4.0
2	3	Longitudinal	5.45	24,000	3.22	76.1	4.5
3	4	Longitudinal	6.11	35,500	3.54	77.9	4.8
5	5	Longitudinal	6.56	38,400	3.93	73.7	5.0
6	6	Left Corner	1.97	5,000	1.38	61.5	1.8
7	7	Left Corner	4.02	5,600	2.42	71.1	4.2
11	8	Left Corner	4.53	12,900	2.73	69.6	5.0
10	9	Left Corner	5.03	14,500	2.97	78.0	4.9
8	10	Left Corner	5.06	19,700	3.02	72.5	5.2
9	11	Left Corner	5.56	34,200	3.35	73.1	5.5*
12	12	Longitudinal	7.05	48,300	4.25	85.8	5.5*
13	13	Longitudinal	7.59	54,900	4.57	75.7	5.9*

*Deflection measured from high speed films; LVDT range exceeded.

Firestone HELP (Pneumatic) Bumper Test Results						
Test No.	Test Type	Impact (mph)	Load Cell (lbf max)	Rebound (mph)	Attn. % KE	Defl. (in max)
1	Longitudinal	1.96	6,500	1.51	42.2	1.2
2	Longitudinal	5.60	14,000	3.48	61.6	3.7
3	Longitudinal	6.05	25,300	4.10	64.4	4.8
4	Longitudinal	7.10	39,500	4.98	71.9	5.4
5	Left Corner	1.97	4,900	1.38	63.7	1.6
6	Left Corner	4.01	7,600	2.63	70.0	3.6
7	Left Corner	4.54	9,400	2.58	82.9	4.5
8	Left Corner	5.03	11,300	2.59	81.1	4.9
9	Right Corner	5.03	11,900	2.63	79.1	4.8

Note: Firestone 96-inch bumper was utilized for these tests. The bumpers were mounted on a pendulum test fixture designed to accept the 102-inch bumper. The resulting mismatch reduced the contact area of the bumper during corner impacts, possibly contributing to a reduction in the bumper's maximum energy absorbing characteristics.

TABLE 8. ENERGY ABSORBING BUMPERS—
COMPARATIVE CAPABILITY

Bumper (Front)	Max Impact Mph		Load Cell lbf		Deflection Inches		Attn. KE %	
	Long.	Corner	Long.	Corner	Long.	Corner	Long.	Corner
AMG Transbus (Pneumatic)	7.02	6.06	32,000	20,000	6.2	7.0	73%	79%
GMC Transbus (Spring)	7.59	4.57	39,000	16,000	#1.0	3.5	88	81
Rohr Transbus (Shock)	6.5	6.08	38,000	19,000	3.8	3.9	94	86
Current Production (GMC) (Spring)	2.58	2.58	7,500	2,500	2.5	5.0	00	00
EASI - (Water)	6.07	4.05	24,000	10,500	7.5	6.7	96	86
EASI - (Foam) (TRANSAFE)	7.00	3.97	39,000	31,000	6.7	6.0	82	75
Firestone (HELP)								
(Pneumatic)	7.10	5.03	39,500	11,900	5.4	4.8	72	79
(Semipneumatic)	7.59	5.56	54,900	34,200	5.9	5.5	76	73

#Low deflection on GMC due to distorted face plate.

4. CONCLUSIONS. The results of this series of controlled bumper tests have demonstrated the potential protection offered by the various new design energy absorbing bumpers. In frontal impacts with a simulated 4,000-pound automobile, all bumpers continued to absorb energy for speeds up to 6.07 mph. It is reasonable to predict, based on an extrapolation from the test data, that a 30,000-pound bus fitted with one of these bumpers would be undamaged when subjected to:

- A 5-mph flat-barrier impact
- A head-on collision with a passenger car moving at 8 to 10 mph
- A rear impact by a passenger car (car strikes bus) at 8 to 10 mph. (These bumpers have a definite potential for rear bumper installation with attendant benefits of front bumpers.)

