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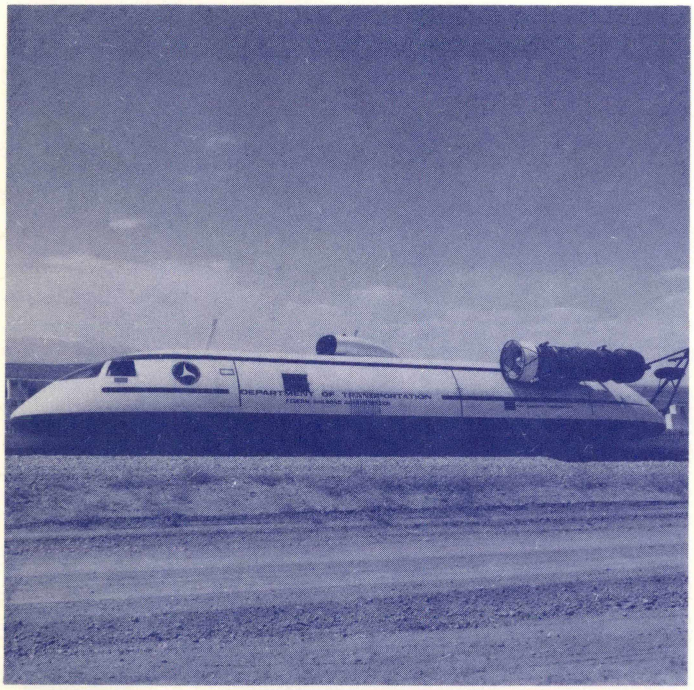
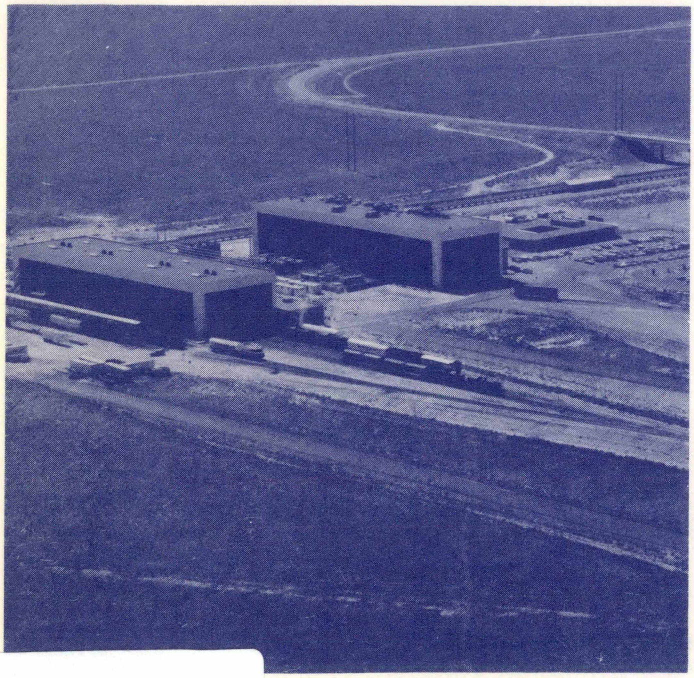
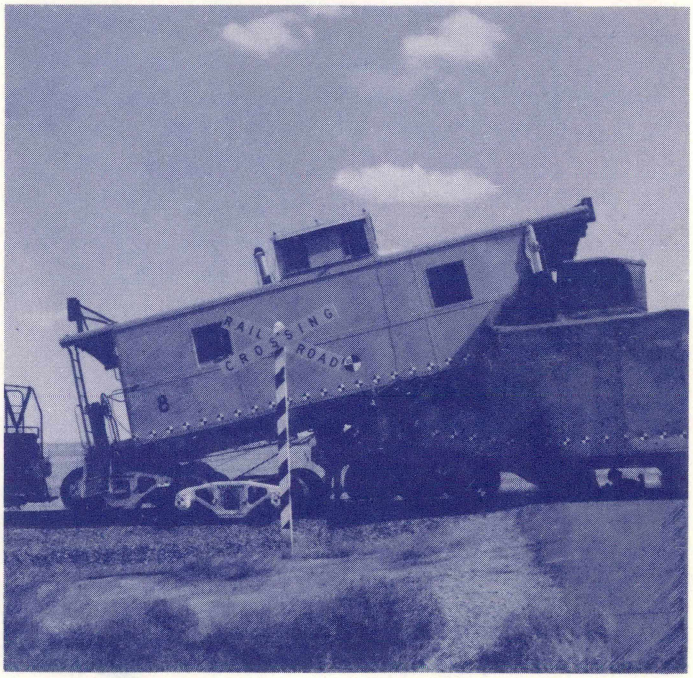
by
The Secretary of Transportation
to
THE PRESIDENT, THE SENATE AND
THE HOUSE OF REPRESENTATIVES

The Tenth and Final Report on

The High Speed Ground Transportation Act of 1965







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The Secretary of Transportation
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The Tenth and Final Report on

The High Speed Ground Transportation Act of 1965

Prepared by
Office of Research and Development
Federal Railroad Administration
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Washington, D.C.

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16. Abstract

This is the tenth and final report to the Congress on research, development, and demonstrations activities authorized by the HSGT Act of 1965. The activities are evaluated, accomplishments described, recommendations presented, and the history of the HSGT Program consolidated into one document.

More than 400 reports were produced on railroad and advanced systems since the Act was signed in 1965. Major accomplishments of the program include: (a) creation of continuing Federal R&D in railroad technology, (b) establishment of the Transportation Test Center, (c) demonstration that quality rail passenger service will be used in this country, (d) system performance and cost estimates for the Northeast Corridor multi-modal regional transportation study, (e) development of data processing of rail passenger statistics now used by Amtrak, (f) conception of Auto Train, (g) initiation of railroad track dynamics research (the first scientific investigation of track in over 30 years), (h) construction of the Rail Dynamics Laboratory, (i) development of automated track geometry inspection, (j) advancement of linear electric motor technology, (k) expansion of knowledge of magnetic levitation, (l) analysis of the dynamics of air cushion levitation, and (m) exploration of the ram air cushion.

DOT should continue to follow research on tracked levitated vehicles and other advanced technology as an option for high-density short-haul routes as future needs may develop for intercity passenger systems.

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Railroad Technology, Railroad Research, Advanced System Technology, High Speed Ground Transportation, International Cooperation, Transportation Test Center

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Preface

This is the tenth and final report in a series of reports to Congress, required under the High Speed Ground Transportation (HSGT) Act of 1965, Section 10(b) which states, "The Secretary shall report to the President and the Congress the results of his evaluation of the research and development program and the demonstration program authorized by this Act, and shall make recommendations to the President and the Congress with respect to such future action as may be appropriate in the light of these results and their relationship to other modes of transportation in attaining the objective of promoting a safe, adequate, economic, and efficient national transportation system." The purpose is to evaluate the activities carried out under the authority of that Act from Fiscal Year 1966 to the present. In addition to presenting the evaluation and making recommendations, this report also presents the history of the HSGT program consolidated into one document.

The primary reference sources used were the previous reports to Congress. (1-11)* More than 400 reports have been published during the course of the HSGT Program; these documents are available from the National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161. In addition, abstracts are available from the Railroad Research Information Service, % the Transportation Research Board, National Academy of Sciences, 2101 Constitution Avenue, N.W. Washington, D C. 20418.

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*References, see page 142.

Contents

Introduction

The High Speed Ground Transportation program evolved from the U.S. Department of Commerce's Northeast Corridor Transportation Project (NECTP). When the NECTP was established in 1964, its mission included cost-benefit comparisons of the various transportation modes that might be used to improve passenger transportation from Washington, D.C. to Boston, Massachusetts. One of the project's first findings was that technology existed for new systems of high-speed ground transportation,[12] but research and development (R&D) must be done to predict the performance and to estimate the cost of those systems. At that time, no authority existed for the Federal Government to conduct such R&D; therefore, the NECTP staff prepared a legislative request to authorize a ground transportation R&D program for the Secretary of Commerce. That request resulted in the passage of the High Speed Ground Transportation Act, Public Law 89-220, by the 89th Congress (see Appendix A). President Johnson signed the Act into law on September 30, 1965, and the first funds were appropriated on October 31, 1965.

Upon the signing of the HSGT Act, the Office of High Speed Ground Transportation (OHSGT) was established as part of the staff of the Under Secretary of Commerce for Transportation. Three basic activities were authorized by the Act:

1. Research and development of high speed ground transportation.
2. Demonstration projects to determine the contribution that high speed ground transportation could make to more efficient and economical intercity transportation systems.
3. A national program to improve the scope and availability of transportation statistics.

OHSGT (subsequently the Federal Railroad Administration), carried out the first two activities and the Office of the Secretary of Transportation, the third.

OHSGT designed the R&D program to advance the technology of high speed ground transportation. The objectives were to advance rail technology as rapidly as possible and to explore technologies that might be useful for new modes of intercity ground transportation.

Until the Federal Railroad Safety Act of 1970, the HSGT Act was the primary authority that FRA possessed to conduct R&D. Under the authority of the 1970 Safety Act, FRA initiated several safety R&D projects as a part of the rail technology program. The HSGT program continued to retain aspects of safety in many of its projects—most notably, the improved track development project which had as a major objective reduction of derailments and track related accidents.

The HSGT Act uses the term "ground transportation" without any limiting language, but the early work was passenger-oriented to support the Northeast Corridor

Transportation Project. Although the HSGT track R&D project was aimed at high speed passenger service, much of the work was general enough so that all track, whether designed for passenger, freight, or mixed service would benefit from the results. In addition to track, OHSGT undertook some freight R&D jointly with the rail industry on some of the critical freight problems, such as long train dynamics, using the HSGT authority in the absence of other specific legislative authority.

The first report to Congress on progress of tasks designated in the HSGT Act, dated September 1966, stated "The R&D program has been started with the emphasis on railroad technology. This emphasis will shift to the new technology projects when facilities, i.e., test cars, test track and instrumentation are all operational."

This final report documents the achievements and results of the HSGT program, the implementation of those results, and the transfer of HSGT technology to other modes of transportation.

One of OHSGT's first actions after passage of the HSGT Act was to request that the Commerce Technical Advisory Board (CTAB) provide advice on the content of a HSGT R&D program. CTAB organized a special panel and, after study of pertinent technology, recommended a number of projects[13]—most of which were incorporated into the OHSGT program.

When the Department of Transportation was established in 1967, the OHSGT became a part of the Federal Railroad Administration. In 1972 a reorganization of FRA incorporated the HSGT activities in a new FRA Office of Research, Development and Demonstrations as part of a broadened R&D program. In 1975, another reorganization placed the hardware R&D under the Office of Research and Development. At that time, the demonstrations begun under the HSGT Act had been completed, and only hardware projects remained.

The efforts to develop a new high-speed ground transportation system as an alternative to increasing the speed of existing rail passenger service were hampered by a series of developments:

- The need for large amounts of Government money to maintain rail service in the Northeast and Midwest—primarily to rehabilitate the road bed and physical plant—caused a major drain on funds available for transportation. Federal funding for rail rehabilitation, which was authorized by the Regional Rail Reorganization Act of 1973 and the Railroad Revitalization and Regulatory Reform Act of 1976, totaled $2.6 billion. The decision to maintain and improve a national network of rail passenger service also added to the drain on transportation funds. The Amtrak deficit and capital grant appropriations through Fiscal Year 1977 totaled more than $1.5 billion. With such large amounts being requested from Congress for the continuation and improvement of conventional rail service it became evident that off-setting reductions would have to be made in less critical programs such as the advanced high-speed ground transportation R&D.
- The growth of demand for transportation had slowed in recent years; forecasts made in the mid-1960s of the time to saturate the capacity of existing transport have been stretched out into the future. Advent of larger aircraft has reduced airport congestion—at least temporarily. Therefore, the pressures to relieve congestion, which seemed so urgent in the 1960s, diminished—at least for a decade.

With all of these factors at work, the decision to discontinue or significantly alter the

HSGT program seemed appropriate to Congress and the Department of Transportation. With the last HSGT funding in Fiscal Year 1975, the remaining HSGT activity was transferred to the Railroad Research and Development Program. While FRA has not requested R&D funding under the HSGT authority in recent years, certain advanced systems work has continued at a reduced scope. In those cases where the U.S. technology was ahead of foreign development and there is a near term potential application work is continuing. An example is the linear motor activity. Further, arrangements were made between FRA and the Assistant Secretary for Systems Development and Technology to assure a low level Tracked Levitated Vehicle activity by funding study activities under the Transportation Planning Research, and Development appropriation. Since there is no current or anticipated request for funding under the HSGT Act, this is the final HSGT report. FRA will use another form for future reports on the progress of Railroad R&D.

The organization changes—starting with the Office of High Speed Ground Transportation (OHSGT) moving from the Department of Commerce to the Department of Transportation and the Federal Railroad Administration (FRA), continuing through the absorption of OHSGT into the FRA Office of Research Development and Demonstrations (ORD&D), and ending with the change of ORD&D to the Office of Research and Development—have not been specifically noted in each chapter or section of this report. Name changes have been incorporated into the accounts of activities in the proper sequence without comment; such comments would be repeated many times in this report if included in the description of each program.

Abbreviations and Acronyms

AAR	—Association of American Railroads
ACV	—Air Cushion Vehicle
AEC	—Atomic Energy Commission —now split into the Nuclear Regulatory Commission and the Energy Research and Development Administration
Amtrak	—National Railroad Passenger Corp.
AT&T	—American Telephone and Telegraph Co.
COFC	—Container on Flat Car
CTAB	—Commerce Technical Advisory Board
DOT	—U.S. Department of Transportation
FAA	—Federal Aviation Administration of the U.S. DOT
FAST	—Facility for Accelerated Service Testing, located at the Transportation Test Center in Colorado
FHWA	—Federal Highway Administration of the U.S. DOT
FRA	—Federal Railroad Administration of the U.S. DOT
GASL	—General Applied Science Laboratories, Inc.
HSGT	—High Speed Ground Transportation
HSGTC	—High Speed Ground Test Center, renamed the Transportation Test Center, of the U.S. DOT
JPL	—Jet Propulsion Laboratory of the California Insititute of Technology
KOMET	—Unmanned magnetically levitated test vehicle of Krauss-Maffei and Messerschmitt-Boelkow-Blohm
LIM	—Linear Induction Motor
LIMRV	—Linear Induction Motor Research Vehicle
LRC	—Canadian passenger train prototype (light, rapid, comfortable)
Maglev	—Magnetic Levitation
NAS	—National Academy of Sciences
NECTP	—Northeast Corridor Transportation Project
NSF	—National Science Foundation
OHSGT	—Office of High Speed Ground Transportation
O&M	—Operations and Maintenance
ORE	—Office of Research and Experimentation of the International Union of Railways
PAD	—Pueblo Army Depot
PCU	—Power Conditioning Units—Linear Motor Control Unit
PINY	—Polytechnic Institute of New York
PRR	—Pennsylvania Railroad (merged into the Penn Central in 1968)
PTACV	—Prototype Tracked Air Cushion Vehicle (formerly Urban Tracked Air Cushion Vehicle)

R&D	Research and Development
RDL	Rail Dynamics Laboratory located at the Transportation Test Center
RPI	Railway Progress Institute (the association of railroad supply companies)
SLG	Synchronous Longitudinal Guidance—control system for multimodal or dual mode
SLRV	Standard Light Rail Vehicle—prototype transit vehicle
SOAC	State of the Art (Transit) Car
TACV	Tracked Air Cushion Vehicle
TACRV	Tracked Air Cushion Research Vehicle (renamed Tracked Levitated Research Vehicle)
THL	Tracked Hovercraft Ltd (a British government supported firm)
TLRV	Tracked Levitated Research Vehicle
TLV	Tracked Levitated Vehicle
TOFC	Trailer on Flat Car
TRANSIM	A computer simulation of the Penn Central New York—Washington operations—(Transportation Simulation)
TSC	Transportation Systems Center of the U.S. DOT, located in Cambridge, Mass.
TTC	Transportation Test Center of the U.S. DOT, located near Pueblo, Colorado
UTACV	Urban Tracked Air Cushion Vehicle (renamed Prototype Tracked Air Cushion Vehicle)
UMTA	Urban Mass Transportation Administration of the U.S. DOT
VPI	Virginia Polytechnic Institute & State University
VVPCU	Variable Voltage Power Conditioning Unit

Chapter 1

Accomplishments of the HSGT Program

Descriptions of the accomplishments reveal that much valuable work has already been done, but HSGT technology is not yet "on-the-shelf" and the work should be continued on a modest scale to complete development of improved technology. (See recommendations).

A recital of the more important achievements of the HSGT program from 1965 also serves to summarize this report.

Federal Rail R&D Program

Until the HSGT Act was passed in 1965, the Federal Government's role in railroad R&D was limited to occasional equipment development by the Department of Defense. The HSGT Act created the first continuing comprehensive Federal rail R&D program. The initial year's expenditure on rail R&D was a little more than $4 million; ten years later, in 1975, the rail R&D budget had grown to $60 million, reflecting recognition by Congress of some success in the ten-year R&D program and, at the same time, the expectation that technology can help to solve the serious financial programs facing the rail industry.

Transportation Test Center

The HSGT advanced system and component R&D programs provided the impetus for construction of the extensive ground transportation test facilities that exist today at the Transportation Test Center (TTC) near Pueblo, Colorado. Once construction of test facilities started, expenditures followed for equipment and facilities to support all testing (e.g., roads, buildings, fences, utility networks). In addition to test facilities, FRA has invested nearly $9 million from the HGST program budget for FY 1970 through 1975 for such support items, and spent another $9 million for operating costs such as fuel, guard services, fire protection, and maintenance. DOT has invested a total of $52 million from all appropriations and today the TTC plays a major role in railroad and transit improvement programs.

The Transportation Test Center provides ground transportation test facilities that should enable industry to produce technology at a rapid pace and help railroads and transit authorities to continue to improve the efficiency of their operations. As technology progresses, new kinds of test facilities may be needed and the future of the TTC should be one of continuing change.

Demonstrations of Improved Rail Passenger Service

Demonstration of an improved quality of rail passenger transportation by the Metroliners and Turbo Trains indicated that demand does exist for such service in heavily traveled corridors. This finding was a factor in the formation of Amtrak and is one of the considerations that influenced Congress to appropriate the current $1.75 billion program to improve the physical plant of the rail passenger system between Boston and Washington.

Amtrak has profited from the demonstration in other ways:

- Of all routes the Metroliners have provided the greatest source of revenue to Amtrak since the corporation began operations.
- The Metroliner car design was the only domestic car design available that could be used on all U.S. mainlines; if Amtrak had had to commission a new design for its Amfleet cars, the cost and delivery schedule would have been higher and longer, respectively—perhaps as much as 50 percent in each.
- FRA procedures for automated data processing of ridership statistics were expanded from the Northeast Corridor trains to the Amtrak national network of routes.
- The Corridor reservation system has been the basis for the Amtrak nationwide reservation system.
- A computer simulation of the Northeast Corridor rail system operations (TRANSIM), developed to aid scheduling the New York-Washington demonstration trains, has been and continues to be used to evaluate proposed improvements to the Corridor rail passenger service.
- The suburban station experiments proved that many travelers whose trips originate or terminate outside central business districts will use suburban stations and constitute additional patronage for Amtrak.

Northeast Corridor

FRA evaluated potential HSGT systems for possible deployment in the Northeast Corridor. From these studies, high-speed conventional rail and tracked air cushion vehicles (TACV) emerged as the two leading candidates. Further engineering defined the performance of the candidates and estimated the investment and operating costs; these results were used in the early Northeast Corridor Project cost-benefit analyses.

Rail Passenger Statistics

As a part of the Metroliner and Turbo Train demonstrations, machine-readable seat checks were used in the development of an automated data-processing system to produce ridership statistics by stations of origin and destination. These statistics have given Amtrak better information on which to plan service.

Auto-Train

Market studies by OHSGT showed a large demand for travel by passengers taking automobiles along on a train. Because the potential market was so promising, Congress would not fund a planned demonstration and the initiative was left to private industry. A new corporation has made a success of this concept for carrying passengers and their automobiles on the same train.

Grade-Crossings

Improvements in grade-crossings protection on the Metroliner and Turbo Train routes sparked an R&D program to improve protection hardware, such as gate motors and control circuitry, and a national program to improve grade-crossing safety.

Track-Geometry Inspection

The FRA Office of Safety has available for track inspection the beginnings of a fleet of automated track-geometry measurement cars that were developed as a project in the HSGT program. These automated cars contain on-board data-processing equipment that provides FRA inspectors and railroad maintenance-of-way engineers exception reports showing compliance with, or violation of, Federal track safety standards. These reports are available at the end of a measurement run without delay for processing. Railroad managements now use such cars for planning track maintenance. The use of automated track-geometry measurement cars to augment field inspectors makes possible an expanded and more reliable FRA safety inspection program and reduces the probability of track failures and train derailments.

Dynamics of Track

In 1968 FRA began measurement of wheel loads imposed on track and the development of a mathematical model of the distribution of wheel loads through the track structure and into the supporting soil. This activity comprised the first such systematic theoretical and experimental investigation since the work done by Talbott for the American Railroad Association in the 1920s and 1930s. The work has expanded into a family of mathematical models which will be used by the AAR and its member railroads.

Linear Electric Motors

The HSGT program, in cooperation with researchers in half a dozen countries, has advanced the technology of linear electric motors from laboratory curiosities to full-scale motor designs available for propulsion applications. The power conditioning (or control circuitry) for linear induction motors (LIM) is ready for both LIM and other applications such as three-phase AC locomotives being considered in Europe. High-speed three-phase power collection techniques demonstrated for FRA are available for future systems with speeds higher than catenary (overhead) power collection can accommodate.

Rail Dynamics Laboratory

The vertical shaker and roller rig in the Rail Dynamics Laboratory (RDL) will provide a capability for controlled tests not possible on the Transportation Test Center tracks or in over-the-road tests on operating railroads. With completion of the RDL, carriers and suppliers will soon have a complete spectrum of facilities to evaluate new designs and investigate dynamics problems.

Ground Transportation Technology

OHSGT and FRA contracts for HSGT and railroad R&D projects have created new centers of expertise in ground transportation at several universities and research institutions. These organizations have expanded or transferred their capabilities into urban transportation and railroad technology programs.

Magnetic Levitation (MAGLEV)

FRA developed international Maglev technical information exchange programs with West Germany, Japan, and Canada. The information gained enabled the FRA to proceed with Maglev development at a much lower cost than would have been possible if all the research had been done by FRA alone. The Office of the Assistant Secretary of Transportation for Systems Development and Technology continues to fund joint programs, using Canadian and German test facilities. In addition, FRA recently engaged in a joint US-USSR magnetic levitation information exchange as follow-up to a commitment by President Nixon and Secretary Brezhnev in their 1974 agreement.

Air Cushion Analysis

Analytical and experimental research at the Massachusetts Institute of Technology resulted in the development of a theory of air cushion performance that was verified by the Tracked Levitated Research Vehicle (TLRV) air cushion tests. The concept is now available for design of any future vehicles.

RAM Air Cushion

The tracked air cushion vehicle (TACV) research done for FRA found that the idea of using the forward speed of a vehicle to pressure air (ram air) for supply to the cushions could significantly reduce the power required for levitation. A TACV system using less energy may be possible utilizing this principle.

Chapter 2

Recommendations

Although the capacity of all modes of passenger travel is not fully utilized today, even in the most heavily traveled corridors, the demand for travel will eventually exceed the capacity of the present systems. Projections by the Office of the Secretary of Transportation indicate that Northeast Corridor transportation modes will be saturated by Year 2010. Whether saturation of the rail network occurs then or earlier because of shifts from other modes brought about by petroleum shortages, transportation planners eventually will have to consider alternative means for expanding the transportation system's capacity to move passengers. The HSGT technology should be available as an option so that consideration of alternatives for increasing the capacity of our passenger transportation systems is not limited to expansion of existing systems. The Department should continue a program of careful, systematic review of progress on improved technologies which could be the basis for final evaluation of future hardware for improved systems. The R&D programs should among other accomplishments enable DOT by 1995 to:

- Do a detailed comparison of a preferred advanced high-speed ground transportation system and improved rail.
- Specify the design, construction, and implementation of a advanced high-speed ground transportation system, if the comparison is favorable.

In the High Speed Ground Transportation Alternatives Study of January 1973, by the Assistant Secretary for Policy and International Affairs,[17] it was concluded:

"TLV is an additional option for our future national transportation system which could provide a safe, comfortable ride at aircraft speeds. TLV is a potential substitute for high-density, short-haul air in the event of either energy or congestion contingencies. The results of the current R&D program are needed to aid in future multi-billion dollar implementation decisions."

Research programs on Maglev and linear motor programs are making good progress in Canada, Germany, and Japan. If the United States continues to have enough information for a fair exchange, progress in this country could be made for a relatively small investment. The exchange programs constitute an extraordinary opportunity for cost-effective research. The German Ministry of Research and Technology has already spent large sums of money on their programs. Likewise, the Japanese National Railways is making considerable investments in this area of research. The Canadian Transportation Development Agency's research budget is much smaller and is largely spent with universities, but the quality of the research is unusually high.

Two U.S. programs which will continue to support both the international information exchanges and the development of future new systems are the linear motor program, funded by FRA, and the small maglev effort, underway in the Office of the Assistant Secretary of Transportation for Systems Development and Technology.

Specific projects that could be carried out on a modest scale under these programs are:

- Experimental work to compare the candidate techniques of levitation—e.g., attraction maglev, repulsion maglev, and ram air cushion—for reliability, ride quality, power consumption, costs, etc.
- Linear electric motor studies to determine the performance of single-sided motors and linear synchronous motors to compare with currently available evaluations of double-sided motors and linear induction motors.
- Linear electric motor control development—power conditioning units—to reduce the size, weight and cost of such equipment.
- Longer life power collection system brush materials.
- Reduction of guideway construction and maintenance costs; including surface, elevated and underground guideways.

Finally, all ground transportation, whether intercity or urban, rail, rubber tired, or levitated can benefit from good engineering cost-effectiveness studies of improved guideway designs and construction techniques.

The Railroad R&D projects carried on under the HSGT Act are now funded from the Railroad Research and Development appropriation and are making good progress. The interest of the railroad industry is evidenced by the large number of joint projects such as Track Train Dynamics, Tank Car Safety and FAST. Another aspect which should be pursued is a continuing examination of possible application to railroads of technology developed in the HSGT program. Some possibilities are single-sided linear electric motors for classification yard retarders, improved pantograph contact shoe materials, and improved train controls.

Chapter 3

Railroad Technology

OHSGT planned its rail technology program on three parallel approaches: analytical studies, laboratory tests, and field tests—each complementing the others to produce maximum results. The test cars, Test Center tracks, and the Rail Dynamics Laboratory are all parts of the program.

Test Cars

Although prototype cars were not included in planning for the Washington-New York rail passenger demonstration, Government engineers recognized from the start that an opportunity to run high speed tests of self-propelled rail passenger cars before completion of the Metroliner production would be useful as a check on the Metroliner design. Also, OHSGT could undertake a variety of railroad R&D activities with such test cars. In December 1965, OHSGT placed an order with the Budd Company to manufacture four cars from existing designs for Philadelphia commuter multi-unit cars to serve as test cars. (See Figure 1).

The test cars were an electric self-propelled type without the passenger interiors and with the addition of high-speed gear boxes for the traction motors. The contract called for Budd to demonstrate 150 mph (241 km/h) capability. Early runs revealed higher aerodynamic drag than calculated, so head-end and rear plastic fairings were installed and a speed of 157 mph (253 km/h) was achieved. Observers and instruments alike found the ride quality at 150 mph (241 km/h) on the OHSGT/Pennsylvania Railroad 21-mile (33.8 km) test track in New Jersey to be excellent. OHSGT accepted the cars in April 1967.

High-Speed Tests—1967. During high-speed runs in New Jersey, pieces of ballast were sucked up from the roadbed as the train passed, damaging the electrical equipment suspended from the floor of the test cars. This led to improved protection for the underfloor equipment on Metroliners: The equipment housing was increased in thickness and all electrical connections were enclosed in them.

High speed runs of the test cars also investigated catenary/pantograph motions for the purpose of reducing the number of interruptions to the overhead transfer of power. These tests revealed that the standard procedure of running multiple-unit (MU) trains with each car's pantograph raised and contacting the catenary conductor wire was unsatisfactory. Each following pantograph amplified the oscillation of the catenary caused by the leading pantograph. Frequently the trailing pantograph contact shoe separated from the conductor wire. Further testing showed that, with one pantograph up for each pair of cars, oscillations decreased and performance improved markedly. Consequently, the PRR installed jumper cables on the Metroliner roofs, electrically linking the two pantographs for each pair of cars. Thus, Metroliner trains now operate with one pantograph per pair of cars raised against the cantenary.

In other tests, different contact shoe materials were evaluated to determine those with the best wear resistance. A sintered metal filled with graphite was found superior to the plain iron shoes that the Pennsylvania Railroad was then using. Tests were also made with small aerodynamic fins fastened to a pantograph which were designed to take advantage of the flow of air produced by the train's movement to keep the pantograph in contact with the catenary more consistently than the normal spring action could do alone. Such aerodynamic fins could prove worthwhile on future high speed trains. Railroad engineers fears of damage from aerodynamic buffeting as Metroliners passed each other were allayed when tests with passing speeds of up to 238 mph (383 km/h) showed no serious buffeting forces.

Upon completion of the high-speed program, OHSGT made one test car available to Bell Telephone Laboratories to develop the on-board telephone system for the Metroliners. The equipment developed included antennas and other vehicle-borne equipment, which Bell Labs tested for performance in conjunction with wayside transceivers. Bell even checked operation of the telephone coin boxes to make sure that the motion of a train would not cause malfunctions.

Soon after OHSGT accepted the test cars, they were offered to private firms as test platforms for prototype devices. Although discussions were held with several companies, the only "device" installed in the cars was a set of tinted window glass in one car by the PPG Company.

AMF Research adapted a submarine surveillance system, to continuously monitor the condition of trucks, wheel bearings, traction motors, and brakes for the test cars. The General Electric Co. successfully used a

Figure 1. FRA Test Cars, Before Removal of Electric Propulsion.

similar device on the Metroliner electric propulsion system. Today, Amtrak is installing such surveillance devices on all its Amfleet equipment. The system includes a display which enables the operator to take corrective action, slowing or stopping the vehicle if necessary.

Development of Track-Geometry Measurements. With preparation for the Metroliner operation out of the way, the major use of the test cars became—and has continued to be for the last eight years—development of improved track-geometry measuring equipment with its associated data recording and analyses.

OHSGT developed the track-geometry measuring system to advance the state-of-the-art in track inspection and, specifically, to evaluate the track to be used for the Washington-New York and Boston-New York demonstrations. This was particularly important on the Boston-New York Corridor, where maintenance-of-way had long been neglected by the former owner, the bankrupt New Haven Railroad.

Most track measuring cars existing in 1965 used mechanical sensors that slid along the rail and limited the speed of the measuring cars to such an extent that their movement along the track interfered with revenue service. They also tended to ride on rough edges of worn rail (flash) rather than the side of the railhead. The data were recorded on paper charts by a mechanical pen and analyses were done manually. Recognizing the advantages of being able to measure track at higher speeds up to 150 mph (241 km/h), not only to lessen interference with traffic, but also to expand coverage of a measuring car,OHSGT, engineers prepared a specification to procure a higher-speed measuring system, including electronic data processing in recognition that higher speeds would produce larger quantities of data. In response Melpar, Inc. developed track measuring instrumentation using proximity sensors.

The track-geometry measuring instrumentation installed in the test cars measures, records, and displays the various parameters of track geometry. These parameters include right and left rail alignment, right and left rail profile, track gage, and crosslevel. In addition, the car is automatically located so that the position of each measurement is known. Signals from the sensors are transmitted to an on-board computer that digitizes signals once every 2.4 ft. (.7 m) of track.

Starting in October 1968, FRA measured the geometry on the upgraded Northeast Corridor tracks for the Metroliner and Turbo Train demonstrations several times each year to detect any deterioration that required maintenance. Demonstration measurements to acquaint railroad officials with the capabilities of the track measuring system have been made for various railroads, starting with the Santa Fe in March 1971.

FRA, the Bessemer and Lake Erie, and the Denver and Rio Grande Western Railroads have, since 1971, cooperated in a study of the application of track-geometry data to maintenance-of-way planning. The objectives of the program are to:

- improve information for long-range maintenance planning,
- determine costs to maintain track to given standards,
- establish quality control of track maintenance, and
- develop data displays for different management levels.

In support of these objectives, track-geometry measuring runs have been made annually on the D&RGW and semi-annually on the B&LE. The railroads have used the data to plan track repairs and long-range maintenance activities. D&RGW and B&LE personnel have provided recommendations for the modification of data processing programs, generation of user-oriented output formats, and establishment of track quality indices.

During the early stages of track measuring development, the strip chart recording was a major analysis tool. Although defects were easy to observe, a measurement run produced roll after roll of paper and analysis was time consuming. Computerized exception reports were then designed to reduce analysis time. These reports recognize good track and print out exceptions by location in digital format. Defects can now be sorted out by severity to give the first line supervisor the information he needs to locate and correct defects. This information can then be summarized for each section of track to be used by middle management for planning maintenance programs. Track quality indices developed for quarter-mile sections of track can be sorted by a computer program to show where maintenance-of-way work should first be done. Examples of these reports are shown in Figure 2.

