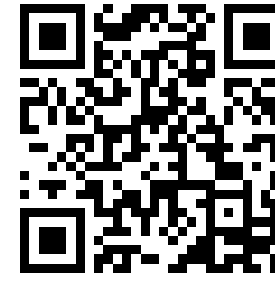

# FIFTH REPORT ON THE HIGH SPEED GROUND TRANSPORTATION ACT OF 1965

1971

By the Secretary of Transportation
to the President, the Senate, and
the House of Representatives

# PREFACE

Section 10(a) of the High Speed Ground Transportation Act of 1965 requires that the Secretary of Transportation report to the President and Congress annually with respect to the activities carried out under the Act. This Fifth Report accounts for OHSGT progress since publication of the Fourth Report in 1970.

Previous reports concerning the programs of the Office of High Speed Ground Transportation have served as source books for Congressional Committees, other DOT organizations, prospective contractors, academicians, and others wanting to know about HSGT program content, accomplishments, or future direction. With the advent of the High Speed Ground Test Center in Colorado and expanding development programs, this Fifth Report will reflect the changing emphasis of the HSGT activities from planning and study to development.

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# 1.0 EXECUTIVE SUMMARY

Support for the High Speed Ground Transportation Act of 1965 and subsequent extensions, both within the Congress and elsewhere, has reflected a concern about the future of transportation in urbanized regions in the United States. The focus of both the High Speed Ground Transportation R&D and demonstrations programs initiated by the 1965 legislation has been to solve intercity transportation problems of urbanized regions.

As an appropriate role for high-speed guided ground transportation in a balanced national transportation system becomes identified, supporting research, development, and demonstrations are being stimulated to move people and goods at higher speeds, with less adverse environmental impact, improved conservation of energy resources, and with greater economy.

Efforts of the Office of High Speed Ground Transportation (OHSGT) of the Federal Railroad Administration, together with those of transportation hardware suppliers, the aerospace industry, railroads, universities and nonprofit research organizations are responsible for advancements being made toward technology which will respond to future transportation needs, and simultaneously to upgrade the Nation's railroads which must serve in the interim.

Information exchanges are maintained with British, French, German, Japanese, and Canadian research organizations so that maximum utilization can be made of current achievements.

The High Speed Ground Transportation Act (See Appendix A) is aimed at promoting a safe, adequate, economical, and efficient national transportation system by administering intercity demonstrations and conducting R&D in high speed ground transportation. Evaluations of the demonstrations center on such factors as new equipment, higher speeds, variation in fares, improved comfort and convenience, and more frequent service.

The Northeast Corridor Project's second report of September 1971 recommended a program to improve the transportation system in the Boston-Washington region. The project was carried on in the OHSGT until September 1970 at which time it was transferred to the Office of the Secretary after completion of the first report.

OHSGT activities fulfill the objectives of the Act through an orderly assessment of transportation needs, conducting R&D on advanced systems and sub-systems, improving rail technology, recommending and conducting demonstrations programs, and coordinating R&D and demonstration planning efforts with AMTRAK. The studies have led to industry-and Government-conducted R&D, utilizing already available test facilities throughout the Nation and the new and specialized DOT High Speed Ground Test Center.

Last year's "Fourth Report on the High Speed Ground Transportation Act of 1965," noted a transition from transportation planning to a technology and hardware orientation. This year has also been characterized as one of transition, with expanding R&D programs and an emphasis on the newest key tool: the High Speed Ground Test Center in Colorado. The Test Center has already begun to provide answers so necessary for validating the systems in

development such as the Linear Induction Motor Research Vehicle (LIMRV) in relation to the Tracked Air Cushion Research Vehicle. The FRA, as the manager of the DOT Test Center, is closely coordinating the physical development of the center with the test program needs of all concerned DOT administrations.

With the advent of the National Railroad Passenger Corporation (AMTRAK) in FY71, an additional responsibility of close coordination has been required of OHSGT. For example, OHSGT has briefed AMTRAK on R&D and Demonstration plans and AMTRAK has briefed OHSGT on their operation and services planning. Close cooperation and coordination is also exemplified by the joint efforts that preceded the Turbo train tours during 1971.

OHSGT 1971 Highlights

The following 1971 highlights represent interim contributions toward accomplishing the HSGT program objectives:

- May 1971 marked the start of the first test program of the Linear Induction Motor Test Vehicle at the High Speed Ground Test Center and ground breaking for the Program Management Building.
- Test Center Technical Service Building requirements study completed.
- Test Center Rail Dynamics Laboratory Engineering design completed.
- Initial 2.4 mile section of Rapid Transit Test Track completed at Test Center.
- Tracked Air Cushion Research Vehicle (TACRV) fabrication started.
- Single-sided Linear Induction Motor (SLIM) studies completed indicating feasibility, and planning for future SLIM testing started.
- Non-lasing diode obstacle detection systems, selected for subsystem development, will provide a technological spin-off which can be applied as a stationary security system.
- Magnetic levitation studies move into laboratory tests.
- Track structures efforts continue with eight test sections with a conventional section for comparison on heavily traveled freight line nearing completion.
- Radiography for field welds developed as a quality control tool in joining steel running rails.
- Ride comfort specifications for advanced vehicles developed.
- Study completed and detail design initiated on non-friction hydrodynamic brakes, capable of high energy dissipation without thermal input to critical suspension elements.

- Three-millionth passenger boarded Metroliner on New York-Washington line with passenger demand continuing to increase.

- Turbo train completes public inspection and equipment operation tour of Northern States and the Nation with an overwhelmingly positive public reaction.

- Four new intermediate cars manufactured for the existing two three-car Turbo trains to increase its productivity and test expanded equipment operation.

## High Speed Ground Test Center

The High Speed Ground Test Center now being built near Pueblo, Colorado, will be a major influence in the development of future ground transportation. Within a few years the Test Center will be the most advanced ground transportation test facility in the world with the linear motor, tracked air cushion vehicle, railroad and transit test tracks plus the rail car dynamic test laboratory. Its capability to test and evaluate ground systems will be equivalent to that supplied for aircraft at the Edwards Air Force Base Flight Test Center in California.

The Test Center is already helping to fulfill two High Speed Ground Program objectives: the advancement of ground transportation technology; and the development of cost and performance data for the evaluation of potential intercity and intracity systems.

A Transportation Week ceremony in May 1971 marked the beginning of a test program for vehicles, guideways, propulsion, and communication devices under projects sponsored by both FRA and the Urban Mass Transportation Administration (UMTA). DOT's Transportation Systems Center in Cambridge, Massachusetts, is managing the transit test program for UMTA. The ground transportation industry and suppliers are expected to use the Center's facilities as completed. Secretary Volpe is shown in Figure 1 at the Test Center ceremony, after which he rode in the LIMRV on the partially completed test track (also illustrated).

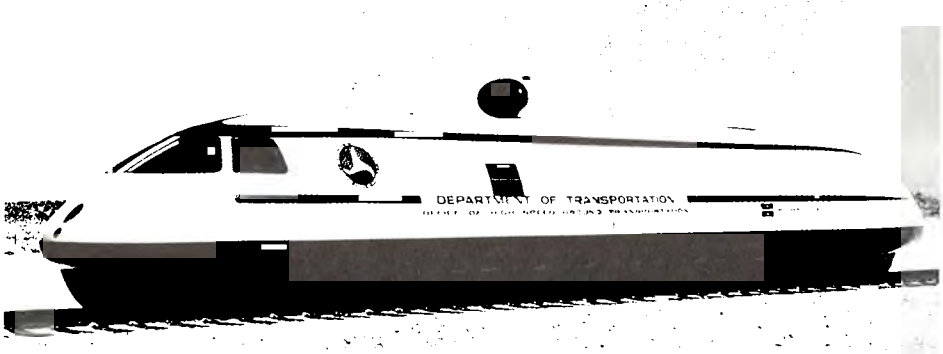
The Test Center is truly a cooperative DOT venture, with FRA managing the development and operation. In addition to its use for FRA programs, other Administrations will also use the Test Center. The Center is being developed to meet the test needs of current and future DOT programs. The present programs are described in later sections.

## Advanced Ground Transportation R&D

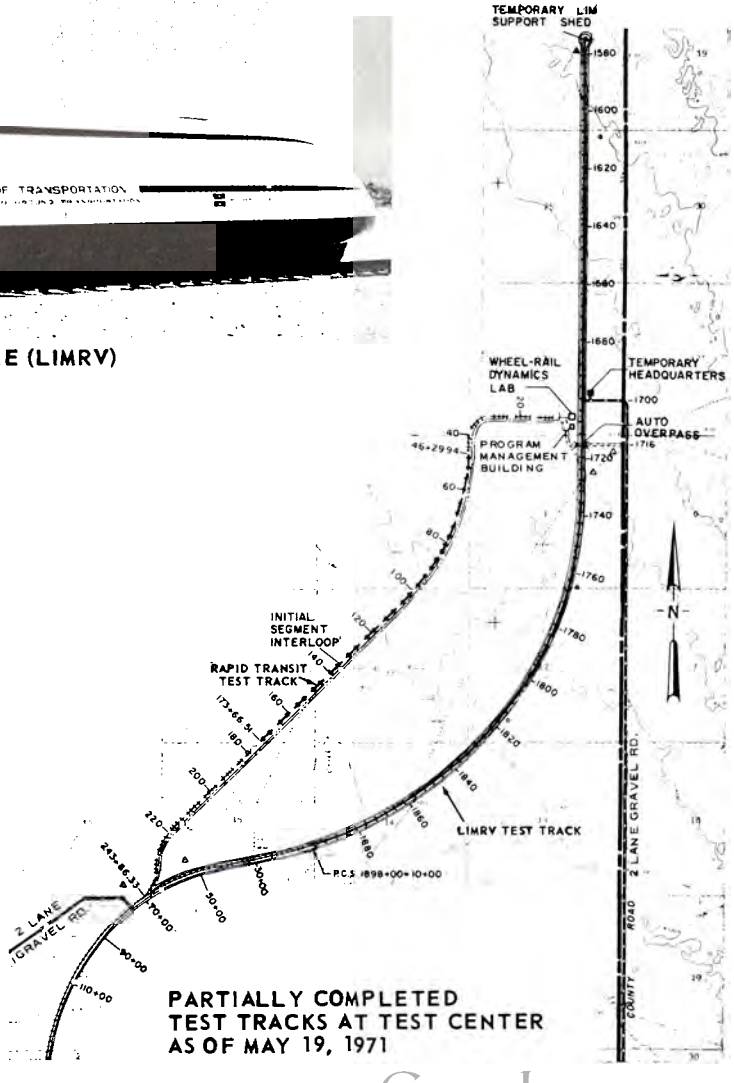
Systems analysis studies and R&D of earlier years have brought a program focus on three vehicle system types: Tracked Air Cushion Vehicle (TACV), Suspended Vehicle System (SVS), and Tube Vehicle System (TVS). The TACV is in engineering development; SVS, in exploratory development; and TVS, in the applied research phase. During FY71 the results of the magnetic levitation research along with the progress made in Germany have brought about an acceleration of development of this technology, and in the coming year the work will be advanced to a system effort.

