REPORT NO. BP 79-001

LOW-FLOOR ARTICULATED BUS DEMONSTRATION

BOOZ·ALLEN & HAMILTON Inc.
TRANSPORTATION CONSULTING DIVISION
4330 EAST WEST HIGHWAY
BETHESDA, MARYLAND 20014

SEPTEMBER 1979

FINAL REPORT

Document is available to the public through the National Technical Information Service Springfield, Virginia 22161

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION

**URBAN MASS TRANSPORTATION ADMINISTRATION
WASHINGTON, D.C. 20590**

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16. Abstract

This report is documentation of a program to demonstrate the stability and anti-jackknifing capabilities of a low-floor articulated bus to the transit industry. To this end a low-floor, high-capacity, articulated bus prototype, developed by Hamburg-Consult of the Federal Republic of (West) Germany, was demonstrated and evaluated at five sites in the U.S. The low-floor concept, seen in the prototype, is an improvement over current articulated vehicle designs. The low floor allows faster and easier boarding, thus increasing productivity, and offering an advantage to elderly and handicapped persons. Data on performance, and reactions of drivers, maintenance and management personnel and on public reactions (news media) were collected. The performance and the industry's favorable reaction to the technology at all five sites is evidence of the prototype's demonstrated stability and anti-jackknifing capabilities.

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Unclassified	Unclassified	45	

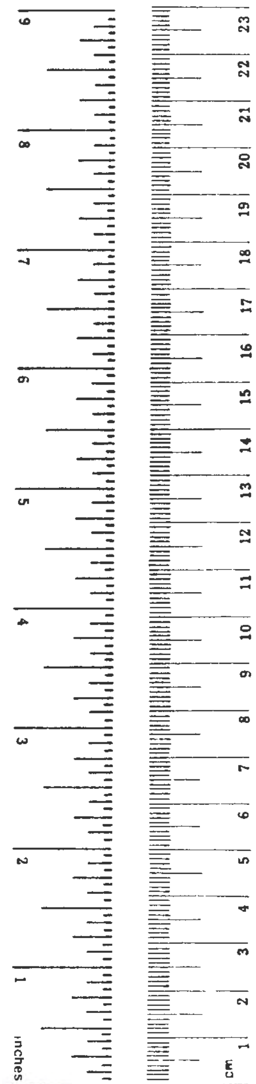
Form DOT F 1700.7 (8-69)

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

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

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



Approximate Conversions from Metric Measures

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

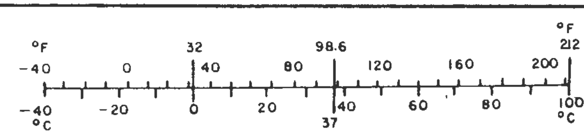


TABLE OF CONTENTS

INDEX OF FIGURES

INDEX OF TABLES

SUMMARY

This report is documentation of a program to demonstrate the stability and anti-jackknifing capabilities of a low-floor articulated bus. For the demonstration program a prototype coach built by the firm of Hamburg-Consult of the Federal Republic of (West) Germany was used. The Hamburg-Consult (HC) low-floor articulated bus was displayed and demonstrated at U.S. Department of Transportation headquarters, the Southeastern Michigan Transportation Authority (SEMTA), the Port Authority of Allegheny County (PATransit), and the Mass Transit Administration of Maryland (MTA). Additionally, testing and evaluation was conducted at the Transportation Research Center of Ohio (TRC).

Representatives from U.S. and Canadian governments, transit authorities, vehicle and component manufacturers, the news media, and the general public observed and rode in the bus during the demonstration period. Data of performance, and reactions of drivers, maintenance and management personnel, and on public reactions (news media) were collected. The prototype's performance and control and the favorable reaction to the technology at all five sites is evidence of the stability and anti-jackknifing capability of a low-floor articulated bus.

LIST OF ABBREVIATIONS

APTA	American Public Transit Association
DIN	Deutsche Ingenieur Nömber [technical rating system used in the Federal Republic of (West) Germany]
DOT	U.S. Department of Transportation
GVW	Gross Vehicle Weight
HC	Hamburg-Consult
MTA	Mass Transit Administration (of Maryland)
PATransit	Port Authority (of Allegheny County) Transit
SAE	Society of Automotive Engineers
SEMTA	Southeastern Michigan Transportation Authority
SLW	Seated Load Weight (curb weight plus one hundred-fifty pounds for every designated passenger seating position and for the driver)
TRC	Transportation Research Center (of Ohio)
UMTA	Urban Mass Transportation Administration
VOV	Verband Öffentlicher Verkehrsbtriebe [Federal Republic of (West) Germany equivalent of APTA]

I. INTRODUCTION

1. BACKGROUND

Many cities in Europe and other parts of the world are using high capacity transit vehicles to improve efficiencies in their mass transit systems. To achieve a higher vehicle capacity than the standard 12-meter (40-foot) urban vehicle, an overall longer articulated or a double-deck bus are used. In 1973, a consortium of American transit operating properties studied the feasibility of using high capacity buses in U.S. transit services.* Some of these cities have since acquired high capacity, articulated buses.

One of the program phases of the 1973 study was a preliminary configuration study of various vehicle arrangements that would permit a low floor height while using U.S. manufactured components. One of the most promising configurations was an articulated bus with a rear mounted engine and rear-axle drive. This design differed from contemporary articulated bus designs which have the engines under the floor of the front unit and are mid-axle driven.

In 1975, Hamburg-Consult (HC) of the Federal Republic of (West) Germany began development of a prototype low-floor, rear-engine, articulated bus. This vehicle has now been completed and thoroughly evaluated by several German bus properties and at least one vehicle manufacturer. The vehicle reportedly has no adverse handling characteristics due at least in part to a unique hydraulic damping and lock-up system in the hinge.

Because the HC articulated bus rear-engine, rear-axle driven configuration represented a technical advancement which would make a low-floor design possible, UMTA conducted a five week demonstration tour of the HC articulated bus at DOT headquarters and transit properties in three major U.S. cities. The vehicle demonstration program also included some performance testing at a test facility.

* High Capacity Bus Conceptual Design Study, Report No. UMTA-PA-06-007-74-2.

2. <u>OBJECTIVE OF THE STUDY</u>

The next DOT planned generation of American transit coaches, called Transbus, has a low-floor configuration. This demonstration intended to show that a high passenger capacity Transbus configuration could be developed embodying the low-floor concept by incorporating anti-jackknifing capabilities in the design and, thus, maintain coach stability. To meet this objective it was necessary to perform the following tasks:

- Demonstrate and exhibit the HC articulated prototype bus to the transit industry and government personnel, and to the transit passenger public in several key geographic locations

- Collect selected data related to operations, riding, and appearance characteristics of the HC articulated bus prototype.

3. <u>SCOPE OF THE PROGRAM</u>

During the demonstration the bus was driven over various types of terrain and in different urban traffic conditions for a total of 3,700 kilometers (2,300 miles). The demonstration program was intended to provide as wide an industry exposure as possible within the limited time available. To accomplish this, operating properties were used to provide local demonstrations.

Operating properties in three different locales were selected as demonstration sites because of their interest in articulated buses, representative terrains, and traffic patterns. By using operating transit properties to demonstrate the bus certain advantages were gained:

- Participants were familiar with the local terrain and media.

- Experienced personnel in all aspects of bus service could participate.

- Public reaction to the bus in actual (non-revenue) service could be studied.

