REPORT NO. UMTA-MA-06-0031-75-1

PERFORMANCE EVALUATION OF AN AIR-LEVITATED AIR-PROPELLED, PASSIVE VEHICLE PERSONAL RAPID TRANSIT SYSTEM

Charles H. Smoot, Editor

JUNE 1975

FINAL REPORT

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Washington DC 20590

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16. Abstract

An eight-passenger Uniflo vehicle was tested to 30 ft/sec on enclosed guideway through curved straight and switch sections.

The following parameters were measured:
- ride quality, as 3 axis acceleration
- noise emission as perceived by passengers and in area near guideway
- vehicle acceleration and service braking
- switch response time
- levitation air flow and power requirements
- propulsion air flow and power requirements
- performance and reliability between -20°F and +90°F

Performance highlights included:
- ride quality approximates goals in UMTA's HPPRT Program
- noise near guideway substantially better than HPPRT goals
- noise in vehicle meets HPPRT goals above 1,000 Hz and improvement at lower frequencies is feasible
- safe and reliable switching with 150 millisecond switching time
- power requirement at 50 ft/sec cruise currently at 0.21 kwh per seat mile, and can be reduced below 0.12 kwh per seat mile
- consistent performance and safety imdependent of weather
- established practicality of field adjustable guideway alignment.

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PREFACE

This report was produced under Contract No. DOT-TSC-367, Modification No. 1, from the U.S. Department of Transportation, Transportation Systems Center, Cambridge, Massachusetts.

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The equipment built and tested for this contract is based on designs developed by Uniflo Systems Company, a subsidiary of Rosemount Inc., 12001 West 78th Street, Minneapolis, Minnesota 55435. These designs were tested, in part, under the preceding phase of this contract and reported in DOT-TSC-73-1. The present report describes performance on a longer installation at speeds to 30 ft./sec.

During this work, some hardware elements were improved and capital cost estimates were refined. International Acoustical Testing Laboratories, Inc. conducted the sound measurements portion of the tests. The Transportation Systems Center furnished some of the equipment for measuring the 3 axis acceleration data.

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1.0 INTRODUCTION

The test facility built under the current contract allows evaluation of major full-scale subsystems of the Uniflo PRT concept. It does not provide all the features of a full PRT system. In order that the test facility may be placed in the proper relationship to a full system, a description of the full Uniflo PRT system is given below.

1.1 UNIFLO SYSTEM DESCRIPTION

1.1.1 Characteristics of the Uniflo System

Several PRT systems are currently being developed, based on different basic concepts. The Uniflo system is unique in that it features completely passive air levitated and air propelled cars operating in a fully enclosed guideway. Stationary blowers located at intervals along the guideway furnish low pressure air (2 to 3 psi) to the guideway duct system for levitation and propulsion. All controls required to regulate vehicle motion and ensure safety are mounted in the guideway, and do not require a central computer. The emergency braking system is gravity powered.

The off-line stations provide for either first-in/first-out loading, or parallel berthing for random operation. Cars may operate on an origin to destination or scheduled mode or in trains. Cars within a train can be dispatched to different destinations, since cars can be safely switched off a moving train to service intermediate stations.

1.1.2 General Description

1.1.2.1 Guideway

Uniflo vehicles operate in a fully enclosed guideway system (See Figure 1-1) that protects the system from weather and from the careless and sometimes malicious acts of the public. The vehicle running surface overlies a duct system that furnishes air through a valve system to the underside of the vehicle for both levitation and propulsion. (See Figure 1-2) The guideway enclosure may be equipped with windows permitting the passenger to view the terrain through which the system passes.

1.1.2.2 Vehicle

The Uniflo vehicle, on which there are no inherent size constraints, will typically be sized to accommodate 4 to 16 passengers. It is fundamentally a passive "people container." It contains no on-board propulsion system, fuel, control system, lighting system, powered ventilating system, or powered door opening system.

The chassis or undercarriage of the Uniflo vehicle carries on its underside the levitation pads which create the air cushions that support the vehicle, the thruster vanes which react with air jets emitted from the track to produce thrust, the brake skids which support the vehicle when it is delevitated, and the ferrous tabs that carry the magnetic binary address bits which enable the system to direct vehicles in transit to their intended destination. It also contains passive lateral guidance and switching devices.

The vehicle is lighted by stationary lights that are mounted on the ceiling of the enclosure. The vehicle is ventilated by air drawn from the levitation pads. A passive heat sink/heat exchanger unit in the vehicle heats or cools the ventilating air as required to maintain proper temperature and humidity. The heat sink/heat exchanger unit is recharged by industrial type heating or refrigerating equipment in the stations during station dwell time.

The vehicle doors are normally opened and closed by the powered berth doors when the vehicle is in a berth at a station. The doors, normally locked closed when the vehicle is in transit, can be manually opened in the event that it comes to rest in the guideway system.

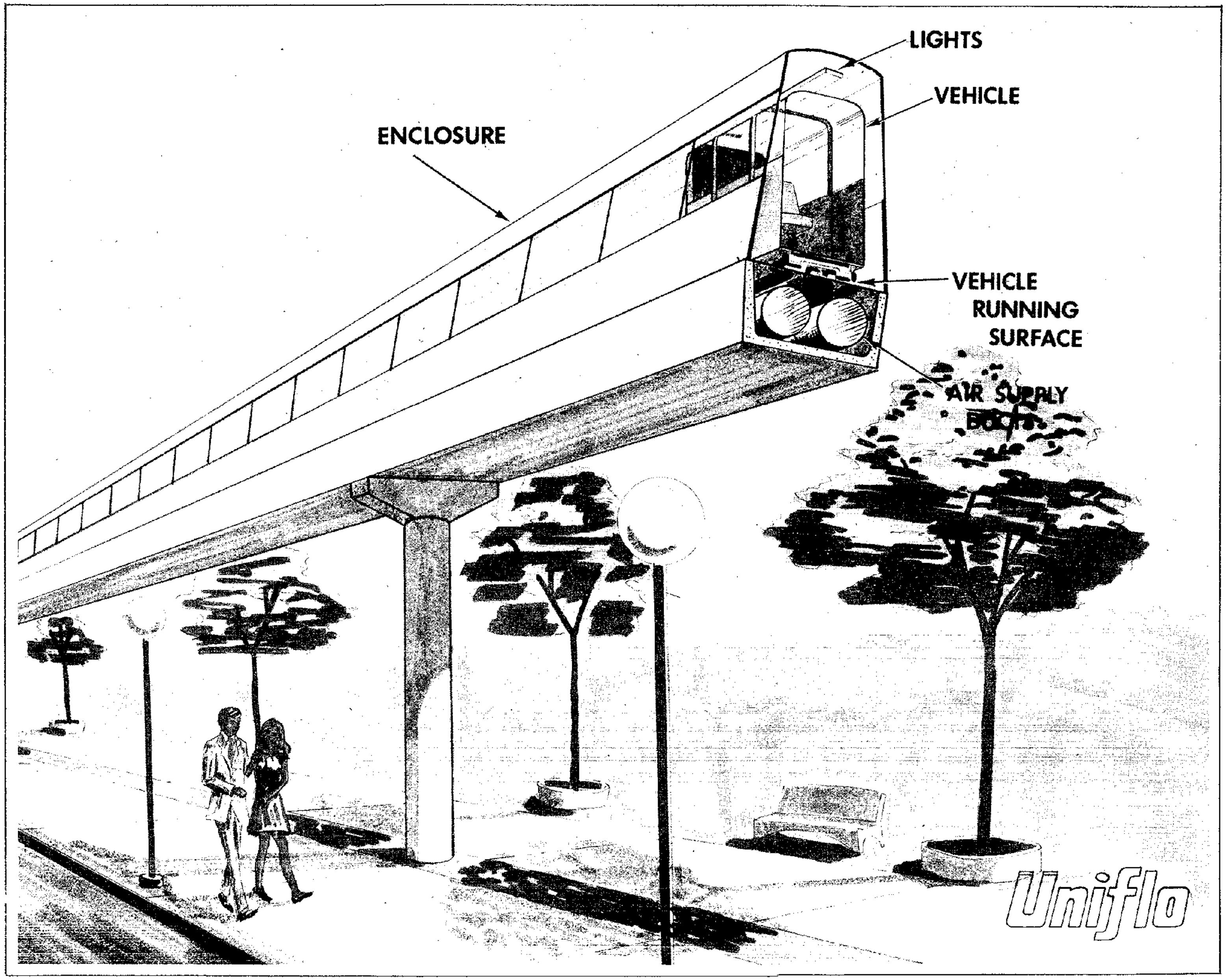

Figure 1-1. Guideway System

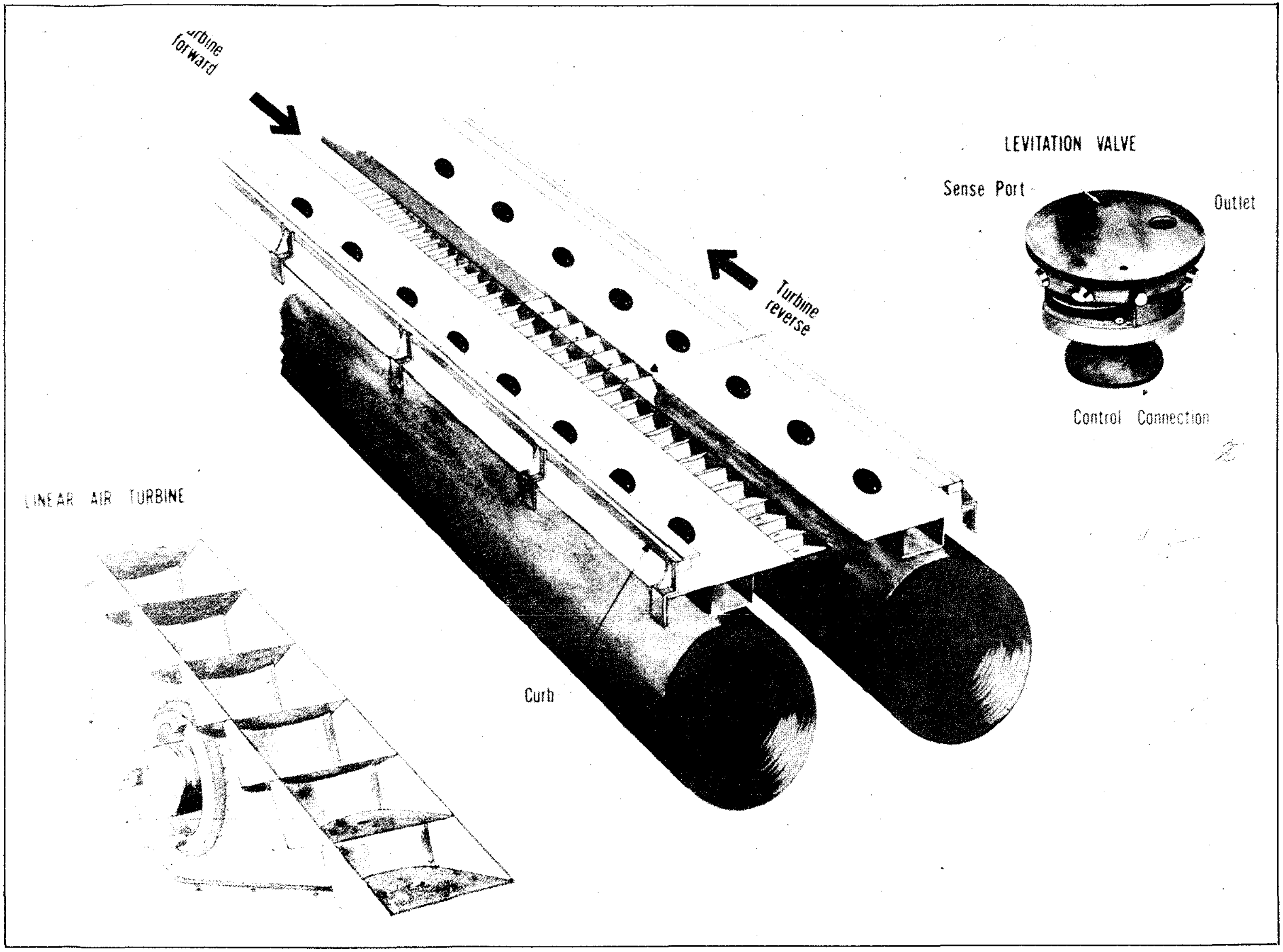

Figure 1-2. Guideway Operating Surface

1.1.2.3 Control

The Uniflo system uses redundant track based controls that govern the speed, maintain safe spacing, and prevent collisions of vehicles in transit. It is composed of many individual control modules which form an iterative control process which does not depend on any one module. A central computer is used to supervise the distribution of empty vehicles, to adapt the system to applied traffic loads, to monitor the operations of the system, and to generate a display of system operation at the central control.

1.1.2.4 Power Supply

The Uniflo system is powered by low pressure (typically about 2 psi) air furnished by stationary blowers located periodically along the guideway. The blowers can be powered by any kind of prime mover, however, it is expected that electric motors will be commonly employed as the prime mover.

1.1.2.5 Stations

Uniflo vehicles in transit never stop on the main line because all stations are off-line. The stations can be designed to off load and load the vehicles on a first-in/first-out basis. Since Uniflo vehicles can move sideways just as easily as forward, Uniflo stations may be designed for parallel berthing, which means that several vehicles can be loaded simultaneously with no constraint on the sequence in which they are dispatched.

With stations designed to provide parallel berthing, Uniflo vehicles can be dispatched as single entities or as trains consisting of two or more vehicles. Vehicles in a train may be dispatched to a common destination or to different destinations. Vehicles bound for intermediate destinations will be switched off (and simultaneously decoupled from the train) as the train passes the diverge switch serving the intermediate station; the balance of the train continues its trip unaffected by the decoupling process.

1.1.2.6 Networks

Deployment of transit systems based on new technology is greatly facilitated if the initial installation can be of modest size, yet capable of expansion into a large integrated network. The Uniflo system can be expanded by a variety of means and strategies:

a. New stations can be added on existing routes with no adverse effect on service.

b. Existing routes can be extended by adding vehicles, guideway, and stations as required.

c. Intersecting or abutting loops can be added featuring stations that facilitate passenger transfers or vehicle transfers, or alternatively, vehicle interchanges.

1.2 PREVIOUS DEVELOPMENT WORK

Uniflo Systems Company, a wholly owned subsidiary of Rosemount Inc., was created in 1969 to develop the Uniflo system. A privately funded program was undertaken to develop components necessary to implement the Uniflo transit system concept. The initial development work was done on components designed for use on a twenty inch gauge track. The twenty inch gauge track is a closed loop with one four-berth parallel loading station. Though still in use for development work, the track is fully operational and demonstrates addressing, dispatching, acceleration, merge, cruise, diverge, deceleration, berthing, and vehicle training options.

Under Contract No. DOT-TSC-367, Uniflo Systems Company constructed 55 feet of full-scale guideway. Tests were conducted on this guideway with a full-scale, eight passenger prototype Uniflo vehicle. The test program yielded data on the performance of the linear pneumatic turbine thrust system, the levitation system, the emergency braking system, ride quality, and noise generation.

Corrolary to the test program, studies were conducted related to system costs and a passive vehicle heating and cooling system.

The results of this contract work were reported in Report No. DOT-TSC-UMTA-73-1.

1.3 CONTRACT GOALS

On October 7, 1972, Uniflo Systems Company was awarded an extension to Contract No. DOT-TSC-367 to evaluate major full-scale subsystems of a pneumatically operated passive vehicle personal rapid transit system.

The contract requires fulfillment of the following items:

1. Furnish data on component reliability, thrust system performance, vehicle ride quality, noise levels inside the vehicle, and noise levels outside of the guideway.
2. Construct a guideway system for the test program consisting of a fully enclosed guideway comprised of a straight section of track, a spiral, 280 foot radius superelevated turn, and a switch—all designed to permit operation of a full-scale, eight passenger car at speeds up to at least 30 feet per second.
3. Provide capital equipment cost estimates for production quantities of the components employed in this project. The results of the test program and the cost estimates shall be included in a final report.

2.0 TEST FACILITY

The test facility is located in Eden Prairie, Minnesota, on the property of our parent firm, Rosemount Inc. Figure 2-1 shows the outside of the completed facility, and Figure 2-2 shows the inside.

2.1 GENERAL DESCRIPTION AND METHOD OF OPERATION

The test facility is composed of 371 ft. of grade level operating surface enclosed in a structure made from precast concrete planks. The facility lies in a north-south direction, and is shown in Drawing E-00550, Sheet 6. Starting at the south end at station 28 is a 280 ft. radius curve which changes to a spiral at station 21. The spiral ends at station 16, which is also the beginning of the tangent for straight through operation as well as the beginning of the spiral for the switch area. On the north end of the main operating surface is a plywood runout section which is provided with levitation capability only. The remaining enclosed area at the north end is used for a shop and work area.

Three vehicle arresting mechanisms are provided—two on the north end, and one on the south end.

An air supply system is composed of a 150 HP centrifugal blower located in an underground pit with inlet and outlet pipes located inside the enclosure. This blower was the same one used in the first phase of the contract.

A control console is located at station 17, which enables the operator to view vehicles during operation. The control is completely manual with control of forward or reverse thrust, levitation enable, levitation start, and switching. A track based switch mechanism is located at station 18 which causes the vehicle switch wheels on one side of the vehicle to be extended, while the switch wheels on the other side of the vehicle are simultaneously retracted.

Stations 12 to 20 are acoustically treated for the sound tests described in Section 4.0.

Turbine modules are provided for thrust in both directions. From stations 5 to 11, full thrust (8 turbine modules per section) is provided in each direction. From stations 14 to 18, full thrust is provided in the south direction. The remainder of the track has 25% thrust capability (2 turbine modules per section in each direction).

The controls can select whether the vehicle will run on 25% thrust (2 turbine modules per section) on the whole track or on full thrust in the areas provided. The vehicle has an 8 passenger capacity, with a 4 passenger per door arrangement. The vehicle is constructed of aluminum channels, tubing, and sheet, with the interior treatment making extensive use of vinyl. Sound absorption and reduction materials were also used. The empty vehicle weight is 2, 100 lbs. and the full loaded weight is 3,700 lbs. (assuming 200 lbs. per passenger).

The 280 ft. radius curve section is 96.25 ft. long (station 28 to station 21). The curve is superelevated 10% which produces zero lateral acceleration at 30 ft./sec.

The curve leads into the spiral which is 68.75 ft. long (station 21 to station 16). The relationship for the spiral is given by:

$$y = (.8647) \times 10^{-5} s^3$$

where

y = distance moved laterally from the tangent line

s = distance moved longitudinally (s is positive in the direction station 16 to 21)

Without superelevation, the jerk on the spiral segment would amount to 0.044g/sec. at 30 ft./sec. Since the track is superelevated for zero lateral acceleration at 30 ft./sec., no lateral jerk would occur at this speed.

The switch section is 151.25 ft. long between tangent points and is offset 74 in. from the main operating surface. The switch curve is composed of four equal spirals which run from station 16 to station 5. The relationship describing the spiral from station 16 to station 13.25 is:

$$y = (0.9465) \times 10^{-5} s^3$$

where

y = distance moved laterally from the tangent line

s = distance moved longitudinally (s is positive in the direction station 16 to station 13)

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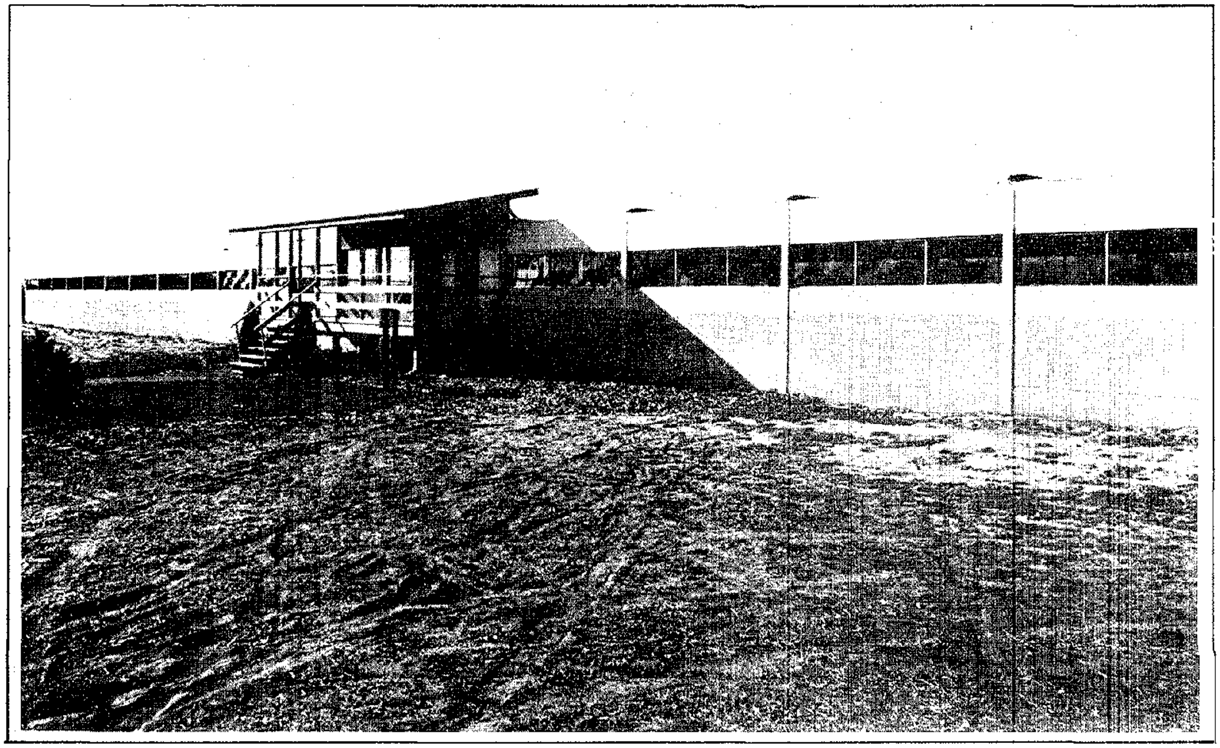


Figure 2-1. Exterior View of Test Facility

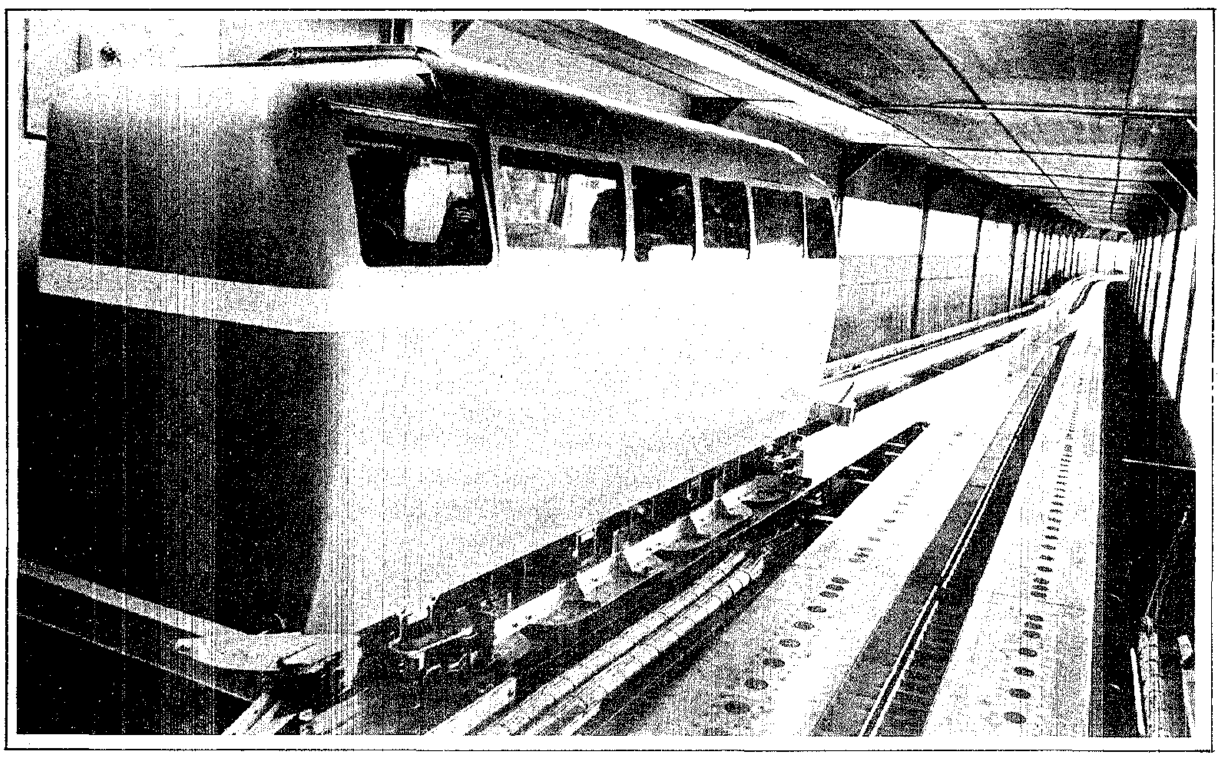
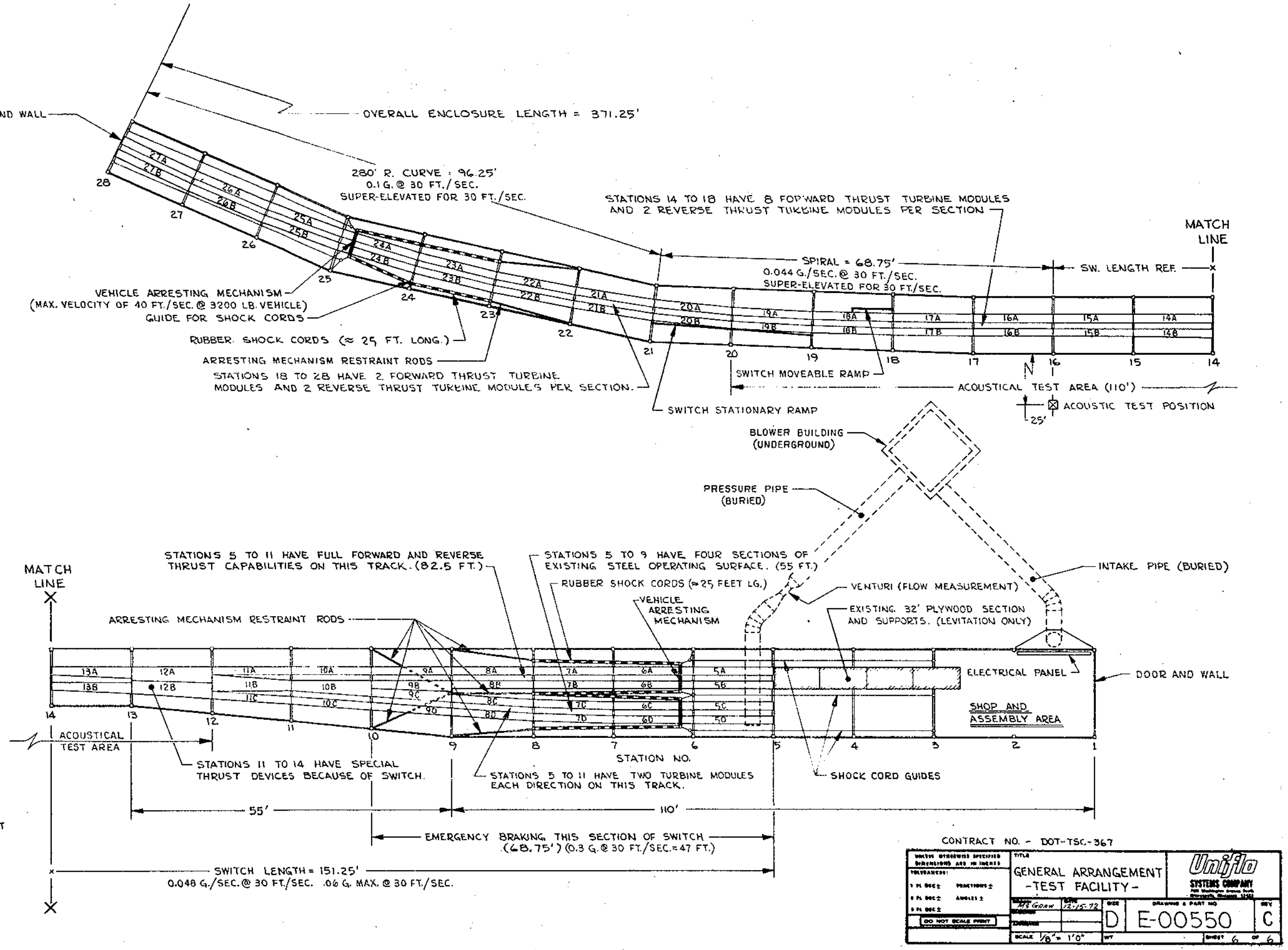


Figure 2-2. Interior View of Test Facility



NOTE:

1. WALLS AND ROOF OF ENCLOSURE MADE OF 4" THICK PRESTRESSED CONCRETE PLANKS.
2. SPACE FOR WINDOWS PROVIDED, BUT ONLY INSTALLED IN ACOUSTICAL TEST AREA, REMAINING SPACES COVERED WITH PLASTIC FILM.

The three remaining spirals have the same shape, but of course have different orientations. The composite switch curve results in a jerk level of 0.048g/sec. with a maximum acceleration of 0.06 g at a system speed of 30 ft./sec.

The general procedure for operation of the vehicle is as follows. The vehicle is levitated and thrust applied. The vehicle accelerates to one end of the track and engages the vehicle arresting mechanism, is brought to rest, and then accelerates back to speed in the opposite direction. At the same time, the operator reverses the thrust direction of the turbine modules; hence, the vehicle continues to accelerate until it engages the other vehicle arresting mechanism. By this process, the vehicle can accelerate to any speed up to 37 ft./sec. with an empty vehicle and 30 ft./sec. with a fully loaded vehicle. At these speeds, the arresting mechanism on the south end is stretched to the limit of the track length.

During any of these shuttles, the switch may be activated, causing the vehicle to be switched off the main line. The vehicle will proceed at speed until it reaches station 10 where emergency braking is applied automatically and the vehicle is brought to rest. With manual operation of the control, the vehicle can be relevitated and moved out of the switch area with the turbine modules in that area. All the test work was accomplished using essentially this operating scheme.

2.2 GUIDEWAY ENCLOSURE & SITE

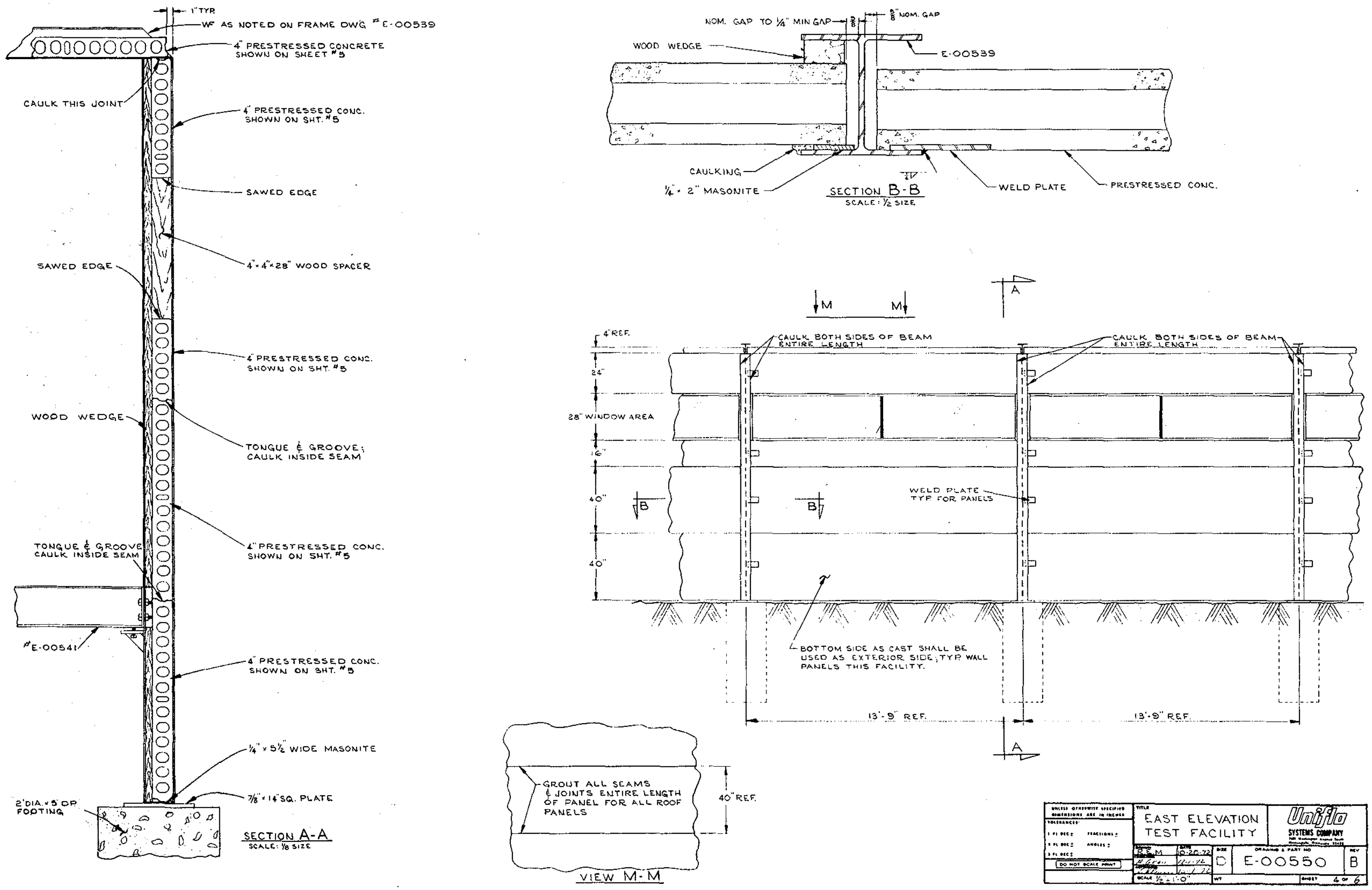
The enclosure was designed with two main objectives, low cost and adequate sound attenuation. In order to fulfill these goals, the enclosure was made from precast concrete planks held in place by steel beams forming inverted U shapes. Drawing E-00550, Sheet 4, shows typical construction details. The north end of the enclosure is 15 ft. wide and 12 ft. 8 in. high and remains at that cross section until station 9. At station 9 it begins to taper, reaching a width of 10 ft. at station 13. The cross section is constant from station 13 to 28.

The general construction process was started by grading a level surface and then boring two holes, 2 ft. diameter by 5 ft. deep, for the footings for each steel frame. Reinforcement bars were set into the holes which were then filled with concrete. After the concrete was cured, the exact location of each beam was surveyed, four holes were drilled for anchor bolts, and prefabricated steel frames were set in place and squared.

The prefabricated concrete panels were installed by sliding them between the flanges of the steel beams. Weld plates were provided on one end of the concrete plank to fasten it to the steel frame. The other end of the plank was held in place by a wood block between the flange and plank. This loose end provided for thermal expansion of the planks. (Figures 2-3 thru 2-6 show the construction steps).

A layer of coarse gravel was applied to the floor of the enclosure.

Plastic sheet windows were installed in all the window areas except in stations 12 to 20 where acoustical glass was installed on the east side. The acoustical testing was carried out in this location. (See Drawing E-00550, Sheet 6).


1" TYP
WF AS NOTED ON FRAME DWG # E-00539
4" PRESTRESSED CONCRETE SHOWN ON SHEET #5
CAULK THIS JOINT
4" PRESTRESSED CONC. SHOWN ON SHT. #5
SAWED EDGE
SAWED EDGE
4"×4"×28" WOOD SPACER
4" PRESTRESSED CONC. SHOWN ON SHT. #5
WOOD WEDGE
TONGUE & GROOVE; CAULK INSIDE SEAM
TONGUE & GROOVE CAULK INSIDE SEAM
4" PRESTRESSED CONC. SHOWN ON SHT. #5
#E-00541
4" PRESTRESSED CONC. SHOWN ON SHT. #5
1/4" × 5 1/2 WIDE MASONITE
7/8" × 14" SQ. PLATE
2' DIA. × 5' DP FOOTING
SECTION A-A
SCALE: 1/8 SIZE
NOM. GAP TO 1/4" MIN GAP
3/8" NOM. GAP
WOOD WEDGE
E-00539
CAULKING
1/4 × 2" MASONITE
SECTION B-B
SCALE: 1/2 SIZE
WELD PLATE
PRESTRESSED CONC.
M
M
A
4" REF.
CAULK BOTH SIDES OF BEAM ENTIRE LENGTH
CAULK BOTH SIDES OF BEAM ENTIRE LENGTH
24"
28" WINDOW AREA
16"
40"
40"
B
B
WELD PLATE TYP FOR PANELS
BOTTOM SIDE AS CAST SHALL BE USED AS EXTERIOR SIDE; TYP WALL PANELS THIS FACILITY.
13'-9" REF.
13'-9" REF.
A
GROUT ALL SEAMS & JOINTS ENTIRE LENGTH OF PANEL FOR ALL ROOF PANELS
40" REF.
VIEW M-M
DO NOT SCALE PRINT
EAST ELEVATION
TEST FACILITY
Uniflo
SYSTEMS COMPANY
D
E-00550
B

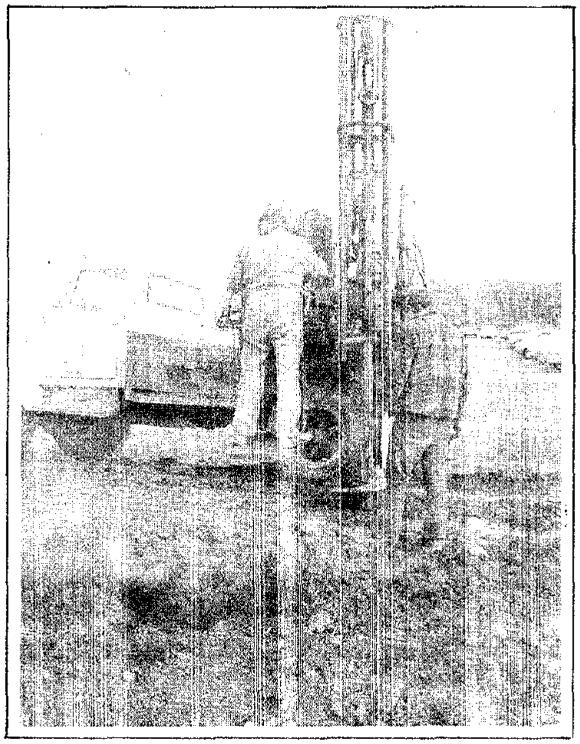


Figure 2-3. Boring Footing Holes

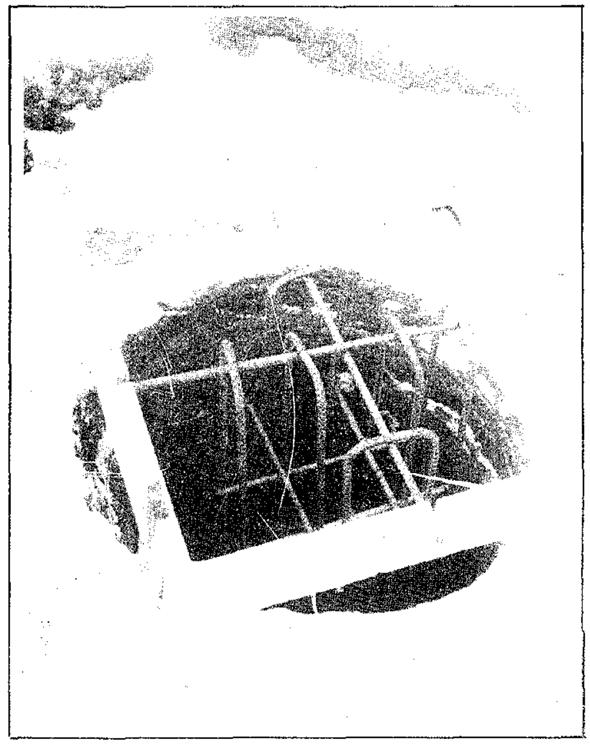


Figure 2-4. Footing Boring Ready for Concrete

Figure 2-5. Setting of Steel Frames

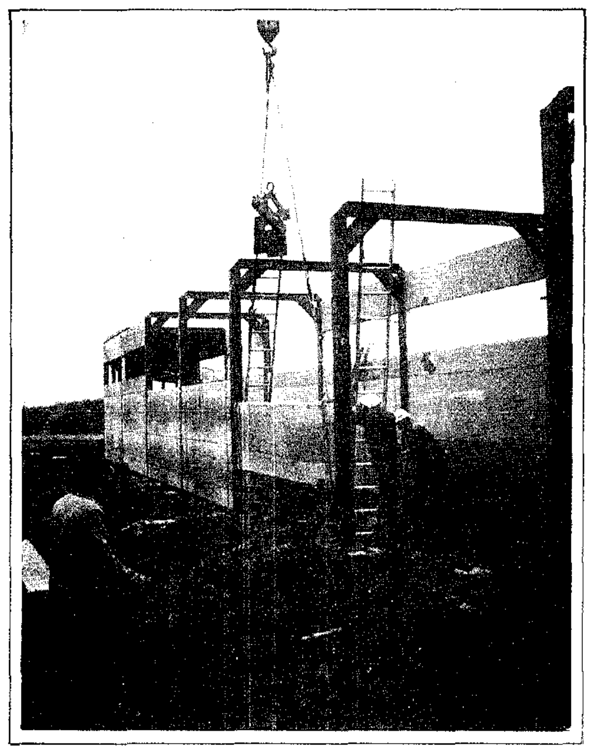


Figure 2-6. Installation of Prefabricated Concrete Panels

2.3 OPERATING SURFACE

The operating surface includes the levitation surface, levitation valves, cross beams, 30" diameter air ducts, turbine modules and guide rails. These are essentially all the unique Uniflo components, and they are interfaced to the supporting structure by the cross beams. The operating surface is divided into 13 ft. 9 in. modules. These modules are preassembled and installed, one-half section at a time, as shown in Figure 2-7.

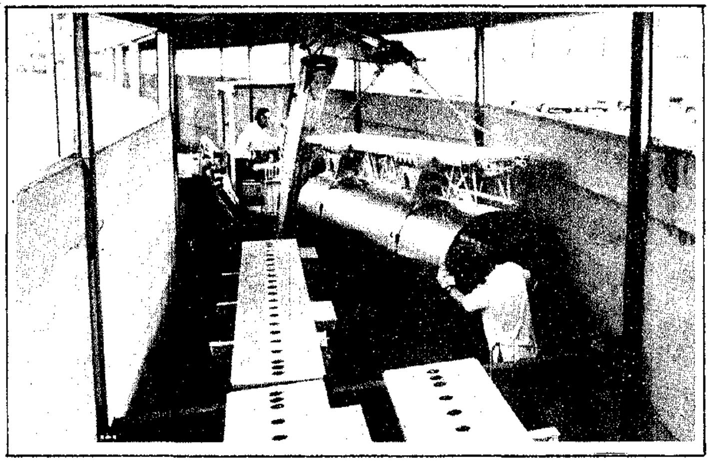


Figure 2-7. Installation of Operating Surface Module

These modules are installed on the cross beams in the proper position to follow track alignment. The guide rails are then attached to the prealigned guide rail brackets. Any further changes in alignment are made by the adjustment provided at the end of the cross beams for either vertical or lateral adjustment. These further adjustments are required to compensate for foundation settling or errors in initial positioning. The installed surfaces are shown in Figure 2-8 and 2-9. Installed in the siding areas of the switch is 55 ft. of prototype guideway which was constructed for use in the previous contract.

Drawing E-00685, E-00686, and E-00687 show the configuration of these surfaces. Drawing E-00688 shows the switch and/or dual guideway configuration.