SECRETARY VOLPE AT TEST CENTER CEREMONY, MAY 19, 1971

SECRETARY VOLPE AT COMPLETION OF RIDE IN LIMRV, MAY 19, 1971




LINEAR INDUCTION MOTOR RESEARCH VEHICLE (LIMRV)




PARTIALLY COMPLETED TEST TRACKS AT TEST CENTER AS OF MAY 19, 1971

## High Speed Ground Test Center

**FIGURE 1**

Major emphasis during FY71 has been on the development of a Tracked Air Cushion Research Vehicle (TACRV) to explore the potentials of air cushion technology, Linear Induction Motor (LIM) propulsion, power systems, and guidance and control at speeds up to 300 mph (483 km/hr). The TACRV will permit full-scale experimental verification of results obtained from prior research, provide data for the design of a commercial prototype TACV system, and make available subsystem capabilities applicable to other advanced systems. The LIM propelled TACRV, fed by three-phase AC wayside power, is a development vehicle that offers promise for relatively quiet and clean propulsion through areas of congested population.

Through liaison and coordination with French and British developers, OHSGT has sought to avoid duplication of research in the planning of its TACV program. Based on foreign technology and OHSGT R&D to date, off-the-shelf technology is being utilized to design a TACV system for demonstration at currently feasible ground speeds for intracity applications by the Urban Mass Transportation Administration.

Design and development of the Suspended Vehicle System and the Tube Vehicle System are behind that of the TACV. The SVS program as now conceived can take advantage of existing rail and highway rights-of-way, while causing minimum disruption to the established use of the right-of-way and to the population in built-up areas. Because of a capability to achieve greater roll angles under sustained speeds around curves than passive overriding suspensions, the SVS promises improved ride comfort at higher speeds along the same routes used by rail and highway transportation. SVS is being designed for testing at the Test Center along with several different approaches to appropriate guideways.

The TVS shows the greatest potential for safe operation at ground speeds up to 500 mph (805 km/hr) under all-weather conditions and with minimum interference with the environment. Additional scale model experimentation work in aerodynamics, suspension, and propulsion is necessary before initiating the engineering design of a large-scale system for testing at the Test Center.

The OHSGT advanced technology program includes efforts to improve the performance of tracked vehicle subsystems which have been identified by systems engineering analysis. The use of a double-sided linear induction motor (LIM) as a means of propulsion has progressed to a 2500 hp (1865 kW) test configuration since the initiation of study in 1966. The configuration is already being tested at Pueblo in a steel-wheeled LIM Research Vehicle. A LIM of 8000 hp (5970 kW) has been designed, and two are being fabricated for propulsion of the TACRV for speeds up to 300 mph (483 km/hr). Planning has started for testing a single-sided LIM, found feasible by the British, which will permit placement of the reaction rail flat in the road bed, thereby avoiding the vehicle having to straddle a vertical rail.

The use of magnetic fields as a noncontact means of supporting and guiding high speed ground vehicles allows the use of a low pressure environment in a tube to reduce vehicle drag and may offer an alternative to air cushions for vehicles on open guideways. Three different means of using magnetic fields in a suspension system are under consideration: servo-controlled electromagnets, superconducting coils, or permanent magnets in the vehicle and guideway.

A considerable amount of analysis and experimentation has been conducted to determine a practical way to bring efficient electrical power onto a vehicle. Wayside power distribution and collection are of concern in all advanced high-speed ground systems. A general investigation of the problems of power collection includes consideration of direct contact and noncontact methods of transferring power. A captive sliding contact system with the onboard slotted plug collector sliding inside three wayside power rails was designed during FY71 for testing on the TACRV. An analog computer simulation, which has provided data on inertia, stiffness, and damping requirements in aid of the design, will be used to interpret behavior of the collector system under full-scale, high-speed conditions on a rocket-sled test track at the Navy's China Lake Test Facility in California prior to installation on the TACRV guideway at Pueblo. Because the thrust and speed of a TACRV/LIM are controlled by changing the voltage and frequency characteristics of the electrical power supply, the power must be processed or conditioned, and is best done on board to avoid the need for many substations along the wayside power supply to assure adequate response to varying demands. Although a rectifier inverter in combination with a synchronous machine is being fabricated as the most promising approach to date to supplying variable-frequency power for high-speed requirements, its weight is so great with respect to the vehicle and LIM that longer range research is now seeking an improved technique for power processing. The most promising is the NASA-developed natural commutation.

A program has been started for development of new engines for propulsion of high-speed guideway vehicles to provide an alternative to wayside power collection. Two types of external combustion engines of advanced design are under study: the Stirling cycle engine and the closed Brayton cycle engine, both at 7,500 and 400 hp sizes. These engines may provide a reduction in emissions below the 1976 Environmental Protection Agency standards by a factor of 10. At the same time, fuel consumption will be reduced by at least one-third below conventional engines and the noise and vibration will be negligible.

Safety of high-speed vehicles requires immediate detection of any foreign objects on the guideway, or damage to the guideway, far in advance of a fast moving heavy vehicle because of extended stopping distances of one to several miles. A nonlasing diode sensor system has been tested favorably under adverse weather conditions and will next be tested at Pueblo for reliability under test vehicle operating conditions.

Higher speeds demand improved and reliable communications between vehicles and wayside locations for safety and operational control. Because of insufficient radio frequencies, communications research has continued to concentrate on large-capacity wave guides and smaller-capacity transmission lines along the right-of-way.

OHSGT has continued to concentrate research on Synchronous Longitudinal Guidance (SLG) for the development of a network control system that is capable of routing and scheduling vehicles to assure maximized capacity and minimized trip time consistent with safety requirements.

Transportation guideways, whether on, above, or below the ground surface, represent a major part of system capital and future maintenance costs. They also have considerable influence on environmental and safety considerations

and, through dynamic interaction with vehicles, determine the speed and comfort capabilities of a system. OHSGT guideway research has continued to seek reductions in capital cost, to establish design criteria, and to plan for experimentation with design tolerances.

Although progress is being made in tunneling techniques to provide the controlled environment for 500 mph (805 km/hr) ground transportation, cost must be reduced further if the Tube Vehicle System (TVS) is to be competitive with ground level or elevated systems. Naturally a less costly method would also benefit those who must tunnel through mountains and under cities. A combination of full-face boring and laser heat-weakening of hard rock offers the prospect of more effective tunneling, provided that a minimum of heat can be selectively applied to the outer edge of the tunnel face directly ahead of the outer gage cutters of the boring machine. Similarly, rock can be fractured for easy excavation by a water cannon now designed and ready for fabrication and testing, utilizing a Russian-patented nozzle for ejecting pulsed "slugs" of water with tremendous impact pressures. A computer program, completed in FY71 and already in widespread use for planning and design, makes possible rapid estimation of the cost of hard rock tunneling.

Higher operating speeds together with technological advancement will make obsolete many existing safety standards applicable to equipment guideways and operations of high speed ground systems. Accordingly, a new safety manual consistent with DOT safety policies is being developed to establish requirements to be met in designing and constructing unique new vehicles, and will be followed by other volumes for guideways and operations.

Rail Technology

To improve the efficiency, safety, and capacity of today's freight and passenger trains, as well as to assure advancement toward higher speed rail systems, OHSGT has continued a wide range of efforts in rail technology. These include the measuring and assessing of existing rail and track conditions; the designing, developing, and testing of new track systems; the conducting of analytical assessments, laboratory tests, correlations, and field demonstrations of suspension system and vehicle dynamics. A most important empirical tool at the Pueblo Test Center will be the Rail Dynamics Laboratory which is designed to provide full-scale test data. The Laboratory has progressed from concept through preliminary design, with construction to start in 1972.

Cost/benefit investigations into methods of providing more stable railroad track structures under high-speed and heavy-load conditions led to the installation of nine different instrumented track structures on a rail route in Kansas. Comparative results of performance, maintenance, and economics will be obtained over a three-year period beginning in March of 1972. Continuous data collection in Kansas, together with results from the Test Center experience and DOT Rail Research Test Cars in the Northeast Corridor over the past several years, should provide suitable track system selection criteria for any prospective wheel-on-rail system.

Train accident frequency and severity during the past decade have indicated that uniformly desirable track stability characteristics do not prevail throughout the national rail system largely because of economic and

technical constraints of an earlier era, reliance on incremental improvement of original structures, and financial distress in the rail industry. FRA studies are now seeking to identify more economical maintenance procedures that can be utilized by the rail industry and to define the stability boundaries of present-day or future track systems.

Continued use of DOT Rail Research Test Cars has been a very cost-effective means of carrying out rail technological research. The flexibility and unique data-gathering capabilities of the four test cars make them a sought-after research tool for the railroad industry.

The cars have been used to develop track surveillance systems, to monitor track conditions for the Metroliner and Turbo train demonstrations, and to study new track structures. Their capabilities are contributing to FRA's fulfillment of the responsibility to set track standards under the new rail safety legislation. Test results from the cars are contributing to the design of the Rail Dynamics Laboratory to be built at the Test Center, to study Metroliner ride-quality phenomena, to measure specification compliance of the Test Center test tracks, and to detect rail maintenance and safety problems. New research is being planned to utilize the cars in measuring the dynamic stiffness of track as a link between track geometry and the dynamic behavior of railroad cars.

A 6.2-mile (10 km) section of track for testing of the LIMRV has been put into operation at the Test Center. Built with greater accuracy than normal railroad construction, the LIM track has a 21 inch high (53.3 cm) center aluminum rail which acts as secondary to the LIM. The track has 8° (0.14 rad) of superelevation for high speeds on curves, and is held to rigorous tolerances governing longitudinal profile and alignment, cross level and gauge relationships. Fine realignments of the rail are possible by virtue of special rail fasteners. Full-ballast consolidation during construction of this track was used for the first time in this country. The rails were polished for a smooth rail-wheel interface. A Track Survey Device (TSD) will provide rapid track-geometry data for operational and maintenance purposes.

Although the primary objective of the LIMRV track is performance testing of the propulsion system, it also permits studies to determine the maximum speed capabilities of steel wheel/rail systems. This knowledge is necessary for designing and constructing advanced rail vehicles.

The approximately 20 miles (32 km) of conventional track to be built at the Test Center will provide the testing ground for total train dynamics, rock and roll characteristics of all classes of equipment, impact effects on equipment and lading, and behavior of variable track and vehicle conditions for both high and low-speed train operations. This trackage will permit studies of track structure, power collection, braking, track stability, controls and communications, crossing protection, switching, test and vehicle checkouts, and train systems. The work will be integrated with that of the Rail Dynamics Laboratory in an effort to define dynamic response characteristics and to categorize types of rail behavior when subject to rail trucks of different geometry and stiffness.