Complementing the operating property demonstrations were performance testing of the bus, a two-day display for transportation officials and other interested parties at DOT headquarters, and a review/evaluation by the Bus Technology Committee of APTA.

4. PARTICIPANTS AND THEIR ROLES

Organizations that participated in the HC articulated bus demonstration and their major roles are presented in Table I-1. UMTA initiated and sponsored the HC articulated bus demonstration program as a result of a transit technology exchange with the Federal Republic of (West) Germany.

Booz, Allen & Hamilton provided program management, coordinated the activities and schedules of the other participants, and provided on-site personnel to coordinate, review and evaluate the responses to the bus concept.

The Bus Technology Committee of APTA was invited to observe and objectively review the HC articulated bus performance.

The vehicle, drivers, and on-road maintenance were provided by Hamburg-Consult.

The three operating properties of Baltimore, Pittsburgh, and suburban Detroit were involved in the demonstration program. These organizations had the specific knowledge of local conditions and were well-equipped to thoroughly conduct a demonstration program. Evaluations encompassed in-house reviews as well as observations on public acceptance of the bus. The operating properties were responsible for demonstration of the bus and logistics support. This included:

- Arranging demonstration and public exhibition schedules. This task was performed in coordination with Booz, Allen & Hamilton.
- Making available property personnel who rode, examined, and commented on the bus. These included drivers, maintenance supervisors, operations, scheduling and management personnel.
- Arranging the public awareness program at demonstration sites. Booz, Allen & Hamilton provided an advance sample press release and Hamburg-Consult bus handouts.

TABLE I-1
Participating Agencies and Their Roles in the HC Articulated Bus Demonstration Program

AGENCY	ROLE
U.S. Department of Transportation Urban Mass Transportation Administration	Sponsoring organization Program evaluation
Booz, Allen & Hamilton	Prime contractor Developed program plan Program management Technical support Prepared final report
Hamburg-Consult	Subcontractor Provided and operated the bus Technical support
Transportation Research Center of Ohio	Subcontractor Provided test facilities
Mass Transit Administration of Maryland (Baltimore)	Participating transit property Evaluated the bus Conducted public demonstrations
Port Authority of Allegheny County (Pittsburgh)	Participating transit property Evaluated the bus Conducted public demonstrations
Southeastern Michigan Transportation Authority (Suburban Detroit)	Participating transit property Evaluated the bus Conducted public demonstrations

- Providing diesel fuels and lubricants normally available at the property, for operation of the vehicle. Unique lubricants or components were provided by Hamburg-Consult.

- Providing garaging and safeguarding of the vehicle.

- Supporting Hamburg-Consult personnel, as needed, in minor maintenance of the vehicle.

In addition, MTA Baltimore assisted Hamburg-Consult personnel in preparing the bus for demonstration after its arrival at the Baltimore dock, and for shipment back to the Federal Republic of (West) Germany after the program was completed.

II. DESCRIPTION OF THE HAMBURG-CONSULT ARTICULATED BUS

The prototype bus demonstrated at various sites in the U.S. represents an advancement in articulated bus technology. Current articulated bus designs are mid-axle driven; this model, because of its rear-mounted engine, is driven by the rear axle (see Figure II-1).

Mid-axle drive, with the middle axle in front of the hinged section, is the current design approach in articulated buses. In this design approach the second, or trailing section of the vehicle is pulled by the front section. To drive the mid-axle it has been necessary to locate the engine under the floor of the front unit. However, this engine location requires a very high floor, particularly so if using an American engine.

To solve the problem of combining a low-floor with articulation, Hamburg-Consult located the engine in the rear of the trailing section, driving the rearmost wheels so that the bus is actually pushed. This resulted in the floor forward of the rear door of the prototype being 54 centimeters (21 3/4 inches) above the street level. For expediency in building the prototype vehicle, the rear undercarriage including the driven axle and tires is from a production high-floor transit bus. Thus, the floor behind the rear door is stepped up approximately 20.3 centimeters (8 inches) and has a 4° 30' slope upward to the rear of the bus. The production version of the HC articulated bus design would incorporate a low-floor trailer section.

For safety reasons, control of the vehicle articulation is of concern on an articulated bus design. To be able to locate the engine in the rear and drive the rear axles, the vehicle articulation must be controlled. To control the angle and motion of the two sections, an electronically-controlled, anti-jackknifing, hydraulic damping and lock-up system was installed in the hinged section. The turning angle of the front, steered wheels is measured electronically. This information is used to control two hydraulic cylinders in the hinged section such that the vehicle is free to move in the direction of the steer up to the angle of the wheels. The hydraulic cylinders will allow relative motion only

FIGURE II-1
The Hamburg-Consult Articulated Demonstration Bus

between this angle and the straight, in-line position of the two sections. Controls on the cylinders damp the relative motion to prevent jackknifing. By design, the articulation is limited to a maximum angle of 45° in either direction.

The prototype, which is 17 meters (55.8 feet) long, 2.5 meters (8.2 feet) wide, and 2.7 meters (8.75 feet) high, seats 57 passengers and is rated for 113 standees. Interior height is approximately 210 centimeters (84 inches), except in the rear where it is less than 175 centimeters (70 inches). The seats are mounted on a 14.75 centimeter (5.9 inch) platform and all face forward, the preferred arrangement in the Federal Republic of (West) Germany. This arrangement leaves a center aisle width of 56 centimeters (22 inches). The major external dimensions of the HC articulated bus and seating arrangements are shown in Figure II-2.

Complementing the low-floor, the first and middle axles are fitted with 275/70R x 17.5 tires with a tire width of 29 centimeters (11.4 inches) and outside diameter of 83 centimeters (32.7 inches). This compares with the tire width of 27 centimeters (10.6 inches) and to 98 centimeters (38.6 inches) outside diameter of the 11/70 x 22.5 standard transit tires on the rear axles. The middle and rear axles are both equipped with dual tires. Weight distribution figures provided by Hamburg-Consult (see Table V-2 in Tests chapter) suggest that the highest loadings are on the front tires. Thus, these figures indicate a load carrying capability of 2,850 kilograms (6,500 pounds) for the 275/70R x 17.5 tires.

Entry and exit is provided by three passenger doorways that glide inwards, opening at the middle toward each side of the passageway. Each doorway has two steps, the lowest being 34 centimeters (13.4 inches) above street level and the second 20 centimeters (7.9 inches) above the first. At the driver's option, the rear door can be passenger-operated with an automatic time-delayed or photocell-activated closing (Figure II-3).

The engine is a six-cylinder, in-line, horizontally mounted diesel manufactured by Daimler-Benz, and is positioned to drive longitudinally forward. The engine is rated by the German standard at 210 DIN horsepower, roughly 250 SAE HP. The prototype is equipped with a three-speed Daimler-Benz automatic transmission (Type W 3D080/x.12) with a torque converter and hydraulic retarder.