Once the exception reports were operational, the next step was to provide real-time exception print outs. It became possible to furnish a list of defects by magnitude and location at the end of a track measuring run. On several occasions, a track supervisor, working from the real-time report, was able to correct critical defects before the off-line processing runs could give him a formal listing. A curve-measuring procedure and a curvature analysis report have also been developed. The computer print out describes the curve—i.e., it identifies the point

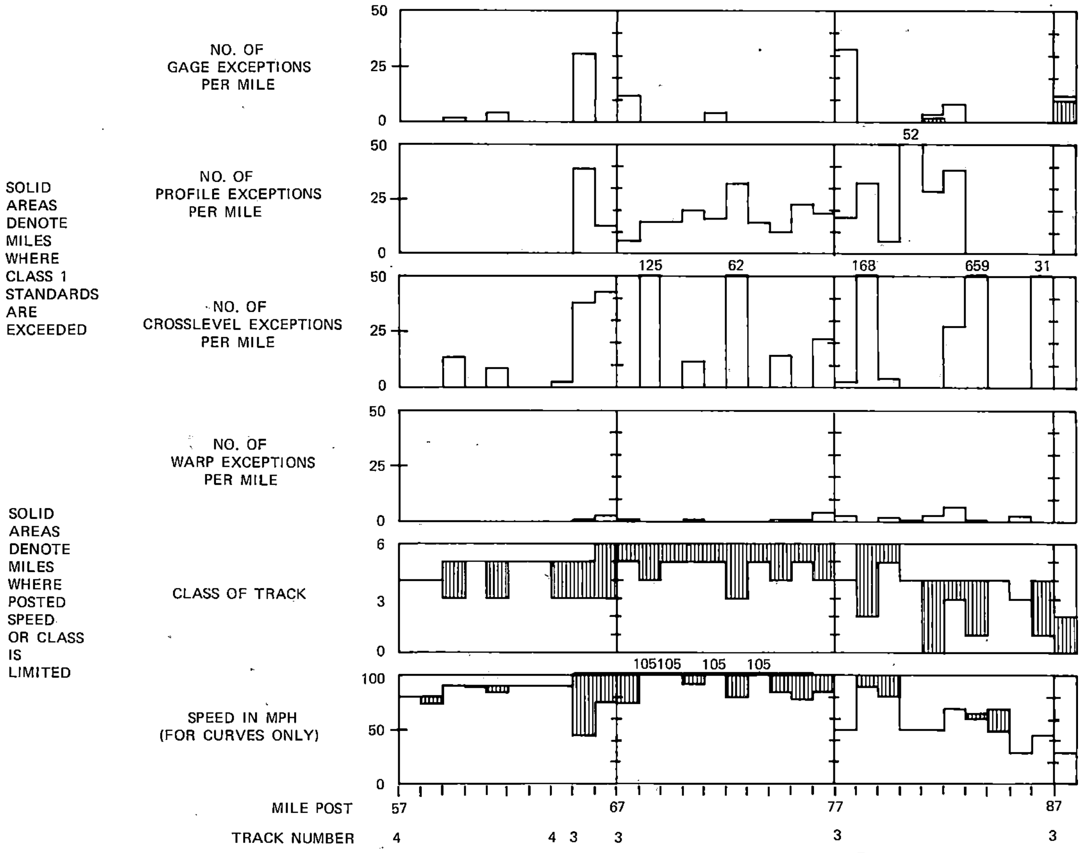

Figure 2. Sample of Track Geometry Exception Computer Printout

of tangent to the spiral, length of spiral, length of curve, average degree of curvature, average super-elevation, and allowable speed.

The proximity sensors installed in the original measuring system have a major drawback in their inability to measure when moisture is present. When rain or snow saturates the air gap, no useful reading can be obtained. ENSCO, Inc. developed an inertial type of profile measurement adapted from a concept by the Electromotive Division of General Motors. This measurement system avoids the moisture problem and has the added advantage of not having a sensor located close to the rail to strike grade-crossings, guard rails, etc. and be damaged.

Test Support. While the track measuring system was in development, the test cars supported numerous field tests:

- Investigation of the rolling of a Southern Railway large hopper car.
- Verification of a track simulation model for Battelle Memorial Institute.
- Measurement of car accelerations for input to The MITRE Corporation car simulation.
- Measurement of freight car vibration for the C&O/B&O Railroad.
- Measurement of ride quality of automobiles in a rail car.
- Measurement of wheel forces in lateral/vertical force ratio tests and the lateral stability tests in support of the government/industry Track Train Dynamics (TTD) Program.
- Survey of the catenary profile on the New Haven Division of the Penn Central. The geometry, the motion, the electrical current and voltage were recorded along with a videotape of the catenary/pantograph.
- Evaluation of a ballast consolidator on five railroads.

All these tests used the data acquisition capabilities of the test cars. Accelerometers, strain gauges, or displacement transducers were attached to cars, wheel sets, etc. and from them wire leads run to data recording equipment in the test cars.

The cars also made special measurements on experimental tracks:

- Checks of the UMTA transit test track at the Transportation Test Center have been made on several occasions.
- Measurements were made of the Kansas Test Track as part of the evaluation of the experimental track sections.
- Prospective test sites on Southern Pacific's lines were measured for the Freight Car Truck Design Optimization Project, and the selected sites were remeasured during the test program to determine the inputs of good and bad track in evaluating truck performance.

Track Inspection. By 1974, track-geometry measuring capability had been perfected to the extent that the test cars could be used in support of the track inspection responsibilities of the FRA Office of Safety. In August of that year, because of an excessive number of derailments, the FRA Administrator ordered that the test cars be used to measure the geometry of the Penn Central's tracks between Chicago and Louisville. After analysis of the data, FRA inspectors found the condition of the tracks did not even meet the FRA standard for the lowest quality of track that permits speeds of no more than 10 mph (16 km/h). The Administrator ordered the line shut down until the condition of the tracks was improved.

This experience demonstrated the value of automated track inspection and FRA developed plans for an automated track inspection program using the capability developed in the test cars under the HSGT program to supplement the FRA Office of Safety track inspectors.

The pair of test cars used in the track measuring R&D program are now used almost full time for track safety inspections. The second pair of test cars is being outfitted with a duplicate set of track measuring and data acquisition equipment at this writing. A former Army hospital rail car has also been outfitted with both track-geometry measuring equipment and sensors to detect flaws and cracks in rails, which will add a new dimension to the safety inspection fleet. The next unit into the fleet will be a prototype of a car designed for higher production track inspection—i.e., wherever possible, automation has been added, such as daily instrument calibration, to achieve the maximum track coverage per day. The prototype and following production cars are each expected to measure 30,000 miles (48,270 km) of track per year. Current FRA plans include production cars, along with highway-rail vehicles with partial geometry-measuring capability to spot-check secondary and branch lines.

On-board processing for immediate presentation of inspection car results is available, and the gage measuring sensors are now magnetic, thus achieving the desired all-weather capability along with the profile system developed earlier. The R&D cars already have inspected some 75,000 miles of track. The additional FRA capability for track inspection is particularly important as roadbeds in the Northeast and Midwest are rehabilitated.

PASSENGER

The rail passenger R&D program started with the high speed testing by the four test cars to support the Metroliner demonstrations. Also part of the passenger R&D program was the on-board surveillance system developed on the test cars and the Linear Induction Motor Research Vehicle high speed truck dynamics testing.

Ride Quality. A prime objective of the passenger R&D program was to improve ride quality of rail passenger cars. In 1965, no devices were available to measure ride quality in this country. The technical community could not define engineering standards for a good ride. Since some work had been done in other countries, OHSGT engineers established tentative standards of vibration amplitude vs. frequency and set about devising measuring techniques. The first attempts to measure ride quality were made with accelerometers mounted on the car structure. Although this technique provided some useful information, there were several shortcomings—i.e., accelerations measured were not those experienced by passengers.

The next step—a cooperative effort with the NASA Langley Research Center—took advantage of their aircraft ride quality work. Researchers at Langley had developed a portable accelerometer package that could be placed on the floor of a rail car or in a passenger seat. This package has been used to measure the ride quality on a number of different trains to compare car designs or the ride resulting from different qualities of track. Using measurements of accelerations and subjective judgments of ride quality, improved standards were developed and used in the levitated vehicle program.

ENSCO, Inc. built a portable battery-powered acceleration-measuring device, similar to the NASA device. The suitcase-sized package was used in several passenger cars, collecting data for FRA and Amtrak.

The high speed running of the LIMRV at speeds up to and over 200 mph (321 km/h) demonstrated the dynamic performance of the Budd Company's passenger car truck. British Rail Research Centre participated in the testing and used the measurements of accelerations to verify their truck mathematical model. The truck performed with greater stability and better ride quality than had been expected.

Braking. Interest in high speed passenger service created a need for improved braking techniques. Conventional friction brakes encounter increasing thermal problems with the wheels as speeds increase; thus attention was directed to braking that could avoid this friction problem—i.e., non-contact brakes.

The most promising of the non-contact concepts proposed was an air retarder that uses an air pump, pressure, and internal friction of the air to absorb braking energy. Calspan successfully bench-tested the device, although the noise level would have to be lowered before it could be used operationally. As interest in high speeds had diminished by the time testing was completed, the project was discontinued.

Active Suspension. Planning for high speed rail passenger service was done with the recognition that right-of-way realignments may be too costly and higher speeds could be sustained only with suspensions that banked the cars to maintain passenger comfort around curves. One approach that OHSGT engineers believed worth investigating was the self-banking, or passive, suspension of the Turbo Train, which was evaluated in the Demonstration Program; a second was active suspension, in which a powered device would tilt the cars. Studies were made of possible active suspension designs by Westinghouse Electric; results indicated the mechanisms to anticipate track condition would be too complex and no further work was undertaken.

Random Process. In another approach to improve the design of rail car suspensions The MITRE Corporation analyzed the dynamics of an FRA test car using mathematical modeling and parameter measurement, which consists of experimental work to determine values to be assigned to the model parameters. A random process technique, which had been used successfully in communications, was adapted for the rail car. The results showed that the analysis of responses to random input of vibration and acceleration can be an effective way to understand the behavior of a large mechanical system.

Metroliner Improvements. In the first few years of operations Metroliner car availability was low because of electrical problems. Some improvement had been made by reducing the acceleration rate to two-thirds of the design rate and making some equipment changes—most notably, replacement of the automatic electric couplers with standard couplers and jumper cables. But, Metroliner availability still was not good and General Electric and Westinghouse each upgraded two coaches which have been in service for three years.

Maintenance costs for the modified cars have been 40 cents per car-mile, compared with 78 cents per car-mile for the remainder of the fleet. The modifications consisted of:

- Relocation of dynamic brake resistors from under the car to the roof—which removed a primary source of heat that had caused deterioration of wiring insulation.
- Placement of air intakes at roof level and addition of a filter to provide cooler and cleaner air to underfloor equipment.
- Improvement of propulsion components

and control logic by grouping the control logic in an electrical locker in a vestibule, solving a dirt and moisture accumulation problem encountered under the car floor and reducing the number of logic circuits by redesign.

- Change of the air supplied to the auxiliary power supply motor alternator from underfloor air to clean air from the roof intake.

Because ride quality of the Metroliners concerned OHSGT from the start of the Washington-New York demonstration LTV Aerospace Company retrofitted one Metroliner with trucks of European design. While ride quality showed some improvement, the cost of the truck and the required maintenance program was too high for Amtrak to consider fleet application. A second effort, still underway at the time of this writing, was by the manufacturer of the present Metroliner trucks, General Steel Industries, to make several changes in the suspension, including full air springs to replace the present secondary parallel coil and air springs.

Support of Amtrak. FRA assisted in the formation of Amtrak by running computer route models used to select the passenger network. Since Amtrak was formed, the HSGT rail passenger R&D projects have aimed at satisfying the new corporation's equipment requirements.

In a joint effort Amtrak, FRA, and General Electric tested a GE locomotive, equipped with a high-speed, 130 mph (209 km/h) gearbox of the type intended for future Amtrak use at the Transportation Test Center and on the Santa Fe railroad. Wheel forces, suspension behavior, and ride quality in the cab were measured. Using the data collected, GE modified the truck to achieve better stability. Similar three-axle locomotive trucks have continued to derail under baffling circumstances and investigations continue.

Present efforts in the Improved Rail Passenger Service Program include development of specifications for train systems and components. Also included are the evaluations of trains of foreign design for future application to Amtrak operations, both on and off the Northeast Corridor.

TRACK

The first railroad R&D task to be implemented under the HSGT Act, the Test Cars, included a wayside instrumentation package to determine rail-roadbed dynamics during train passage and to measure the long-term effects of repeated wheel loadings. In spite of several inconclusive attempts, the effects of long-term passage were not adequately measured until the Facility for Accelerated Service Testing (FAST) at the Transportation Test Center provided a totally test-oriented environment.

The first HSGT report to Congress of September 1966 stated: "A major problem for railroads is the maintenance necessary to keep roadbed and track structure in good enough condition to provide good ride quality. Maintenance could be reduced if a more stable, yet affordable, track structure could be devised." (The annual maintenance of-way costs paid by U.S. railroads in 1975 reached $2.5 billion.) In view of the multibillion dollar roadbed rehabilitation program which is now underway in the Northeast and Midwest, brought about by enactment of the Railroad Revitalization and Regulatory Reform Act of 1976, the two tasks OHSGT chose to start the track R&D program—measuring the long-term effects of wheel loadings and trying to devise a more stable track structure—were aimed at high priority problems.

Dynamic Analysis. Two continuing contract programs with Battelle Memorial Institute and Materials R&D, Inc. started in the first year of the HSGT program, have improved track engineers' understanding of track performance and provided them answers to special track problems. Under the first contract Battelle developed computer programs to analyze track response to static and dynamic vehicle loadings. The programs were validated by measuring the track response to passage of the FRA test cars at various speeds up to 125 mph (200 km/h) and of Metroliners and freight traffic. Analyses based on these models identified increased track stiffness as a means of reducing maintenance-of-way costs. Model simulation also identified a track stiffness that would impose one pulse per truck, rather than the two (one per axle) normally imposed—thus, lowering the pulse frequency below the natural resonant frequency of substandard soil. Pulses applied at frequencies near the soil's natural frequency can excite soil particles into unwanted movement. Battelle recommended three track designs for experimental evaluation: cast-in-place slab, cast-in-place twin beams, and precast twin beams. The Kansas Test Track included all three.

Using the models developed for FRA, Battelle went on to do similar analyses of transit track for the Urban Mass Transportation Administration.

Ballast Stabilization. Under the second contract, Materials R&D Inc., stabilized ballast by spraying on a thermoplastic polymer to glue the individual pieces together to reduce their movement under the track, thus forming a weak beam and increasing ballast system stiffness. When the polymer coated ballast showed satisfactory compressive strength on small laboratory samples, and in a repeated load test on an eight-foot (2.5 m) section of track in the AAR Technical Center Laboratory, FRA planned field tests under revenue traffic.

Figure 3. Installation of Instrumentation in the Kansas Test Track, Experimental Slab Track.

Kansas Test Track. By 1968, FRA had made plans for construction and field test of a number of short segments of track of new designs and accepted an offer by the Santa Fe Railroad to provide a test site, 45 miles northwest of Wichita, Kansas. The location—a straight section nearly two miles (3.2 km) long on a slight grade—carried more than 40 million gross tons(36.3 million metric tons) annually.

The test track paralleled the Santa Fe main line—offset 30 feet (9.1 m). To be certain that test results would reflect differences in load-carrying performance of the various test sections, undistorted by differences in soil support, the designers took great care to ensure uniform soil conditions throughout. All test sections were on an embankment of the same height, with the same mixture of locally available clay soils and identical compaction. The construction contractor completed the subgrade in 1971. Nine test sections—including concrete ties at three different spacings and two ballast depths, a continuous reinforced concrete slab, continuous cast-in-place concrete twin beams, precast twin beams, stabilized ballast, and a control section typical of Santa Fe track—comprised the test track, totaling 1.5 miles (2.4 km) in length. The designs were not all new, but none has been tested over a sufficient period of time with continuous data collection to determine differences in performance. See Figure 3.

During track construction, readings were taken periodically from instruments buried in the embankment to record roadbed settlement. Construction of all nine sections was completed in April 1973. In early May, the Santa Fe opened the Kansas Test Track to mainline freight traffic. See Figure 4. Within 24 hours, Santa Fe personnel detected 16 failures in the 1920 rail fasteners on the concrete beams and slab. Operations

Figure 4. Main Line Traffic Over Kansas Test Track-Concrete Tie & Beam Test Sections.

over the test track were discontinued immediately, and the Cement and Concrete Research Institute conducted an investigation of the failures at the site and in the laboratory.

The Institute found the cause of the failures to be random combinations of the concrete construction tolerances and the as-manufactured lack of straightness in the new rails. Where the two combined in opposite-direction variation, the rail fastener exerted pull-out forces on the anchor in excess of its design strength. A new fastener anchorage procedure, designed to accommodate the pull-out forces, was devised, and the Santa Fe reinstalled the fasteners and anchors. The information gained and procedures devised will prevent fastener anchorage failures on future installation of concrete slab-supported track.

In December 1974, the Santa Fe reopened the Kansas Test Track to traffic. Between that time and June 1975, 20 million gross tons (18.1 million tonnes) passed over it. In June, the test track was removed from service because of lateral track buckling in the concrete tie test section having the widest tie spacing. Investigation by the Waterways Experiment Station of the Corps of Engineers led to the conclusion that when clay embankments are overloaded, rigidly supported track deteriorates rapidly and cross-tied track suffers from rapid, upward migration of embankment soils into the ballast material. A further conclusion, corroborated by research in Europe at about the same time, is that clay soils—especially swelling clays of the type so common in Kansas—should be avoided as foundation material for slab-supported track. Or, if these soils must be used, slab-track or conventional track must be separated from the base material by a filter layer such as sand, suitably graded gravels, or the synthetic woven fabrics now being offered by manufacturers.

The Kansas Test Track taught a lesson: Research is often seriously compromised by in-service tests carried out on tracks of an operating railroad. Traffic requirements obviously must take precedence over the needs of investigators. The experience gave support to the argument that the rail industry needed test facilities capable of simulating in-service conditions for track and rolling stock. From this lesson has grown the experimental dedicated track and equipment test facility at the Transportation Test Center, the Facility for Accelerated Service Testing (FAST).

FRA has tested stabilized ballast at installations other than the Kansas Test Track. Ballast shoulders and cribs of the Linear Induction Motor Research Vehicle (LIMRV) track were sprayed with polymer emulsion before the LIMRV testing began. Although the loading imposed on the track by the test vehicle has been too small to cause deterioration, the environmental action over five years, even in a semi-arid climate, could cause movement of the track. Nevertheless, the track today is almost exactly where it was laid in 1971.

The second location for tests of the polymer was the Alaska Railroad. Continually settling track in certain locations has been a constant problem to the railroad, and at one such site the stabilized ballast performance has been good—the rail level has stayed within tolerance during two winters. However, the shoulders of the ballast have settled—raising a question as to why the track did not settle. Further investigation is needed.

In 1974, the Office of Research and Experimentation (ORE) of the International Railway Union in Utrecht, Netherlands, decided that the polymer ballast binder performance was so good that the European Railways should investigate its possible use in areas of poor soil on their lines. The cost of the polymer used to stabilize ballast is high and, at present, cost is the obstacle to further use. Work should be done to see if the cost can be reduced.

Convinced of the importance of knowing the dynamic compliance of track under many conditions, in May 1973, FRA requested design of equipment for the continuous measurement of dynamic compliance characteristics of track; development is still underway.

Models. A university research program started in 1971 to study mathematical models of track stability. Most existing models are of foreign origin. Translation of technical papers proceeded—followed by evaluation, selection, and refinement of the most suitable models for use in this country. Models for vertical and lateral buckling of track were developed. An experiment to complement the model of lateral buckling was conducted on the main track of the C&O/B&O at Sabot, Va., where sections of track with variations of wood and concrete ties were displaced laterally with known forces. The displacement was measured to determine the lateral stiffness. The analytical and experimental work has resulted in an integrated family of track simulation models that are available to assist in the improvement of track performance by designers and maintenance-of-way planners.

Starting in Fiscal Year 1973, track R&D was funded out of the Railroad Research and Development appropriation, along with safety and freight R&D. Other track improvement projects have also been started in that program, including development by the AAR of a 14-element matrix of track models—greatly expanding the initial FRA university research.

Freight

Freight R&D has grown from a small effort early in the HSGT program to be the major part of the FRA program in Railroad Research. Only projects started under HSGT are described here.

Train Dynamics. The first HSGT report to Congress, in September 1966, reported joint studies under way with the Southern and Canadian National Railways on the dynamics of long trains, especially on slack action; later the AAR joined in the study. The participants concluded that a computer simulation of the dynamics of a long train could be developed if the coefficients in the mathematical models for it could be verified by measurements on trains under controlled conditions. From this conclusion grew the plans for a dynamics test track at the Transportation Test Center.

The AAR and FRA research staffs developed plans for a dynamics test track with an alignment designed to create dynamic action within a train and a train structure with provision to introduce disturbances (simulating defects or deteriorated track) to cause other types of dynamic action in a train. Grading of the test track right-of-way started at the Test Center in July 1972. The 5.7-mile (9.2 km) track includes a 0.9 percent grade and a 4° curve, with an easement spiral having sufficient embankment width to permit large lateral changes in the spiral's alignment. This grade-curve sequence is severe enough to investigate both the dynamics of long trains and derailments caused by the motions of cars within trains. Part of the dynamics track opened in 1973 and the remainder, in 1975.

The joint government/industry Track Train Dynamics Program has used the dynamics track to run two series of tests—lateral/vertical force ratio and lateral stability. Some of these tests employed a most unusual test train configuration—five locomotives, three buffer freight cars, a test freight car (for concurrent truck tests), five more locomotives and, usually, a two-car set of the FRA test cars to record track and equipment data—designed to create forces comparable to those encountered in a train of approximately 150 cars. When the train started up a grade, the front locomotives pulled while the rear locomotives braked, to simulate the load from a large number of following cars. Going down a grade, the front five locomotives braked while the rear five pushed, to simulate the force of following cars rolling downhill. The resulting high compression (buff) and tension (draft) forces illustrated the forces in long trains.

In another Track Train Dynamics test on train and car stability, a section of track was perturbed with undulating lengths of rail placed alternately on opposite sides of the track to produce "rock and roll" in a test train. Tests on the dynamics track ascertained the stability of several Department of Defense hazardous materials cars.

A cooperative effort with the C&O/B&O Railroad completed in Fiscal Year 1970 produced data on the dynamics of freight cars running over various track irregularities. The study showed the effect of a number of vibration-reducing mechanisms and provided new data for car builders to use in designing new equipment.

Aerodynamics. The Second Report to Congress, for 1967, reported a freight car R&D project—OHSGT planned to conduct wind tunnel tests on special-purpose freight cars to investigate the possibility of reducing aerodynamic drag and saving fuel. The C&O/B&O Railroad and the AAR joined with FRA to sponsor tests of an automobile-carrying rack car in the Naval Ship R&D Center's wind tunnel. Tests of a 1:24 scale model showed adding sides to rack cars reduced aerodynamic drag. Neither car manufacturers nor carriers tried the enclosed-car idea until 1975, when the need for protection from vandalism made sides doubly worthwhile.

Automatic Couplers. In 1968, an ad hoc government/industry group assembled to determine if use of freight car automatic couplers could realize any operational economies and flexibilities. The automatic couplings considered included mechanical, pneumatic, and electrical, permitting controls to be train-lined. Many new operational procedures would be possible with train-lined controls; for example, hopper car doors could be opened and closed from the locomotive. The ad hoc group made recommendations for research, but no action resulted for several years until the AAR formed an automatic coupler committee under the Track Train Dynamics Program.

Adhesion Improvement. Also in 1968, the British Rail Research Centre began an evaluation of cleaning rail running surfaces with a plasma torch to improve wheel/rail adhesion. Contaminants, such as oil or grease, which cause wheel slip, can be burned off with the high temperature plasma torch, leaving a clean surface and improved adhesion. The Research Centre mounted a plasma torch on the front truck of a locomotive and ran field tests. The plasma torch was effective in eliminating spots of low adhesion and improving the general adhesion level. Further tests were to be run in the United States on a C&O/B&O locomotive to answer the question of how long the effect would last and how frequently the rails would have to be cleaned. However, the auxiliary power unit for the torch could not be fitted into the locomotive, and the tests were never made.

A contract with MIT, which started at the beginning of the HSGT program, included a task on the theory of rolling contact. Accepted theory was modified through theoretical analyses and laboratory experiments to include the effects of surface roughness and contamination.

Starting in Fiscal Year 1973, freight research has been funded from the Railroad Research and Development appropriation.

Rail Dynamics Laboratory

While the railroad technology program included laboratory testing in its plans, no agreement existed in the railroad technical community in 1966 as to what would be the best type of laboratory test facility. A survey was made therefore of possible techniques, including scale model and full scale. Preliminary planning ended in 1969 when, from a series of candidates General American Transportation Corp. recommended a full-scale roller rig with capability to handle cars and locomotives at full speed and power, with vibrations applied through the wheels to simulate track conditions. Representatives of railroads and suppliers assisted FRA in preparing performance specifications for the simulator. FRA engineers opened communications with experts in other countries who had operated similar facilities to use their experience in preparation of the specifications. In order to leave options open for testing advanced systems, such as the tracked air cushion vehicles, the simulator speed capability was designed for up to 300 mph (483 km/h).

The completed specifications called for the test vehicle wheels to rest on rollers, which were to be shaken vertically and laterally to simulate track irregularities. Tests planned for the simulator included investigations into wheel and rail impact stresses, roadbed dynamics, adhesion, guidance stability, and suspension design. The intention was to evaluate hardware under controlled and repeatable conditions.

The Urban Mass Transportation Adminis-

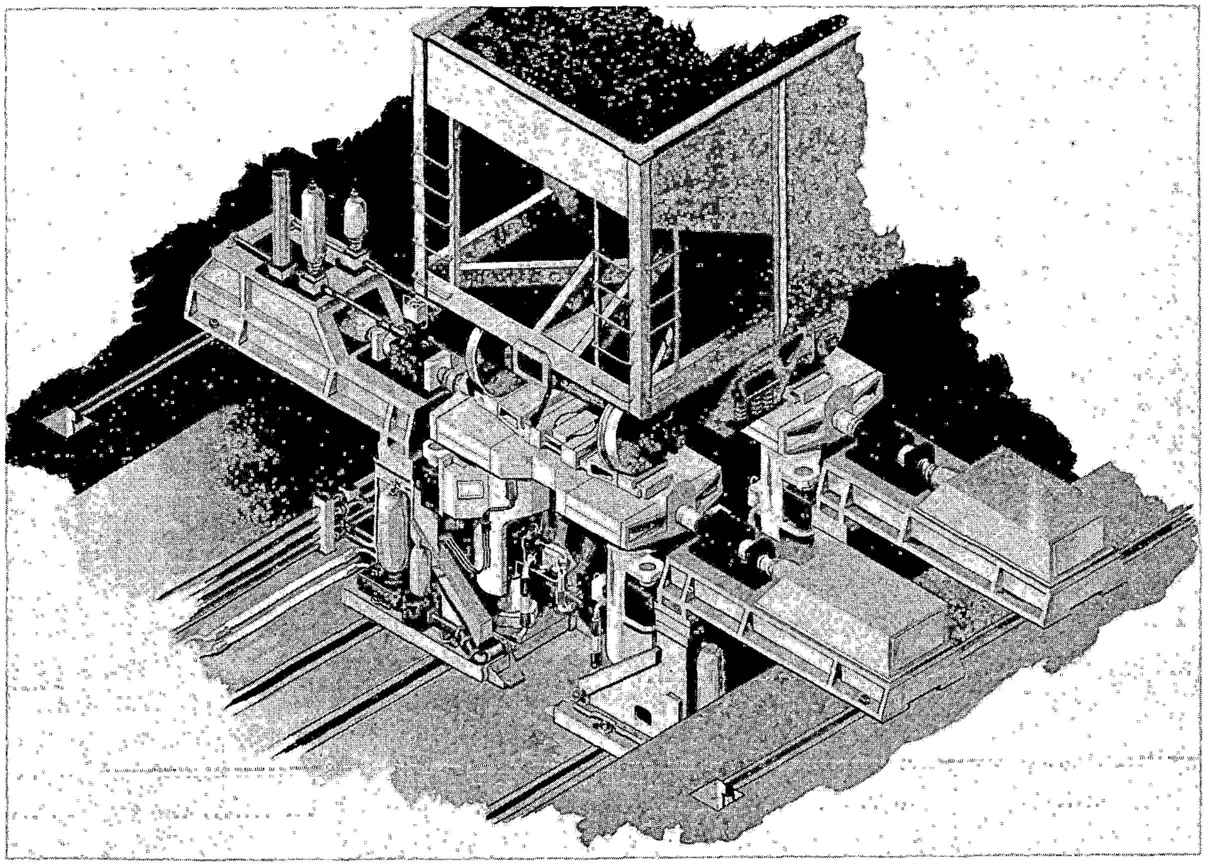

Figure 5. Rail Dynamics Laboratory's Vibration Test Unit.

tration joined in funding the project so that transit vehicles could also be tested in the laboratory and agreed with FRA to locate the simulator in a laboratory at the Test Center in Colorado. FRA placed the construction contracts for a 350-foot (107 m) long by 150-foot (46 m) high-bay building in 1972, along with contracts for the fabrication of the simulator, control computers, instrumentation, and communications. When the building was occupied in April 1974, before completion of the simulator and its associated equipment, contractors began using the test vehicle preparation area to instrument the test vehicles running on the Center's test tracks. Also, a vertical shaker, consisting of four independently operated vertical actuators placed under the four wheels of a car truck, to shake one end of a rail car to determine its response to vertical vibration, was installed.

In mid-1975, after the simulator contractors had encountered continuing developmental problems, a DOT Task Force reviewed the design status and concluded because of recent progress in mathematical modeling that the simulator could be simplified to reduce the technical risk and cost with little loss in testing capability. On the basis of the Task Force findings, FRA decided . . . that the simulator should be replaced by a double-ended vertical shaker and a separate rolling unit without vibration. At this writing, the redesigned test facility, shown in Figures 5 and 6, is scheduled to begin operation in early 1978.

During 1975 and 1976, the existing vertical shaker system was tested, both loaded and unloaded. The item used for the loaded tests was an 89-foot (27.1 m) long TTX flatcar supporting two highway trailers, each loaded with 50,000 lb. (22,500 kg) of "dead" lading. At the successful completion of these demonstration tests, the first RDL R&D testing began, using the same TTX car and trailers, to study the effects of freight-car truck components and highway van/trailer loading distributions on the lading response in Trailer-on-Flatcar (TOFC) configurations.

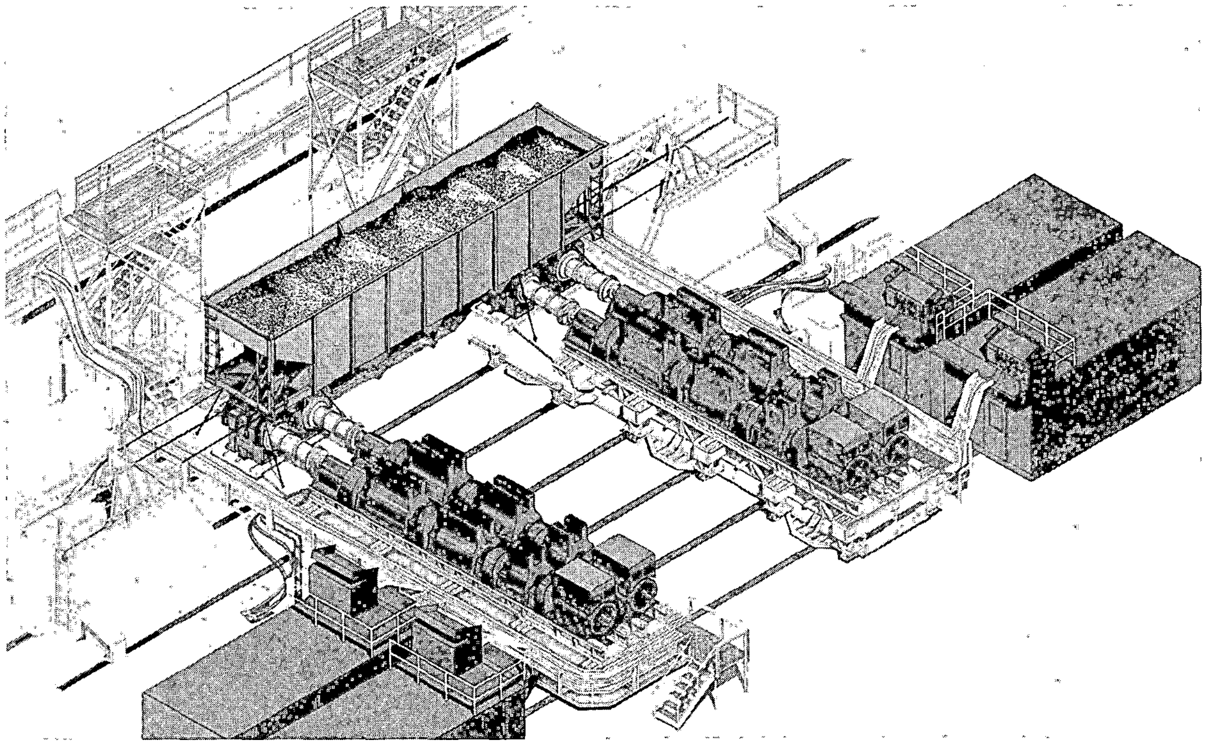

Figure 6. Rail Dynamics Unit's Roll Dynamics Unit.