## Demonstrations

The two OHSGT rail passenger demonstrations--the Metroliners between New York and Washington and the Turbo train between Boston and New York--are now coordinated with the intercity passenger operations conducted by the National Railroad Passenger Corporation (AMTRAK) on the Penn Central. In two and one-half years of scheduled service, the demonstration trains have shown that travelers, when given service improvements, will respond with increased patronage. Technical problems that accompanied the initiation of demonstration services have now been isolated and both types of equipment are being modified to improve ride quality, reliability, and maintainability; to reduce costs; and to serve as prototypes for meeting AMTRAK's requirements for new equipment. The two three-car Turbo trainsets are also being expanded to five cars each in order to experiment with increased passenger-carrying capacity.

A new suburban station--Metropark--has been opened at Woodbridge, New Jersey, for park-and-ride service, while patronage continues to expand at the Capital Beltway Station in Lanham, Maryland. Feeder bus services at Lanham and Union Station in Washington have all been discontinued for lack of patronage. The Metroliner service between Washington and New York has been increased to twelve round trips daily. One of these has been extended to New Haven, Connecticut, and one of these twelve trips makes possible an across-the-platform transfer of passengers with the Turbo train at Penn Station in New York.

Broad public interest and acceptance of the Turbo train seem evident from the overwhelming enthusiastic response received on tours to the Colorado Test Center in May 1971 and through 31 states of the AMTRAK network in August 1971.

Because the Northeast Corridor is not typical as to traffic flow or volume, OHSGT has contracted for surveys which would aid transportation planning as well as to identify other possible demonstration corridors. The surveys to be completed in 1972 will estimate the traveler potential for improved rail service between Chicago and St. Louis; Chicago and Minneapolis-St. Paul; Seattle and Portland; and New York and Miami-Tampa-St. Petersburg. Meanwhile the survey of traveler response to Northeast Corridor trains has continued through the use of machine-readable seat tags, onboard questionnaires, and Census Bureau collection of travel data.

Three alternative transportation combinations have been analyzed for the purpose of providing a rail connection from Friendship Airport in Maryland to Baltimore and Washington. A combined railroad routing over two railroads was selected for further study.

In another study required by the Congress, OHSGT contracted with the Washington Metropolitan Area Transit Authority to determine the feasibility of providing access to Dulles Airport in Virginia by extending the regional rapid transit system currently being developed. The results of the study suggested an integrated local service, with two intermediate stops between downtown Washington and the Airport.

## 2.0 HIGH SPEED GROUND TEST CENTER

The DOT High Speed Ground Test Center was designed to bring closer the realization of DOT's mission to establish a balanced national transportation system. Plans were announced to construct the 30,000 acre (121 405 640 $m^2$) Test Center, located northeast of Pueblo, Colorado, in December 1969. The Test Center site was leased to DOT by the State of Colorado in August 1970 and the design and construction of the site and facilities soon followed.

May 19, 1971, marked the official opening of the Center, with the testing of the LIM test vehicle as shown in Figure 2.

The Test Center meets a long-standing need for improved ground transportation test facilities. It will provide the capability of testing full-scale vehicles and subsystems of both conventional railroad systems and developing systems.

The Pueblo location has the advantage of providing test situations under a variety of weather conditions. Average mean temperatures range from 14 degrees F. (-10°C) in winter to 92 degrees F. (33°C) in summer. The average annual precipitation is 11.84 inches (30.07 cm) and the mean yearly snowfall is 31.7 inches (80.5 cm). Figure 3 shows the site as a treeless range with the LIM track passing the temporary trailer offices in the foreground and a section of the transit track in the background.

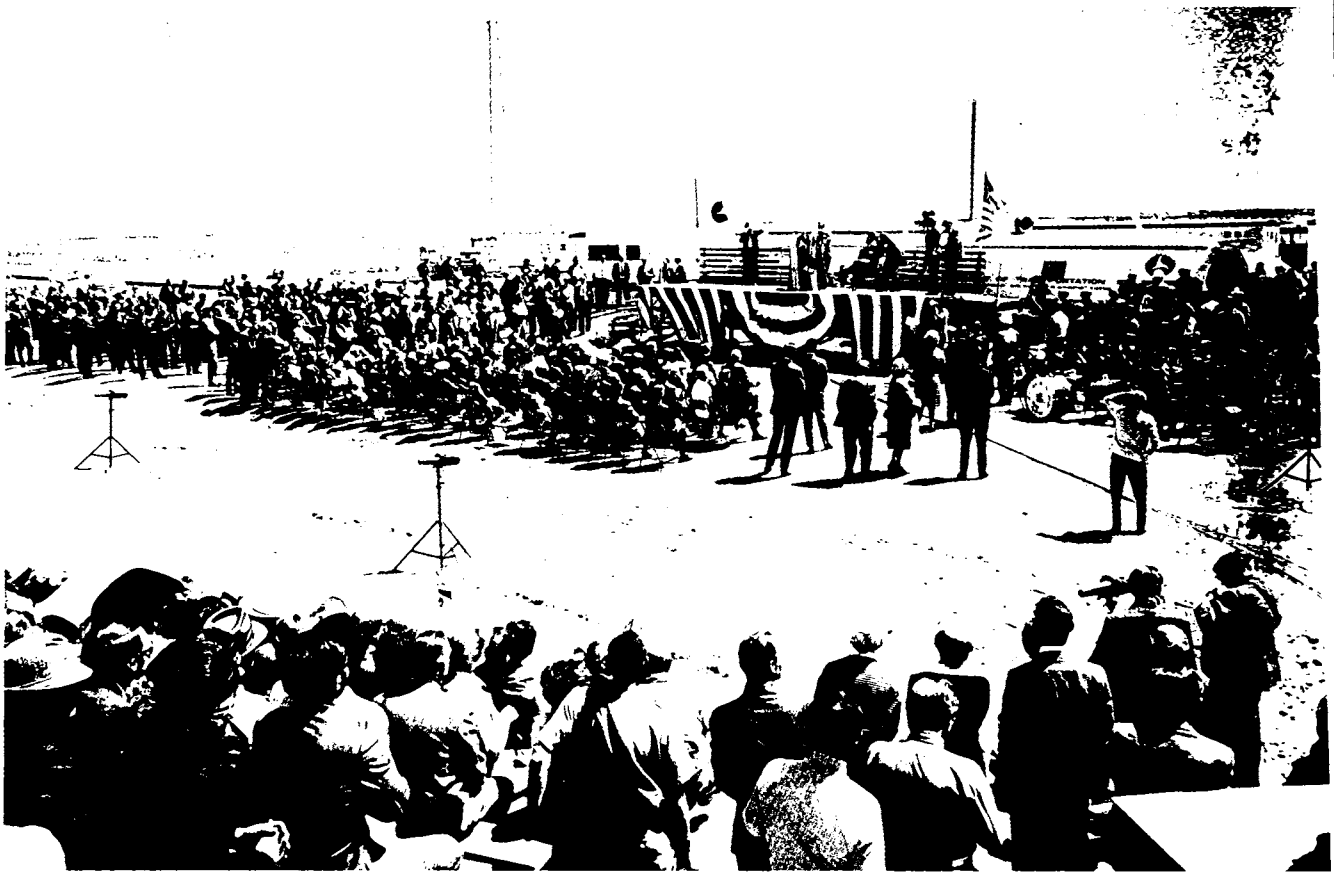
The Test Center will help to fulfill the objectives of advancing ground transportation technology, and developing cost and performance data on potential systems for intercity and intracity transportation.

In meeting these objectives, construction of experimental tracks was begun even before buildings and supporting facilities. Initial segments of a Linear Induction Motor (LIM) research vehicle test track and a rail transit test track have been completed, and testing started. The completion of these tracks, the construction of additional tracks, and a dynamics laboratory will soon follow.

### Test Center Responsibilities and Cooperation

The Federal Railroad Administration (FRA) has responsibility for managing the development and operation of the Test Center because of its mission to develop high speed ground systems, and for insuring proper coordination with other organizations which will use the Center. Other Administrations will use the Test Center but the greatest number of test programs will be FRA. The Test Center facilities will be available to Government agencies and private industry, and are expected to encourage the development of advanced transportation systems and to improve existing ones.

To date, the only element of DOT, other than FRA, to construct test facilities at the Center is the Urban Mass Transportation Administration (UMTA). Working through DOT's Transportation Systems Center in Cambridge, Massachusetts UMTA is constructing an oval track for testing transit cars and track, and is participating with the FRA in the planning and construction of the Rail Dynamics



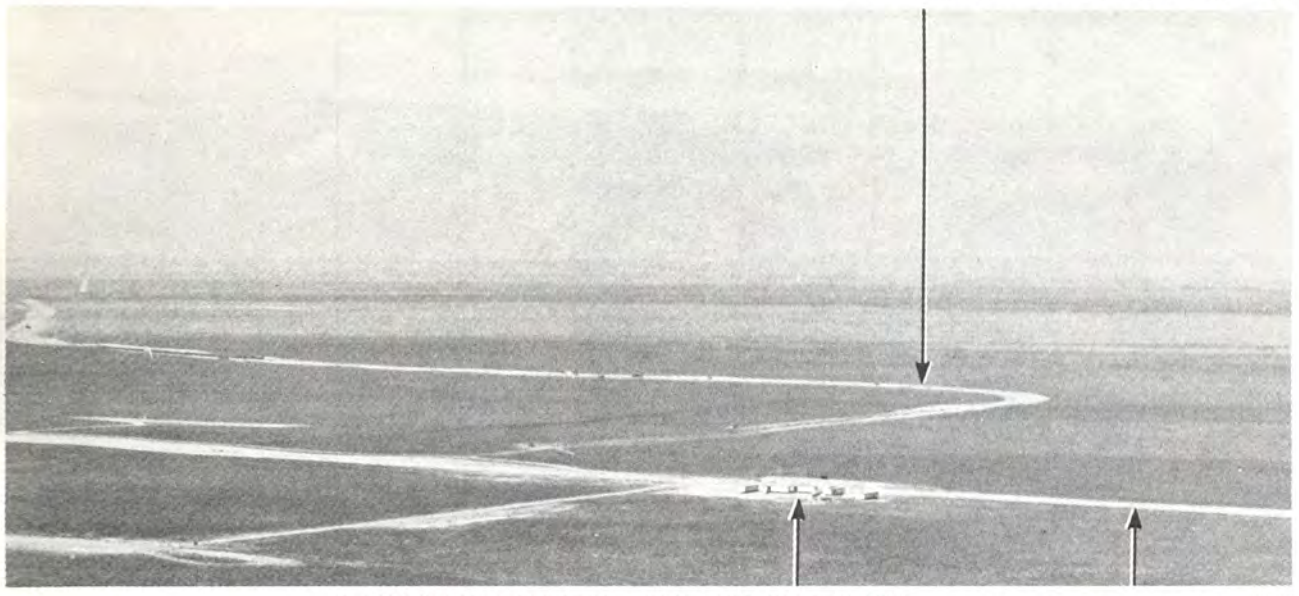
**High Speed Ground Test Center Ceremony, May 1971.**

**FIGURE 2**

Research Laboratory.