In addition, it is predicted that no significant damage should occur to a 1974- or later-model passenger car when involved in 8- to 10-mph impacts, providing the car was equipped with energy absorbing bumpers in compliance with FMVSS-215. Beyond the 8- to 10-mph impact speed, the structural characteristics of the vehicles (bus and car) will determine the point at which significant damage will occur. Test results reported by bumper manufacturers yield results close to those stated above. However, these manufacturers' tests were not witnessed by Booz, Allen. Based on the results of the bumper tests and manufacturer's reports, it is conceivable that energy absorbing bumpers, such as those described in this report, with an effective mounting structure, could protect a transit bus from significant damage at impact speeds in the 15- to 20-mph range. However, automobile damage, which is economically significant in terms of claims costs, will begin to occur at lower impact speeds, i.e., in the 10- to 20-mph range.

As indicated in the bumper test results (Tables 1 through 7), all bumpers except the baseline current production bus bumper (Table 3) exhibited effective energy absorbing characteristics under pendulum test conditions established under FMVSS-215, and displayed a relatively constant effectiveness throughout the range of impacts. The comparative performance characteristics for each type of energy absorbing bumper system for longitudinal impacts at 6 mph and corner impacts at 4 mph are summarized in Table 9.

a. Projected Benefits. Based on an analyses of the bumper characteristics and the test results data (Tables 1 through 8),

TABLE 9. ENERGY ABSORBING BUMPERS— COMPARATIVE PERFORMANCE

Bumper (Front)	6 mph Impact	4 mph Impact	Load Cell lbf		Deflection Inches		Attn. KE %	
	Long.	Corner	Long.	Corner	Long.	Corner	Long.	Corner
AMG Transbus (Pneumatic)	6.03	4.05	21,500	13,000	6.2	2.6	65%	62%
GMC Transbus (Spring)	6.05	4.05	34,000	7,500	3.2	4.3	64	79
Rohr Transbus (Shock)	6.0	4.03	23,000	8,500	3.5	3.2	92	92
EAS - (Water)	6.07	4.05	24,000	10,500	7.5	6.7	96	86
EAS - (Foam) (TRANSAFE)	6.01	3.97	33,000	31,000	6.2	6.0	76	75
Firestone (Pneumatic)	6.05	4.01	25,300	7,600	4.8	3.6	64	70
HELP (Semipneumatic)	6.11	4.02	35,500	5,600	4.8	4.2	78	71

it is concluded that all bumpers tested, except the current production bus bumper, are predicted to:

- Exhibit energy absorbing capability equivalent to or exceeding the requirements set forth in FMVSS-215

- Provide effective protection to the bus, including the bumper itself, resulting from random minor accident hazards encountered during routine revenue service

- Contribute to a reduction in coach life-cycle ownership costs, through a reduction in direct claims costs and bus accident damage resulting from accidents. The initial and maintenance costs (Table 10) will be low enough to provide a positive cost/benefit ratio. Since analysis of accident records indicates that car/bus crashes involving vehicles without energy absorbing bumpers began to produce damage in the 2.5-mph range, the energy absorbing bumpers' performance should result in substantial cost savings. Additional weight effect (relative to current production bus bumpers) on fuel consumption will be negligible.

b. Specific Conclusions. Specific conclusions for each type energy absorbing bumper involved in this test program is summarized in Table 10.

5. RECOMMENDATIONS. The following bumper recommendations are incorporated in the Transbus Procurement Requirements,[8] Part II, Technical Specifications, Section 3.6.2. The recommendations are based on analyses of accident reports and the results of the bumper test program.

a. General Recommendations. The bumpers should be designed to protect the coach 6 inches above and below the normal 20-inch bumper height of automobiles, including the corners of the coach, to the extent practicable without exceeding the allowable width limitation, and should demonstrate the following impact-absorbing capability and attendant characteristics.

- Impact Absorbing Capability. The front bumper should provide impact protection so that no damage to any part of the coach, including the bumper, results from a 5-mph impact with a fixed flat barrier parallel to the longitudinal centerline of the coach at wet weight. In addition, the bumper should protect the