Chapter 4

Advanced Systems

A question facing OHSGT in 1965 was: "How fast *is* high-speed ground transportation?" OHSGT researchers developed an answer based on power requirements and energy consumption. A plot of the power required vs. speed for propulsion of various vehicles in Figure 7 shows the region of 300 mph (483 km/h) was a reasonable range because power requirements above that limit increase to where increased fuel expenditure for marginal time savings make higher speeds unattractive, at least in open air. In evacuated tubes, the lower air pressure presents less drag, and speeds of 600 mph (966 km/h) might be practical.

Systems Engineering

OHSGT-sponsored studies focused the R&D on providing the best high-speed ground concepts as candidates in the Northeast Corridor Transportation Project cost-benefit comparisons. The comparisons sought to identify the best alternative for improvement of passenger transportation in the corridor between Boston and Washington. The first objectives of the systems engineering program were to predict performance of the candidates and to identify deficiencies in the technology required to achieve the predictions.

TRW, Inc. assembled all known concepts for new HSGT systems and did in-depth engineering analyses to determine those which were technically feasible. OHSGT held discussions with some 200 different organizations and individuals for the purpose of extending the HSGT state-of-the-art review performed by MIT in 1965.[12] The systems engineers then derived a representative transportation system from each group, and made detailed engineering studies on them during the 1967-1971 period. Those representatives were High Speed Rail, Tube Vehicles, Suspended Monorails, Dual Mode (includes automated highways and combinations of high-speed ground and automobile), and Tracked Air Cushion Vehicles. A R&D program on rail components started at the beginning of the HSGT Program. While the rail systems engineering study did assist in pinpointing technical deficiencies requiring further R&D for high speed passenger service, the cost and performance estimates provided to the Northeast Corridor analyses were the major contribution.

MITRE and TRW analyses of Tube Vehicles found exceptionally high performance with low expenditures of energy in partially evacuated tubes. As the studies progressed, environmental and aesthetic considerations pointed to the desirability of operating in tunnels rather than in tubes on the surface. Maintenance of low pressures could be relatively easy in hard rock tunnels. Tunneling costs however, would have to be drastically reduced before such systems will be economically competitive. On preliminary investigation, several proposed tunneling techniques appeared to hold promise of such costs reductions, therefore, while a tunneling program endeavored to reduce construction cost, the Tube Vehicle R&D

was confined to aerodynamic studies. (The tunneling projects are described in a separate section.)

Magnetic levitation was first studied for support of vehicles in evacuated tubes and, as more was learned about magnet technology and its advantages, FRA included magnetic levitation as a HSGT candidate system in the cost-benefit comparisons. Studies of suspended monorails showed possible applications on existing rail or highway rights-of-way if inexpensive and aesthetically pleasing elevated structures can be developed. The only component research on suspended systems was done on elevated structures in an attempt to minimize costs. That work is described in the Guideways section.

Studies on dual modal and automated highways revealed that the feasibility of these concepts hinged on the availability of sophisticated controls with capabilities beyond any proposed up to that time. All research on these systems was confined to controls. That effort is described in the Controls section.

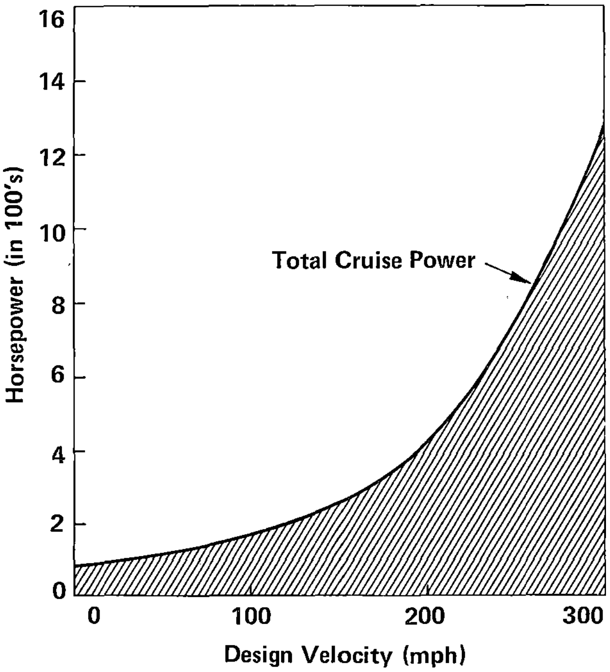

Figure 7. Tracked Air Cushion Vehicle's Power-Velocity Curve

In the later stages of the HSGT program, from 1972 on, both advanced systems and component R&D concentrated on levitated vehicles—magnetic and air cushion—along with propulsion suitable for wheel-less vehicles. Comparisons of possible means of propulsion—propellers, jet engines, rockets, linear turbines, and linear electric motors—led to selection of the last on the basis of performance, least undesirable impact on the environment, and safety. The HSGT systems engineering effort from 1973 to 1975 had as its principal objective, through a cost-effectiveness comparision, selection of the better means of levitation for continued development.

As described at the beginning of this section, the TRW system definition studies were inputs to the cost-benefit comparisons of alternative high-speed ground systems with other modes of travel. The HSGT systems were first compared with each other and then with rail, highway, and air. The fully defined systems are: tracked air cushion vehicle (TACV), suspended vehicles, tube vehicles, and dual modal vehicles. The last two required further research to make operational implementation possible. Suspended vehicles could achieve moderate speeds without further research, leaving TACV as the only candidate far enough along in the R&D to be started in development. Therefore, TACV and High Speed Rail were compared in the NECTP 1971 report. That report showed that High Speed Rail and TACV costs to be of the same order of magnitude, but the cost-benefit trade-offs and cost per minute of travel time saved favored an improvement of High Speed Rail—at least until TACV costs are reduced or the rail lines' capacity saturated.

Tracked Air Cushion Vehicles (TACV)

As noted in the Systems Engineering section, one of the technologies chosen for detailed systems analysis was TACV. A TACV is supported and guided by cushions of air, formed by a flow of pressurized air from on-board compressors and controlled by a small leakage gap between the vehicle and the guideway. The vehicle weight is distributed over a large area without contact and resulting friction. (See Figure 8 for schematic representations of various air cushion designs.)

TACVs evolved from development of marine air cushion vehicles (ACV) and their land-based versions, called Ground Effect Machines. The British invented the marine ACV and later pursued development of TACVs through the organization of Tracked Hovercraft Ltd. The French built the first large-scale TACV. The Societe d' Aerotrain built a half-scale propeller-driven model and a 4.4-mile (7 km) test track in 1965. The half-scale vehicle made hundreds of runs, carrying a crew of two and up to four passengers. These demonstrations gathered data on ride quality and aerodynamic forces. With rocket boosters and a jet engine substituted for the turbo prop engine, the Aerotrain reached speeds of up to 215 mph (346 km/h). A second Aerotrain, carrying 80 passengers on an 11-mile (17 km) elevated guideway, went into operation in 1968. The 80-passenger vehicle ran a reliability test of 15,538 miles (25,000 km) with good performance. Aerotrain proposed several routes from Paris to nearby cities, but the French government did not provide the necessary funds. Testing continues with the vehicle and guideway, See Figure 9.

The British government, through Tracked Hovercraft Ltd. (THL), sponsored research on linear motor-propelled TACVs. After laboratory tests on linear motors and air cushions, THL built an unmanned test vehicle and an elevated guideway. Tests were run for some months, but a change of governments in 1973 brought an end to funding.

Study of data obtained from Aerotrain and Tracked Hovercraft led OHSGT to conclude that a large-scale research vehicle was practical and, in fact, was the only way to get the accurate performance and cost data needed to supplement the HSGT program's theoretical systems analyses. Small

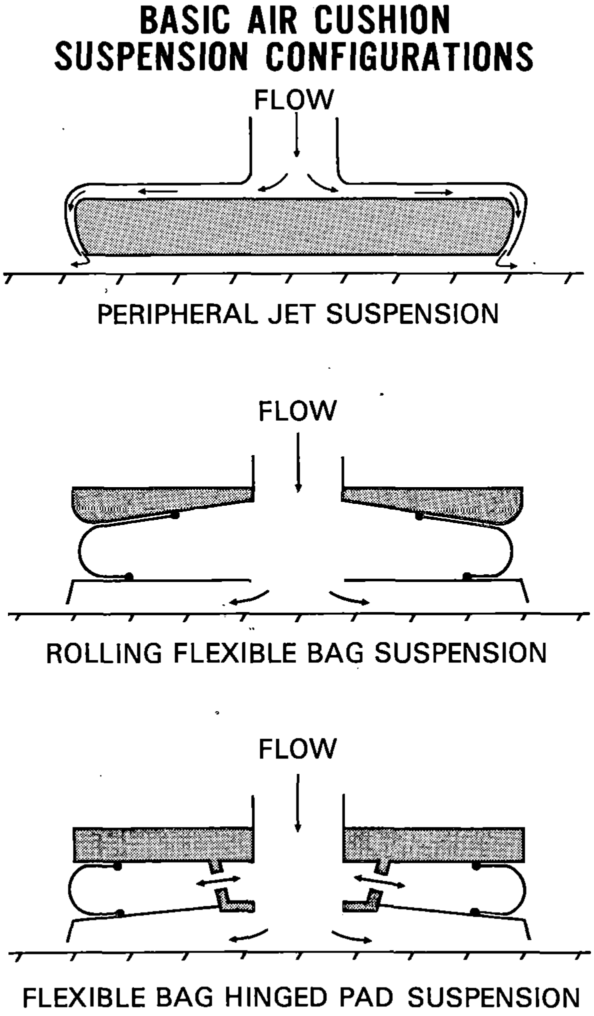

Figure 8. Different Designs of Air Cushion

models could provide qualitative comparisons of design variables, but scaling laws had not been developed and quantitative answers could come only from large-scale tests.

In 1969, TRW conducted a systems engineering study of a TACV system which resulted in a recommendation for a U-shaped guideway to protect the vehicle from crosswinds—which, at 300 mph (483 km/h), can cause severe rolling—and to make sure vehicles cannot leave the guideway.

Component Research. While OHSGT went forward with plans for a research vehicle and test program, TACV component research projects were begun by several contractors and the NASA Langley Research Center. Langley undertook aerodynamic experiments as a part of the NASA low-speed aerodynamics research program and ran tests of various vehicle bodies and air cushions in a moving-floor wind tunnel. Not surprisingly, bodies with semi-circular cross sections showed the least rolling in cross-winds. MIT, Princeton and IIT Research Institute carried out theoretical and laboratory studies of: the dynamic stability of air cushions, the feasibility of using the forward speed of a vehicle to supply air to the cushions (the ram air cushion concept), and the efficiency of a nozzle to pressurize air (the Coanda effect). The MIT research produced mathematical models of air cushion dynamic performance, which have since been used by other investigators studying tracked air cushion vehicle technology.

The ram air cushion research produced evidence that the energy requirements for suspension could be reduced significantly below vehicles that compress the cushion air on-board. Theoretical studies of the ram air cushion concept, conducted at Princeton and MIT, produced mathematical models of air flow under a vehicle close to the ground. Small-scale models were glide tested on a 10-foot (3 m) long, inclined U-shaped guideway in a laboratory at the DOT Transportation Systems Center and showed good stability with little rolling or pitching. Scale-model tests in a 300-foot (91 m), U-shaped guideway at Princeton gave qualitative verification of system engineering studies. The studies showed that a ducted fan at the front of the vehicle can direct its wake underneath the vehicle for levitation. Lift, guidance, and propulsion can all be produced from a single fan (propeller). This

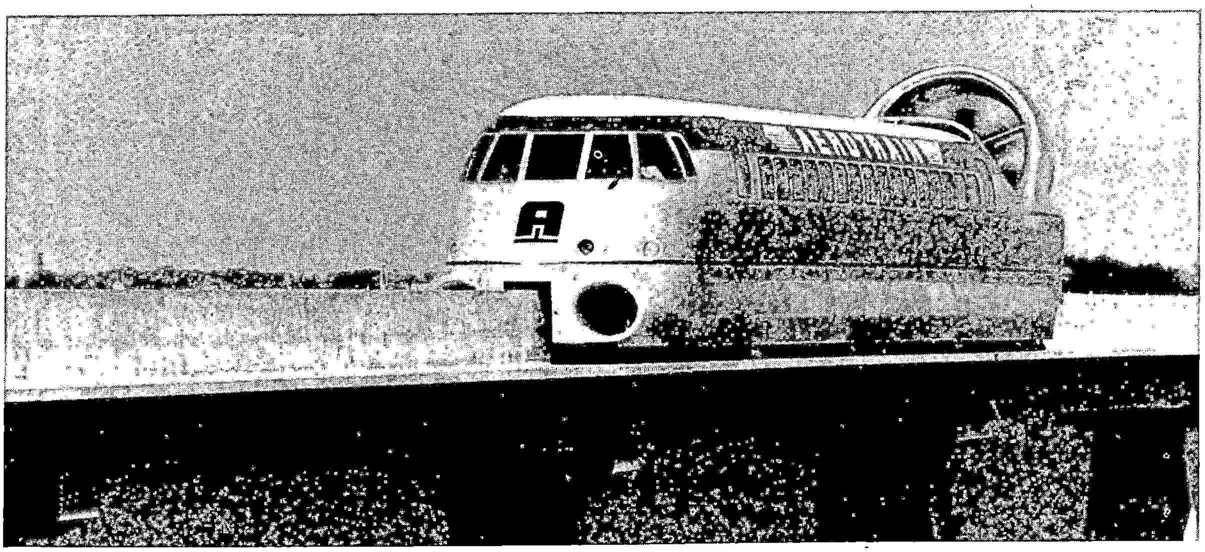

Figure 9. 80-Passenger French Aerotrain on Test Track.

design is technically quite simple and could use the Tracked Levitated Research Vehicle (TLRV) channel guideway or minor modifications of it. Figure 10 shows a ram air cushion vehicle model on the Princeton guideway. The ducting around the fan along with the walls of the channel guideway provide sufficient attenuation of the propeller noise to overcome this objection to a propeller.

In 1970, a formal exchange of information began with Tracked Hovercraft Ltd. (THL). THL studied:

- costs of constructing the British, French, and U.S. guideway designs;
- air cushion power required to keep a vehicle stable in crosswinds; and
- single-sided and double-sided linear motors for TACV propulsion.

Tracked Levitated Research Vehicle. In March 1970, Grumman Aerospace Corporation started design of an air cushion research vehicle—first called the Tracked Air Cushion Research Vehicle and, later, the Tracked Levitated Research Vehicle (TLRV)—with a maximum speed of 300 mph (483 km/h). The TLRV program plan called for research in:

- dynamic response of vehicle and guideway
- air cushion design, scale effects, and wearability
- air supply systems
- aerodynamic performance and stability
- ride quality
- secondary suspension requirements for passenger comfort
- analytical models of the vehicle/guideway system
- linear induction motor performance
- high-speed power collection

Design of the TLRV involved much that was unique—not only the vehicle and air cushions but also the secondary suspension between the air cushion and the body, the second-generation linear motor propulsion, the on-board power conditioning unit, and the power collection equipment. In order to avoid development of electric air compressors—even though the technical risk was known to be low—FRA selected aircraft turbofan engines as a "no development" air supply; the engine by-pass air was ducted to the air cushions. The turbofans also had an advantage over electric compressors—the

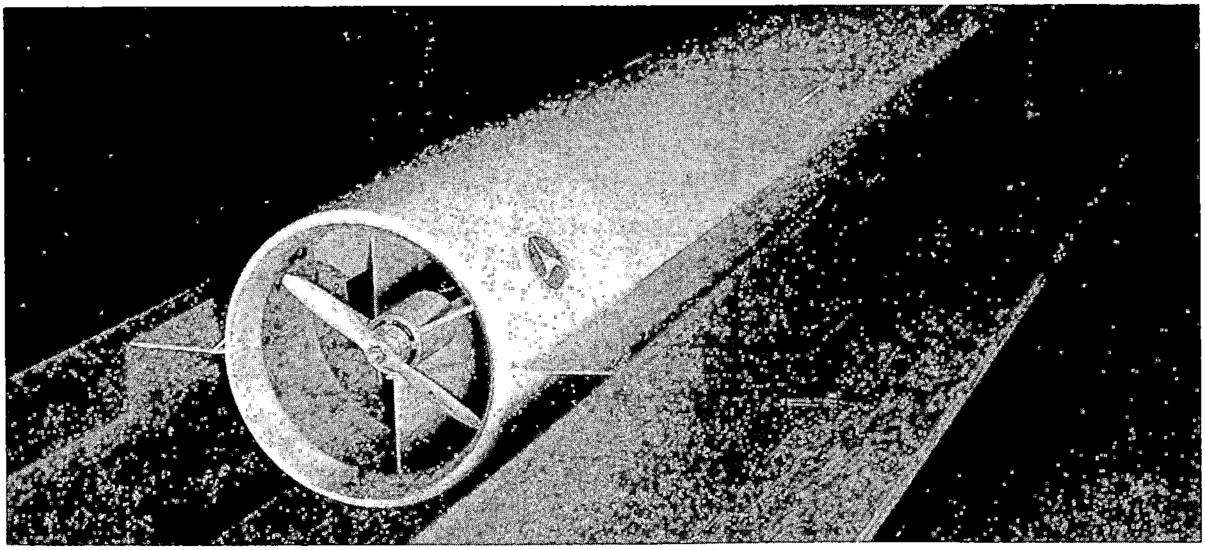

Figure 10. Model of Ram Air Cushion Vehicle.

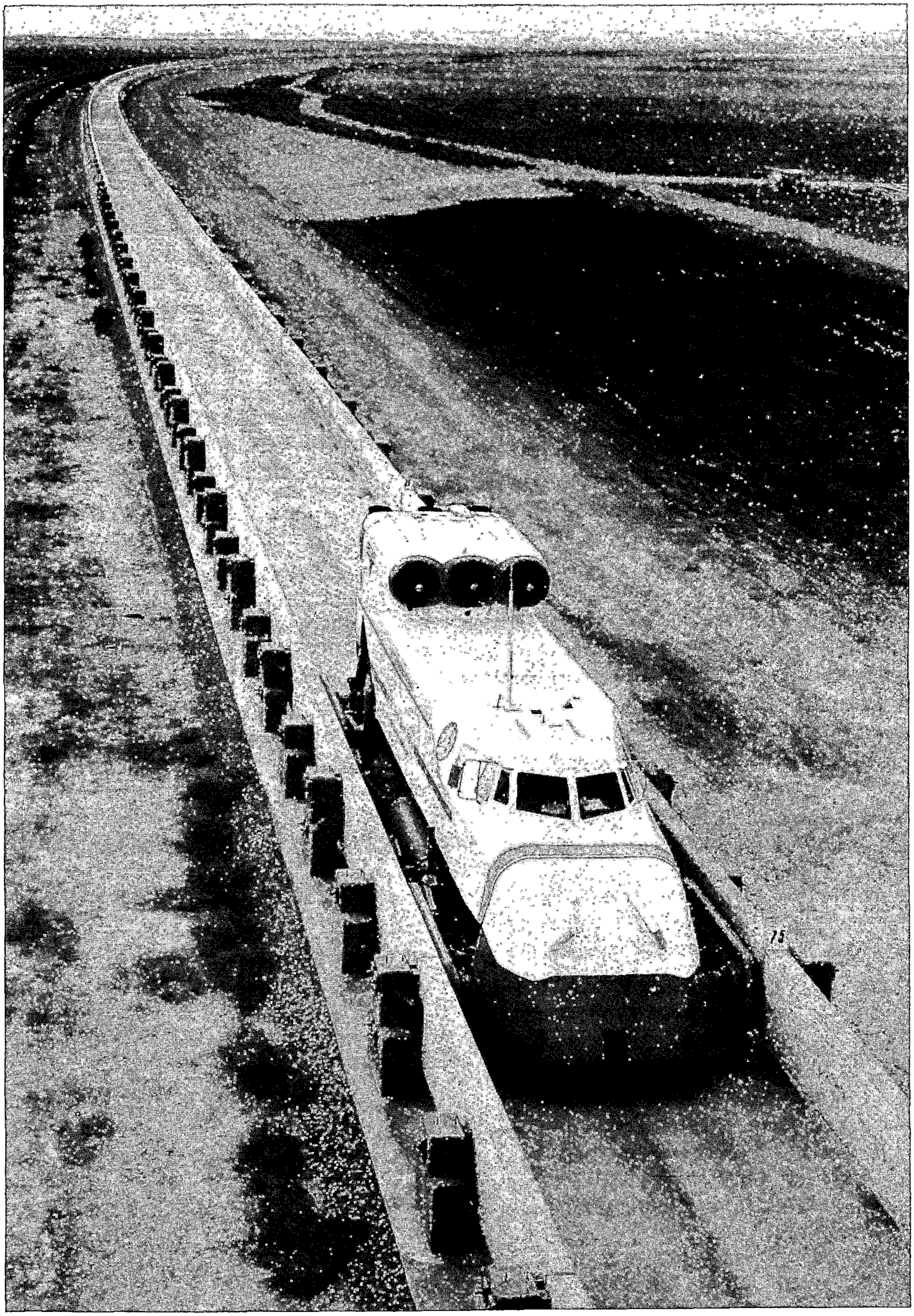

Figure 11. Tracked Levitated Research Vehicle (TLRV) U-Shaped Guideway at the Transportation Test Center.

exhaust gas provided thrust that could propel the vehicle at speeds of more than 100 mph (160 km/h), making test runs possible even if development problems held up delivery of the LIM.

The TLRV was unveiled in April 1972 and displayed at TRANSPO '72 in June before being moved to the Transportation Test Center (TTC), in Colorado, where Grumman installed and calibrated instrumentation. The test plan called for an 8 x 5 mile (12.8 x 8 km) oval right-of-way. Guideway construction was rescheduled six months later than planned because urgent test programs required expediting the UMTA rail transit test track construction; the first 1.5 miles (2.4 km) segment was completed in March 1973. Building of a second segment of the same length began in February 1973. See Figure 11.

The linear motor and associated power conditioning equipment and controls for the TLRV were in themselves a significant development program, as described in the section on linear electric motors. The first phase of TLRV testing executed without the electric propulsion system, lasted considerably longer than had been anticipated, due to development difficulties with the motor controls, power conditioning equipment, and water cooling. Testing began with aeropropulsion (exhaust of the turbofans) on the first section of guideway, increased speeds as more guideway became available until a maximum speed of 91 mph (146 km/h) was reached on the 3 miles (4.8 km), after construction completion in November 1973. Additional guideway would be needed to reach higher speeds.

In the TLRV test program, which lasted more than three years, the first phase checked out the air cushions and secondary suspension. The second phase determined

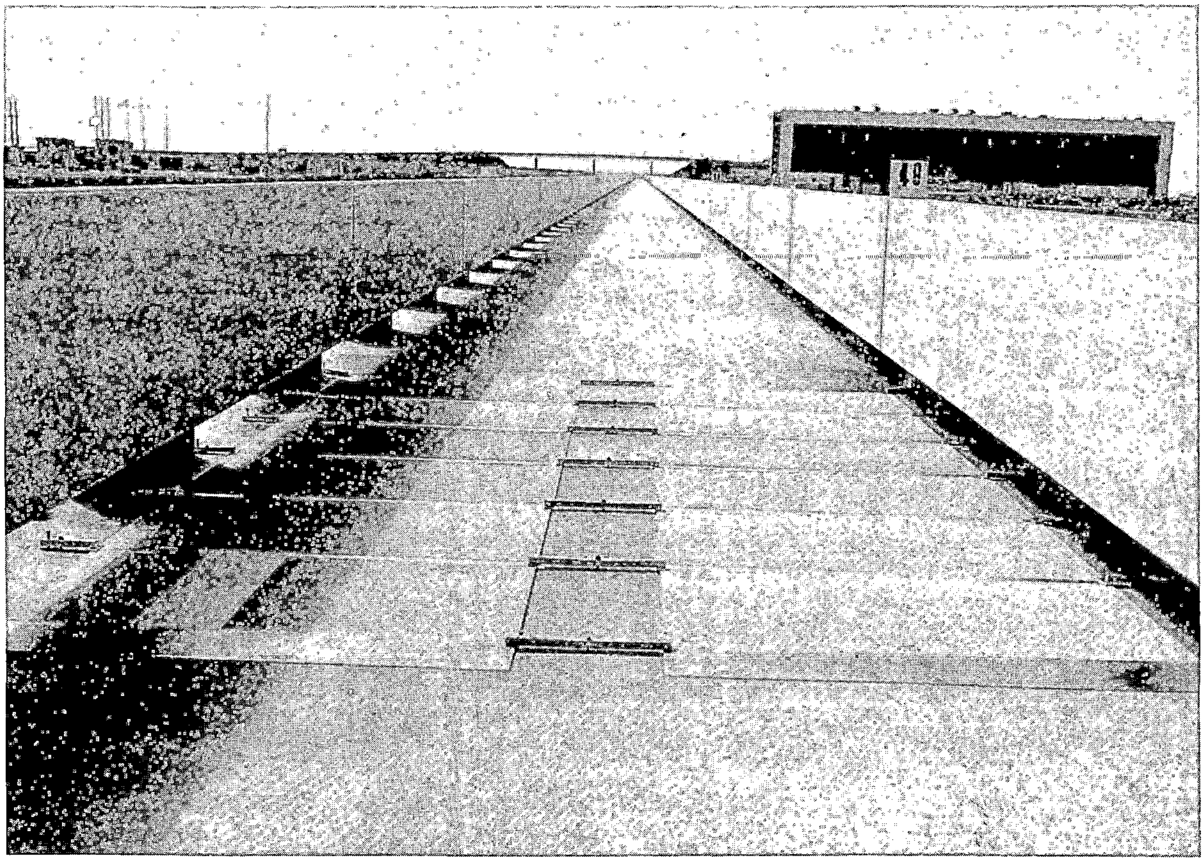

Figure 12. Surface Irregularities in TLRV Guideway to Study Vehicle Response and Behavior..

the vehicle tolerance to irregularities in the guideway, and the third was to operate the linear motor propulsion. Only minor mechanical difficulties appeared in the first phase, the principal one requiring a modification to the air supply ducts from the turbofans to equalize air flow from the three engines to the four levitation cushions.

In the second phase known excitations were applied to the air cushions. Perturbation surfaces were attached to the guideway: a long ramp, 1½ in. (38 mm) high, and a ramp/step, 1 in. (25 mm). For some tests, the perturbation surface extended all the way across the guideway to excite pitching motions; for others, the surface was placed only on one side, to excite rolling. Body accelerations were measured and used to calibrate a computer model of the vehicle. See Figure 12.

The third phase was run in 1975 to demonstrate satisfactory operation of the linear motor propulsion system.

Prototype Tracked Air Cushion Vehicle. In 1970, the Secretary of Transportation directed the development of a prototype TACV (PTACV) intended for airport access applications. Management and funding of the program were assigned to UMTA with technical direction by FRA. After almost three years, management and funding also became FRA's responsibility.

One purpose of the prototype vehicle was to demonstrate an air cushion vehicle to transportation planners. At that time (1970), various regional authorities were looking at alternative ways to provide a link between a city center and an airport. Another purpose of the PTACV program was to obtain performance data on an all-electric vehicle.

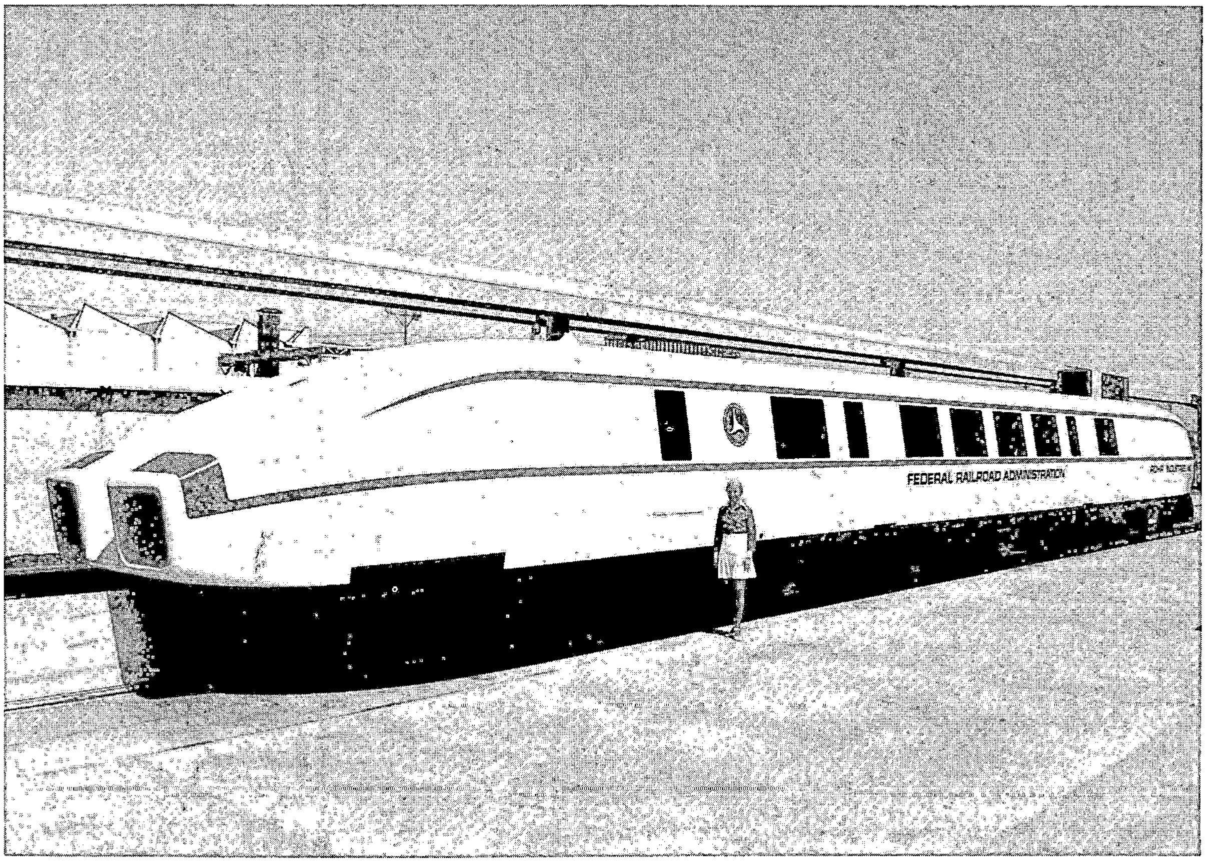

Figure 13. Prototype Track Air Cushion Vehicle (PTACV) on Manufacturer's Test Guideway.

The Rohr Corp. fabricated a 60-passenger, 150 mph (241 km/h) all-electric vehicle, based on the French Aerotrain design, propelled by a linear electric motor, with cushion air supplied from electric air compressors, and power picked up from the wayside. See Figure 13. The PTACV cushions applied low pressure uniformly over the entire area of each cushion—a plenum chamber. Air cushions for the TLRV were of quite different design—high pressure air blown through a narrow nozzle running around the periphery of each cushion—a peripheral jet. The two cushion designs offered a chance for comparison of their performances during the test programs.

During PTACV fabrication, Rohr constructed a 500-foot (152 m) track at their plant. Due to late delivery of the motor controls low-speed testing was conducted by connecting the LIM directly to the power supply with an on/off control. The controls were installed before the PTACV left the Rohr plant for the Test Center. Building an inverted-T guideway for the PTACV began at the TTC in May 1973. The vertical member in the center of the guideway slab (the leg of the inverted-T) guides the vehicle and also acts as the reaction rail for the linear motor. See Figure 14. The PTACV acceptance test program testing included one day of demonstration rides in 1976. The Department acknowledges that if transit authorities do display sufficient interest additional testing will be needed before deployment.