The Federal Highway Administration (FHWA) has provided continuous and significant assistance to FRA in the initial development of the Center. It has provided technical assistance in surveying, mapping, grading, earth moving, erosion control, and drainage. FHWA has also assisted in the preparation of construction plans and specifications, and is the contract administrator for the construction of LIM and transit test tracks, roads, specifications, and is the contract administrator for the construction of LIM and transit test tracks, roads and bridges. The Federal Aviation Administration and the Office of the Secretary of Transportation have also provided procurement assistance for construction.

Several other sectors of Government, external to DOT, are assisting in the development of the Center. These include the State of Colorado, Pueblo County, the United States Army Materiel Command through the Pueblo Army Depot, the Corps of Engineers, and the National Oceanic and Atmospheric Administration. In all, the Test Center is a truly cooperative venture, with the FRA managing its development.




**Aerial View of Southeast Area of Test Center Showing Location of LIM Track Beyond Trailers and Section of Rapid Transit Track in Background.**

**FIGURE 3**

## Master Planning

Figure 4 shows the master plan for the High Speed Ground Test Center. The one-mile (1.61 km) grid lines on the plan provide the physical division of the area in sections, and the solid and dashed lines illustrate completed and planned track and guideway. The discussion of the Test Center that follows will refer to this illustration.

The Federal Highway Administration Region 8 (Denver) engineering organization has completed surveying and has prepared contour maps of the 30,000-acre (121 405 640 $m^2$) site. Permanent monumentation along the proposed 21.8-mile (35.1 km), 300 mph (483 km/hr) oval test track has been completed and will enable the construction of tracks and guideways to a high degree of accuracy. Soil investigations have been obtained, essential to the design of foundations for tracks, guideways, buildings, and other facilities which will be constructed at the Test Center.

## Test Center Operations

The Test Center headquarters area (circled with an enlarged insert on Figure 4) shows the location of the five trailers which serve as temporary offices for the Government and contractor test personnel. The trailer at the far left of Figure 5 contains the LIM vehicle control and instrumentation; the others are used for offices. The temporary headquarters area will be replaced by permanent facilities as shown in Figure 4 in the enlarged insert. The first of these permanent facilities is the Program Management Building. Figure 6 shows the building under construction with occupancy planned for February 1972.

# HIGH SPEED GROUND TEST CENTER MAP AND TRACK LAYOUT (PRESENT AND FUTURE )

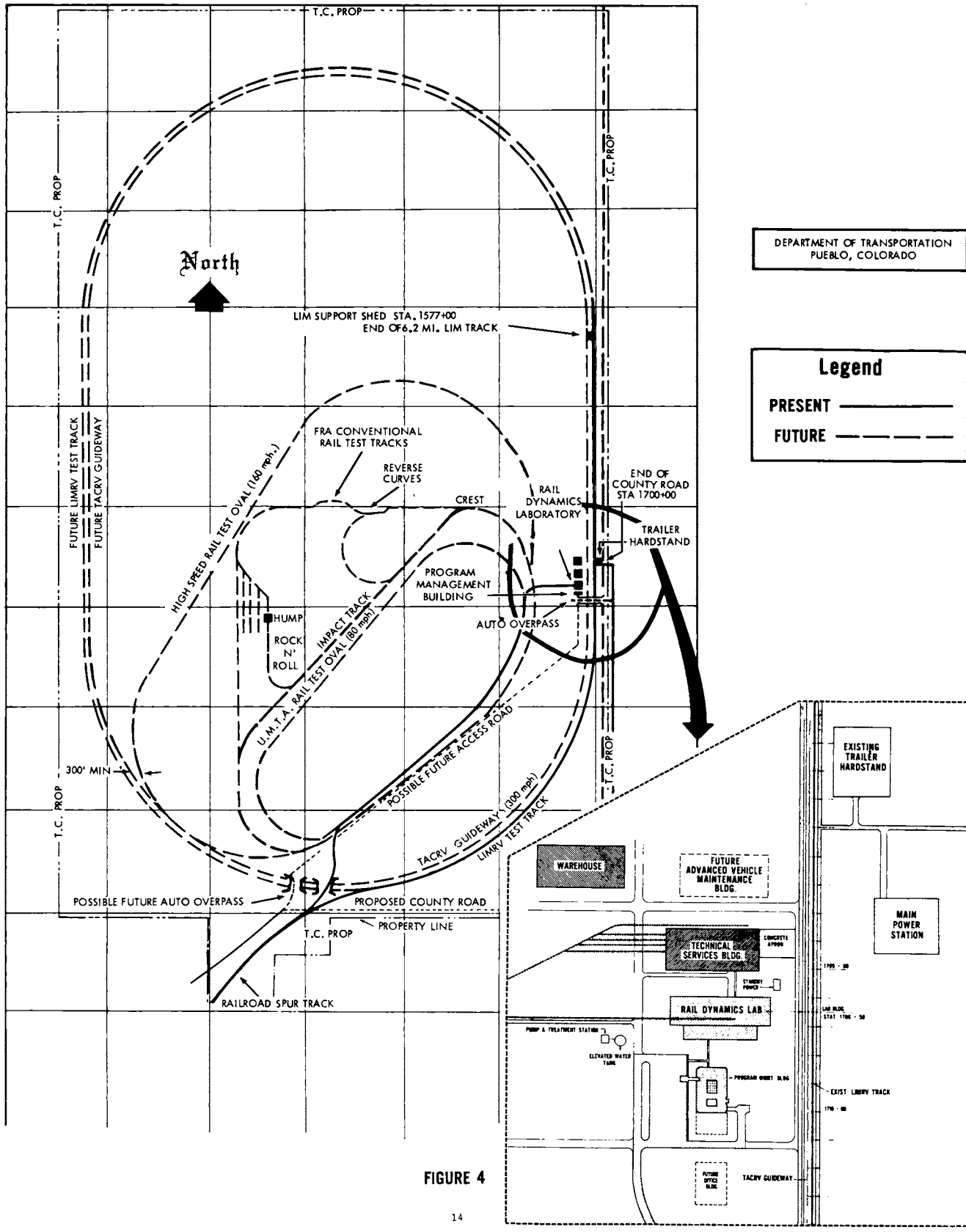
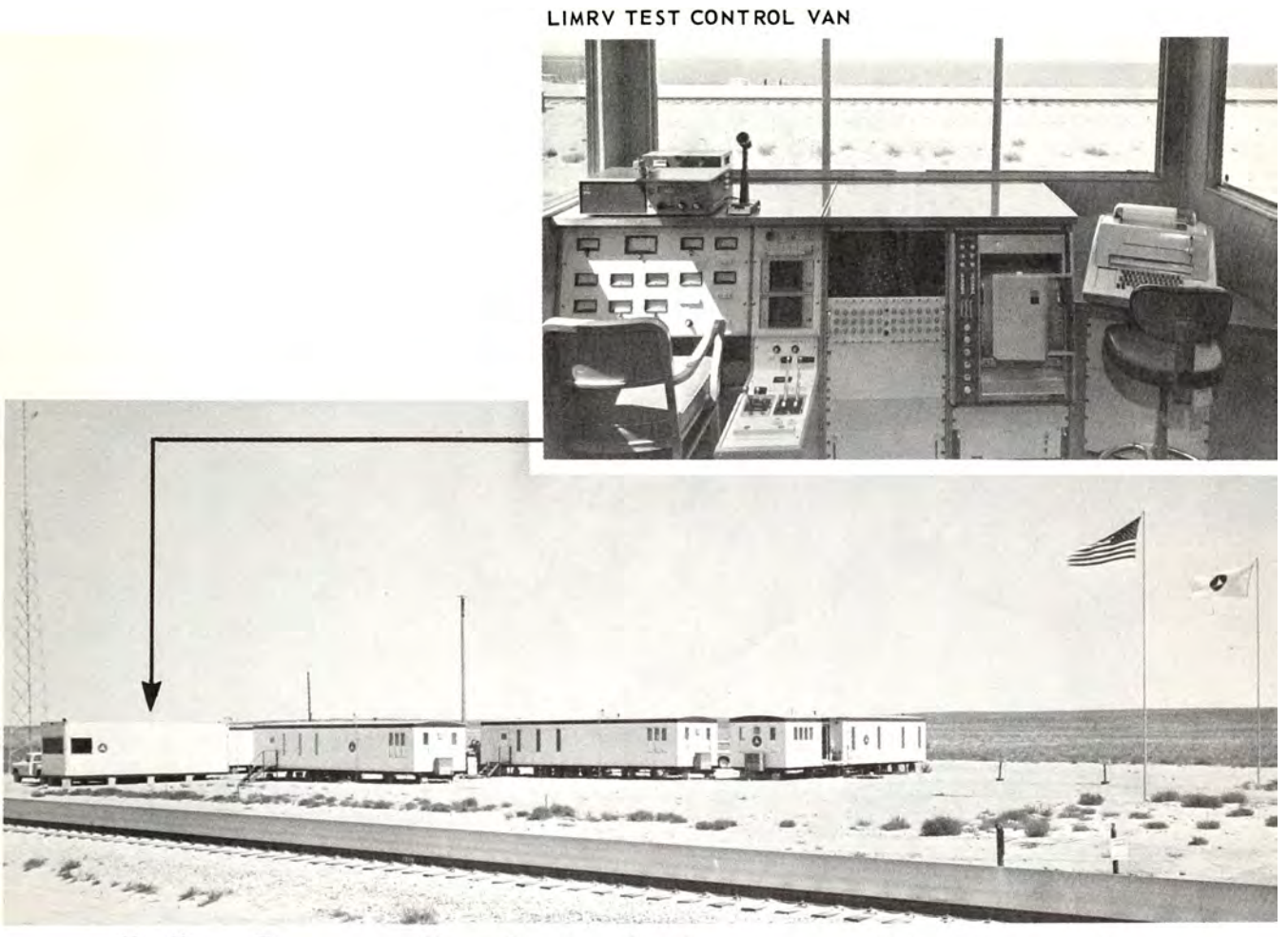