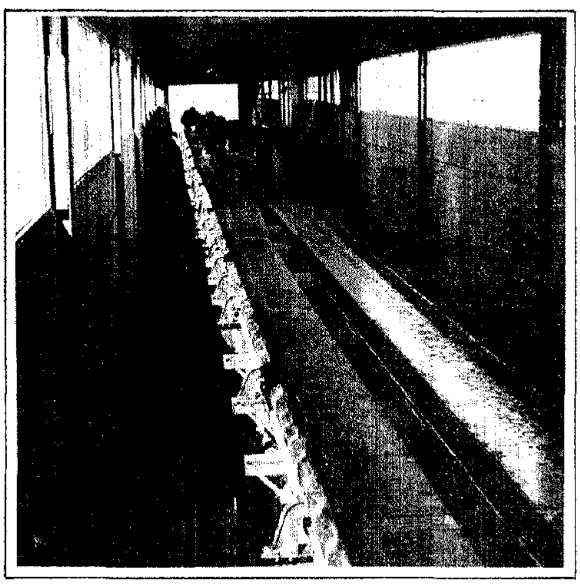
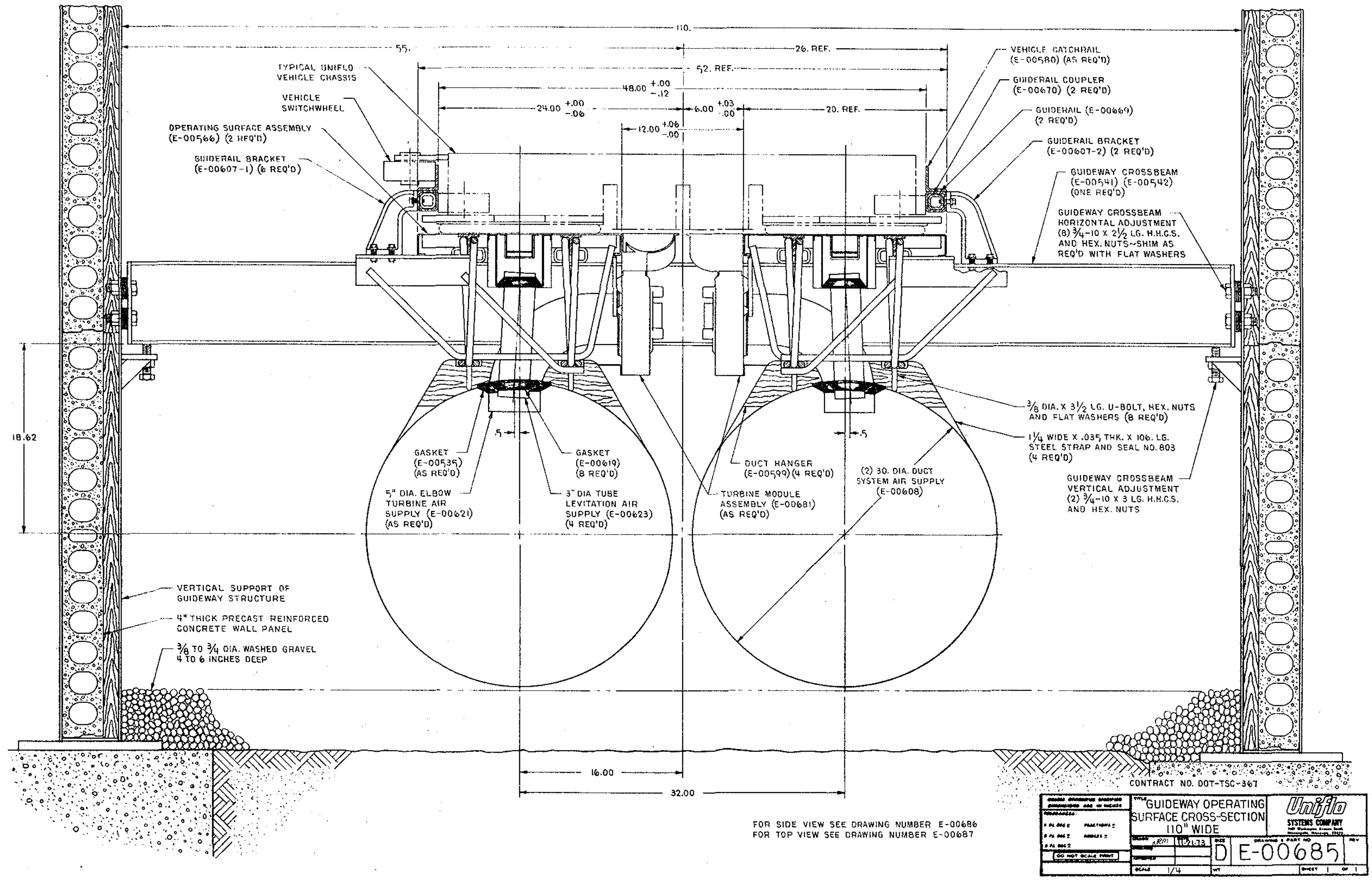
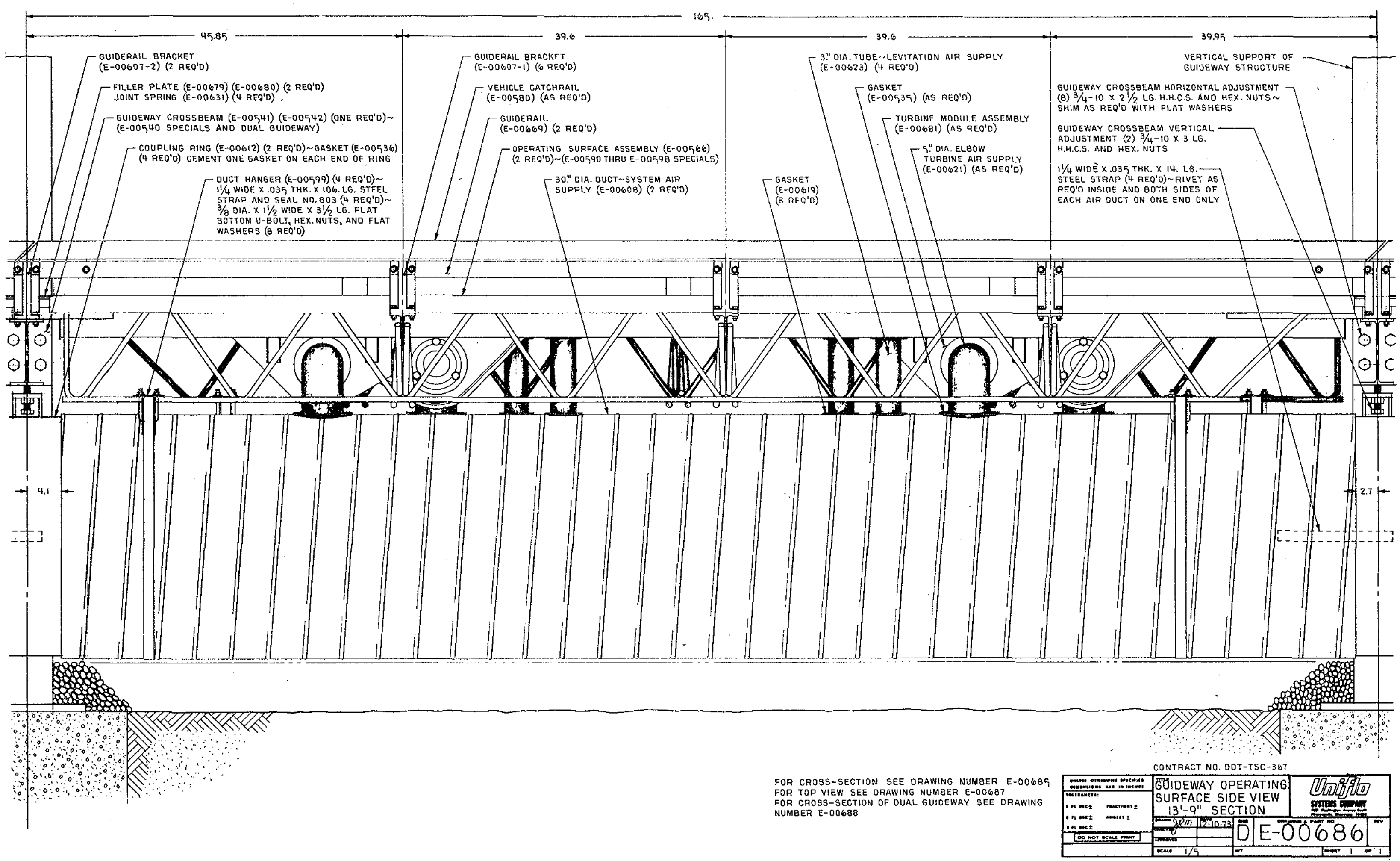


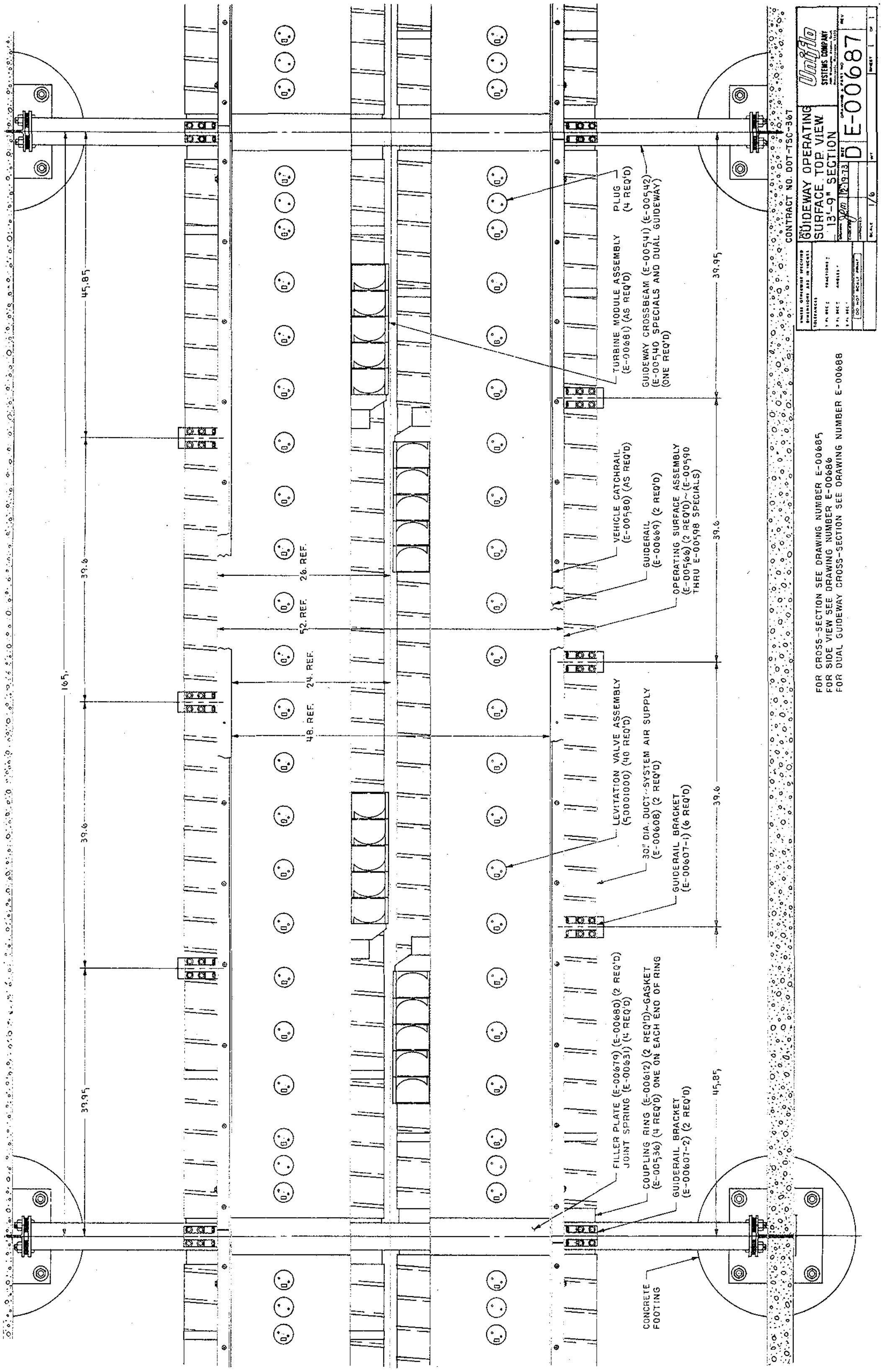
Figure 2-8. Installed Surfaces Looking North

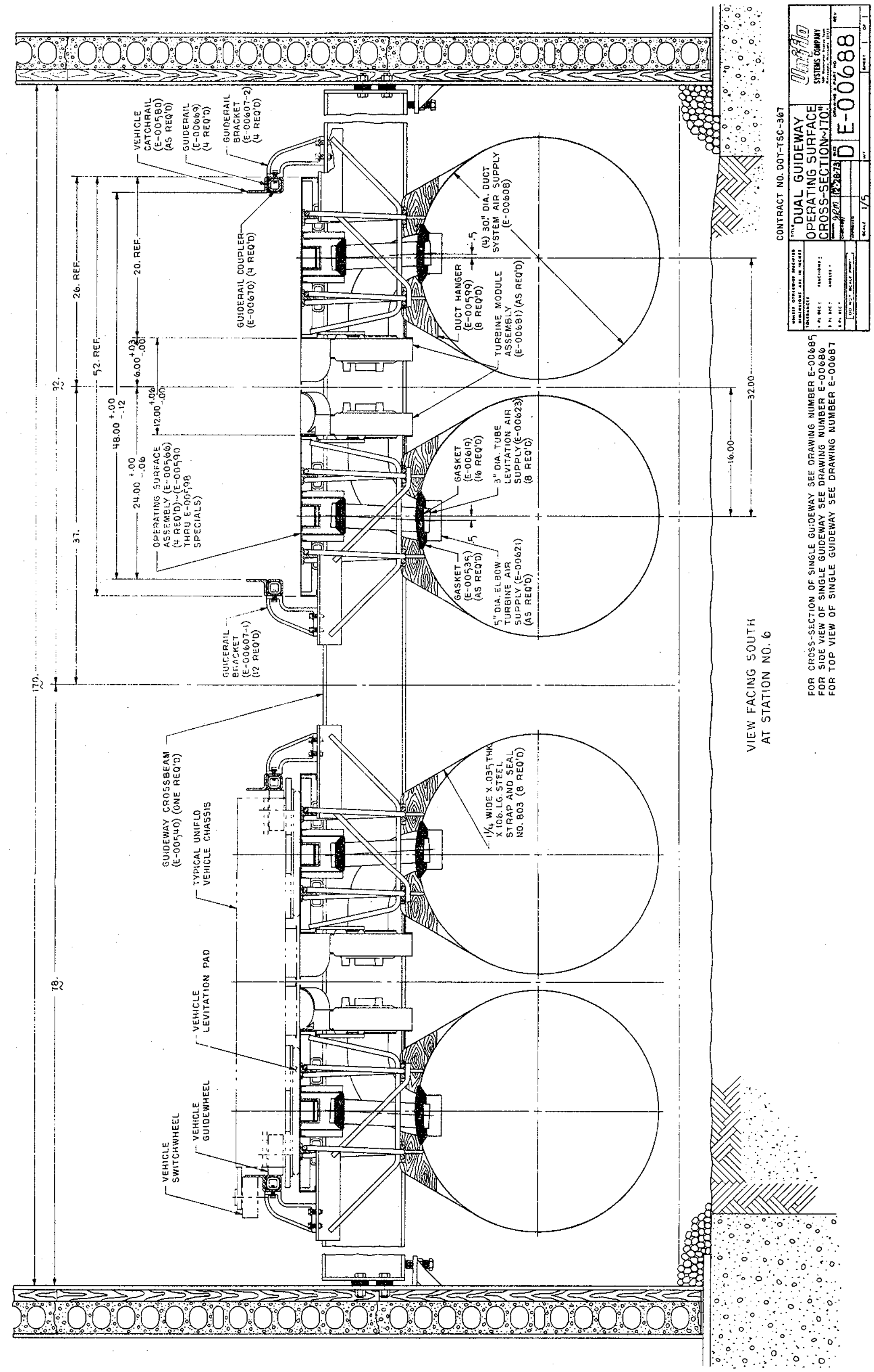
Figure 2-9. Installed Surfaces Looking South



110.
55.
26. REF.
52. REF.
48.00 +.00 -.12
24.00 +.00 -.06
6.00 +.03 .00
20. REF.
12.00 +.06 -.00
TYPICAL UNIFLO VEHICLE CHASSIS
VEHICLE SWITCHWHEEL
OPERATING SURFACE ASSEMBLY (E-00566) (2 REQ'D)
GUIDERAIL BRACKET (E-00607-1) (6 REQ'D)
VEHICLE CATCHRAIL (E-00580) (AS REQ'D)
GUIDERAIL COUPLER (E-00670) (2 REQ'D)
GUIDERAIL (E-00669) (2 REQ'D)
GUIDERAIL BRACKET (E-00607-2) (2 REQ'D)
GUIDEWAY CROSSBEAM (E-00541) (E-00542) (ONE REQ'D)
GUIDEWAY CROSSBEAM HORIZONTAL ADJUSTMENT (8) 3/4-10 X 2 1/2 LG. H.H.C.S. AND HEX. NUTS~SHIM AS REQ'D WITH FLAT WASHERS
3/8 DIA. X 3 1/2 LG. U-BOLT, HEX. NUTS AND FLAT WASHERS (8 REQ'D)
1 1/4 WIDE X .035 THK. X 106. LG. STEEL STRAP AND SEAL NO. 803 (4 REQ'D)
GUIDEWAY CROSSBEAM VERTICAL ADJUSTMENT (2) 3/4-10 X 3 LG. H.H.C.S. AND HEX. NUTS
18.62
5
GASKET (E-00535) (AS REQ'D)
GASKET (E-00619) (8 REQ'D)
5" DIA. ELBOW TURBINE AIR SUPPLY (E-00621) (AS REQ'D)
3" DIA TUBE LEVITATION AIR SUPPLY (E-00623) (4 REQ'D)
DUCT HANGER (E-00599) (4 REQ'D)
TURBINE MODULE ASSEMBLY (E-00681) (AS REQ'D)
(2) 30. DIA. DUCT SYSTEM AIR SUPPLY (E-00608)
VERTICAL SUPPORT OF GUIDEWAY STRUCTURE
4" THICK PRECAST REINFORCED CONCRETE WALL PANEL
3/8 TO 3/4 DIA. WASHED GRAVEL 4 TO 6 INCHES DEEP
16.00
32.00
FOR SIDE VIEW SEE DRAWING NUMBER E-00686
FOR TOP VIEW SEE DRAWING NUMBER E-00687
CONTRACT NO. DOT-TSC-367
GUIDEWAY OPERATING SURFACE CROSS-SECTION 110" WIDE
Uniflo SYSTEMS COMPANY
11-21-73
D
E-00685
DO NOT SCALE PRINT
1/4
SHEET 1 OF 1


165.
45.85
39.6
39.6
39.95
GUIDERAIL BRACKET (E-00607-2) (2 REQ'D)
FILLER PLATE (E-00679) (E-00680) (2 REQ'D) JOINT SPRING (E-00631) (4 REQ'D)
GUIDEWAY CROSSBEAM (E-00541) (E-00542) (ONE REQ'D)~ (E-00540 SPECIALS AND DUAL GUIDEWAY)
COUPLING RING (E-00612) (2 REQ'D)~GASKET (E-00536) (4 REQ'D) CEMENT ONE GASKET ON EACH END OF RING
DUCT HANGER (E-00599) (4 REQ'D)~ 1/4 WIDE X .035 THK. X 106. LG. STEEL STRAP AND SEAL NO. 803 (4 REQ'D)~ 3/8 DIA. X 1 1/2 WIDE X 3 1/2 LG. FLAT BOTTOM U-BOLT, HEX. NUTS, AND FLAT WASHERS (8 REQ'D)
GUIDERAIL BRACKET (E-00607-1) (6 REQ'D)
VEHICLE CATCHRAIL (E-00580) (AS REQ'D)
GUIDERAIL (E-00669) (2 REQ'D)
OPERATING SURFACE ASSEMBLY (E-00566) (2 REQ'D)~(E-00590 THRU E-00598 SPECIALS)
30" DIA. DUCT~SYSTEM AIR SUPPLY (E-00608) (2 REQ'D)
3" DIA. TUBE~LEVITATION AIR SUPPLY (E-00623) (4 REQ'D)
GASKET (E-00535) (AS REQ'D)
TURBINE MODULE ASSEMBLY (E-00681) (AS REQ'D)
5" DIA. ELBOW TURBINE AIR SUPPLY (E-00621) (AS REQ'D)
GASKET (E-00619) (8 REQ'D)
VERTICAL SUPPORT OF GUIDEWAY STRUCTURE
GUIDEWAY CROSSBEAM HORIZONTAL ADJUSTMENT (8) 3/4-10 X 2 1/2 LG. H.H.C.S. AND HEX. NUTS~ SHIM AS REQ'D WITH FLAT WASHERS
GUIDEWAY CROSSBEAM VERTICAL ADJUSTMENT (2) 3/4-10 X 3 LG. H.H.C.S. AND HEX. NUTS
1 1/4 WIDE X .035 THK. X 14. LG. STEEL STRAP (4 REQ'D)~RIVET AS REQ'D INSIDE AND BOTH SIDES OF EACH AIR DUCT ON ONE END ONLY
4.1
2.7
FOR CROSS-SECTION SEE DRAWING NUMBER E-00685
FOR TOP VIEW SEE DRAWING NUMBER E-00687
FOR CROSS-SECTION OF DUAL GUIDEWAY SEE DRAWING NUMBER E-00688
CONTRACT NO. DOT-TSC-367
GUIDEWAY OPERATING SURFACE SIDE VIEW 13'-9" SECTION
Unifio SYSTEMS COMPANY
DO NOT SCALE PRINT
D E-00686
SCALE 1/5
SHEET 1 OF 1


GUIDEWAY OPERATING SURFACE TOP VIEW 13'-9" SECTION
CONTRACT NO. DOT-TSC-367
Uniflo SYSTEMS COMPANY
D E-00687
TURBINE MODULE ASSEMBLY (E-00681) (AS REQ'D)
PLUG (4 REQ'D)
GUIDEWAY CROSSBEAM (E-00541) (E-00542) (E-00540 SPECIALS AND DUAL GUIDEWAY) (ONE REQ'D)
VEHICLE CATCHRAIL (E-00580) (AS REQ'D)
GUIDERAIL (E-00609) (2 REQ'D)
OPERATING SURFACE ASSEMBLY (E-00566) (2 REQ'D)~(E-00590 THRU E-00598 SPECIALS)
LEVITATION VALVE ASSEMBLY (50001000) (10 REQ'D)
30" DIA. DUCT-SYSTEM AIR SUPPLY (E-00608) (2 REQ'D)
GUIDERAIL BRACKET (E-00607-1) (6 REQ'D)
FILLER PLATE (E-00679) (E-00680) (2 REQ'D)
JOINT SPRING (E-00631) (4 REQ'D)
COUPLING RING (E-00612) (2 REQ'D)~GASKET (E-00536) (4 REQ'D) ONE ON EACH END OF RING
GUIDERAIL BRACKET (E-00607-2) (2 REQ'D)
CONCRETE FOOTING
45.85
39.6
165.
39.6
39.95
26. REF.
52. REF.
24. REF.
48. REF.
39.95
39.6
39.6
45.85
FOR CROSS-SECTION SEE DRAWING NUMBER E-00685
FOR SIDE VIEW SEE DRAWING NUMBER E-00686
FOR DUAL GUIDEWAY CROSS-SECTION SEE DRAWING NUMBER E-00688


VEHICLE CATCHRAIL (E-00580) (AS REQ'D)
GUIDERAIL (E-00669) (4 REQ'D)
GUIDERAIL BRACKET (E-00607-2) (4 REQ'D)
GUIDERAIL COUPLER (E-00670) (4 REQ'D)
(4) 30" DIA. DUCT SYSTEM AIR SUPPLY (E-00608)
DUCT HANGER (E-00599) (8 REQ'D)
TURBINE MODULE ASSEMBLY (E-00681) (AS REQ'D)
GASKET (E-00619) (16 REQ'D)
3" DIA. TUBE LEVITATION AIR SUPPLY (E-00623) (8 REQ'D)
GASKET (E-00535) (AS REQ'D)
5" DIA. ELBOW TURBINE AIR SUPPLY (E-00621) (AS REQ'D)
OPERATING SURFACE ASSEMBLY (E-00566) (4 REQ'D) (E-00590 THRU E-00598 SPECIALS)
GUIDERAIL BRACKET (E-00607-1) (12 REQ'D)
GUIDEWAY CROSSBEAM (E-00540) (ONE REQ'D)
TYPICAL UNIFLO VEHICLE CHASSIS
VEHICLE LEVITATION PAD
VEHICLE GUIDEWHEEL
VEHICLE SWITCHWHEEL
1¼ WIDE X .035 THK X 106 LG. STEEL STRAP AND SEAL NO. 803 (8 REQ'D)
26. REF.
20. REF.
52. REF.
32.
37.
48.00
24.00
12.00
6.00
16.00
32.00
170.
78.
VIEW FACING SOUTH AT STATION NO. 6
FOR CROSS-SECTION OF SINGLE GUIDEWAY SEE DRAWING NUMBER E-00685
FOR SIDE VIEW OF SINGLE GUIDEWAY SEE DRAWING NUMBER E-00686
FOR TOP VIEW OF SINGLE GUIDEWAY SEE DRAWING NUMBER E-00687
CONTRACT NO. DOT-TSC-367
DUAL GUIDEWAY OPERATING SURFACE CROSS-SECTION ~170
SYSTEMS COMPANY
D E-00688

In the switch area the operating surfaces required special shapes to diverge from one track to two. By making use of standard operating surface sections, only 8 special surfaces were required for the switch. In a portion of the switch area, no turbine modules could be mounted. In this area (station 11 to 13) levitation valves with angled nozzles were used for propulsion. The level of thrust provided by these valves is small, but sufficient to move a stopped vehicle from the area. When the vehicle is at speed, it can easily coast over the area against the thrust of these valves.

The levitation surface is made from 12 gauge galvanized steel and is supported by two 13 in. bar joists. The surface is held to the bar joists by tack welds. The surface has 20 formed holes for the levitation valves. The levitation valves are installed by a 22° turn that locates the mounting tabs in detents of the formed holes. A connection to a rectangular tube control header is made automatically when the valve is installed. Under and attached to the levitation surface is a 5 in. square duct which supplies levitation air to the valves. The duct is attached to the levitation surface by spot welding. Sealing of the duct-levitation surface interface is with a weld through sealant applied before the duct is welded to the levitation surface. Two 3 in. diameter tubes connect this duct to the main 30 in. diameter air supply duct. Pressure sealed rubber gaskets are used on both ends of the 3 in. tube.

Main air supply is by two 30 in. diameter ducts. Each 30 in. diameter duct is held by strapping to the bar joist of each levitation surface. This tubing is made from spiral wrapped 22 gauge galvanized steel strips joined together by lock seams. This tubing is commercially available and made for heating and air conditioning systems. The seam strength of the tubes is sufficient to contain 48 psi pressure within the tube. Weight of the tube is 12.7 lb./ft.

A gap in the levitation surface occurs at each cross beam. This gap is bridged with a spring held plate. (See Drawings E-00690 and E-00691). This plate allows for thermal expansion at the joint and still maintains continuity of the surface without losing air from the levitation pads.

Connections between the 30 in. diameter tubes are made with a short piece of pipe which fits inside the 30 in. tubes. On each end of the short pipe is a pressure activated rubber gasket. The short pipe is held in place by a strap riveted to one tube and the short pipe. This short pipe allows the 30 in. tubes to be slightly misaligned, to change directions as required for curves and spirals, and to take up any thermal expansion movement.

Guide rails are attached to cast steel brackets along each side of the operating surface. The rails are 2 in. square by 3/16 in. wall tubing. A 1 1/2 in. square steel tube placed inside the 2 in. tube makes the connection between the individual rails. The ends of the guide rails are cut at 45° so the wheel can transverse the joint without falling in the gap.

On top of the guide rail, a 2 in by 2 1/2 in. by 1/4 in. steel angle is attached for the catch rail in the switch areas. Drawing E-00692 shows the vehicle operating surface/guidance interface.

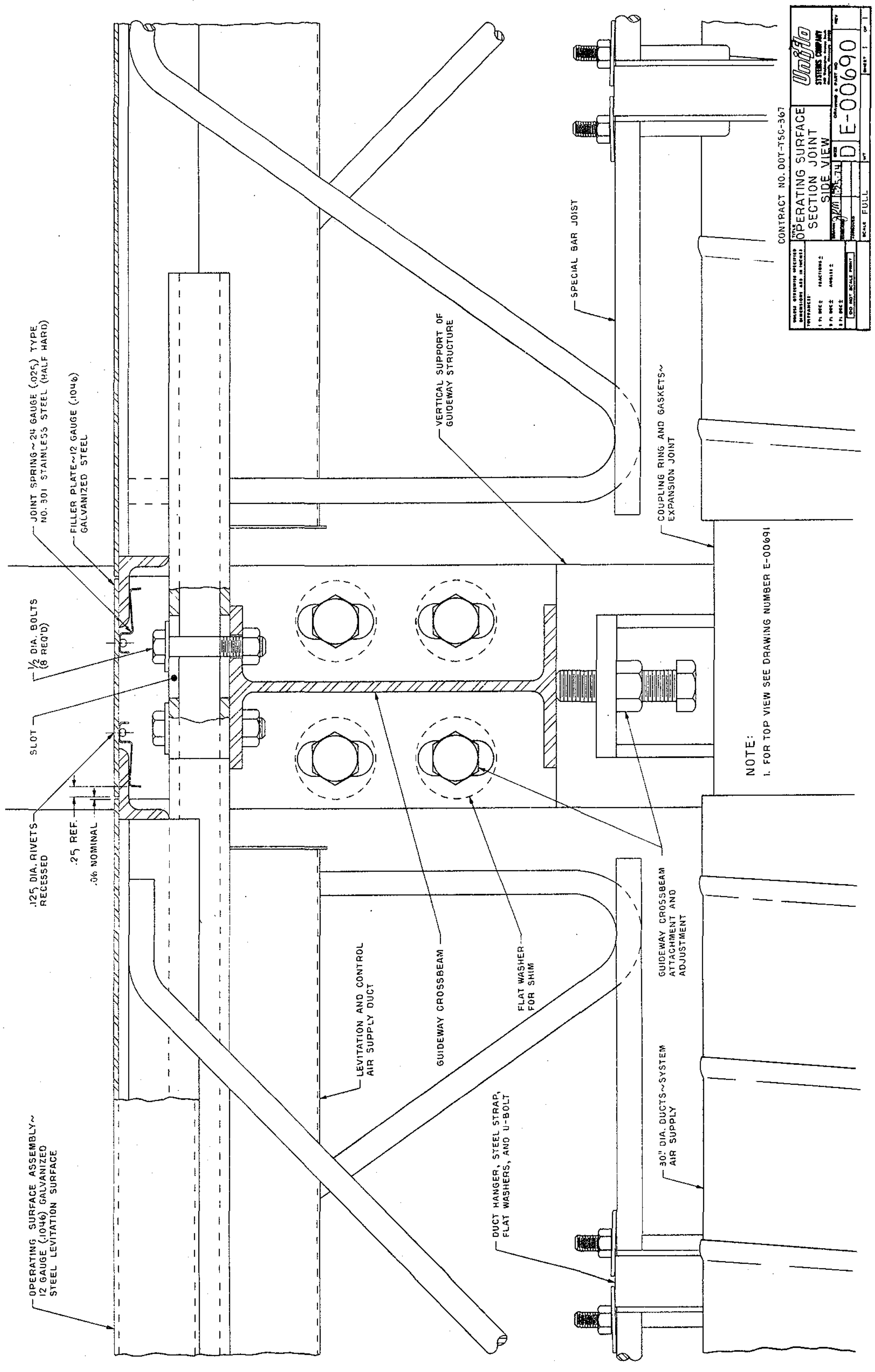
Turbine modules are installed in the operating surface with two brackets which connect to a bent flange on the levitation surface. A clip from the bottom of the bar joist to the bottom of the turbine holds the turbine from tipping due to thrust and pressure forces.

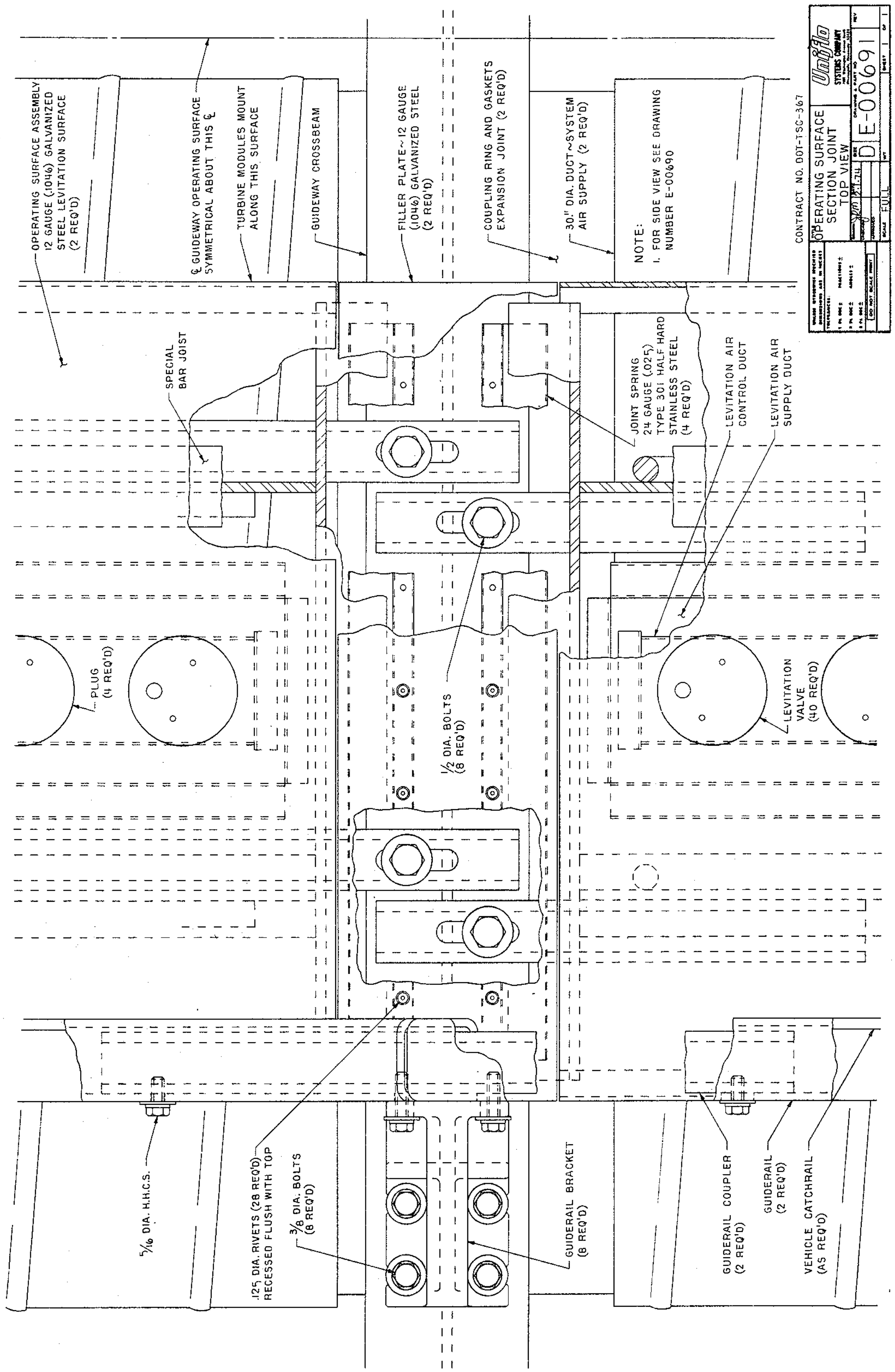
Air connection from the 30 in. diameter duct to the turbine is made by a 5 in. diameter elbow with pressure activated seals on the ends.

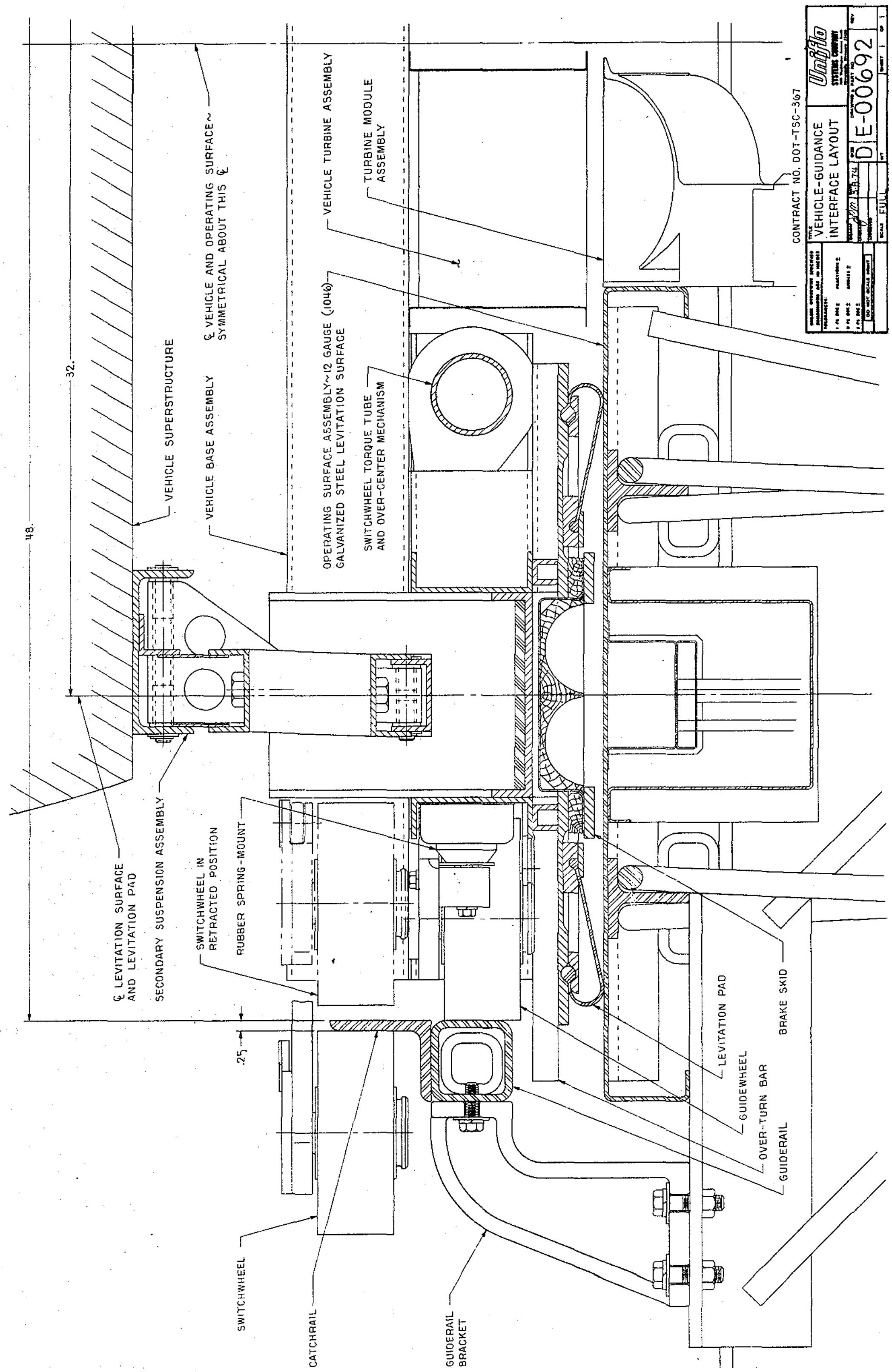
The operating surface was checked for deflections due to vehicle imposed loads. With a fully loaded vehicle (3,700 lbs.) centered between cross beams, the measured deflections were .050 in. at the center of the bar joist span, with a cross beam deflection of .023 in. With the vehicle centered on the cross beam, the deflection increased to .029 in. The bar joist deflection alone calculated at .027. These deflections show no substantial change in stiffness from the operating surface used in the previous contract.

The weight of the operating surface, including cross beams, is approximately 100 lbs. per foot.

The use of rubber pressure activated seals introduced a leakage problem during cold weather start up operation (+10°F – -20°F). The rubber became very stiff at the lower temperatures, and the seals would only partially seat until the system had run for a period of time. Both the slight warming of the air by the blower and the length of time the pressure acted on the seal reduced the leakage. Several changes are necessary to have a more effective seal. The effectiveness of the seal at low temperatures can be improved by employing a different rubber material instead of neoprene (which is subject to crystalization at low temperatures) and by modifying the configuration of the seal.


OPERATING SURFACE ASSEMBLY~ 12 GAUGE (.1046) GALVANIZED STEEL LEVITATION SURFACE
.125 DIA. RIVETS RECESSED
.25 REF.
.06 NOMINAL
SLOT
1/2 DIA. BOLTS (8 REQ'D)
JOINT SPRING~24 GAUGE (.025) TYPE NO. 301 STAINLESS STEEL (HALF HARD)
FILLER PLATE~12 GAUGE (.1046) GALVANIZED STEEL
LEVITATION AND CONTROL AIR SUPPLY DUCT
GUIDEWAY CROSSBEAM
VERTICAL SUPPORT OF GUIDEWAY STRUCTURE
DUCT HANGER, STEEL STRAP, FLAT WASHERS, AND U-BOLT
FLAT WASHER FOR SHIM
SPECIAL BAR JOIST
30" DIA. DUCTS~SYSTEM AIR SUPPLY
GUIDEWAY CROSSBEAM ATTACHMENT AND ADJUSTMENT
COUPLING RING AND GASKETS~ EXPANSION JOINT
NOTE:
1. FOR TOP VIEW SEE DRAWING NUMBER E-00691
CONTRACT NO. DOT-TSC-367
OPERATING SURFACE SECTION JOINT SIDE VIEW
Uniflo
SYSTEMS COMPANY
D E-00690
SCALE FULL


OPERATING SURFACE ASSEMBLY 12 GAUGE (.1046) GALVANIZED STEEL LEVITATION SURFACE (2 REQ'D)
℄ GUIDEWAY OPERATING SURFACE SYMMETRICAL ABOUT THIS ℄
TURBINE MODULES MOUNT ALONG THIS SURFACE
GUIDEWAY CROSSBEAM
FILLER PLATE~12 GAUGE (.1046) GALVANIZED STEEL (2 REQ'D)
COUPLING RING AND GASKETS EXPANSION JOINT (2 REQ'D)
30." DIA. DUCT~SYSTEM AIR SUPPLY (2 REQ'D)
NOTE:
1. FOR SIDE VIEW SEE DRAWING NUMBER E-00690
CONTRACT NO. DOT-TSC-367
OPERATING SURFACE SECTION JOINT TOP VIEW
D E-00691
FULL
SPECIAL BAR JOIST
JOINT SPRING 24 GAUGE (.025) TYPE 301 HALF HARD STAINLESS STEEL (4 REQ'D)
LEVITATION AIR CONTROL DUCT
LEVITATION AIR SUPPLY DUCT
PLUG (4 REQ'D)
1/2 DIA. BOLTS (8 REQ'D)
LEVITATION VALVE (40 REQ'D)
5/16 DIA. H.H.C.S.
.125 DIA. RIVETS (28 REQ'D) RECESSED FLUSH WITH TOP
3/8 DIA. BOLTS (8 REQ'D)
GUIDERAIL BRACKET (8 REQ'D)
GUIDERAIL COUPLER (2 REQ'D)
GUIDERAIL (2 REQ'D)
VEHICLE CATCHRAIL (AS REQ'D)



℄ VEHICLE AND OPERATING SURFACE~ SYMMETRICAL ABOUT THIS ℄
VEHICLE SUPERSTRUCTURE
VEHICLE BASE ASSEMBLY
OPERATING SURFACE ASSEMBLY~12 GAUGE (1046) GALVANIZED STEEL LEVITATION SURFACE
SWITCHWHEEL TORQUE TUBE AND OVER-CENTER MECHANISM
VEHICLE TURBINE ASSEMBLY
TURBINE MODULE ASSEMBLY
CONTRACT NO. DOT-TSC-367
VEHICLE-GUIDANCE INTERFACE LAYOUT
D E-00692
FULL
32.
48.
.25
℄ LEVITATION SURFACE AND LEVITATION PAD
SECONDARY SUSPENSION ASSEMBLY
SWITCHWHEEL IN RETRACTED POSITION
RUBBER SPRING-MOUNT
SWITCHWHEEL
CATCHRAIL
GUIDERAIL BRACKET
LEVITATION PAD
BRAKE SKID
GUIDEWHEEL
OVER-TURN BAR
GUIDERAIL

Several improvements were made on the design of the operating surface during this phase of the contract. The major items which were improved are listed below:

The levitation valves were mounted in a socket formed directly into the operating surface.

The levitation valve control line was changed from a fabricated bracket and tube assembly to a simpler rectangular tube.

The edges of the levitation surface were formed to increase the edge stiffness.

Pressure activated rubber seals were employed for all air supply connections, replacing clamped connections previously employed in some locations.

A splice plate was developed to simplify the assembly of levitation surfaces to the supporting cross beams.

Guide rail brackets were redesigned as a casting in place of the previous weldment.

The air supply connections to the turbine modules were redesigned for simplified pressure seal connections.

The end supports for the operating surface modules have been redesigned to improve the load distribution on the cross beam flanges and to allow for thermal expansion.

2.4 AIR SUPPLY

The main air supply is provided by a 150 HP electric motor/centrifugal blower combination. The blower, a standard unit manufactured by Buffalo Forge Co., New York, was used for the previous contract work. The performance curve furnished by the manufacturer is shown in Figure 2-10. The blower has variable inlet vanes which allows some pressure regulation with flow (see Figure 2-10). These vanes are normally set so

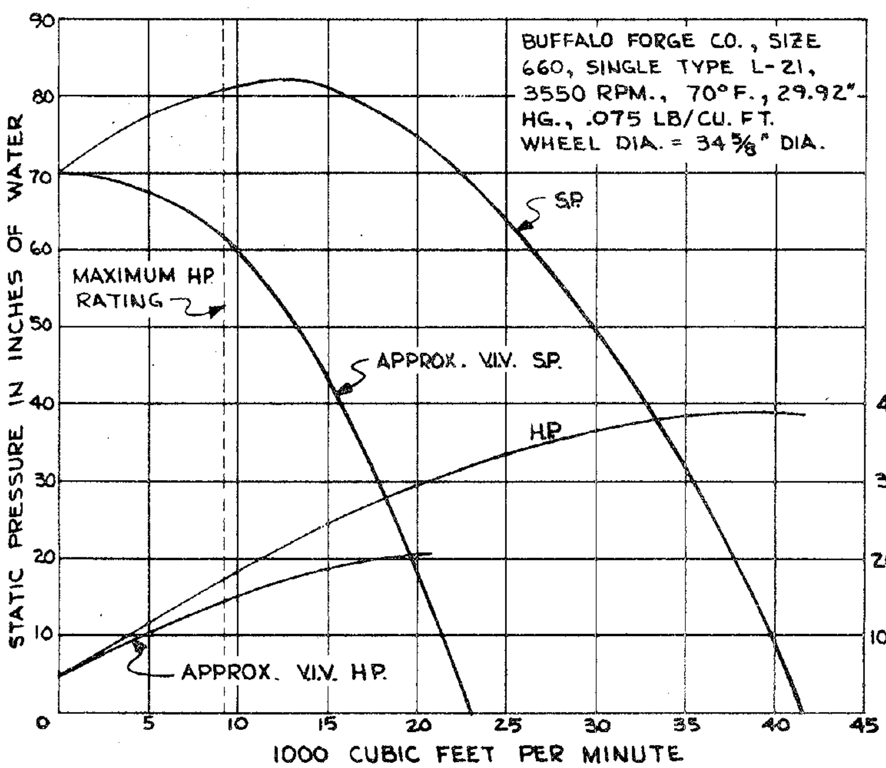


Figure 2-10. Blower Performance Curves Per Manufacturer

the blower will not surge under low flow conditions. The performance curve measured in our system is shown in Figure 2-11. This curve presents electric horsepower into the motor, output pressure, and efficiency versus flow at the variable inlet vane setting used for the turbine performance tests in Section 6.0. This blower is operating much below normal efficiency for these tests. The observed 40% to 50% efficiency should improve to 80% for a properly sized blower in its normal load range. This particular blower was designed for a 400 HP motor and much higher flows than the test work required.

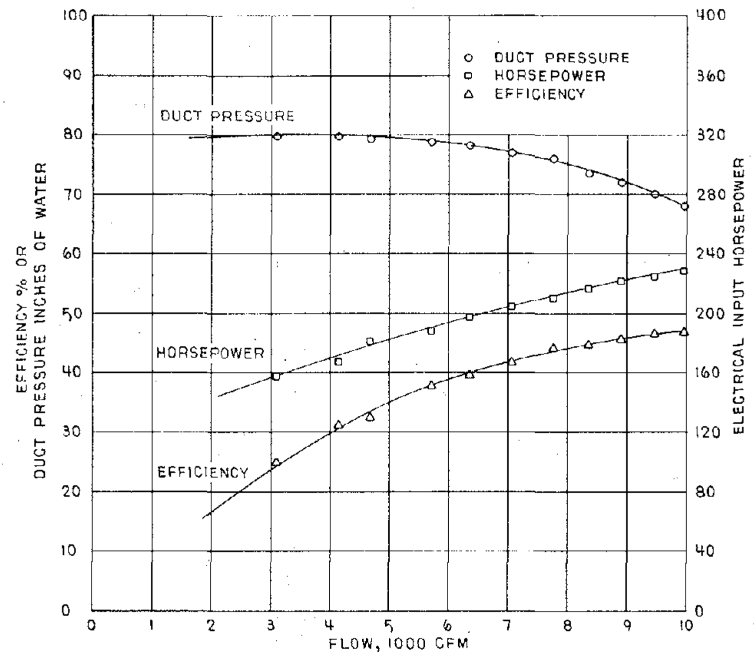


Figure 2-11. Installed Air Supply System Performance

The blower was installed in an underground concrete block pit with inside dimensions of 10 ft. square, with a depth of 8 ft. The roof was made from 6 in. precast concrete planks, and covered with 6 in. of dirt. Figure 2-12 shows the installation. An underground inlet pipe (30 inch dia.) leads from an inlet box (with filter) located in the window area of station 1 to the blower. Approximately 25 ft. of this inlet pipe is of the

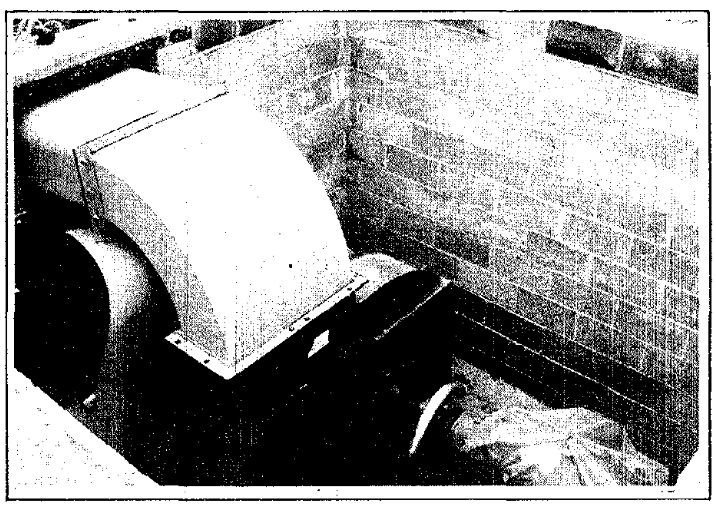


Figure 2-12. Blower Installation

acoustical type (outer tube with a perforated inner tube with the annular space, approximately 1 in. filled with fiberglass). The outlet pipe (30 inch dia.) runs from the blower through 25 ft. of acoustical pipe and then through a 12 in. venturi section. The venturi is used to measure air flow. The pipe is connected with 45° laterals to the four 30 in. main air pipes at station 5. Figure 2-13 and 2-14 show the inlet and outlet pipes before they were covered with fill.

By placing the blower underground, a substantial noise reduction was obtained. Noise above the blower pit was 63dBA facing away from the trap door opening. At 25 ft. from the blower pit, the sound level was 50dBA. In the blower pit the noise level was 108 dBA.

A 460 volt, 60 hertz, 160 KW supply with a silicon controlled rectifier starter for reduced voltage starting was provided for the motor. The main disconnect, wattmeter and other electrical service controls were located inside the enclosure. Lighting and 115 volt circuits were provided with a 208 volt, 3 phase, 15 KW transformer.

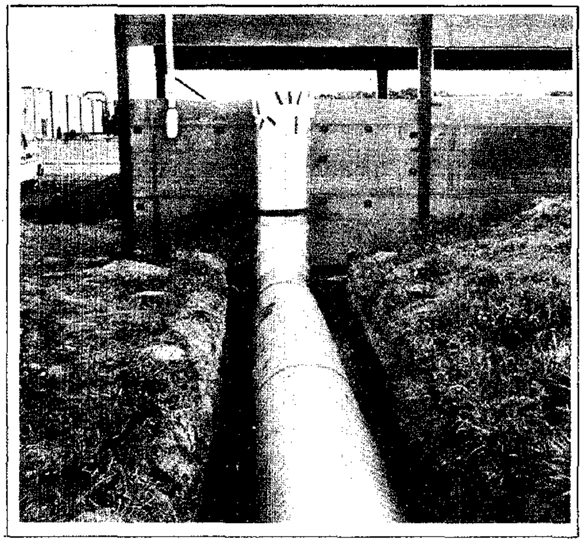


Figure 2-13. Blower Inlet Pipe

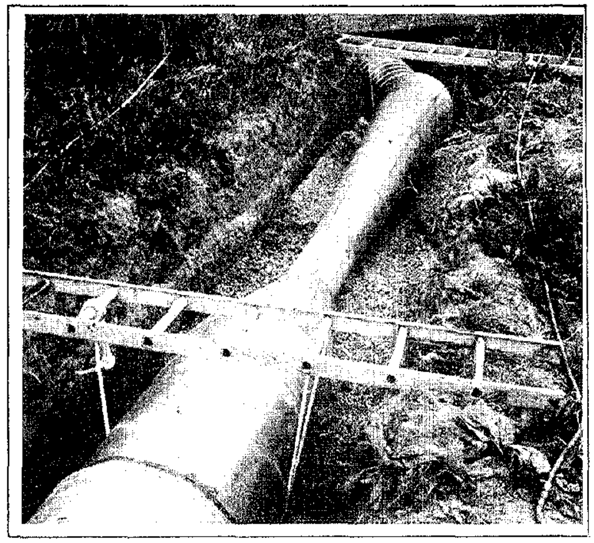


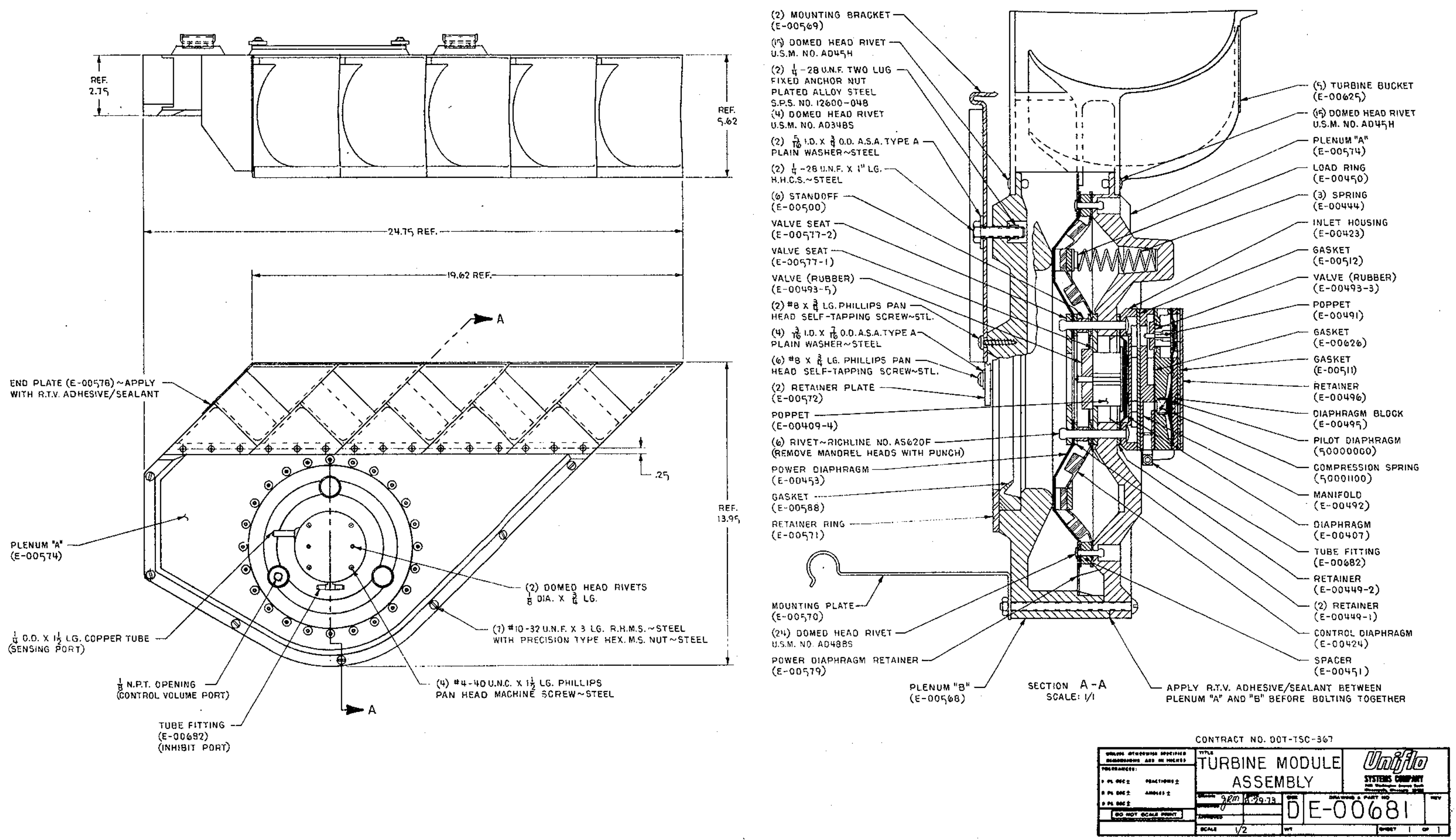
Figure 2-14. Blower Outlet Pipe-Venturi Section

2.5 TURBINE MODULES

Turbine modules are used to provide the thrust for vehicle propulsion. They are essentially a linear form of a rotating, re-entry, impulse turbine. Air at low pressure (2 to 3 psi) is provided to a nozzle which reacts with the vehicle bucket. This air is then redirected back to a stationary bucket which redirects it back to the vehicle bucket. When the air is redirected in the stationary bucket, it is mixed with the nozzle flow to increase its momentum and sustain the process. The air which reacts with the vehicle bucket provides the forward thrust. Performance tests of the turbine are contained in Section 6.0.