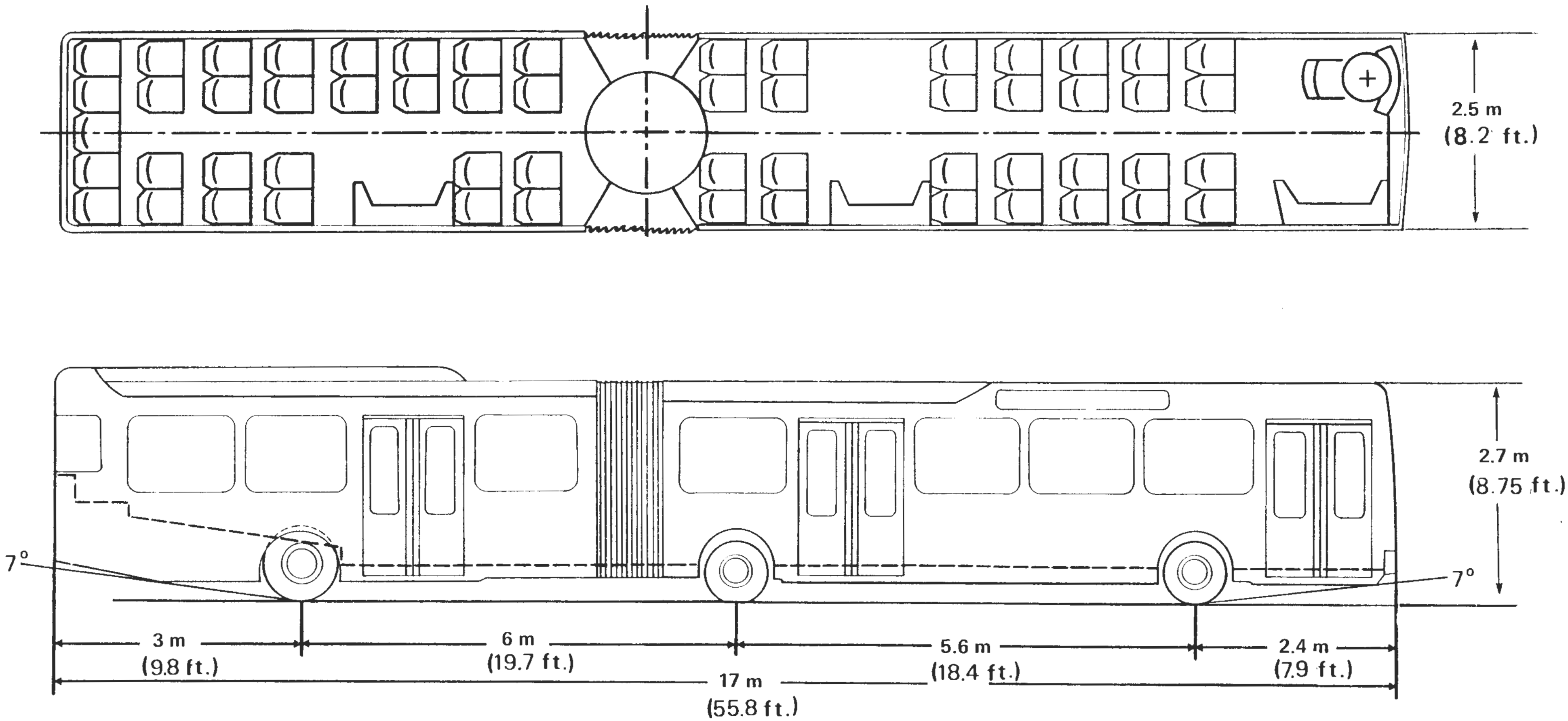


FIGURE II-2
Major External Dimensions - HC Articulated Transbus

FIGURE II-3
Passengers Boarding

Two additional features of the HC prototype articulated bus that distinguish it from American coaches are the air conditioning and heating systems. The HC articulated bus, typical of Federal Republic of (West) Germany buses, does not have air conditioning. The coach heater system is a hot water system which supplements the engine heat with an oil-fired boiler. The boiler is diesel fuel powered, with fuel stored in a tank separate from the main fuel storage tank. The supplemental hot water heating capability is used to pre-heat the engine prior to start, a feature that increases engine life. This capability also allows for a rapid coach warm-up.

III. DEMONSTRATION SCHEDULE

The bus demonstration schedule was planned for maximum exposure to target groups identified during the planning phase of the program (see Table III-1). The major scheduled stops of the demonstration were the following:

- U.S. Department of Transportation (DOT)
- Southeastern Michigan Transportation Authority (SEMTA)
- Transportation Research Center (of Ohio) (TRC)
- Port Authority (of Allegheny County) Transit (PATransit)
- Mass Transit Administration (of Maryland) (MTA).

A description of these follows.

1. U.S. DEPARTMENT OF TRANSPORTATION (DOT) DISPLAY

The articulated bus was on display and available for rides at the U.S. Department of Transportation (DOT) headquarters in Washington, D.C. During these first two days of inspection, Urban Mass Transportation Administrator, Richard Page, and Secretary of Transportation, Brock Adams, rode and reviewed the bus. Reporters from local affiliates of the three television networks, the independent television network, and the Westinghouse Broadcasting System covered the event.

2. SOUTHEASTERN MICHIGAN TRANSPORTATION AUTHORITY (SEMTA)

The SEMTA demonstration was scheduled for four days, one day longer than the other two transit property demonstrations because of its proximity to bus manufacturing companies and the automotive industry. During the four days, two exhibitions were held, one for Canadian industry representatives and one for regional transit authority personnel. One main press conference for television and the major Detroit newspapers was supplemented with two others for the suburban media.

This site was chosen because the SEMTA locale is characterized by long distance hauls with high average route speeds. The bus was used on a variety of routes including main line local, suburban express, and a park-and-ride. Management, maintenance personnel, and drivers from the three SEMTA terminals inspected, rode on the bus, and offered comments on its viability.

TABLE III-1
Hamburg-Consult Bus Schedule

Date	Location	Activity
Nov. 6	Baltimore	Off-load from ship
Nov. 8-9	Washington	On display at DOT
Nov. 10-11		Transport to Detroit
Nov. 11, 13-15	Detroit	On display at SEMTA
Nov. 16		Transport to TRC
Nov. 17	TRC	Testing
Nov. 20	TRC	Testing
Nov. 21	TRC	Bus Technology Committee review
Nov. 22		Transport to Pittsburgh
Nov. 28-30	Pittsburgh	On display at PATransit
Nov. 30-Dec. 1		Transport to Baltimore
Dec. 4-6	Baltimore	On display at MTA
Dec. 15		On-load on ship to Germany

3. TRANSPORTATION RESEARCH CENTER (TRC)

The test track phase of the low-floor articulated bus demonstration encompassed testing of the anti-jackknifing characteristic and the overall coach stability. Also covered were performance tests required for Transbus designs. The tests covered acceleration, maneuverability, braking, ride quality, control, and noise levels. Procedures and results are discussed in Chapter V.

4. PORT AUTHORITY (OF ALLEGHENY COUNTY) TRANSIT (PATransit)

Pittsburgh was a particularly appropriate demonstration site because of its hilly terrain and varying traffic conditions. The program included a demonstration run, a park-and-ride, and a local haul. Personnel from all five PATransit garages and terminals were given the opportunity to observe and ride the vehicle. A news conference and public display in the downtown area were covered by local affiliates of the three networks as well as Pittsburgh area newspapers.

5. MASS TRANSIT ADMINISTRATION OF MARYLAND (MTA)

The concluding demonstration site in Baltimore, Maryland was chosen because of its particularly narrow and congested traffic patterns. This site visit included a downtown press conference and public display, review at all MTA terminals, and runs at various Baltimore locations.

Figure III-1 is a map indicating sites and dates of the HC bus demonstration.