FIGURE 4



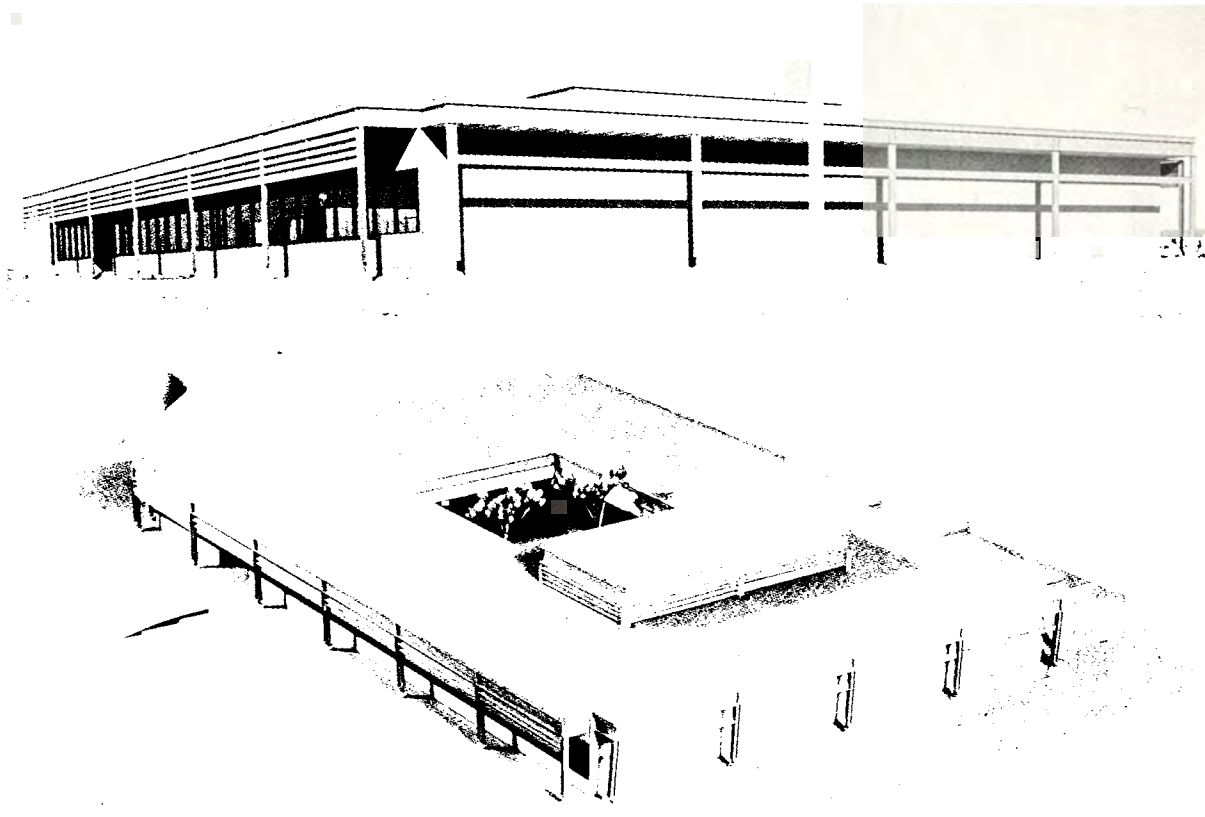

**Trailers--Temporary Test Center Headquarters and Test Control Area.**
**FIGURE 5**

The Program Management Building was designed by Bertrum Bruton Associates of Denver under an Architect-Engineer contract awarded in February 1971 under a Section 8A minority-owned business contract. A construction contract was awarded by the FAA Western Regional Office in Los Angeles in June 1971. The 14,000 sq. ft. (1300 m2) building will provide office space for the DOT Test Center staff, the operations and maintenance contractor personnel, test contractor teams, data processing, reproduction, and a photographic laboratory.

Preliminary planning has also been completed for the design of an industrial-type, multi-purpose Service Building to house shops and facilities for the repair and maintenance of transit, railroad, and advanced high-speed test vehicles.

Test Facilities

The Test Center as planned will have three sets of test tracks:



**Test Center Program Management Building.**
**FIGURE 6**

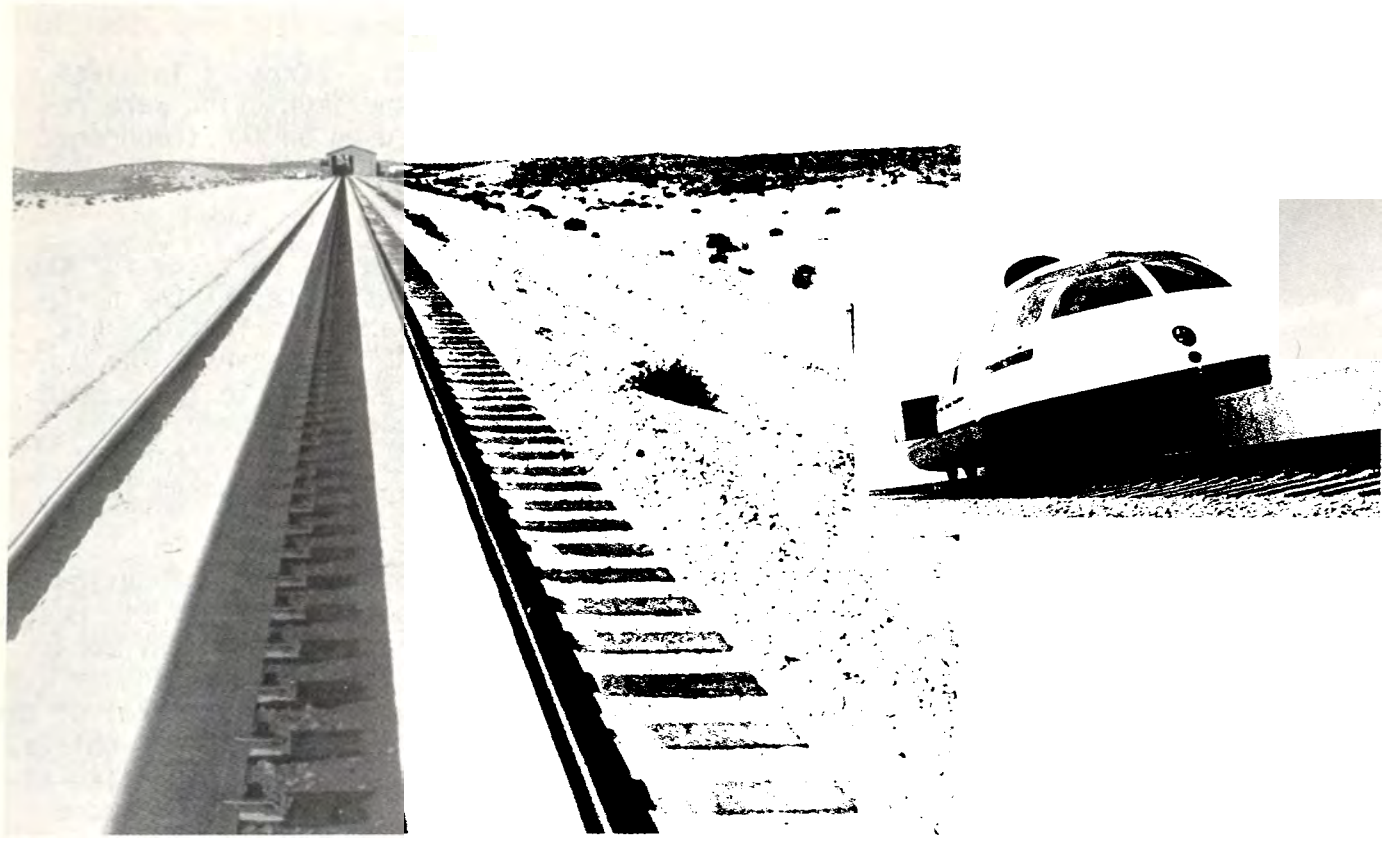
- A high-speed oval right-of-way for speeds up to 300 mph (483 km/hr). Both the LIM track and a Tracked Air Cushion Research Vehicle guideway will be on this 21.8-mile (35.1 km) oval.

- A complex of conventional railroad test tracks for speeds up to 160 mph (258 km/hr), plus tracks for hazardous tests and normal freight operations.

- A transit car test oval for speeds up to 80 mph (129 km/hr).

The location of each of the test facilities described below is shown on Figure 4.

Linear Induction Motor Research Vehicle (LIMRV) Test Track and Maintenance Building. Construction of 6.2 miles (10 km) of LIMRV test track on the high-speed test oval right-of-way and 3.2 miles (5.1 km) of access spur track connecting to the Pueblo Army Depot tracks was begun in August 1970 under a contract awarded to Colorado Constructors of Denver, for earth moving and grading. Shortly thereafter, a second contract was awarded to Morrison-Knudsen for



**LIM Track and Maintenance Shed and LIM Research Vehicle (LIMRV)**
**FIGURE 7**

track construction, which was completed in April 1971. The finished LIMRV track is seen in Figure 7.

The design and construction of the test track are discussed under Section 4.0, Rail Technology, except for the reaction rail described here. The reaction rail is the secondary of the LIM (the primary being the windings in the vehicle). It is an aluminum extrusion, 21 inches (53.3 cm) high, fastened to the center of the ties as seen in Figure 7. The LIM thrust is a result of the magnetic forces between localized electric currents in the reaction rail and the fields in the windings on the vehicle. However, the reaction rail is not electrified in the conventional sense and is completely passive, except when the vehicle moves over it.

The reaction rail was manufactured and shipped by Dow Chemical Company to the Pueblo Army Depot (PAD) while the track was being constructed, and procedures were developed to machine the ends of the 100-foot (30.5 m) sections so that true butt joints could be produced for welding. New tools and fixtures were developed and PAD machined the aluminum reaction rail on schedule for installation.

The Garrett Corporation, the LIMRV contractor, subcontracted installation of the reaction rail to Richard A. Peck, Inc., of Albuquerque, New Mexico. Installation included electric arc welding the sections together, grinding the joints flush, X-raying the welds for porosity, distressing the rail by heating,

and clamping it in place.

The welding specifications were prepared by Garrett. Since it involved a complex thin-walled structure, substantial study and experimentation were required. The procedure developed was simpler than that used on the temporary test track at the Garrett plant in Torrance, California (described in the HGST Fourth Report).

Since a permanent vehicle maintenance facility could not be ready for the start of the LIMRV testing, a temporary building was constructed at the north end of the test track. See Figure 7. The building is a prefabricated metal structure, and the layouts were made by Garrett and OHSGT engineers. The construction contract was awarded through the Denver office of FAA to the Schout Construction Company. Facilities in the building include a pit beneath the track for maintenance of the LIM, jacks, spares storage, and simple machine tools. Power is supplied by a portable generator and water is trucked in, similar to the arrangements for the trailers.

Tracked Air Cushion Research Vehicle (TACRV) Guideway. The final design of the TACRV guideway was completed in 1971 by Sverdrup and Parcel of St. Louis, Missouri, under subcontract to Grumman Aerospace Corporation, the TACRV contractor. Grading work for the initial 5 miles (8 km) of the TACRV guideway was completed with the LIM test track construction. The first 3 miles (5 km) of the U-shaped TACRV guideway, which is designed for the 300-mph (483 km/hr) vehicle, will be at grade in a tangent alignment located near the east property line adjacent to the Test Center operations area. Sections of guideway to be added later will be both elevated and at grade, with switches included.

Rapid Transit Test Track. The 9.1-mile oval (15 km) transit test track being constructed for UMTA (Figure 4) is designed for speeds up to 80 mph (129 km/hr). The first 2.4-mile (3.9 km) section was completed in August 1971 by Morrison-Knudsen. Two New York subway cars will be used for ride-quality noise, track-geometry and track dynamics testing.