For the test work 200 modules were constructed. The configuration of the module is shown in Drawing E-00681. Previous contract work presented in Report DOT-TSC-UMTA-73-1 indicated some short-range improvements were necessary, both in mechanical and performance aspects. Time limited the scope of the changes undertaken, but those accomplished were:

1. Redesigned the passageways to reduce pressure losses inside the turbine module by increasing the power diaphragm opening area, use of an aluminum flow shield, and a more gradual expansion of the flow area downstream of the power diaphragm sealing surface.
2. Increased bucket size from 4.5 in. to 5.0 in., reducing the number of buckets per module from 6 to 5, and addition of side skirts. These changes allowed a better sized exhaust area in the vehicle bucket, reduced air leakage, and increased the thrust by 11%.


REF. 2.75
REF. 5.62
24.75 REF.
19.62 REF.
A
END PLATE (E-00578) ~ APPLY WITH R.T.V. ADHESIVE/SEALANT
.25
REF. 13.95
PLENUM "A" (E-00574)
(2) DOMED HEAD RIVETS 1/8 DIA. X 1/4 LG.
(7) #10-32 U.N.F. X 3 LG. R.H.M.S. ~ STEEL WITH PRECISION TYPE HEX. M.S. NUT ~ STEEL
1/4 O.D. X 1 1/2 LG. COPPER TUBE (SENSING PORT)
1/8 N.P.T. OPENING (CONTROL VOLUME PORT)
(4) #4-40 U.N.C. X 1 1/2 LG. PHILLIPS PAN HEAD MACHINE SCREW ~ STEEL
TUBE FITTING (E-00692) (INHIBIT PORT)
(2) MOUNTING BRACKET (E-00569)
(15) DOMED HEAD RIVET U.S.M. NO. AD45H
(2) 1/4-28 U.N.F. TWO LUG FIXED ANCHOR NUT PLATED ALLOY STEEL S.P.S. NO. 12600-048
(4) DOMED HEAD RIVET U.S.M. NO. AD34BS
(2) 5/16 I.D. X 3/4 O.D. A.S.A. TYPE A PLAIN WASHER ~ STEEL
(2) 1/4-28 U.N.F. X 1" LG. H.H.C.S. ~ STEEL
(6) STANDOFF (E-00500)
VALVE SEAT (E-00577-2)
VALVE SEAT (E-00577-1)
VALVE (RUBBER) (E-00493-5)
(2) #8 X 3/8 LG. PHILLIPS PAN HEAD SELF-TAPPING SCREW ~ STL.
(4) 3/16 I.D. X 7/16 O.D. A.S.A. TYPE A PLAIN WASHER ~ STEEL
(6) #8 X 3/8 LG. PHILLIPS PAN HEAD SELF-TAPPING SCREW ~ STL.
(2) RETAINER PLATE (E-00572)
POPPET (E-00409-4)
(6) RIVET ~ RICHLINE NO. AS620F (REMOVE MANDREL HEADS WITH PUNCH)
POWER DIAPHRAGM (E-00453)
GASKET (E-00588)
RETAINER RING (E-00571)
MOUNTING PLATE (E-00570)
(24) DOMED HEAD RIVET U.S.M. NO. AD48BS
POWER DIAPHRAGM RETAINER (E-00579)
PLENUM "B" (E-00568)
SECTION A-A SCALE: 1/1
(5) TURBINE BUCKET (E-00625)
(15) DOMED HEAD RIVET U.S.M. NO. AD45H
PLENUM "A" (E-00574)
LOAD RING (E-00450)
(3) SPRING (E-00444)
INLET HOUSING (E-00423)
GASKET (E-00512)
VALVE (RUBBER) (E-00493-3)
POPPET (E-00491)
GASKET (E-00626)
GASKET (E-00511)
RETAINER (E-00496)
DIAPHRAGM BLOCK (E-00495)
PILOT DIAPHRAGM (50000060)
COMPRESSION SPRING (50001100)
MANIFOLD (E-00492)
DIAPHRAGM (E-00407)
TUBE FITTING (E-00682)
RETAINER (E-00449-2)
(2) RETAINER (E-00449-1)
CONTROL DIAPHRAGM (E-00424)
SPACER (E-00451)
APPLY R.T.V. ADHESIVE/SEALANT BETWEEN PLENUM "A" AND "B" BEFORE BOLTING TOGETHER
CONTRACT NO. DOT-TSC-367
TURBINE MODULE ASSEMBLY
Uniflo SYSTEMS COMPANY
SCALE 1/2
D E-00681
SHEET 1 OF 1

3. Improved the mounting of the module to increase its rigidity and make installation easier.
4. Replaced the flexible hose and hose clamps for connection of the module to the main air supply with a metal elbow and pressure activated rubber seals. This resulted in easier installation and a more reliable connection.
5. Integrated a pressure relief valve in the amplifier valve, the purpose of which was to keep the turbine from turning off with high levitation pad pressures.

The operation of the turbine module can be explained by reference to Drawing E-00681. Supply air is provided through a 5 inch diameter opening on the side of the module. This air is directed to the nozzles in the module, and is turned on and off by the action of the power diaphragm. When a vehicle pad passes over a port on the levitation surface, the pad pressure is directed to the sensing port on the amplifier valve. The amplifier valve increases the sense port signal and operates the large poppet valve in the center of the power diaphragm. The air pressure between the power diaphragm and the control diaphragm is changed from supply pressure to atmospheric pressure. The power diaphragm then moves, opening the supply air passageway to the nozzles until stopped by the control diaphragm. The position of the control diaphragm is set before the module is activated by the vehicle. Its position is set by bleeding the air, contained between the control diaphragm and the outer case of the module, through an orifice for a preset period of time. The amount of opening of the power diaphragm will determine the total pressure at the nozzle by the throttling action produced between the power diaphragm and its seat. The nozzle total pressure is directly related to the thrust produced by the module. A typical plot of thrust versus bleed time of the control diaphragm is shown in Figure 2-15. This process is referred to as modulation or thrust modulation in the report. This approach to thrust modulation produces some undesirable results. The throttling process is inefficient, and when set at low thrust levels, the power diaphragm produces reeding with the accompanying noise. In future work the module should be designed so nozzle area is changed to produce changes in thrust level. This can be accomplished, for instance, with individual valves on each nozzle and by turning on the number desired for a required thrust level. This can give 40 steps in thrust from zero to maximum available. Because of the above mentioned problems and others described in the control section (2.7), thrust modulation for testing was done by blocking the number of nozzles required to obtain proper thrust levels.

Another function provided on the module is the ability to inhibit its operation. This is accomplished by putting supply pressure in the inhibit port of the amplifier valve. This biases the primary or pilot diaphragm of the amplifier valve against the levitation pressure forces. Since pad pressure can never be higher than supply pressure, positive inhibiting is obtained.

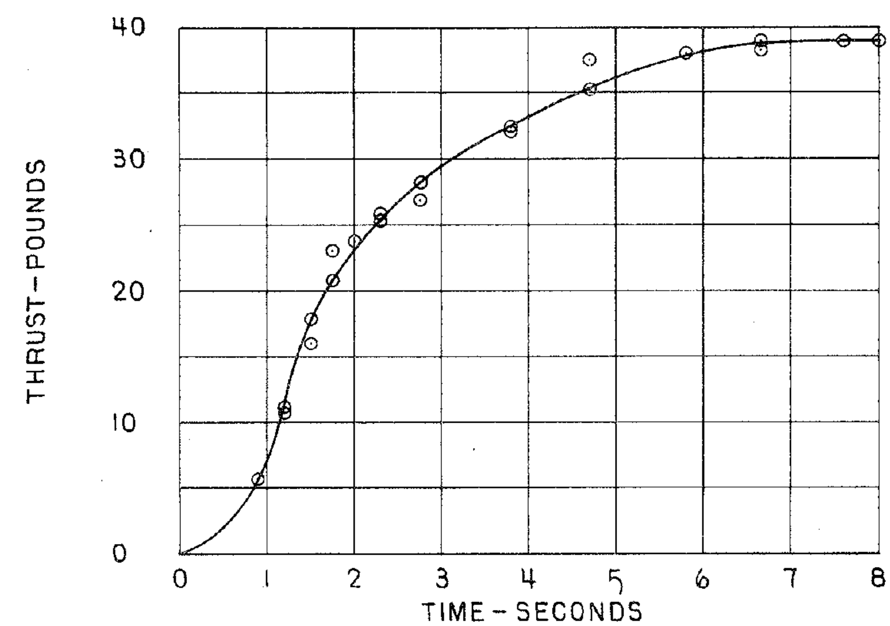


Figure 2-15. Thrust Output Versus Control Diaphragm Bleed Time

The basic shell and buckets of the module are made from polyester fiberglass. The diaphragms are made from neoprene rubber, and the other parts of the amplifier valve are made of phenolic. For future designs, the material of construction should be reevaluated in order to increase production rates, lower costs, reduce maintenance due to breakage, and generally improve performance of the various parts.

Because of the dimensional change in the buckets, a new bucket mold was constructed. The molds for the plenum halves were modified to incorporate the changes discussed above. Each turbine module was checked for proper operation and then installed in the operating surface in groups of eights and twos. The modules used in the previous contract work were installed in the siding area of the switch.

2.6 LEVITATION VALVES

The levitation valves turn the levitation air on and off in response to levitation pad pressure as the vehicle passes. Figure 2-16 shows a cutaway view of the valve. The levitation pad pressure acts on the pilot diaphragm through the sensing port and opens the pilot orifice. This reduces the pressure behind the power diaphragm because the air from supply pressure through the bleed orifice is insufficient to maintain the pressure. The supply air can then pass out the nozzle by movement of the power diaphragm. When levitation pad pressure is removed, the spring under the pilot diaphragm moves it to close off the pilot orifice and pressure increases under the power diaphragm which closes off the nozzle. The inverted cone of rubber on the bottom of the valve connects its control port to a control header in the opening surface. When duct pressure is applied to the control header, the pilot diaphragm is held against the pilot orifice, and the valve is inhibited. When the levitation valve is inhibited, the vehicle passing over it will go into the emergency braking mode.

Two different styles of levitation valves are used in the system: one as shown in Figure 2-16 which imparts a horizontal component to the air jet to provide thrust, and the second which is identical to the thrust type except it has a restricted outlet on the nozzle which discharges a vertical jet and thus provides only levitation air.

For this contract, 1,000 valves were constructed and generally operated satisfactorily. When cold weather operations (+10°F to -15°F) were tried, several valves produced erratic operation. Two failure modes were observed. In one, the inverted rubber cone which connects the control port to the control

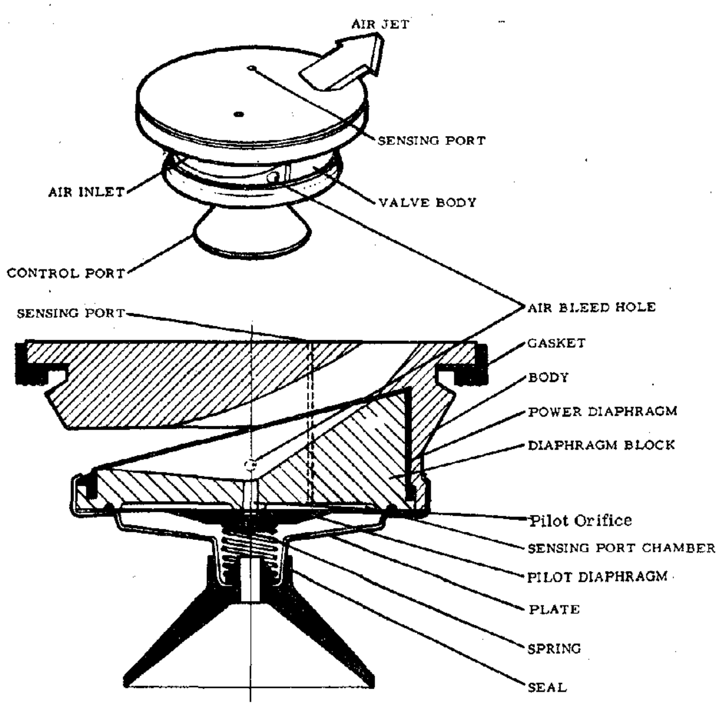


Figure 2-16. Levitation Valve

header became very stiff and exhibited a compression set. Supply air would then leak into the control header and increase its pressure until the levitation pad pressure was insufficient to turn the valve on and the vehicle would stop. This problem can be overcome by redesign of the valve/control header connection. The second problem observed was that some of the valves stayed on after the vehicle had passed. This resulted from a pressure buildup in the sensing port chamber caused by supply leaks into the chamber from the pilot orifice. Effectively, this amounts to having too large an air bleed hole, and is caused by rubber seal stiffness and compression set. However, in all cases, the valves will close when inhibited by supply pressure in the control header.

These two problems will require modest further development work on the levitation valve. The failures observed do not compromise system safety. One results in system stoppage if enough operating surface sections are involved, and the other uses excessive system supply air.

2.7 CONTROL SYSTEM

The control system was designed to provide for manual operation of the system, and is electric with solenoids which perform the electric to pneumatic signal conversion. A fully implemented control system would use a track based speed, spacing and safety system.

The control system enables the operator to control vehicle levitation, direction and amount of thrust application, as well as the switching function. (See Section 2.8). Levitation control has two functions: one function (levitation start) initiates the self-perpetuating levitation pad pressure, and the second function inhibits the valves for emergency braking. Thrust control is obtained by selecting forward or reverse thrust, cruising on groups of two turbines or groups of eight turbines per section, and modulation of the thrust produced in each module. The operator's control console, shown in Figure 2-17, contains the switches that provide the electrical signals needed to control the vehicle movements.

As described in Section 2.5, thrust modulation is accomplished by bleeding air from the control volume. When applied to a single turbine, this technique works as described. However, to reduce costs, groups of 8 to 12 turbines were connected to bleed into a common manifold with the result that modulation became imprecise. This occurs because the flow interacts between interconnected control volumes and causes the turbines to shut off, rather than to operate at a modulated setting. For proper operation, individual module control valving is necessary.

Because of the difficulties noted above, speed modulation for the test program was effected by blocking up to three nozzles in each turbine module. This, in combination with the selection of groups of two turbines or groups of eight turbines, allowed the desired thrust level to be obtained.

In the siding area of the switch, the last 5 sections of track are always inhibited unless the operator holds a momentary switch closed. This ensures that the vehicle will be stopped on the shorter track available, when switched off at high speeds.

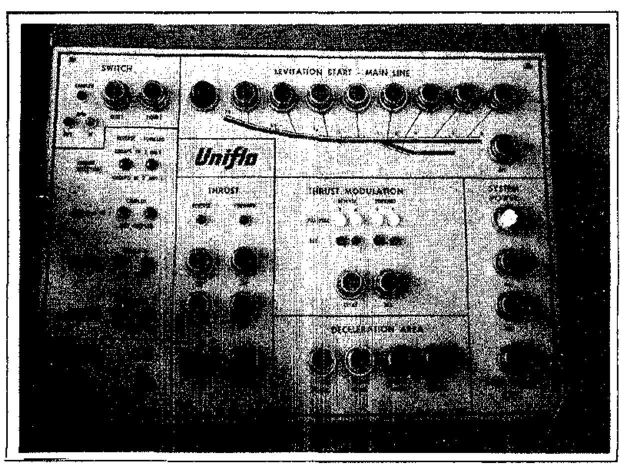


Figure 2-17. Control Console

Future development work on a control system will not be aimed at the type of control discussed above, but will be a track based control system composed of repeating identical control modules for each section of guideway.

2.8 SWITCH

A vehicle will switch or not switch off the main line, depending upon the position of a set of wheels on the vehicle base. The wheel position is determined by a stationary ramp and a movable switch arm. The switch wheels engage a catch rail formed by an angle located on top of the guide rails. The mechanical positioning of the switch wheels, guide wheels, guide rail, and catch rail is shown in Drawing E-00692, Section 2.3. These catch rails occur only in switch and merge areas of the guideway, and produce single side guidance of the vehicle, rather than the two sided guidance normally employed. The catch rail is straight on one side of the switch area for guiding the vehicle straight through.

An identical pattern of catch rails and guideway is used in merge areas, but the use of a movable switch arm is not required. A stationary ramp located after merging is complete moves the switch wheels to the straight through position, the normal position for travel on the guideway.

Details of the vehicle based switch mechanism are given in Section 3.3.

The switch was designed to permit selective switching of trailing vehicles in a multi-vehicle train traveling at 70 ft./sec. The required switch response time is 0.1 sec. from the time the vehicle is at the reader (which decodes the addressed magnetic tabs on the vehicle) until the switch is locked. This rapid response time facilitates the switching of vehicles coupled together in trains. The basic premise is that vehicle trains are made up in a station with the vehicle, or vehicles, for the closest destination at the rear of the train. The vehicle with the next closest destination is next, with the vehicle with the farthest destination first in the train. When the train approaches the switch, the switch arm operates on the rearmost vehicles first; hence, the switch arm has to move in approximately 1/2 vehicle length to miss the forward vehicles and switch the rear vehicle. It should be noted that switching can be accomplished by action of the ramp on either the front or rear switch wheels. The process is repeated at each succeeding switch that is a destination for the vehicles, removing the rear vehicles until all have reached their destinations.

The switch is composed of a ramp, or movable arm, 84 inches long which pivots about the upstream end and translates laterally 5.25 inches at the downstream end. Translation is obtained by the action of a cam follower mounted on a guided plate. The plate is moved by the action of a linear induction motor (Polynoid manufactured by Skinner Precision Industries, Inc., of New Britain, Connecticut), and the cam follower moves a half sine wave (peak to peak) shaped plate which is attached to the moving switch ramp. Figure 2-18 shows a photograph of these elements. The ramp is in the switch position in the figure. The cam plate has a

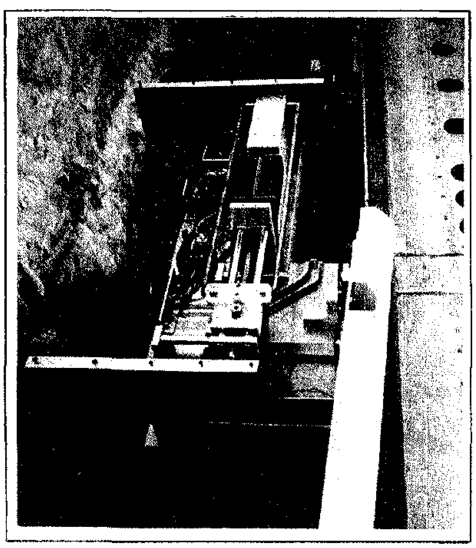


Figure 2-18. Switch Drive Mechanism

runout section tangent to the two peaks of the sine wave to allow overtravel of the cam follower plate and to provide positive locking of the moveable arm at its two extreme positions. In addition, it allows the linear motor rod to start moving before it encounters any significant resistance.

The linear induction motor is highly overpowered, and therefore has a duty cycle of 2.5%. A holding coil keeps the motor rod at the end of its travel, and the motor is turned off to avoid overheating.

In the test facility, the switching cycle is set up by pressing the switch enable button on the control console which arms the circuitry. A pressure sense port located in the deck upstream from the switch arm is connected to a pressure switch. When a levitated vehicle moves over the port, the pressure switch closes and energizes the linear motor contactor and holding circuits. After the vehicle passes the switch, a pressure switch is activated which drops out the holding circuits and the motor rod is retracted by springs connected to it. Two springs are used for redundancy.

Figure 2-19 shows the arm in the divert position, and Figure 2-20 shows the arm in the straight through position. Figure 2-21 shows the vehicle switch wheel moving along the ramp. In Figure 2-22, the switch wheels are about to engage the leading edge of the catch rail which is ramped slightly for smooth engagement.

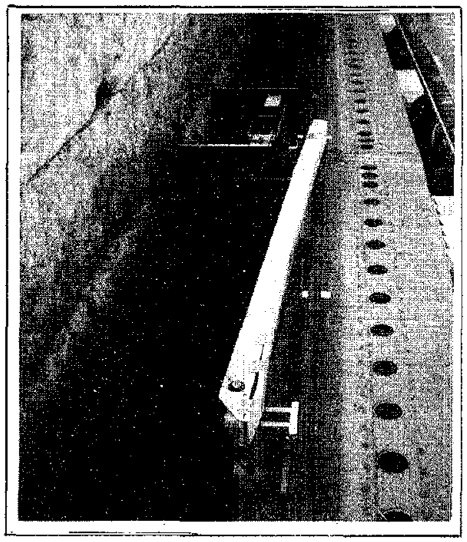


Figure 2-19. Switch Arm in Divert Position

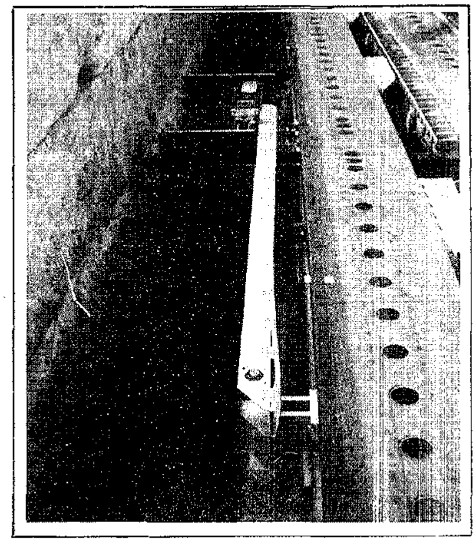


Figure 2-20. Switch Arm in Straight-Through Position

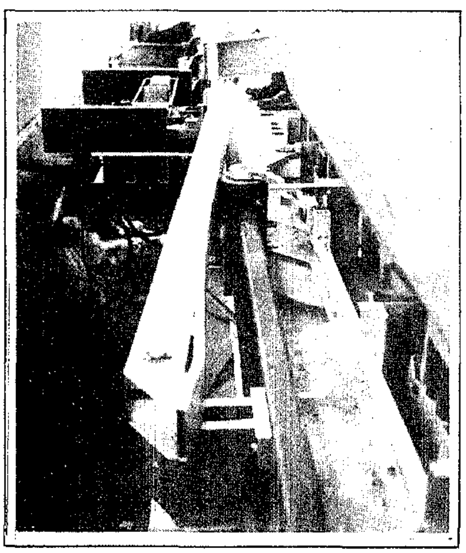


Figure 2-21. Switch Arm Moving Switch Wheels

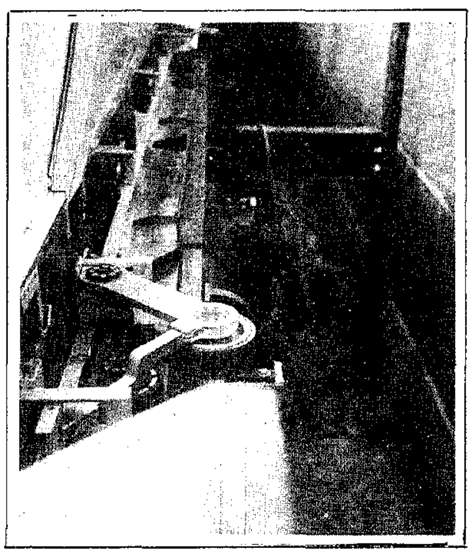


Figure 2-22. Switch Wheels About to Engage Catch Rail

Since speed of operation is an important criterion of the switch, all parts were made of aluminum where feasible, and minimum weight was obtained by removing excess material.

The response times of the various elements of the switch were determined by plotting their actuation times through the use of an oscillograph (see Section 5.2. 1, Item 1). In order to determine the response time of the pressure switch, the position detector (Section 5.2.1, Item 8) was adjusted to denote the point where the pressure switch closed with the vehicle moving slowly. For the test runs shown in Table 2-1, time zero was taken as the time when the vehicle reached the position detector.

TABLE 2-1 RESPONSE TIMES OF SWITCH COMPONENTS

Run No.	Vehicle Velocity (ft./sec.)	Elapsed Time (Milliseconds)			
		Pressure Switch Closed	Linear Motor Energized	Switch Arm Motion Starts	Switch Arm Locked
1	4	21	31	61	143
2	8	21	33	64	145
3	16	21	35	65	146
4	19	22	35	66	147
5	21.5	21	35	65	146
6	23	21	38	69	152
7[1]	15	19	31	62	145

[1] For this run, an 850 lbs. load was added to the vehicle in the front passenger compartment to raise the levitation pad pressure.

Table 2-1 shows the response time of the pressure switch to be 0.021 seconds, and constant at velocities of 4 ft./sec. and up. Increasing the pad pressure caused a slight decrease in pressure switch delay. The contactor requires .012 to .017 seconds to close. The variation probably depends on where in the voltage curve of the 60 Hz line the pressure switch is closed. In the table, the "Switch Arm Motion Starts" column is when the arm has moved 0.3 inches. The delay from the time the motor is energized is very consistent, and is .031 seconds.

The "Switch Arm Locked" times are .112 seconds within ±.002 seconds from motor energization. The motor rod travels further, is decelerated by a shock absorber, and comes to rest. However, the locking of the arm is safely completed before the rod comes to rest. The total motion of the switch arm is 5.25 inches.

The operating time for the switch is from .122 to .131 seconds from contactor energization ("Pressure Switch Closed"). A reader for the coded magnetic tabs can be expected to have a delay time less than .01 seconds. Therefore, the maximum overall switching time for this switch would be .141 seconds. This switch time will allow trains up to 50 ft./second. Minor changes will accommodate higher speeds. Switch operation time for this design is a non-critical item in systems employing individual vehicles.

To reduce the loads on the vehicle switch wheels and mechanisms, the shape of the switch arm was designed so as to accelerate the switch wheels at a constant rate to a desired lateral velocity, and to then keep the wheels moving laterally at this velocity. The constant acceleration portion of the switch arm occupies the first 33% of its length and was designed to impart an acceleration of 5 g to the switch wheels at a vehicle speed of 70 ft./sec. The constant acceleration section on the arm can be observed in Figure 2-19 and 2-20. At this vehicle speed, the design lateral velocity is 5.2 ft./sec. while the wheels are moving on the constant velocity portion of the switch arm. At 35 ft./sec., the design lateral velocity is 2.6 ft./sec. and the design lateral acceleration is 1.25 g. The actual lateral accelerations and lateral velocities of the switch wheels were not measured.

The stationary ramp shown in Figure 2-23 was also designed with constant acceleration and constant velocity sections. At a vehicle speed of 70 ft./sec. the design lateral acceleration of the wheels is 1.43g, and the design lateral speed at the constant velocity portion is 2.75 ft./sec.

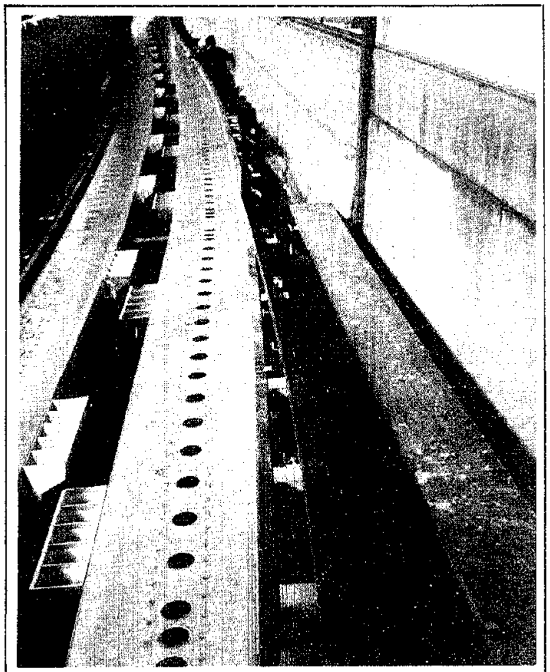


Figure 2-23. Stationary Ramp

The function of the stationary ramp is to ensure that the switch wheels are in the "not switch" position when approaching the switch arm. Since the vehicle travels in both directions on the test track, it is necessary that the stationary ramp be bidirectional (a ramp in both directions). For an installation where vehicles travel in one direction only, a single ramp will suffice.

Because of the bidirectional travel of the vehicle in this test installation, an arm safety interlock is provided which retracts the switch arm if it should happen to be in the "switch" position when the vehicle is moving opposite the normal switching direction.

The switch has been used for vehicle speeds up to 35 ft./sec. with no malfunctions. Approximately 500 switch cycles have been achieved.

Future switch development work should investigate switch wheel and mechanism loads, testing of the switch at higher speeds, testing with trains, testing with an address reading device, and improving switch response times.

2.9 ARRESTING MECHANISM

Three vehicle arresting mechanisms are provided—two on the north end and one on the south end. Figure 2-24 shows the installed arresting mechanisms. They are made from rubber exerciser cord. The exerciser cord is a cotton covered multistranded rubber of 5/16 in. diamter. 144 strands of cord are used, 72 on each side of the track. The two ends are joined together with steel cable which mates with the vehicle bumper, and the remaining ends are anchored to the enclosure structure.

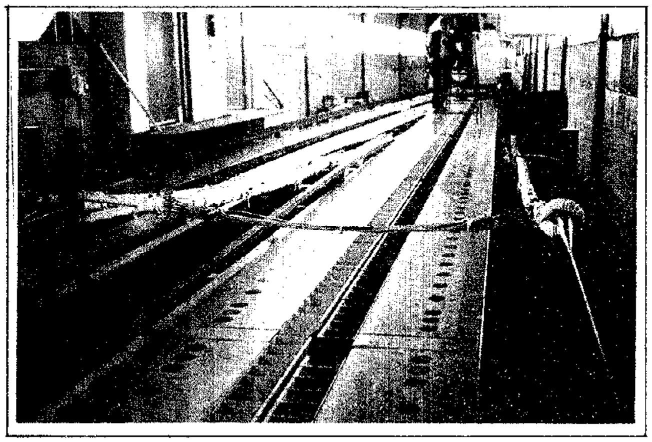


Figure 2-24. Vehicle Arresting Mechanism Installation

Two loops made of the exerciser cord retain and align the mechanism in its rest position. A pair of steel cables retain these loops when the cords are elongated so they will catch the mechanism on the return stroke.

The spring constant for the mechanism was designed to be 83.7 lbs./ft.; however, the cords used had an elasticity on the low side of nominal. This resulted in a spring constant for the cord on the north end of 70 lbs./ft. and a spring constant on the south end of 53.5 lbs./ft. This limited the maximum speed to 30 ft./sec. loaded, and 37 ft./sec. empty to keep the vehicle from going off the track on the south end. The working extension limit of the cords is 50 ft., and at this limit they store 88,000 ft.-lbs. of energy (north) and 67,000 ft.-lbs. of energy (south).

2.10 SUMMARY AND RECOMMENDATIONS

The test facility consisting of 371 feet of operating surface, a control system, and a switch which are enclosed in a structure fabricated from precast concrete planks was completed and operated.

Components of the operating surface include the levitation surface, levitation valves, air supply and turbine modules.

The turbine module was modified to increase its efficiency, increase its thrust, and make installation easier. Turbine performance characteristics are treated more fully in Section 6.

The levitation valves used were of the same design as was used for the original contract. Some malfunctions in cold weather operation were observed which could result in vehicle delevitation or increased air consumption due to leaks. These malfunctions are of the "nuisance" type and do not compromise system safety. Additional development efforts, while modest in scope, should be expended to correct these malfunctions.

The switch design concept was demonstrated to perform satisfactorily. The switch responds rapidly enough to switch trailing vehicles in a train moving at 50 ft./sec., while allowing leading vehicles to continue on the main line. Additional development work should include testing with trains, testing with an address reading device, and improving the switch response times.

The control system, using electric solenoid valves for controlling the various functions, was designed for manual control of the system. Future development work should be directed toward the track-based automatic control system. Top priority should be given to the full scale implementation of this system.

The air supply was provided by the same electric motor/centrifugal blower combination used on the previous contract. The blower was installed underground to reduce noise levels.

Most of the elements of the Uniflo system described above are near the implementation stage. The additional development suggested above for the various elements could be carried out during production engineering phases of design and construction.

Other areas requiring consideration are train operation, vehicle-berth interface and operation, lighting systems, and safety systems.

3.0 FULL SCALE VEHICLE

3.1 GENERAL DESCRIPTION AND DESIGN GOALS

The Uniflo vehicle, a passive, nonpowered people container, was designed with several objectives in mind. These are to comfortably contain the people in a pleasant environment, provide easy ingress and egress, provide safety, and efficiently carry them to their destination. To provide these conditions, the vehicle empty weight per passenger should be low, sound levels pleasant, ride quality good, seats comfortable, and visibility and lighting adquate.

To accomplish these goals, the vehicle design incorporated an all aluminum structure. The empty weight is 2,100 lbs. (260 lbs. per passenger), and with a payload of 1,600 lbs. the gross weight is 3,700 lbs. The vehicle seats 8 people in two compartments of four with facing seats. A sound level criteria of NCA-60 was adopted as the design goal based on previous contract work. To accomplish this, lead-foam sandwiches were used for sound attenuation. Windows were used in the sides of the vehicle for passenger visibility and along the top for future lighting trials. The windows used were chosen for their sound reduction, thermal insulation, and weight reduction properties.

A secondary suspension was provided for good ride quality. A switching mechanism on board the vehicle and operated by a track based mechanism was designed for speed of operation and simplicity. This will allow its future use with trains of vehicles. The guidance and switch wheels were designed for loads to 800 lbs. each, and speeds to 70 ft./sec.

Overall size of the vehicle, less bumpers, is 15 ft., 3 in. long, 3 ft., 10 in. wide, and 6 ft., 5 in. high. Drawing E-00689 gives the outline dimensions of the vehicle.

In the test installation, special bumpers had to be designed for mating with the vehicle arresting mechanism and would not be typical of a normal vehicle.

During testing and operation, the vehicle traveled approximately 260 miles without any maintenance or repairs required. Although this is a short distance, the operation with no problems indicates first level of reliability. However, long term life and wear tests should be undertaken to prove its reliability and routine maintenance requirements.

3.2 VEHICLE SUPERSTRUCTURE CONSTRUCTION

The structural framing and skins of the superstructure were made entirely of aluminum. Standard extruded aluminum shapes were used for the framing to reduce costs and make construction possible without elaborate tooling. All the skins had single curvatures, so no compound forming was necessary. The finished weight of the superstructure alone was 1,570 lbs. The individual components' contribution to this weight were:

Basic framing, floor and skins – (including acoustic floor treatment)	610 lbs.
Seats –	240 lbs.
Windows –	220 lbs.
Interior acoustic treatment, carpeting, and trim moldings –	420 lbs.
Bumpers	80 lbs.

The superstructure floor forms the structural base to which the vehicle base and superstructure frame are attached. It is constructed out of aluminum squares, channels and angles (See Figure 3-1). Aluminum sheet is riveted to the top, then the assembly is sprayed with Sound-off mastic to dampen the floor structure (See Figure 3-2). A sandwich of 1/4 in. urethane foam, 0.5 lb./ft.^{2} lead, 1/2 in. foam, 0.5 lb./ft.^{2} lead, and 1/2 in. foam was put in place (See Figure 3-3) and the bottom sheet was riveted to the floor structure (See Figure 3-4).

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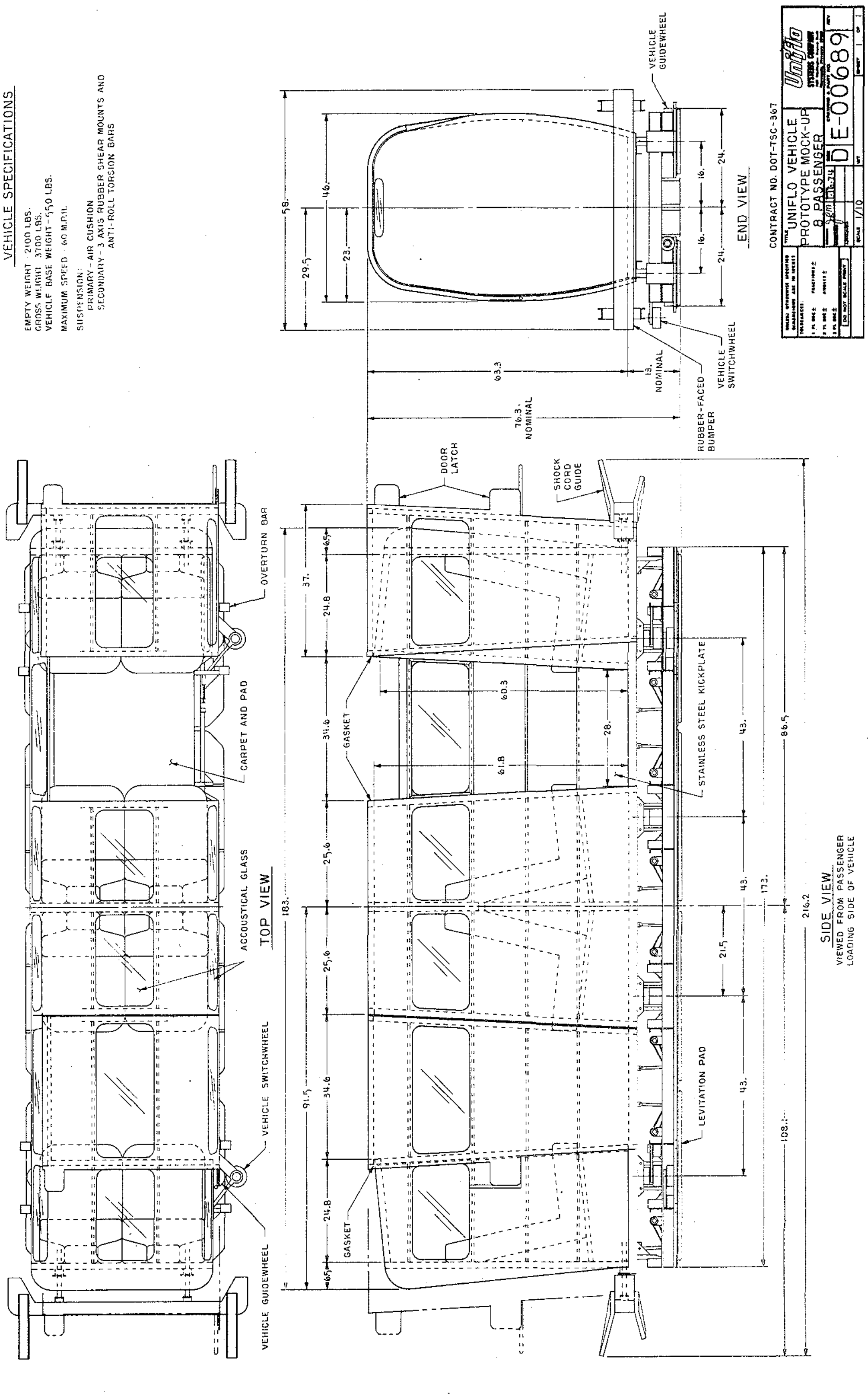

VEHICLE SPECIFICATIONS
EMPTY WEIGHT 2100 LBS.
GROSS WEIGHT 3700 LBS.
VEHICLE BASE WEIGHT-150 LBS.
MAXIMUM SPEED 60 M.P.H.
SUSPENSION:
PRIMARY - AIR CUSHION
SECONDARY - 3 AXIS RUBBER SHEAR MOUNTS AND ANTI-ROLL TORSION BARS
VEHICLE GUIDEWHEEL
VEHICLE SWITCHWHEEL
RUBBER-FACED BUMPER
NOMINAL
END VIEW
CONTRACT NO. DOT-TSC-367
UNIFLO VEHICLE PROTOTYPE MOCK-UP 8 PASSENGER
DE-00689
SCALE 1/10
OVERTURN BAR
CARPET AND PAD
ACCOUSTICAL GLASS
TOP VIEW
DOOR LATCH
SHOCK CORD GUIDE
GASKET
STAINLESS STEEL KICKPLATE
LEVITATION PAD
SIDE VIEW
VIEWED FROM PASSENGER LOADING SIDE OF VEHICLE

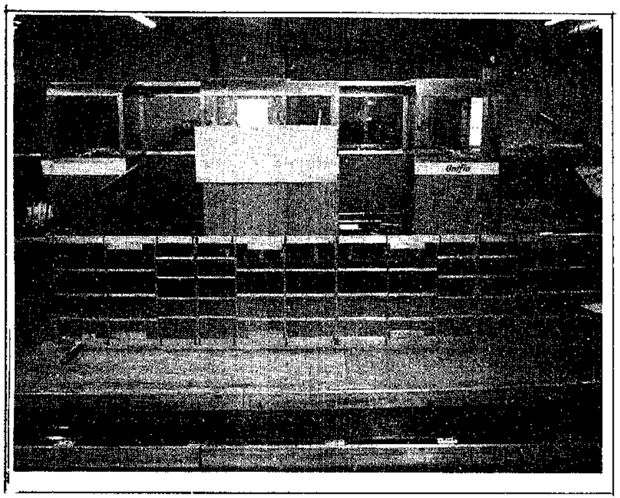


Figure 3-1. Superstructure Floor Framework

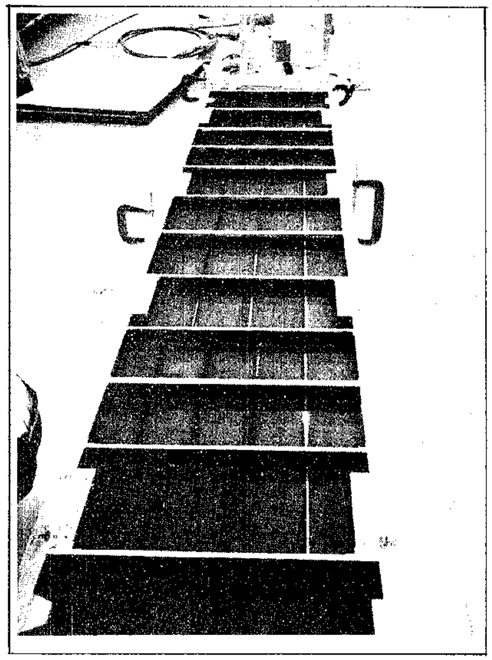


Figure 3-2. Framework with Sound Damping Applied

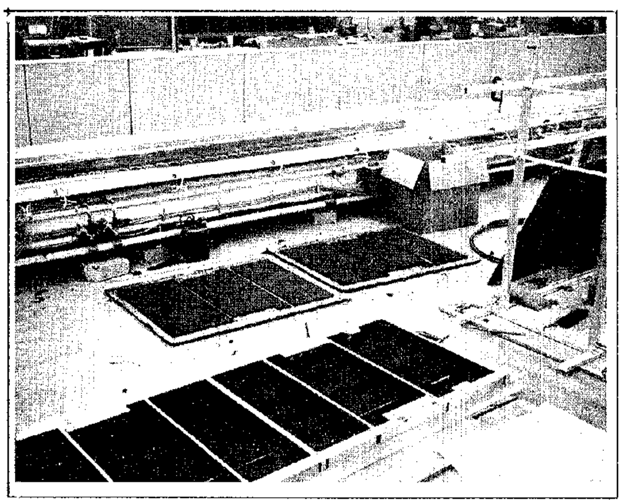


Figure 3-3. Sound Damping Sandwich Ready to be Applied

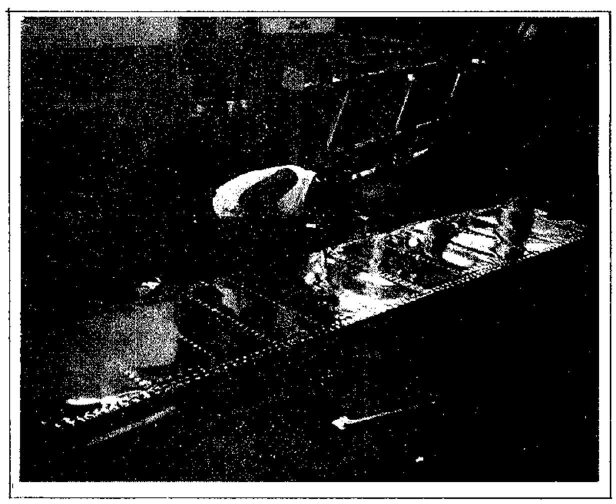


Figure 3-4. Riveting of Bottom Sheet to Floor

At the same time, a jig structure was constructed for aligning the seven structural frames. Figure 3-5 shows the fixture. The frames were made out of aluminum square tubing, which was bent by filling with polyglycol. Slots were cut to form the small radii. The frames were assembled on the jig structure and connected together by channels as illustrated in Figure 3-6. After the frames and the longitudinal channels were riveted together, the jig structure was disassembled and removed (Figure 3-7). Braces for lateral stiffness and seat frames were constructed (Figure 3-8). The end frames were formed from aluminum channels as

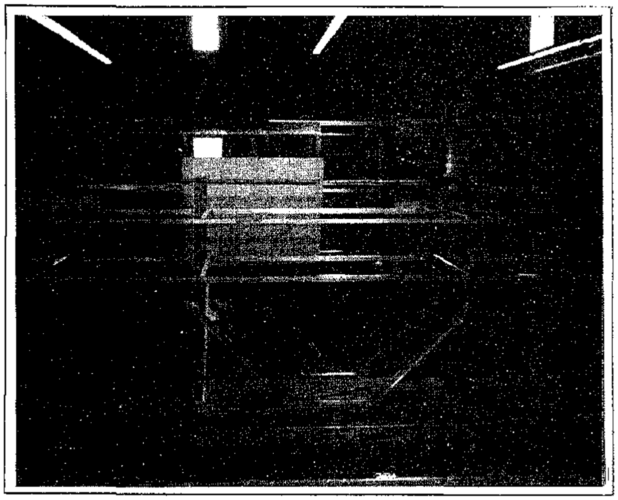


Figure 3-5. Superstructure Frame Alignment Fixture

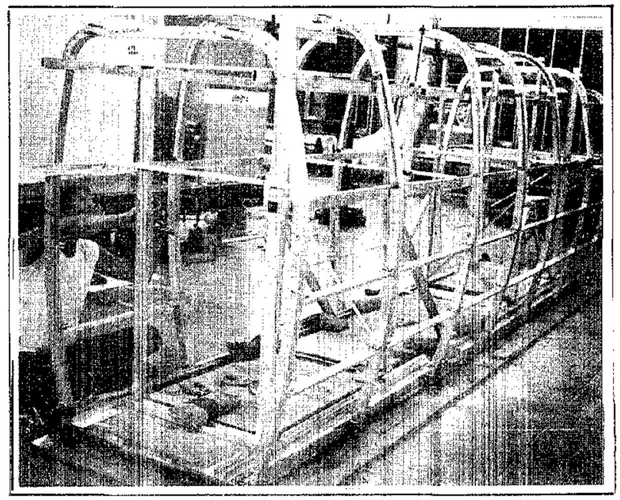


Figure 3-6. Assembly of Superstructure Frame Using Fixture

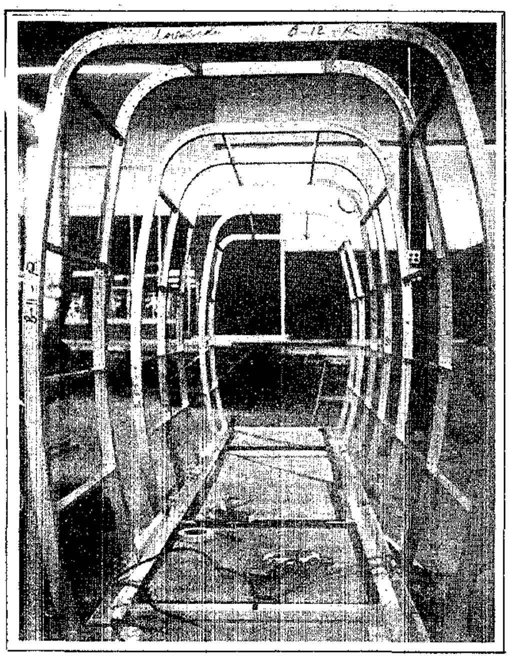


Figure 3-7. Completed Superstructure Frame
with Fixture Removed

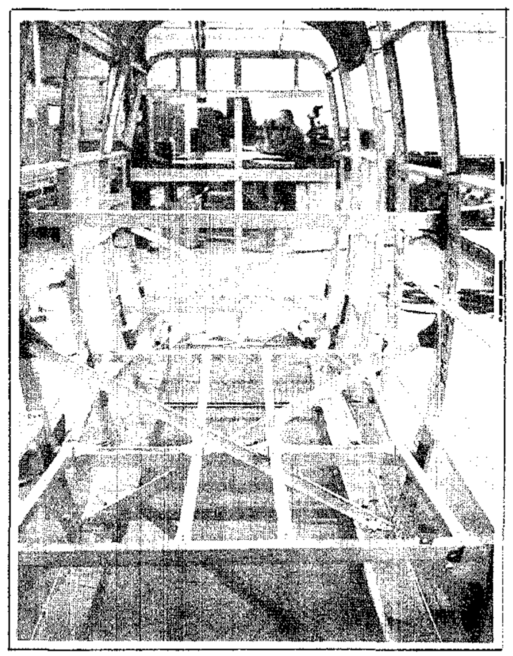


Figure 3-8. Seat Frames and Lateral Bracing

shown in Figure 3-9. The door frames were constructed in place using the same method as the other frames. The top and bottom of each door has a square aluminum tube, which holds two flanges. Each flange has two roller bearings perpendicular to each other, which means that each door is carried by eight roller bearings—four for vertical loads, and four for lateral loads. These bearings run inside a square aluminum tube fixed to the floor and upper door opening of the vehicle. The bumper support bearings were fixed to the square floor tubes. Weather seals on three edges of the door performed satisfactorily. However, the placement of a seal on the rear of the door was difficult because of the close fit of the door and vehicle surface. This seal was placed in only part of the rear edge and hand placed seals were used in the acoustical testing.