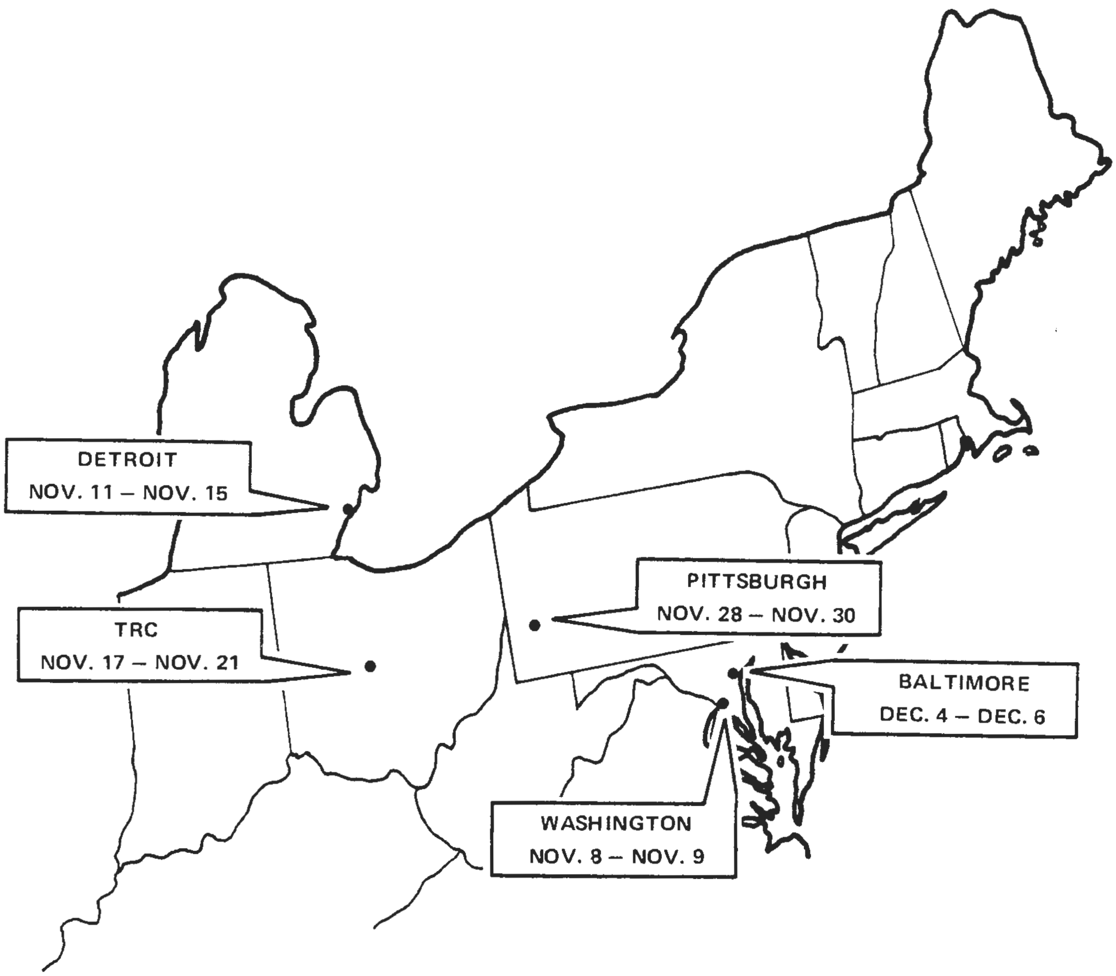


FIGURE III-1
Hamburg-Consult Articulated Bus
Demonstration Sites - 1978

IV. SUBJECTIVE RESPONSES

Throughout the demonstration many people had the opportunity to observe the bus operation, ride on the bus, question project personnel, and reach their own conclusions about the various aspects of the bus. With due consideration to the idiosyncrasies of this particular vehicle and the conditions under which it was demonstrated, a fair and objective evaluation was made. For this demonstration, three types of subjective responses were assessed. These were the following:

- Interviews - Responses of drivers, maintenance and operations personnel were recorded on data forms.
- Public Awareness - The amount and type of media coverage was indicative of the likely public response and interest in the low-floor articulated bus concept.
- Rider Responses - Live interviews with riders, including interested parties and random boarders, yielded candid responses and insight into the ride quality of the bus.

Figure IV-1 shows the HC articulated bus on a demonstration run.

1. INTERVIEWS

At the three operating properties where the vehicle was demonstrated, all types of transit personnel had the opportunity to review the design. Their responses were gathered through personal interviews . To achieve better focus and obtain more detailed information from respondents in each category, transit personnel were classified into three types:

- Drivers
- Maintenance Supervisors
- Operations/Management Personnel.

Responses of these are presented in Appendix A.

In brief, the drivers and management personnel were favorably disposed while maintenance personnel exhibited some hesitancy toward the HC articulated bus, due more to its metric standards than its technology.

FIGURE IV-1
HC Articulated Bus Demonstration Run

2. PUBLIC AWARENESS

Local media coverage was arranged through the DOT Office of Public Information. All articles emphasized the local aspects (e.g., time and place of demonstration) and the novelty of the articulated features.

The broadcast media showed particular interest in the vehicle as evidenced by the presence of reporters from most local stations. Footage that appeared on the air included excerpts from interviews with UMTA and local transit personnel.

3. RIDER OBSERVATIONS

Comments were recorded from riders representing both the public and industry on their perspective of the ride quality of the bus. Features that they found to be particularly appealing were the ride quality of the seats, the increased visibility, the wide doors, and the low floor. One undesirable aspect mentioned was the noisiness in the back, where seats were directly over the engine.

V. TESTS

Stability and performance testing of the HC articulated bus was conducted at the Transportation Research Center (TRC) of Ohio at East Liberty, Ohio.

1. TEST APPROACH

Testing of the articulated bus included measurements, acceleration, gradability, braking, maneuverability, noise levels, and ride quality. These tests were conducted because they afforded a basis for comparison with other types of buses using a minimum of instrumentation and time. The daily testing schedule is presented in Table V-1.

TABLE V-1
Test Schedule for Hamburg-Consult Articulated Bus

Day	Tests
1	. Pylon maneuverability . Ride quality on durability course . Turning radius . Top speed . Dry braking . Wet braking
2	. Noise . High speed control (dry pavement) . Ride quality . 20% grade braking . Acceleration
3	. APTA committee observation . Weight

The test results of the prototype vehicle may vary somewhat from those of actual production vehicles. Depending on the options and configuration selected by an operating property, the performance characteristics of similarly produced vehicles may vary as well. This variability, based on design changes, must be considered when comparing a bus with alternative vehicles, and when adhering to operating requirements.

Instrumentation of the vehicle was kept to a minimum, with the following equipment utilized for testing:

- Fifth wheel - to measure bus velocity and accumulated distance
- Electronic tachometer - for engine speed
- Stop watch - to measure elapsed time
- GenRad sound level meter - for noise tests.

2. TEST RESULTS

A discussion of the results of each test follows.

(1) Measurements

Selected measurements of the bus were made to verify information provided by Hamburg-Consult.

The vehicle was weighed to estimate the SLW. The test weight varied from the unloaded weight, as several seats had been removed and two spare parts containers installed for the U.S. demonstration. The test track weight and other significant weights are presented in Table V-2.

TABLE V-2
Weights of Vehicle for Various
Conditions and Configurations

	Curb[1]	Measured[2]	SLW	GVW[1]
Front axle	3,380 kgs. (7,452 lbs.)	3,290 kgs. (7,253 lbs.)		5,800 kgs (12,787 lbs.)
Center axle	2,695 kgs. (5,941 lbs.)	3,880 kgs. (8,554 lbs.)		8,000 kgs. (17,637 lbs.)
Rear axle	6,455 kgs. (14,231 lbs.)	6,800 kgs. (14,991 lbs.)		10,000 kgs. (22,046 lbs.)
Total Weight	12,530 kgs. (27,624 lbs.)	13,970 kgs. (30,798 lbs.)	17,250 kgs. (38,029 lbs.)	23,800 kgs. (52,470 lbs.)