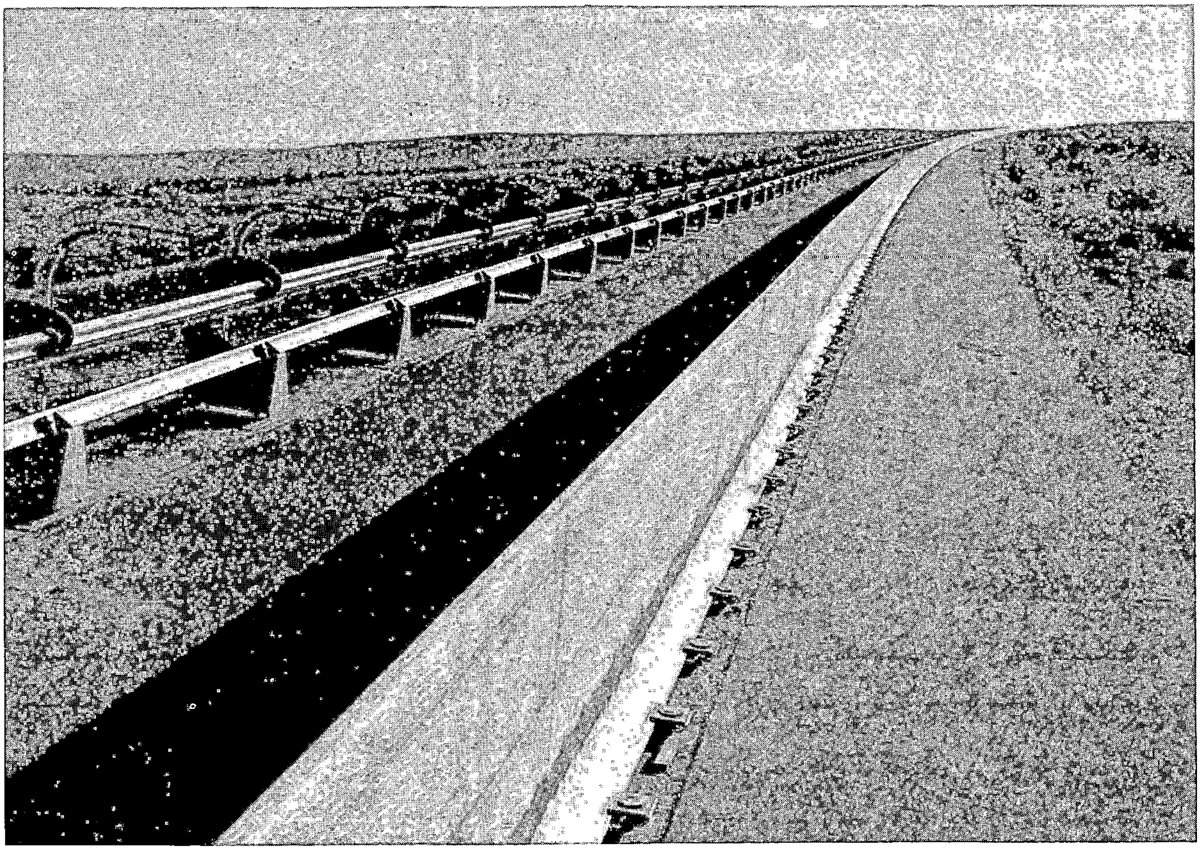

Figure 14. PTACV Guideway at Transportation Test Center. Reaction Rail in Center and Power Distribution Rails on Left.

Magnetic Levitation. During the 1966 surveys of technology for HSGT, magnetic levitation of vehicles was not chosen for inclusion in the R&D program. At that time, only two possibilities appeared: permanent magnets and electromagnets. In both cases, with magnets on-board the vehicle, the weight would be too great; with magnets in the track, the expense would be too high. Because of these findings, the early work on vehicle levitation concentrated on air cushions.

When studies of tube vehicles progressed to consideration of evacuated tubes, interest in magnetic levitation revived because evacuated tubes and air cushions were incompatible. Two physicists at Brookhaven National Laboratory conceived a system of magnetic suspension, which came to the attention of OHSGT. At about the same time, research on magnetic levitation started in Germany and Japan.

The new look at magnetic levitation (maglev) revealed more possibilities than just the two originally considered. Cryogenic technology had made possible superconducting electromagnets of vastly increased power, reducing their weight and size to be acceptable for on-board a vehicle and making possible air gaps from several inches to a foot (75 to 300 mm) between the vehicle and track. The newly developed rare earth/colbalt permanent magnets made possible gaps of 1 or 2 inches (25-50 mm), rather than a fraction of an inch (few millimeters) as was possible with earlier permanent magnets. These developments made magnetic levitation a contender for support of vehicles on open tracks as well as in tubes. Ford Motor Company and Stanford Research Institute investigated both of these new possibilities. Three magnet concepts were studied in depth: servo-controlled electromagnets, superconducting coils, and permanent magnets. The last type was ruled out again because the cost of the rare earth magnets was found to be too high.

Maglev research in Germany, sponsored by the Ministry of Research and Technology, centered on servo-controlled electromagnets riding under a steel rail with a clearance of about 15 mm (.6 inch), the vehicle body supported by attraction between the rails and magnets. The early program was almost entirely experimental with large-scale vehicles running demonstrations.

Two German companies built demonstration maglev vehicles, in 1971, Messerschmitt-Boelkow-Blohm (MBB) constructed a 660-meter (2165 ft) test track, which limited speeds to under 60 mph (96 km/h) and later that year, Krauss-Maffei (KM) began runs on a 930-meter (3051 ft) guideway and reached speeds of 105 mph (169 km/h). Both vehicles were propelled by linear electric motors. KM then built a 2400 meter (1.5 miles) elevated guideway to test at speeds up to 155 mph (250 km/h). In 1972, MBB began operation of a magnet test vehicle powered by a steam, or hot water, rocket. Later, a larger, faster hot water rocket-propelled vehicle (KOMET), with speeds up to 401 km/h (249 mph), began magnet testing on an 1800-meter track. KOMET was used during 1976 in the U.S./German test program funded by the Assistant Secretary for Systems Development and Technology.

Meanwhile, the German Ministry of Research and Technology also sponsored a third industrial group, headed by Siemens, to study repulsion maglev and linear synchronous motors. A 280 m (918 ft.) diameter circular test track facility for models was constructed for tests at 200 km/h (124 mph). Tests were run first with a wheeled vehicle carrying a magnet and, later, with a magnetically levitated vehicle. Large

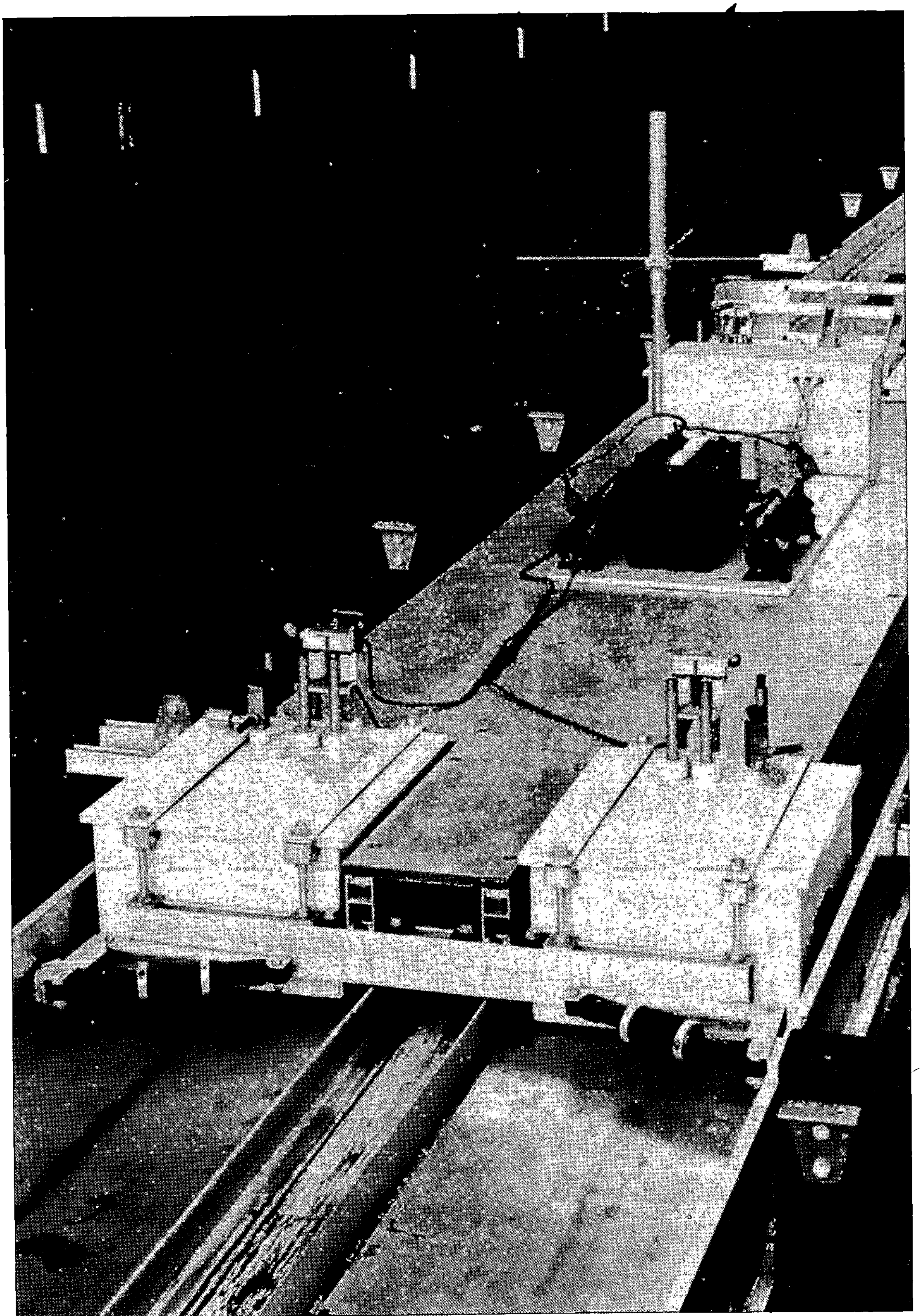

Figure 15. Magnetically Levitated Test Vehicle on Aluminum Guideway (Repulsive System).

superelevation on the circular track caused forces on the magnets which masked their performance in early tests.

The Japanese program includes university and industrial research as well as that by the Japanese National Railway research staff. The railway work is with superconducting coils in the vehicle and aluminum coils in the guideway. Superconducting coils operating with a larger clearance than electromagnets (without excessive power consumption for control) appear to be more tolerant of guideway irregularities. In this concept, lift is obtained from repulsive forces between the coils and eddy currents induced in conductors on the track by passage of the vehicle.

Early analysis in the U.S. showed that aluminum plates would serve as well as coils for the conductor in the track, and later research concentrated on the aluminum plate design. Ford ran the analyses and tested a very small laboratory model on a rotating wheel. The model was supported by permanent magnets simulating superconducting coils. Magnetic lift and drag forces measured provided a better understanding of maglev performance.

Stanford Research Institute constructed a 300 foot (91.4 m) long U-shaped aluminum guideway and tested a superconducting coil in a wheeled vehicle to study magnet performance and the effect of vibration on the magnet and cryostat container. Results of the initial SRI tests were so encouraging that the test vehicle was converted to magnetic suspension. See Figure 15. The first maglev runs at SRI produced severe heave and pitch when the vehicle passed over unwelded joints between the aluminum plates of the guideway. After the joints were welded the tests proceeded without further vehicle heave or pitch. Various disturbances were placed in the guideway and no instabilities were found. Active damping was added, which greatly attenuated the vehicle oscillations. These tests provided a good understanding of the dynamics of repulsion.

Ford also conducted laboratory experiments on a servo-controlled electromagnet. A small model subjected to vibration found the controls able to change the magnetic field strength quickly enough to prevent the magnet from dropping away from the steel rail or clamping onto it.

The MITRE Corporation calculated the total power (lift and propulsion) required by the two magnetic suspension concepts and an air cushion. The results show that the superconducting coils (repulsion) and the air cushion use roughly the same power; the servo-controlled electromagnet (attraction) uses considerably less. FRA analyzed these data along with information gained through exchanges with Japanese and German research organizations without deciding which is best, for the lower power requirements of the attraction technique, are offset by its inherent instability and tight guideway tolerances.

The FRA R&D Office decided to use both types of magnetic suspension to levitate platforms which could be pushed by rockets on the Naval Weapons Center rocket track and to conduct a "fly-off" to choose the better system for test in a test bed vehicle for comparison with air cushions. Cooperative programs had been worked out with the Germans for exchange of test results and to coordinate test programs. Contracts for the test platform projects and conceptual design of a revenue system had just been awarded when budget restrictions forced termination of the program. The repulsion conceptual design was documented, but the attraction design was not.

The advanced systems program in the office of the Assistant Secretary for Systems Development and Technology has continued a small cooperative maglev project with the Germans, including participation in the KOMET testing.

Japanese National Railways (JNR) continues with experiments, having constructed a 7 km (4.4 miles) test track, and with research by supply companies and universities. JNR estimates the present high-speed rail lines will be saturated in the early 1980s and sees the need for new capacity in parallel lines. The technical staff of JNR believes maglev is the answer to the requirements for high-speed, high-capacity service, with less noise than the railroad. Noise and vibration of the high speed trains have been the only complaints against the trains.

The Canadian Transportation Development Agency (TDA) is also sponsoring research on magnetic levitation and linear electric propulsion, looking to the future when the present rail corridors are saturated by freight and new alignments will be needed. If a new alignment for dedicated passenger services is required, the Canadians believe the cost of either rail or advanced non-contact technology will be of the same order of magnitude.

The TDA program includes research on electrodynamic (super-conducting) and ferromagnetic (electromagnetic) levitation and linear induction and linear synchronous electric motors. A 7.6-meter (25-foot) diameter test wheel has been constructed for scale-model testing.[15] This wheel is also to be used in a program funded by the Office of the Assistant Secretary of Transportation for Systems Development and Technology to evaluate a maglev system of integrated levitation and propulsion.

The maglev research sponsored by FRA has provided better understanding of the physical phenomena involved. This knowledge, which has been provided to German and Japanese researchers in the exchange programs, includes the following findings:

- Relationships involving electromagnet lift, guidance, drag, coil size and shape, guideway dimensions, and speed.
- Superconducting magnets, which had previously been used only in static applications, were shown to be able to withstand shock and vibration.
- Dynamics of magnetically suspended vehicles were found to be stable. Oscillations produced by disturbances in the guideway or gusts of wind could be damped out with demonstrated techniques.

International information exchanges with the Germans, Japanese, and Canadians have been productive; to continue to benefit from the foreign research the United States will need to have information to exchange.

Tube Vehicles

The 1965 MIT survey of HSGT technology drew attention to the safety and all-weather capabilities of tube or tunnel guideways for high-speed vehicles. At that time, aerodynamics of vehicles traveling in tubes was a relatively unknown subject. Accordingly, aerodynamic research projects were funded with a number of research organizations and universities, including: Rensselaer Polytechnic Institute; Carnegie-Mellon; MIT; Ohio State; Oceanics, Inc.; General Applied Science Laboratories; MITRE; and TRW. The most difficult problem encountered in these studies was the piston effect of a tight-fitting moving vehicle compressing air in front of it.

Theoretical analyses and water tunnel tests at Oceanics, Inc. developed the stability derivatives needed to design the slender body tube vehicles for stable movement.

Studies begun at MIT and concluded at Carnegie-Mellon University developed aerodynamic drag coefficients for various ratios of vehicle to tube diameters. Both Oceanics and MIT studies found that porous tube walls markedly decrease vehicle aerodynamic drag.

The most extensive tube vehicle studies were done at Rensselaer Polytechinc Institute where a 2000-foot (609.6 m) long, one-foot (.3 m) diameter scale-model test facility was constructed. However, problems of propelling and stabilizing the model vehicles turned out to be very difficult. The Rensselaer researchers tried using model airplane engines which did not have the reliability necessary to operate in the multiples required for adequate power to propel a model the full 2000 feet (609.6 m). A "hopped-up" chain saw motor had better performance, but tests of a propeller-driven wheeled model demonstrated a need to stabilize the model to prevent rolling around the longitudinal axis. Faced with such difficulties, the experimental project was abandoned.

Rensselaer also studied transmission of electric power to tube vehicles, using the tube as a waveguide and an antenna mounted on the rear of each vehicle to collect power. Solutions were not found to all the technical problems, so the study was terminated. Another Rensselaer task was the analysis of a tube vehicle propulsion system that ingests air at the nose of a vehicle and expels it at the rear in a vortex, creating a bladeless propeller. Such propulsion solves the piston effect, but the technical risk was so much higher than for evacuated tubes that the idea was not pursued beyond the conceptual stage.

Computer programs were developed by TRW and MITRE to simulate the aerodynamics of vehicles moving through tubes or tunnels. The MITRE computer program was expanded to include the conditions encountered when a train enters a tunnel. Tunnel entry at high speed causes pressure waves that can buffet the train and cause passenger ears to "pop." When the New Tokaido 130 mph (210 km/h) line first began operating in Japan, entrance into tunnels caused severe discomfort to the passengers. To prevent this, air vents on trains are now closed before they enter tunnels. The MITRE computer program can be used to investigate other solutions, such as changing the shape of the tunnel entrance to inhibit formation of the pressure pulse. Tunnel entry pressure pulses were also studied in laboratory experiments at MIT.

Of all the techniques investigated to solve the piston-effect problem, partial evacuation of the tube was the most practical solution. Studies of an evacuated system concluded that speeds of more than 300 mph (483 km/h) can be achieved in evacuated tubes without excessive power consumption and that an evacuated-tube vehicle system (including vacuum pumps as well as propulsion) would consume less energy than a similar vehicle traveling in the open air at the same speed.

With the current interest in freight pipelines, it is possible that some of the tube vehicle work (e.g., fluid dynamics, stability of slender bodies, and computer simulations) will find application in the concept of encapsulated freight, which might be a small-scale version of a passenger tube system. Some of the aerodynamic theory developed in the tube vehicle program is now being used in the Northeast Corridor rail passenger service improvement program to determine high-speed passing requirements and clearances along the wayside and also to reduce drag and power consumed by freight trains.

Multimodal

The HSGT system engineering studies examined travel requirements from origin to destination. The majority of the new systems analyzed and high-speed rail are terminal-to-terminal types, and interfaces with collection and distribution links should be planned as part of the system. The interface (or transfer) between the line-haul and feeder links can be eased by using automobiles for both beginning and end portions of a trip. This is possible if automobiles are driven to and from terminals and carried on other vehicles for the intercity, high-speed trip segment. Various systems that use automobiles in such a manner are grouped under the "multimodal systems" engineering analysis.

One variation of multimodal is the carrying of automobiles on a flat platform which could be a rail flatcar or a platform supported by air cushions or magnetic levitation. Another variation is the carrying of automobiles inside another vehicle which could be a rail or levitated vehicle. Auto-Train is an example of this sort of multimodal system. A third variation is the use of the automobile itself for the intercity link, but with control taken from the driver and completely automated. This has been called "dual mode" (for urban applications) or "automated highway."

The flatcar, or pallet, concept is considered to be more suitable for moderate speeds, because the automobiles on-board would create large aerodynamic drag at higher speeds. On completion of the pallet system engineering study, a demonstration was contemplated; an unusual situation existed in New Orleans, where a rail line ran between two sections of an unfinished express highway. Preliminary estimates indicated that the cost of a pallet operation would be less than the cost to construct a multilane highway. However, no local governments were interested, and the project did not get beyond the conceptual stage.

As discussed above in the systems engineering section, the multimodal analyses found that controls development was vital to attain the high capacity needed for a cost-effective system. Pallets and automated highway can use the same controls; the concept developed for such applications by TRW was Synchronous Longitudinal Guidance (SLG) and is described in the controls section. Work was stopped on SLG when no feasible way could be found to satisfy the requirement for providing high automobile reliability when under automatic control.

Suspended Vehicles

Elevated systems in which the vehicles travel below the guideway are referred to as "suspended vehicle systems." FRA began studies of such systems as they appeared to be the most promising for early public demonstration on short stage-length passenger routes. Elevated guideways would disrupt activities in built-up areas less than roadbeds at grade. Grade crossings are avoided and the "Chinese Wall" effect of dividing communities and forcing long roundabout trips between two points a few hundred feet or meters apart can be avoided. The unique advantage of suspended vehicles is in self-banking, as the vehicle swings outward like a pendulum on curves. This characteristic permits negotiating curves at higher speeds and makes possible use of existing rights-of-way, particularly railroad lines, for high-speed service.

An experimental suspended vehicle and a one-kilometer test track were constructed by the Safege Company in France in the mid-1960s but no operational deployment followed.

In a study of suspended vehicle dynamics completed by TRW Inc. in 1971, the outstanding problem was how to minimize the cost of the elevated guideway (a need common to all new surface systems) while achieving the maximum in aesthetics. In the past, elevated structures have been massive and often ugly-usually referred to as the "Third Avenue El" look, from the New York City transit structure that epitomized the worst in aesthetics.

Rigid-span guideways were compared to cable-supported flexible guideways in cost effectiveness and guideway/vehicle dynamic interactions.

The first of two system definition studies of suspended vehicles, finished in 1971, defined a 125 mph (201 km/h) system requiring no development of components. The second, in 1972, defined a second-generation system capable of speeds above 150 mph (241 km/h). Upon completion of the studies, no application for a suspended vehicle was in sight; none of the short-stage-length routes, such as airport access, which had been considered by various transportation authorities, materialized. Therefore, the systems work was not continued. FRA considered the research on lowering the cost of cable-supported guideways to be worth pursuing for possible use in Tracked Levitated Vehicle Systems so that work was continued in the Guideway Technology program.

Chapter 5

Advanced Technology

The initial HSGT state-of-the art reviews by both MIT[12] and the Department of Commerce Technical Advisory Board[13] recommended that OHSGT undertake R&D in components and subsystems that are common to all ground transportation systems; subsystems included were guideways, propulsion, communications, and controls. After the propulsion project came to concentrate on linear electric motors, power conditioning and power collection became projects; obstacle detection was separated from the overall controls project.

Linear Electric Motors

The 1965 survey by MIT revealed that linear electric motors were a promising means of propelling levitated vehicles. Systems engineering studies by TRW confirmed the potential of linear motors. The concept of a linear motor had been known for almost half a century (see Figure 16), but little research or development had been done prior to 1965. An experimental aircraft launcher employing a linear motor had been built for the U.S. Navy in 1946, but the project was dropped when the Royal Navy developed the steam catapult. In the early 1960s, Professor Eric Laithwaite of Imperial College, University of London, undertook a number of laboratory experiments with several linear electric motor designs, which revived interest.

There are a number of variations possible in the design of linear motors—induction or synchronous, single-sided or double-sided, windings in the vehicles or in the track. Because of the limited technological knowledge, problems were anticipated with single-sided and synchronous designs, and because the cost of installing windings in the track on intercity routes is high, the OHSGT research managers decided to concentrate on the configuration with the least technical risk—a double-sided induction design with windings in the vehicle. In 1966, the Department of Commerce requested proposals to study the theory of linear induction motors (LIM).

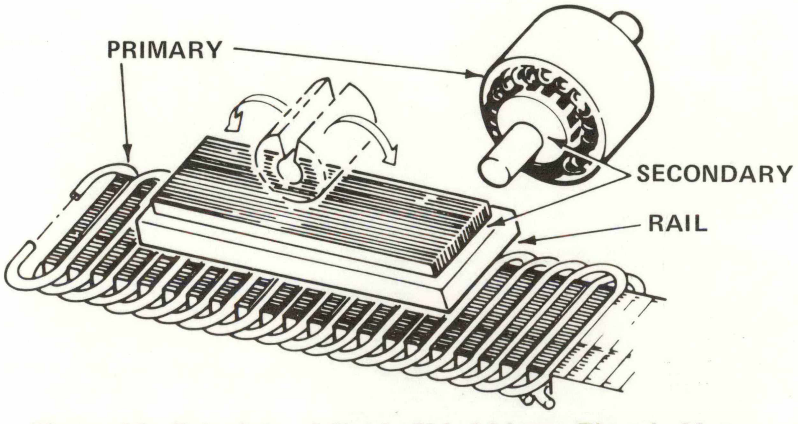

Figure 16. Principle of Single-Sided Linear Electric Motor

The contract was won by the Garrett Corp., which performed analyses and laboratory experiments on a small model of a crude motor. That work showed information was lacking on size effects and dynamics, particularly as to electromagnetic behavior at the ends of the windings (end effects, problems obviously not present in rotating motors). The OHSGT R&D office decided to build a full-scale motor to be tested in a vehicle to learn more about such phenomena and the dynamic performance of a LIM.

Linear Induction Motor Research Vehicle. The vehicle chosen as a test bed for the LIM has steel wheels on steel rails—high-speed passenger car trucks, combined with conventional railroad track. The use of railroad suspension avoided possible development problems that might have interferred with testing of the LIM. The choice of a railroad vehicle provided an opportunity to investigate the suspension dynamics of high-speed rail passenger vehicles. The test vehicle, known as the Linear Induction Motor Research Vehicle (LIMRV) thus served a dual purpose. The rail dynamics aspects of the program are described in the Rail Technology section of this report.

Because test speeds would be well above those at which power had been routinely collected from either third rail or overhead catenary, the LIMRV was designed to generate power on-board and thereby avoid another set of development problems—i.e., high-speed power collection. The Garrett Corp. designed and built the motor; construction of the vehicle body was subcontracted by Garrett to Halibrand Engineering. The LIMRV is shown in Figure 17.

The on-board power generating equipment for the LIMRV wax an aircraft gas turbine, from a crashed NASA airplane, driving an alternator. Control of the linear motor thrust

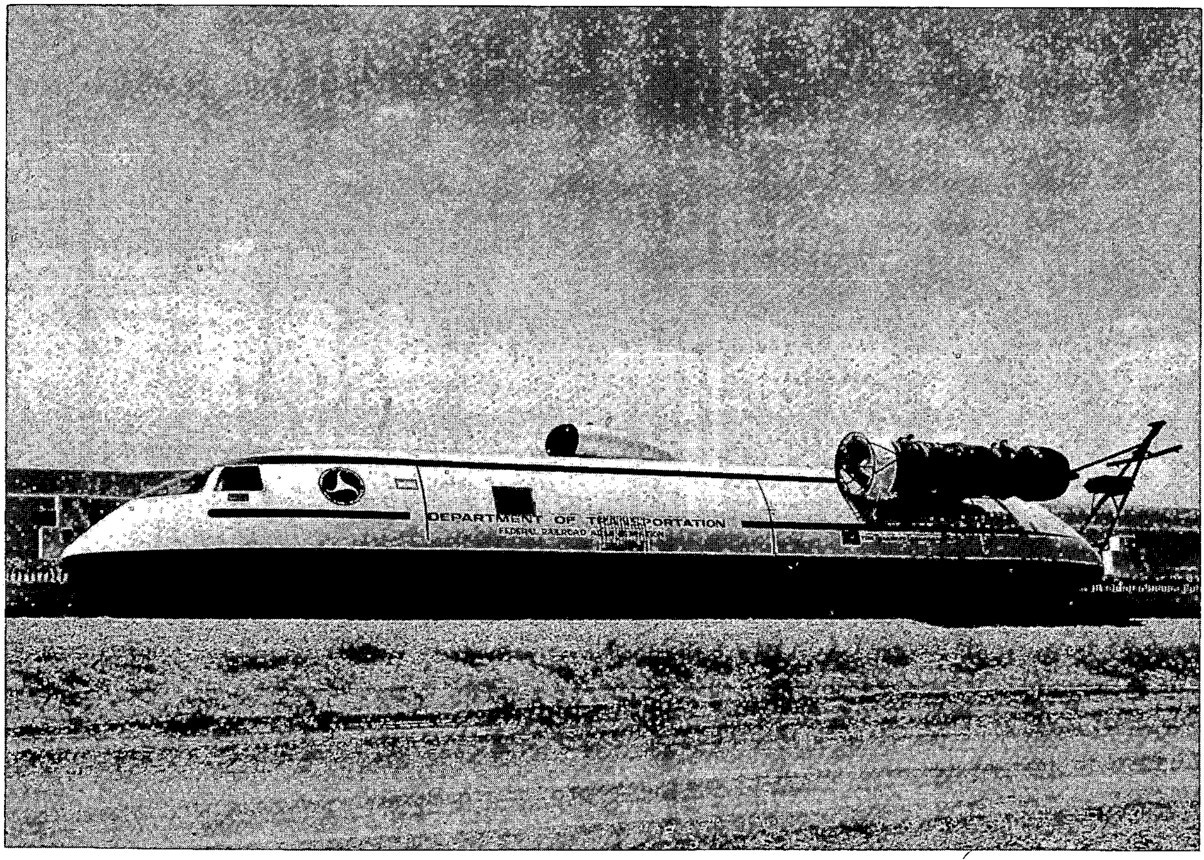

Figure 17. Linear Induction Motor Research Vehicle (LIMRV) at Transportation Test Center.

is accomplished by varying the speed of the turbine, which, in turn, varies the frequency and voltage of the power supplied to the LIM.

Testing of the LIMRV at low speeds started on a quarter-mile track at the Garrett plant to ensure no major design problems existed before shipment to the Test Center and to allow time for construction there of a high-speed track. Calculations showed that the test track should be 10 miles (16 km) long to achieve the design speed. The available funds were sufficient, however, only for 6.2 miles (10 km) which was long enough for all of the initial testing.

The LIMRV track is standard gauge with 119 lb/yard (49.4 kg/m) rail laid on wood crossties with crushed stone ballast, but the construction tolerances are tighter and the control of geometry is more precise than any track ever built. Precise alignment is made possible by the use of shims in the tie plates. An additional feature is a vertical aluminum rail—T-shaped, hollow, 22 in. (559 mm) high, ⅝ in. (16 mm) thick, with a 5 in. (12.7 mm) wide base fastened to the crossties and centered between the rails. This reaction rail acts as the secondary side of the linear motor and can be seen in Figure 17.

The LIMRV and its associated data acquisition system were delivered to the Test Center in the spring of 1971, and testing began in May. The system obtains data as voltages from sensors located on the vehicle. These signals are transmitted via telemetry to a trailer, where they are recorded on magnetic tape. Several channels of telemetered data can be displayed on a cathode ray tube (CRT) during a run for control or safety purposes. The trailer also contains remote control equipment for unmanned test runs (See Figure 18).

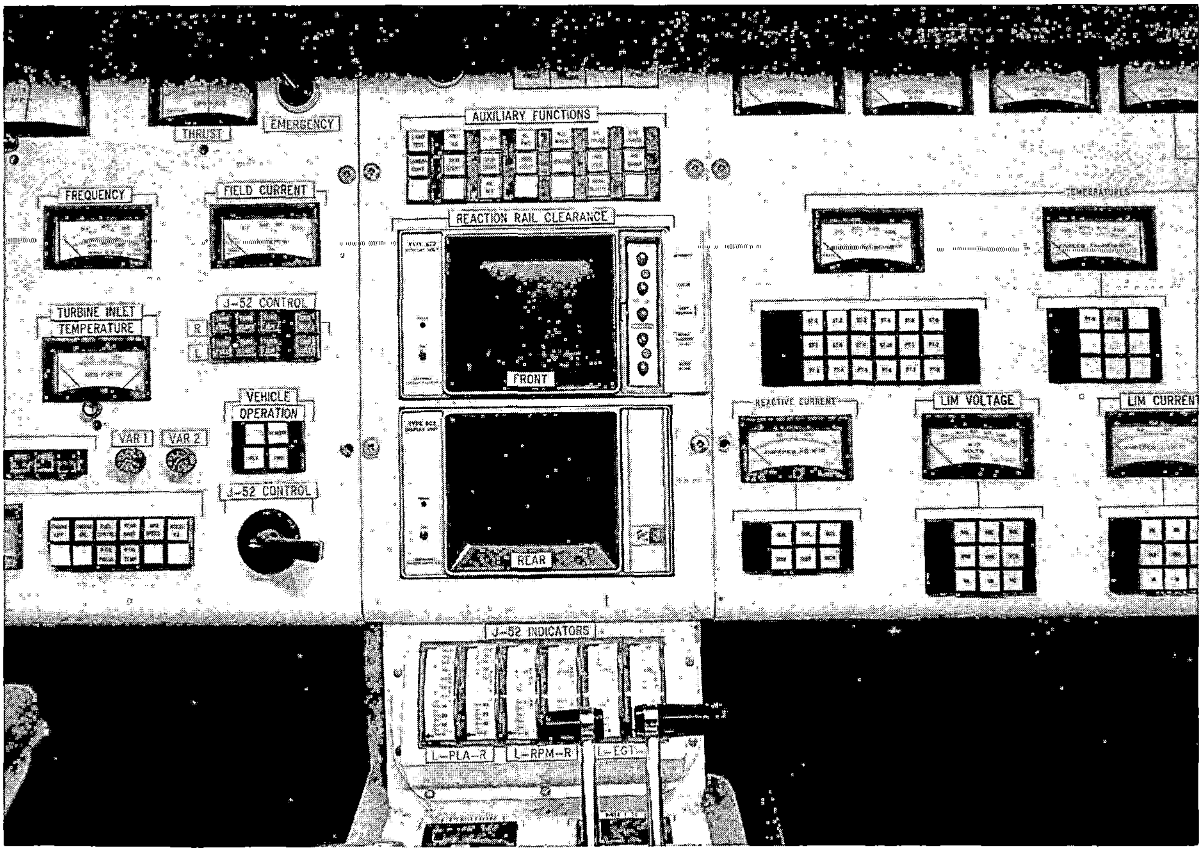

Figure 18. LIMRV Instrument Van Remote Control Panel.

Temperatures of −16°F (−27°C) caused weld failures and the reaction rail pulled apart in several places. Examination of the failures led to the development of an improved welding procedure and fastening the reaction rail to the ties at a lower temperature to prevent reoccurrances. All doubtful welds in the 6.2-mile (10 km) length were rewelded and none of the rewelded joints has failed, even though temperatures have fallen as low as −20°F (−29°C). The vehicle was running again by February 1972. Tests up to 80 mph (129 km/h) were conducted on the undamaged reaction rail, while reaction rail repairs were being made.

After all repair welding was completed, high-speed testing was resumed. The top speed reached was 191 mph (307 km/h). The length of track available, 6.2 miles (10 km), prohibited higher speeds. Rather than extend the track, a less expensive alternative was devised. Two jet engines (surplus from an Air Force missile program) were added as boosters so that the LIMRV could accelerate more quickly.

In August 1974, the LIMRV attained a world's record speed of 255.4 mph (411 km/h), slightly above the design speed. More than a dozen earlier runs had exceeded 200 mph (322 km/h). These tests were conducted primarily for rail dynamics purposes.