TABLE 10. ENERGY ABSORBING BUMPERS CONCLUSIONS SUMMARY

Factors	AMG Transbus Pneumatic	GMC Transbus Free Spring	ROHR Transbus Elastomer Shock	EAS Water	EAS Foam (TRANSAFE)	Firestone Pneumatic (HELP)	Firestone Semi-Pneumatic (HELP)
1. Weight	264 lbs.	207 lbs.	187 lbs.	271 lbs. (filled)	170 lbs.	173.5 lbs.	159 lbs.
2. Support Requirements	15 PSI Air Supply	None	None	Water/Glycol	None	15 PSI Air Supply	None
3. Maximum Capability (Fixed Barrier)							
. Front	6.4 mph	7.6 mph	6.5 mph	6.1 mph	7.0 mph	7.1 mph	7.6 mph
. Corner	7.0 mph	4.6 mph	6.1 mph	4.1 mph	4.0 mph	5.0 mph	5.6 mph
4. Life Expectancy	10 years	15 years	15 years	10 years	10 years	10 years	10 years
5. Readiness (Reset Feature)	Auto. refill if connected to coach air supply.	Automatic	Automatic	Manual refill	Automatic	Auto. refill if connected to coach air supply.	Automatic
6. Maintenance Requirement							
. Periodic	Valve/plumbing inspection	None	None	Water ejector valves & water level	None	Valve/plumbing inspection	None
. Est. Overhaul Time	8 hours	2 hours	5 hours	4 hours	3 hours	4 hours	3 hours

TABLE 10 — Continued

Factors	AMG Transbus Pneumatic	GMC Transbus Free Spring	ROHR Transbus Elastomer Shock	EAS Water	EAS Foam (TRANSAFE)	Firestone Pneumatic (HELP)	Firestone Semi-Pneumatic (HELP)
7. Problems							
. Vandalism Susceptibility	Punctures	None	None	Punctures	Slashing of face cover	Punctures	Punctures (minor problem)
. Other	Valves/plumbing air leaks	Faceplate opening too large & distorts easily under minor impacts.	None	Water ejector plugs eject under minor impacts.	None	Valves/plumbing air leaks	None
8. Safety - Low Impact Attenuation	1 mph 72% 2 mph 70%	1 mph 22% 2 mph 71%	1 mph 20%* 2 mph 63%*	1 mph 59% 2 mph 91%	12 mph N/D 3 mph 74%	1 mph N/D 2 mph 42%	1 mph N/D 2 mph 59%
9. Aesthetic Features	Good	Good	Good	Poor	Excellent	Excellent	Excellent
10. Versatility For Rear Application	Practical	Not practical due to large center opening.	Practical	Not practical too heavy & requires periodic maintenance.	Practical	Practical, but requires additional air plumbing.	Practical
11. Approximate Initial OEM Cost	Out of production.	Out of production.	$600 (102")	$450 (102")	$345 (102")	$450 (102")	$350 (102")
12. Comparative Performance (See Table 9)							

* Estimated.
N/D No Data

coach and a 4,000-pound, post-1973, American automobile from damage when the coach strikes the rear bumper of the automobile parallel to the longitudinal centerline of the coach at 6.5 mph, and up to a 30-degree angle to the longitudinal centerline of the coach at 5.5 mph. The rear bumper and its mounting should provide impact protection to the coach from a 2-mph impact with a fixed flat barrier parallel to the longitudinal centerline of the coach at wet weight. In addition, the rear bumper should provide energy absorbing capability to withstand impacts by the striker (defined in FMVSS-215) loaded to 4,000 pounds at 3 mph, parallel, or up to a 30-degree angle, to the longitudinal centerline of the coach.

- Rebound Characteristics. Bumpers should exhibit energy-attenuation capability of not less than 70 percent of the input kinetic energy (within the bumper's physical limitations) to minimize rebound which could contribute to serious secondary results.

- Pedestrian Protection Characteristics. Bumpers should present a soft exterior for impact with objects at low speeds and should exhibit substantial deflection (1.0 to 1.5 inches) before significant force build-up is encountered. This should be useful to protect pedestrians and other objects during minor impacts. All bumpers tested need a slower rate of force onset, i.e., a soft face. The cost savings of soft face bumpers cannot be quantified at this time; further development in this field is needed.

- Readiness Characteristics. Bumpers should be designed to provide immediate, automatic resetting (within physical limitations) after impact without any adjustments or manual operations. All bumpers tested, with the exception of the water bumper, currently have this feature.

- Maintainability Characteristics. Bumpers should be designed to be nearly maintenance free, including periodic inspection and servicing. In addition, when maintenance action is required, due to a severe

impact, the failed bumper system should be restoreable to usable condition within four hours active repair time. This time includes removal from the bus, disassembly, replacement of failed component parts, reassembly and replacement on the bus. Rear bumper attachment brackets should be designed for quick removal/replacement without special tools, to minimize access time for engine maintenance that requires bumper removal.