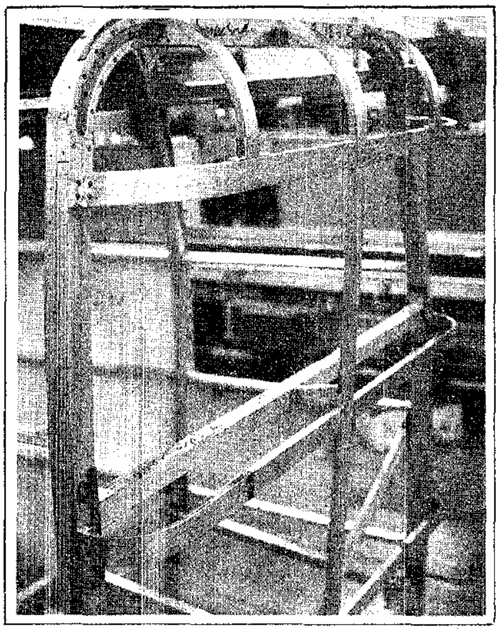


Figure 3-9. View of End Frames

The skin of the superstructure is .040 alclad aluminum sheet, which was formed and drilled in place, and then riveted to the frame using countersunk rivets. See Figure 3-10 and 3-11. The spherical corners were constructed from polyester auto body filler applied to preformed aluminum screen (See Figure 3-12). The finished structure ready for painting is shown in Figure 3-13.

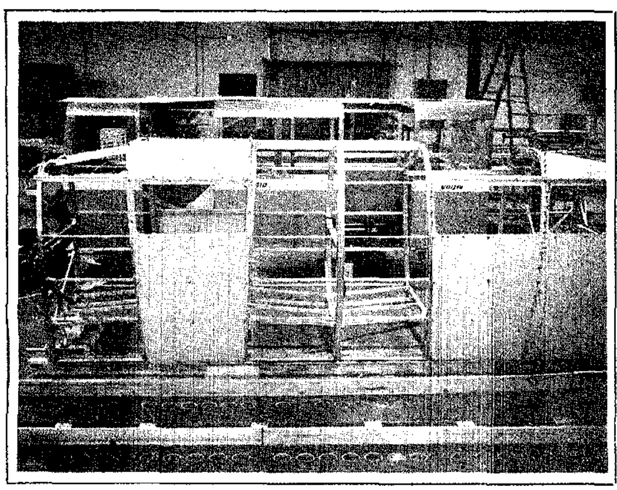


Figure 3-10. Superstructure Skin Applied to Frame

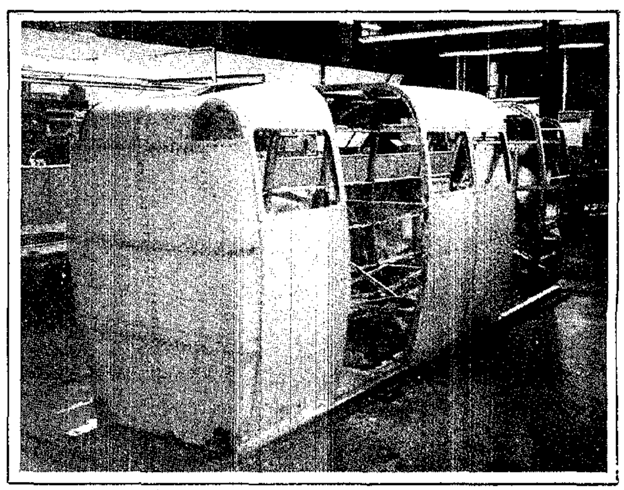


Figure 3-11. Superstructure Skin Applied to Frame

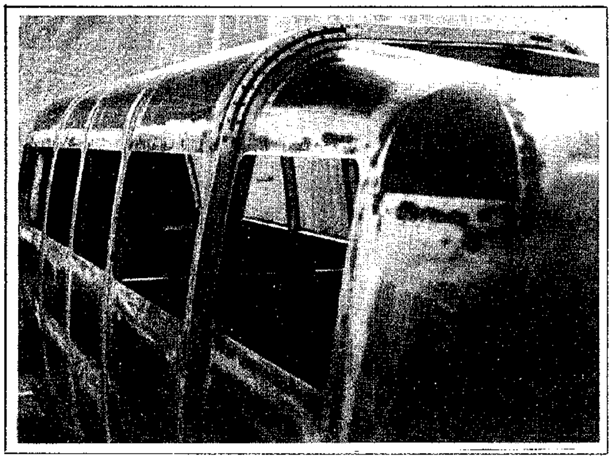


Figure 3-12. Detail of Spherical Corner Construction using Polyester Filler

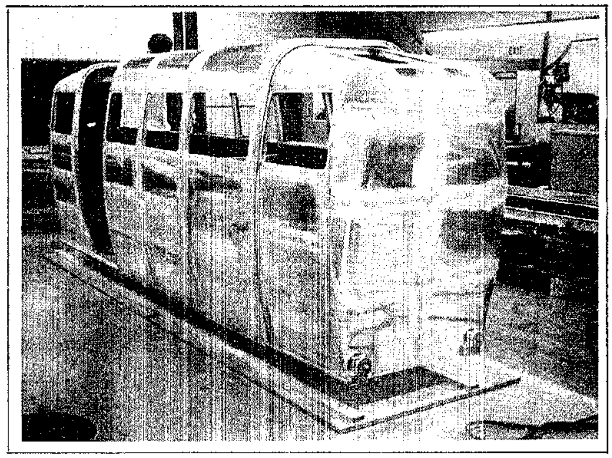


Figure 3-13. Completed Structure Awaiting Painting

The interior of the vehicle is finished with frosty metallic blue, crushed grain, perforated vinyl. This vinyl is the surface of the acoustic material laminated the same as described above with the vinyl applied to the 1/2 in. foam. A pressure sensitive adhesive on the 1/4 in. foam aided attachment. The interior was fixed to the superstructure frame using polished aluminum trim moldings. Stainless steel sheets were added next to the floor and between the seats to protect the acoustic material. Windows were insulated glass made up of the following: Acousta-Pane 36; 3/4 in. air gap; hard cote polycarbonate with Acousta-Pane on the inside. Eight vinyl bucket seats of the type used in Chevrolet Vega automobiles were bolted on the seat frames. Figure 3-14 shows a view of the interior on the finished superstructure, and Figure 3-15 shows a view of the interior through the door.

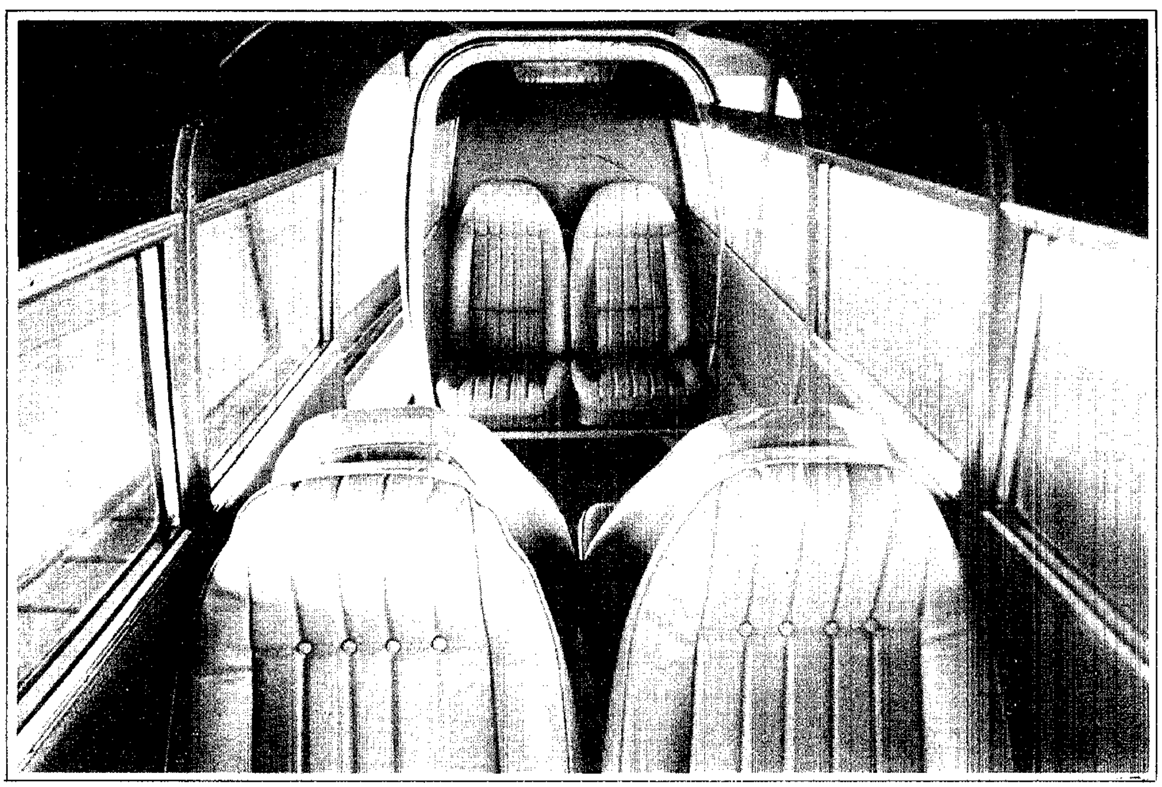


Figure 3-14. Vehicle Interior

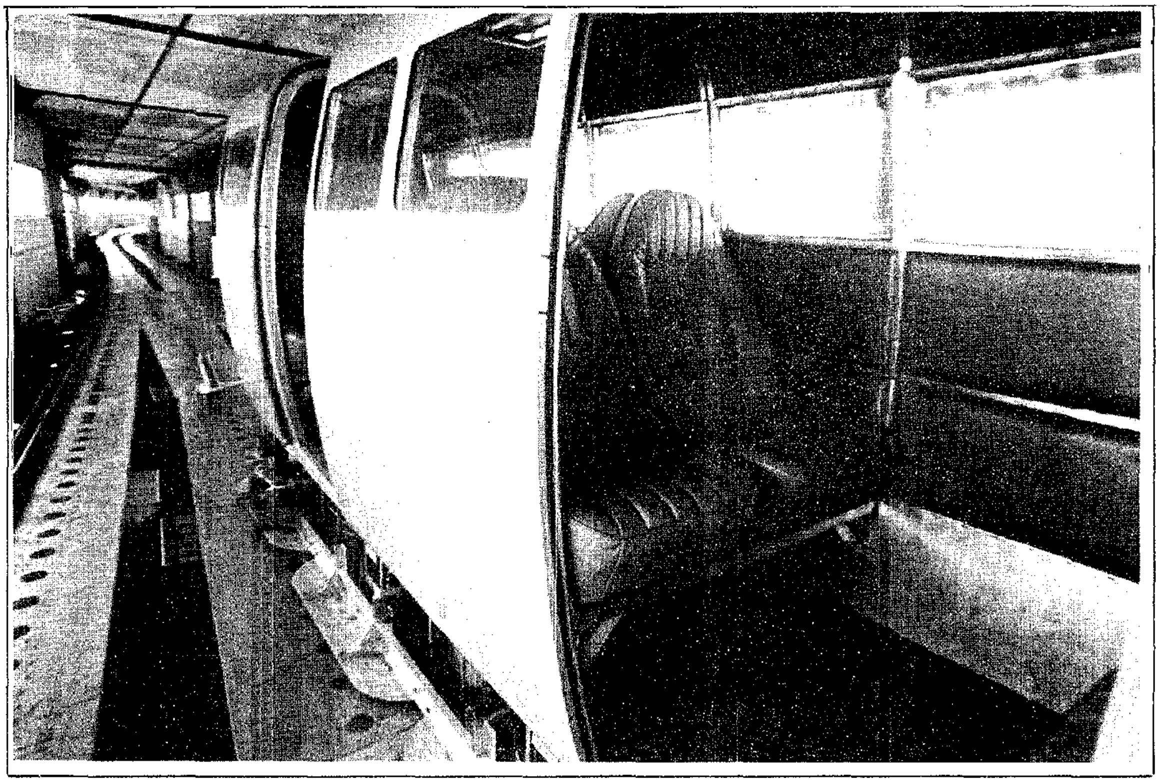


Figure 3-15. Vehicle Interior

The vehicle superstructure performed satisfactorily with the exception of the rear seal on the doors, and favorable comments were received from passengers given rides.

In this prototype, a heating, ventilating and air conditioning system was not installed. A description of this system based on a passive heat sink is reported in the Report No. DOT-TSC-UMTA-73-1.

Future development work on the superstructure should include the heating and air conditioning system, acoustical noise reduction (See Section 4.0), and vehicle door/berth door interface.

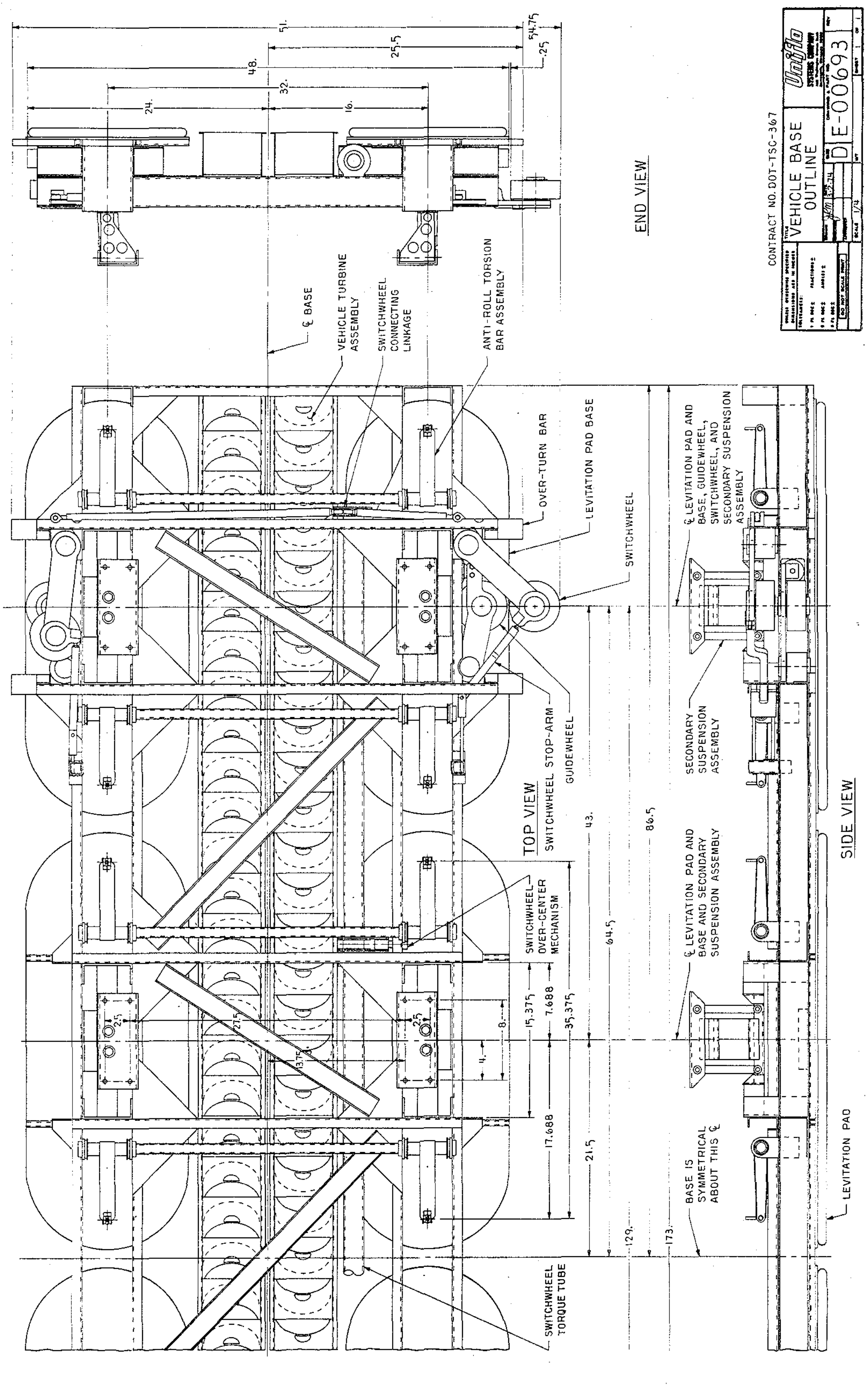
Through a more detailed structural analysis of the frame, an optimized design can be reached which will result in a lighter frame. More work on reducing the noise at its prime source will result in using lighter and less expensive acoustical material. The materials and methods of construction used for the vehicle are convenient for a prototype. For production purposes, both the materials and production methods should be revised. Plastics should be considered, especially for the ends of the superstructure. Better door seals should be considered.

A weight reduction program, as well as a safety analysis of the superstructure, are required additions to the development work.

3.3 VEHICLE BASE CONSTRUCTION

The vehicle base, constructed almost completely of aluminum, contains the levitation pads with an air interconnect system and emergency braking skids, the mating half of the linear turbine, secondary suspension, roll restraining torsion bars, guide wheels, switch wheels and overcenter mechanism, and a structural frame to connect the assemblies together. Drawing E-00693 shows the assembly and outline dimensions and Figure 3-16 is a photograph of the completed assembly.

The structural frame is composed of four 3" x 1" x 1/8" aluminum channels running the full length of the base. Ten 3" channels run laterally and are connected to the longitudinal channels. Diagonal 2" x 1" x 1/8" channels are connected to make the frame a truss in the horizontal plane. This truss uniformly trans-


END VIEW
TOP VIEW
SIDE VIEW
℄ BASE
VEHICLE TURBINE ASSEMBLY
SWITCHWHEEL CONNECTING LINKAGE
ANTI-ROLL TORSION BAR ASSEMBLY
OVER-TURN BAR
LEVITATION PAD BASE
SWITCHWHEEL
SWITCHWHEEL STOP-ARM
GUIDEWHEEL
SWITCHWHEEL OVER-CENTER MECHANISM
SWITCHWHEEL TORQUE TUBE
BASE IS SYMMETRICAL ABOUT THIS ℄
℄ LEVITATION PAD AND BASE, GUIDEWHEEL, SWITCHWHEEL, AND SECONDARY SUSPENSION ASSEMBLY
SECONDARY SUSPENSION ASSEMBLY
℄ LEVITATION PAD AND BASE AND SECONDARY SUSPENSION ASSEMBLY
LEVITATION PAD
CONTRACT NO. DOT-TSC-367
VEHICLE BASE OUTLINE
D E-00693
SCALE 1/4

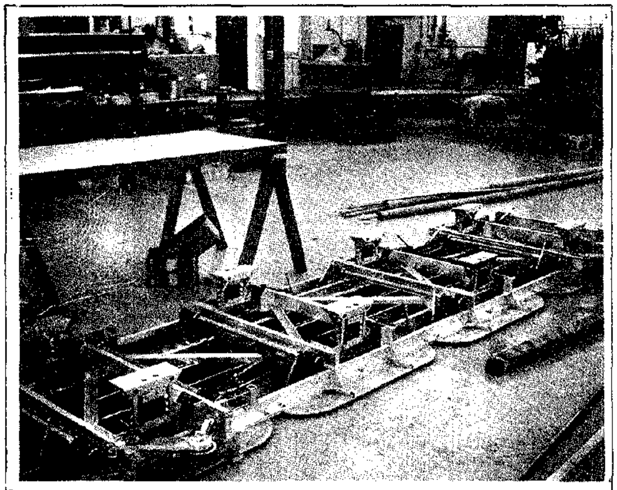


Figure 3-16. Completed Base Assembly

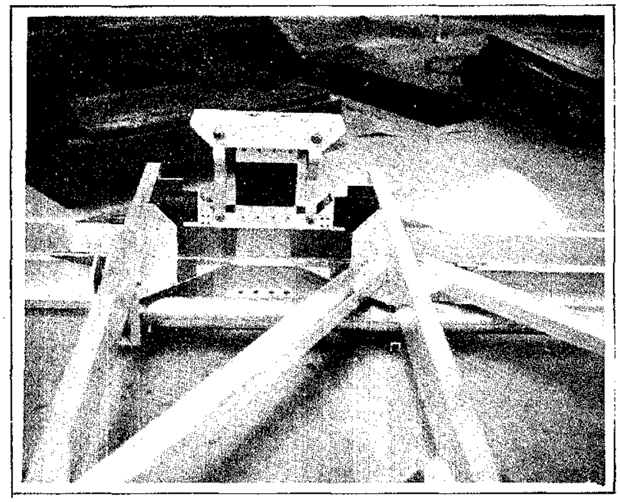


Figure 3-17. Secondary Suspension Assembly

fers loads from switch and guidance wheels through the secondary suspension to the superstructure. The structure is held together by stainless steel rivets. The structure is very flexible in the vertical plane and in rotation through a longitudinal axis to allow the base to conform to the operating surface in spirals, horizontal curves and vertical curves.

Eight levitation pad assemblies are attached to the frame in two rows of four. Directly above the center of each pad a secondary suspension assembly is mounted. These assemblies, shown in Figure 3-17, provide three axis suspension. Two horizontal rubber shear mounts provide vertical and lateral suspension, as well as pitch, roll and yaw suspension. The two vertical shear mounts provide longitudinal suspension through the action of a four-bar mechanism. The platform on top of the suspension assembly is bolted directly to the superstructure, while the horizontal shear mounts are bolted to the structural frame of the base. The vehicle vertical spring constant is 1,300 lbs./in. from measuremeant of height change with vehicle load. The longitudinal spring constant is 1,100 lbs./in. calculated from measurements on one suspension mount. The lateral spring constant calculated value is 600 lb./in.

To improve the roll resistance in the longitudinal axis of the suspension, eight torsion bars were connected across the vehicle. These bars increased roll stiffness approximately four times. This stiffness reduces the need for damping in the suspension. Although no damping was added to the suspension, more analysis and testing would be desirable to improve suspension characteristics.

In each corner of the vehicle are mounted a pair of guidance wheels (See Figure 3-18); one fixed wheel for the normal two rail guidance, and one movable wheel for switching. The wheels are made from cast aluminum hubs which are covered with a 1/2" thick band of urethane rubber. Each wheel uses two tapered roller bearings on a steel axle. The axle is mounted to a moving arm whose pivot point is a steel axle with two tapered roller bearings mounted in a square aluminum hub. The hub is attached to the base structural frame. The switch wheel and guide wheel are similar in mounting. The travel of the guide wheel is limited to 1/4" by a compression mount made from rubber with a high damping coefficient. The switch wheels have two positions as shown in Figure 3-18 and 3-19, and are held in these positions by an overcentering spring device. Outward travel of the wheel is controlled by a link and parallel bar slider (See Figure 3-18 and 3-19) which is attached to the end of the switch wheel arm. This link also carries part of the switching loads into the base. At the other end of the switch wheel arm is a reach rod which connects to one end of a longitudinal torsion bar. (See Figure 3-20). The torsion bar connects the front two switch wheel arms to the rear two switch wheel arms. At two locations on the torsion bar an overcenter spring mechanism is placed. Figure 3-21 shows a photograph of the overcenter spring.

In the connection between the reach rod and switch wheel arm, a rubber bushing is used to reduce shock loads on the system. A rubber stop is also used on the parallel bar slider to reduce impact shocks.

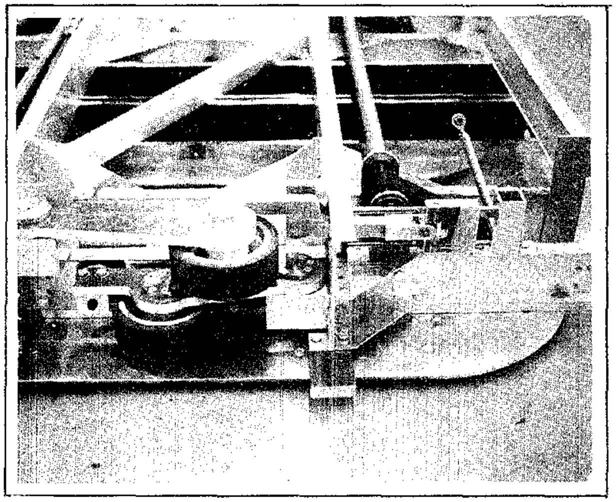


Figure 3-18. Guidance Wheel and Switch Wheel

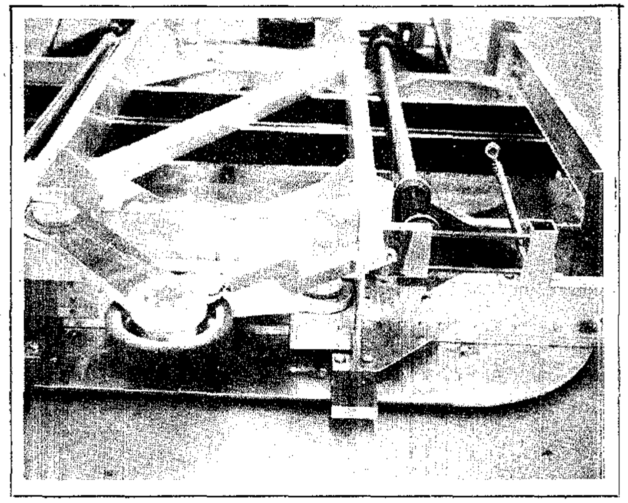


Figure 3-19. Switch Wheel Extended

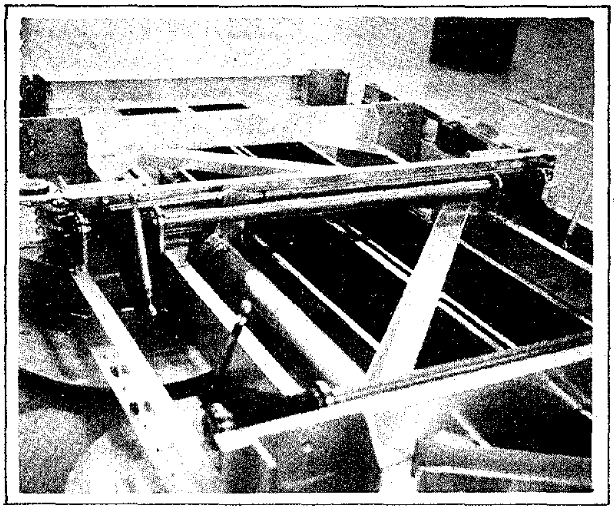


Figure 3-20. Reach Rod and Torsion Bar

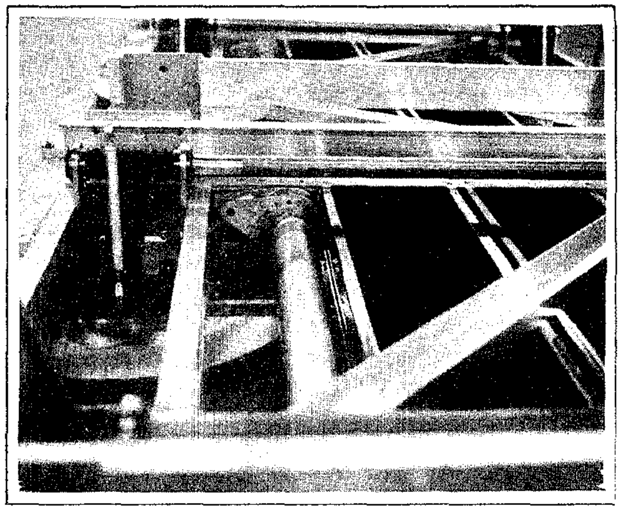


Figure 3-21. View Showing Over center Spring

Eight levitation pad assemblies are mounted on the base. These assemblies have an aluminum back plate to which a neoprene rubber pad is attached. Figure 3-22 and 3-23 show the assemblies. The levitation pad system has a spring constant of 6.8×10^4 lbs./in. To promote load sharing between pads because of the high spring constant, an interconnect system was installed. This system puts a pressure signal from the highest pressure pad to the lower pressure pad, which causes the lower pressure pad to extend. This increases its pressure, and therefore, its share of the load.* In the center of the pad a double row of turbine buckets are placed to derive thrust from the angled nozzle of the levitation valves in the switch area. Along each side of the pad buckets a brake skid is placed. Two different materials are used to achieve a braking friction coefficient of .3 g.

On each of the four corners of the vehicle, two rectangular bars extend which fit under the guide rails. (See Figures 3-22 and 3-23) These bars keep the car from overturning.

* U.S. Patent 3,757,699 further describes the levitation system.

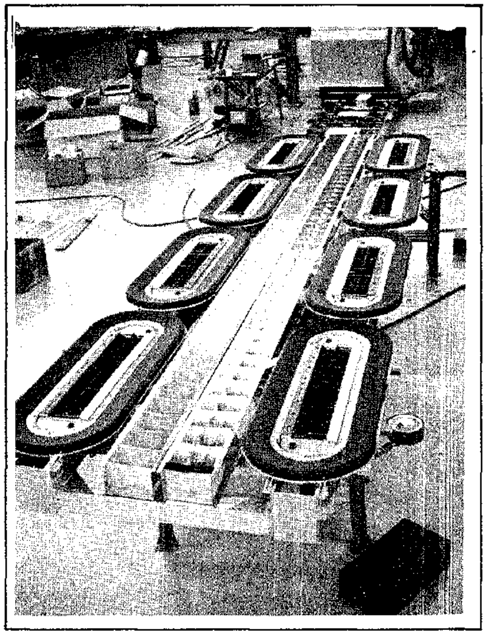


Figure 3-22. Levitation Pad Assemblies

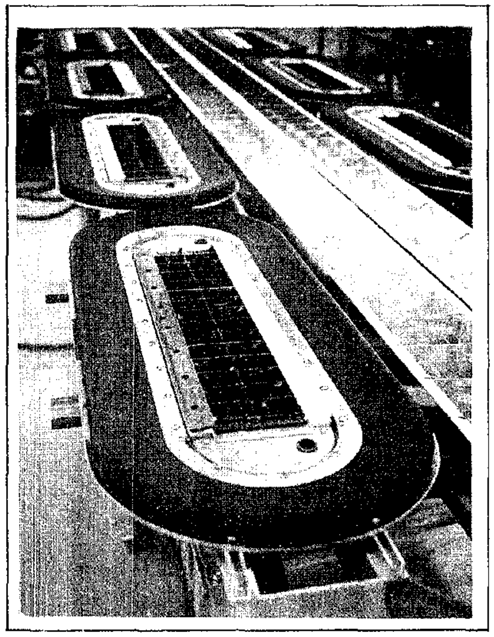


Figure 3-23. Closeup of Levitation Pad

In the center of the base, two rows of turbine buckets are attached, one for the forward direction, and one for reverse. These assemblies are made from light gauge aluminum, and riveted together. A damping compound was sprayed on the assembly to reduce vibrations. The top of the turbine was covered with a sound absorbing baffle (not shown in the figures).

The total weight of the base is 550 lbs., which is above a desired goal of 400 lbs. Several areas of weight reduction are possible, and future work should include a weight reduction program.

3.4 SUMMARY AND RECOMMENDATIONS

Since the Uniflo vehicle is a passive, nonpowered lightweight people container, simple construction using standard aluminum extrusions and sheet was possible. Vehicle windows and interior trim, while selected for their noise reduction characteristics, also enhance the aesthetic treatment.

The prototype vehicle constructed and tested in this contract performed satisfactorily, and proved the soundness of the basic concepts. Additional work should be directed toward improvements in the suspension system, acoustic noise reduction, weight reduction and simplified construction methods. Also, reliability and maintenance requirements need additional consideration.

An area which should receive first attention in future work is the heating, ventilation, and air conditioning system.

4.0 SYSTEM NOISE DESIGN AND TESTING

4.1 INTRODUCTION

Vehicle interior and guideway exterior sound levels of the Uniflo system were measured and analyzed. Exterior noise levels were very low, placing the system in the "no impact" regime for suburban areas. The levels meet the criteria of NCA-45 or PNC-50 at 25 feet from the guideway during all operations. Maximum level observed during operations was 50 dBA.

Vehicle interior noise levels were slightly higher than desired. During cruising up to 30 ft./sec., the interior levels would meet the criteria of NCA-65. However, during deceleration the levels were slightly above NCA-70. The maximum "A" weighted levels were 68 dBA for cruising and 77 dBA for deceleration. A reduction of 10 dBA at frequencies below 1,000 Hz would bring the noise level to the NCA-60 criteria. The following sections describe the noise reduction design, sound level measurements and analysis of the measurements.

4.2 DESIGN CONSIDERATIONS FOR ENCLOSURE AND VEHICLE

The noise reduction design was based on the recommendations of the previous contract work reported in Report No. DOT-TSC-UMTA-73-1. The noise criteria cited in that work was NCA-60. The enclosure was made of 4 in. thick concrete planks which represents the material used for an elevated guideway structure; however, the concrete would probably be 8 to 12 inches thick in the lower half of the structure. The sound transmission loss for 4 in. concrete (taken from National Bureau of Standards Test No. 804) shown in Table 4-1 would be more than adequate to meet NCA-60 sound levels.

The enclosure windows used were Acousta-Pane 36 made by Amerada Glass Company. The glass is 9/32 in. thick, and is made by laminating two plies of glass with an interlayer of soft transparent plastic. This plastic reduces the resonance and coincident effects which single panes of glass exhibit.

The transmission loss for this glass is also shown in Table 4-1 as tested by Riverbank Acoustical Laboratories.

TABLE 4-1 SOUND TRANSMISSION LOSS dB

Frequency Hz	125	175	250	350	500	700	1,000	1,400	2,000	2,800	4,000
Acousta-pane 36	25	28	28	30	33	35	36	36	35	35	39
4 in. Concrete	37	33	36	44	45	50	52	–	60	–	67

The glass recommended in previous work was Polarpane, manufactured by C. E. Glass, Inc., and would average about 7 dB more reduction than the Acousta-pane 36. The Polarpane is constructed of a 1/4 in. glass plate panel separated by 51 mm from a 3/16 in. glass panel. This construction increases costs, and there is some question about the suitability of this type of construction in an unheated structure because of the sealed inner air chamber.

Acousta-pane glass is available with higher transmission losses, but the glass, being thicker, is made of plate instead of sheet, which increases the cost.

Mounting of the glass was by use of a rubber "H" gasket, which will increase the transmission loss up to 5 dB.

The sound level of NCA-60 was expected to be achieved due to the combination of low percentage (17%) of glass area on the side of the enclosure and the rubber mounting of the glass. In fact, levels much lower than NCA-60 were realized.

To further improve noise levels outside the enclosure and inside the vehicle, the walls and ceiling of the enclosure were lined with 3 1/2 in. fiberglass household insulation to increase sound absorption. A 24 ft.

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strip of insulation was also put along each side of the operating surface and below the turbine modules. Measurements in the enclosure indicated the insulation reduced the sound levels by 5 to 7 dBA.

Installation of the insulation was from station 12 to station 20, and the Acousta-Pane was installed in the same sections, but on the acoustical test side only. The acoustical testing was done only in these sections. To reduce the noise levels from the air supply system, the blower was put in an underground pit with the feed pipes buried. In addition, the pipes were lined with sound absorbing materials.

In the vehicle design the use of massive structures to reduce the noise levels was unacceptable. The recommendation from the previous contract was the use of lead-urethane foam laminated materials. The material chosen was composed of 1/4 in. urethane foam, 1/2 lb. per square foot lead, 1/2 inch foam, 1/2 lbs. per square foot lead, and 1/2 in. foam covered with perforated vinyl which was the interior upholstery. The interior aluminum skin and frames of the superstructure walls and ceiling were first covered with a sprayable damping compound, and then the vinyl lead-foam sandwich applied.

The vehicle windows were the thermal insulating type with the inner pane of Acousta-Pane 36, a 3/4 in. air gap and then an outer pane of 1/8 in. hard coat polycarbonate. The use of a polycarbonate outside pane was to reduce weight and still have an insulating window which is deemed necessary when air conditioning and heating of the vehicle is undertaken. The floor of the vehicle was made from aluminum sheet, top and bottom separated by aluminum frames, and the same lead-foam material used on the walls, but with no vinyl. These aluminum sheets and frames were also sprayed with the damping compound. The floor of the vehicle was covered with a sponge rubber rug pad, then a 1 lb. per square foot lead sheet, and finally a nylon carpet.

On the back edge of the doors, the seals did not perform as expected for purely mechanical reasons, and they were omitted. Therefore, additional seals were put in place by hand during testing of the noise levels inside the vehicle. A 3 dBA change in noise level with the additional seals was observed.

The interior seats were vinyl covered with a limited number of perforations which contribute to the sound absorption.

The turbine buckets in the vehicle base were covered with the sprayable damping compound, and a baffle made from aluminum sheet and covered with 1 in. urethane foam was placed over the buckets.

Additional vehicle construction details are given in the vehicle Section 3.0 of this report.

4.3 TEST EQUIPMENT AND METHOD

The acoustical measurements, test equipment, and data reduction were performed by International Acoustical Testing Laboratores, Inc. (INTEST) of St. Paul, Minnesota.

Tests were made inside the vehicle as well as 25 ft. from the guideway with the vehicle loaded and unloaded. In addition to these basic conditions, several variations in speed and performance were recorded. For the outside sound measurements the unloaded vehicle weighed 2,430 lbs. with speed monitoring equipment and associated operator. Inside-the-vehicle testing increased the total weight by 200 lbs. to 2,630 lbs. In the loaded condition, for both the inside and outside measurements, the vehicle weight was increased to 3,723 lbs. Under the above four basic test configurations, the following variations were measured:

Ambient – blowers off
Ambient – blowers on
Levitated– at rest
Cruising – 10 ft./second
Cruising – 20 ft./second
Cruising – 25 ft./second
Cruising – 30 ft./second
Full Dynamic Braking from 25 ft./second
Full Acceleration from 25 ft./second

The speed was held within 1 ft./second of the desired velocity in the acoustical test area. The thrust was modulated by closing the number of nozzles required to maintain constant speed through the test area (See Section 2.5 and 2.7 for details).

Weather conditions during the outside testing were wind from the south/southwest at 3-5 knots, temperature 15° F and relative humidity 57%.

The equipment used for sound level monitoring was:

- Kudelski (NAGRA) Precision Portable Tape Recorder
- Bruel & Kjaer Impulse Precision Sound Level Meter Model 2204
- Bruel & Kjaer 1 in. Microphone Model 4145
- Tripod and 3 Meter Cable
- Pistonphone Calibrator Model 4220
- Windscreen Model UA 008A (outside measurements only)

Figures 4-1 and 4-2 show the test setup and microphone positions for the sound level measurements.

The data was recorded on tape with witness marks for indicating when the vehicle entered and left the acoustical test area.

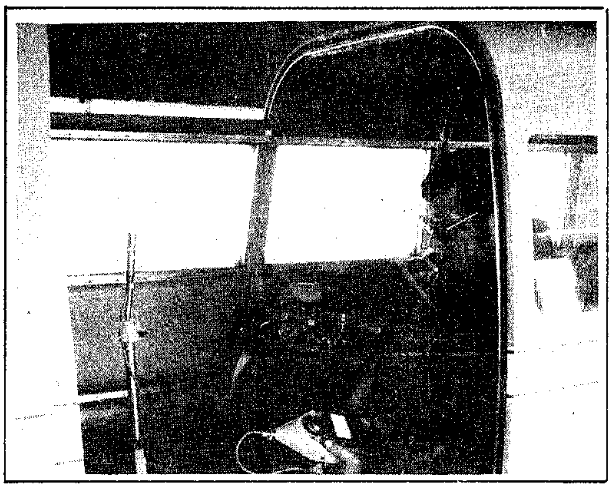

Figure 4-1. Acoustical Test Equipment for Vehicle Interior Noise Levels

Figure 4-2. Acoustical Test Equipment for Exterior Noise Levels

4.4 TEST RESULTS

The sound data was reduced at the INTEST facility using the following equipment:

- Kudelski (NAGRA) precision tape recorder
- Bruel & Kjaer impulse sound level meter Model 2204
- Bruel & Kjaer 1/3 octave band filter Model 1612
- Bruel & Kjaer high speed level recorder Model 2304

The data was reduced in two forms--1/3 octave band sound pressure levels, and A-weighted sound level time histories for each variation indicated above. (See Appendices B and C).

4.4.1 Vehicle Interior Noise

Figure 4-3 plots the background levels inside the vehicle with the blower on and off. Also, the A-weighted value is given. The background levels for the vehicle are sufficiently low so the measurements of interior noise are not affected by them. Only when the blower is on and at the low frequency and high frequency ends of the plots is the background noise level close to the levitated only levels. However, since the blower is a part of the system, its noise should not be discounted in the overall effect.

Figures 4-4 and 4-5 plot the levels for an empty and a loaded vehicle for cruising and levitated at rest. The cruising plots were made from the data by plotting the highest and lowest level at each frequency band without regard for vehicle speed. The plot essentially gives the range of noise levels for cruising. Appendix B has a table for the noise levels at each speed with levels generally increasing with vehicle speed with more effect shown for a loaded vehicle.

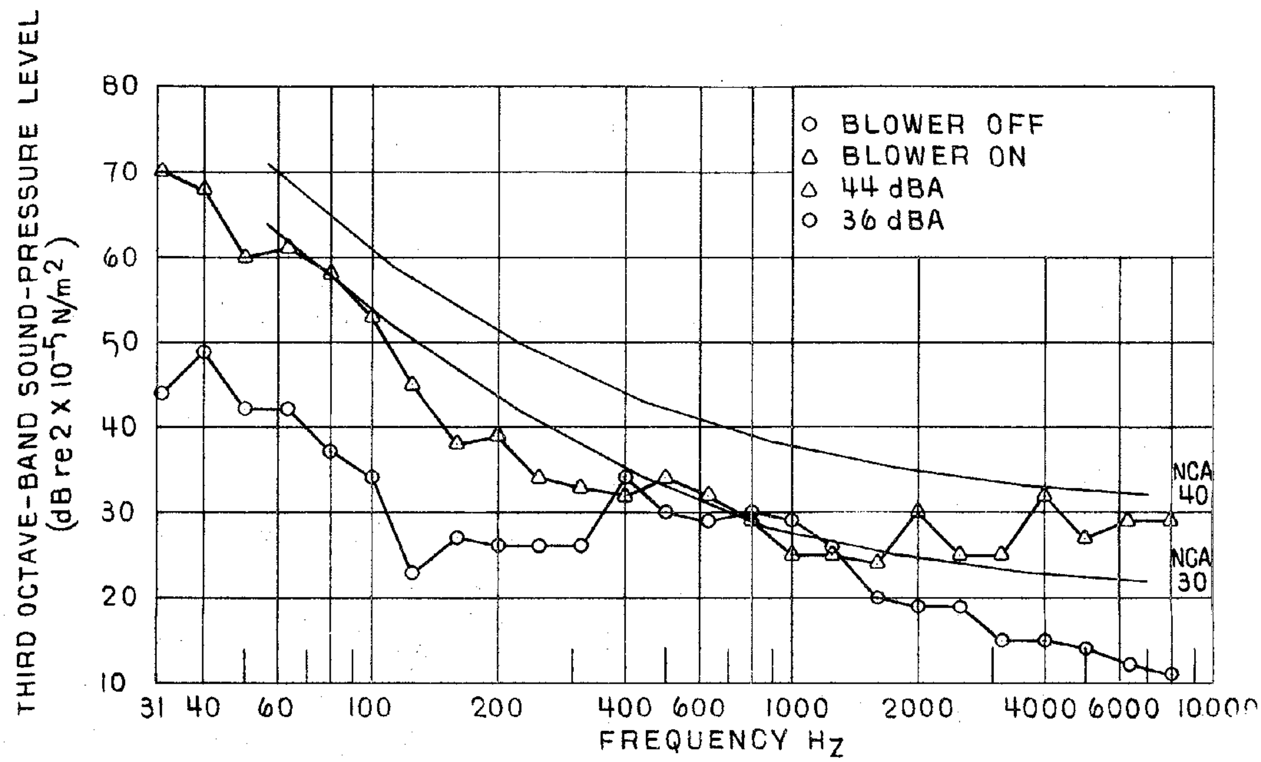

Figure 4-3. Background Sound Pressure Levels Inside Vehicle

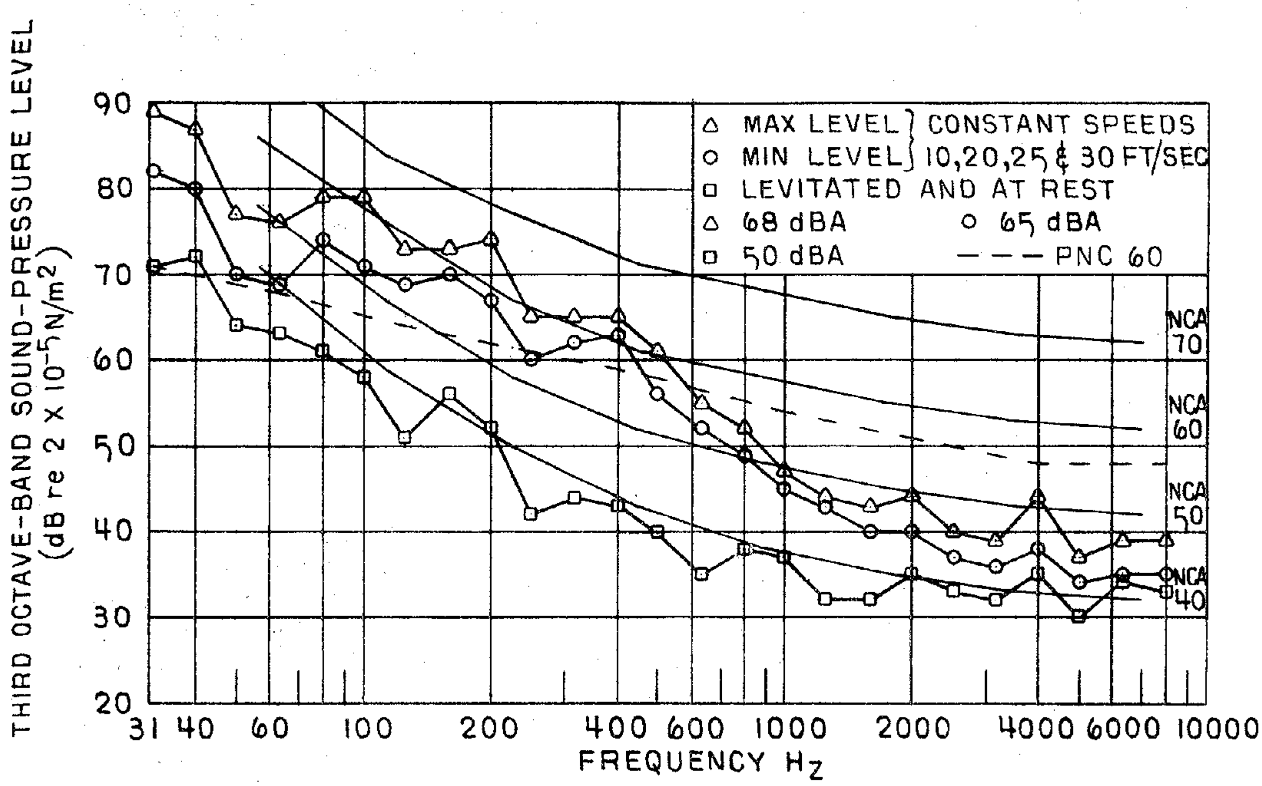

Figure 4-4. Sound Pressure Levels Inside Empty Vehicle

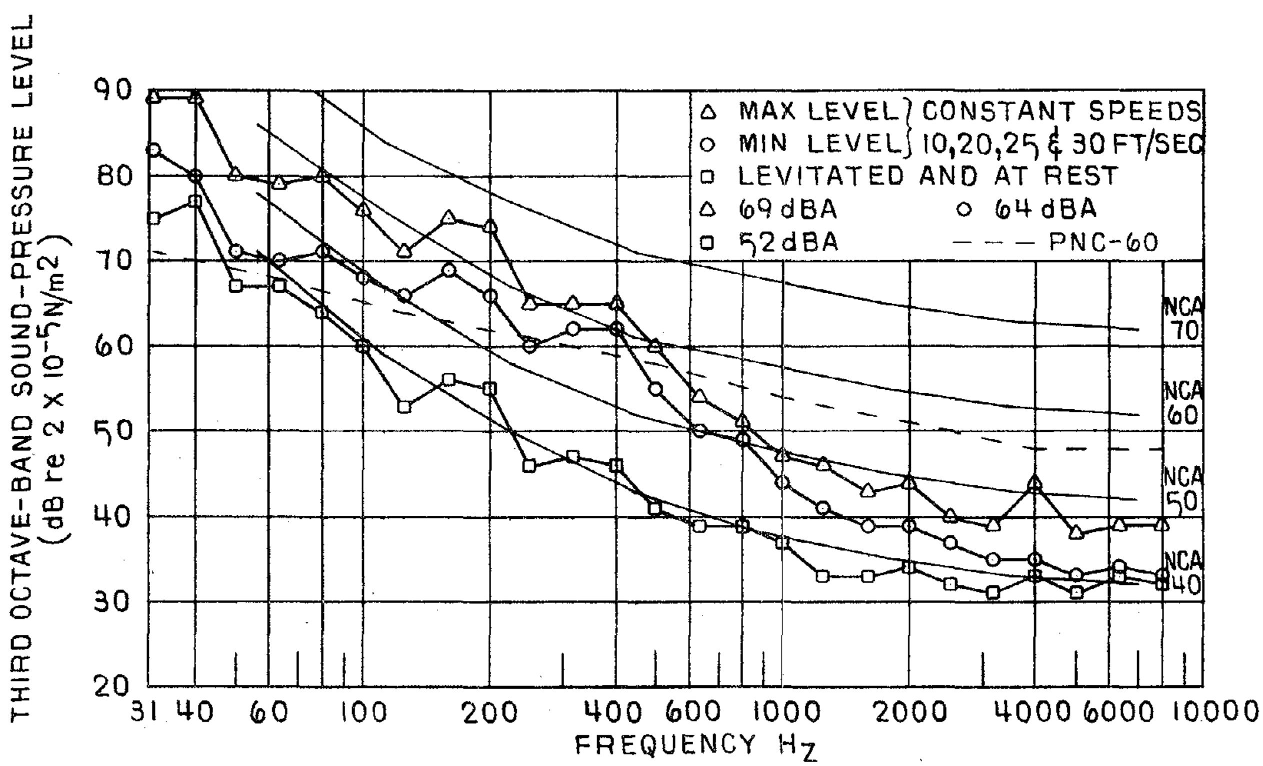

Figure 4-5. Sound Pressure Levels Inside Full Vehicle

In the levitated at rest condition, the loaded vehicle has a slightly higher level (2 dBA) than the empty vehicle, which is most likely caused by the higher pad pressure. The levels for cruising are generally the same for a loaded and empty vehicle, and meet the requirements of NCA-60, except for a few db in the 100 to 400 Hz range. Since the curves are plotted in one-third octave bands, the noise criteria curves plotted in the figures of this section have been reduced by 5 db from their normal presentation in one-octave bands.