Subsequent to the dynamics tests, electrical performance tests were begun to determine thrust, efficiency, and electrical characteristics of the LIM. The results have verified mathematical models to calculate thrust developed in the United States, Japan, Germany, and Switzerland. Information was also gathered on dynamic braking, motor-edge effect, and magnetic wake to aid in the design of improved linear motors.

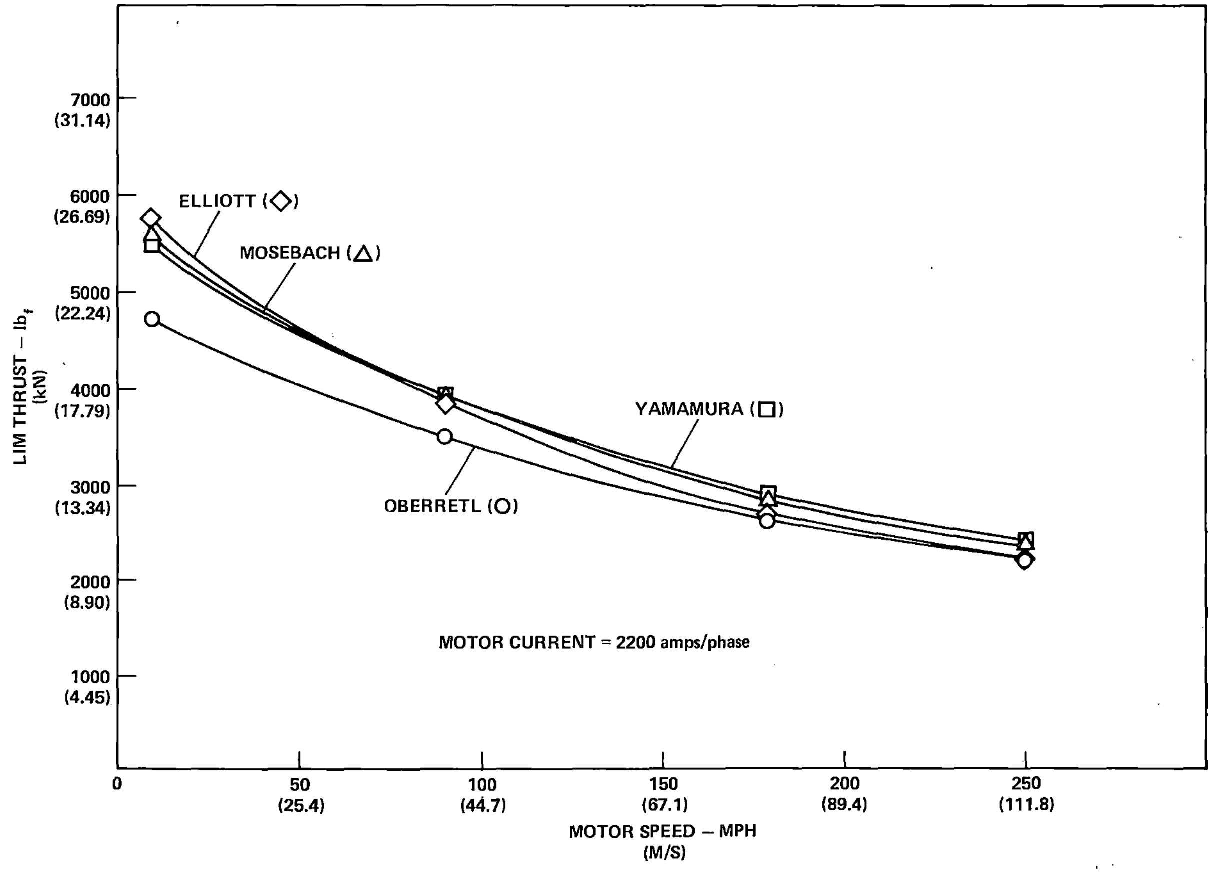

Figure 19. Comparison of LIM Thrust Calculated by Four Different Mathematical Models

Upon the completion of these tests, the LIM windings were reconnected to produce a shorter motor. The purpose of the change was to test different motor characteristics and gain a better understanding of linear motors.

Mathematical Models. The Jet Propulsion Laboratory (JPL) at the California Institute of Technology developed a mathematical model to predict linear motor performance, which could be used for design of linear motors. FRA contacted other researchers throughout the world who had also been working on models of linear motors. Three of these models were programmed for a computer by the Transportation Systems Center (TSC) and compared with the JPL model. The predictions of the four models agree closely (see Figure 19), giving designers confidence that new designs will perform as expected.

Tracked Levitated Research Vehicle (TLRV) Motor. The designing and low-speed testing of the 2500 hp (1865 kw) air-cooled linear induction motor for the LIMRV provided sufficient experience for the Garrett Corp. to design a second-generation LIM for the TLRV; water-cooled to raise the thrust to weight ratio and with power picked up from the wayside. The LIMRV motor control concept was abandoned for a new control unit (see Power Conditioning). The new LIM rating was 4000 hp, or 7500 lbs of force (33,300 N). Garrett designed and built the water-cooled LIM with only minor problems of water leaks which were solved with fitting changes. The LIM and its controls, the Power Conditioning Unit, (PCU) were successfully static tested in a test cell before being shipped to the Transportation Test Center for installation in the TLRV. During low-speed tests, up to 44 mph (70 km/h) the LIM performed satisfactorily through starting, acceleration, and braking.

Single-sided Motors. In 1971, studies completed by TRW and MITRE showed that the technical problems anticipated with single-sided linear motors at the start of the program could be avoided. Information exchanges with Tracked Hovercraft, the Japanese National Railways, and the German consortium of Siemens/AEG-Telefunken/Brown Boveri and studies by the Polytechnic Institute of New York (PINY) confirmed these findings. FRA engineers began planning to convert the LIMRV motor to a single-sided motor upon completion of the testing of the original double-sided configuration. Garrett began the conversion in the summer of 1976.

The PINY research found that synchronous motors rather than induction motors could be the better means of propulsion because of the following advantages:

- Greater clearances between the motor windings in the vehicle and the reaction rail in the track are possible, thus requiring less precise clearance control.
- Better power factor, implying lighter onboard equipment.
- Higher efficiency, thus saving energy and reducing operating costs.

Laboratory testing of single-sided linear synchronous motors is currently under way at General Electric.

The LIM program has produced good motor designs that have performed about as predicted. Large LIMs could be operated successfully; the feasibility of linear motor propulsion for high-speed tracked vehicles has been proven. Linear motors are rugged and reliable and have potential application in railroads as well as in advanced high-speed ground systems. The Japanese National Railways have in operation a classification yard using linear motors to replace mechanical retarders at the point where final precise control is important. The linear motors have the significant advantage of continuous control and can accelerate as well as retard moving cars to prevent them from stopping short of coupling or avoiding impacts at speeds high enough to cause damage to cars and/or lading.

Another possible application for linear motors is in urban systems where the number of vehicles is sufficient to put the windings in the track. This arrangement simplifies power transfer to the vehicles and replaces the traction motors with a short length of reaction rail. Other urban systems could use linear motors with windings in the vehicle. Linear motors with the windings in the track might also find applications as boosters on railroad lines with steep grades or to accelerate trains out of terminals with wheel/rail adhesion problems.

Guideways

Because guideways are by far the most expensive component of any new ground transportation system, substantial efforts throughout the HSGT program have been aimed at reducing the cost per mile of guideway. One part of these efforts was focused on tunneling; another was directed at surface and elevated guideway construction.

Early in the HSGT program, MIT created a computer program to predict settlement and heave of embankments. The program was tested by installing instrumentation in an embankment on I-95 in Massachusetts.

In conjunction with systems engineering studies, TRW formulated a technique to compute earthwork costs, which was used to calculate the cost of Northeast Corridor routes for the various candidate HSGT systems.

After the first few years, OHSGT directed its attention to reducing the cost of guideway construction, both at-grade and elevated. Methods of analyzing the dynamics of vehicle/guideway interaction to optimize structures were developed by TRW, MIT, and Duke University. The objective was to use these analytical methods to search out lightweight, inexpensive guideway structures for levitated vehicles.

Still later in the program, FRA joined with UMTA and TSC to contract with TRW and ABAM Engineering to reduce the cost of tracked air cushion vehicle guideways, both surface and elevated, by developing new designs to save materials and construction labor costs.

Another effort was a joint TRW-Virginia Polytechnic Institute (VPI) exploration of a cable-supported elevated guideway concept; analyses were conducted by TRW and VPI dynamically tested a multiple-span 1:24-scale model cable-supported guideway. Simulated vehicles were moved across the structure and stresses measured in the supporting cables. See Figure 20.

The MITRE Corp. also conducted guideway studies, starting with those for magnetically levitated vehicles and expanding the analyses to air cushion vehicles. The magnitude of deflections under passing vehicles over continuous beams of various numbers of spans were analyzed. For the specialized cases analyzed, the findings were that a continuous beam extending beyond six spans had little effect on deflection and camber (upward curvature) of the beams decreased cabin accelerations (improvement in ride quality).

While the theoretical research was under way, construction of test guideways at the Transportation Test Center was being used as another means to reduce cost. The

Tracked Levitated Vehicle (TLRV) guideway was to be built in sections—each section incorporating cost-reducing changes based on the experience of previous sections. Two sections were constructed. The second, with minor changes from the first, realized a significant reduction in the cost from \$1.42 million per mile (\$882,000 per km) to \$1.18 million per mile (733,000 per km). The cost decrease was a result of the design changes and the learning process on the first section; which was the first U-shaped guideway ever built.

The techniques developed by TRW/ABAM were applied in the design of a third section of the TLRV guideway to bring about another substantial cost decrease. However, construction of this section was not undertaken.

At the time the program was scaled down, preliminary studies had been started on using the TLRV guideway for testing both repulsion and attraction maglev vehicles.

Power Conditioning

The speed and thrust of linear electric motors is controlled by varying the voltage and frequency of the power supplied to the motor. Speeds above 150 mph (241 km/h) require variable voltage and frequency. The first linear electric motor built for the HSGT program, to propel the Linear Induction Motor Research Vehicle (LIMRV), is supplied power by an on-board gas turbine driving an alternator. The voltage and frequency of the power are controlled by varying the speed of the gas turbine. This arrangement was relatively simple, requiring only the design and fabrication of a special alternator to match a 2500 hp (1865 kw) aircraft gas turbine.

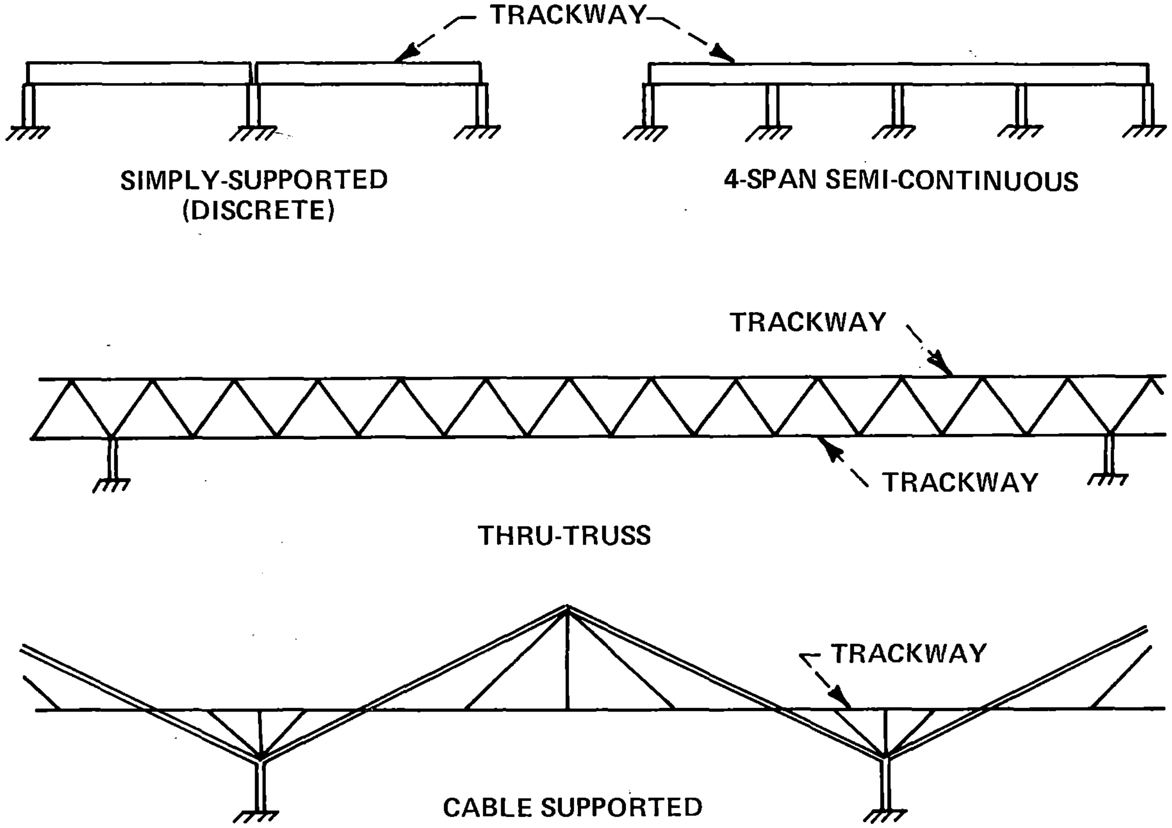

Figure 20. Elevated Guideway Design Concepts

The second linear motor, built for the Tracked Levitated Research Vehicle (TLRV), is controlled by an on-board power conditioning unit (PCU), which transforms constant-voltage, constant-frequency power picked up from the wayside into the variable-voltage, variable-frequency power required to control the linear motor. Such a unit had never been built and was technically more complex to design than the linear motors, partly because it had to be light and compact to be carried on a tracked air cushion vehicle.

The Garrett Corp., builder of the LIMRV, also designed and built the motor and PCU for the TLRV. The PCU consists of high-voltage (8250 v), water-cooled components which achieve a power density of more than 0.3 kw/lb (0.7 kw/kg). By early 1976, field testing at the Transportation Test Center commenced with only a 1640-foot (500 m) section of guideway electrified. The test bed vehicle (the TLRV) tests were halted in mid-1976, but continued to be used for limited LIM and PCU field tests. While all of the program objectives were not demonstrated, the PCU did operate satisfactorily in low-speed tests. The tests confirm the availability of variable-voltage, variable-frequency controls for both linear and rotating three-phase electric motors. Three-phase motors are lighter and have greater torque at low speeds than the DC motors now used in locomotives, and are being considered in Europe for application in locomotives.

A variable-voltage, fixed-frequency PCU was built for the linear induction motor in the Prototype Tracked Air Cushion Vehicle (PTACV). The builder was GECR of England, which encountered technical difficulties that delayed delivery until after the PTACV had been tested at low speed at the manufacturer's plant and shipped to the Transportation Test Center. The variable-voltage (VV) PCU performed satisfactorily in the tests run at the TTC, and, although the curtailed test programs did not permit a complete evaluation of the VVPCU, its limitation to low speeds was confirmed.

Although the Garrett PCU was smaller and lighter per kilowatt than any similar equipment ever known for the power level of the TLRV motor, it was still large. Therefore, in an effort to find still smaller and lighter power conditioning equipment, TSC was asked to undertake a long-range research program. TSC chose five concepts to investigate for lighter weight power conditioning. After preliminary evaluation, work was concentrated on an all solid state design in the belief that the state-of-the-art could be advanced further than that of rotating machinery. Laboratory equipment was purchased for experimental work. Assembly of the laboratory equipment was a lengthy process and was not completed until 1975. Experiments are continuing in a program to advance the state-of-the-art for future use of power conditioning in three-phase electric propulsion for railroad, transit, or advanced systems.

Electrified systems with power distributed along the wayside by either a third rail or overhead by a conductor wire (catenary) were of interest to OHSGT for two reasons: First, the Washington-New York rail passenger demonstration was operated on electrified railroad and; second, the most promising advanced high-speed ground systems being studied were electrically propelled. Generation on-board high-speed vehicles was not selected as the source of electrical power because of a desire to minimize air pollution and noise along the right-of-way.

The first research task was to improve performance of railroad pantograph/catenary power collection. As described in the Railroad Technology section of this report two studies were run with the FRA test cars; one study found that power interruptions to Metroliner cars could be reduced by operating with one pantograph per pair of cars, and the other, study found that pantograph contact shoes made of sintered metal last longer than those of the carbon steel normally used.

In an attempt to reduce further both power interruptions and shoe wear, a servocontrolled pantograph that could follow the conductor wire with light pressure was investigated. The results were not encouraging and the project was dropped.

As a part of the power collection research, General Electric developed a computer simulation of the Penn Central catenary for evaluation of possible modifications to improve the catenary's performance.

After the railroad power collection technique studies were completed, FRA attention was turned to the problem of collecting power at the higher speeds of the advanced ground systems. The systems studied were intended to reach speeds as high as 300 mph (483 km/h); power collection had never been attempted at such high speeds. In an attempt to avoid wear and interruption problems, several non-contact techniques were evaluated by GE—among them, inductive, capacitive, and plasma arc. All the techniques had drawbacks serious enough that none were pursued beyond the initial study. Inductive and capacitive techniques required such large collectors on the vehicle, they were impractical; plasma arc radiates electromagnetic interference that would disrupt all radio communications in the vicinity.

Westinghouse Electric studied other possibilities for high-speed power distribution

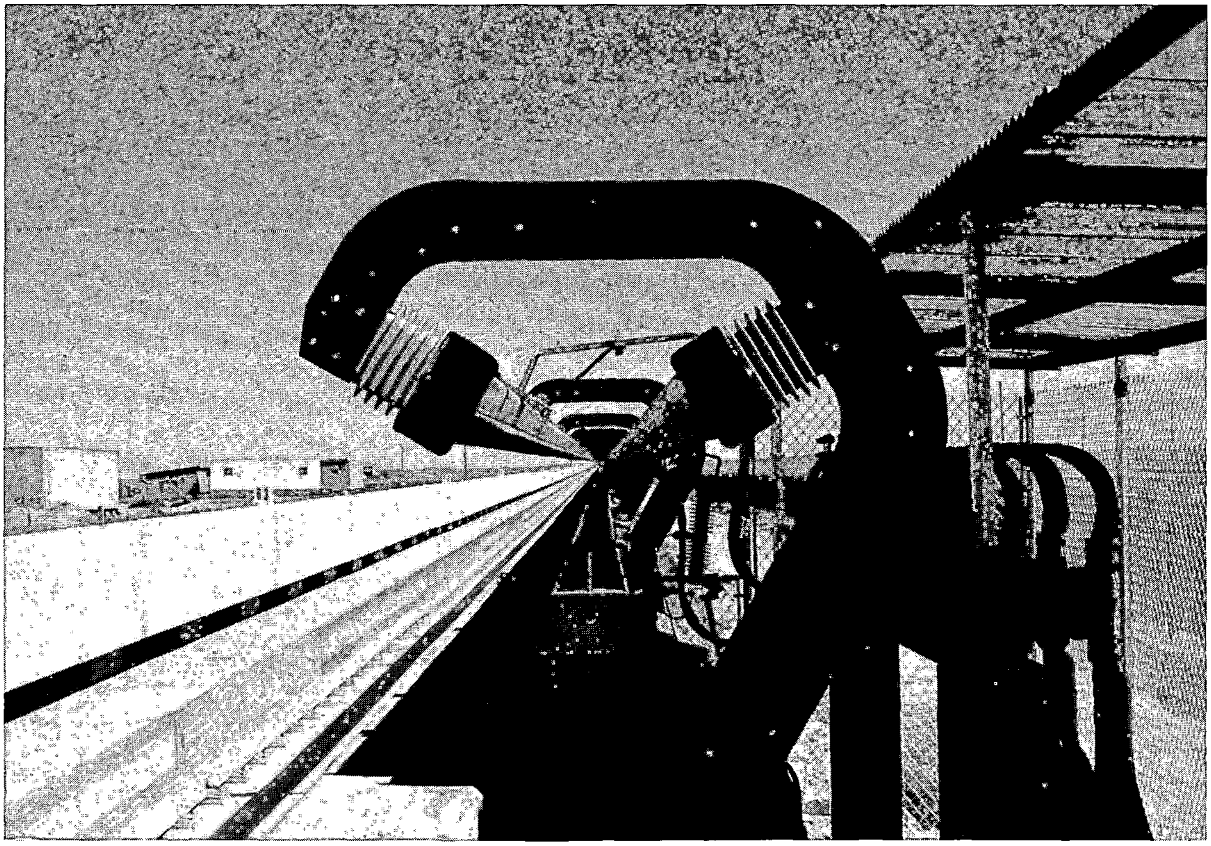

Figure 21. High-Speed Power Distribution Rails.

systems—stiff conductor rails. Comparisions were made of DC and AC, both single-phase and three-phase. DC was ruled out, because studies showed if an arc were to occur between the vehicle collector and the distribution rails there would be no means of extinguishing it. Three-phase turned out to be cheaper than single-phase because of a difference in spacing and size of substations.

After completion of the studies to select the best technique for high-speed power collection, Garrett designed the distribution and collection equipment for the Tracked Levitated Research Vehicle (TLRV) and its guideway at the Transportation Test Center. Garrett designed a sliding contact for the 8250 V. system, consisting of an aerodynamic shaped plug on an arm extended from the side of the vehicle and captive inside a triangular array of contact rails (see Figure 21).

The design was tested on a rocket sled at the Naval Weapons Center, China Lake, California. One thousand amperes were transferred from batteries on the rocket sled to the rails and the mechanical and aerodynamic performance was excellent at speeds up to 313 mph (504 km/h). Wear of carbon brushes mounted in the plug and sliding on the distribution rails appeared to be excessive. TSC made laboratory tests to compare wear of various brush materials and identify the most durable. The tests were run on an apparatus developed by TSC to simulate the loads, vibrations, moisture, and dirt to be encountered. Several graphite compounds had sufficient wear resistance to serve as high-speed brushes.

In the design of the power distribution rails and supports, Garrett examined several designs to ensure that the supports chosen would remain dimensionally stable and hold the conductor rails in accurate alignment, because minor misalignments could cause catastrophic failure of the collector arm and plug. Different materials were investigated to keep the cost of the distributor structure as low as possible.

After the rocket sled tests were successfully completed, the conductor rails and supports used were moved from China Lake and installed on 1640 ft (500 m) of the TLRV guideway at the Transportation Test Center in an effort to economize. This measure enabled the TLRV testing to continue long enough to demonstrate low-speed capability of the power collection system (along with the LIM and PCU).

Controls

The first research contract placed under the HSGT Act was with MIT. One of the tasks under that contract was the organization of system controls, control of vehicle spacing, and scheduling. Another early contract, with TRW, Inc. for systems engineering, included system control research. The importance given to controls research was based on the assumption that some of the candidate high-speed ground systems would involve high vehicle density and require automatic controls for efficient and safe operation.

The MIT work produced mathematical models for headway and traffic merging and a theory of optimum control. Rendezvous techniques were studied to permit high-speed vehicles to receive and discharge passengers without stopping the train.

TRW investigated numerous control devices, including radar, sonar, isotope detectors, laser beams, and wiggly wires. Wiggly wire is a device that transmits signals along wires laid on the track. The other devices are not practical because of an inability to "see" around curves and the signal spillover to adjacent tracks or lanes. From this investigation emerged a concept designed to improve on wiggly wire—Synchronous Longitudinal Guidance (SLG).

SLG consists of computer control of vehicles from entry into a transportation network, continuing during passage through the network until exit. Entry times and routes would be controlled according to traffic flows in the network. The objective of SLG is to prevent internal traffic jams and achieve maximum throughput and minimum vehicle time within the network. Control in the network would be by means of cables buried in the guideway through which electronic signals pass. Sensors on vehicles lock on to the signals in the cables—i.e. synchronize the vehicles and signals.

SLG identified a theory and an algorithm for optimizing vehicular flow through a network. This work was used extensively in studies of an urban dual mode system for UMTA. This work was also used during the Denver transit project where synchronous, quasi-synchronous, and asychronous systems were modeled and studied.

SLG loads a network to capacity and leaves no space for faltering or disabled vehicles. This demands vehicle reliabilities so high as to be impractical today. However, the research has made possible much more informed evaluations of proposed automatically controlled systems.[16]

Obstacle Detection

As high-speed operation necessitates long stopping distances, system safety would be enhanced by the detection of foreign objects that intrude onto the roadway or damage the guideway. In 1967, OHSGT surveyed potential obstacle detection techniques and selected an optical laser beam on which to start research.

The RCA Research Center developed a wayside scanning system using lasers. Although performance of a prototype on field tests was excellent, the cost of the scanner proved to be prohibitive. General Applied Science Laboratories (GASL) did further work on scanning and non-scanning lasers with the unexpected finding that when laser beams are projected over concrete pavement at the height of a few inches (75-100 mm) they are bent upwards on hot days, thus missing the receiver and becoming inoperative. GASL then investigated electrostatic devices, which were dropped when a new technique, a near-infrared beam produced from a diode, was demonstrated to FRA by Applied Metro Technology (AMT) in July 1970. The cost of the diode is much lower than for lasers and the beam is not subject to bending. AMT later marketed the technique as a burglar alarm system, which was the first non-transportation spin-off of HSGT technology.

Approximately 500 ft (152.4 m) of the TLRV guideway at Pueblo was instrumented with miniature near-infrared transmitters located 25 ft (7.6 m) apart along the edge of the guideway. Receivers 50 feet (15.2 m) apart detected the beams. The transmitters were sequentially turned on (ripple-fired) and the central station monitored the signals to the receivers. After installation in 1973, the system worked satisfactorily for a period of two months—i.e., obstacles were detected with an acceptable false alarm rate. Then two types of failure occurred; ambient sunlight caused high false-alarm rates in several receivers and the optical filters became pockmarked. AMT was unable to correct the deficiencies so the concept has not been used.

Communications

Reliable automatic control of vehicles requires a reliable communications link between vehicles and the wayside. Radio frequencies are overcrowded and a non-radio link was considered to be necessary by the HSGT system engineers. A communications link with sufficient capacity could handle passenger and crew communications in addition to control signals.

One communications link that would avoid problems of cables in the guideway or dependency on sliding contacts or wheel contact is a surface wave transmission line. The Telecommunications Laboratory of the Environmental Science Services Administration undertook to investigate this concept for application in HSGT. The surface wave transmission line would parallel the track or guideway and the surface wave would travel along the line in a space a few feet in diameter around the line. An antenna mounted on the vehicle would extend into the space occupied by the surface wave to both receive and transmit signals.

A similar concept is a surface waveguide; the coupling to a vehicle antenna is also the same, but the radiation is in a lobe rather than 360° around a line. Another device that produces a lobe of radiation is the leaky waveguide, which is a tube with holes or slots to allow the radiation to "leak" out. All require a metal conductor extending along the right-of-way. General Applied Science Laboratories (GASL), Wheeler Laboratories, Sumitomo Electric of Japan, and Hughes Research Laboratories studied various waveguides. After the initial studies were completed, FRA selected the dielectric waveguide investigated by GASL for laboratory experiments.

New Mexico State University developed a methology for comparison of communications techniques in the form of a computer simulation, and TSC investigated mechanical problems of installation and operation, such as misalignment and sag. In 1972, TSC started evaluation of a leaky coaxial cable in a field test. A coaxial cable would have less capacity than waveguides but greater tolerance for sag and misalignments and would be cheaper to install. In 1974, the MITRE Corporation was asked to reexamine the problem of capacity. Study showed that the majority of cable capacity requirements that had been used as goals were for passenger telephone service and other communications. If the passenger requirements were reduced, the leaky coaxial cable had more than enough capacity. A thorough evaluation of coaxial cable applications has not been completed.

Surface wave transmission lines, surface waveguides, leaky waveguides, and leaky coaxial cables have been evaluated and compared. Any future communications studies for ground vehicle systems will have a knowledge base on which to build.

From the Metroliner telephone operation, the good quality of VHF radio propagation has been demonstrated through the electromagnetic environment of an electrified railroad. This information is important in the potential application of VHF for both voice and data transmission to and from railroad vehicles and transit cars. TRW used the information in the preliminary design of the Denver light rail system and a Voice Train Control System for a Chessie freight line.

Chapter 6

Demonstrations

The HSGT Act authorized the Secretary to contract for demonstrations to determine the contributions that HSGT could make to more efficient and economical intercity passenger transportation systems. The demonstrations were essentially market tests in which specific and measurable service elements were introduced in various combinations and successive phases.

Under that authority, OHSGT planned demonstrations of improved passenger service designed to measure and evaluate such factors as the public response to new equipment, higher speeds, variations in fares, improved comfort and convenience, and more frequent service. The data obtained were to be a base against which alternative systems of transportation could be evaluated for the Northeast Corridor Transportation Project. An objective was to obtain information on public response to rail system improvements with relatively modest expenditures and small developmental lead times. Planning began even before passage of the HSGT Act.

Two demonstrations were conducted—Washington-New York and Boston-New York—at a cost of about $13 million each which proved that there is a market for good rail passenger service, and eventually led to legislation to proceed with the $1.9 billion rail passenger service improvement program for the Northeast Corridor.

Washington-New York Demonstration

The route between Washington and New York was selected as the site of the first demonstration because it has the largest intercity rail passenger volume in the United States and serves a greater population than any other rail route of similar length.

Demonstration Contract. In 1966, the Government reached agreement with the Pennsylvania Railroad (PRR) for a two-year demonstration of improved passenger service between Washington and New York. The terms of the contract called for a payment of approximately $10 million to the railroad. In return, the railroad would purchase 50 new cars, improve the right-of-way, maintain the track to keep it in the improved condition, and operate the service. Any profits from the demonstration were to be divided equally between the railroad and the Government, until the Government's investment was recovered.

The new cars were to be self-propelled and electric, capable of 160 mph (256 km/h); the improvements in the roadway, including the catenary, were to be sufficient to sustain speeds of 100 to 110 mph (160 to 176 km/h) wherever the alignment of the right-of-way would permit.* To ensure the service would be given a fair trial, the rail-

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* The cars were required to have a speed capability higher than the track could accommodate, so that if the service were successful, further track upgrading and higher speeds could be accomplished.

road was required to undertake an advertising and promotion campaign and conduct training for railroad employees who would be in contact with the public. A $1.7 million training program was organized for these employees, plus maintenance and operating personnel who would be working with the new cars. A grant was obtained from the Department of Labor to pay half the cost.

Metroliner Car Purchase. L. T. Klauder Associates prepared a car specification for OHSGT to be used by PRR in the purchase of new cars, based on the philosophy of using the best technology available without engaging in a development program. Great attention was given to passenger amenities to make the cars as attractive and as pleasant as possible. The railroad issued a request for proposals for cars to meet that specification. From the proposals submitted, a design by the Budd Company was selected (and later named the Metroliner). See Figure 22. A decision was made to equip half the cars with General Electric equipment and the other half with Westinghouse propulsion equipment.

As manufacture was about to begin, the Southeast Pennsylvania Transportation Authority (SEPTA) applied for an UMTA grant to pay for 11 Metroliners to operate between Philadelphia and Harrisburg. The grant was not approved, but the 11 cars were built anyway. They remained at the Budd factory, however, until Amtrak purchased them.

In retrospect the Metroliner program should have had a single product development

Figure 22. Metroliner with Amtrak Markings.

manager for the cars, rather than to have delegated part of the authority. Had there been a government manager with full authority, problems such as poor ride quality—caused by substitution of coil springs for air bags, cross talk between control circuits—caused by mid production wire routing changes, and out of station production line component installation (hindering quality control)—caused by production schedule slippages and attempts to make up lost time, might not have occurred.

Facility Improvements. While the cars were being fabricated, the railroad upgraded the roadbed with heavy maintenance and installation of 190 miles (306 km) of continuous welded rail. New, heavier conductor wire was installed in the catenary along the entire distance between Washington and New York. Including the Metroliner cost of $22 million, the PRR management estimated that $58 million was spent in preparation for the demonstration. The OHSGT-Pennsylvania Railroad contract required construction of high level platforms at Washington, Baltimore, Wilmington, and Trenton to eliminate car steps and expedite loading and unloading. OHSGT made improvements in decor in the Washington and Trenton stations; those at Trenton were part of an upgrading by the city for commuter service, and included track rearrangement to speed movement of trains through the station. Moving ramps for the handicapped and for baggage carts between the train platform and the street level were installed at Baltimore. The OHSGT also installed automatic train information boards at Baltimore, Wilmington, Philadelphia, Trenton, Newark, and New York. Television screens were installed in the Washington station for the same purpose, to make it more convenient for travelers to obtain train arrival and departure information.

Suburban Stations. To initiate projects for suburban park-and-ride stations in Maryland and New Jersey, FRA agreed to pay for the cost of high-level platforms, pedestrian tunnels, and track changes at both locations. At Lanham, in the Washington Metropolitan area, the State of Maryland made land available worth $500,000 and Prince Georges County committed about $128,000 for the parking lot. OHSGT spent $200,000 on the building and track relocations.

The Lanham Station, located near the Capital Beltway, was opened in March 1970. Concurrent with the opening, FRA contracted with bus operators for experimental feeder buses to connect Annapolis and Rockville with selected trains. The service never attracted significant patronage and was soon discontinued.

At Woodbridge, N.J., the State Department of Transportation paid the cost of land acquisition and all other facility construction. The station was opened in November 1971 to inter-city trains and later to commuter trains.