1 Figures provided by Hamburg-Consult
2 Measured on scales at TRC (nine people on board)

Turning radii include wall-to-wall and curb-to-curb dimensions. These figures, along with the requirements for UMTA-funded bus procurements, are displayed in Figure V-1.

(2) Acceleration

Acceleration performance was determined by measuring the times required for the vehicle to accelerate from a standstill to various speeds. These times were corrected to SLW, and the resulting acceleration curve plotted (Figure V-2).

For comparison, the minimum performance specifications for Transbus vehicles were used.

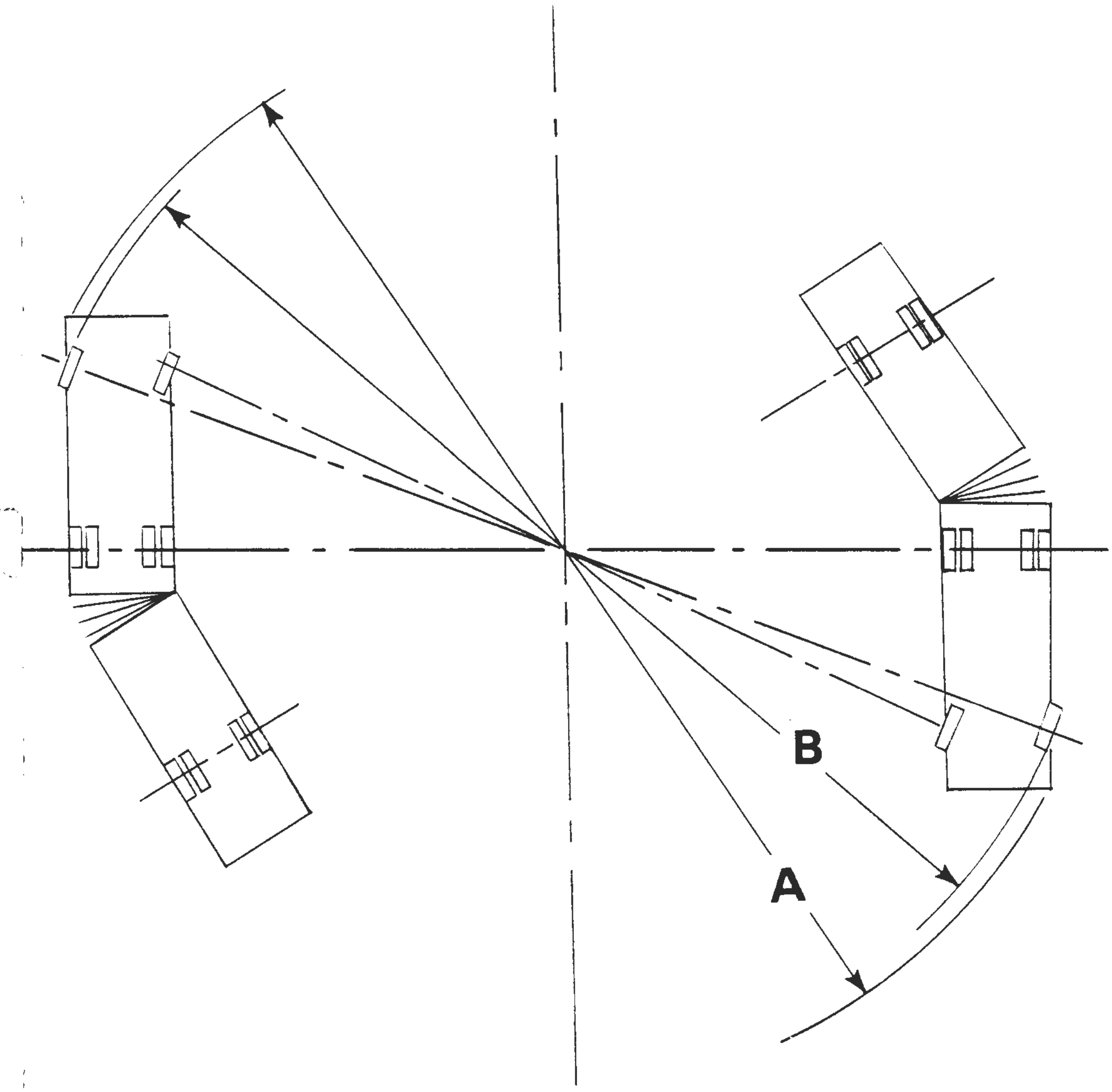
Because of its configuration and top speed, the correct basis for comparison of the HC bus should be the low-power alternative.

The articulated bus acceleration performance is measurably better than that of the low-power option. Indeed, the HC bus appears comparable with the standard power plant specifications.

(3) Gradability

The gradability of any transit vehicle is the speed which that vehicle can maintain on a given grade slope. Since the dimensions, acceleration rate, and horsepower of the HC bus are known, the power requirements at any given speed can easily be determined. The excess power available at that speed is used to maintain a given speed on a slope.

The gradability curve was determined by computer analysis. In conjunction with this, we performed a sensitivity analysis of all characteristics specific to this vehicle (e.g., coefficient of drag, transmission efficiency). The resulting gradability curve (Figure V-3) is relatively insensitive to these values.