The track is standard gauge, electrified with 600 v D.C. power supplied by third rail. The first section is of wood-tie, welded-rail construction. Sections to be added will include concrete ties.

High Speed and Conventional Rail Tracks. Preliminary studies and site investigations for the conventional railroad test track layouts, and extension of the transit test track, are nearly completed. These layouts are optimized around the existing terrain in order to take advantage of the natural land features and to reduce the amount of earth moving. Development of the final engineering design is now in process.

Various low-and high-speed sections, difficult curve and grade combinations, impact-testing, switching facilities, and sundry other track layouts will be built starting in the spring of 1972 and continuing over several years. The first item of rolling stock for the facility--a 300 hp (2240 kW) diesel locomotive--is now on the site.

Rail Dynamics Laboratory. The Rail Dynamics Laboratory, for which the engineering design was completed during this past year, will be located next to the Program Management Building at the Test Center. Detailed design is

underway, construction will start during 1972, tests will begin in the spring of 1973, and full operational status is scheduled for late 1975. This Laboratory is the first of its kind in the United States, building upon the state-of-the-art developed overseas and similar research test techniques used by NASA. It will be equipped with simulators and instrumentation for testing full-scale railroad vehicles and related equipment performing in a controlled environment.

The laboratory objectives are to investigate the physical phenomena involved in rolling support and wheel/rail interaction. Specific testing will involve fundamental research in wheel/rail interactions, tests of existing and new equipment design, and investigations of wheel and rail impact stresses, road-bed dynamics, adhesion, guidance stability, suspension design, and noise generation. The testing activities will include analysis of the ride quality of existing vehicles, restaging of field problems and accidents from regular railroad operations, and prototype shake-down tests. The laboratory will provide an empirical and analytical tool heretofore unavailable in the design and development of rail systems.

Tube Vehicle Plans. Along the east property line of the Test Center a 1/2-mile (0.8 km) wide by 20-mile (32 km) long easement has been secured and is planned for locating the Tube Vehicle System test facility. Since the R&D requirements for the Tube Vehicle Systems are in the formative stages, only the space has been allocated for future testing.

## Supporting Facilities

At the time of the Fourth Report no support facilities had been started at the Center, and the offices were in space loaned by the Pueblo Army Depot. During the past year, much has been accomplished in master planning, and several facilities have been completed while others are now being constructed.

The four office trailers mentioned earlier were installed on a hardstand constructed with a septic tank system, electric power distribution, and a water system. Power is provided from leased diesel generators and the water is hauled by truck from Pueblo and stored in a 1500-gallon (5679 liters) tank. After the Program Management Building is occupied, the trailers will be placed at various locations along test tracks for use in test supervision, data acquisition, and construction offices.

A 3000-hp (2240 kW) General Electric diesel locomotive was purchased, with FRA and UMTA sharing the cost. It is used to move test cars and other rolling stock around the Test Center and Pueblo Army Depot tracks, and will power freight test trains in 1972. It is being used as a temporary electric power source for the transit test track, pending installation of regular utility power facilities.

The Pueblo Army Depot is the storage point for spare parts and extra materials. The Depot also provides photographic support and use of their machine shop.

More than 16 miles (26 km) of service roads have been constructed, and plans are complete for an automobile overpass across the high-speed test oval to provide access into the building complex. Plans have also been started for a railroad overpass so that the access spur from the Pueblo Army Depot tracks

can be elevated over the high-speed right-of-way to permit extension of the LIM test track and construction of the TACRV guideway.

## Visitors

The Center has drawn visitors from all sections of the Nation, as well as from Canada, England, France, Germany, Japan, Mexico, and Nicaragua.

## Future Plans

The Test Center development schedule requires that test and support facilities be completed at the time vehicle test programs are initiated. This requires considerable lead times to meet certain equipment and facility construction requirements. Figure 8 shows the planned development schedule for the next five years.

# HIGH SPEED GROUND TEST CENTER DEVELOPMENT SCHEDULE

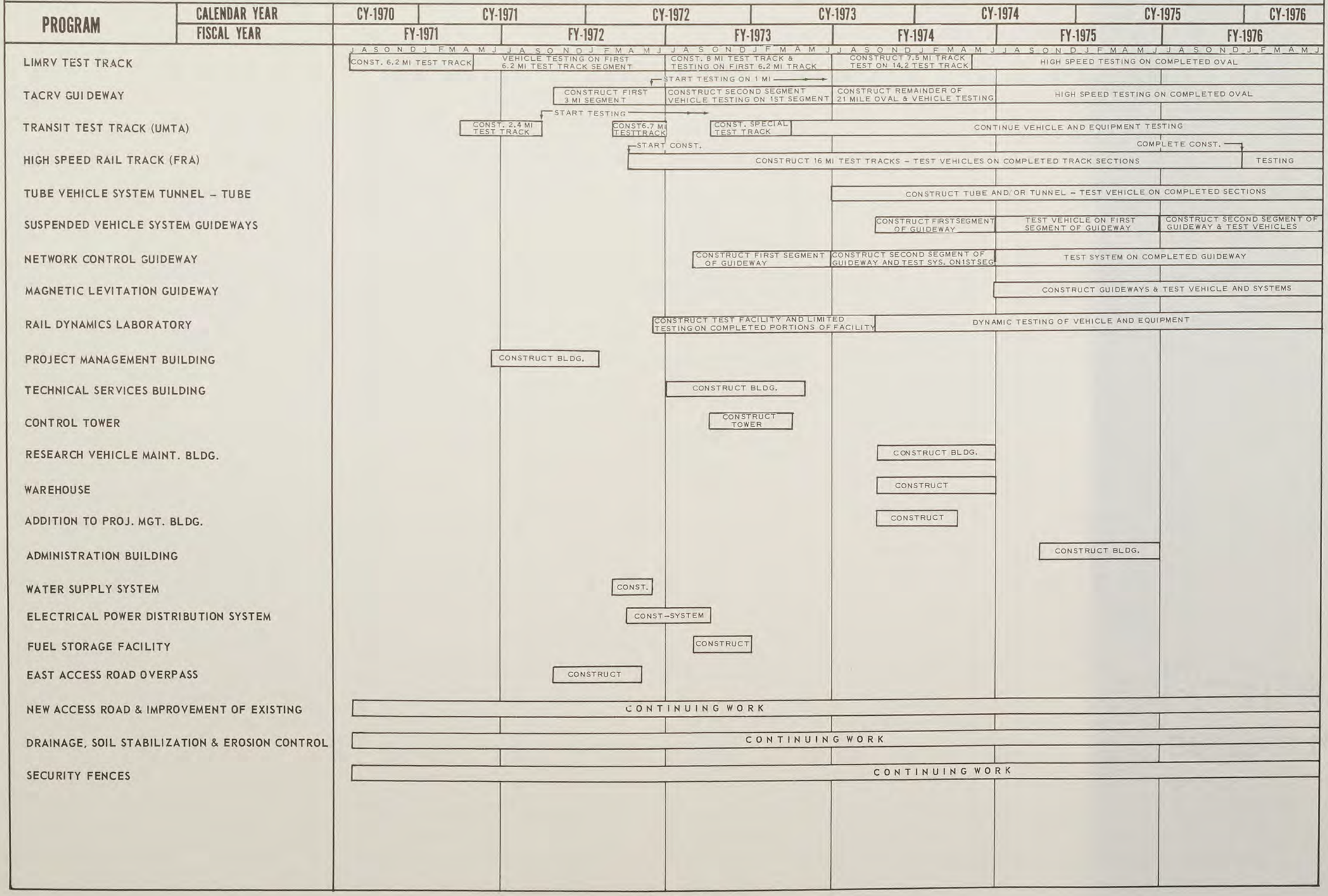



FIGURE 8

Systems analyses and engineering studies in earlier years under OHSGT have resulted in work in FY71 on the following three systems: the Tracked Air Cushion Vehicle (TACV), Suspended Vehicle Systems (SVS), and the Tube Vehicle Systems (TVS). The state-of-the-art is different for each and consequently the effort on each is in a different part of the R&D spectrum.

The TACV--the system furthest advanced technologically--is in engineering development, the SVS is in exploratory development, and TVS is in applied research.

Systems engineering studies were completed on TACV and TVS two years ago. The systems engineering on TACV revealed sufficient R&D successfully completed so that the next logical step was full-scale testing. The TVS systems engineering studies revealed large gaps in technology, particularly in aerodynamics. Therefore, an aerodynamics research program was started so that the largest gap could be filled first. Systems engineering on SVS is incomplete, however a first generation system was defined in FY71. Public demonstrations will be planned if these systems are found to be economically and technically practical.

The Tracked Vehicle Development Tree, Figure 9, identifies subsystems that are being pursued by OHSGT at the present time. The progress during FY71 for each of the above-mentioned vehicle systems and supporting advanced technology subsystems is discussed in this section of the report. For the reader and researcher who wish to pursue the High Speed Ground Transportation subject further, Appendix B contains the OHSGT Published Reports Bibliography. As noted, these reports may be obtained from the National Technical Information Service.

## Systems Engineering

The DOT Office of the Assistant Secretary for Policy and International Affairs continued a systems analysis of transportation in the densely populated Northeast Corridor. The results of this analysis have been presented in a three-volume report entitled "Recommendations for Northeast Corridor Transportation," dated September 1971. Briefly, with regard to OHSGT activities, the study recommends:

- "The Administration support implementation of improved high-speed, non-reservation, high frequency rail service along the Washington to Boston Spine. The Department of Transportation should seek legislation to insure that necessary funding for this effort is made available (loan, loan guarantees, etc.) DOT policy should be to stimulate improved high-speed rail service to attract more short-haul passengers between New York, Boston, and intermediate points. . . . . .

- "The DOT should begin at once to explore possible routes for a right-of-way suitable for a Tracked Air Cushion Vehicle System and to investigate possible institutional arrangements for an operating system.