Shuttle Bus Service. In another experiment, a shuttle bus service was begun in September 1970 to run between the Washington, D.C. Union Station and a circuit of hotels and government buildings. The bus company estimated 14,000 riders per month would be needed to make the operation profitable. In spite of considerable publicity, monthly ridership reached only slightly over 2000 and the experiment was discontinued in May 1971.

New Jersey Test Track. As part of the HSGT rail R&D program, a high-speed test track was created by using one of the Pennsylvania Railroad's four mainline tracks between Trenton and New Brunswick, New Jersey. FRA paid for the upgrading of one of the tracks to permit high-speed runs. This track was used for acceptance testing of both the Washington-New York equipment (Metroliners) and the Boston-New York equipment (Turbotrains) in between passage of PRR revenue trains.

Telephone Service. At the suggestion of FRA, the American Telephone and Telegraph Company (AT&T) developed and installed in the Metroliners the first on-board telephones that could receive as well as initiate calls. The $2.1 million cost was borne by AT&T. The telephone service proved very popular at the start of Metroliner service—so popular, that the available radio channels were saturated. At about 7,000 calls per month, AT&T lost money. The charge was raised from a minimum of $1 to $3, which resulted in increased revenue (though still a loss), while usage dropped to 4,000 calls per month. Although the service has not been profitable for the telephone company, it has been liked and used by passengers.

Demonstration Service. The Penn-Central Transportation Company began Metroliner service in January 1969 (after the Pennsylvania Railroad merged with the New York Central Railroad in 1968), with three daily round trips between Washington and New York. The runs were made in less than three hours, except for one non-stop run each way in two-and-a-half hours which was discontinued after six months.

The formal demonstration started in October 1970, when sufficient Metroliner cars had been accepted from the manufacturer to operate seven round trips a day. Service was gradually increased, reaching 14 trains in each direction in April 1972, running hourly from 6:00 am to 8:00 pm (except for 7:00 pm). At that time, train service from Washington through New York was also inaugurated, with one Metroliner running daily between Washington and New Haven, and the conventional trains from Washington to Boston increased from seven to nine.

OHSGT devised machine-readable tags that serve as passenger seat checks for the railroad and as means of collecting passenger travel statistics. Use of the data tags began in July 1966 to develop a time series for the Northeast Corridor studies and as a means to evaluate the demonstrations. FRA continues to process data from Amtrak.

UCLA developed a computer simulation of Penn-Central's Northeast Corridor rail system operations, called TRANSIM, to aid in scheduling the New York-Washington demonstration trains. TRANSIM was used to test proposed schedules for interference with other traffic, including freight, and to calculate running time. TRANSIM is being used at this writing to evaluate proposed improvements in the $1.9 billion Northeast Corridor rail passenger improvement program.

The two-year "test period" of the Washington-New York demonstration was extended through a third year, ending on September 30, 1973. The revenue-sharing provision of the first two years was not continued in the third year due to the financial condition of the Penn-Central. During the first two years, Penn Central estimated the Government's share of the net profit amounted to $2,095,259; later audits by Amtrak reduced this to $1,251,932.

When Amtrak was formed in 1971, the demonstration was coordinated with the new Corporation's service. In October 1973, Amtrak took over the service and later purchased the Metroliner fleet.

Ridership. The Metroliner service

showed that the American public would use quality rail passenger service. Although, at first, ridership on the conventional trains continued to drop, the decrease in total ridership in the Northeast Corridor stopped. Growth of Metroliner ridership offset the drop-off on conventional trains so that total ridership remained steady, which is in striking contrast to all other routes where ridership decreased precipitously in the pre-Amtrak years.

The years 1974 and 1975 reflect the effects of the oil embargo. Ridership increased when gasoline was difficult to obtain for automobile trips, but decreased as concern over the fuel shortage eased. Statistics for the first five months of 1976 show that, as the new Amfleet equipment went into service, ridership on the conventional trains has increased (May 1976 ridership was 17 percent above May 1975). While the Metroliner ridership has fallen, the total ridership for all trains for May 1976 was 3.5 percent above May 1975.

The two Metroliner suburban stations have attracted passengers in large numbers. In FY 1973, 125,000 passengers used the Capital Beltway Station, an increase of 36 percent over the previous year. During that year, the number of trains stopping at that station was increased from 15 to 20 daily. To accommodate the additional patronage, the parking area was increased by 67 percent and the station ticketing equipment and waiting room were enlarged.

The Lanham Station is being moved a short distance, to the New Carrolton rail transit station, which should make access to rail service even more convenient.

Metropark Station, in Woodbridge, New Jersey, also attracted a large patronage; a total of 35,374 intercity rail passengers used the station in the last half of 1972, with 11 trains a day serving the facility.

The Metroliner car design has been used for the locomotive-hauled Amfleet coaches purchased by Amtrak. When the first request for bids for new passenger cars was issued by Amtrak, no U.S. manufacturer was building intercity equipment. If the Budd Company had not been able to use the Metroliner design and tooling, start-up costs would have increased the cost of cars and lengthened delivery times. Amtrak has ordered 492 Amcoaches from Budd, 348 of which had been delivered by the end of 1976. During that year, as cars were steadily accepted, the portion of Amtrak's short-

Annual Rail Passenger Traffic Between New York-Washington[14]

Year	Metroliner	% Change From Previous Year	Conventional Trains	% Change From Previous Year	All Trains	% Change From Previous Year
1967	—	—	6,841,186	—	6,841,186	—
1968	—	—	6,976,228	+ 2	6,974,228	+ 2
1969	604,624	—	6,881,385	− 1	7,486,009	+ 7
1970	1,251,958	+107	5,507,428	−20	6,759,386	−10
1971	1,625,068	+ 30	4,848,216	−12	6,473,284	− 4
1972	2,153,165	+ 35	4,498,821	− 7	6,651,986	+ 3
1973	2,352,763	+ 9	4,491,910	− 0	6,844,673	+ 3
1974	2,493,601	+ 6	5,066,996	+13	7,560,597	+10
1975	2,266,128	− 9	4,796,525	− 5	7,062,653	− 6

haul passengers carried in Amcoaches reached over 50 percent.

Budd has also used the Metroliner structure design in a new self-propelled diesel car, the SPV 2000, scheduled for prototype operation in early 1978.

While the Northeast Corridor plant that Amtrak inherited from the Penn-Central was badly deteriorated, it would have been worse if it had not been for OHSGT, Pennsylvania Railroad, and state and county expenditures on the demonstration. In summary, these improvements were:

- New, heavier conductor wire in the catenary from New York to Washington.
- Continuous welded rail installed on 190 additional miles (306 km) of track.
- Twenty-one miles (34 km) of superb track between Trenton and New Brunswick, N.J., which was used for high-speed test runs in 1967.
- Two new suburban stations.
- Platform improvements in the Washington, Baltimore, and Wilmington Stations.
- Improvements to the interior of Union Station in Washington, with TV information boards and modernized waiting room.

The Washington-New York and Boston-New York demonstrations created the highest revenue routes in the Amtrak system. Without these successful demonstrations, it is possible the current $1.9 billion Northeast Corridor Improvement would not have been undertaken. Amtrak's expectations are that the improved Corridor service will have a "cascade" effect, creating demand on other routes, commencing with those that feed into the Corridor.

Boston-New York Demonstration

The second rail passenger demonstration was intended to test public reaction to improved technology as represented by gas turbine-powered trains; differing from Washington-New York, which tested public reaction to improved service, not technology. First plans were for service between Boston and Providence. Short gas turbine trains were to shuttle back and forth over the 44 miles (70.8 km) between the two cities, providing fast, frequent service. On the basis of that plan, equipment specifications were prepared for two short trains.

When the Boston-Providence intentions were revealed, the State of Connecticut Transportation Authority proposed financial support for the program if the service were run between Boston and New York. Because the New Haven Railroad was in bankruptcy and could not pay for either roadbed rehabilitation or the incremental expense of operating the experimental trainsets, the Federal Government proposed that Connecticut pay for roadbed and structure improvements in Connecticut to reduce the Federal cost of the expanded demonstration. Although a tentative agreement was reached and the program began on that basis, the support from the Connecticut Transportation Authority never materialized.

United Aircraft Corporation agreed to lease to OHSGT two three-car gas turbine trainsets whose design included lightweight aluminum aircraft-type structures and a pendulous suspension with steered axles to round curves at speeds up to 30 percent faster than conventional equipment with equivalent passenger comfort. United named the design "Turbo Train." See Figure 23.

The service was planned with intermediate stops at Route 128 outside Boston, Providence, New London and New Haven, on a 3-hour, 15-minute schedule. By the beginning of 1968, the first trainset had been completed and tested on the high-speed test track in New Jersey, where a speed of 170 mph (273.5 km/h) was reached. United established a maintenance facility in Providence where railroad personnel, under the direction of United Aircraft's engineers and technicians, maintained the trains.

Inclusion of the New Haven in the merger of the Pennsylvania and New York Central railroads into the Penn Central, and negotiations of another agreement with the new management delayed the start of the demonstration. United utilized this period for additional testing of the trainsets and adjustment of the equipment. Service began on April 8, 1969, with one round-trip daily. Additional weekend runs in August and September 1969 revealed the maintenance capability was not sufficient to operate the two trains concurrently on a continuous basis. By June 1970, the performance had improved, so much that an additional round-trip was run on Fridays and Sundays.

From January 1971 through September 1972, successive programs of refurbishment, improvements in soundproofing and ride quality, operations outside the Northeast Corridor, and increase of the number of cars per train limited the availability of the Turbo Trains to one trainset daily Monday through Friday.

Two cars were added to each trainset, increasing seating from 144 to 240. The enlarged trainsets began operating in August 1972. In cooperation with Amtrak, one five-car Turbo Train operated between Washington, D.C. and Parkersburg, W. Va.

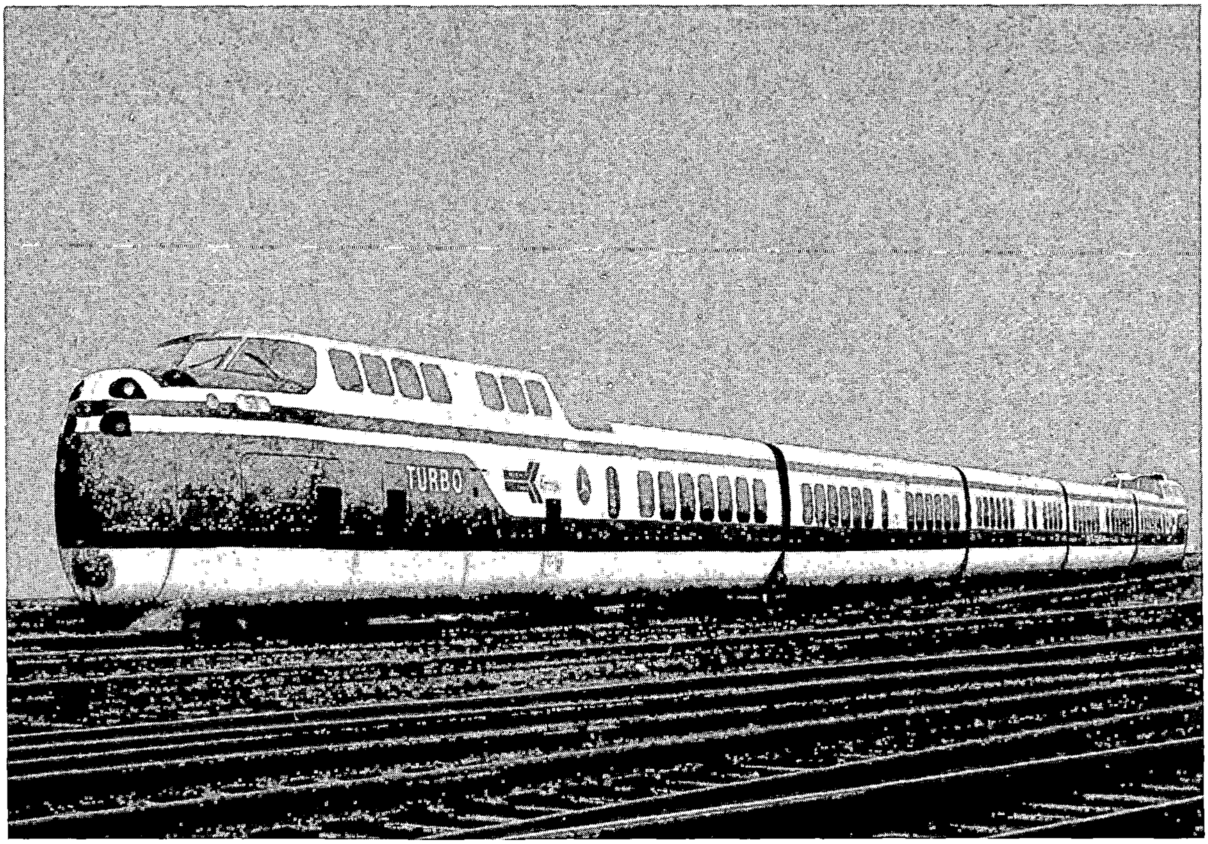

Figure 23. Turbotrain Five-car Set with Amtrak Markings.

for three months. The purpose of the experiment was to test performance in seven-day-a-week service in mountain terrain, cold, and snow. The experience yielded technical data not available on the level and warmer Boston-New York route. Maintenance away from the home base was also an experience of value for future operations. A secondary objective was to determine traveler response in a rural area to new equipment. In spite of Amtrak advertising, the load factor was never good.

The Boston-New York demonstration ended January 22, 1973. Amtrak purchased the equipment and continued service without interruption. Although the Turbo Train program was concerned with experimental equipment, 293,210 passengers were carried and the load factor averaged 58 percent.

The two trainsets were the first newly designed intercity passenger equipment in the United States since the mid-1950s, and the first trains in the world to go into revenue service powered by aircraft-type gas turbines. United Aircraft built five other seven-car Turbo Trains for the Canadian National Railways. These trains had various technical problems, some peculiar to the Canadian version, and were in and out of service for several years. At this time, three trainsets are running in regular Toronto-Montreal service.

French gas turbine trains are in use in both France and this country. The French National Railways have 29 trainsets in regular service and an advanced prototype that has run at speeds up to 185 mph (298 km/h). Amtrak has purchased four French trains manufactured in France and seven more manufactured in this country by Rohr under license.

The demonstration showed that gas turbines are highly reliable, with little maintenance required, and provide excellent acceleration. The lightweight trains permit high braking rates; the aircraft design techniques produce cars that are not only lightweight, but also the stiffest cars ever tested in compression by the Association of American Railroads.

The pendulous suspension provides an excellent ride at high speeds and permits higher speeds on curves. However, ride quality at low speeds on jointed rail is not as good as at high speeds, due to the articulated, single-axle suspension. Some components, chiefly in the mechanical transmission system, turned out to be unreliable and need improvement in future applications.

Auto-Train Demonstration

The first report to Congress on progress of the HSGT program, included plans for an "Auto Ferry" demonstration.[1] The name was changed to Auto-Train after OHSGT received a letter from one of the maritime unions asking to participate in the Auto Ferry demonstration.

Auto-Train was conceived as a demonstration in which private automobiles and their occupants would be transported in rail cars, with the automobiles serving as the principal seating. The demonstration was based on the recognition that long-haul rail passenger service was no longer competitive with air and highway, and that such a service might be a new source of profit for railroads. The risks involved in an experiment with the service seemed to be greater than the railroads would accept. If Auto-Train proved popular and profitable, it was hoped that the railroads would establish service in other parts of the country.

In June 1966, a test of riding performance on rail cars was conducted with AAR by

OHSGT to determine characteristics of rail equipment needed for auto-on-train service. An engineering consultant was engaged to prepare a design and specifications for the service.

Exploration of possible routes indicated a high traffic potential between Washington, D.C. and Jacksonville, Florida. A contract was signed for a market study of automobile travel to Florida. Data on origin, destination, car occupancy and reaction to the proposed auto-on-train service were collected by Florida Atlantic University and the Florida Tourist Bureau. Travel desires of median-income families in nine cities—Boston, New York, Newark, Philadelphia, Baltimore, Washington, Miami, Tampa, and Jacksonville—were obtained. More than 6000 groups entering Florida by automobile were interviewed. The response indicated a projected annual demand of 540,000 cars, which would far exceed the capacity of the proposed test service.

The engineering consultant, L. T. Klauder and Associates, had as a major design objective the easy passage of private autos on and off the rail cars. A bi-level rail car design was chosen and was intended to provide easy access for customers from their cars to restrooms, lounges, entertainment areas, and food service. Terminals were designed with ramps for the bi-level rail cars.

In June 1966 tests had shown freight-car suspensions do not give good enough ride quality for auto-train passengers to ride in their automobiles. The solution seemed to be passenger car suspensions. To ensure passenger car suspension would give a good ride, two automobiles were loaded into an FRA test car and the ride quality was checked on a Florida train by observers and instruments in the seat of one of the automobiles. The ride quality was good and the design of the auto-train cars was completed on the assumption that available passenger car trucks would be used.

The Seaboard Coastline Railroad agreed to operate a 750-mile Washington to Jacksonville run in approximately 12 hours and also to maintain the proposed 15-car train and locomotives. Funds originally available for the demonstration were sufficient to cover design of the equipment and construction of the terminals. However, when additional funds were requested, they were denied by Congress with the reasoning that the market studies showed such favorable potential that there was no need for the Government to pay for a demonstration—industry would take advantage of the opportunity.

Attempts were then made to get industrial firms to join with FRA to conduct a demonstration of Auto-Train, but without success. However, an employee in the Office of the Secretary of Transportation was so confident that auto-train could be a success, he resigned to organize a firm to provide such a service and was able to obtain financing. With the change to carrying autos in closed auto-carrying cars and carrying passengers separately in coaches, he has made an outstanding success of the Auto-Train Corporation.

Airport Access Demonstrations

OHSGT found inadequate ground access to airports in large metropolitan areas to be a major deterrent to more effective use of air transportation and during Fiscal Year 1967 conducted an airport user survey for National, Dulles, and Friendship Airports in the Washington metropolitan area. Analysis of the survey information revealed that a high-speed ground link to Friendship Airport would improve access.

On that basis, engineering studies were begun of a high-speed rail shuttle service between Baltimore and Washington, which would use the existing Penn Central mainline with a new access track to the airport. As the study progressed, the scope was broadened to consider use of the B&O Railroad tracks, either alone or in conjunction with the Penn Central tracks and a rail/bus transfer, rather than a new access track. The cost estimates ranged from $51 million to $71 million, based on the railroads' requirements for track improvements and the purchase of new self-propelled cars. Faced with such costs, the project was not pursued further at that time.

Nine years later, in 1976, Amtrak announced plans for service to the Baltimore-Washington International Airport (Friendship) and a station is to be constructed on the old Penn Central mainline (now Amtrak-owned) with bus service between the railroad station and the airport terminal.

In complaince with the National Capital Transportation Act of 1969, FRA awarded a contract to the Washington Metropolitan Area Transit Authority (WMATA) for a study of the feasibility of extending the regional rail rapid transit system to Dulles Airport. The study considered five alternatives, all using the same trains as planned for the regional system, with tracks in the median of the Dulles access highway, and a subway approach to the airport terminal building. The alternative that was found capable of handling the largest number of passengers was integrated service, with two intermediate stops, to downtown Washington. The cost was estimated to be $90 million. The findings were submitted to the Office of the Secretary of Transportation in July 1971, but with costs already rising above the budget for the existing Metrorail plan, no action was taken.

Several airport access demonstrations outside the Washington area were considered. A Los Angeles Airport demonstration, where highway access was extremely inadequate, progressed to the point of preliminary engineering. In cooperation with UMTA, FRA developed a plan for Tracked Air Cushion Vehicle service, with the first phase of construction to provide service from the San Fernando Valley, with possible extension later to a proposed new airport at Palmdale, California. Local opposition to the planned service was intense enough that the project was not carried beyond the preliminary planning stage.

The principal features of the TACV system developed in the Los Angeles Airport study were used in a study of a system operating between the Capital Beltway and the Dulles Terminal in the Washington, D.C. area. System designs were solicited from Rohr and LTV, Inc. However, Congressional committees would not go along with funds for the project and it had to be cancelled.

The Secretary of Transportation decided to continue with the vehicle design and development for the purpose of demonstrating TACV technology, and to do the demonstration at the Transportation Test Center. A contract was given to Rohr for a prototype urban application, 150 mph (241 km/h) TACV. This was the beginning of the Prototype TACV Project which is described in the Advanced Systems section of this report.

Data Collection

Information to evaluate the use of the two rail passenger demonstrations was obtained in the following ways:

- OHSGT devised a means of obtaining passenger counts by stations of origin and destination, data, and class, identified by train, using machine-readable tags that were also used by the Pennsylvania and New Haven Railroads as seat checks. OHSGT installed a data tag reader on-line with a computer to process the ridership statistics. The tags have been providing ridership statistics since July 1966.

- Questionnaires were filled out by passengers through the first two years of the Metroliner demonstration as a means of evaluating changes in service and to provide information on travel behavior. The questionnaires showed that the new train riders were prior automobile and airplane travelers.

In 1966, OHSGT arranged with the U.S. Census Bureau to increase coverage in the Northeast Corridor by the National Travel Survey, starting in 1967, which was used to determine how travel behavior was affected by the demonstrations. The National Travel Survey shows a decline in air passengers, while auto use continues to increase and rail has held even as a percentage of all travel.

After Amtrak took over the Corridor service, the data tag statistical collection was continued and, in January 1973, extended to the Philadelphia-Harrisburg and New Haven-Springfield runs. Other nationwide data were collected through a matrix system. As of July 1976, input to the computer system was switched from the data tag system to the Amtrak Train Earnings Ridership data base. FRA now produces ridership statistics on all Amtrak routes from the tapes.

Chapter 7

Grade-Crossing Safety

In 1968, the Secretary of Transportation directed the FRA and Federal Highway Administration to form a joint national program to improve railroad-highway grade-crossing protection. FRA participation was based on the prospect of more frequent and faster service on the Washington-Boston routes; special emphasis was given to the Northeast Corridor. The first inventory made was of the public crossings on the Penn Central between Washington and New York, followed by an inventory of those between Boston and New York.

FRA contributed funds for grade-crossing protection in Maryland in a joint program with the state of Maryland, Prince Georges County, and the City of Baltimore. A second joint program was with the State of Delaware. Protection was improved at 20 grade-crossings through the two programs. The improvements included changes in highway approaches, removal of sight obstructions on approaches, and installation of train-activated warning devices and advance warning highway signs. Similar programs followed in Connecticut, Rhode Island, and Massachusetts.

The national program continued this type of action through the Association of American Railroads; a national inventory has been created and the FHWA receives annual appropriations for grants to states to improve crossing protection. FRA, as a part of the safety R&D program, is developing improved hardware, especially, lower cost devices, so that the available funding can be used to protect the maximum number of crossings.

Chapter 8

Transportation Test Center

Site Selection

After the first two years of HSGT R&D, when some of the initial technical studies were completed, planning began for test and evaluation of the hardware that was to be developed. A look at both industry and government testing facilities revealed none that could test high-speed ground vehicles or other major HSGT system components. The only high-speed railroad test track in the United States was the Pennsylvania Railroad's mainline between Trenton and New Brunswick, New Jersey, which had been upgraded for OHSGT use in the Demonstration Program, and operational and safety constraints severely limited its use for tests.

The early planning for the Center was on a narrow basis, primarily to find a site where high-speed test runs could be made in isolation, protected from interference and without danger to passersby or nearby property. Several abandoned rail lines were considered, but all either had grade-crossings or were not straight enough to permit the high speeds envisioned. As it became apparent that an entirely new site was needed, FRA's thinking broadened to consider long-term requirements and also the possibility that other DOT administrations—e.g., National Highway Traffic Safety or Urban Mass Transportation—might find co-location of test facilities desirable.

An initial search was made by OHSGT engineers in 1967 through the real estate records of other Federal departments, especially Defense, Interior, Agriculture, and the General Services Administration. The search was conducted on the assumption that the test facility would be located on property owned by the Federal Government, most probably on a military installation. A review of the inventory of military bases disclosed that none that were suitable could be released or shared. For various reasons, no other agency could locate a site that could be used.

Next, data compiled by the Atomic Energy Commission in its 1964-1966 search for a location to build a linear accelerator was suggested as a source of potential sites. The AEC provided their evaluation of over 100 localities. From these records, the former Lowry Air Force Base bombing range, now owned by the State of Colorado was selected as a potentially suitable location. While the original plan had been to consider only Federally controlled land, the Lowry Range became a possibility when the State of Colorado offered to make the land available. However, later analysis of earthwork for a high-speed loop found the terrain was too rough.

When Lowry was inspected, the news media reported the visit. Consequently, a number of other state and local governments, as well as Indian tribes, began proposing use of their lands. During the December 1967 to February 1968 period, 41 proposals were received, including two more from Colorado. A preliminary survey of data submitted eliminated the great majority because of unsuitable terrain, inaccessibility, or insufficient area.

At this point, it became apparent that the quantity of engineering data was much too large to be handled by the small FRA staff and that the decision should be carefully documented in view of the intense competition for the test facility. In April 1968, a contract was awarded to collect the necessary data from the most promising sites. A set of criteria was established and an organized site search was begun. Each site was judged on the following criteria:

- As wide a variation as possible in climatic conditions, to approach all-weather testing.
- Relatively smooth terrain, to minimize earth-moving costs yet permit some grades.
- An area on the order of 50 square miles.
- Land at no cost to the Federal Government.
- No public roads on site, to avoid grade-crossings on test tracks.
- Nearby communities with suitable living conditions for employees; industrial and technical support; and, preferably, a university with technical and/or scientific departments; no residential or business areas close enough to be disturbed by noise of testing.
- Little or no economic activity that would be displaced by the facility.

OHSGT evaluated the contractor's report—including data on the terrain, weather, industrial and technical support—for seven sites and presented the findings to the Office of the Secretary of Transportation. The result was a directive from the Secretary to do a formal site evaluation by a board to be chaired by a representative of the Office of the Secretary, with members from each of the administrations within DOT.

The board used the FRA studies, looked at preliminary data of additional sites, and then visited the locations that the preliminary review showed to be the best. The characteristics of each location, how well it met the criteria, and any other pros and cons were presented in a report to the Secretary. On the basis of that report, in December 1969, the Secretary selected a site northeast of Pueblo, Colorado, to be the Transportation Test Center (TTC).

Establishing the Facility

When DOT informed the State of Colorado of the site selected, the state land board had to acquire several small tracts of land before the entire 50 square miles (127.4 sq. km) could be leased to DOT. On August 22, 1970, representatives of the State of Colorado and DOT met in Pueblo and signed a 50-year lease with an option to renew. The cost to DOT was $10. That same month, ground was broken for the first test facility—a test track for the Linear Induction Motor Research Vehicle (LIMRV). At this time, the Urban Mass Transportation Administration decided to locate the rail transit test activities at the Test Center.

Road access to the test site was gained when Pueblo County extended a north-south gravel county road north to the southern boundary of the site and halfway up the eastern boundary, a total of six miles (9.6 km). Later, with money raised by a special tax assessment, Pueblo County graded a road running northwest from the Pueblo Municipal Airport, 19 miles (30.6 km) to the southwest corner of the test site, and along the southern boundary to join the original road along the site's eastern edge. This road considerably shortened the distance and driving time between the city of Pueblo and the Test Center. On occasion, however, heavy rains washed out the airport road where it crosses two creeks. Then, until the earth was moved back, the original road was again the only access into the test site.

The Test Center lies two miles north of the northern border of the Pueblo Army Depot, one of the reasons for choice of the site. Shortly after construction started, offices for the Test Center manager were set up in space loaned by the Army Depot. The Army provided much help in the first stages of establishing the center and the cooperation continues today.

Immediately after selection of the site for the TTC, the Federal Highway Administrator offered FRA the services of the FHWA regional office in Denver for construction activities at the Center. The offer was accepted, and FHWA surveying crews were at work even before the lease with the state was signed. The Denver office provided surveying, specification preparation, contracting, and construction supervision on all of the early test track construction. The FHWA assistance was considered so valuable at the peak of construction activity that FRA manpower allocations were transferred to the Denver office to assure continuation of the effort. In addition to surveying done by FHWA to locate test facilities, the Coast and Geodetic Survey surveyed the entire site to the highest order of accuracy and established permanent survey monuments.

Construction of the LIMRV test track included a spur track connecting it to the rail network in the Army Depot. The depot is linked to the Santa Fe/Missouri Pacific mainline, which runs east from Pueblo. Construction materials for the LIMRV track were hauled in on the spur track. Switches were installed in the spur to provide rail access to the Center buildings and test tracks. Today, the spur is used to ship materials, equipment, and test vehicles into the Center.

Test Facilities

Because of the need for early testing, construction of the LIMRV test facility started in August 1970 with just preliminary plans for the Test Center and incomplete test facility requirements.

The first set of test requirements was published in the Fourth Report on the HSGT Program, which covered the period ending September 30, 1970.[6] Excerpts from that report given a picture of the planning at that stage:

- LIMRV: . . . will be used to test the linear induction motor (LIM) up to 200 mph 322 km/h). . . .
- Tracked Air Cushion Research Vehicle: . . . to test the LIM up to 300 mph (483 km/h) . . . while collecting power from the wayside . . . will include vehicle aerodynamics, air cushions, secondary suspension . . . obstacle detection and communications.
- TACV Prototype: . . . 150 to 200 mph (241 to 322 km/h) for airport access and, subsequently, a 300 mph (483 km/h) prototype for intercity service.
- Railroad . . . both conventional and high-speed . . . to include: suspension/track interaction and stability, including derailment; propulsion, braking and adhesion; wheel and rail wear; and track failure experiments. It should also include provisions for prototype testing . . . high-speed rail and contemporary locomotive-hauled freight equipment should be accommodated.

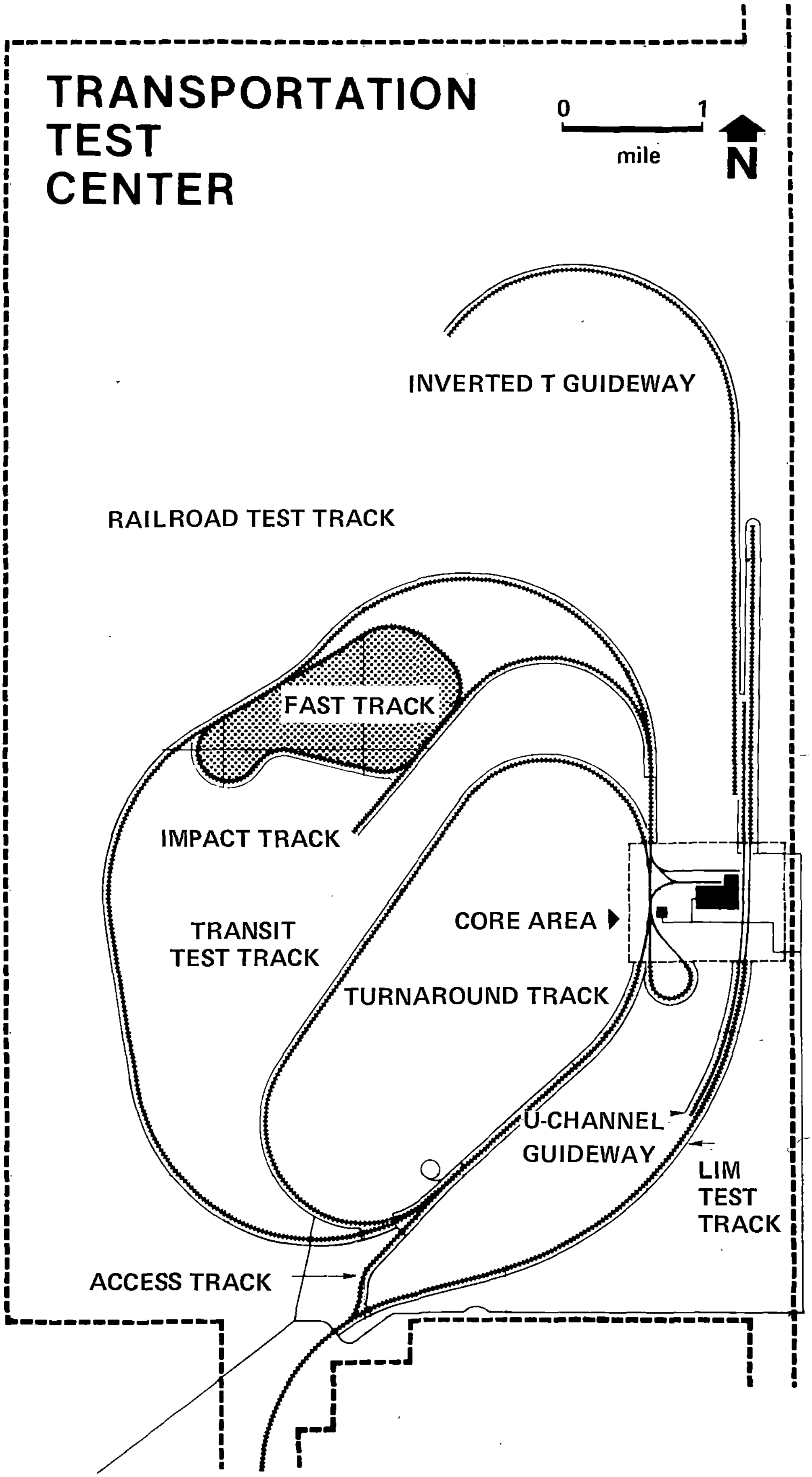

Figure 24. Transportation Test Center Layout.