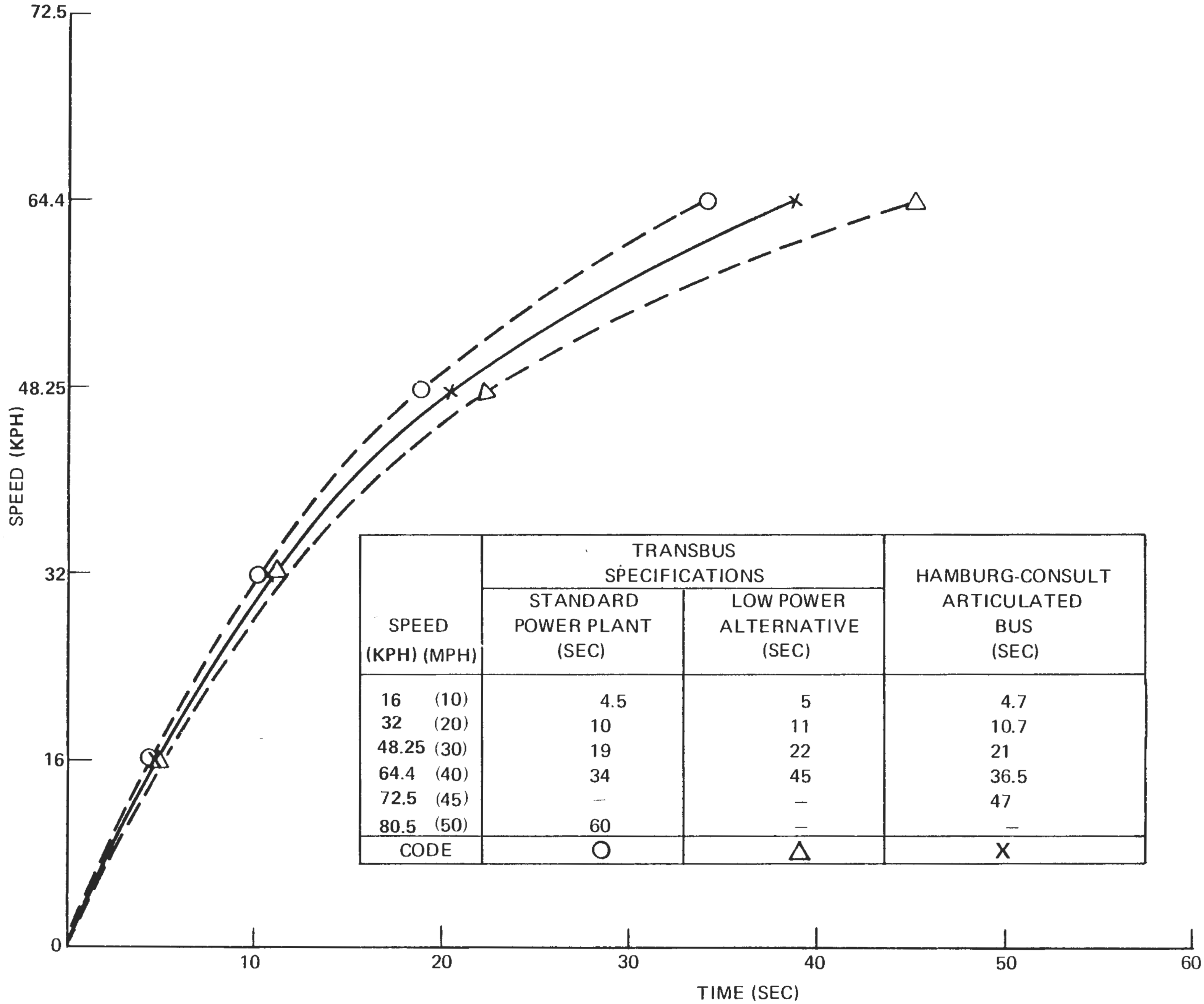
HC BUS DIAMETERS

A – WALL-TO-WALL DIAMETER: 24 m (79.5 ft)
B – CURB-TO-CURB DIAMETER: 21 m (69.5 ft)

UMTA TRANSBUS REQUIREMENTS

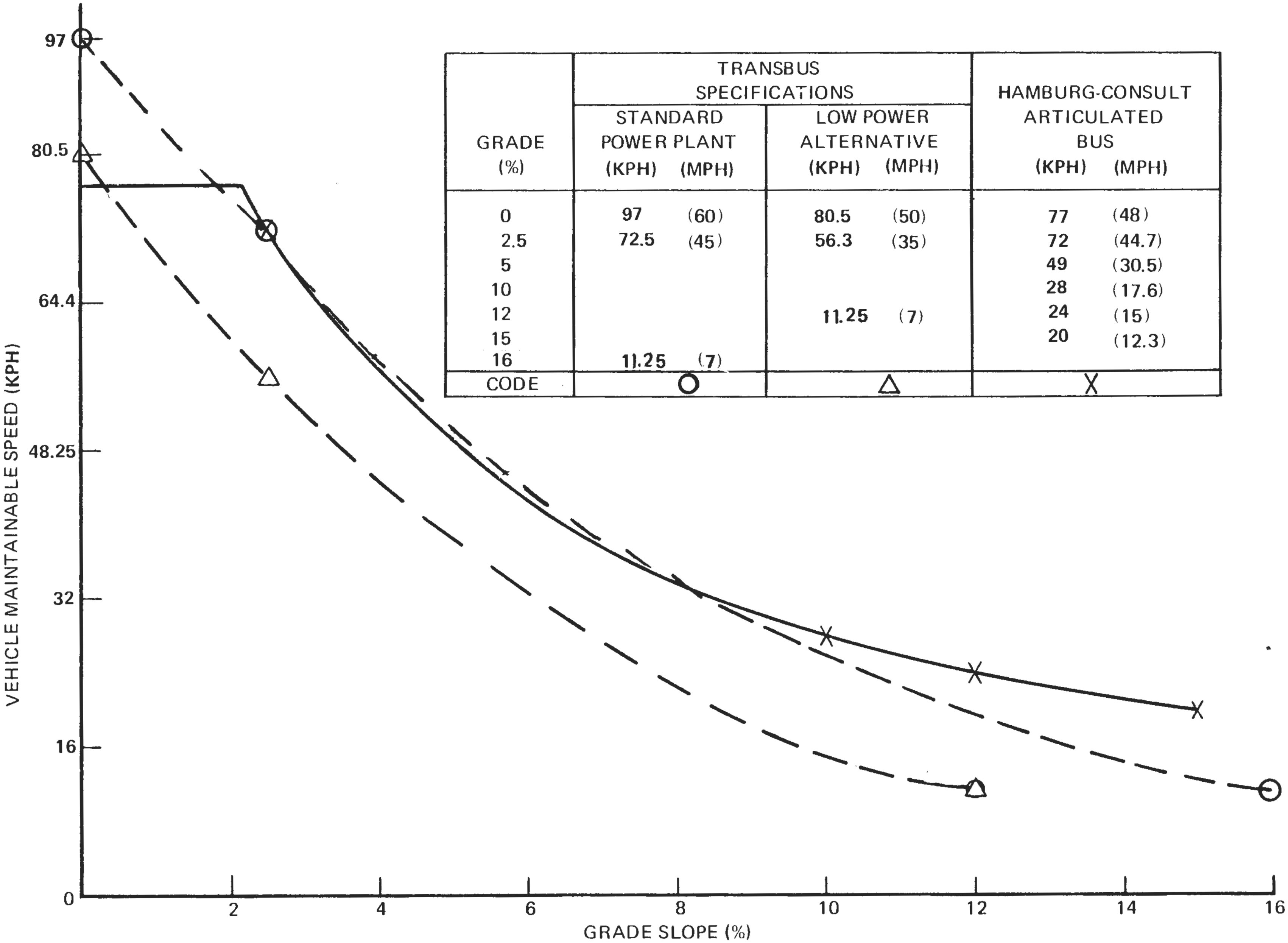
A – WALL-TO-WALL DIAMETER FOR 12 m (40 ft) TRANSBUS: MAXIMUM 26.8 m (88 ft)
B – WALL-TO-WALL DIAMETER FOR 10.7 m (35 ft) TRANSBUS: MAXIMUM 23.8 m (78 ft)

FIGURE V-1
Turning Radii of Hamburg-Consult Bus
and UMTA Transbus Requirements



SPEED (KPH) (MPH)	TRANSBUS SPECIFICATIONS STANDARD POWER PLANT (SEC)	TRANSBUS SPECIFICATIONS LOW POWER ALTERNATIVE (SEC)	HAMBURG-CONSULT ARTICULATED BUS (SEC)
16 (10)	4.5	5	4.7
32 (20)	10	11	10.7
48.25 (30)	19	22	21
64.4 (40)	34	45	36.5
72.5 (45)	–	–	47
80.5 (50)	60	–	–
CODE	○	△	X

FIGURE V-2
Acceleration Curve



GRADE (%)	TRANSBUS SPECIFICATIONS STANDARD POWER PLANT (KPH)	(MPH)	TRANSBUS SPECIFICATIONS LOW POWER ALTERNATIVE (KPH)	(MPH)	HAMBURG-CONSULT ARTICULATED BUS (KPH)	(MPH)
0	97	(60)	80.5	(50)	77	(48)
2.5	72.5	(45)	56.3	(35)	72	(44.7)
5					49	(30.5)
10					28	(17.6)
12			11.25	(7)	24	(15)
15					20	(12.3)
16	11.25	(7)				
CODE	O		△		X	

FIGURE V-3
Gradability Curve

(4) Braking

The bus was braked at various speeds on both wet and dry surfaces, with no "fishtailing" of the rear section, or unusual control problems. The vehicle stopped in a straight line regardless of the steering wheel angle or wheel lock-up.