Figures 4-6 and 4-7 show the noise levels during acceleration and deceleration for the loaded and empty vehicle. These levels approach the NCA-70 criteria and exceed it at 400 Hz when an empty vehicle is decelerated. This may indicate more structural-born vibrations from the turbines when the vehicle is empty. The length of time these levels persist is relatively short (approximately 10 seconds) since full acceleration and deceleration occur at the start and finish of each trip. This time factor has to be weighed in the overall effect. As cruising speeds and thrust levels increase, the noise will move toward these levels so additional work on the lower frequency end is desirable.

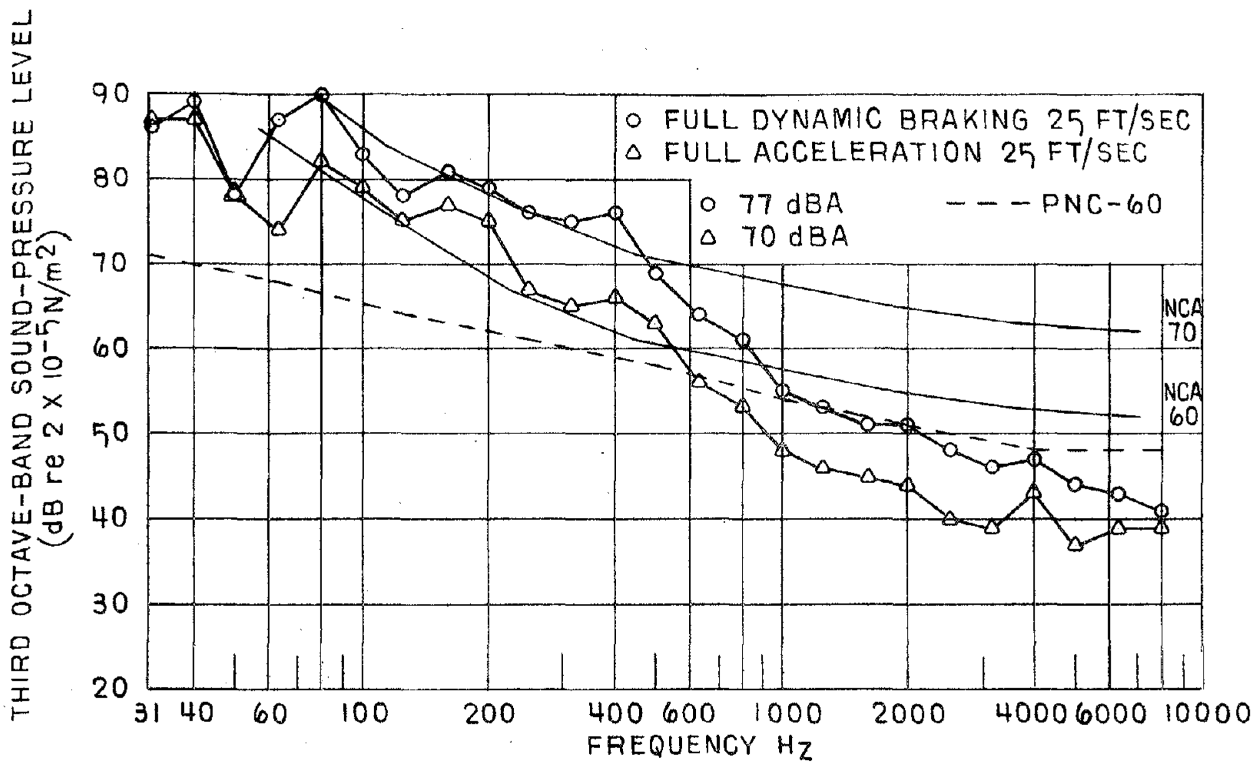

Figure 4-6. Sound Pressure Levels Inside Empty Vehicle

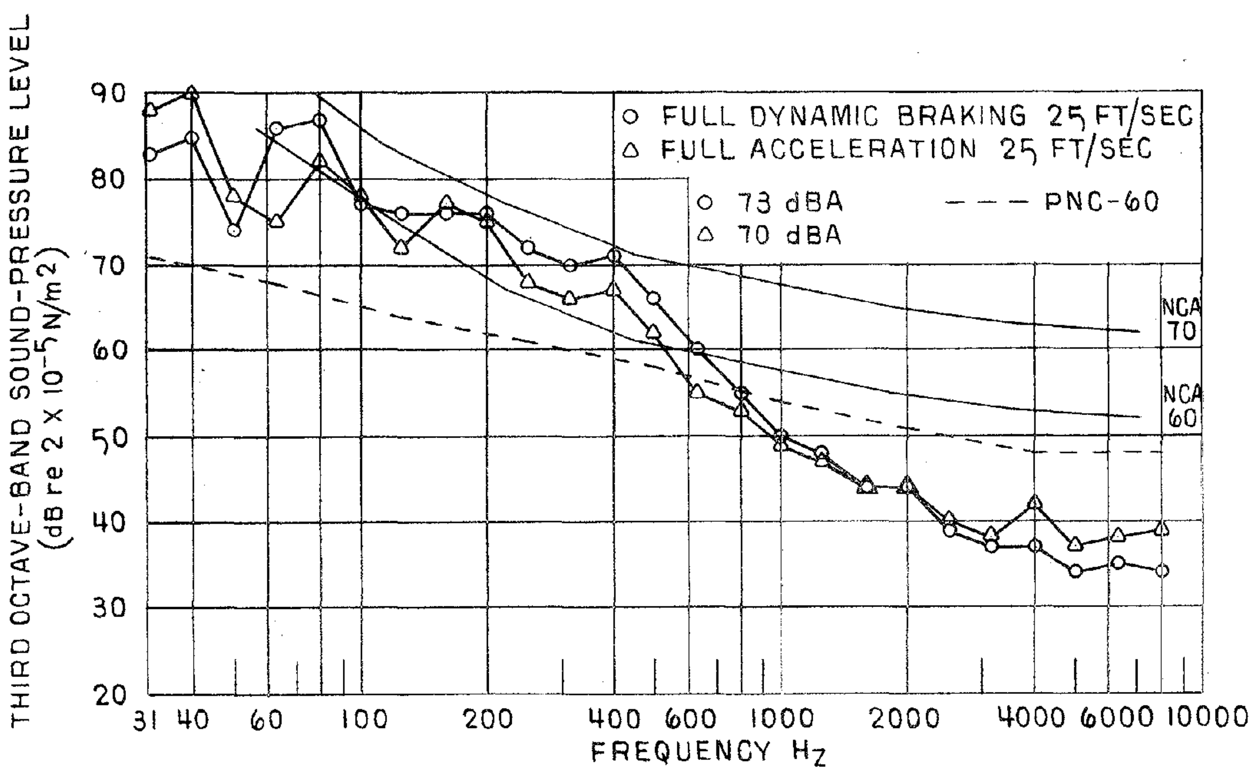

Figure 4-7. Sound Pressure Levels Inside Full Vehicle

In order to get a better understanding of the problem, the PSIL (Preferred Speech Interference Level) was obtained from the data. The PSIL is defined as the arithmetic average of the sound pressure levels in the 500, 1,000, and 2,000 Hz octave bands.

Reference 1 gives a table of speech difficulty related to PSIL which was taken from Peterson and Gross (reference 2) and is given in Table 4-2.

TABLE 4-2
MAXIMUM PERMISSIBLE VALUES OF PSIL FOR RELIABLE CONVERSATIONS
(IN dB re $2x10^{-5}N/m^2$)

Distance (ft.)	Voice Level			
	Normal	Raised	Very Loud	Shouting
1	70	76	82	88
3	60	66	72	78
6	54	60	66	72
12	48	54	60	66

Reference 1 also recommends a PSIL of 60 which would give understandable conversations at 3 ft., which is the probable separation of people in each compartment of the vehicle.

Table 4-3 gives the PSIL obtained from the acoustical tests for the various test conditions. In addition, another factor contributing to speech difficulty, loudness level (LL), is also shown. The difference in LL and PSIL (LL-PSIL) is also given. The overall level in dBA is shown for reference.

Beranek (reference 3) recommends that the LL-PSIL should not exceed 22 dB for acceptable noise levels for executive office personnel and a PSIL of 40 or less. However, in stenographic and large engineering drafting rooms, a PSIL of 55 and a LL-PSIL of 30 dB for conversations "often" to "very often" at 3 to 4 ft. give a favorable acoustic environment. From this criteria of PSIL and LL difference of 22 and 30, the NC and NCA curves, respectively, were developed where the particular curve is the PSIL rating. As can be seen in Table 4-3, the PSIL of 55 was accomplished in all cruising conditions. During acceleration the PSIL reaches 56, but during deceleration the PSIL reaches 64 and 58 for an empty and loaded vehicle respectively. The subjective rating from Beranek would fall between moderately noisy and noisy for these periods, and below moderately noisy for the cruising conditions. Since the LL-PSIL is about 30 units, this rating would apply. Beranek also recommends that LL-PSIL should not exceed 30 units for transportation vehicles. In addition, he recommends an NCA-60 criteria to avoid passenger complaints on trips of any significant length. Reference 1 recommends the use of PNC-60 for personalized rapid transit vehicles. The PNC curves are very similar to the NC curve, but were developed more recently to reduce the unpleasantness of sound levels matching the NC and NCA curves. PNC-60 criteria is plotted in Figures 4-6 and 4-7. The NCA curves allow more low and high frequency sound levels than the PNC curves, but have been more commonly used for latest transit noise levels. The trip time probability has some influence on the criteria, but a subjective rating was not available. To meet the NCA-60 criteria for all conditions, a reduction of 10 dB in the frequency range of 60 to 800 Hz will be required. If the PNC-60 criteria is used, a reduction of 15 to 20 dB at 100 Hz is required. Noise reduction in this frequency area is more difficult and expensive and probably will add weight to the vehicle. As the development of the system proceeds, economic considerations will play an important role in determining which criteria will apply, particularly for reducing the noise levels on the low frequency end.

Future noise design work on this system should concentrate on the lower frequencies to make a more pleasant interior acoustic atmosphere. However, noise levels are probably acceptable at the present time, considering trip time, economics, and what passengers of presently operating transit modes experience.

TABLE 4-3

PREFERRED SPEECH INTERFERENCE LEVEL (PSIL), LOUDNESS LEVEL (LL) AND INTERIOR NOISE (dBA) (IN dB re $2x10^{-5}N/m^2$)

	Ambient (No Blower)	Ambient (Blower On)	TEST CONDITION: Levitated At Rest	Cruising 10 ft./sec.	Cruising 20 ft./sec.	Cruising 25 ft./sec.	Cruising 30 ft./sec.	Dynamic Braking from 25 ft./sec.	Acceleration from 25 ft./sec.
PSIL									
Empty Vehicle	31	33	41	52	54	55	54	64	56
Loaded Vehicle	31	33	42	51	54	54	54	58	56
LL									
Empty Vehicle	46	59	66	80	84	84	83	91	87
Loaded Vehicle	46	59	69	79	83	84	85	88	87
LL-PSIL									
Empty Vehicle	15	26	25	28	30	29	29	27	31
Loaded Vehicle	15	26	27	28	29	30	31	30	31
dBA									
Empty Vehicle	36	44	50	65	68	68	68	77	70
Loaded Vehicle	36	44	52	64	67	68	69	73	70

4.4.2 Exterior System Noise

Figure 4-8 shows the background noise for the testing with the blower on and off. Since the background with the blower off is somewhat variable during the tests and very close to results of the tests, its influence is important. No attempt has been made to subtract the background noise from the test results because its variation and the system noise including background produce acceptable noise levels for a community.

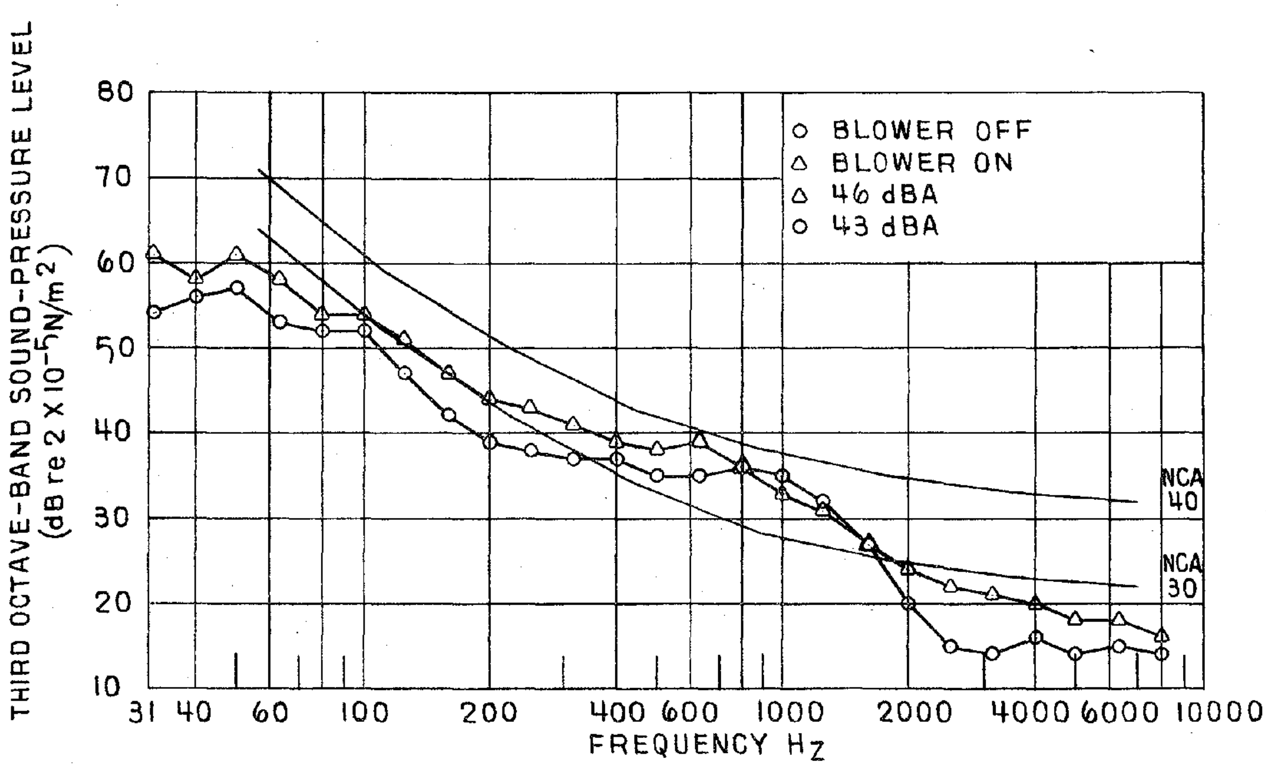

Figure 4-8. Background Sound Pressure Levels 25 Ft. From Guideway

A measure of annoyance or objectionableness of a sound can be made by determining the "Perceived Noise Level" (PNL). Table 4-4 lists the PNL 25 ft. from the guideway for various operating conditions.

The table shows that operating the system typically increases the PNL level only 5-8 PNdB.

Figures 4-9 through 4-12 present the exterior noise levels under the various test conditions. As can be seen from the plots, the noise emissions produce sound levels that are below NCA-45 criteria. They only exceed NCA-40 in the range of 200 to 2,000 Hz under deceleration conditions. These conditions only occur in station areas, and are less in number during the nighttime hours when recommended noise levels are lower.

TABLE 4-4

PERCEIVED NOISE LEVELS 25 FT. FROM GUIDEWAY (PNdB)

	Ambient (No Blowers)	Ambient (Blowers On)	Levitated At Rest	10 ft./sec.	20 ft./sec.	25 ft./sec.	30 ft./sec.	Full Dynamic Braking 25 ft./sec.	Full Acceleration 25 ft./sec.
Empty Vehicle	55	59	59	60	60	61	62	63	62
Fully Loaded Vehicle	55	59	56	59	61	60	61	62	60

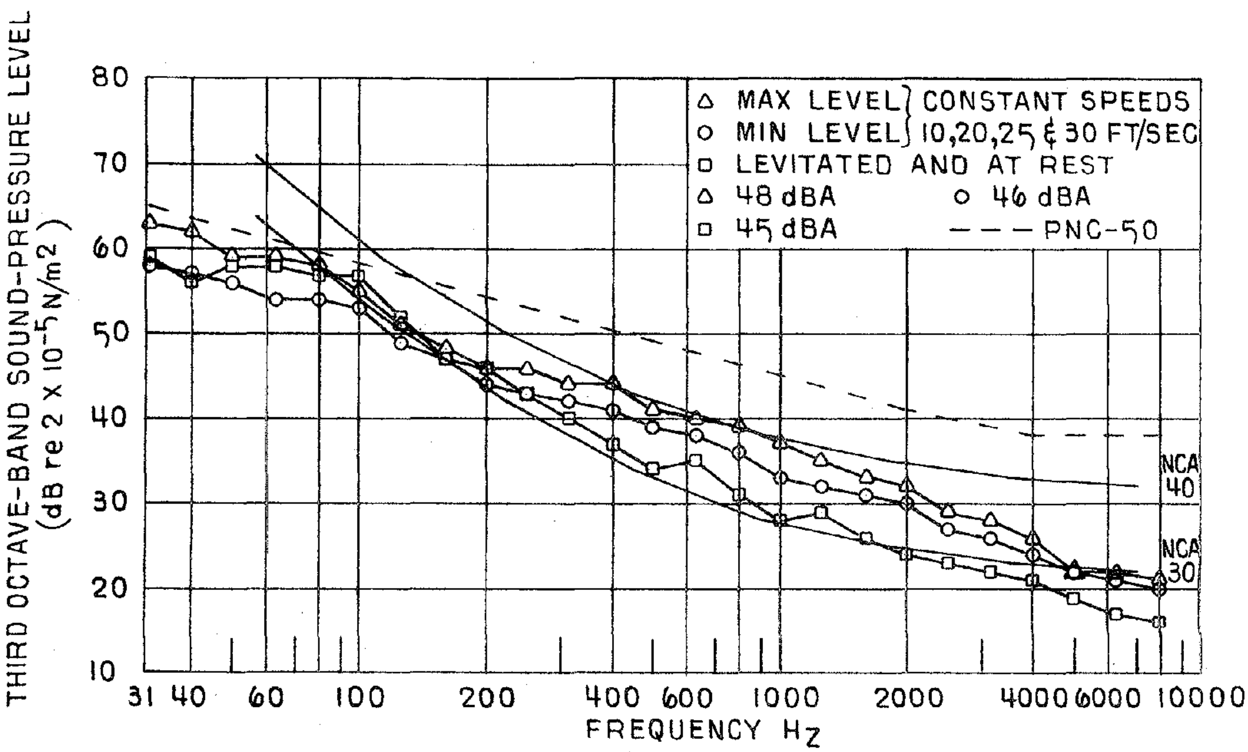

Figure 4-9. Sound Pressure Levels, 25 Ft. From Guideway, Empty Vehicle

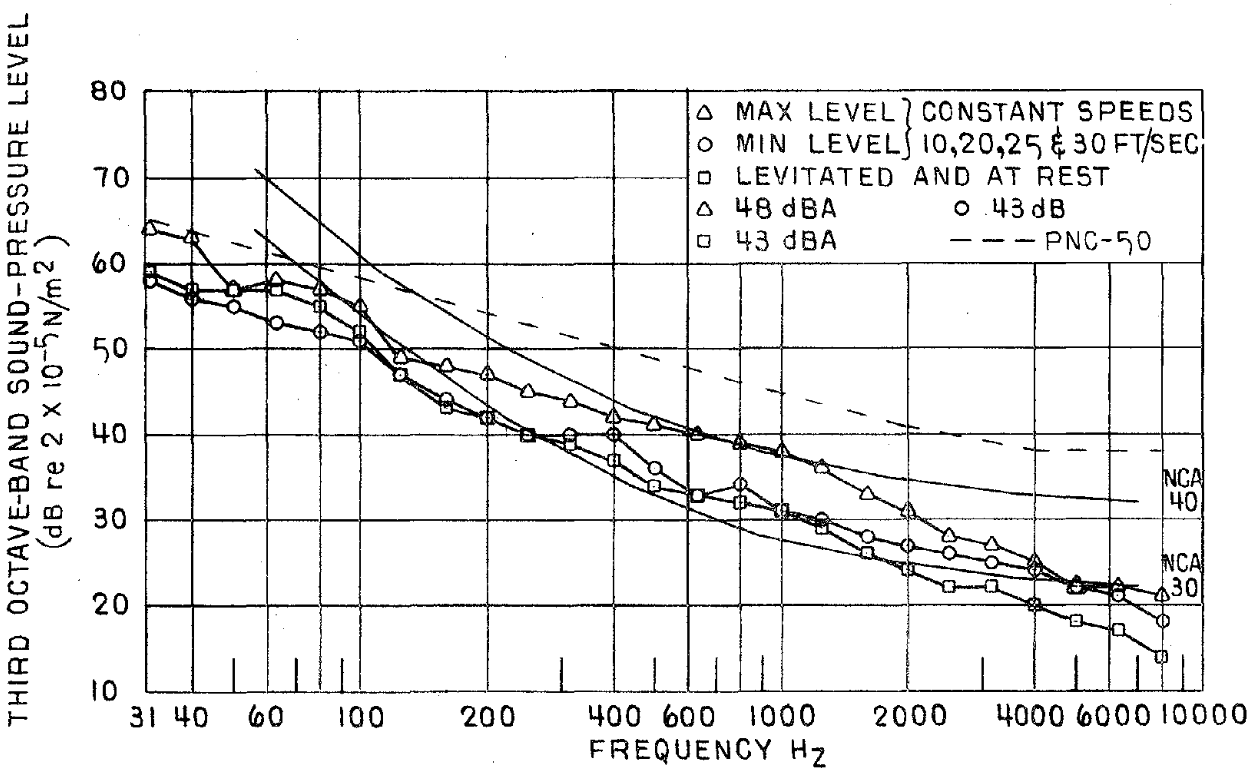

Figure 4-10. Sound Pressure Levels, 25 Ft. From Guideway, Full Vehicle

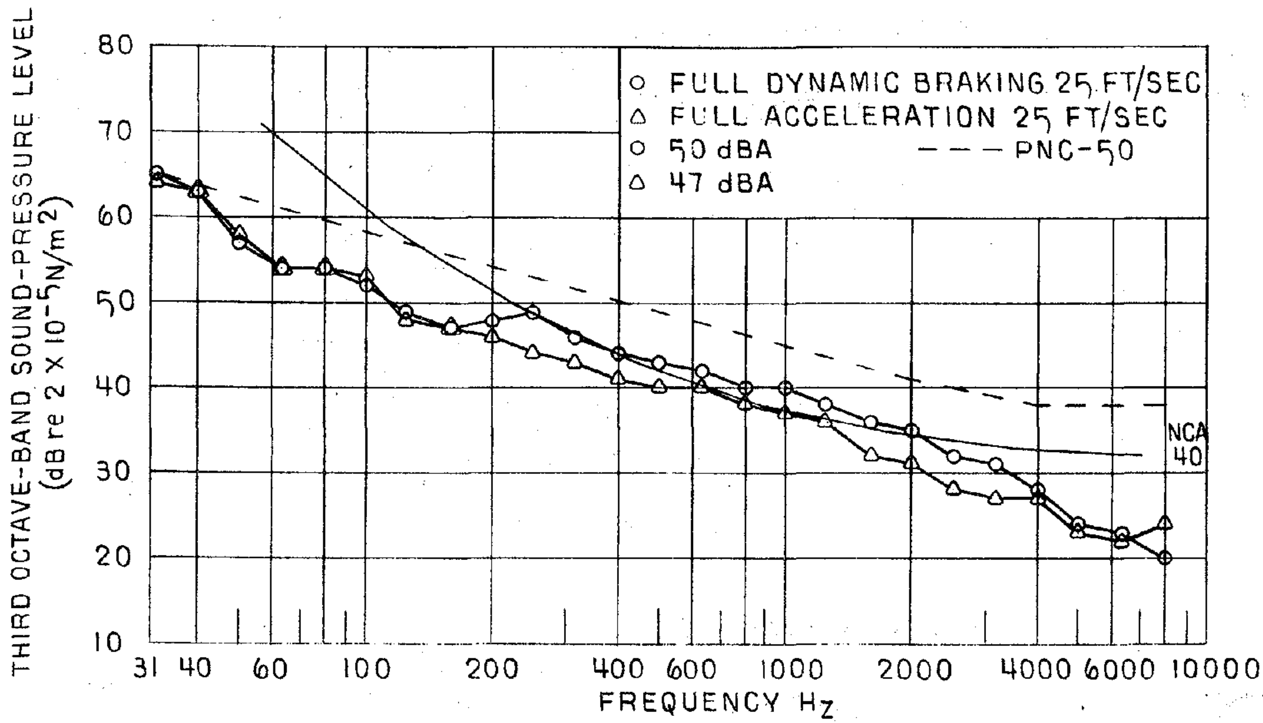

Figure 4-11. Sound Pressure Levels, 25 Ft. From Guideway, Empty Vehicle

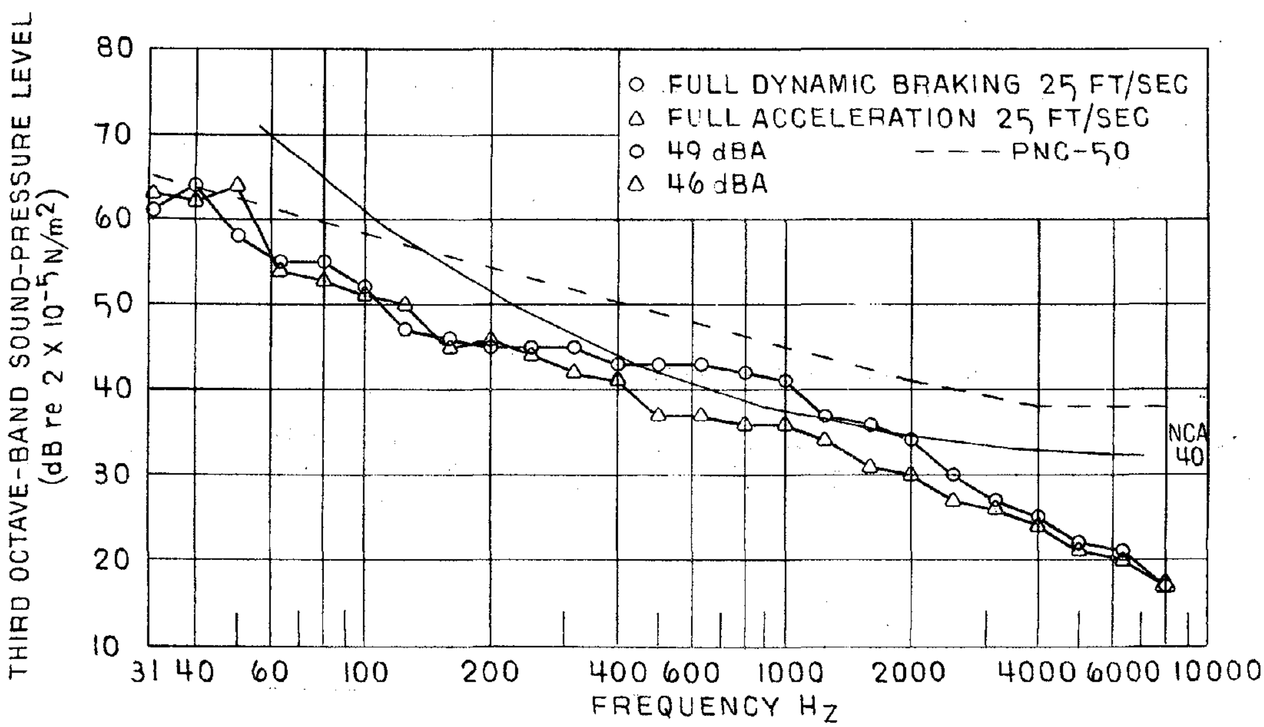

Figure 4-12. Sound Pressure Levels, 25 Ft. From Guideway, Full Vehicle

Reference 1 recommends a noise level of PNC-50 for future PRT systems. His analysis indicates a PNC-50 would increase the level of the suburban community by 10 dB and would be 5 dB above a "minor impact" level. The system noise spectrum is less than that allowed for PNC-50 as shown in Figures 4-11 and 4-12. Reference 1 calculates a level of 57 dBA represents the PNC-50 criteria at 25 feet, and 48 dBA at 100 feet. Since all the noise levels for the system were 50 dBA and below, the system would be expected to raise the suburban noise level by 3 dBA, which falls into the "no impact" range. At 100 feet, the noise level would calculate 41 dBA which would be accepted in most suburban areas. In more active areas, some of the sound reduction of the enclosure can be reduced such as the absorption material on the walls, etc. The amount of relaxation on internal sound absorption has an affect on the vehicle interior noise, and consequently requires careful study. The whole area of sound treatment on the enclosure needs cost analysis to determine its effectiveness.

4.5 CONCLUSIONS AND RECOMMENDATIONS

The sound levels measured inside the vehicle indicate a reduction of 10 dB is required on the low frequency end to meet the criteria of NCA-60, but the levels presently would most likely be acceptable to users of the system. Further study of cost effective sound treatment of the vehicle is desirable.

The noise levels introduced into the community are in the "no impact" area, which makes them acceptable at present. However, some cost analysis of sound reduction methods is necessary to optimize the costs.

5.0 RIDE QUALITY TESTING

5.1 INTRODUCTION

Ride quality testing was performed by measuring accelerations in the lateral, longitudinal, and vertical directions while the empty or fully loaded vehicle was subjected to various conditions. These conditions included switching, cruising and banked turns; all were performed at various speeds. Ride quality information was recorded separately on instrumentation supplied by Uniflo Systems Company (USC) and the Transportation Systems Center (TSC).

5.2 TEST EQUIPMENT AND METHOD

5.2.1 Equipment

The following items were used during the testing:

1. Honeywell Visicorder, Model 1508A
2. Lambda Power Supply, Model LP-412A-FM
3. Terado Inverter, Model 50-202-3
4. Statham Accelerometer, Model A5-2-350 (range ± 2 g) (two)
5. Statham Accelerometer, Model A45-2-350 (range ± 2 g) (one)
6. Dynalco Corporation Tachometer, Model T421
7. Uniflo Systems Company Signal Conditioner
8. Uniflo Systems Company Position Detector
9. Battery, 12V
10. Ithaco Power Supply, Model R
11. Ithaco Preamplifier, Model 143-LM-102 (three)
12. Data Acquisition Amplifier, Model 451 (three)
13. Endevco-Dynamics Accelerometer (three axis), Model 2223D
14. TEAC Corporation of America Recorder, Model R-70
15. General Radio Calibrator, Model 1562A

NOTE: Items 1 through 9 were supplied by USC
Items 10 through 15 were supplied by TSC.

5.2.2 Method

The USC and TSC accelerometers were mounted to a wood block (Model A5-2-350 were used for vertical and lateral measurement, Model A45-2-350 used for longitudinal measurement, TSC unit provided three axis in a single unit). The wood block was attached to a steel beam (box section) which was attached to the seat support structure of two facing seats. The accelerometers were centered between the two seats on their common centerline. (See Figure 5-1)

The tachometer was connected to a drive wheel, and was mounted as shown in Figure 5-2.

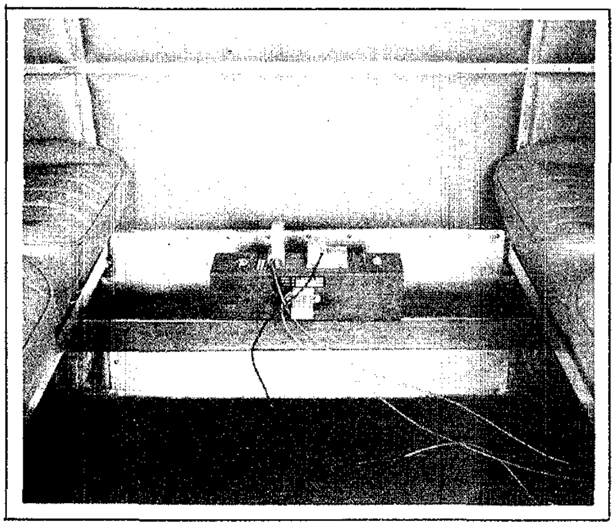

Figure 5-1. Accelerometer Mounting

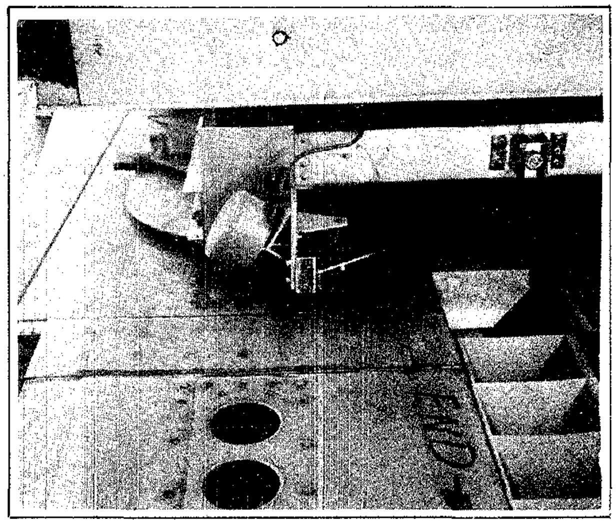

Figure 5-2. Tachometer Mounting

The position detector was mounted on the vehicle. Indicating tabs were mounted every 5 ft. along the guide rail with additional tabs being used at particular stations to simplify vehicle position identification.

The remaining test apparatus was mounted as shown in Figure 5-3. The battery in conjunction with the inverter provided an on-board source of 110V, 60 Hz power.

The mounting of the TSC equipment is not shown.

The USC accelerometer, tachometer, and position detector outputs were connected to the signal conditioner, and the conditioned outputs were then fed to the Visicorder galvanometers. The acceleration galvanometers which were used were M24-350 with a damping factor of 1.15 on each channel. This resulted in an amplitude reduction of 7% at 5 Hz, 21% at 10 Hz, and 49% at 20 Hz. The tachometer also was connected to a M24-350 galvanometer. The position detector was connected to a M5000 galvanometer.

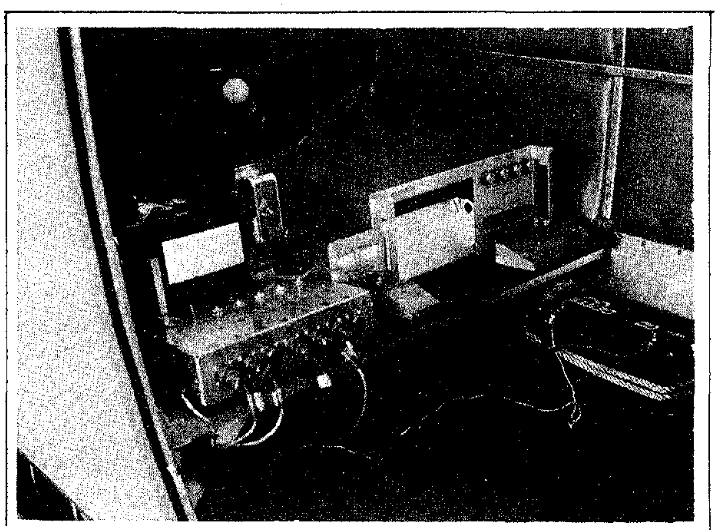

Figure 5-3. Test Equipment

The TSC accelerometer channels were connected to the preamplifier, then the amplifier, and then into the recorder where they were recorded on magnetic tape.

Calibration of the USC accelerometer channels was done by orienting the appropriate accelerometer to a position where it would experience 0.5 g, and then adjusting the Visicorder to give a 5 in. deflection.

Calibration of the TSC accelerometer channels was performed using the General Radio calibrator adjusted to give a signal of a known frequency, since the data was recorded in FM on magnetic tape.

Gross vehicle loaded weight during the testing was 3,734 lbs. This simulates the loading encountered when carrying eight passengers each weighing 200 lbs. Gross vehicle "empty" weight during the testing was 2,434 lbs., which includes a 200 lb. passenger and the test equipment.

Each test run sequence was as follows:

The vehicle was brought to approximately the desired cruise velocity while northbound at the north end of the track. (Refer to Figure E-00550, Sheet 6). It entered the arresting mechanism, which reversed its direction at some loss of velocity. Data recording commenced prior to the vehicle leaving the arresting mechanism. With the vehicle now heading south, thrust was applied as required to bring the vehicle to the desired cruise velocity. At the south end of the track, the arresting mechanism again caused the vehicle to reverse its direction. As the vehicle headed north, the switch mechanism was energized, causing the vehicle to switch off the main line. The run terminated with an emergency stop in the switch area.

5.3 TEST RESULTS

5.3.1. Vehicle Natural Frequencies

Table 5-1 below lists the values of the natural frequencies for the six motions. These values were computed from the vehicle weight and spring rates, with adjustments in the values made based on apparent natural frequencies which were observed upon examination of the oscillograph records of various operating conditions.

TABLE 5-1

VEHICLE SECONDARY SUSPENSION NATURAL FREQUENCIES

Axis	Vehicle Empty (Gross Weight 2434 lbs.)	Vehicle Loaded (Gross Weight 3734 lbs.)
Vertical	2.6 Hz	2.0 Hz
Lateral	1.7 Hz	1.3 Hz
Longitudinal	2.4 Hz	1.8 Hz
Yaw	1.9 Hz	1.3 Hz
Roll	2.3 Hz	2.1 Hz
Pitch	2.6 Hz	1.9 Hz

The primary suspension (air cushions) has a spring rate of approximately 6.8×10^4 lb./in. (loaded) which gives a natural frequency of 13.1 Hz.

5.3.2 Vertical and Lateral Ride Quality

Figure 5-4 shows a typical trace obtained on the USC equipment. Figure 5-5 shows the results of the same run as recorded on TSC equipment with the data subsequently processed to produce an RMS g

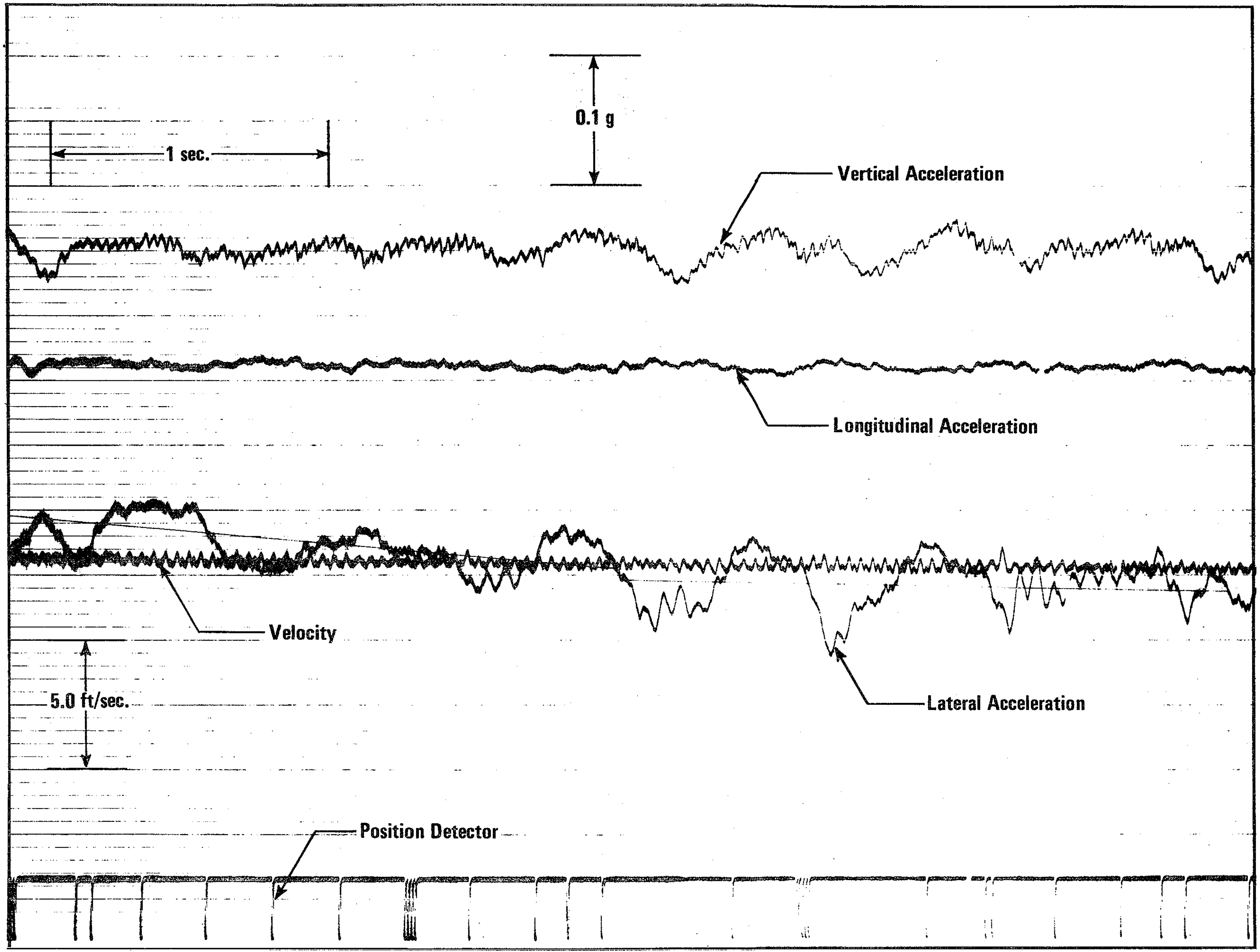

Figure 5-4. Oscillograph Record For Loaded Vehicle Moving at 20 ft/sec in Spiral and Curve

level trace. Separate traces were prepared for the vertical and lateral directions. In Figure 5-5, 80 dB corresponds to an acceleration of 0.01 g, and 100 dB corresponds to an acceleration of 0.1 g. The levels shown when the vehicle contacts the arresting mechanism would not be encountered in a continuous track, since the arresting mechanism would not be required. See Section 5.2.2 for a further description of the test sequence.

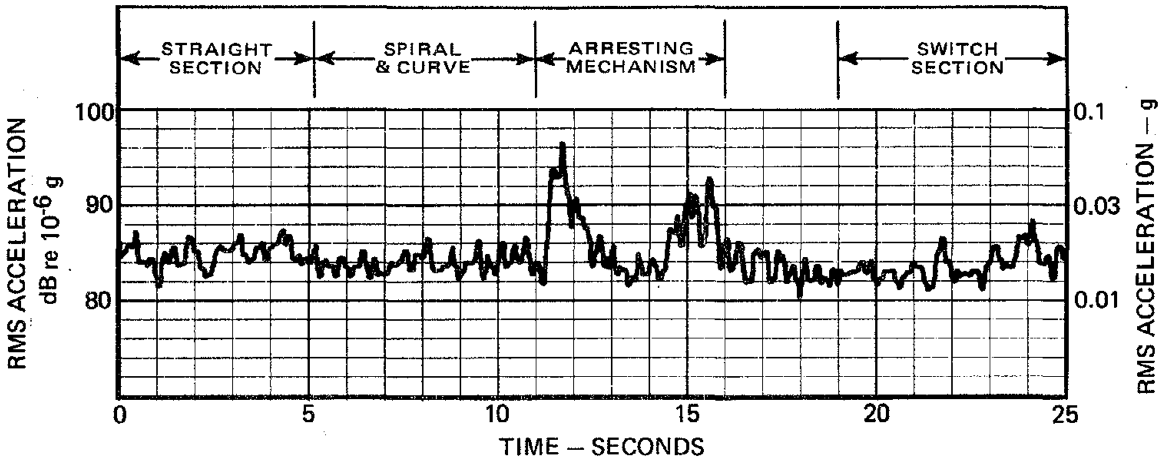

Figure 5-5. RMS Vertical Acceleration Levels for Loaded Vehicle Moving at 20 ft/sec in Spiral and Curve

Also as part of the data reduction, one-third octave frequency spectra were prepared by TSC (See Figure 5-6). The vertical and lateral ride quality in the straight section, in the spiral and curve, and through the switch segment were analyzed separately. Thus, in Figure 5-6, only the vertical acceleration in the spiral and curve portion of the run is shown. Note that in addition to the levels in the various frequency bands, the total RMS level is also shown. The integration was performed for the band from 1.5 Hz to 1,250 Hz. In Figure 5-6, the total RMS is approximately 0.018 g (85 dB).

Appendix D shows all the frequency spectra for the various test conditions.

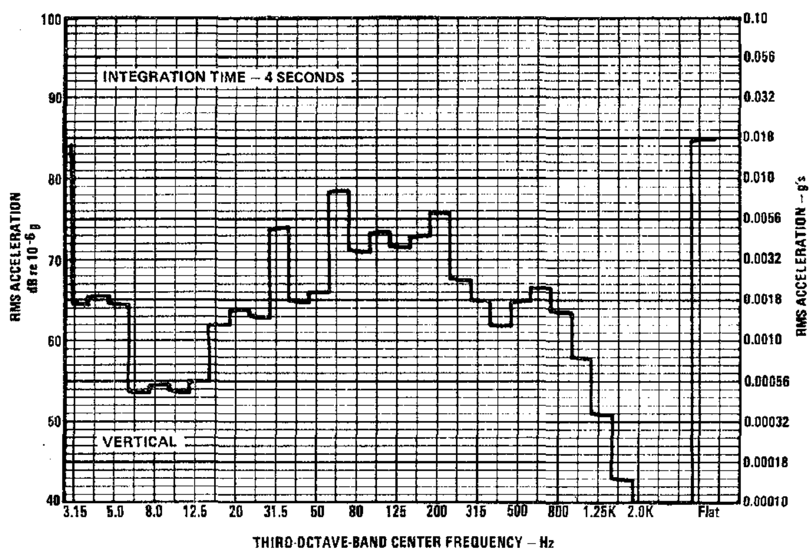

Figure 5-6. Third Octave Band Frequency Spectrum for Loaded Vehicle Moving at 20 ft/sec in Spiral and Curve

Table 5-2 shows the total RMS acceleration levels for the various test conditions in the frequency band from 1.5 Hz to 1,250 Hz. Examination of Table 5-2 shows generally higher RMS levels in the lateral direction than in the vertical direction. The table shows the lateral acceleration levels to be greatest in the straight section, with the exception of the cases where the vehicle is moving in the spiral or curve section at a speed of 25 ft./sec. In the spiral and curve section the operating surface is made up of plane sections, rather than curved sections. Thus, the vehicle receives discrete changes in direction at intervals corresponding to the section length, rather than continuous changes in direction. At 25 ft./sec. in the curve section, the vehicle encounters a new operating surface section at a frequency close to the natural frequency of the vertical and pitch directions. Due to the interaction of the suspension in the vertical, lateral, and pitch, roll, and yaw directions, the vertical inputs also cause lateral movement.

TABLE 5-2

RMS ACCELERATION IN THE FREQUENCY BAND 1.5Hz TO 1250 Hz-g's

Vehicle Speed	Vertical: Straight Section	Vertical: Spiral & Curve	Vertical: Switch Section	Lateral: Straight Section	Lateral: Spiral & Curve	Lateral: Switch Section
Loaded Vehicle						
20 ft./sec.	.018	.018	.015	.028	.026	.023
25 ft./sec.	.022	.028	.018	.038	.053	.032
	.021	.036	.018	.040	.050	.030
30 ft./sec.	.025	.020	.022	.040	.032	.032
	.042	.020	.023	.053	.033	.033
Empty Vehicle						
35 ft./sec.	.029	.023	.020	.050	.045	.042
	.033	.023	.020	.063	.041	.042

Figures 5-7 to 5-12 show the maximum and minimum measured values of RMS acceleration in the lateral and vertical direction for various operating conditions. Also shown are the 95% probability instantaneous acceleration limits, as well as the 95% probability instantaneous acceleration limit specification for two recent D.O.T. RFP's. (Ref. 5 and Ref. 6) Figures 5-7 to 5-9 show the RMS values for a loaded vehicle, and Figures 5-10 to 5-12 show the RMS values for an empty vehicle. The RMS acceleration is plotted in octave bands from 3 to 50 Hz.