- Tube Vehicle Systems: . . . both evacuated and atmospheric pressure systems need to be tested, together with operations in tunnels of surface vehicles like the TACV . . .
- Network Controls. Several automobile-related systems will require . . . control of headways, switching and exit. . . .
- Suspended Vehicle Systems: . . . dynamic interaction between vehicle and guideway up to 150 mph (241 km/h). . . .
- Growth Potential: . . . Safety—including destructive impact and survival testing. Passenger—automobile and freight interchange. . . .

The Fourth Report also stated in the Rail Technology section: "Final design and construction of a wheel-rail dynamics laboratory is under contract to Wyle Laboratories, Inc. The laboratory, to be included in the Test Center at Pueblo, Colorado, will be used to study the dynamics of both freight and passenger railroad vehicles. . . ."

The Tube Vehicle, Network Control, and Suspended Vehicle test facilities have not been built, but all the others are operational. Although the Rail Dynamics Laboratory does not yet have the full testing capability, the growth potential has already been achieved for safety testing and in addition, a rail transit testing facility exists at the TTC. See Figure 24.

In March 1971, construction began on the first section of the 9.1 mile (14.6 km) transit oval, electrified with a third rail 600 volt DC system. The first section, of 2.8 miles (4.5 km), was dedicated in August 1971. A second construction phase to close the loop was completed in the fall of

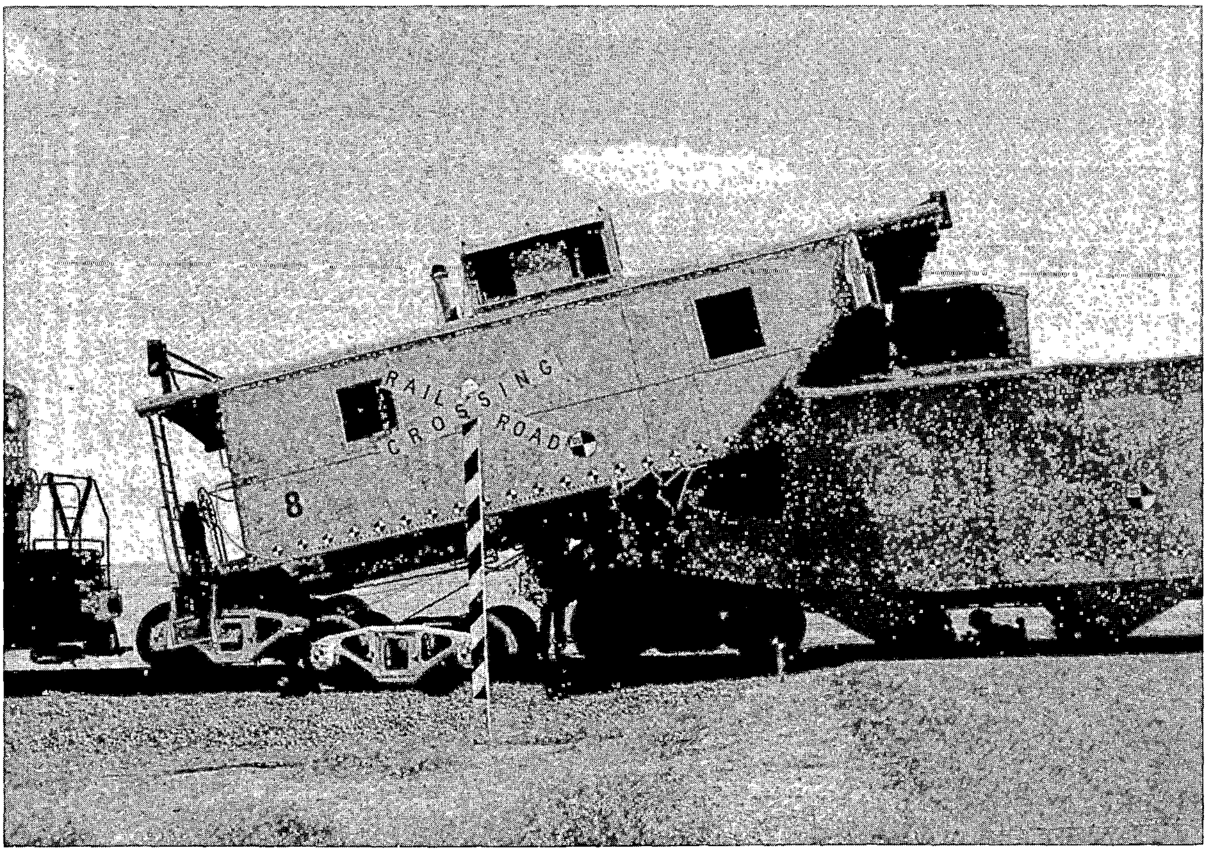

Figure 25. Train to Train Crashworthiness Test.

1972. The facility consists of the track and a 7700 sq. ft. (715 m^2) maintenance building containing a 100 ft (30.5 m) service pit, 600 volt DC power source, and a track scale. The transit oval includes six different combinations of welded or jointed rail and wooden or concrete crossties. In the summer of 1975, catenary was erected to test Standard Light Rail Vehicles; test vehicles can now use third rail or overhead electrification.

With the start of operations on the Facility for Accelerated Service Testing (FAST) in September 1976, the conventional railroad test tracks at the TTC totaled a little over 22 miles (35.4 km) in length. The first two tracks were completed in mid-1973: the .76-mile (1.2 km) Impact Track and part of the Dynamics Track of 5.7 miles (9.2 km). The 14-mile (22.5 km) high-speed loop was built in two sections, both started in 1975. FAST is used to life-test track and rolling stock components. A train operating 16 hours a day around the 4.8-mile (7.7 km) loop exposes track and equipment to loads ten times as rapidly as in revenue service. The Impact Track is used for destructive testing—train-to-train collisions, see Figure 25. The Dynamics Track is used to measure wheel forces, vibration characteristics, truck oscillations, and long train dynamics. Tests that have been run on the Dynamics Track are described in the Rail Technology section. The TTC complex of test tracks is now superior to any railroad test facility anywhere in the world. The only other facilities like FAST are in the USSR and Czechoslovakia, but those facilities do not have the complex of other types of test tracks that the TTC has.

FAST is the result of outstanding cooperation between government and industry. Railroads (through the Association of American Railroads) and suppliers (mostly

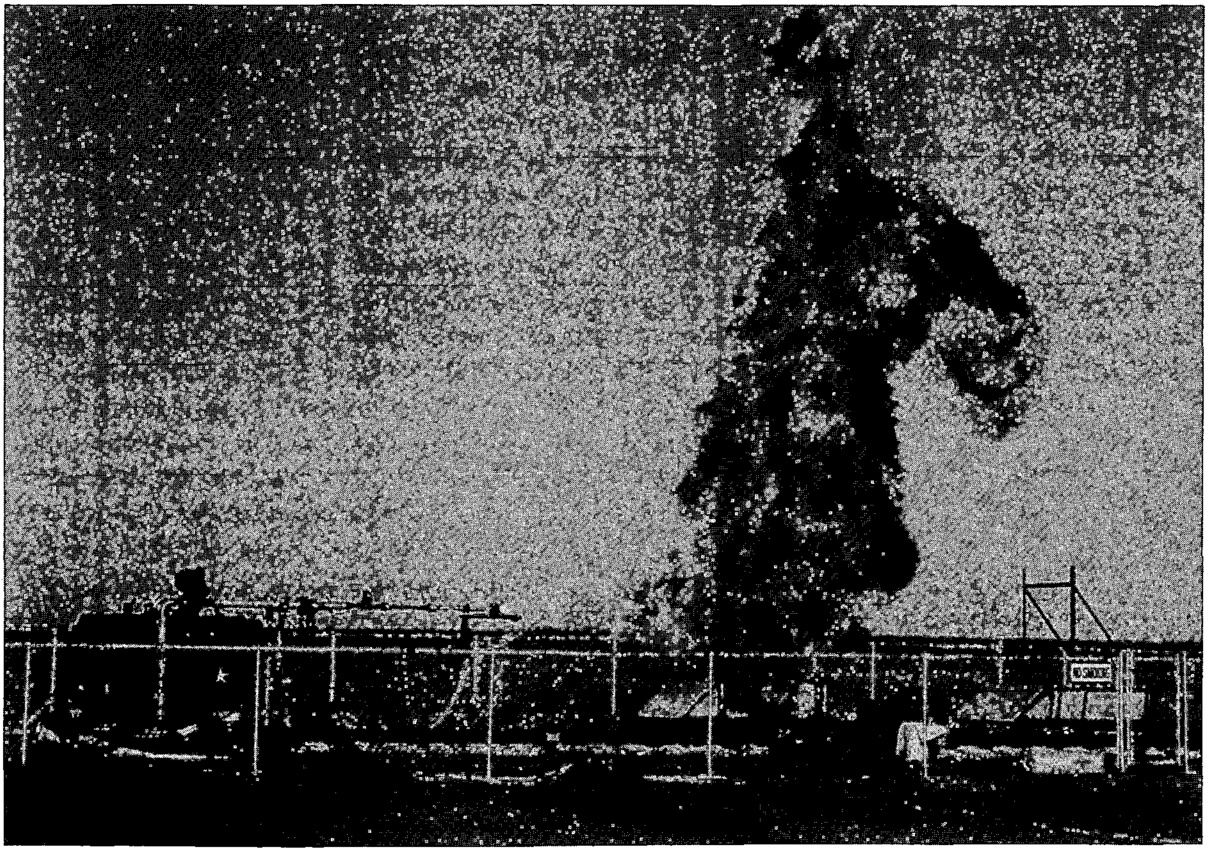

Figure 26. Torch Test on Coated Track Car Section.

through the Railway Progress Institute) furnished the track components, ballast, and rail (welding rail into 1440 ft (439 m) lengths), ties, spikes, turnouts, and switches. Railroads furnished locomotives and cars; railroads and suppliers furnished car parts. The FRA funded the construction and maintains the track and the train, and funds the operation.

The only test facility at the TTC that does not involve moving vehicles (or simulation) is the Tank Car Torch Test Facility. In the center of a half-mile (0.8 km) radius safety zone, tank car thermal insulations are subjected to high temperatures from a propane torch to simulate a fire after an accident. This facility is operated under the joint Association of American Railroads/Railway Progress Institute/FRA Tank Car Safety Project. (See Figure 26).

Support Facilities

The first support facilities at the Test Center were four office trailers on a gravel hardstand. As construction of test tracks proceeded, so did the construction of service roads which grew to 40 miles (64 km) by the end of 1973. An automobile overpass, carrying the main entrance road over the LIMRV and TLRV guideways into the core area (the building complex) of the Center, was completed in July 1972.

In February 1971, an architect-engineer contract was awarded to a minority business enterprise for design of the project management building. Although the building was designed for the test program management offices, it also temporarily housed the Center headquarters. The 14,000 sq. ft. (1,300 sq. m) building was occupied in February 1972. Although designed to accomodate 70 people, the building housed 90 people before the end of 1972.

A five-year electric utility contract was signed in June 1972, and Southern Colorado Power Company began the construction of an 11-mile (18 km), 115 kv transmission line to the Center operations area.

In addition to surveying and construction supervision, the FHWA regional office in Denver took on the job of finding a supply of water for the Center. All local information indicated that any aquifer was several thousand feet down and the most logical way to obtain water was to purchase it from the cattle companies whose wells were located on the edges of the site. After a study of the formations under the Test Center, a FHWA geologist directed the drilling of a test well almost in the exact center of the site and, at 180 ft (54.9 m), struck a sufficient flow of water to supply all the Test Center's needs for the foreseeable future. A water supply system, consisting of a 300,000-gallon (1.135 megalitre) storage tank with pump and distribution lines to the various buildings and fire hydrants, was completed in January 1973.

During 1972, a centerwide communications system went into operation, with a three-frequency portable radio network. The MITRE Corporation began a communications requirements study as part of a master planning effort for future expansion of facilities and test activities.

Construction began in 1973 on the Center Services Building, a 63,000 sq. ft (5850 sq. m) facility to house a high bay repair and maintenance area for rail test vehicles, research vehicles, and test center locomotives and rolling stock. In that year, FRA assumed responsibility for paving the road to the airport, and FHWA began design of an all-weather road. Design of an operations building to house the Center headquarters and relieve the overcrowded Program Management Building began in 1973. In

October of that year, the Operations and Maintenance contractor completed a five-year technical development program to guide expansion of the Center.

By the fall of 1974, there were seven permanent or semi-permanent buildings in use and two more under construction. In use were four test vehicle maintenance buildings, for the Linear Motor Research Vehicle, the Tracked Levitated Research Vehicle, the Prototype Tracked Air Cushion Vehicle, and Transit vehicles, and the Program Management building, Rail Dynamics Laboratory, and a storage and maintenance building. Construction had started on the Operations Building and the Center Services Building which the Center occupied in January 1975. Twenty office trailers were in use at the various test tracks and facilities for data collection, instrumentation storage, etc. The 28,000 sq. ft (2600 sq. m) Operations Building passed final inspection in August 1975. See Figure 27.

Substations for power to the PTACV and TLRV guideways were operating in 1975 and construction had begun on the Rail Transit loop substation. Two 750 kw standby generators were available to supply power in emergencies and the internal power distribution system was substantially complete. Other new construction included two 30,000-gallon (113,550 litre) fuel storage tanks. By September 1975, all but a short section of the airport road was paved—that section required a bridge for which additional funds had to be requested. September 1975 also saw the first proposed master plan for the Center.

Fence building became a continuing activity early in the life of the Test Center. Nearby ranchers who had leased the land for cattle grazing before the state leased it to DOT continued to graze their cattle on the unoccupied portions as long as they did not interfere with construction or test activities. Barbed wire fences were built not only to keep cattle away from the active areas, but also to keep out antelope and people. As construction of facilities progressed, the fences were extended until the center was completely enclosed. Barbed wire has been used because more solid fence, such as chain link, accumulates banks of tumbleweed.

Conservation and environment have entered into facility construction in more ways than one. For example, if areas denuded of vegetation during construction are not reseeded, "blow-outs" occur. The high winds scoop the dust out and large craters are formed; the windborne dust is an air pollutant. For the first construction project, the Agriculture Extension Service was asked for recommendations on restarting vegetation. At the start of earth-moving, the top few inches of soil were stockpiled and respread after completion of the project. Then, a mixture of grass seeds, which the Extension Service recommended, were sown, and the area was mulched. Experience showed that water was necessary to germinate the seeds and irrigation pipe has been used to get water to the seeded areas. Wind erosion has continued to be a problem and several schemes were tried—from elaborate arrangements of snow fences to laying old tires close together over bare areas—none of which was very successful. Restarting vegetation has proven to be the best answer.

Operations

The first phase of operations at the TTC was predominately construction activity. From August 1970 until the Operations and Maintenance contractor personnel began to arrive in July 1972, other agencies of the Federal Government, primarily from DOT, assisted a small number of FRA and UMTA

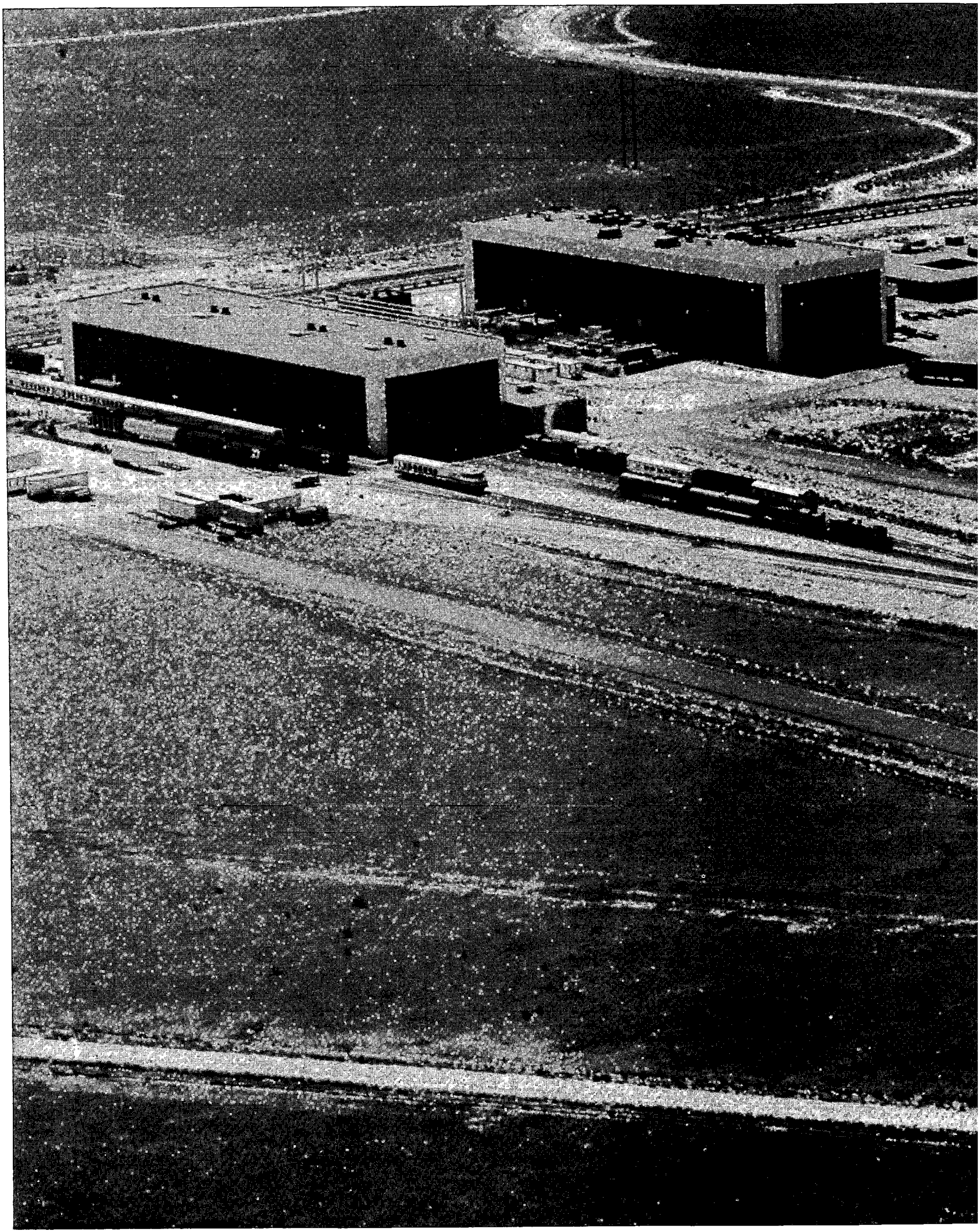

Figure 27. The Core Area of Transportation Test Center.

representatives to supervise construction contractors. As described above, FHWA surveyors and civil engineers were at work soon after the Secretary's announcement of the site selection; other personnel, inspectors and engineers from the FAA, the Corps of Engineers, and the Pueblo Army Depot (PAD), participated before the end of 1970. During the first phase, security was provided by a small business minority contractor from Pueblo.

The support equipment acquisition began with borrowing from PAD, leasing from GSA, and purchasing. The initial major piece of equipment purchased was a 3000 hp (2240 kw) diesel electric locomotive.

When Kentron-Hawaii, Ltd. started as the first operations and maintenance (O&M) contractor, the number of support personnel was built up quickly to provide direct support to test contractors as well as perform the logistics and housekeeping functions. A four-man fire department was formed to provide standby protection during testing (which test contractors had provided for themselves). Kentron began a systematic review of government surplus lists to acquire as much equipment and supplies as possible without spending Test Center Funds. The most valuable surplus equipment obtained were 13 diesel electric locomotives from the Army. These 1500 hp (1119 kw) locomotives were built late in World War II, and after service in Iran, had been in storage since 1946. The locomotives, with little maintenance other than new batteries, were put right to work as switchers and test vehicles in grade-crossing impacts. Several have been used in locomotive/caboose collision tests and tank car impacts.

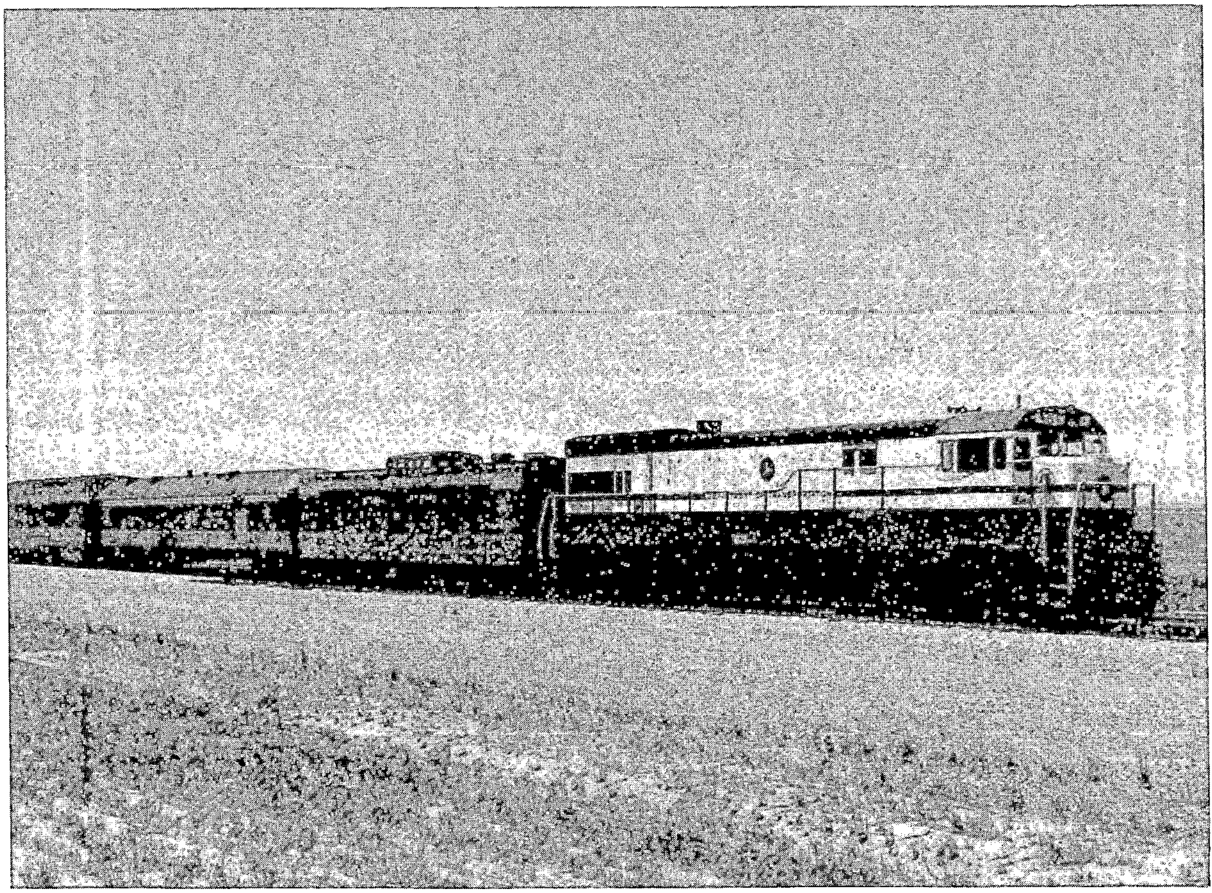

Figure 28. A Test Train Consist Pulled by DOT Locomotive.

Other major equipment purchased includes fire trucks and mobile radios. Much surplus road and track maintenance equipment and machine tools have been found. Other machine tools had to be purchased. The O&M contractor took over the test control function to ensure safety and proper logistics support to the test contractors. Test activity has increased to an average of two tests a day, with as many as six or seven conducted in one day.

Test programs run include tests for manufacturers and Amtrak in addition to those described in other sections of this report. Some of these are:

Railroad

1. LRC—passenger train ride quality and reliability evaluation for a Canadian consortium of companies
2. Freight Car Truck—American Steel Foundries proprietary test
3. High-Speed locomotive—evaluation of high-speed performance for Amtrak
4. Freight Car Truck—Dresser Industries proprietary test
5. Hazardous Materials Car Stability—performance of Dept. of Defense cars
6. Amfleet Cars—reliability tests for Amtrak
7. Rohr Turboliner tests for Amtrak
8. Freight Car Truck—ACF proprietary tests

(An example of a railroad test is shown in Figure 28).

Transit

1. Track Geometry Measuring Equipment—developmental tests

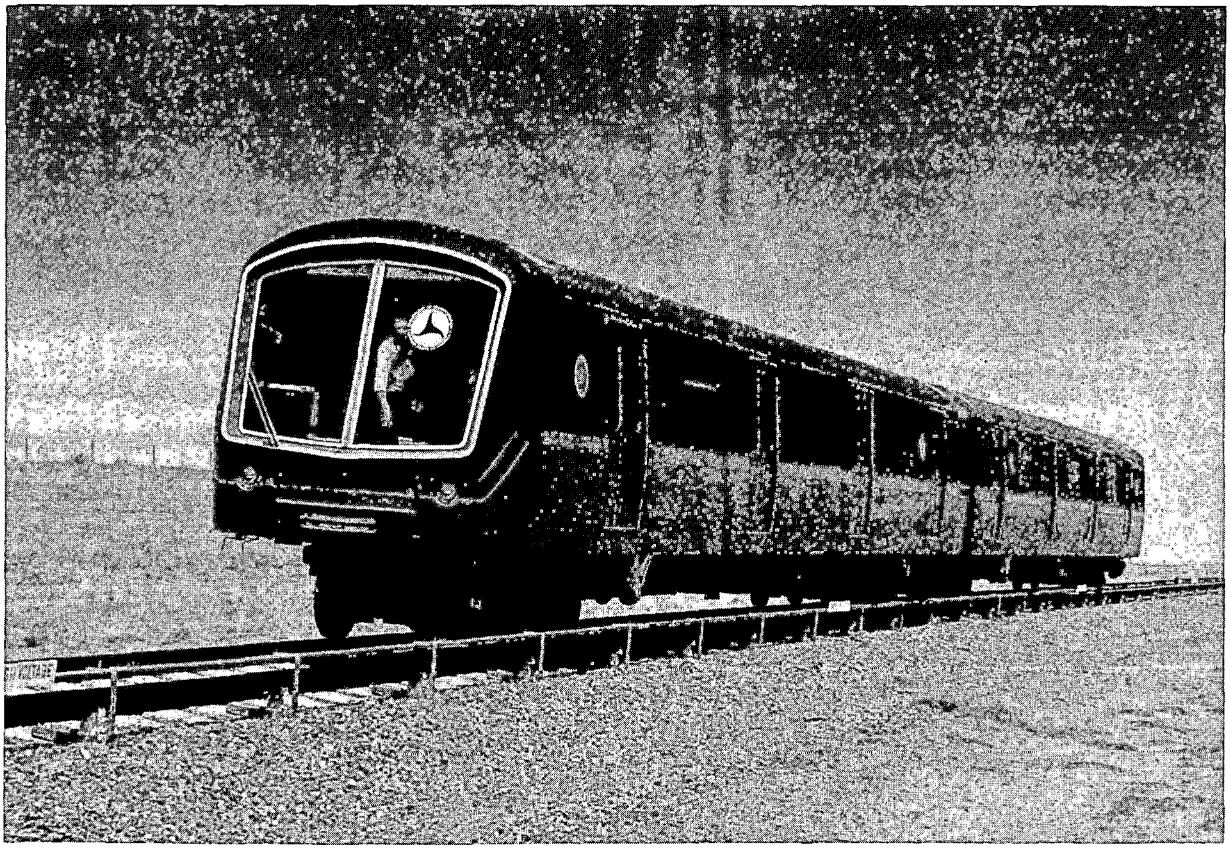

Figure 29. State of the Art Cars (SOAC) on UMTA's Rail Transit Test Track.

2. SOAC—reliability and performance of transit car
3. Gas Turbine/Electric—performance tests of dual propulsion
4. Stored Energy Car—performance and reliability tests of flywheel
5. SLRV—performance of light rail vehicle

In 1976 Dynelectron won a recompetition of the O&M contract and took over from Kentron-Hawaii. By the fall of 1976, over 300 employees were at work at the TTC.

(An example of a transit test is seen in Figure 29).

Chapter 9

Tunneling

The first studies of high-speed ground transportation made for the Department of Commerce in 1965, concluded that tunnels would be important to any future ground transportation systems. This conclusion was reached, because high speeds require protected and relatively level guideways—for which tunnels excel, and also because the cost of surface routes through urban centers was, in some cases more expensive than tunneling. If the cost of tunneling were to be reduced significantly, subsurface routes might be used more for all modes of ground transportation.

In 1966, OHSGT joined with the Bureau of Mines, the Bureau of Reclamation, the Corps of Engineers, the Bureau of Public Roads, the Geologic Survey, the Atomic Energy Commission, and the Air Force in an Ad Hoc Committee on Rapid Excavation. The committee's first action was to sponsor a study by the National Academy of Sciences (NAS) to review possible new tunneling techniques. The NAS found that with adequate research, savings of more than $10 billion might be possible in the construction of 3,000 miles of tunnels that they forecast for construction for the period between 1967 and 1990. An additional $13 billion could be saved in mining.

The size of the possible savings justified an extensive research program. Therefore, after the U.S. Department of Transportation was established, a R&D program was organized under the direction of the Office of the Secretary of Transportation, with the FHWA, UMTA, and FRA participating. FRA was assigned primary responsibility for hardrock tunneling research.

The intercity transportation systems studied in the HSGT program would require long tunnels to go beneath urban areas. On intercity trips, tunnels can be deep in the ground because ascent to and descent from the surface are infrequent. Deep tunnels do have advantages—avoidance of building foundations and utilities—which can be realized if the cost can be reduced.

Rock Cutting

Most hard-rock tunneling has been done by drilling small holes into the tunnel face, inserting explosives, blasting out several feet of rock, and then removing the rock fragments. This is a batch process and can be relatively slow and expensive. A continuous cutting process, when feasible, should be less costly. Mechanical boring machines, which are continuous, have been used with some success in soft to medium hard rock. However, the cutters wear rapidly, even in softer rock, and constitute a large part of the boring expense.

The OHSGT program started with a search for other continuous rock-cutting techniques that would be faster and significantly cheaper than "drill and blast." The first technique to be evaluated was one to improve the effectiveness of cutting with jets of water. Water-jet cutting had been used but the speed was not enough to decrease tunnel boring costs. The proposal was to introduce cavitation (air bubbles) into a jet of water, the reasoning being that cavitation causes rapid wear of ships' propellers and, therefore, should erode rock. However, laboratory tests showed insufficient improvement of water jets with cavitation over those without.

Another technique to reduce the cost of hard-rock tunneling was to adapt the flame-jet technique used to quarry stone blocks. The flame jet produces noise, heat, and fumes, which can be tolerated in the open air, but in a tunnel would be dangerous to tunneling crews. United Aircarft Corporation Research Laboratories, in looking at ways of using flame jets in the tunnel environment, developed a concept of flame jets to cut numerous grooves in the rock face, followed by mechanical or hydraulic arms to break out the rock between grooves. The answer to the environmental problems was to enclose the crew in an environmentally controlled cab and have them operate the equipment remotely. This concept was technically feasible, but the cost savings appeared to be marginal and it required a rather large investment to develop. To date, no excavation machinery manufacturers have been willing to risk the necessary investment.

OHSGT sponsored theoretical work at MIT on the mechanics of rock fracture and the effects of chemicals on the strength of rock. Laboratory tests showed a noticeable decrease in the strength of the wetted area of several types of rock when various chemicals were sprayed on them. A field experiment was conducted in a Chicago storm sewer being excavated by machine through limestone. Aluminum chloride was mixed with the water sprayed on the tunnel face to keep dust down. The rate of advance of the boring machine increased by 10 percent over the rate achieved without aluminum chloride in the spray water.

Surfactant work also continues under the sponsorship of the National Science Foundation (NSF). Different types of surfactants have been tested with diamond-tipped drills and may reduce wear rather than weaken the rock. Another approach to weakening rock was studied by MIT graduate students using a laser borrowed from Raytheon Corporation. Laser beams had been tried on rock before, but merely melted small holes that could not be used effectively to fracture rock. The students found an unfocused laser beam did not melt the rock, but heated it sufficiently to weaken it considerably. Results were so encouraging that a system engineering study was done on a laser boring machine.

An early finding in that study was that the power required for a machine to bore a transportation-sized tunnel exceeded the largest laser built or proposed. The study was then changed to a "laser-assisted" boring machine. On mechanical boring machines, which rotate the entire boring head, the outer cutters wear fastest as they travel farthest. A machine was designed to incorporate a laser beam with an array of mirrors to divide the beam into smaller beams and direct each of the small beams on to the rock in front of a cutter on the outer periphery of the machine head. The heat from the laser beam produces weakening or thermal stress and the mechanical stress introduced by the cutter is lower. Although the design significantly reduced the power, it still required a laser larger than those commercially available.

High-pressure water jets are being investigated further by NSF to assist mechanical boring machines in much the same fashion as the laser-assisted boring machine concept. Results have been encouraging and attention has been directed toward the reliability of high-pressure pumps.

Still another technique proposed for fracturing rock was the use of very high-velocity gas guns developed to simulate meteoroid impact on space vehicles. In experiments performed at the Naval Research Laboratory, small nylon pellets did shatter a substantial volume of rock, but significant improvement in rates of advance cannot be accomplished without a rapid firing gun. The magnitude of the potential improvement in rate of excavation was not judged by FRA to be large enough to warrant the investment necessary to develop such a gun.