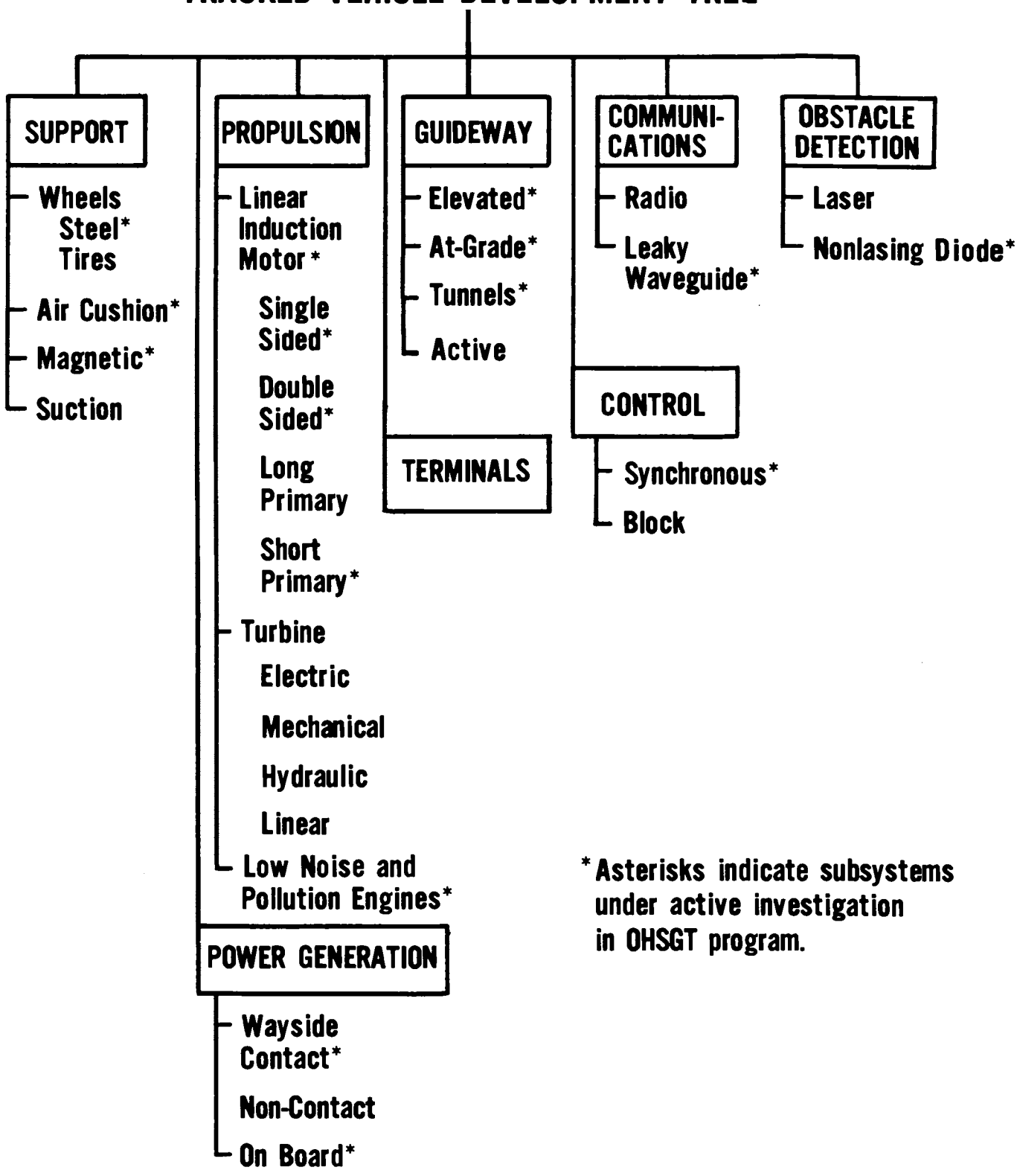



FIGURE 9

- "Research and development efforts for TACV should be expanded and accelerated, and should include heavy emphasis on the environmental impact of the system (including electric power sources).

- "Major investment decisions should be deferred until the requirement is established to go beyond the interim recommendations, and until the results of the TACV, STOL, and VTOL R&D programs are evaluated. A definite date should be set for such evaluation, and R&D programs should be oriented toward meeting such a date. The year 1976 has been recommended.

- "The ongoing research in tunneling and magnetic levitation technology, as well as in tube-vehicle systems, is necessary to the development of a broad-based future capability for high-speed ground transportation."

As in the past, the systems engineering analyses will be used to provide inputs for planning the OHSGT R&D program.

Advanced Systems

Tracked Air Cushion Vehicle (TACV) Systems. The potential of TACV technology for intercity passenger transportation is being explored at speeds up to 300 mph (483 km/hr). The program has proceeded from studies into experimental hardware development. During FY71 the program's emphasis has been on development of a Tracked Air Cushion Research Vehicle (TACRV). The TACRV provides a test bed for many of the subsystems which are candidates for a variety of high speed ground systems. R&D efforts have continued to look for better subsystems. For example, air suspension studies were continued at MIT with the past year's investigation of flexible-base air cushions. Aerodynamically supported vehicles, which use aerodynamic forces from forward motion to lift and guide the vehicle were studied at the Transportation Systems Center. Model tests were conducted in a small-scale glide facility. Use of ram air could reduce the power required for levitation at high speeds.

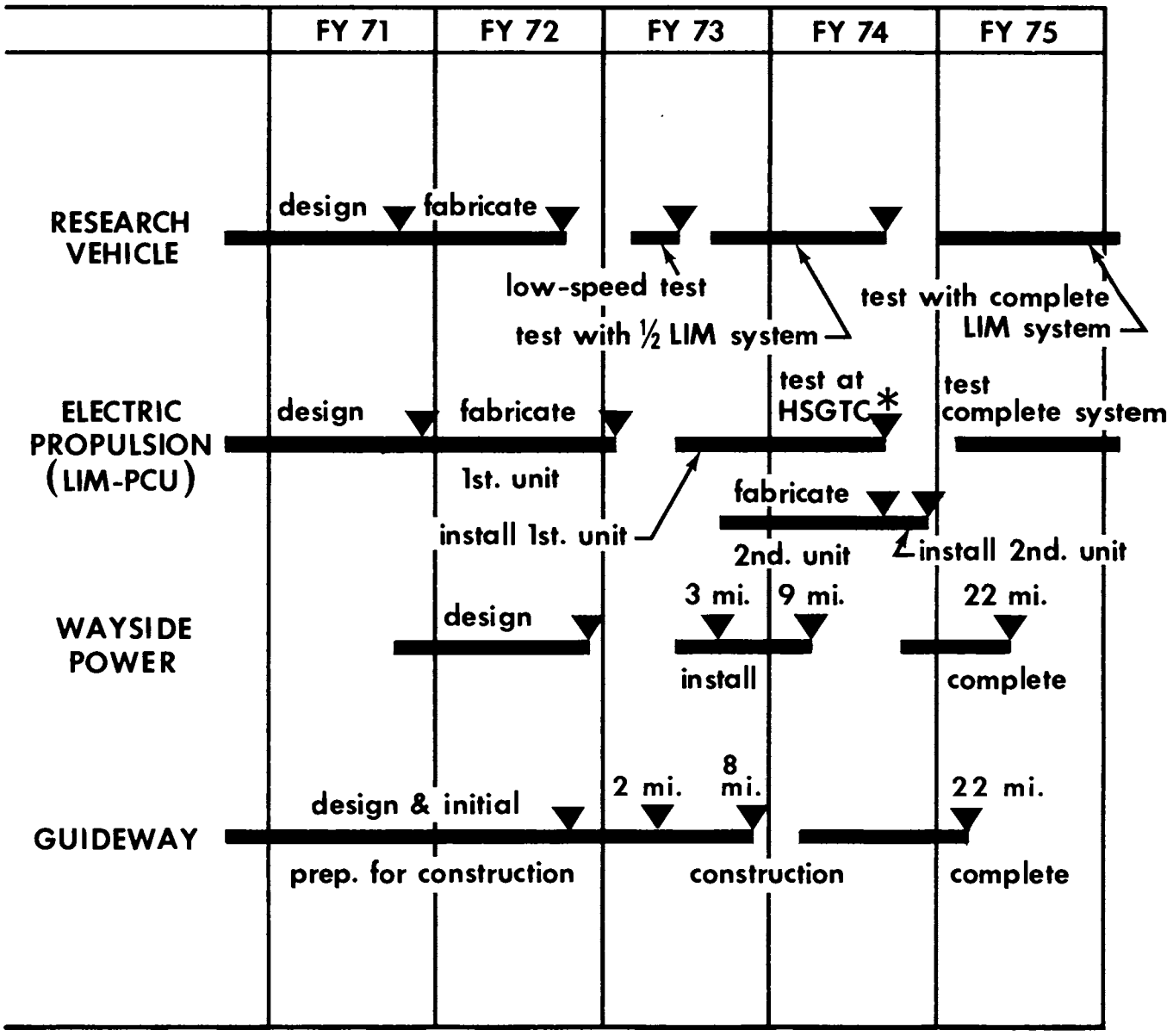
OHSGT has maintained close liasion with French and British developers of TACVs. This continuing information exchange has aided in prevention of duplication of R&D. Visits have been exchanged with Tracked Hovercraft Ltd. in England in FY71 as in prior years, and the Aerotrain test track was visited with a ride on the 80-passenger Aerotrain prototype vehicle.

The TACRV development plan, for the 300 mph (483 km/hr) test bed vehicle is shown in Figure 10. At each phase, milestones have been established where decisions to proceed will be made upon successful achievement of the milestones. The need for full-scale verification of study results led to the decision to design the TACRV.

The TACRV, as shown in an exploded view in Figure 11, will serve as a test bed for full-scale testing in the following areas:

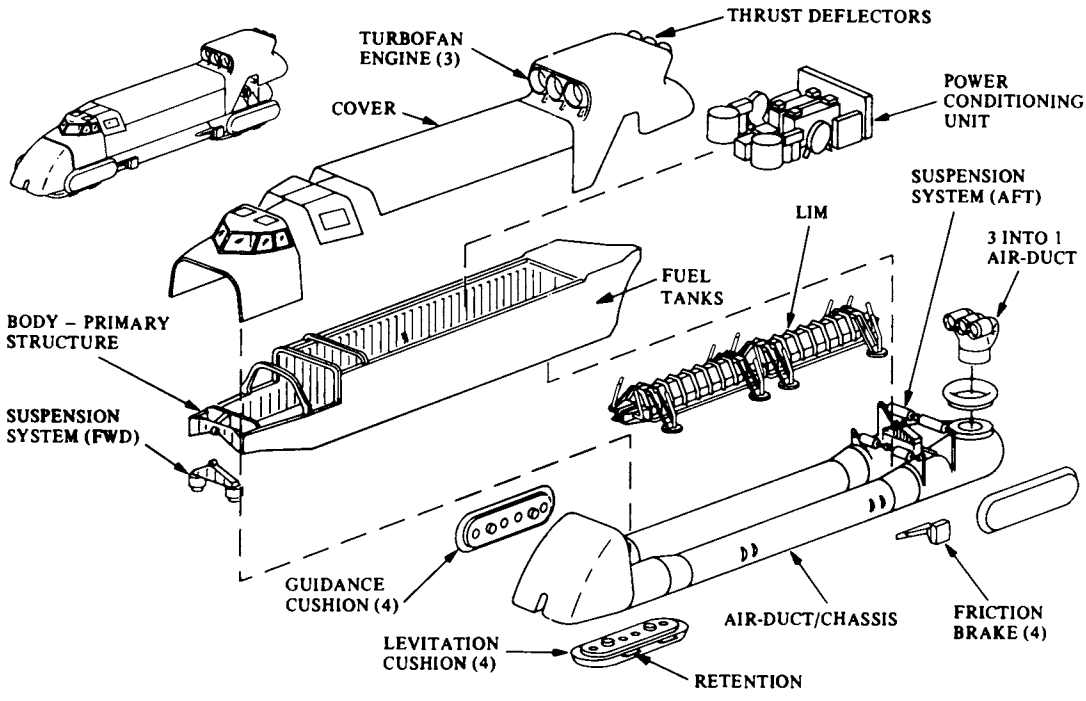
- Air cushion and air supply performance.