The parking brake was tested on a 20 percent brake slope; no slippage problem was noted.

(5) Maneuverability

Maneuverability was measured with a low speed slalom course and high speed yaw and roll control on dry and wet surfaces.

The low-speed slalom course consisted of five pylons placed equidistant apart. The bus was driven on alternating sides at speeds ranging from 8 to 24 kilometers per hour (5 to 15 miles per hour) (Figure V-4). The distance between pylons was decreased until the vehicle was not able to negotiate the prescribed course without running over one or more pylons. The minimum distance between pylons was found to be 11.25 meters (37 feet), which could be negotiated at 8 to 16 kilometers per hour (5 to 10 miles per hour) with good clearance at each pylon.

The second test was a handling maneuver at high speed to observe driver control, vehicle stability, and ride quality (Figure V-5). The bus was driven at various speeds, including top speed, with the driver performing alternating right and left turns as fast as possible. No loss of control or handling difficulty was recorded. Since this is an extreme maneuver, one should anticipate larger motion forces on riders. However, while the visual effects were dramatic, there were no unusual or unacceptable forces on the riders. There was no measureable difference in effect between the wet and dry surfaces.

(6) Noise

Test sites were selected to conform to SAE J366b requirements.

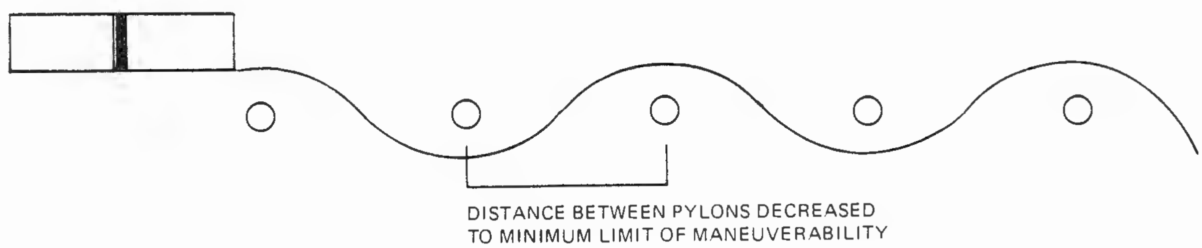


FIGURE V-4
Maneuverability Test
Low-Speed Slalom Course

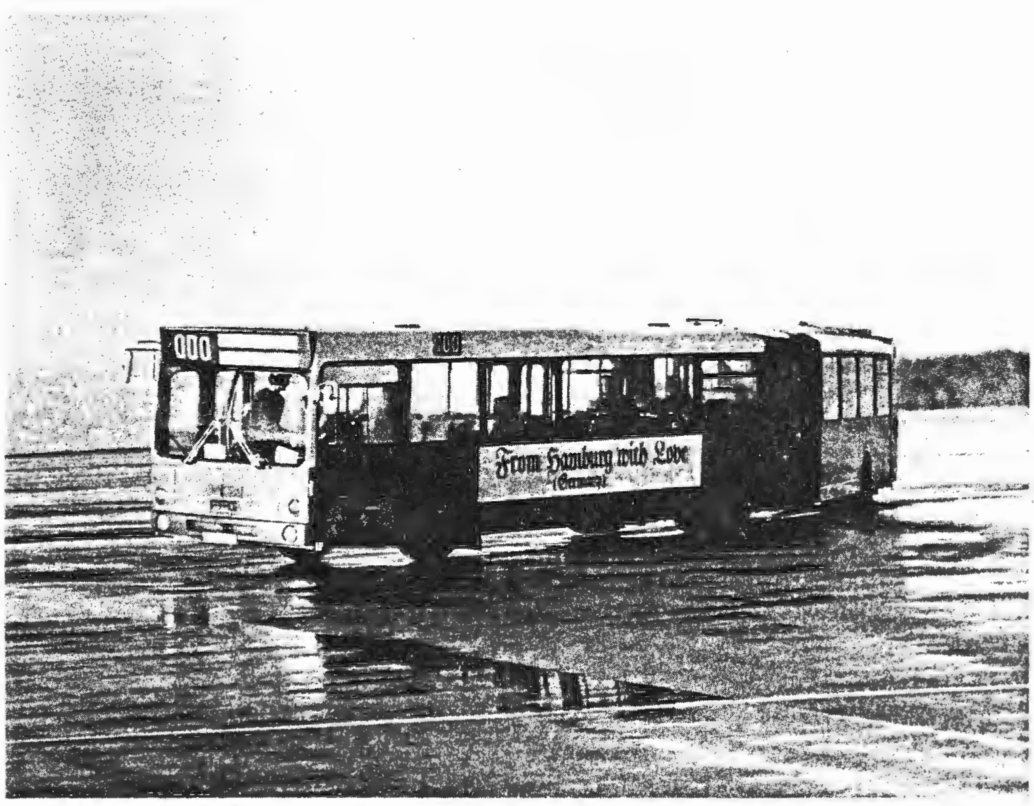


FIGURE V-5
High Speed Handling Test

This series included two repetitions each of the EPA/SAE J366b acceleration tests. For each bus pass-by, the maximum observed A-weighted sound level was recorded. Runs were repeated for each side of the bus until two maxima within two dBA were recorded. (Average sound levels were recorded for the stationary idle test.) The series of nine exterior measurements is shown in Table V-3.

TABLE V-3
Exterior Noise Test Measurement Series
(Each Series Bi-Directional)

A	EPA/SAE Accelerated Run
B	Constant Speed Cruise-by at 48 kph (30 mph)
C	Constant Speed Cruise-by at 88 kph (55 mph)
D	DOT Pull-Away
E	Coast-Down from 40 kph (30 mph)
F	Coast-Down from 88 kph (55 mph)
G	EPA/SAE Acceleration Run
H	Idle
I	DOT Pull-Away

Interior noise measurements were made at three locations along the longitudinal centerline of the bus:

- Front (just behind the driver's seat)
- Hinge axis
- Rear (just forward of the rear seat).

These measurements were made with the bus stationary, the engine idle, and the engine at governed speed.

The HC articulated bus prototype tested significantly quieter than in-service American transit buses. This difference is approximately 1½ dBA curbside and

4 dBA streetside, as shown in Table V-4. The prototype also fully meets the U.S. EPA proposed first-step noise emission limits, meets the second-step exterior noise emission limit, and approaches the interior noise limit.

(7) Ride Quality

No instrumentation was used for this evaluation, so all results are based on subjective observation and reactions. To examine the ride quality, the bus was evaluated on various surfaces, including sections of the TRC durability course. [These were the 5 centimeter (2-inch) sine wave, 2.5 centimeter (1-inch) deep random chuckholes, 1.9 centimeter (3/4-inch) chatter bumps at 15°, and the high crown intersection sections.]

TABLE V-4
Comparison of HC Articulated Bus Prototype to In-Service American Transit Buses and Proposed EPA Regulations
(dBA re 20 μ Pa)

		Exterior Noise (from SAE J366b)		Interior Noise at Rear (From SAE J366b)
		curbside	streetside	
In-service American transit buses*		80.0 79.9	81.5 83.8	84.3 84.2
HC articulated bus prototype		78.5	78.5	83.5
EPA proposed noise emission regulation**	Step 1	83		86
	Step 2	80		83
	Step 3	77		80

* Proposed Bus Noise Regulation—Background Document, U.S. EPA 550/9-77-201, August, 1977.