- Reliability Characteristics. The mean time between failure (excluding major impacts beyond those required by the Transbus Specification) should not be less than 100,000-revenue-miles and the life expectancy should be a minimum of 12 years and/or 500,000 miles of in-service use. The life of the energy absorbing bumpers tested has not been determined, but general characteristics appear to be at least 10 years.

- Safety Characteristics. The bumper physical exterior should be designed with a smooth, soft exterior surface without sharp protrusions and should incorporate wrap-around features to provide maximum protection to corner panels of the bus. Rear bumpers should be designed to fare into the rear portion of the coach to prevent unauthorized riders from securing a toehold.

b. Specific Recommendations for Product Improvement.

- General. All bumper markers should be corrosion-resistant and the visible surfaces should be color-coordinated with the coach exterior.

- AMG Transbus Energy Absorbing Bumper. Recommendations for improvement are not delineated, because this bumper has been superseded by Firestone's HELP bumper (mentioned later).

- GMC Transbus Energy Absorbing Bumper. The faceplate of this bumper was easily deformed when impacted above 3 mph. No recommendations, because there are no current plans for production of the bumper by General Motors Truck and Coach.

- Rohr Transbus Energy Absorbing Bumper. This bumper has exhibited excellent energy absorbing characteristics. However, in the field demonstrations, the bumper face elastomer cover has proven to be easily smudged and difficult to clean. This cover should be improved in the interest of maintenance costs.

- EAS Energy Absorbing Bumper

  - Water Type. This bumper provides effective energy absorbing performance and is particularly effective in pedestrian-type accidents because of its "soft" face. However, it requires excessive time expenditure to ascertain bumper readiness. Improvements to decrease inspection/servicing time should be considered.

  - Foam Type (TRANSAFE)(9). No recommendations, due to insufficient in-service data.

- Firestone Energy Absorbing Bumper

  - Pneumatic (HELP)(10). No recommendations, due to insufficient in-service data. This type bumper should include devices that would provide quick visibility of bumper air pressure/ leaks.

  - Semi-Pneumatic (HELP)(10). No recommendations, due to insufficient in-service data.

c. Purchase of Energy Absorbing Bumpers. The results of this evaluation, supported by accident data which was related to operating costs, clearly indicate that energy absorbing bumpers have significant positive benefits. Transit authorities preparing purchase specifications should strongly consider equipping their new buses with energy absorbing bumpers both in front and in the rear. Data presented in this report should serve as a guide to the state-of-the-art for purposes of specification development.

REFERENCES

1. Booz, Allen Applied Research, The Benefits of Absorbing Energy Bumpers for Transit Buses, Department of Transportation, Report No. TR 73-013, November 1973.

2. Energy Absorption System, Inc., Impact Absorbing Water Bumpers. Brochure available from Energy Absorption Systems, Inc., One IBM Plaza, Chicago, Illinois 60611.

3. Gieck, Jack E., et al, "A High Energy Level Pneumatic Energy Absorbing Bumper," Society of Automotive Engineers, Paper Number 730029, January 1973.

4. Booz, Allen Applied Research, Transbus Technical Data, Department of Transportation, Report No. UMTA-IT-0025-74-1, November 1974.

5. Kendall, Giles A., "The Menasco Energy Absorbing Unit and Its Application to Bumper Systems," Society of Automotive Engineers, Paper Number 710536, June 1971.

6. Energy Absorption Systems, Inc., TRANSAFE the Ultimate Energy Absorbing Bumper. Brochure available from Energy Absorption Systems Inc., One IBM Plaza, Chicago, Illinois 60611.

7. Gieck, Jack E., et al, "The Production HELP Bumper: Evolution, Testing, and Evaluation," Society of Automotive Engineers, Paper Number 740062, February 1974.

8. Transbus Procurement Requirements, Department of Transportation, Urban Mass Transportation Administration, Washington, D.C. April 1976.

9. "Newest Safety Bumper Attractive and Maintainance Free," (TRANSAFE), Bus Ride, December 1975 issue.

10. "Does HELP Help?", (HELP Bumpers), Bus Ride, December 1975 issue.