The most extensive effort in the HSGT program to improve rock fracture techniques was in the use of intermittent high-velocity jets of water. Several contracts were awarded to universities and research organizations to study different aspects of this technology. On the basis of their results and work done in the USSR, a contract was given to Terraspace, Inc., to design and test a single-shot, very high-velocity water "cannon." The cannon was built with a Russian-patented nozzle calculated to extrude water at velocities up to 12,000 ft/sec (3660 m/sec).

After laboratory tests on cubes of rock, the cannon was tested in a limestone and a granite quarry. The calculated velocities were not achieved, but results were satisfactory in the volume of rock fractured. See Figure 30.

Further development is required to reduce noise, to simplify the mechanisms, and to design a rapid firing mechanism (without which a respectable rate of advance could not be achieved). This additional development has not been undertaken as other R&D tasks have been judged to be of higher priority and/or have a greater chance of success.

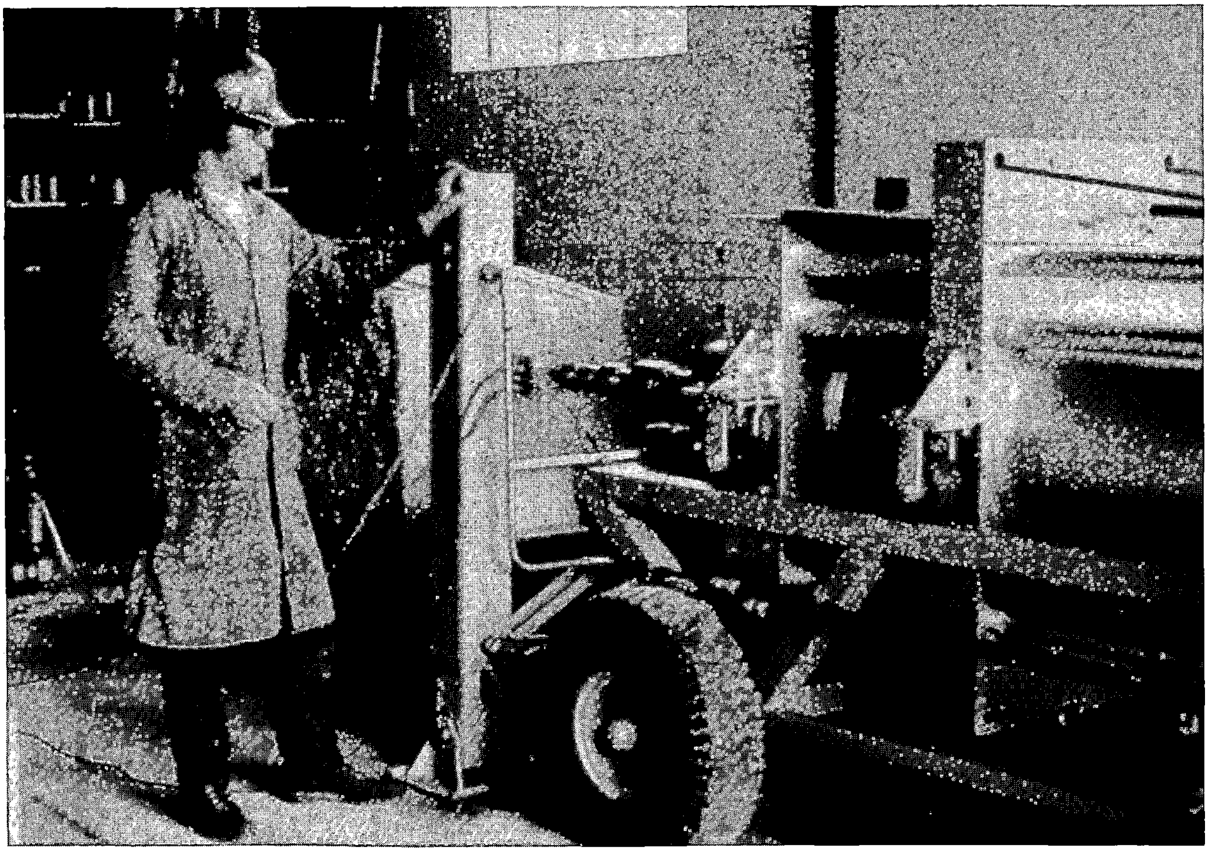

Figure 30. High Pressure Water Cannon Being Tested on Rock Test Cube.

Cost Estimating

To obtain better cost estimates, Harza Engineering developed a computer program that improved the accuracy of estimating the cost of proposed hard rock tunneling. The programmed input consists of such data as: geology, diameter, depth and length of the tunnel, method of excavation, and thickness and type of lining. The program computes costs for labor, materials, and supervision for tunnels and shafts. The program was so well received that the FRA contract with Harza was extended to modify the computer program to handle soft ground tunneling estimating as well. The Boston District Office of the Corps of Engineers had a copy made of the deck of computer cards for use in planning a water supply system for Hartford, Connecticut.

The cost estimating model is in use at this writing, in a study sponsored by the National Science Foundation of "Comparative Costs of Tunnels with Depth of Construction in Urban Areas," for which the model is computing costs of tunnels at various depths.

Tunnel Lining

The largest single research effort in the HSGT tunneling program was research on tunnel linings, which can constitute as much as 30 to 40 percent of the construction cost. Even in hard rock, the linings are a significant portion of the tunneling cost. A program at the University of Illinois, which started in 1967 and continued throughout the remainder of the HSGT program, studied a number of different aspects of tunnel liners and made important contributions to the state-of-the-art. The objectives were to examine the theory of earth pressures and their effect on liner design, and to investigate new liner materials and cheaper methods of placing liners. Increasing the rate of liner installation was singled out as particularly important, since lining technology is inadequate to keep up with the rate of boring in many types of rock formations.

To speed the rate of liner installation, Illinois came up with a concept of a continuous-lining tunneling system. The system consists of a tunnel-boring machine; concrete handling, mixing, and pumping equipment; and slipforms, seals, and jacks for thrusting against the wet concrete to move the tunnel boring machine forward. The Office of the Assistant Secretary for Systems Development in 1976 began the development of a prototype extruded linear system.

Continuous lining has been made possible by the development of wire-reinforced regulated-set concrete. One-inch (25 mm) long wires are added to concrete during mixing and are scattered randomly through the mix to add tensile strength. The regulated-set concrete investigation resulted in the development of mixes that achieve a compressive strength of 1000 psi (70 kg/cm^2) in 1½ hours, but will allow adequate handling time before it sets. These characteristics offer possibilities in sprayed-on concrete, such as shotcrete, as well as with slipformed linings. Experimental mixes having various quantities of wire fibers and regulated-set cements were tested to arrive at the optimum characteristics. The work included pumping tests through pipes. Control of the flow is difficult because the wires jam valves and clog pipes at bends and connections.

From the laboratory experiments, the Illinois staff prepared a manual for shotcrete practice in underground construction, which contains design considerations, engineering properties, application techniques, and shotcrete specifications. Also included are information dealing with the use and engineering properties of fiber and regulated-set cement shotcrete, and guidelines for placing shotcrete underground.

In addition to the continuous lining and materials research at Illinois, a new large-scale test facility for liners and sets* were constructed in the University's civil engineering laboratory. The facility consists of eight massive reinforced-concrete abutments, against which 60-ton (54.4 metric ton) hydraulic jacks can react to provide the loading forces. The abutments are bolted to the structural testing floor of the building to help take the loads from the jacks. Liners up to 10.2 ft (3.1 m) in diameter have been tested. This is half-scale for a single track transportation tunnel. See Figure 31.

Steel sets that have been tested include: "H" sections and both hollow and concrete-filled rectangular and round tubular sections. Conventional concrete, polymer, and steel fiber reinforced concrete liners were also tested. The test program showed that the rolled steel H sections normally used for the temporary sets are not as strong as tubular sections.

Through the work on the FRA contracts, the Civil Engineering Department of the University of Illinois has built up an outstanding ability for research on tunnel lining materials and techniques. The test facility is available for other organizations to evaluate new liner designs. The first use has been under a joint UMTA/OST project; a precast liner designed for a section of Baltimore subway was tested. That design has been included as a bid option in the Invitation for Bids for construction of a 1700-ft (518 m) section of tunnel.

Completion of mix tests and preparation of the manual for wire-reinforced shotcrete for

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*Sets are temporary supports used until permanent lining can be installed.

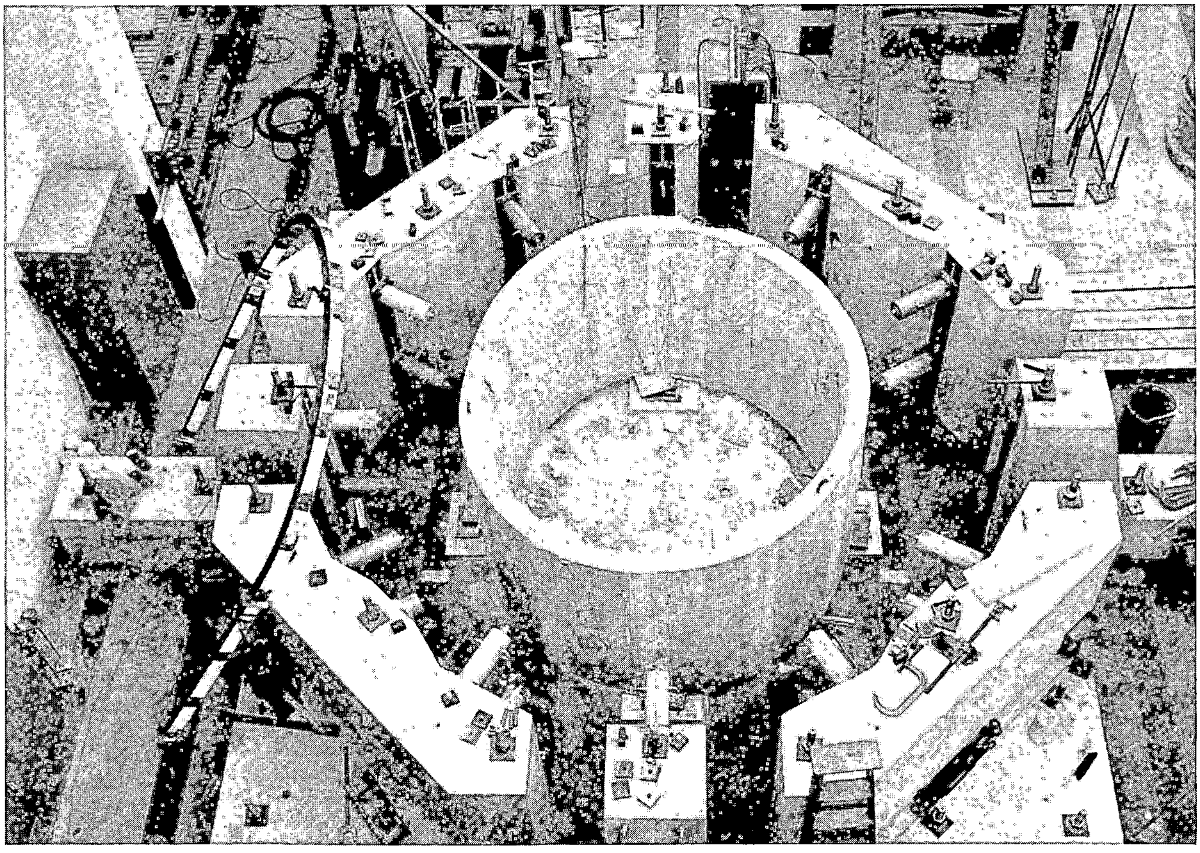

Figure 31. Linear Test Facility at the University of Illinois.

tunnels, described above, has completed the research. Commercial organizations in England and Germany are now marketing equipment for wire-reinforced shotcrete, but as yet, no U.S. company has used the technology.

Work is continuing on the extruded liner concept under OST sponsorship; a contract is expected in early 1977.

Soft-Ground Tunneling

Early in the HSGT tunneling program, a survey was made by Fennix and Sisson, Inc. of soft-ground tunneling methods, with a comparision of their cost-effectiveness. Cost differences between the most promising alternatives—dredgehead, soil-water balance, and wheel-and-shield concepts—were found to be small.

Materials Handling

A similar survey by Holmes and Narver, Inc., of materials handling (spoil removal and construction materials) produced evidence that the current practice of using rail cars could be improved upon by use of a new wayside propulsion method—moving horizontal wheels pushing against the sides of the cars.

When the decision was made by FRA not to request any HSGT funds for FY 1976, the tunneling program was transferred to the Office of the Assistant Secretary for Systems Development and Technology.

Chapter 10

International Cooperation

In 1966, the OHSGT staff made their first visits to organizations doing research on high-speed rail and HSGT systems in other countries. The organizations visited were: Japanese National Railways, British Rail, British Hovercraft, Office of Research and Experiments (ORE) of the International Union of Railways, German Federal Railways, and the Societe d' Aerotrain. From these visits grew cooperative projects and contracts with British Rail Research Centre, Tracked Hovercraft Ltd. (a company formed in 1967 to take over the British tracked air cushion vehicle development), and French Aerotrain.

OHSGT sponsored a small laboratory experiment on an air cushion by a post doctoral fellow from the University of Palermo. This resulted in an information exchange on air cushion vehicle and linear electric motor development between OHSGT and Palermo.

After the DOT Office of International Research Cooperation was formed, FRA participated in the DOT international exchange programs with a number of countries. The contacts made with the Japanese National Railways developed into a part of the formal DOT annual information exchange meetings.

In 1973, FRA joined the International Union of Railways and ORE, and soon afterward, an R&D office representative participated with representatives of British Rail, German Federal Railways, Italian Railways, French National Railways, and Japanese National Railways, in a survey of HSGT technology and research activities. A report was published to be used by member railroads in considering high-speed ground systems as alternatives in their long-range planning.

With the changed FRA goals and priorities for undertaking R&D efforts in the solution of more near term conventional railroad problems, international, bi-lateral agreements with some of the foreign countries were redirected in order to complement FRA's R&D efforts. The FRA agreement with the Soviet Union was given greater importance due to the high degree of development of the Soviet rail technology and similarities between Soviet and U.S. systems. The technology exchange program with the Soviet Union has resulted in FRA receiving several hundred technical documents from them. There have been several visits and discussions between the two countries on topics of pressing importance. Additionally, FRA and DOT have another agreement with the Soviet Union on advanced systems research. Under this agreement the U.S. has been providing the Soviets with the results from the R&D which was done under the HSGT program and the Soviet side has been undertaking further research in the areas of Magnetic Levitation and Linear Electric Motor propulsion. Since U.S. effort in the advanced systems has been reduced, the results of the work which the Soviets are doing will be available to the U.S. for its possible future application in this country. The agreement with the U.S.S.R. calls for reassessment of the present technology and to develop plans for further research. Accordingly, the FRA is keeping the PTACV in storage. This may serve as an excellent test bed for a possible cooperative activity should the Soviets succeed in making major advances in these two areas.

Another country with which FRA has placed greater importance for collaboration in conventional rail research is the Federal Republic of German (FRG). The agreement with the FRG has been restructured to take advantage of their advanced technology in conventional rail. The FRA has received valuable technical information from the German Ministry of Transport and German Federal Railways which will prove to be highly useful in the revitalization of the U.S. railroads. As with the Soviet Union, DOT has a program with the German Ministry of Research and Technology (MORT) under an existing agreement for cooperation in advanced systems research. Under this agreement, Germany is conducting tests on their Maglev vehicle and guide-way to validate the U.S. computer model for determining the vehicle/guideway response to the guideway characteristics. Similar tests based on the German computer model will be conducted and the results used to compare the two.

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APPENDIX A HSGT Act and Extensions—1965—1968—1970—1972

Public Law 89-220
89th Congress, S. 1588
September 30, 1965

An Act

To authorize the Secretary of Commerce to undertake research and development in high-speed ground transportation, and for other purposes.

High-speed ground transportation study.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That, consistent with the objective of promoting a safe, adequate, economical, and efficient national transportation system, the Secretary of Commerce (hereafter in this Act referred to as the "Secretary") is authorized to undertake research and development in high-speed ground transportation, including, but not limited to, components such as materials, aerodynamics, vehicle propulsion, vehicle control, communications, and guideways.

Demonstration program.

SEC. 2. The Secretary is authorized to contract for demonstrations to determine the contributions that high-speed ground transportation could make to more efficient and economical intercity transportation systems. Such demonstrations shall be designed to measure and evaluate such factors as the public response to new equipment, higher speeds, variations in fares, improved comfort and convenience, and more frequent service. In connection with contracts for demonstrations under this section, the Secretary shall provide for financial participation by private industry to the maximum extent practicable.

SEC. 3. Nothing in this Act shall be deemed to limit research and development carried out under the first section or demonstrations contracted for under section 2 to any particular mode of high-speed ground transportation.

Transportation data, collection.

SEC. 4. The Secretary is authorized to collect and collate transportation data, statistics, and other information which he determines will contribute to the improvement of the national transportation system. In carrying out this activity, the Secretary shall utilize the data, statistics, and other information available from Federal agencies and other sources of the greatest practicable extent. The data, statistics, and other information collected under this section shall be made available to other Federal agencies and to the public insofar as practicable.

Advisory committee, establishment.

SEC. 5. (a) There is hereby established in the Department of Commerce an advisory committee consisting of seven members who shall be appointed by the Secretary without regard to the civil service laws. The Secretary shall designate one of the members of the Advisory Committee as its Chairman. Members of the Advisory Committee shall be selected from among leading authorities in the field of transportation.

(b) The Advisory Committee shall advise the Secretary with respect to policy matters arising in the administration of this Act, particularly with respect to research and development carried out under the first section and contracts for demonstrations entered into under section 2.

Common carrier employees. Protective arrangements.

SEC. 6. (a) In carrying out the provisions of section 2 of this Act, the Secretary shall provide fair and equitable arrangements, as determined by the Secretary of Labor, to protect the interests of the employees of any common carrier who are affected by any demonstra- 79 STAT. 893. 79 STAT. 894. tion carried out under a contract between the Secretary and such carrier under such section. Such protective arrangements shall include, without being limited to, such provisions as may be necessary for (1) the preservation of rights, privileges, and benefits (including continuation of pension rights and benefits) to such employees under existing collective-bargaining agreements, or otherwise; (2) the continuation of collective-bargaining rights; (3) the protection of such individual employees against a worsening of their positions with respect to their employment as a result of such demonstration; (4)

54 Stat. 905.

assurances of priority of reemployment of employees terminated or laid off as a result of such demonstration; and (5) paid training or retraining programs. Such arrangements shall include provisions protecting individual employees against a worsening of their positions with respect to their employment as the result of such demonstrations which shall in no event provide benefits less than those established pursuant to section 5(2)(f) of the Interstate Commerce Act (49 U.S.C. 5). Any contract entered into pursuant to the provisions of section 2 of this Act shall specify the terms and conditions of such protective arrangements.

Labor standards.

49 Stat. 1011; 78 Stat. 238. 40 USC 276a-276a-5.

63 Stat. 108.

(b) The Secretary shall take such action as may be necessary to insure that all laborers and mechanics employed by contractors or subcontractors in the performance of construction work financed with the assistance of funds received under any contract or agreement entered into under this Act shall be paid wages at rates not less than those prevailing on similar construction in the locality as determined by the Secretary of Labor in accordance with the Davis-Bacon Act, as amended. The Secretary shall not enter into any such contract or agreement without first obtaining adequate assurance that required labor standards will be maintained upon the construction work. The Secretary of Labor shall have with respect to the labor standards specified in this subsection, the authority and functions set forth in Reorganization Plan Numbered 14 of 1950 (15 F.R. 3176; 64 Stat. 1267; 5 U.S.C. 133z-15), and section 2 of the Act of June 13, 1934, as amended (48 Stat. 948; 40 U.S.C. 276c).

SEC. 7. In exercising the authority granted in the first section and section 2 of this Act, the Secretary may lease, purchase, develop, test, and evaluate new facilities, equipment, techniques, and methods and conduct such other activities as may be necessary, but nothing in this Act shall be deemed to authorize the Secretary to acquire any interest in any line of railroad.

Contracts with public or private agencies.

SEC. 8. (a) (1) In exercising the authority granted under this Act, the Secretary is authorized to enter into agreements and to contract with public or private agencies, institutions, organizations, corporations, and individuals, without regard to sections 3648 and 3709 of the Revised Statutes (31 U.S.C. 529; 41 U.S.C. 5).

(2) To the maximum extent practicable, the private agencies, institutions, organizations, corporations, and individuals with which the Secretary enters into such agreements or contracts to carry out research and development under this Act shall be geographically distributed throughout the United States.

79 STAT. 894.

79 STAT. 895.

(3) Each agreement or contract entered into under this Act under other than competitive bidding procedures, as determined by the Secretary, shall provide that the Secretary and the Comptroller General of the United States, or any of their duly authorized representatives, may, for the purpose of audit and examination, have access to any books, documents, papers, and records of the parties to such agreement or contract which are pertinent to the operations or activities under such agreement or contract.

60 Stat. 810.

(b) The Secretary is authorized to appoint, subject to the civil service laws and regulations, such personnel as may be necessary to enable him to carry out efficiently his functions and responsibilities under this Act. The Secretary is further authorized to procure services as authorized by section 15 of the Act of August 3, 1946 (5 U.S.C. 55a), but at rates for individuals not to exceed $100 per diem, unless otherwise specified in an appropriation Act.

SEC. 9. In exercising the authority granted under this Act, the Secretary shall consult and cooperate, as he deems appropriate, with the Administrator of the Housing and Home Finance Agency and other departments and agencies, Federal, State, and local. The Secretary shall further consult and cooperate, as he deems appropriate, with institutions and private industry.

Reports to President and Congress.

SEC. 10. (a) The Secretary shall report to the President and the Congress not less often than annually with respect to activities carried out under this Act.

(b) The Secretary shall report to the President and the Congress the results of his evaluation of the research and development program and the demonstration program authorized by this Act, and shall make recommendations to the President and the Congress with respect to such future action as may be appropriate in the light of these results and their relationship to other modes of transportation in attaining the objective of promoting a safe, adequate, economical, and efficient national transportation system.

Availability of information.

(c) The Secretary shall, if requested by any appropriate committee of the Senate or House of Representatives, furnish such committee with information concerning activities carried out under this Act and information obtained from research and development carried out with funds appropriated pursuant to this Act.

Appropriation.

SEC. 11. There are hereby authorized to be appropriated such sums as may be necessary to carry out the provisions of this Act, but not to exceed $20,000,000 for the fiscal year ending June 30, 1966; $35,000,000 for the fiscal year ending June 30, 1967; and $35,000,000 for the fiscal year ending June 30, 1968. Such sums shall remain available until expended.

Termination date.

SEC. 12. Except for section 4, this Act shall terminate on June 30, 1969. The termination of this Act shall not affect the disbursement of funds under, or the carrying out of, any contract commitment, or other obligation entered into pursuant to this Act prior to such date of termination.

Approved September 30, 1965.

LEGISLATIVE HISTORY:

HOUSE REPORTS: No. 845 accompanying H. R. 5863 (Comm. on Interstate & Foreign Commerce) and No. 1017 (Comm. of Conference).
SENATE REPORT No. 497 (Comm. on Commerce).
CONGRESSIONAL RECORD, Vol. 111 (1965):
July 23: Considered and passed Senate.
Sept. 2: Considered and passed House, amended, in lieu of H. R. 5863.
Sept. 17: House agreed to conference report.
Sept. 20: Senate agreed to conference report.

Public Law 90-423
90th Congress, H. R. 16024
July 24, 1968

An Act

82 STAT. 424

To extend for two years the Act of September 30, 1965, relating to high-speed ground transportation, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That (a) the first section of the Act entitled "An Act to authorize the Secretary of Commerce to undertake research and development in high-speed ground transportation, and for other purposes", approved September 30, 1965 (79 Stat. 893; Public Law 89-220; 49 U.S.C. 1631), is amended by striking out "Secretary of Commerce" and inserting in lieu thereof "the Secretary of Transportation".

High-speed ground transportation. Research extension.

(b) Section 5 of such Act of September 30, 1965, is amended by striking out "Department of Commerce" and inserting in lieu thereof "Department of Transportation".

Advisory committee.
49 USC 1635.

(c) Section 7 of such Act of September 30, 1965, is amended by adding at the end thereof the following: "In furtherance of these activities, the Secretary may acquire necessary sites by purchase, lease, or grant and may acquire, construct, repair, or furnish necessary support facilities. In furtherance of a demonstration program, the Secretary may contract for the construction of two suburban rail stations, one at Lanham, Maryland, and one at Woodbridge, New Jersey, without acquiring any property interest therein."

Secretarial authority.
49 USC 1637.

(d) Section 9 of such Act of September 30, 1965, is amended by striking out "Administrator of the Housing and Home Finance Agency" and inserting in lieu thereof "Secretary of Housing and Urban Development."

49 USC 1639.

(e) The first sentence of section 11 of such Act of September 30, 1965, is amended by striking out "and" and by striking out the period at the end thereof and inserting in lieu thereof a semicolon and the following: "$16,200,000 for the fiscal year ending June 30, 1969; and $21,200,000 for the fiscal year ending June 30, 1970."

Appropriation.
49 USC 1641.

(f) The first sentence of section 12 of such Act of September 30, 1965, is amended by striking out "1969" and inserting in lieu thereof "1971".

Termination date.
49 USC 1642.

Approved July 24, 1968.

LEGISLATIVE HISTORY:

HOUSE REPORT No. 1606 (Comm. on Interstate & Foreign Commerce).
SENATE REPORT No. 1436 (Comm. on Commerce).
CONGRESSIONAL RECORD, Vol. 114 (1968):
July 12: Considered and passed House.
July 19: Considered and passed Senate.

Public Law 91-444
91st Congress, S. 3730
October 13, 1970

An Act

To extend for one year the Act of September 30, 1965, as amended by the Act of July 24, 1968, relating to high-speed ground transportation, and for other purposes.

High-speed ground transportation. Research extension.

82 Stat. 424.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That (a) the first sentence of section 11 of the Act entitled "An Act to authorize the Secretary of Transportation to undertake research and development in high-speed ground transportation", approved September 30, 1965 (Public Law 89-220; 79 Stat. 893; 49 U.S.C. 1631-1642), as amended, is amended by striking out ", and" and the period at the end thereof and inserting a semicolon and the following: "and $21,700,000 for the fiscal year ending June 30, 1971.".

Termination date.

(b) The first sentence of section 12 of such Act of September 30, 1965, as amended, is further amended by striking out "1971" and inserting in lieu thereof "1972".

Approved October 13, 1970.

LEGISLATIVE HISTORY:

HOUSE REPORT No. 91-1251 accompanying H.R. 17538 (Comm. on Interstate and Foreign Commerce).
SENATE REPORT No. 91-1036 (Comm. on Commerce).
CONGRESSIONAL RECORD, Vol. 116 (1970):
July 30, considered and passed Senate.
Sept. 30, considered and passed House, in lieu of H.R. 17538.

Public Law 92-348
92nd Congress, S. 979
July 13, 1972

An Act

To amend the Act of September 30, 1965, relating to high-speed ground transportation, to enlarge the authority of the Secretary to undertake research and development, to remove the termination date thereof, and for other purposes.

High-speed ground transportation. Research extension.
79 Stat. 893.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That (a) the first section of the Act entitled "An Act to authorize the Secretary of Commerce to undertake research and development in high-speed ground transportation, and for other purposes", approved September 30, 1965 (49 U.S.C. 1631), is amended by inserting "and door-to-door ground transportation" immediately after "high-speed ground transportation".

Demonstration program.

(b) The first sentence of section 2 of such Act (49 U.S.C. 1632) is amended to read as follows: "The Secretary is authorized to contract for demonstrations to determine the contributions that high-speed ground transportation and door-to-door ground transportation could make to more efficient, safe, and economical intercity transportation systems.".

Contracts.

SEC. 2. (a) Section 8(a) of such Act (49 U.S.C. 1638(a)) is amended by redesignating paragraphs (2) and (3) as paragraphs (3) and (4) respectively, and by inserting immediately after paragraph (1) the following new paragraph:

"(2) In awarding contracts in connection with research and development and demonstration projects under this Act, the Secretary shall give priority to proposals which will increase employment in labor areas (as those areas are described by the Secretary of Labor in title 41 of the Code of Federal Regulations)—

"(A) which are experiencing a rate of unemployment of 9 per centum or more of the area's work force, or a rate of unemployment of 150 per centum or more of the federally determined unemployment rate for the entire United States; or

"(B) which have experienced a 1 per centum increase in unemployment, as determined by the Secretary of Labor, of the available work force as a result of the termination or reduction of a federally financed or supported program and such increase in unemployment continues to exist.

Nothing in this paragraph shall be construed to require that any contract awarded under this Act must be wholly performed in any one labor area.".

(b) Paragraph (3), as so redesignated by subsection (a) of this section, is amended to read as follows:

86 STAT. 462
86 STAT. 463

"(3) Except as provided in paragraph (2) of this subsection, the private agencies, institutions, organizations, corporations, and individuals with which the Secretary enters into agreements or contracts to carry out research and development under this Act shall, to the maximum extent practicable, be geographically distributed throughout the United States.".

Appropriation.
82 Stat. 424;
84 Stat. 915.

SEC. 3. The first sentence of section 11 of such Act (49 U.S.C. 1641) is amended by striking out "and" and by striking out the period at the end thereof and inserting in lieu thereof a semicolon and the following: "$97,000,000 for the fiscal year ending June 30, 1973; $126,000,000 for the fiscal year ending June 30, 1974; and $92,900,000 for the fiscal year ending June 30, 1975.".

Repeal.

SEC. 4. Section 12 of such Act (49 U.S.C. 1642) is repealed.

72 Stat. 569.

SEC. 5. (a) Section 504(a)(3) of the Interstate Commerce Act (49 U.S.C. 1234(a)(3)) is amended by striking out "fifteen years after the date thereof" and inserting in lieu thereof "twenty-five years after the date thereof".

72 Stat. 569.

(b) Section 505 of the Interstate Commerce Act (49 U.S.C. 1235) is amended by inserting immediately after "renewal or extension of any such guaranty" the following: "for any period of time not exceeding twenty-five years from the date of the original guaranty".

SEC. 6. Part V of the Interstate Commerce Act (49 U.S.C. 1231 et seq.) is amended by renumbering section 510 as section 511 and by inserting immediately after section 509 the following new section:

"AUDIT BY COMPTROLLER GENERAL

"SEC. 510. (a) In any case in which—

"(1) there is outstanding any guaranty by the Commission made under this part; or

"(2) the Secretary of the Treasury is required to make any payment as a consequence of any guaranty by the Commission made under this part;

the financial transactions of the common carrier by railroad subject to this Act with respect to which such guaranty was made may be audited by the Comptroller General of the United States under such rules and regulations as he may prescribe. The representatives of the Comptroller General shall have access to all books, accounts, records, reports, files, and other papers, things, or property belonging to or in use by such common carrier by railroad pertaining to its financial transactions and necessary to facilitate the audit, and such representatives shall be afforded full facilities for verifying transactions with the balances or securities held by depositories, fiscal agents, and custodians.

Report to Congress.

"(b) A report of each such audit shall be made by the Comptroller General to the Congress. The report to the Congress shall contain such comments and information as the Comptroller General may deem necessary to inform the Congress of the financial operations and condition of the common carrier by railroad involved in such audit, together with such recommendations with respect thereto as he may deem advisable. The report shall also show specifically any program, expenditure, or other financial transaction or undertaking observed in the course of the audit, which, in the opinion of the Comptroller General, adversely affects the financial operations or condition of the common carrier by railroad involved in such audit or lessens the protection afforded the United States at the time the original guaranty was made. A copy of each report shall be furnished to the Commission at the time it is submitted to the Congress.".

Approved July 13, 1972.

LEGISLATIVE HISTORY:

HOUSE REPORTS: No. 92-855 accompanying H.R. 11384 (Comm. on Interstate and Foreign Commerce) and No. 92-1195 (Comm. of Conference).

SENATE REPORT No. 92-147 (Comm. on Commerce).

CONGRESSIONAL RECORD:

Vol. 117 (1971): June 15, considered and passed Senate.

Vol. 118 (1972): Mar. 2, considered and passed House, amended, in lieu of H.R. 11384.

June 29, House agreed to conference report.

June 30, Senate agreed to conference report.

Appendix B

High Speed Ground Transportation Appropriation Program

Allocation of Funds

($ in thousands)

	10-Year Total FY 1966-75
Research and Development	
Systems Engineering	$ 11,447
Test Center	28,722
High Speed Rail Research	41,896
Advanced Systems	39,502
Supporting Technology	23,036
TOTALS	$144,603
Demonstration	
Washington-New York (Metroliner)	$ 13,000
Metroliner & Station Improvement	14,357
New York-Boston (Turbo-Train)	13,996
Data Collection	4,583
Improved Passenger Train	1,659
Potential Demonstrations and Studies	4,243
TOTALS	$ 51,838
Administration	$ 12,935
GRAND TOTALS	$209,376

Tenth and Final Report on the High Speed Ground Transportation Act of 1965, US DOT, FRA, Office of Research and Development, 1977 -12-Safety

DEPARTMENT OF TRANSPORTATION ★ UNITED STATES OF AMERICA ★

MAY 1977