It is seen that the highest levels are experienced in the lateral direction when moving on the straight section. This effect can perhaps be attributed to the fact that the straight section has only single sided guidance. Although this is also true for the switch section, when the vehicle moves through the switch, the guide wheels are loaded due to the switch curvature. This was not the case in the straight section. Clearances of 0.125 in. to 0.250 in. were observed in the catch rail/guide rail/guide wheel/ switch wheel alignment. Additional work should be done to quantify the effects of this clearance. The levels in the lateral direction when moving on the spiral and curve section, as well as in the switch section, drop significantly above 12 Hz. It is difficult to make any generalized statements concerning the vertical direction, except that the RMS levels tend to be lower in the vertical direction than in the lateral direction.

The instantaneous acceleration comfort limits established by the HPPRT specification (Ref. 5) and the Dulles specification (Ref. 6) state that the indicated values shall not be exceeded more than 5% of the time throughout a sample period of 10 seconds or longer. The specifications also state that

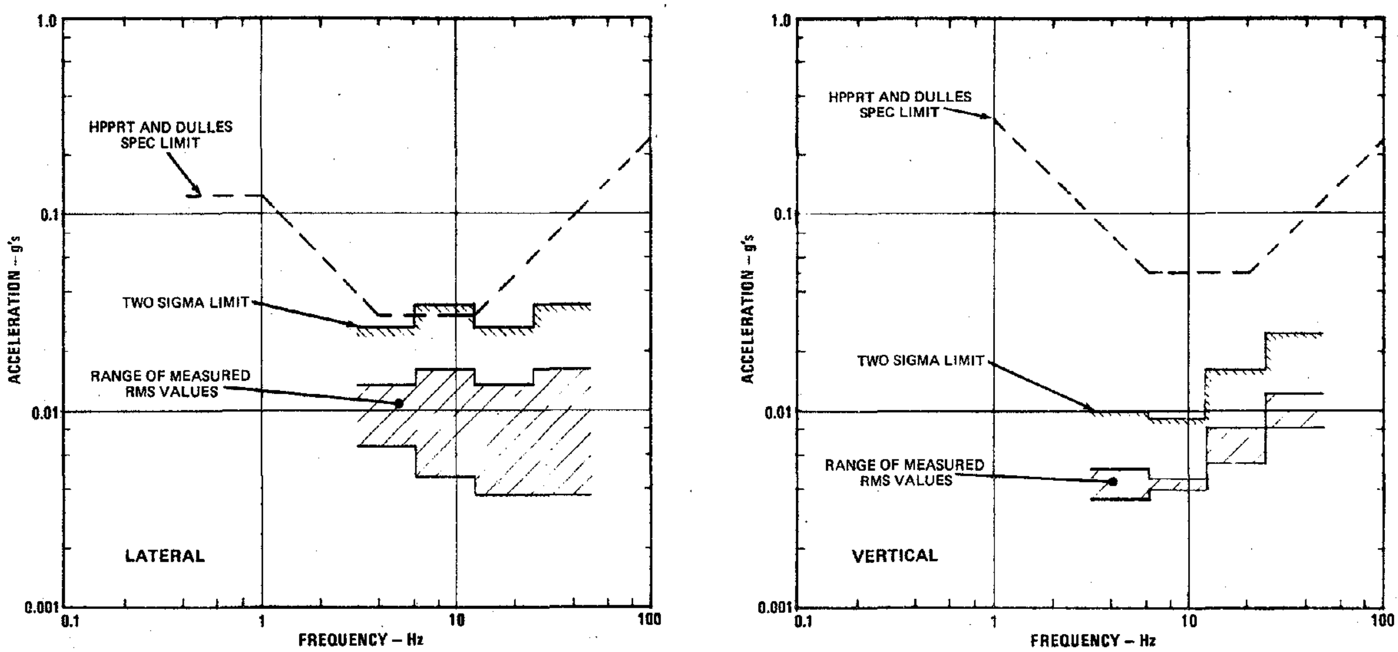

Figure 5-7. Acceleration Levels – Straight Guideway Section – Loaded Vehicle – 20 to 30 ft./sec.

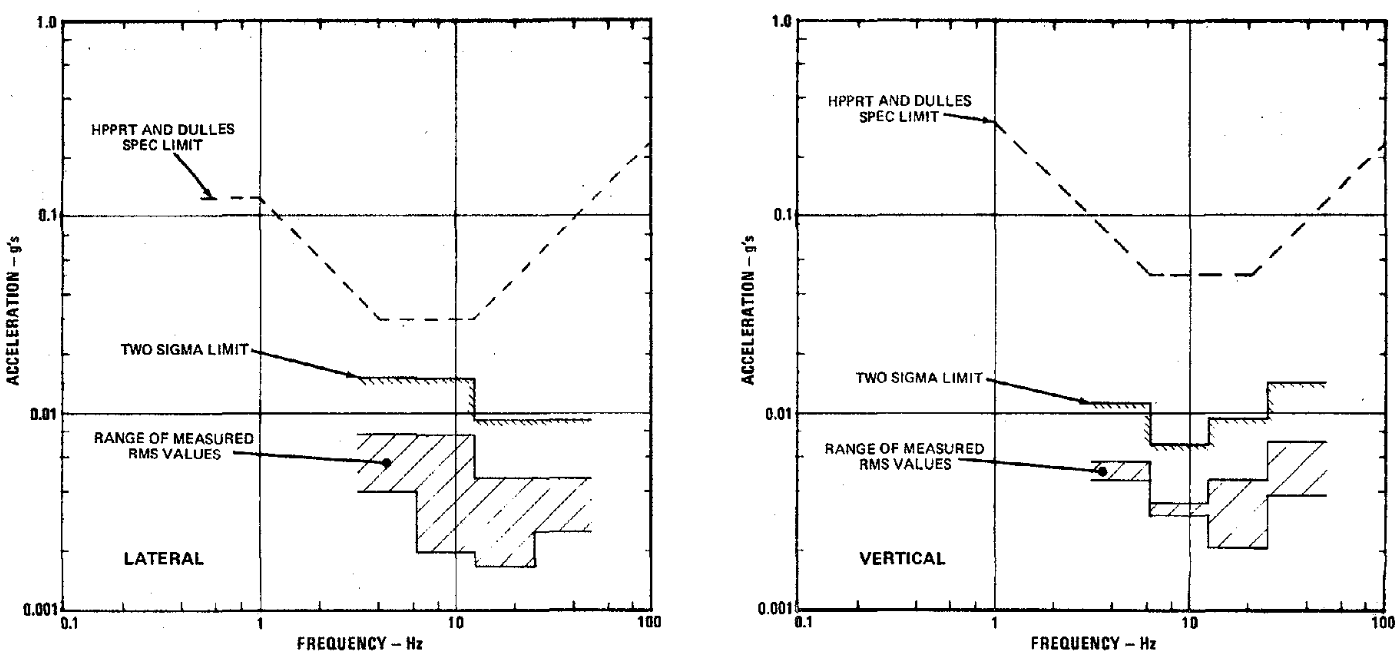

Figure 5-8. Acceleration Levels – Spiral and Curve Section – Loaded Vehicle – 20 to 30 ft./sec.

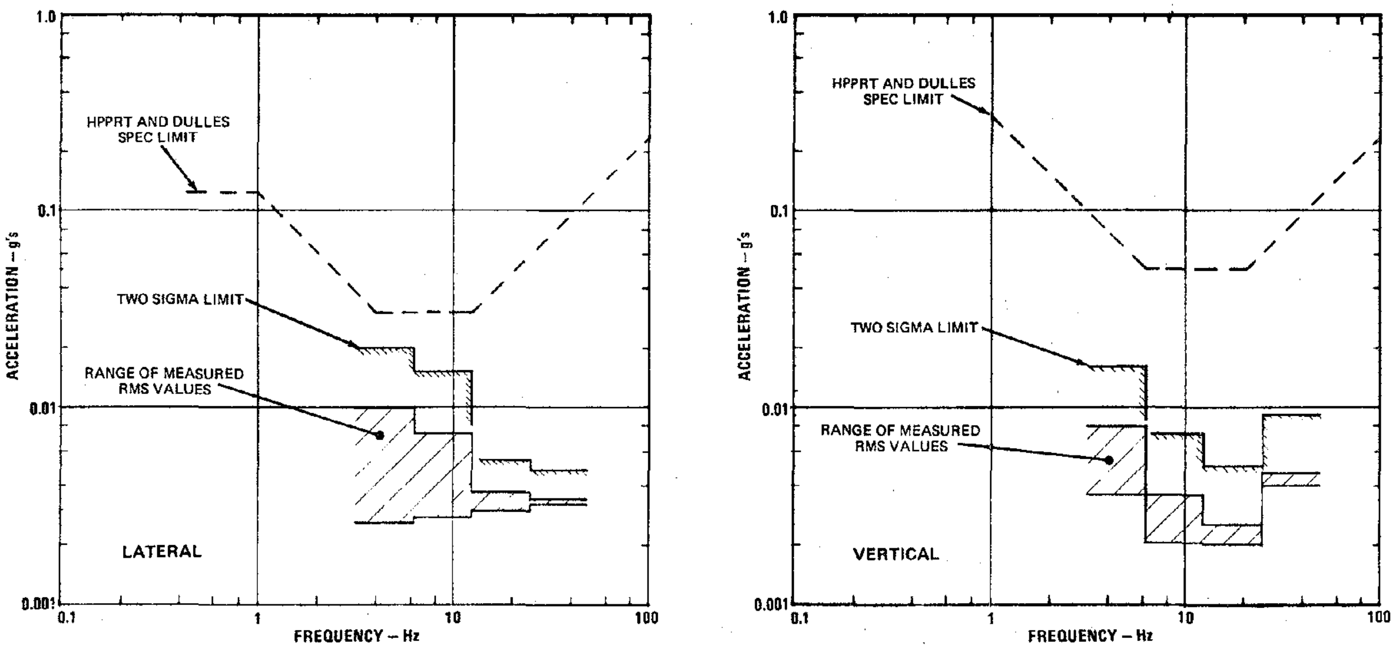

Figure 5-9. Acceleration Levels – Switch Section – Loaded Vehicle – 20 to 30 ft./sec.

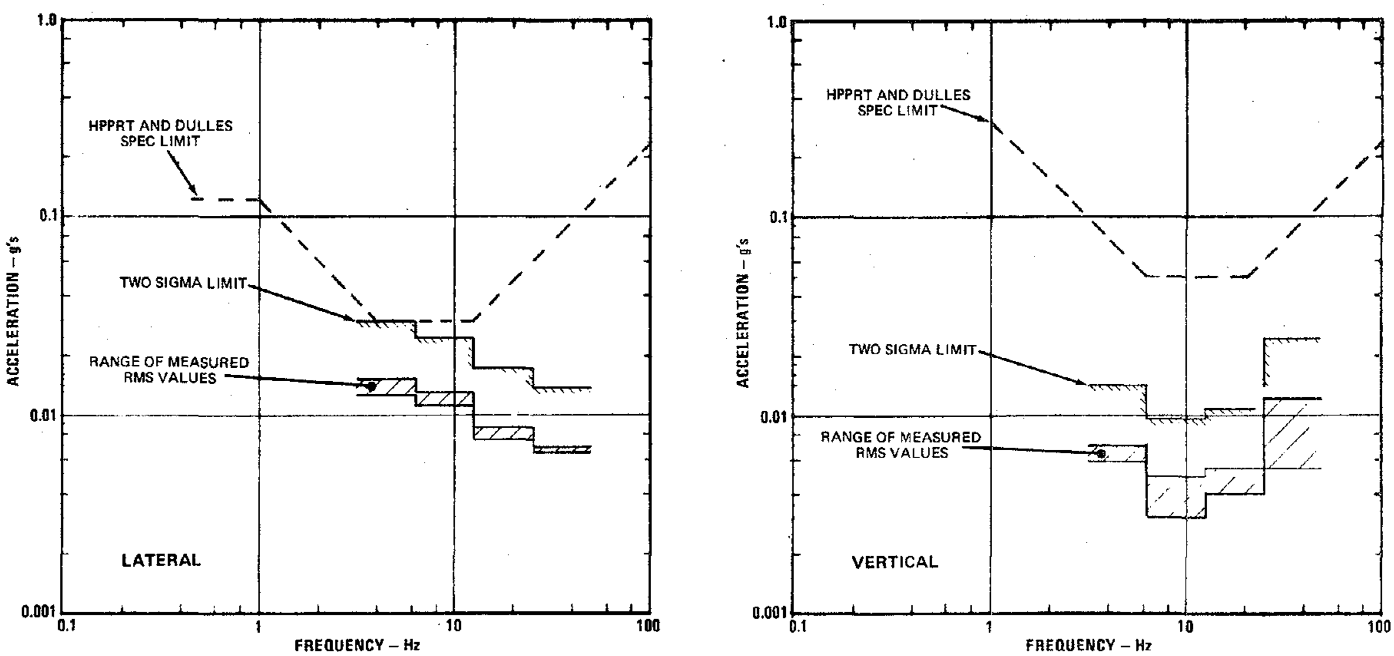

Figure 5-10. Acceleration Levels – Straight Guideway Section – Empty Vehicle – 35 ft./sec.

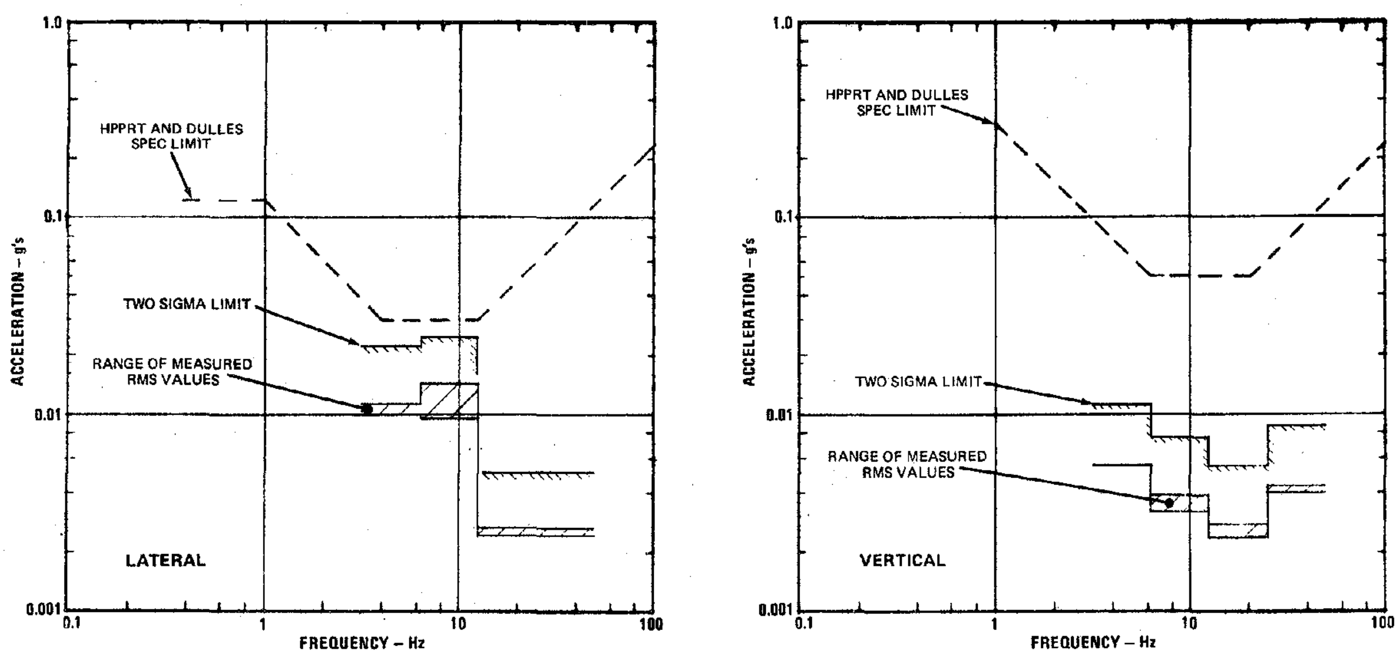

Figure 5-11. Acceleration Levels – Spiral and Curve Section – Empty Vehicle – 35 ft./sec.

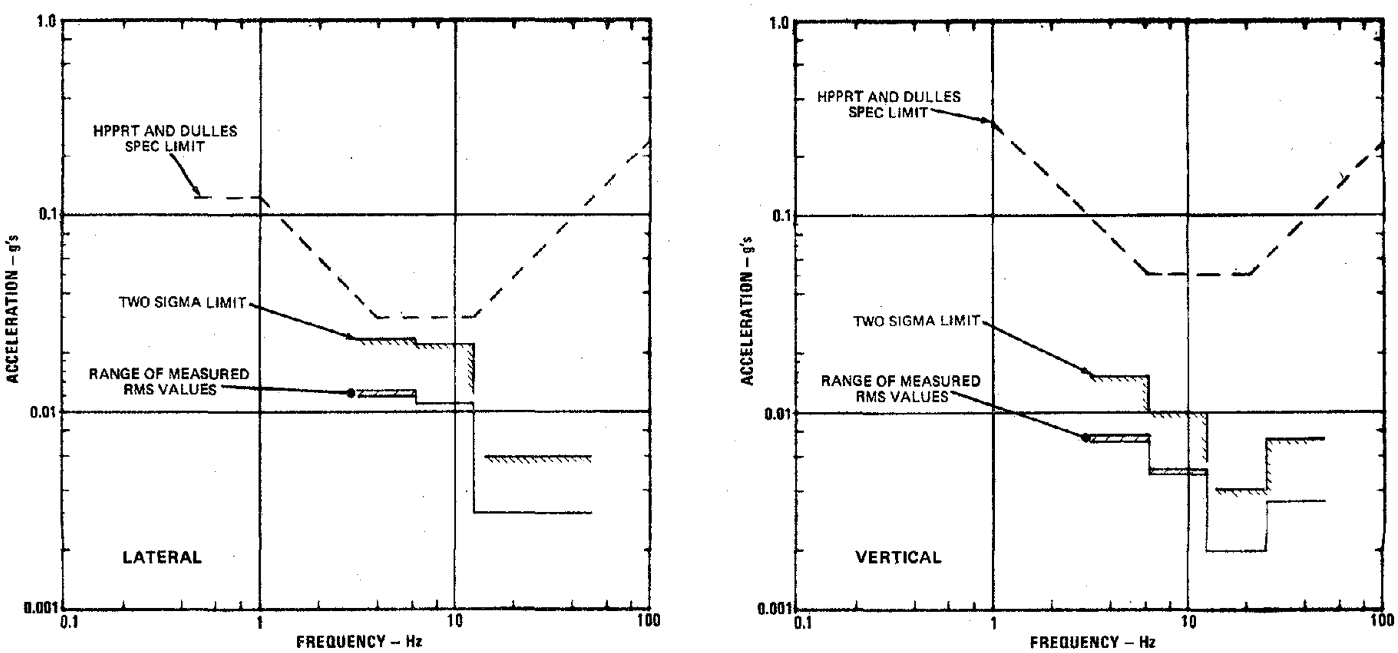

Figure 5-12. Acceleration Levels – Switch Section – Empty Vehicle – 35 ft./sec.

the maximum peaks shall not exceed the indicated values by more than a factor of two using one-octave filters. Note that the ride quality test data is plotted in RMS levels—not instantaneous levels. If the ride data were sinusoidal, the maximum instantaneous acceleration could be determined by multiplying the RMS value by 1.414. If the ride data were a true random function, then the acceleration levels would be distributed normally about the mean value of zero. Since the RMS value corresponds to the one sigma limit, the instantaneous acceleration levels would not exceed twice the RMS value (two sigma) more than 5% of the time for the true random condition. Therefore, for the test conditions, we may conclude that the instantaneous acceleration will not be greater than twice the RMS value more than 5% of the time, and more likely would fall somewhere between 1.4 and 2 times the RMS value. Referring to Figure 5-7 to 5-12, we see that the ride conditions meet the 5% specifications limits with the possible exception of the lateral direction with the vehicle moving in the straight section (6 to 12 Hz band).

Since the highest measured RMS level is approximately one-half the indicated specification value, and since the specification allows maximum peaks of twice the indicated values, it follows that the four sigma limit defines the percent of time that the "maximum peak" specification will be met. The four sigma limit will be exceeded less than 0.01% of the time, so we may conclude that the "maximum peak" specification is also met.

In order to provide an indication of the actual peak values observed during the testing, Table 5-3 was prepared using data from the oscillographs. It shows the maximum acceleration levels (peaks) with any sustained acceleration considered as the mean. No attempt was made to identify the frequency associated with a particular acceleration level. However, it can be seen that in the vertical direction, all the values meet even the most severe requirement (6 to 20 Hz band). In the lateral direction, at speeds up to 30 ft./sec, with a fully loaded vehicle, even the most severe requirement is met (except for one value of 0.08 g in the switch section). At 35 ft./sec. with an empty vehicle, peak values in the range of 0.070 g to 0.1 g are observed. However, since the frequency composition of the peaks is unknown, it is not possible to compare these peak values directly with the specification.

5.3.3 Longitudinal Ride Quality

The vibratory acceleration levels in the longitudinal direction are significantly lower than in the lateral or vertical direction. Also, analysis of the oscillograph data indicates that the frequencies experienced are normally above 8 Hz. The turbine modules apparently cause little vibration in the longitudinal direction, indicating a smooth transition and application of thrust, even in those sections with only two turbine modules.

5.3.4 Damping

Secondary suspension damping was provided by the solid damping of the rubber shear mounts, which are the primary elements of the secondary suspension. To determine the equivalent viscous damping in the vertical direction, the logarithmic decrement was determined from the vertical amplitude oscillograph trace. This value was then used in equating the energy dissipated per cycle in the solid damping to the equivalent energy dissipation with viscous damping. Finally, this value was used to determine the equivalent viscous damping ratio of 0.14.

Damping in the lateral and longitudinal directions was calculated by the same method. The equivalent lateral viscous damping ratio is 0.07. The equivalent longitudinal viscous damping ratio is 0.11. The differences in the damping ratios are attributable to friction in the suspension components.

Tests were also made in which additional damping was provided by attaching one or two Volkswagen shock absorbers at each end of the vehicle at approximately a 30° angle to the horizontal. This configuration thus provided additional damping primarily in the lateral direction, with some effect in the vertical direction, and none in the longitudinal direction. Several different attachment techniques were used. In general, based on analysis of the oscillograph records, the additional damping provided no significant improvement under any operating conditions, and resulted in degraded ride characteristics under some operating conditions.

TABLE 5-3

PEAK ACCELERATION LEVELS-g's

Vehicle Velocity	Vibratory Direction	Straight Section	Spiral & Curve	Switch Section
10 ft./sec.	Lateral	.020	.025	.050
	Vertical	.020	.010	.015
	Longitudinal	.010	.010	.010
10 ft./sec.	Lateral	.015	.025	.045
	Vertical	.015	.015	.015
	Longitudinal	.010	.010	.010
20 ft./sec.	Lateral	.030	.050	.025
	Vertical	.020	.025	.015
	Longitudinal	.015	.010	.010
20 ft./sec.	Lateral	.025	.050	.030
	Vertical	.020	.025	.020
	Longitudinal	.015	.010	.015
25 ft./sec.	Lateral	.030	.050	.035
	Vertical	.030	.035	.015
	Longitudinal	.015	.010	.015
25 ft./sec.	Lateral	.040	.050	.035
	Vertical	.025	.040	.015
	Longitudinal	.010	.010	.015
30 ft./sec.	Lateral	.035	.060	.080
	Vertical	.030	.040	.045
	Longitudinal	.015	.015	.015
30 ft./sec.	Lateral	.035	.050	.060
	Vertical	.025	.040	.050
	Longitudinal	.015	.015	.015
35 ft./sec.	Lateral	.030	.060	.095
	Vertical	.030	.070	.040
	Longitudinal	.015	.020	.020
35 ft./sec.	Lateral	.040	.075	.100
	Vertical	.035	.070	.030
	Longitudinal	.020	.020	.020

5.4 CONCLUSIONS AND RECOMMENDATIONS

The passenger experienced vibrations are the result of deflections and irregularities in the operating surface and changes in vehicle direction (lateral and/or vertical) due to spirals, curves, or switches. However, the vibration levels which were seen indicate that the present system (Operating surface, guide rails, primary and secondary suspension) produces a very acceptable ride up to 30 ft./sec. in the straight section, in the spiral and curve, and in the switch section. Additional testing and analysis should be done to verify the suitability of the present system at higher speeds, and to investigate such things as the effects of misalignments in the operating surface and guide rails. Also, additional work should be done on the damping to optimize the secondary suspension. This work may consider such things as different damping ratios, or possibly the addition of semiactive or active damping.

6.0 VEHICLE ACCELERATION CAPABILITY

6.1 INTRODUCTION

The Uniflo passive vehicle system may have variable acceleration capability at different sections of its guideway. The linear air turbine elements can be installed in varying densities up to a maximum depending upon the power required for the local conditions. Normally, maximum power is required only for climbing steep grades or rapid acceleration and deceleration.

Figure 6-1 shows the acceleration test arrangement. Maximum acceleration capability was installed in two locations, labeled the south test area and north test area. Lower acceleration capability existed throughout the rest of the track. At each end of the track a restraint/rebound mechanism permits vehicle speed to be built up beyond the normal capability of such a short test track.

The test program was designed to provide data on vehicle drag, vehicle acceleration, reversed thrust braking, and linear air turbine performance.

Vehicle behavior was measured by recording the outputs of sensors measuring vehicle position (at discreet points along the guideway), instantaneous vehicle velocity, and longitudinal acceleration. Additionally, the vehicle static drag was measured with a spring scale, and system air flow was determined from the differential pressure measured at the venturi in the supply pipe.

Due to the track length limitations, a relatively short period of full vehicle acceleration was available for each run. Numerous runs were performed to determine the consistency of the results.

Vehicle acceleration capability is the result of the linear air turbine thrust acting on the vehicle weight and vehicle drag. Testing at speeds up to 34 ft./sec. and with weights representing nearly empty and fully loaded vehicles was carried out. In the absence of thrust, the measured deceleration of a coasting vehicle permits the calculation of vehicle drag. When thrust is applied, the resulting acceleration, combined with the previously determined drag, allows the turbine thrust to be calculated. The turbine output and its efficiency were computed using vehicle velocity, turbine thrust, incremental air flow, air pressure and incremental power to the blower motor.

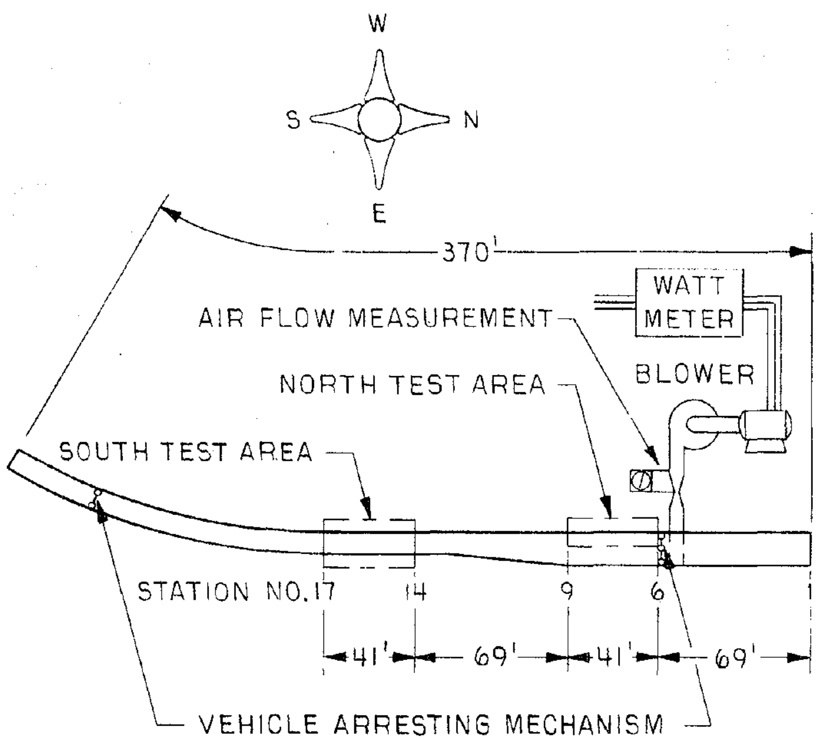

Figure 6-1. Acceleration Test Arrangement

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6.2 DRAG TESTS

6.2.1 Test Conditions

Drag tests were conducted in the areas identified as south test area and north test area. These places were selected because it was planned to conduct acceleration tests in the same zones. Measurements were taken for a large number of runs in each direction, and at three different initial speeds. The vehicle was brought up to the desired test speed and was then allowed to coast with no thrust input from the turbines until the speed had been reduced to about 8 ft./sec. During the coasting portion of the run, vehicle speed and longitudinal deceleration were recorded. The instrumentation described in Section 5.0 was utilized for these measurements.

The vehicle runs covered a variety of conditions. The lightest load in the vehicle produced a total weight of 2,434 lbs. gross, and the heaviest load produced a vehicle weight of 3,734 lbs. gross. These corresponded to a vehicle with a single passenger and some test instrumentation for the light case, and a fully loaded vehicle for the heavier example. Test information from the south test area is representative of a smaller vehicle enclosure than that at the north test area. The single track section of the south area has a ratio of enclosure area to vehicle area of 3.2 to 1.0. At the north test area in the dual track section the ratio of enclosure area to vehicle area is 4.9 to 1.0. In all cases measurements were taken with vehicles moving in both north direction and south direction and at three different speeds. All tests are based on measurements of two or more runs for the same conditions. Finally, some tests were run with the south end of the enclosure open to the outside atmosphere to measure any possible influence on vehicle drag for such conditions.

6.2.2 Test Results

Figure 6-2, Variation of Vehicle Drag with Velocity, summarizes the results of the drag testing program. The total vehicle drag may be divided into two parts. There is a static drag which does not depend upon vehicle velocity, and a variable drag, which may be attributed to the aerodynamic drag of the vehicle. The size of the static drag is somewhat dependent on the vehicle weight. Static drag measurements averaged 6 lbs. for an empty vehicle and 8 lbs. for a full vehicle. The static drag forces are attributed to the lateral guidance system and the levitation pad system.

There is a considerable variation in the drag measurements under various conditions. The causes of these variations are not always obvious. For example, in northerly moving vehicles, the drag is greater in the south test area than at the north test area. This could be explained by the larger drag coefficient inherent in the reduced enclosure/vehicle area ratio. However, there are also differences in the drag between northbound runs and southbound runs not explained by the area ratio rationalle. Figure 6-3 shows the range of calculated drag for various conditions and various test runs.

The vehicle drag results as shown in Figure 6-2 may be represented by an equation as follows:

$$D = D_o + .043\,V^2 \text{ or } D = D_o + 1/2\,\rho\,AC_dV^2 \quad \text{where}$$

D = vehicle drag in lbs. at velocity V
D_o = vehicle drag at zero speed
= 6 lbs. for empty vehicle
= 8 lbs. for full vehicle
V = vehicle velocity ft./sec.
ρ = air density (.0024 slug/ft.^{3})
A = vehicle frontal area = 24 ft.^{2}
C_d = drag coefficient = 1.5

The values of the zero speed drag were verified by a pull test at very low speeds.

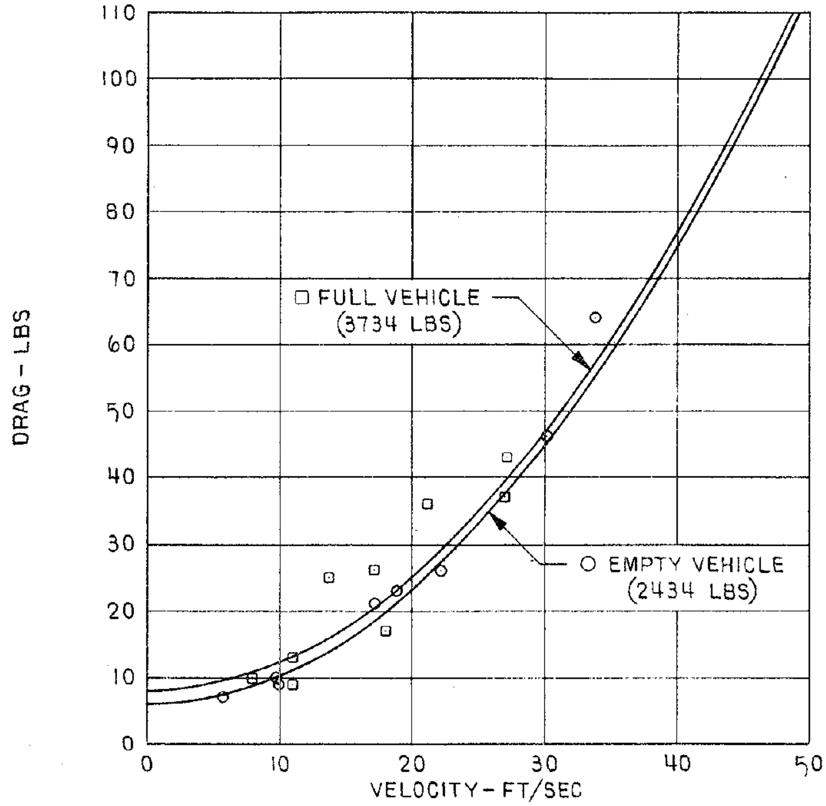

Figure 6-2. Variation of Vehicle Drag With Velocity

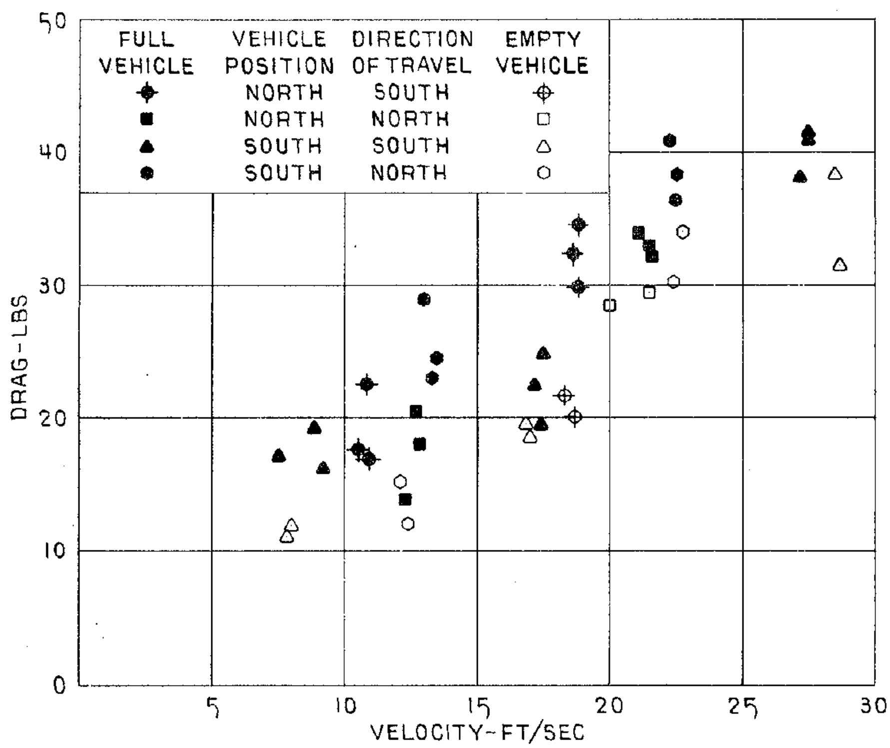

Figure 6-3. Test Results Showing the Variation of Vehicle Drag With Vehicle Position and Direction of Travel

6.2.3 Conclusions

The vehicle drag changes with vehicle weight, its position on the track, its direction and its speed. The drag formula given above could be used in future designs to estimate vehicle drag. Additional studies should be made to minimize the aerodynamic drag. This will result in improving the propulsive efficiency of the system, especially since this drag represents a major factor at higher speeds. More tests and studies should be done to define the change of the drag coefficient with the enclosure/vehicle area ratio.

6.3 VEHICLE ACCELERATION TESTS

6.3.1 Test Methods

Acceleration tests were run to determine the maximum acceleration capability of both empty and loaded vehicles. The same north and south test areas were utilized for acceleration testing as had been employed to measure vehicle drag. Vehicle acceleration was measured both directly with a longitudinal accelerometer and also by the rate of change of instantaneous velocity. The instrumentation used was described in Section 5.0. Acceleration was tested at various speeds up to 34 ft./sec.

Since the Uniflo passive vehicle system derives its acceleration from track based linear turbine modules, the acceleration applied to a vehicle may be varied as it moves over various sections of track. Both the north test area and the south test area have a short section of track in which the maximum number of turbine modules have been installed per section. The maximum number of thrust modules is 8 units per 13 ft. 9 in. track section. Other portions of the test track contain fewer turbine modules per section.

As in the drag test, vehicles are accelerated to the desired test speed by cycling back and forth between the end restraints until the required velocity for initiating the test acceleration run has been achieved. While continuous recordings are being made of both velocity and acceleration, the full available thrust is applied to the vehicle traversing the test section. Both the change in velocity and the instantaneous acceleration values are used to determine the actual vehicle acceleration.

Because of the limitations in the test track, the periods of acceleration and data gathering are relatively short. Therefore, numerous runs were conducted to improve the reliability of the results.

Since the acceleration tests were also to be used to determine the linear air turbine performance, simultaneous measurements were also taken of the system air pressure, system air flow, and blower motor electrical input power.

Because of the variation in thrust at various points along the test track, the system air flow, system air pressure, and electrical horsepower inputs are quite variable. To make comparisons under varying conditions more meaningful, all of the acceleration data were converted to equivalent data for a duct pressure of 2.5 psi. This permits all of the reported results to be compared without inconsistencies.

The air supply and distribution system has a relatively high "tare" value of air flow and input horsepower. This is not representative of commercial systems, but is a reflection of the extremely small size of the test system coupled with a blower designed for much larger air flows.

6.3.2 Test Results

Figure 6-4 shows a summary of vehicle acceleration at varying vehicle velocities. The accelerations are shown for normal forward vehicle acceleration and also for reverse thrust braking. The curve shows the results for a fully loaded vehicle and a vehicle with minimum instrumentation and operator load.

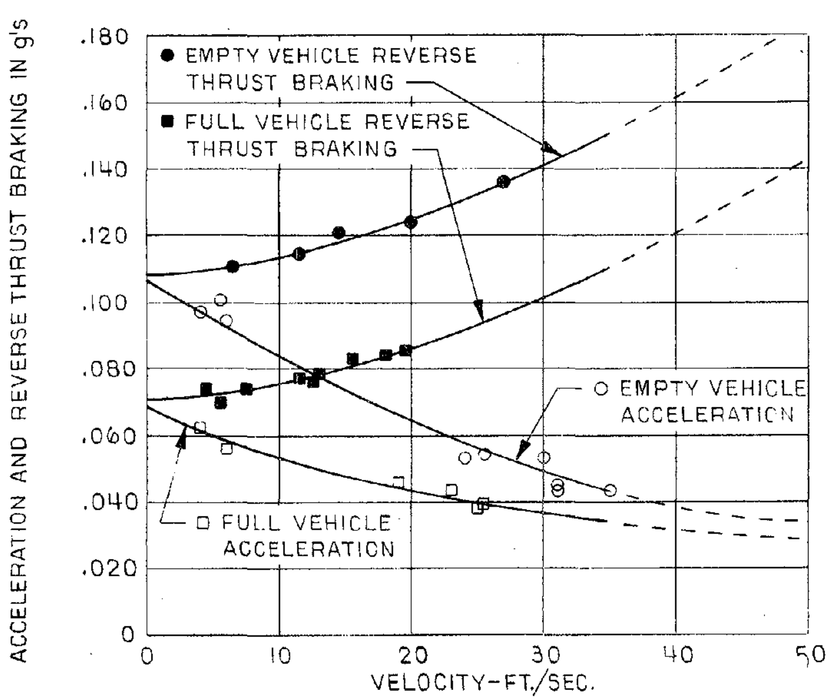

Figure 6-4. Vehicle Acceleration and Reverse Thurst Braking

The tests showed the relationship between changes in vehicle thrust and vehicle velocity. They also indicate that it would be desirable to increase the thrust available throughout the vehicle speed range. Increased thrust can be achieved by increasing the system supply pressure, by changes in nozzle size and location, and by changes in bucket configuration. Another more promising version of a linear air turbine is discussed in the conclusions and recommendations.

6.4 TURBINE PERFORMANCE

6.4.1 Test Method

The information acquired in the vehicle drag tests and vehicle acceleration tests combined with air flow, air pressure, and electrical power measurements were utilized to determine the linear air turbine performance. The air turbine thrust force is equal to the force required to accelerate the vehicle mass at the observed rate, plus the force required to overcome the aerodynamic and static drag forces. For reverse thrust braking runs, the turbine thrust is equal to the force required to decelerate the vehicle at the observed rate minus the aerodynamic and static drag forces.

By utilizing these thrust forces and the vehicle velocity, the effective power output of the linear air turbine is calculated. The air power input to the linear turbine was computed from the supply air pressure and the air flow through the turbine. To convert the air power requirement to electrical input power, the efficiency of the blower/motor combination and distribution losses must be taken into account.

Since the system utilizes the same air for levitation purposes and makeup of any system leaks, the turbine air flow and power input requirements were determined by the change in system air flow and system power input as the turbine sections were turned on. From the air flow measurements, an empty stationary vehicle required 10 $ft.^3$/sec. for levitation and a loaded stationary vehicle required 8 $ft.^3$/sec. for levitation. While the vehicle was moving during the drag tests, these values increased to

15 $ft.^3$/sec. to levitate a moving empty vehicle, and 12 $ft.^3$/sec. to levitate a moving fully loaded vehicle. Some of the increase between a moving and stationary vehicle air flow was due to levitation valves staying open after the vehicle had passed (see Section 2.6). Table 6-1 summarizes the air flow changes in the various operating modes and the range of duct pressure. Quiescent air flow was 63 $ft.^3$/sec.

TABLE 6-1

TEST DATA SUMMARY

Operating Mode	Duct Pressure lbs./$in.^2$	Incremental Flow $ft.^3$/sec.
Empty Vehicle Levitated, At Rest	2.75	9-10
Full Vehicle Levitated, At Rest	2.75	8
Empty Vehicle Levitated, Moving	2.75	15
Full Vehicle Levitated, Moving	2.75	12
Vehicle Accelerating (Turbine Air Flow Only)	2.4 - 2.7	66 - 83
Vehicle Braking (Turbine Air Flow Only)	2.4 - 2.7	66

6.4.2 Test Results

Vehicle acceleration was measured both by a record of the longitudinal accelerometer installed in the vehicle and by a recording of the instantaneous vehicle velocity. In all cases the acceleration as measured by the accelerometer indicated higher values than the acceleration measured by the change in vehicle velocity. The accelerometer records were subject to greater variation and it was felt that these higher values were less credible than the accelerations indicated by vehicle velocity. For this reason all values shown in the graphs are based on the more conservative indications from changes in vehicle velocity. Figure 6-5 shows the turbine thrust at velocities varying between 0 and 30 ft./sec. in both the acceleration and reverse thrust braking modes. The chart also shows the net effective propulsive power supplied by the linear air turbine in the accelerating mode.

The type of reentrant impulse turbine tested and reported above is the result of several modifications intended to improve its performance over varying operating conditions. Prior to applying this turbine to the test track and vehicle bottom, many minor variations were modeled and tested on a static test stand. The version used for this test track included a modification to the vehicle portion which increased the turbine's tolerance to lateral misalignments. These changes, unfortunately, did not substantially improve the performance of the turbine over the version tested in the previous contract.

Figure 6-6 shows the turbine efficiency plotted against vehicle velocity. These curves indicate the turbine efficiency will reach its peak value at vehicle speeds in the range of 40 to 50 ft./sec. The curves also show the expected turbine efficiency as computed from static test stand measurements of zero speed thrust and a thrust vs. speed relationship, percentagewise, the same as the test track results.

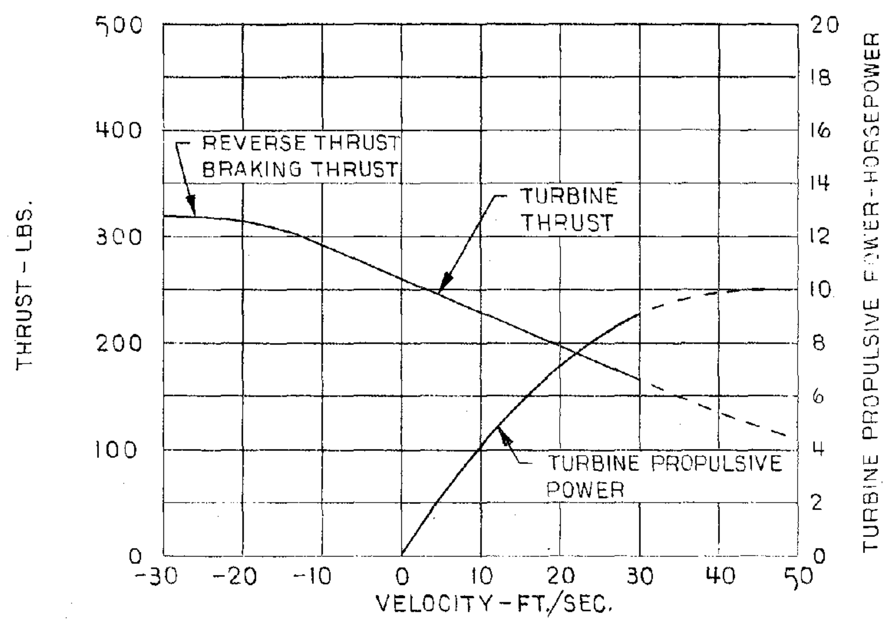

Figure 6-5. Turbine Performance

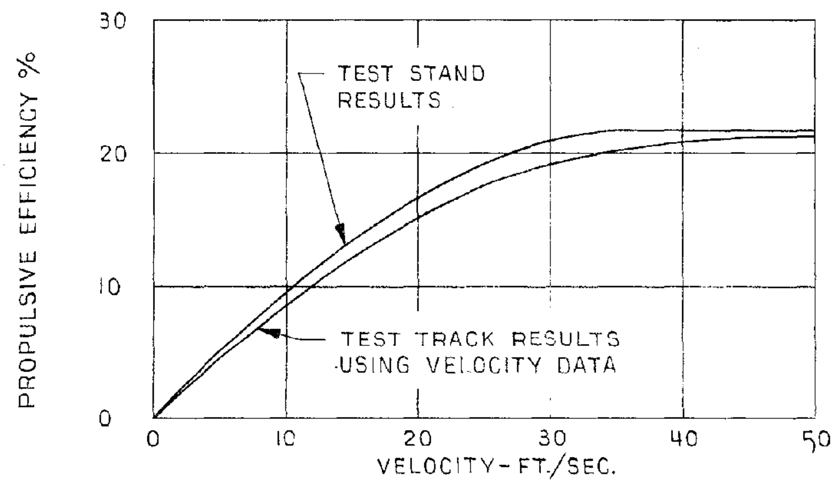

Figure 6-6. Turbine Efficiency

6.5 CONCLUSIONS AND RECOMMENDATIONS

From the results of the above testing, two areas of further work were indicated. The first is reduction of the aerodynamic drag of the vehicle. Drag improvements may be found in changes of vehicle shape, use of pressure recovery blades, or the use of turbine air flow exhaust to control air flow over the vehicle. Tunnel to vehicle area ratios should also be studied.

The second area of work is in turbine performance. The basic requirements of the propulsive system for Uniflo passive vehicles are quite different from conventional systems. It has to be inexpensive, since it is distributed along the guideway, rather than being vehicle based. The propulsion system efficiency does not need to be as high as conventional systems to achieve the same energy consumption per seat mile. This results from the very low weight vehicle in combination with low drag. The present turbine design would have application in low speed systems with small vehicles. However, increased acceleration capability and higher efficiencies are desirable for high performance systems.

Because of these demands, Uniflo started work on other turbine configurations to meet these higher design goals. After analytical evaluations and model tests of several turbine configurations, a significant improvement was realized. An increase in efficiency of two times was indicated by a new design. This new design is a two-stage impulse turbine with air flow in an upward direction from the track. This turbine does not employ the reentrant vortex path of air flow and the associated mixing losses, but uses more conventional rotor and stator blading. Static tests of this turbine indicate turbine propulsive efficiency will reach 62% at speeds of 105 ft./sec., and 48% at 60 ft./sec. This turbine is also capable of considerable increase in thrust per unit length. Vehicle accelerations of .25 g's at all loads and speeds to 60 ft./sec. are indicated.

It is, therefore, recommended that a prototype of this turbine version be developed, installed in the present facility, and tested throughout the available load and speed range.

7.0 COMPONENT COST ESTIMATES

7.1 BACKGROUND

The contract work objective was to provide cost estimates in accordance with the following:

a. Provide a detailed breakdown of all system component costs obtained on this contract.

b. Provide capital equipment cost estimates based on production quantities of all equipment items evaluated on this contract.

Under this contract, certain Uniflo system components were designed and built as prototype units for the functions of support and guidance, air distribution, acceleration and levitation. A prototype vehicle and a switch assembly were also built under this contract.

The cost breakdowns reported in Section 7.2 are based on actual costs incurred on this contract for building the prototype units. The costs are broken into three main categories of design and development engineering, fabrication, and tooling. These categories are cost reported as direct material, direct labor, overhead of 130% (less than the actual USC rate) of direct labor and general and administrative expense of 20% (also less than the actual USC rate). No profit is included in these costs.

7.2 SYSTEM COMPONENT COSTS

The actual system component costs obtained on this contract are listed below. To facilitate visualizing the various components, refer to Figure 7-1, Uniflo System Components. Detailed descriptions of these components are given earlier in this report. The actual costs incurred in this contract are listed in the first column of costs. The second cost column is an estimate for producing the same number of components as the contract required, but reflect the dropping of nonrecurring costs of engineering and tooling plus the learning curve factors. The installation costs were for installing the operating surface cross beams, air distribution (not including blower and its air ducts), turbine modules, levitation valves, guide rails, and alignment of the guide rails and operating surface. The cost of installing controls is not included.