** Bus Noise Emission Standard—Notice of Proposed Rulemaking, U.S. EPA 42 RF 45 776, September 12, 1977.

There was little distinguishable difference between ride motion or forces in the very front and the very back of the vehicle. The area of the bus that did have a different quality of ride was between the middle axle and the articulation joint. The reaction points for road bumps are the free ends, the axles, and the articulation joint, and those seat positions on the bus experience choppier and more pronounced suspension system travel than seats positioned on the longer reaction areas. However, the only seats where the choppiness is pronounced are the eight (four per side) directly in front of the articulation section and behind the middle axle.

The ride quality in the driver's seat was distinctly smoother than that of standard U.S. transit buses due in part to a spring-loaded, driver weight-calibrated, seat suspension.

VI. CONCLUSIONS

This program to demonstrate the Hamburg-Consult articulated bus was conducted to exhibit the latest in technology in high-capacity, low-floor bus design. Specifically, the program intended to demonstrate to the U.S. transit industry and to bus manufacturers that a low-floor is feasible in an articulated bus. For this demonstration the HC articulated bus served as an example of this technology as accomplished in the Federal Republic of (West) Germany through the use of an anti-jackknifing device that maintains vehicle stability and control with no sacrifice in performance.

During operations on city streets and at the test track, no adverse characteristics were observed that could be attributed to the vehicle's length or its articulation feature. As part of the vehicle's design evaluation, transit property operators drove the bus through numerous urban maneuvers including tight turns, steep ascents and descents, dense traffic conditions, and combinations of these. In all instances, the subjective assessments suggested that the bus handled as well as, or better than, standard U.S. 12-meter (40-foot) urban transit buses. At the test track turning radii, maneuverability, acceleration, noise testing, and ride quality were all comparable to standard U.S. 12-meter (40-foot) urban transit bus requirements. Therefore, it can be concluded that this low-floor design approach appears to be technically feasible for articulated high-capacity transit buses.

APPENDIX A

INTERVIEW RESPONSES

DRIVER RESPONSES

Total Responses: 8

(Responses to individual questions may not add up to 8, since all respondents may not have answered all questions.)

1. Bus driving experience

	Years	Type of Service	
Under 5 yrs.	4	Transit	8
5-10 yrs.	1	School	1
Over 10 yrs.	1	Intercity	1

2. Prior to this demonstration, to what extent were you familiar with articulated buses?

Drove one once	2
Familiar with but never drove one	2
Unfamiliar	4

3. What was your reaction upon learning about this type of vehicle?

Enthusiastic	3
Willing to try it	5
Negative	0

4. What was your reaction after trying it out?

Enthusiastic	7
Need more experience	0
Negative	0

5. Did you operate the bus under any abnormal conditions?

Yes	3
No	1

Traffic?	Heavy 3	Med 1	Light 0
Road Conditions?	Detour 2		
Service?	Special Event 2		

Driver Responses
Page Two

6. Did you like the way the bus handled?

Yes	7
Not sure	0
No	0

7. How did you feel about the handling of the vehicle?

Secure	6
Need more practice	0
Insecure	0

8. As compared with the bus you normally drive, how would you rate this vehicle's performance while making the following maneuvers:

	Better	About the Same	Slightly More Difficult	Much More Difficult
Cornering	5	1	0	0
Stopping	3	1	1	0
Changing Lanes	1	1	3	0
Accelerating	3	2	0	0
Backing	1	1	0	2
Overall Control	3	1	1	0

9. Was the visibility of the rear-most doors adequate?

Yes	3
No	2

10. Did you encounter blind areas in the operation of this bus?

Yes	1
No	4

11. Given the opportunity, would you prefer driving this bus rather than the bus you normally operate?

Yes	3
Not sure	3
No	0

MAINTENANCE SUPERVISOR RESPONSES

Total Responses: 14

(Responses to individual questions may not add up to 14, since all respondents may not have answered all questions.)

1. From a maintenance standpoint, how familiar are you with articulated buses?

Familiar with but never worked on	4
Unfamiliar	10

2. Please comment on the capability of your shop facilities to accommodate an articulated vehicle such as the Hamburg-Consult bus.

	Adequate	Need Minor Modification	Need Major Modification
a. Length of bays	3	3	6
b. Lifts	2	1	11
c. Pits	0	1	3
d. Room inside shop	3	5	6
e. Parking in yard	14		

3. There are features on an articulated bus which are not found on standard buses. Do you feel these components will cause major maintenance problems?

Yes	6
Not sure	7

4. Under normal in-revenue service of an articulated bus, what level of effort (in monthly manhours) do you feel will be required for maintenance and repair of the following components?

   Respondents felt they needed more experience with the bus before they could answer this question.

5. Is existing shop equipment adequate for normal maintenance and repair of those components unique to the articulated bus?

Yes	2
Not sure	5
No	6

Maintenance Supervisor
Responses
Page Two

6. Would your mechanics need significantly more training (more than 3 weeks) to perform normal maintenance and repair of those components unique to the articulated bus?

Yes	10
Not sure	2
No	1

7. In comparison with the standard bus you normally repair, what level of maintenance effort would be required to accomplish the following tasks on an articulated bus?

	About the Same	Slightly More	Much More
a. Fuel, wash & clean	3	6	4
b. Perform routine inspection tasks	-	4	8
c. Perform major overhaul operations			
Engine	-	7	4
Transmission	-	7	4
Axles	3	2	3
Brakes	5	4	2
Steering	1	5	5
Suspension	3	5	3

8. Overall, how do you feel the cost to maintain an articulated bus compares to the cost to maintain the standard bus? (Please consider all maintenance costs to include labor, parts, facilities, equipment, etc.)

Slightly more	4
Much More	8

9. Do you feel vehicle design or components could be modified or rearranged on the articulated bus in order to improve maintainability?

Yes	3
Not sure	7
No	2

OPERATIONS/MANAGEMENT RESPONSES

Total responses: 7

(Responses to individual questions may not add up to 7, since all respondents may not have answered all questions.)

1. Identify your major area of responsibility within the transit property.

Management	4
Operations	3
Scheduling	0

2. Approximately what percentage of your transit routes would you consider as high density routes?

	Peak Periods	Slack Periods
Under 20%	1	5
20-40%	3	2
Over 40%	3	0

3. Prior to this demonstration, how familiar were you with articulated buses?

Very familiar	0
Somewhat familiar	4
Unfamiliar	3

4. After seeing the demonstration of the bus, how do you feel about its design characteristics and performance?

Excellent	0
Good	6
Need improvement	0
Not sure	1

5. How do you feel about the potential of high capacity/articulated buses in the transit industry as a whole?

Excellent	3
Fair	3
Poor	0
Not sure	1

Operations/Management Responses
Page Two

6. Based on your current operations, are you having some problems meeting passenger demands in high density routes during peak periods?

No problem	0
Some problem	7
Not sure	0

7. To what extent would the operation of some articulated buses in your fleet assist in meeting high passenger demands on high density routes?

Greatly	2
Somewhat	4
No effect	0
Not sure	1

8. From an efficiency standpoint, what advantage would result from the operation of some articulated buses in your fleet?

High	2
Fair	2
None	0
Not sure	3

9. Would you be interested in continuing to pursue the potential application of articulated buses in your transit fleet?

Very	2
Somewhat	3
No	0
Not sure	1