SUPPORT & GUIDANCE

	This Contract Cost Per Foot of Guideway Based on 344 ft. Built (FY '73 Dollars)	Cost Per Foot to Extend Existing Track 344 ft. (FY '73 Dollars)
Design and Development Engineering		
Direct Labor	$ 15.15	$ *
Overhead (130%)	19.70	*
Fabrication		
Direct Labor	6.89	5.84
Overhead (130%)	8.96	7.59
Material	97.04	106.74
Tooling		
Direct Labor	---	---
Overhead (130%)	---	---
Material	12.32	*
Total Labor & Material	160.06	$120.17
General & Admin. (20%)	32.01	24.03
TOTAL COST	$192.07	$144.20

*These costs are nonrecurring because of existing design and tooling.

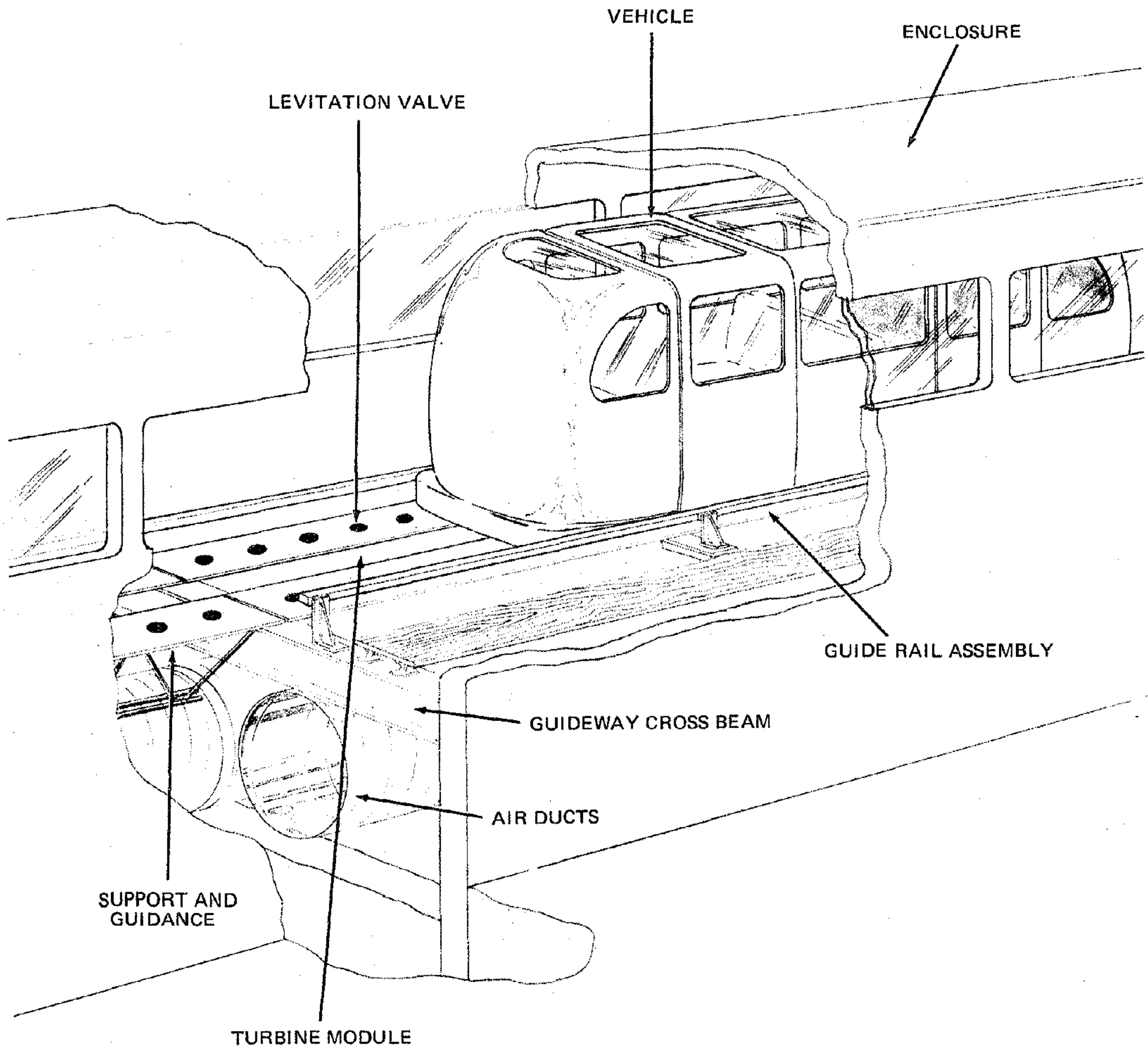

Figure 7-1. Uniflo System Components

AIR DISTRIBUTION

	This Contract Cost Per Foot of Guideway Based on 344 ft. Built (FY '73 Dollars)	Cost Per Foot to Extend Existing Track 344 ft. (FY '73 Dollars)
Design and Development Engineering		
Direct Labor	$ 2.67	*
Overhead (130%)	3.47	*
Fabrication		
Direct Labor	1.22	$ 1.04
Overhead (130%)	1.59	1.35
Material	23.76	26.17
Tooling		
Direct Labor	1.49	*
Overhead (130%)	1.94	*
Material	.67	*
Total Labor & Material	$36.81	$28.56
General & Admin. (20%)	7.36	5.71
TOTAL COST	$44.17	$34.27

*These costs are nonrecurring because of existing design and tooling.

TURBINE MODULE ASSEMBLY

	This Contract Per Unit Cost Based on 200 Units (FY '73 Dollars)	Cost to Extend Existing Track Based on 200 Units (FY '73 Dollars)
Design and Development Engineering		
Direct Labor	$ 11.38	*
Overhead (130%)	14.79	*
Fabrication		
Direct Labor	31.51	$ 31.51
Overhead (130%)	40.96	40.96
Material	33.15	33.15
Tooling		
Direct Labor	26.94	*
Overhead (130%)	35.02	*
Material	2.34	*
Total Labor & Material	$196.09	$105.61
General & Admin. (20%)	39.22	21.12
TOTAL COST	$235.31	$126.73

*These costs are nonrecurring because of existing design and tooling.

LEVITATION VALVE

	This Contract Per Unit Cost Based on 1,000 Units (FY '73 Dollars)	Cost to Extend Existing Track Based on 1,000 Units (FY '73 Dollars)
Design and Development Engineering		
Direct Labor	$0.37	*
Overhead (130%)	0.48	*
Fabrication		
Direct Labor	1.60	1.60
Overhead (130%)	2.08	2.08
Material	1.22	1.22
Tooling		
Direct Labor	0.69	*
Overhead (130%)	0.90	*
Material	— — —	— — —
Total Labor & Material	$7.34	$4.90
General & Admin. (20%)	1.47	.98
TOTAL COST	$8.81	$5.88

*These costs are nonrecurring because of existing design and tooling.

INSTALLATION COSTS OF OPERATING SURFACE INCLUDING AIR DISTRIBUTION, TURBINE MODULES, AND LEVITATION VALVES

	This Contract Cost Per Foot of Guideway Based on 344 ft. Built (Fy '73 Dollars)	Cost Per Foot to Extend Existing Track 344 ft. (FY '73 Dollars)
Design and Development Engineering		
Direct Labor	— — —	— — —
Overhead (130%)	— — —	— — —
Fabrication		
Direct Labor	$16.47	$13.18
Overhead (130%)	24.01	17.13
Material	3.49	2.97
Tooling		
Direct Labor	1.45	*
Overhead (130%)	1.89	*
Material	0.12	*
Total Labor & Material	$47.43	$33.28
General & Admin. (20%)	9.49	6.66
TOTAL COST	$56.92	$39.94

*These costs are nonrecurring because of existing tooling.

GUIDEWAY SWITCH ASSEMBLY

	This Contract Per Unit Costs Based on 1 Prototype Unit (FY '73 Dollars)	Cost to Produce 1 Additional Unit (FY '73 Dollars)
Design and Development		
Engineering		
Direct Labor	$1,249.00	*
Overhead (130%)	1,623.70	*
Fabrication		
Direct Labor	704.73	$ 528.54
Overhead (130%)	916.15	687.11
Material	1,076.57	861.26
Tooling		
Direct Labor	---	---
Overhead (130%)	---	---
Material	---	---
Total Labor & Material	$5,570.15	$2,076.91
General & Admin. (20%)	1,114.03	415.38
TOTAL COST	$6,684.18	$2,492.29

*These costs are nonrecurring because of existing design.

UNIFLO 8-PASSENGER PROTOTYPE VEHICLE

	This Contract Per Unit Cost Based on One Prototype Unit (FY '73 Dollars)	Cost to Produce 1 Additional Unit (FY '73 Dollars)
Design and Development		
Engineering		
Direct Labor	$11,842.00	*
Overhead (130%)	15,394.60	*
Fabrication		
Direct Labor	15,475.80	$13,928.22
Overhead (130%)	20,118.54	18,106.69
Material	11,279.73	9,587.77
Tooling		
Direct Labor	---	---
Overhead (130%)	---	---
Material	588.00	*
Total Labor & Material	$74,698.67	$41,622.68
General & Admin. (20%)	14,939.73	8,324.54
TOTAL COST	$89,638.40	$49,947.22

*These costs are nonrecurring because of existing design and tooling.

GUIDEWAY ENCLOSURE

	This Contract Cost Per Foot of Guideway Based on 371 ft. Built (FY '73 Dollars)	Cost Per Foot to Extend Existing Track 371 ft. (FY '73 Dollars)
Design and Development Engineering		
Direct Labor	$ 2.49	*
Overhead (130%)	3.23	*
Fabrication		
Direct Labor	15.67	$ 12.54
Overhead (130%)	20.37	16.30
Material	101.69	101.69
Tooling		
Direct Labor	---	---
Overhead (130%)	---	---
Material	---	---
Total Labor & Material	$143.45	$130.53
General & Admin. (20%)	28.69	26.11
TOTAL COST	$172.14	$156.64

*These costs are nonrecurring because of existing design.

7.3 ESTIMATED CAPITAL EQUIPMENT COSTS

The following capital cost estimates cover the components of the Uniflo Personal Rapid Transit System which have been evaluated on this contract. These estimated costs are based on the production quantities indicated, using a fully developed design with tooling and production facilities designed specifically for producing the Uniflo equipment.

In order to establish a quantity for estimating the cost of the components, we have assumed a 20 lane-mile system for estimating a normal volume production quantity. After establishing the quantities involved, estimates were secured from the local suppliers who furnished the equipment for this contract. These estimates covered finished parts prepared for final assembly, and shipped to Uniflo Systems Company.

The guideway enclosure was not included in these estimates, since the current design is not applicable to a demonstration or installed system. The enclosure would be satisfactory for a test system where enclosure aesthetics are not important. The installation costs for the operating surface and air distribution were not estimated for the 20 lane-mile system, since the installation costs on the present contract did not cover all the items which have to be installed in a deployed system.

The estimated capital equipment costs are priced FOB Uniflo Systems Company, and do not include installation.

HYPOTHETICAL 20-LANE MILE SYSTEM

Estimated Capital Costs

Item	Production Quantities	Unit Cost Basis	Capital Cost	Typical Number of Units Per Mile	Capital Cost Per Mile for Single Lane
Support and Guidance	105,600 ft.	per foot	$ 103	5,280	$ 543,840
Air Distribution	105,600 ft.	per foot	23	5,280	121,440
Turbine Module	46,080	each	67	2,304	154,368
Levitation Valves	307,200	each	5.70	15,360	87,552
Switch	60	each	1,740	3	5,220
Vehicle	400	each	13,270	20	265,400
				TOTAL	$1,177,820

7.4 SUMMARY AND CONCLUSIONS

The costs of components manufactured for this contract have been detailed. In our previous contract, DOT-TSC-367, the actual costs of some of the same items were reported. A comparison of these costs is shown below. The cost for the earlier contract did not include development engineering, and an overhead rate of 120% was used. The comparison shown below has used an overhead rate of 130% on both sets of costs and the development engineering has been dropped from the current contract costs. In the case of the turbine module, the tooling costs have been dropped from the present contract since existing tooling was used in the previous contract. These changes make it possible to compare the two contracts and the production estimates on an equivalent basis. The earlier contract was based on 55 feet of single-lane guideway, while the present contract is for 344 feet. The production cost estimates are shown for a 20-lane mile system.

The comparison shows the general decrease in costs produced by increased quantities and learning factors. This trend tends to support the production cost estimates.

COST COMPARISONS

Item	Contract DOT-TSC-367	Contract DOT-TSC-367/Mod I	Production Quantities
Support and Guidance	$204.23 per foot	$ 150.25 per foot	$ 103.00 per foot
Air Distribution	$ 51.69 per foot	$ 36.80 per foot	$ 23.00 per foot
Turbine Module	$196.77 each	$ 126.73 each	$ 67.00 each
Levitation Valve	$ 6.26 each	$ 7.79 each	$ 5.70 each
Switch	Not Applicable	$ 3,236.94 each	$ 1,740.00 each
Vehicle	Not Applicable	$56,248.88 each	$13,270.00 each

LIST OF REFERENCES AND RELATED PUBLICATIONS

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2. A.P.G. Peterson and E.E. Gross, Handbook of Noise Measurement (Sixth Edition), West Concord, Massachusetts, General Radio Co., 1967, p. 63.
3. Noise Reduction, Leo L. Beranek, McGraw Hill, 1960.
4. Richard H. Lyon, Lectures in Transportation Noise, Grozier Publishing, 1973.
5. High Performance Personal Rapid Transit System, RFP DOT-UT-30014, Statement of Work, p. 64-66.
6. Dulles Demonstration of People Mover Systems, RFP DOT-UT-10027, Office of the Secretary of Transportation, Washington, D.C., May 1971.
7. W. T. Thompson, Mechanical Vibrations, Prentice-Hall, 1960.
8. Fan Engineering (Seventh Edition) Buffalo Forge Company.

APPENDIX A

REPORT OF INVENTIONS

Modification 1 of Contract DOT-TSC-367 is intended to measure and evaluate full-scale subsystems of the Uniflo pneumatically operated passive vehicle personal rapid transit system. In order to fulfill the objectives, considerable construction of prototype equipment was required. The prototypes, however, were based on designs already developed, and therefore, involved little opportunity for fundamental development or invention.

Some significant improvements, although not believed patentable, may be worthy of note.

The air distribution system was improved by providing flexible connections between each 13 ft. 9 in. section of guideway operating surface. This involved the use of a pair of pressure actuated lip seals at each end of a connecting sleeve between distribution piping sections. The air supply to the turbine modules was also improved by eliminating a flexible air hose having clamp type connections, and substituting a metalic connection utilizing pressure seals both at the distribution pipe and turbine module ends.

The linear air turbine modules were modified to reduce the pressure losses across the control valve and approach to the turbine nozzles.

A vehicle door latch was developed which produces equalized loading along door seals of complex shape.

A switching arrangement was tested utilizing movable on-board switching wheels which are preset by a trackside device.

A three axis secondary suspension system composed of rubber shear mounts was designed and tested.

It is believed that the above mentioned improvements and other features of the system as it was tested represent good engineering practice, but do not meet the requirements of patentable inventions.

Therefore, we believe that no patentable inventions were developed or first reduced to practice during the performance of this contract.

APPENDIX B

This appendix contains tables of 1/3 octave band sound pressure levels measured 25 ft. from the guideway and inside the vehicle at various operating conditions. This data was used to prepare the plots shown in Section 4.0, and also for Tables 4-3 and 4-4.

TABLE B-1

NOISE EMISSIONS AT GEOMETRIC CENTER OF PASSENGER COMPARTMENT
ALL VALUES WITH VEHICLE EMPTY
dB REF. 0.0002 MICROBAR

Freq. (Hz)	Ambient (No Blowers)	Ambient (Blowers On)	Levitated At Rest	Cruising 10 ft./sec.	Cruising 20 ft./sec.	Cruising 25 ft./sec.	Cruising 30 ft./sec.	Full Dynamic Braking 25 ft./sec.	Full Acceleration 25 ft./sec.
31.5	44	70	71	82	89	85	83	86	87
40	49	68	72	80	84	87	84	89	87
50	42	60	64	70	74	75	77	78	78
63	42	61	63	69	76	74	72	87	74
80	37	58	61	74	75	79	77	90	82
100	34	53	58	71	76	75	79	83	79
125	23	45	51	69	73	71	70	78	75
160	27	38	56	70	72	73	70	81	77
200	26	39	52	67	71	71	74	79	75
250	26	34	42	60	64	65	64	76	67
315	26	33	44	62	63	64	65	75	65
400	34	32	43	63	65	65	64	76	66
500	30	34	40	56	59	61	59	69	63
630	29	32	35	52	53	54	55	64	56
800	30	29	38	49	51	51	52	61	53
1000	29	25	37	45	47	47	47	55	48
1250	26	25	32	43	44	44	43	53	46
1600	20	24	32	40	42	43	41	51	45
2000	19	30	35	40	44	44	42	51	44
2500	19	25	33	37	40	40	37	48	40
3150	15	25	32	36	39	38	36	46	39
4000	15	32	35	38	44	44	43	47	43
5000	14	27	30	34	37	37	35	44	37
6300	12	29	34	35	39	39	36	43	39
8000	11	29	33	35	39	39	36	41	39
dBA	36	44	50	65	68	68	68	77	70
dBLin	52	75	74	86	90	90	88	95	92

TABLE B-2

NOISE EMISSIONS AT GEOMETRIC CENTER OF PASSENGER COMPARTMENT
ALL VALUES WITH VEHICLE LOADED
dB REF. 0.0002 MICROBAR

Freq. (Hz)	Ambient (No Blowers)	Ambient (Blowers On)	Levitated At Rest	Cruising 10 ft./sec.	Cruising 20 ft./sec.	Cruising 25 ft./sec.	Cruising 30 ft./sec.	Full Dynamic Braking 25 ft./sec.	Full Acceleration 25 ft./sec.
31.5	44	70	75	83	89	86	85	83	88
40	49	68	77	80	85	89	89	85	90
50	42	60	67	71	74	75	80	74	78
63	42	61	67	70	79	72	73	86	75
80	37	58	64	71	73	80	77	87	82
100	34	53	60	68	73	74	76	77	78
125	23	45	53	66	71	71	69	76	72
160	27	38	56	69	70	73	75	76	77
200	26	39	55	66	71	70	74	76	75
250	26	34	46	60	63	65	65	72	68
315	26	33	47	62	62	63	65	70	66
400	34	32	46	62	64	65	64	71	67
500	30	34	41	55	58	59	60	66	62
630	29	32	39	50	53	54	54	60	55
800	30	29	39	49	51	51	51	55	53
1000	29	25	37	44	47	47	46	50	49
1250	26	25	33	41	46	45	44	48	47
1600	20	24	33	39	43	42	42	44	44
2000	19	30	34	39	44	42	42	44	44
2500	19	25	32	37	40	39	36	39	40
3150	15	25	31	35	39	37	36	37	38
4000	15	32	33	35	44	43	40	37	42
5000	14	27	31	33	38	37	35	34	37
6300	12	29	33	34	39	38	35	35	38
8000	11	29	32	33	39	39	35	34	39
dBA	36	44	52	64	67	68	69	73	70
dBLin	52	75	80	87	91	92	91	92	93

TABLE B-3

NOISE EMISSION 25 FT. FROM CENTER OF GUIDEWAY
ALL VALUES WITH VEHICLE EMPTY
dB REF. 0.002 MICROBAR

Freq. (Hz)	Ambient (No Blowers)	Ambient (Blowers On)	Levitated At Rest	Cruising 10 ft./sec.	Cruising 20 ft./sec.	Cruising 25 ft./sec.	Cruising 30 ft./sec.	Full Dynamic Braking 25 ft./sec.	Full Acceleration 25 ft./sec.
31.5	54	61	59	58	63	61	61	65	64
40	56	58	57	57	60	62	60	63	63
50	57	61	58	56	58	58	59	57	58
63	53	58	58	54	59	58	56	54	54
80	52	54	57	54	58	57	55	54	54
100	52	54	57	53	54	55	54	52	53
125	47	51	52	50	49	51	50	49	48
160	42	47	47	47	47	48	48	47	47
200	39	44	46	46	44	46	47	48	46
250	38	43	43	46	43	44	45	49	44
315	37	41	40	44	42	44	44	46	43
400	37	39	37	42	41	43	44	44	41
500	35	38	34	41	39	40	41	43	40
630	35	39	35	38	38	39	40	42	40
800	36	36	31	36	36	38	39	40	38
1000	35	33	28	33	34	37	37	40	37
1250	32	31	29	32	33	35	35	38	36
1600	27	27	26	31	31	32	33	36	32
2000	20	24	24	31	30	30	32	35	31
2500	15	22	23	29	28	27	28	32	28
3150	14	21	22	28	26	26	27	31	27
4000	16	20	21	24	26	26	26	28	27
5000	14	18	19	22	22	22	22	24	23
6300	15	18	17	21	22	21	22	23	22
8000	14	16	16	20	21	20	21	20	24
dBA	43	46	45	46	46	47	48	50	47
dBLin	62	69	68	66	68	68	68	69	68

TABLE B-4

NOISE EMISSION 25 FT. FROM CENTER OF GUIDEWAY
ALL VALUES WITH VEHICLE LOADED
dB REF. 0.0002 MICROBAR

Freq. (Hz)	Ambient (No Blowers)	Ambient (Blowers On)	Levitated At Rest	Cruising 10 ft./sec.	Cruising 20 ft./sec.	Cruising 25 ft./sec.	Cruising 30 ft./sec.	Full Dynamic Braking 25 ft./sec.	Full Acceleration 25 ft./sec.
31.5	54	61	59	58	59	61	64	61	63
40	56	58	57	56	59	61	63	64	62
50	57	61	57	55	57	57	57	58	64
63	53	58	57	53	58	54	56	55	54
80	52	54	55	52	53	54	57	55	53
100	52	54	52	51	51	52	55	52	51
125	47	51	47	47	48	48	49	47	50
160	42	47	43	44	44	44	48	46	45
200	39	44	42	42	44	45	47	45	46
250	38	43	40	40	43	42	45	45	44
315	37	41	39	40	43	41	44	45	42
400	37	39	37	40	42	41	42	43	41
500	35	38	34	36	40	40	41	43	37
630	35	39	33	33	39	38	40	43	37
800	36	36	32	34	39	38	38	42	36
1000	35	33	31	31	38	37	38	41	36
1250	32	31	29	30	36	35	36	37	34
1600	27	27	26	28	33	32	33	36	31
2000	20	24	24	27	30	29	31	34	30
2500	15	22	22	26	27	26	28	30	27
3150	14	21	22	26	26	25	27	27	26
4000	16	20	20	24	24	24	25	25	24
5000	14	18	18	22	22	22	22	22	21
6300	15	18	17	21	22	21	21	21	20
8000	14	16	14	20	21	18	18	17	17
dBA	43	46	43	43	47	46	58	49	46
dBLin	62	69	66	64	66	66	69	68	68

APPENDIX C

This appendix contains time history plots of A-weighted sound pressure levels measured 25 ft. from the guideway and inside the vehicle at various operating conditions.

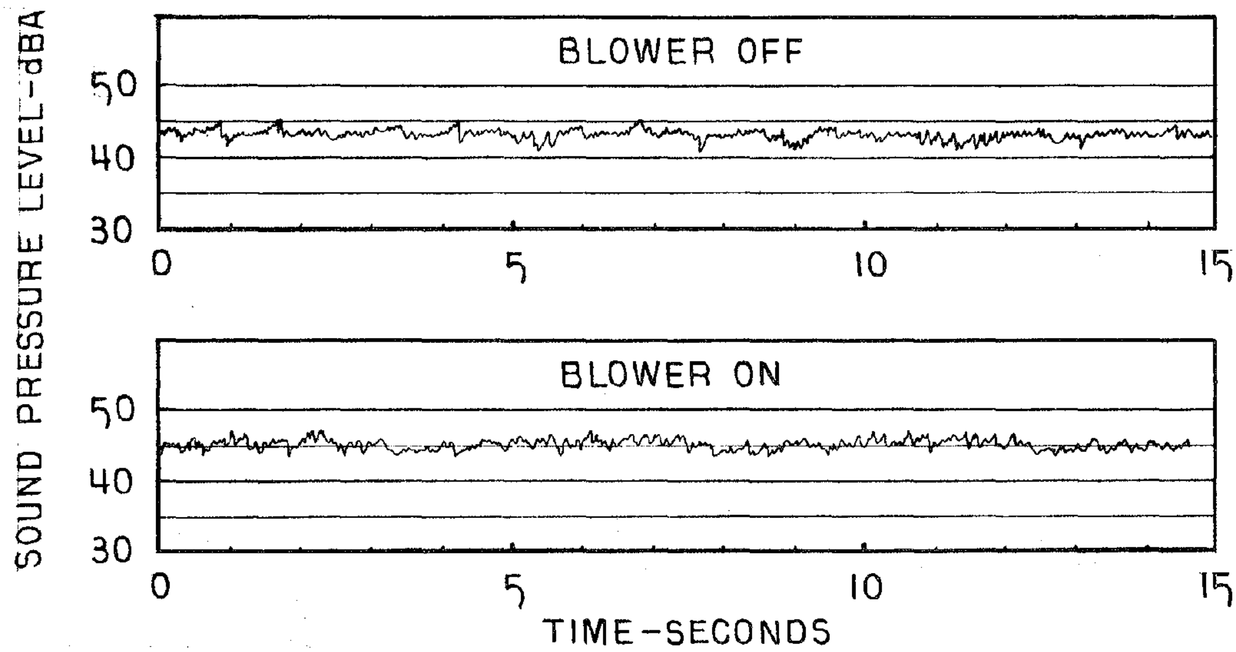

Figure C-1. Background Noise 25 Feet From Guideway

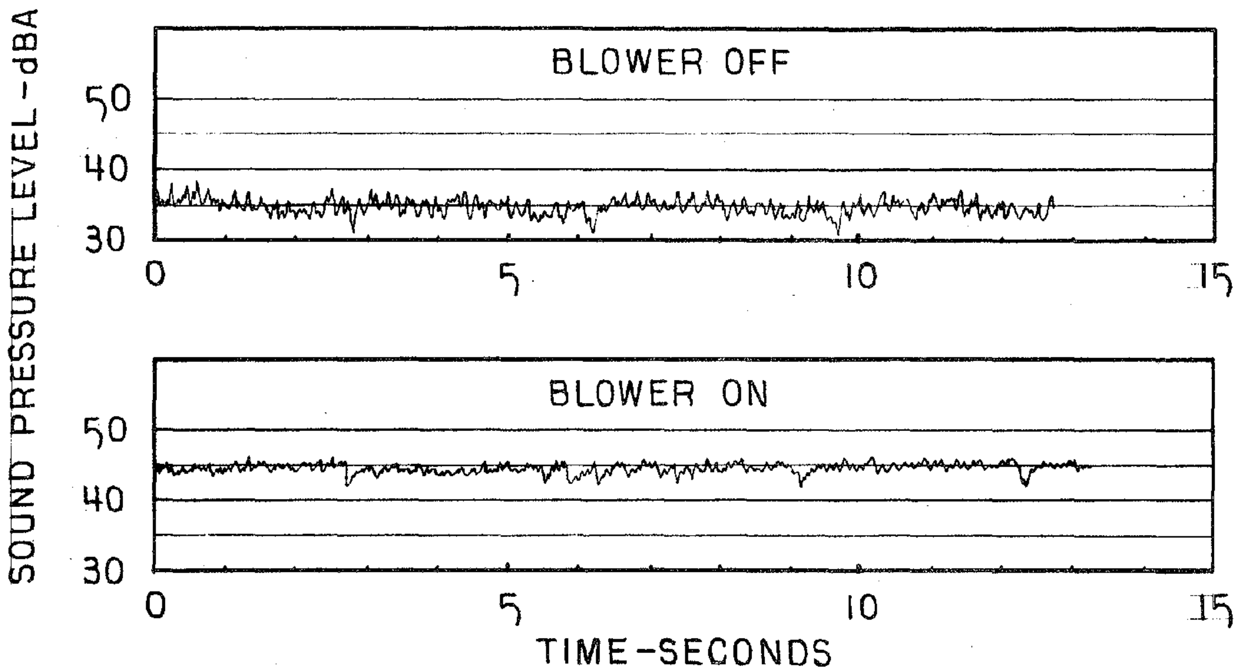

Figure C-2. Background Noise Inside Vehicle

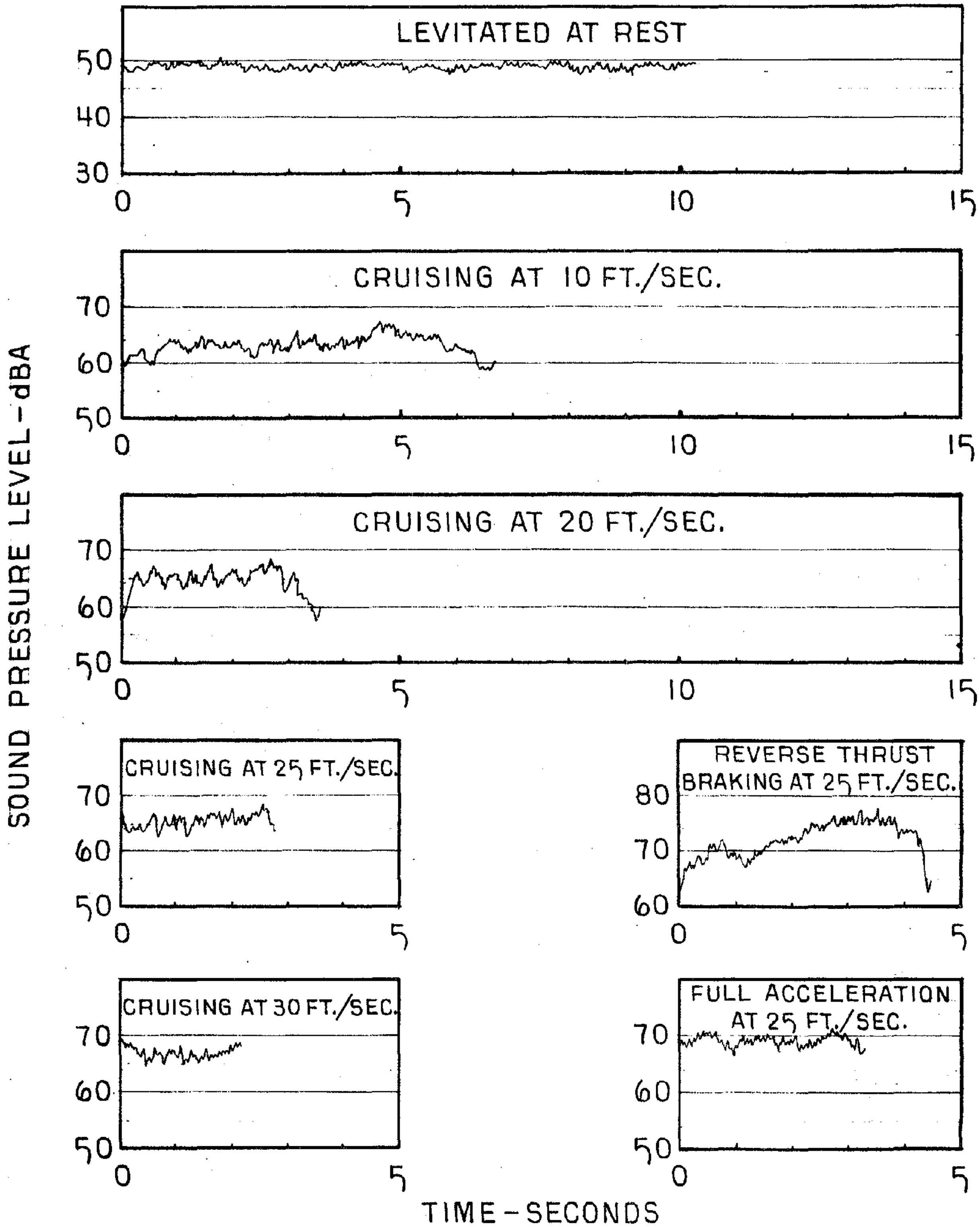

Figure C-3. Empty Vehicle Noise Emissions Measured Inside Vehicle

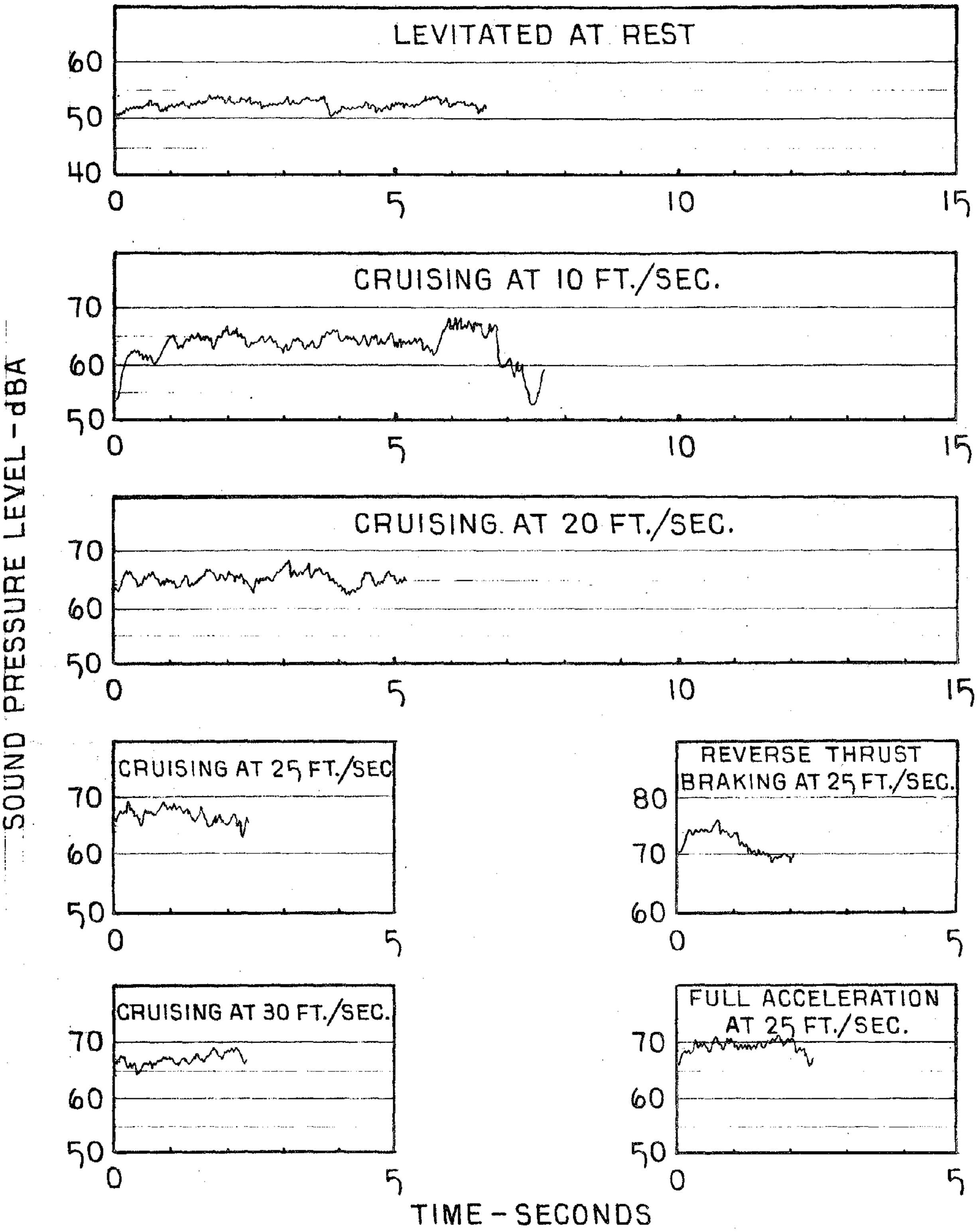

Figure C-4. Full Vehicle Noise Emissions Measured Inside Vehicle

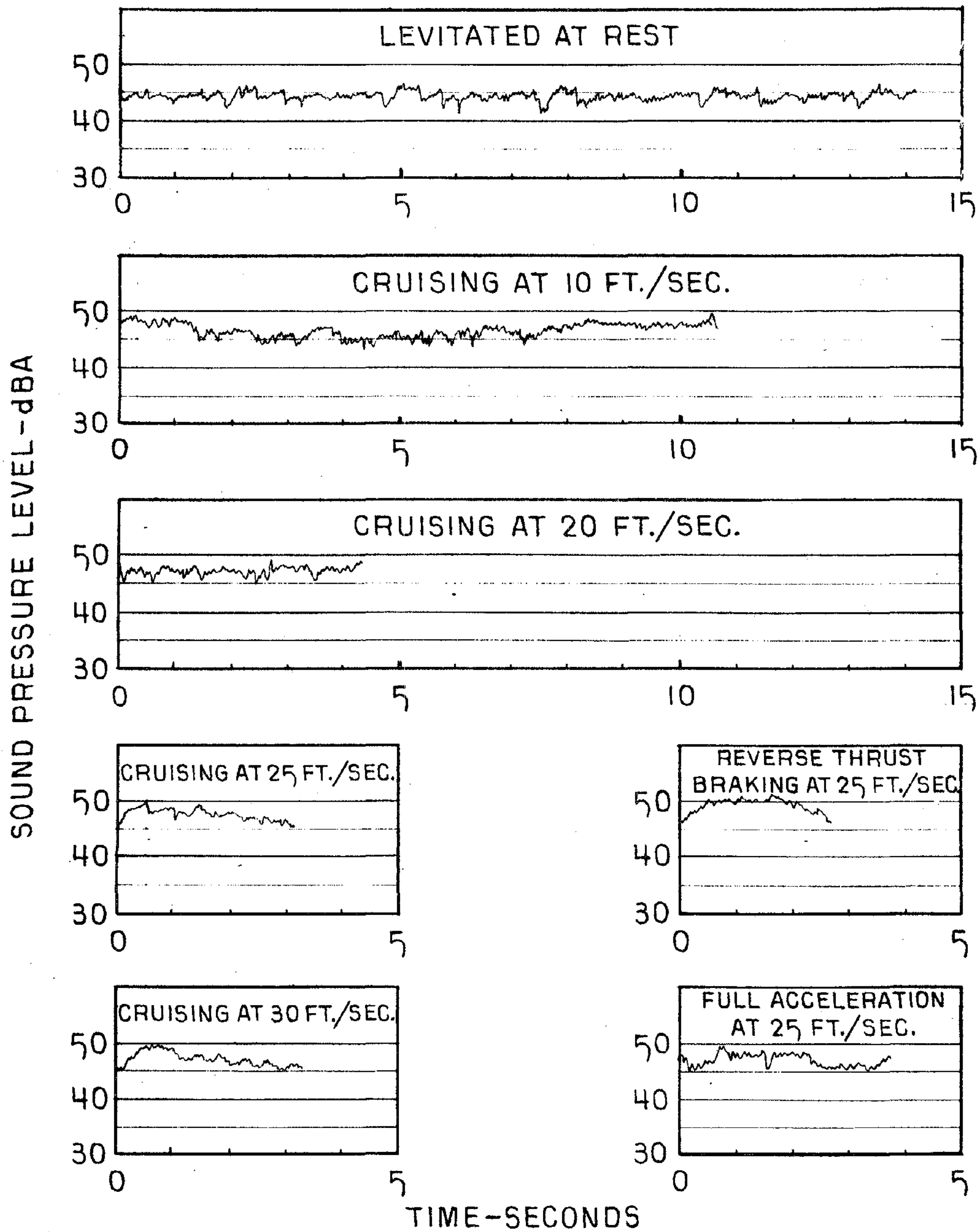

Figure C-5. Empty Vehicle Noise Emissions Measured 25 Feet From Guideway

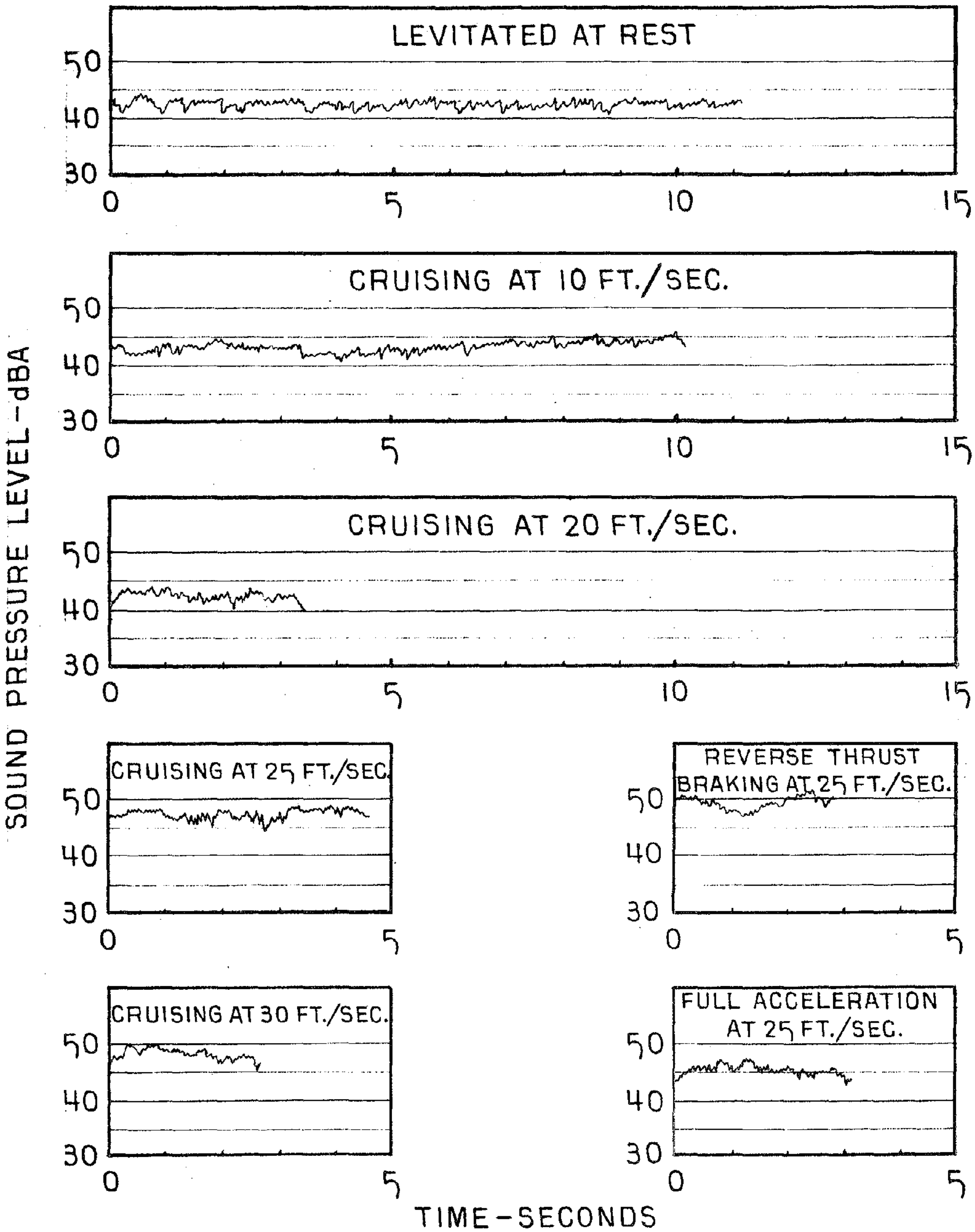

Figure C-6. Full Vehicle Noise Emissions Measured
25 Feet From Guideway

APPENDIX D

THIRD-OCTAVE-BAND FREQUENCY SPECTRA FOR LATERAL AND VERTICAL ACCELERATION

This appendix shows the third-octave-band frequency spectra which were prepared by TSC from acceleration data recorded under various test conditions. The loaded vehicle (gross weight 3734 lbs.) speed was varied from 20 to 30 ft./sec., while the empty vehicle (gross weight 2434 lbs.) was run only at 35 ft./sec. The data was analyzed separately for the vehicle on the straight section, on the spiral and curve, and through the switch.

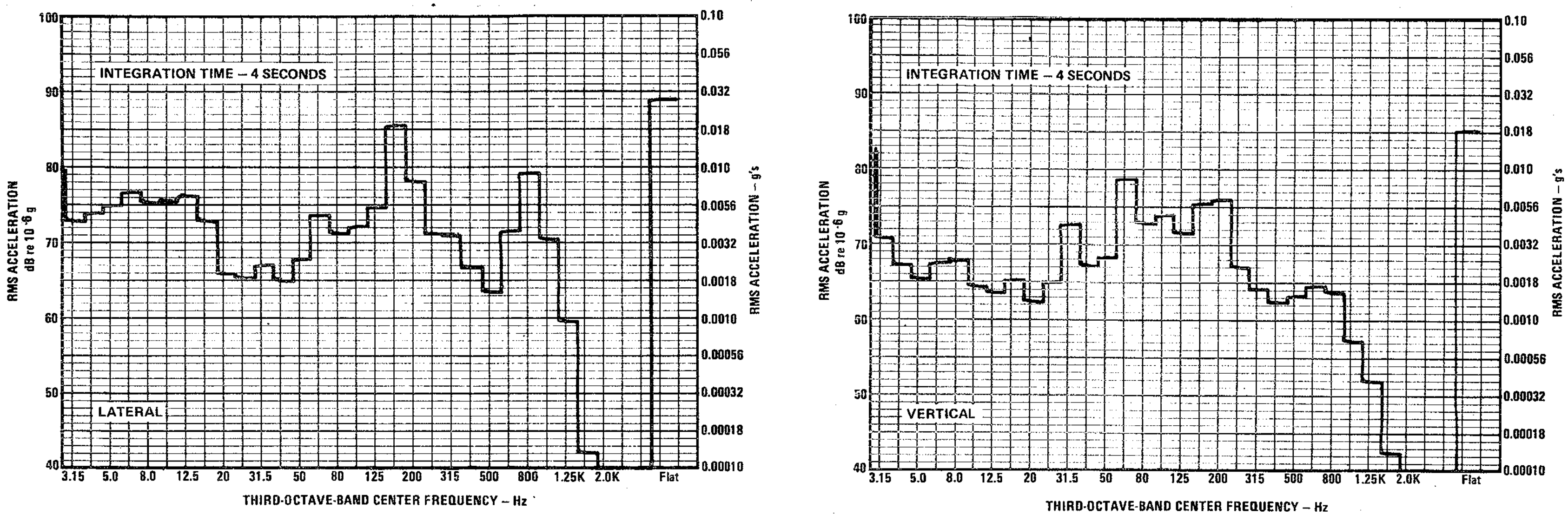

Figure D-1. Acceleration Levels – Straight Guideway Section –
Loaded Vehicle – 20 ft./sec.

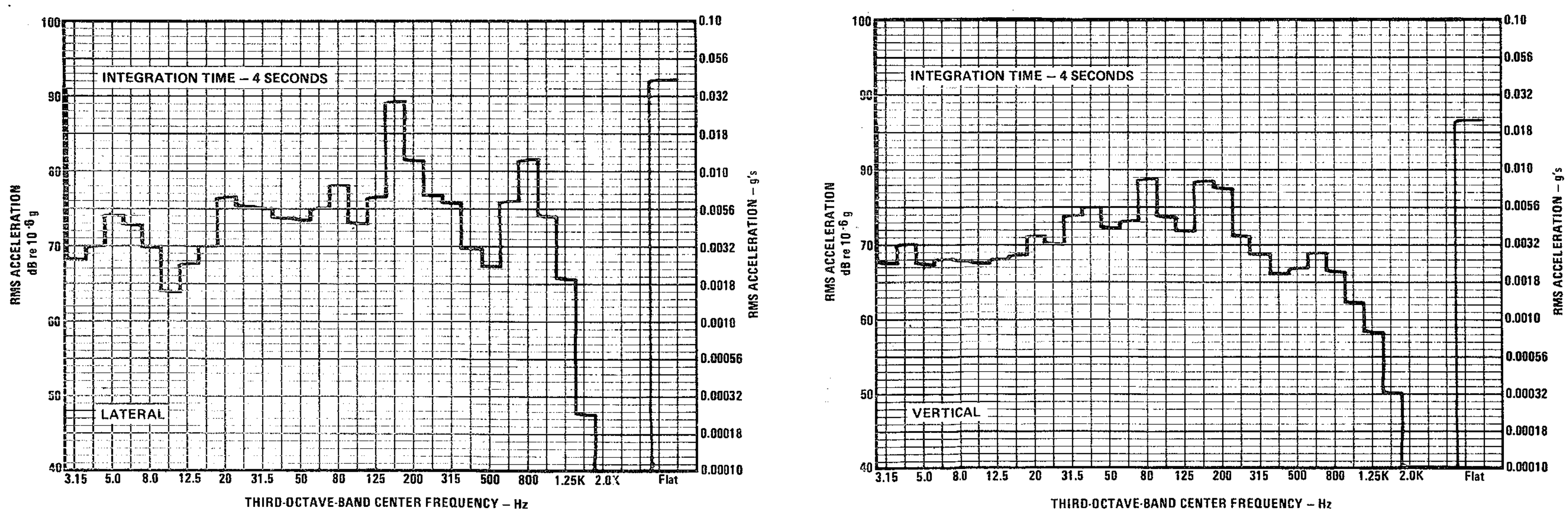

Figure D-2. Acceleration Levels – Straight Guideway Section –
Loaded Vehicle – 25 ft./sec.

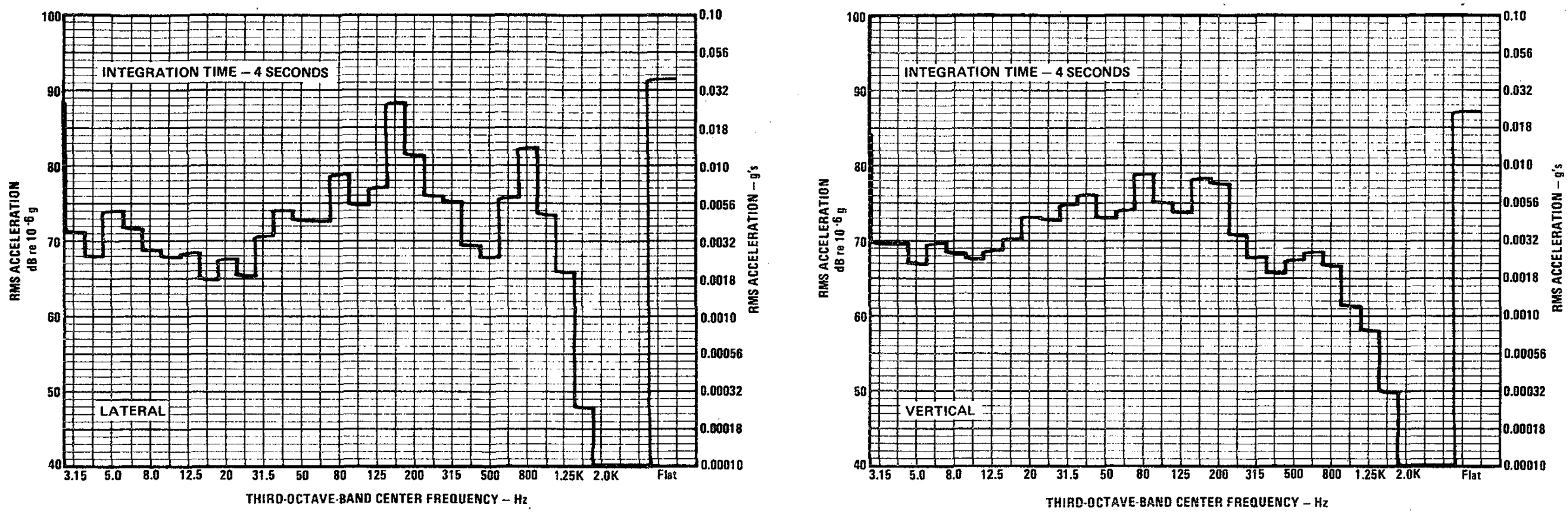

Figure D-3. Acceleration Levels – Straight Guideway Section – Loaded Vehicle – 25 ft./sec.

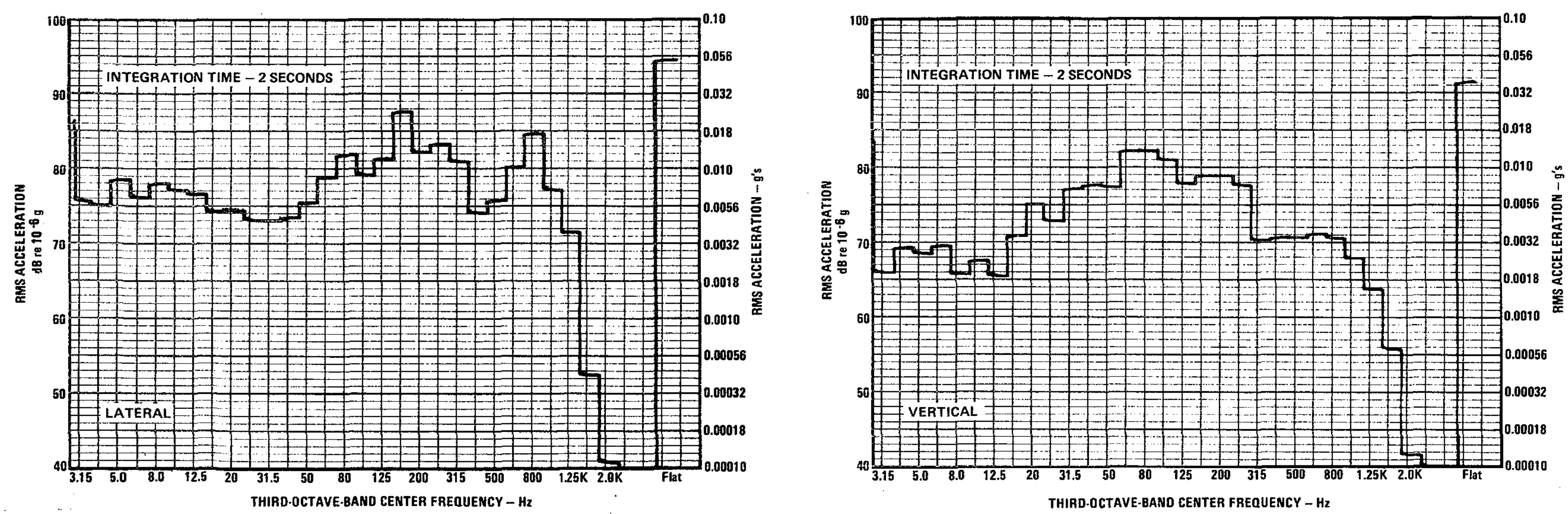

Figure D-4. Acceleration Levels – Straight Guideway Section – Loaded Vehicle – 30 ft./sec.

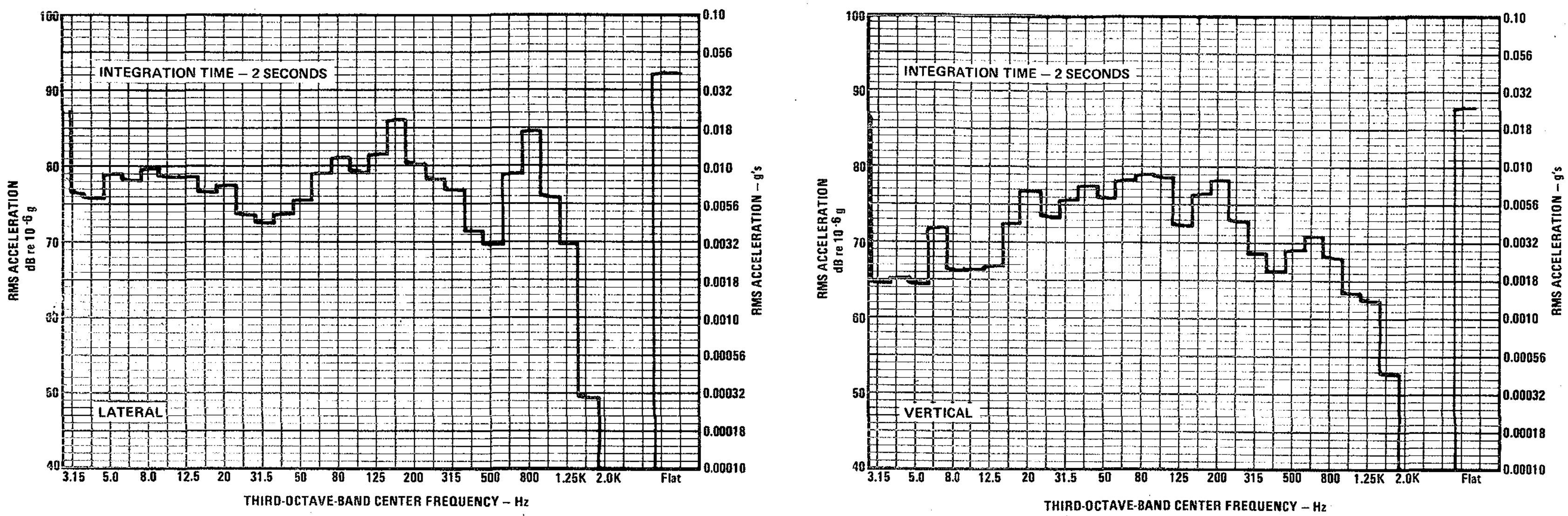

Figure D-5. Acceleration Levels – Straight Guideway Section –
Loaded Vehicle – 30 ft./sec.

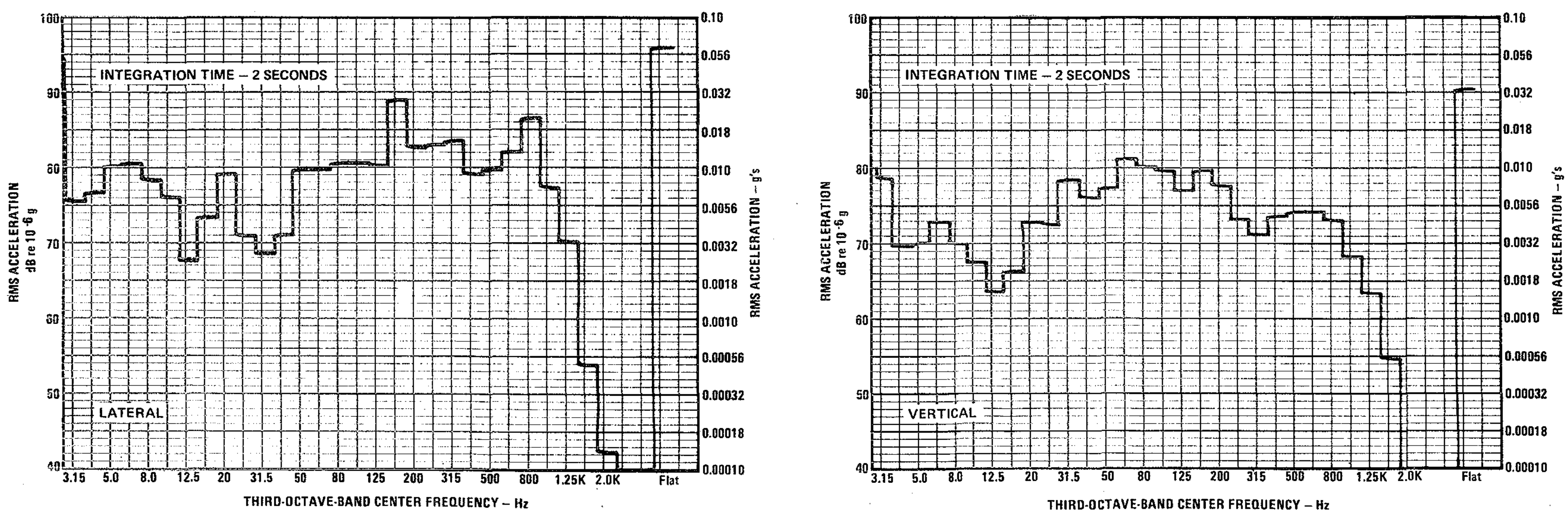

Figure D-6. Acceleration Levels – Straight Guideway Section –
Empty Vehicle – 35 ft./sec.

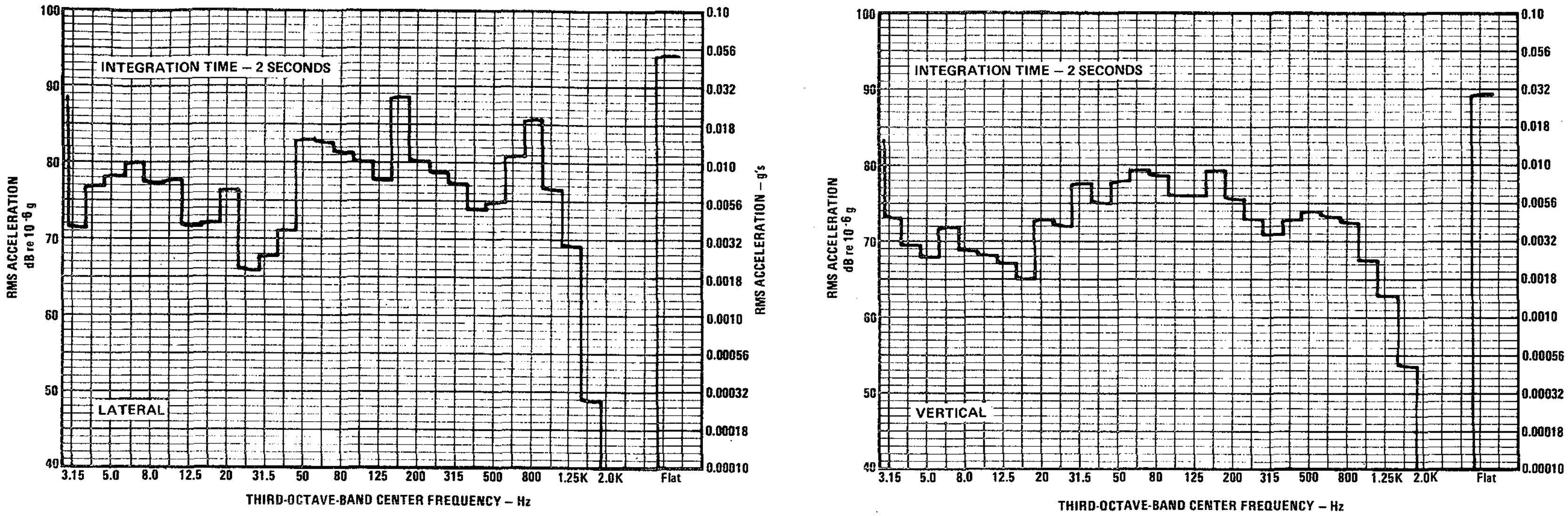

Figure D-7. Acceleration Levels – Straight Guideway Section – Empty Vehicle – 35 ft./sec.

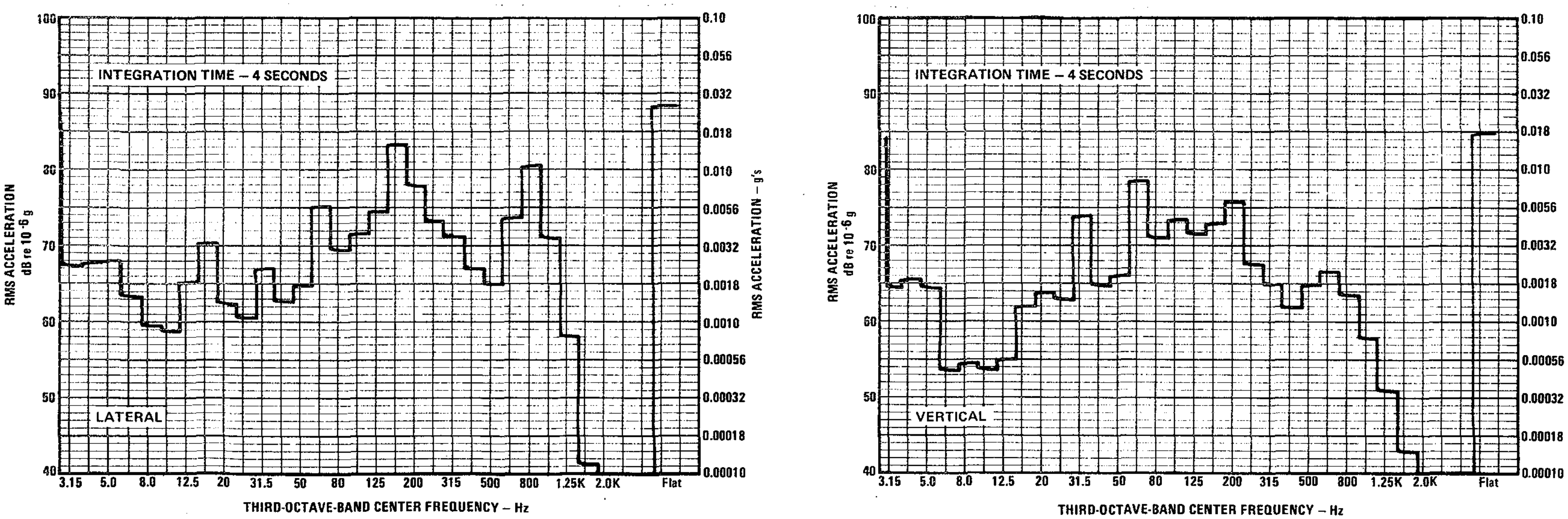

Figure D-8. Acceleration Levels – Spiral and Curve – Loaded Vehicle – 20 ft./sec.

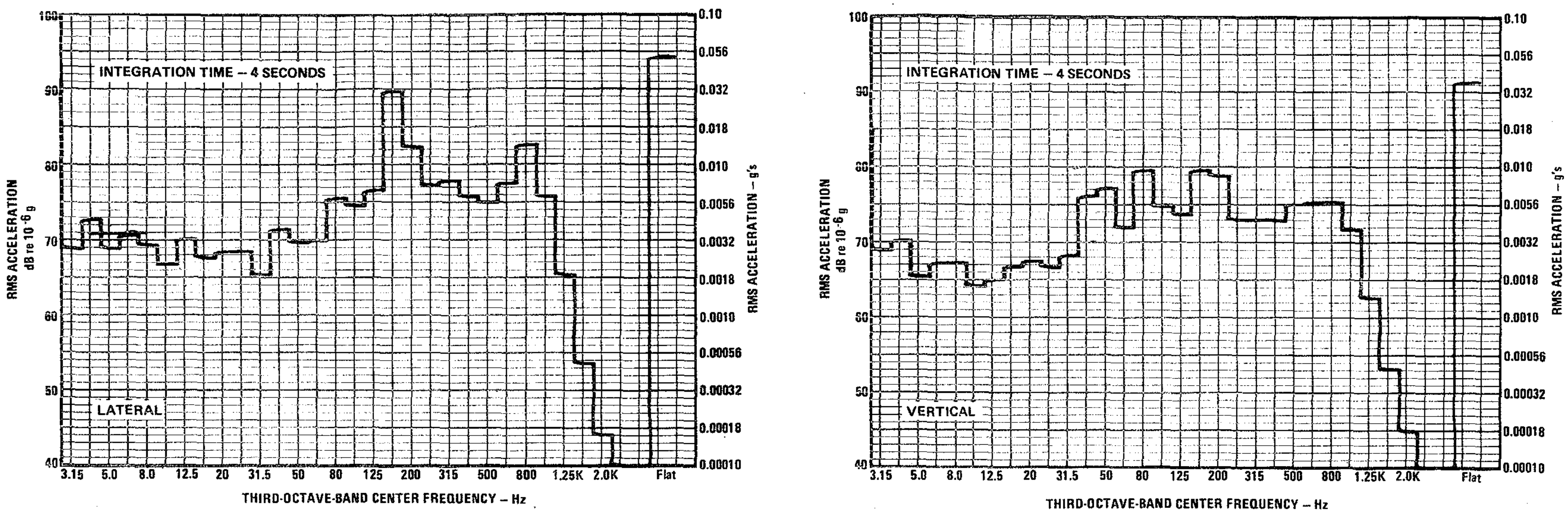

Figure D-9. Acceleration Levels – Spiral and Curve – Loaded Vehicle – 25 ft./sec.

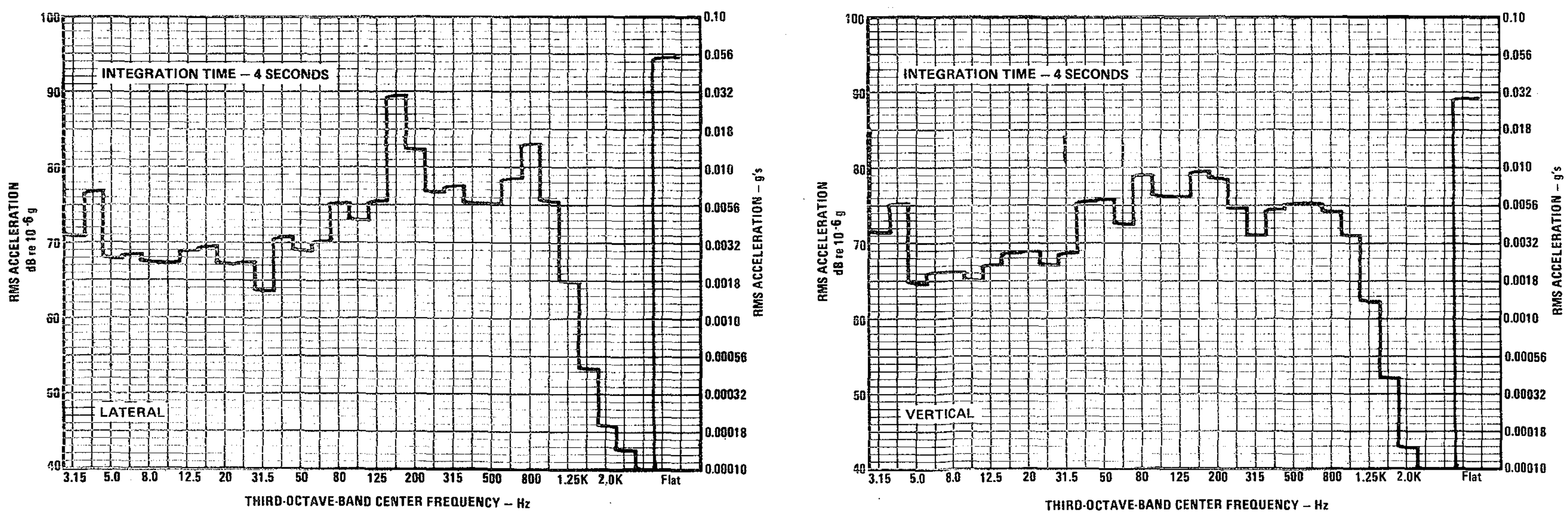

Figure D-10. Acceleration Levels – Spiral and Curve – Loaded Vehicle – 25 ft./sec.

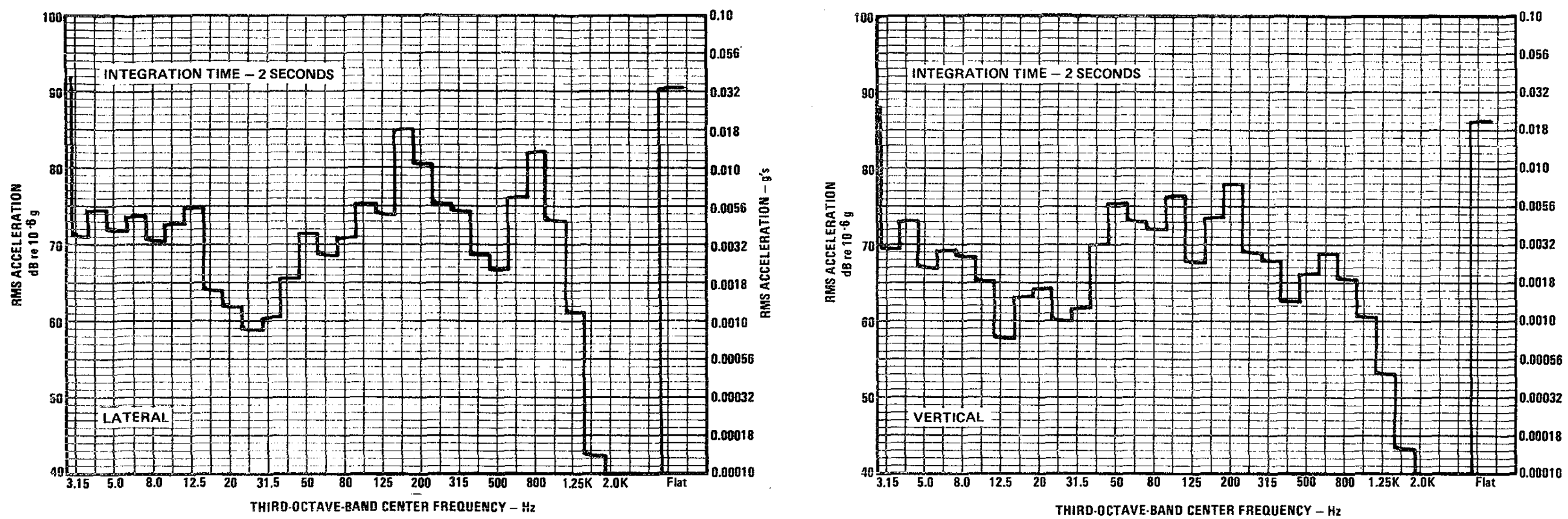

Figure D-11. Acceleration Levels – Spiral and Curve – Loaded Vehicle – 30 ft./sec.

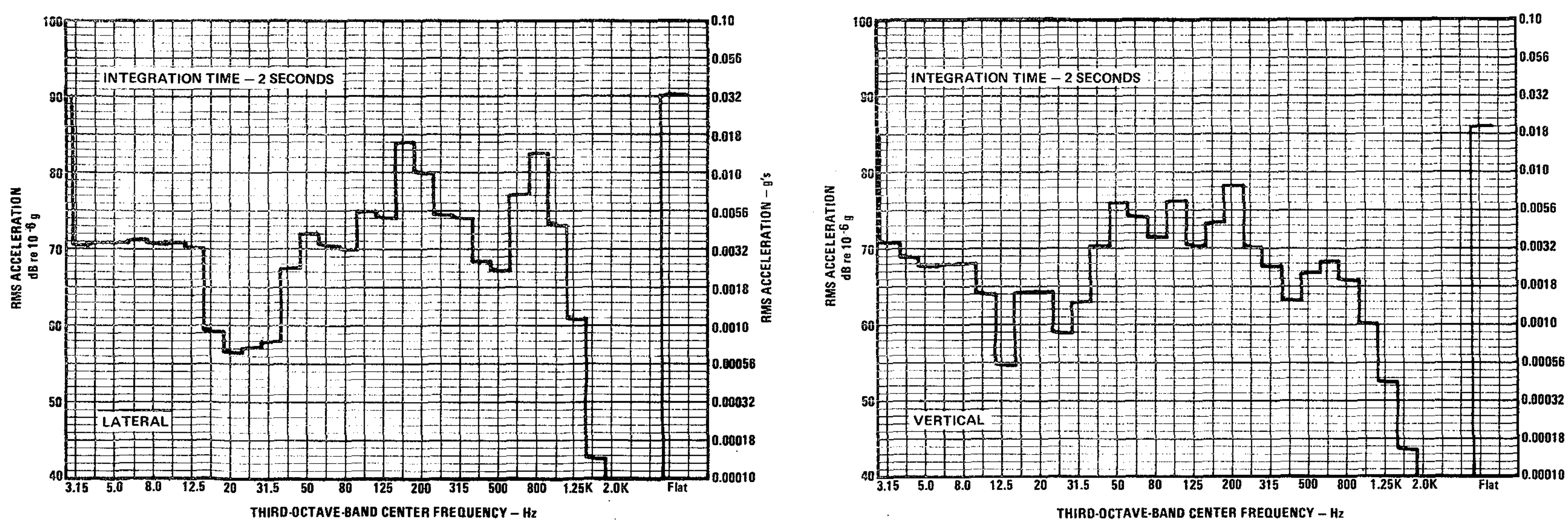

Figure D-12. Acceleration Levels – Spiral and Curve – Loaded Vehicle – 30 ft./sec.

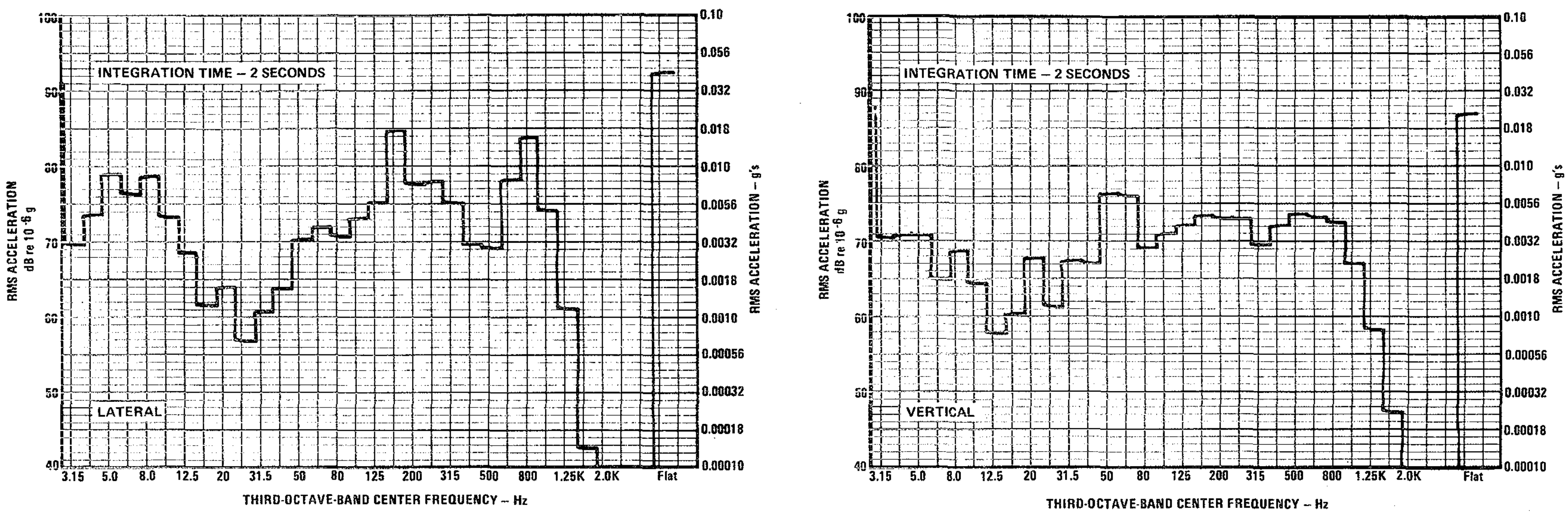

Figure D-13. Acceleration Levels – Spiral and Curve –
Empty Vehicle – 35 ft./sec.

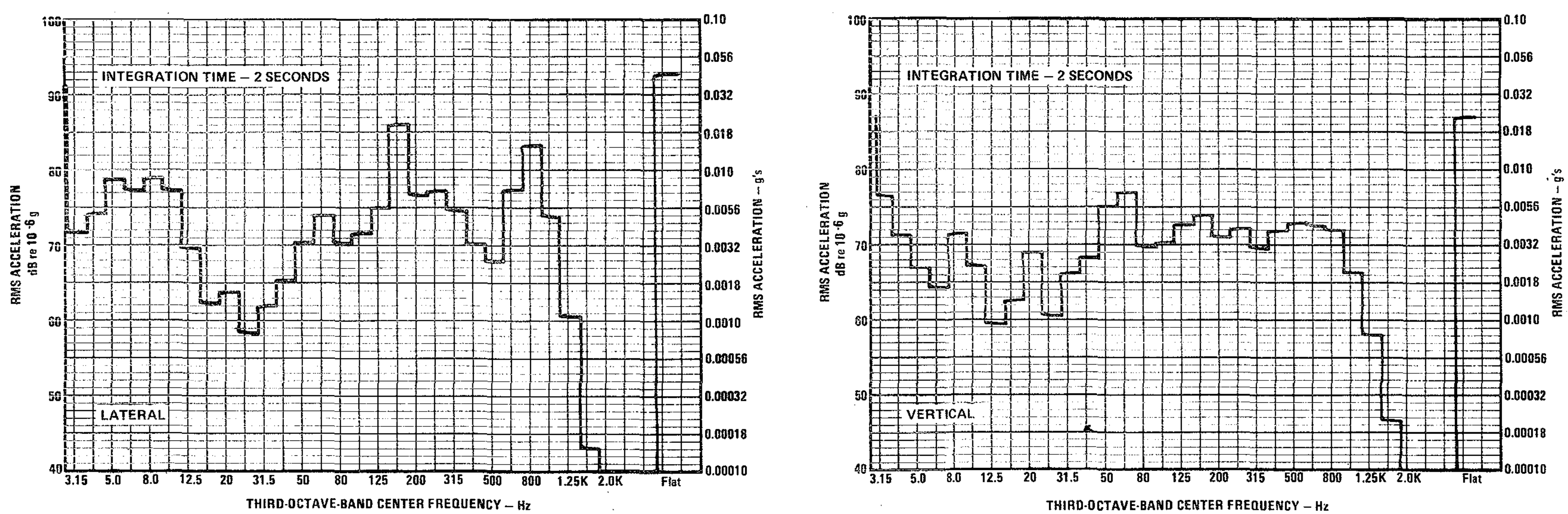

Figure D-14. Acceleration Levels – Spiral and Curve –
Empty Vehicle – 35 ft./sec.

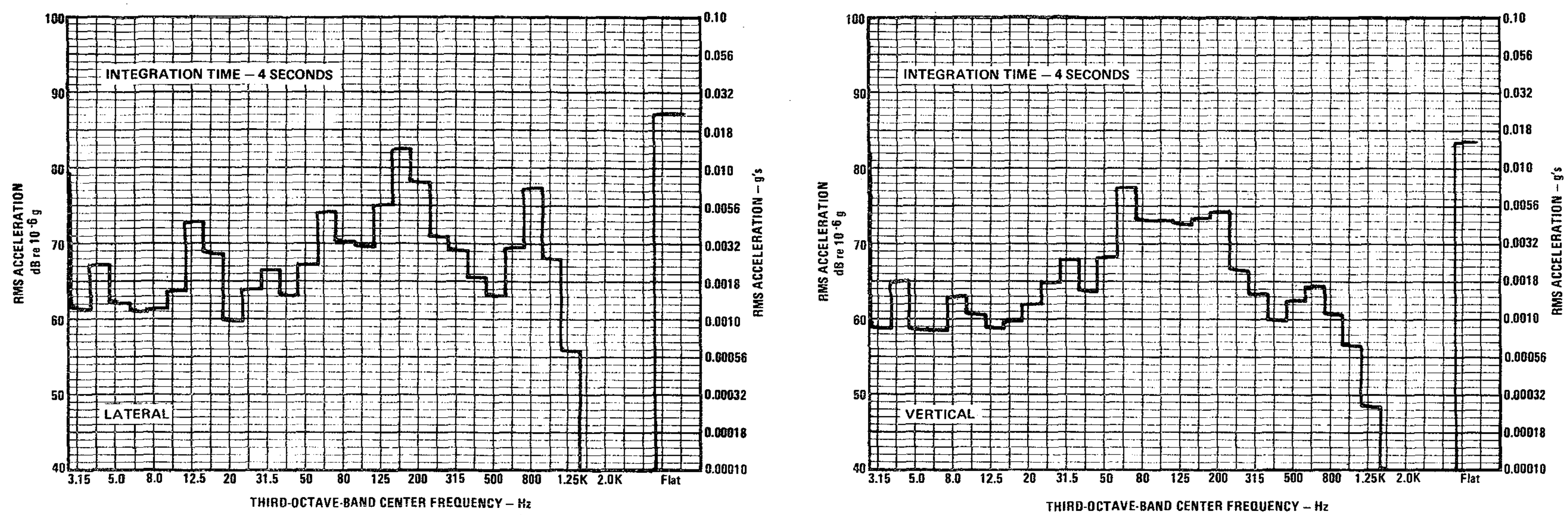

Figure D-15. Acceleration Levels – Switch Section – Loaded Vehicle – 20 ft./sec.

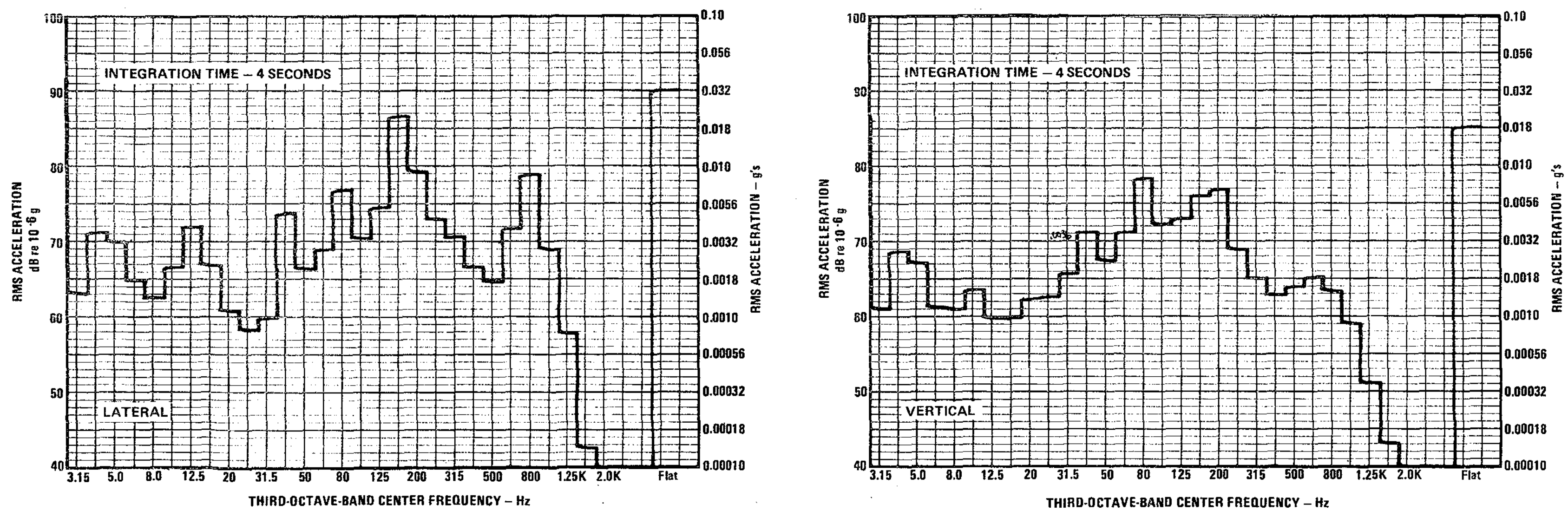

Figure D-16. Acceleration Levels – Switch Section – Loaded Vehicle – 25 ft./sec.

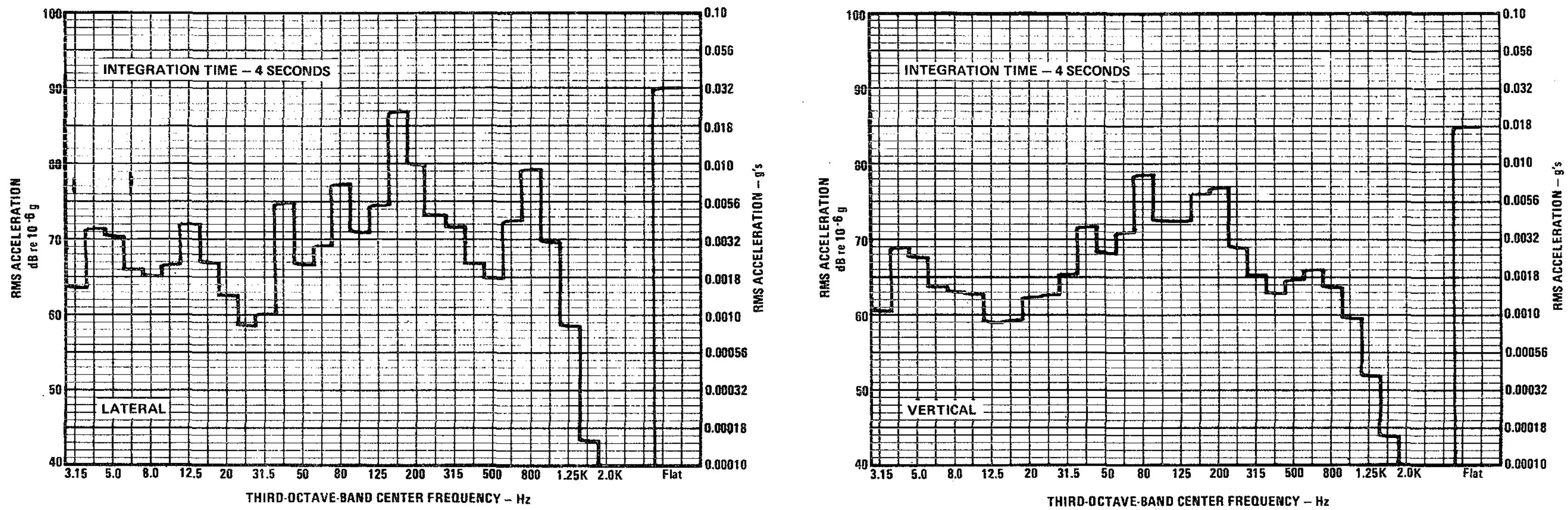

Figure D-17. Acceleration Levels – Switch Section – Loaded Vehicle – 25 ft./sec.

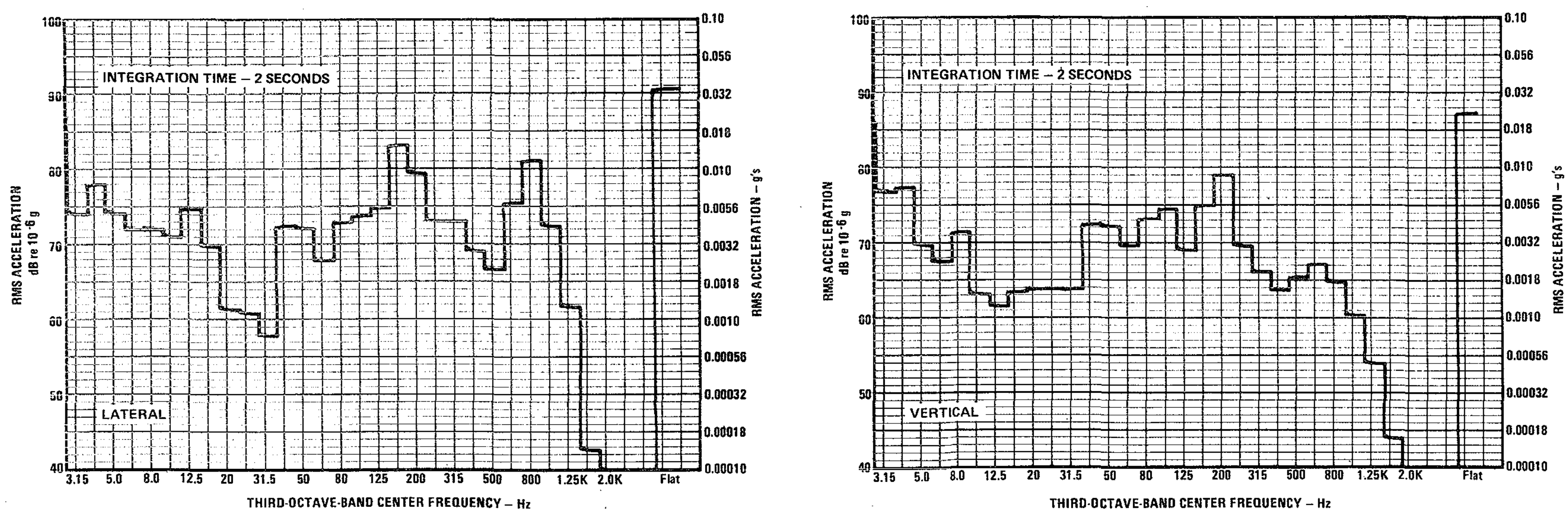

Figure D-18. Acceleration Levels – Switch Section – Loaded Vehicle – 30 ft./sec.

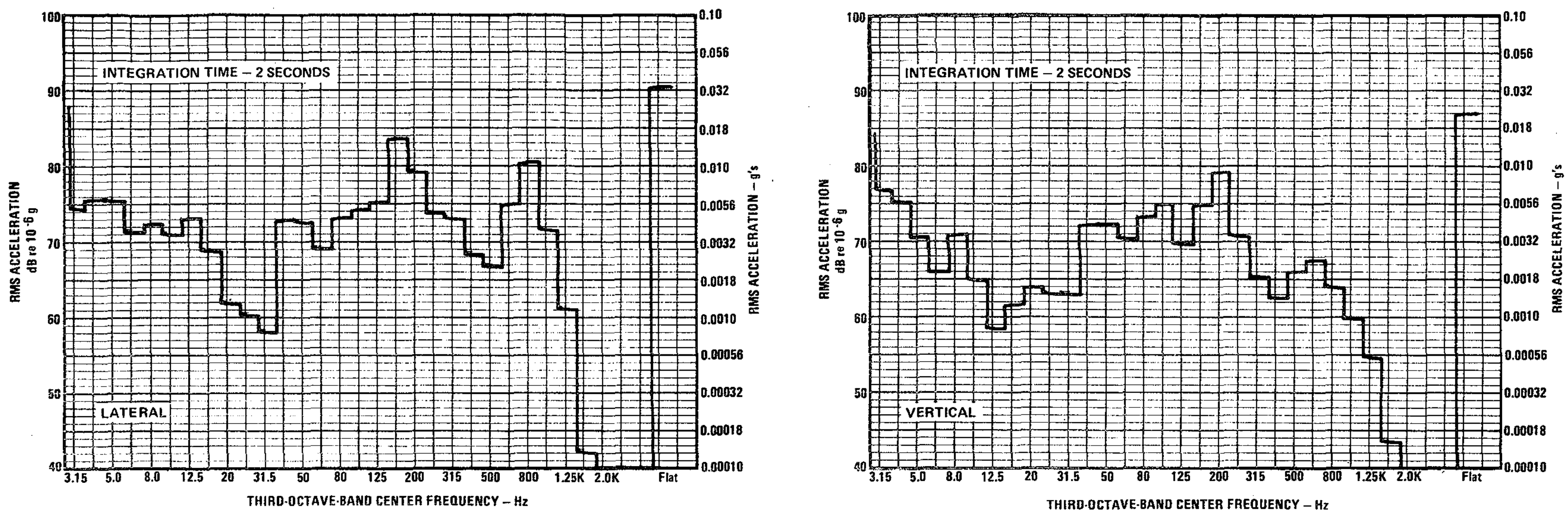

Figure D-19. Acceleration Levels – Switch Section –
Loaded Vehicle – 30 ft./sec.

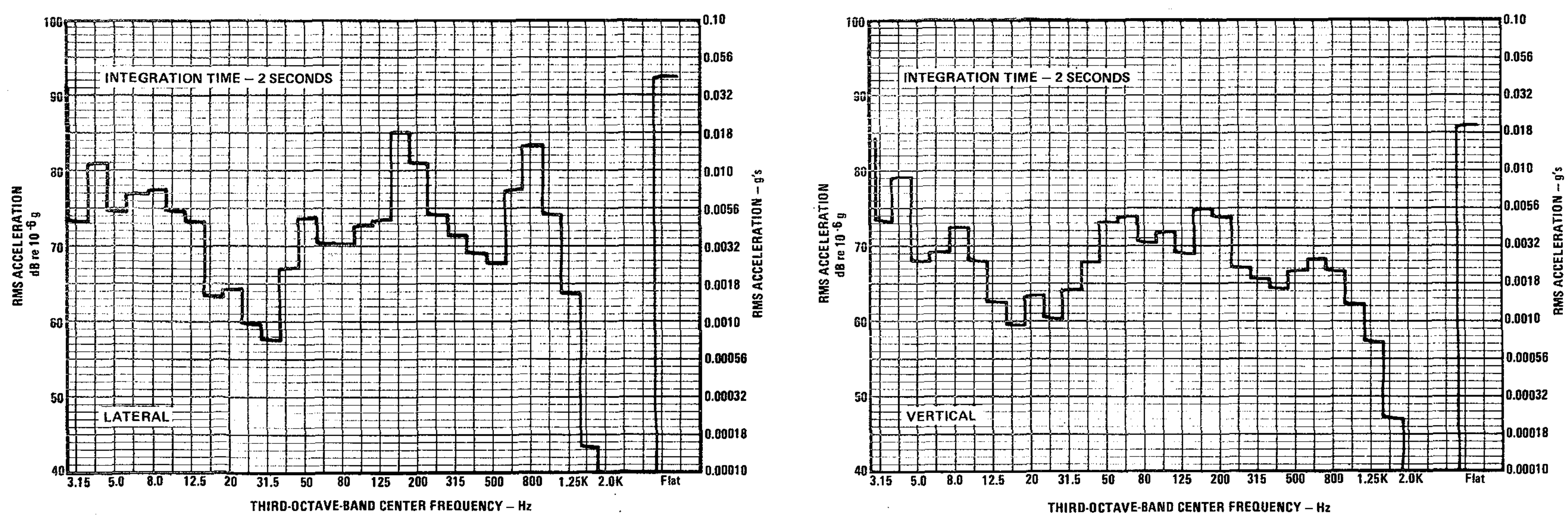

Figure D-20. Acceleration Levels – Switch Section –
Empty Vehicle – 35 ft./sec.

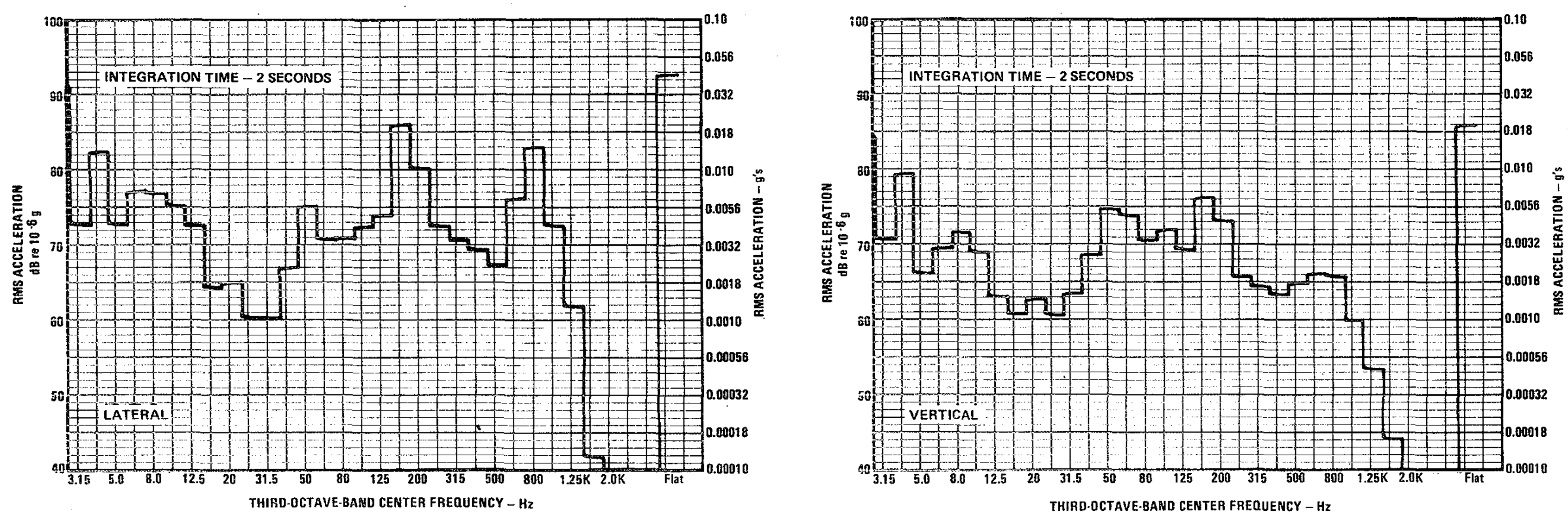

Figure D-21. Acceleration Levels – Switch Section –
Empty Vehicle – 35 ft./sec.