# TRACKED AIR CUSHION
# RESEARCH VEHICLE DEVELOPMENT PLAN




*High Speed Ground Test Center

FIGURE 10




**Exploded View of TACRV.**

**FIGURE 11**

- Improvement of ride comfort through advanced secondary suspension design.
- Vehicle aerodynamics and stability.
- Linear electric motor propulsion with associated power conditioning.
- High-speed collection of electric power from the guideway.
- Dynamic response of vehicle and guideway.

Grumman Aerospace Corporation completed the TACRV design in March 1971, and within the estimated cost. Design of the guideway was subcontracted to Sverdrup and Parcel. The Sverdrup and Parcel designs have been forwarded to FHWA Denver office for incorporation into an Invitation for Bid (IFB).

The dimensions and performance are given below:

TACRV Physical Dimensions and Performance

| | | |
|---|---|---|
| Vehicle Dimensions | Length: | 50 ft. (15.2m) |
| | Width: | 12 ft. (3.66m) |
| | Height: | 13 ft. (3.96m) |

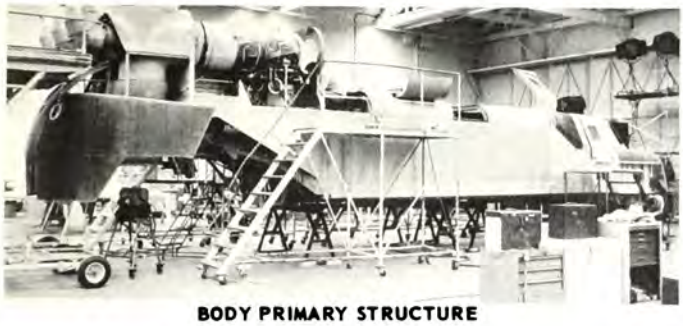
| | |
|---|---|
| Total Vehicle Weight | 59,000 lbs. (26 800 kg) |
| Vehicle Performance | Speed: 0-300 mph (483 km/hr) |
| | Acceleration: 0-300 mph (483 km/hr) in 75 seconds |
| | Braking: 1.5 miles (2.4 km) |
| Power Input | 3 phase, 60 Hz. 8250 volts |
| Power Rating - continuous | 8000 horsepower (5970 kW) or 10,000 lbs. (44.5 kN) thrust |

Grumman began fabrication of the TACRV immediately after completion of design. An artist's concept of the vehicle, along with photography of the manufacturing sequence is shown in Figure 12. The TACRV operates in a U-channel guideway and utilizes air cushions for support and guidance, turbofan engines for air supply, and linear induction motors for propulsion. Power is picked up from conductor rails along the guideway. The status of the LIM power conditioning and power collection developments are presented in the section entitled Advanced Technology. A secondary suspension system will be evaluated to determine the ride quality which can be attained. The secondary suspension may be operated either passive or actively controlled, using accelerometer sensors and servomechanisms. Three United Aircraft of Canada Ltd. JT-15D turbofan engines are the source of the cushion air supply. Their exhaust is directed rearward producing thrust which supplements that of the LIM. In fact the thrust of the air supply engines is calculated to propel the vehicle up to 120 mph (193 km/hr), and the early tests to evaluate cushion and other vehicle subsystem performances will be run without the LIM.

Fabrication is scheduled to be completed in March 1972, after which the vehicle will be shipped to the High Speed Ground Test Center for testing.

NASA has continued to support OHSGT with both personnel and facilities at its Langley Research Center. Their most recent technical support consisted of static and dynamic development testing of the air cushion support and guidance system for the TACRV's linear induction motor. The tests confirmed the calculated performance of the air cushions, but resulted in a change of the flexible skirt material. See the LIM subsection for additional pictures and illustrations.

Urban TACV. An Urban TACV (UTACV) capable of speeds up to 150 mph (241 km/hr), using presently available technology is being designed for an intracity application, possibly between an outlying airport and a city center. Both Rohr Corporation and Vought Aeronautics have contracts for the design of 60-passenger vehicles. The Rohr design will use an inverted T-guideway and the Vought Aeronautics design will use a U-Channel guideway as illustrated in Figure 13. UTACV performance requirements and physical characteristics are listed below.



BODY PRIMARY STRUCTURE

VEHICLE AIR CUSHION ASSEMBLY

AIR DUCT CHASSIS – FRONT VIEW






BACK END OF AIR DUCT CHASSIS



AIR DUCT CHASSIS – REAR VIEW

BODY PRIMARY STRUCTURE AND AIR DUCT CHASSIS FABRICATION AND ASSEMBLY AREA

MATING OF BODY PRIMARY STRUCTURE WITH AIR DUCT CHASSIS

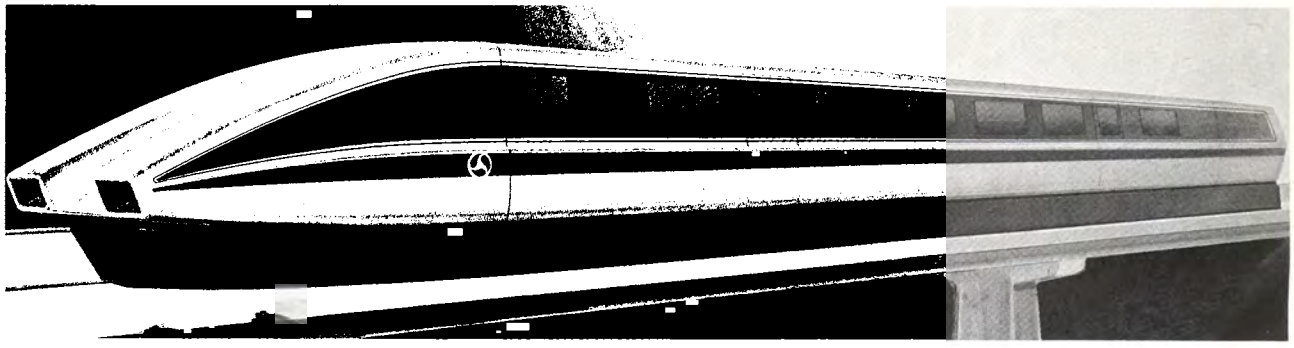
BODY PRIMARY STRUCTURE

MATING OF BODY PRIMARY STRUCTURE WITH AIR DUCT CHASSIS

**Tracked Air Cushion Research Vehicle (TACRV)**

**FIGURE 12**

VOUGHT AERONAUTICS UTACV USING U-GUIDEWAY



ROHR CORPORATION UTACV USING INVERTED T-GUIDEWAY

**Planned Urban Tracked Air Cushion Vehicle (UTACV)**

**FIGURE 13**

UTACV Performance Requirements and Physical Characteristics

| | |
|---|---|
| Vehicle Speed Capability | 0-150 mph (241 km/hr) |
| Thrust | 5600 lb. (24.91 kN) continuous |
| | 8800 lb. (39.14 kN) overload acceleration thrust, short term |
| Power Input | 3-phase, 60 Hz, 4160 volts AC max. variable voltage control |
| Total Vehicle Weight (target) | 60,000-78,000 lb. (27215-35380 kg) |

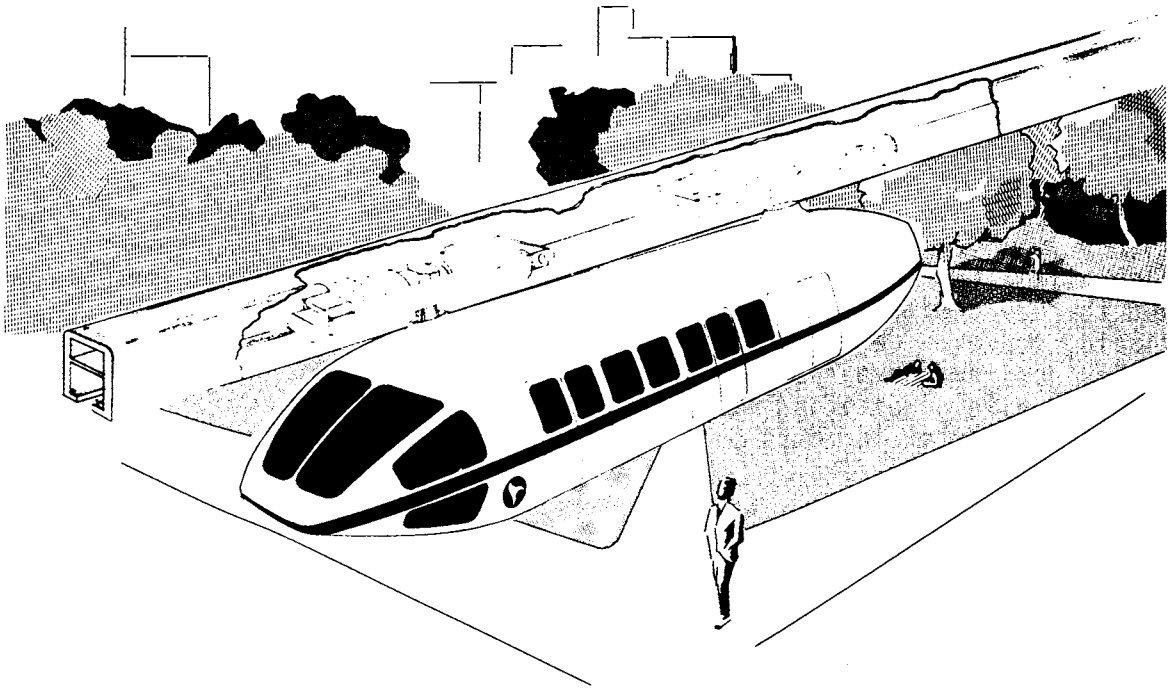
Subsequent phases of the project call for fabrication, testing, and demonstration. The Urban Mass Transportation Administration (UMTA) is funding and managing the project, with OHSGT providing technical direction based on the results of previous research and development on TACV's, including the 300-mph (483 km/hr) TACRV. The Transportation Systems Center (TSC), Cambridge, Massachusetts, is giving technical support to both OHSGT and UMTA on this project.

Suspended Vehicle Systems (SVS). A suspended vehicle system (SVS) is one in which the vehicle hangs below an elevated guideway shown in Figure 14. The SVS permits the car to roll about the point of suspension and thereby capitalizes on the stabilizing gravitational force when negotiating curves. Centrifugal force causes the vehicle to achieve roll angles desired for passenger comfort. The SVS promises improved ride comfort while negotiating curves at speeds considered impractical with other transportation modes without expensive superelevated (banked guideway) structures.

The SVS program objectives are to design and develop a transportation system having the cost advantage associated with the use of existing rights-of-way, while causing little disruption in adding an additional transportation mode. Elevated guideways have three advantages: avoidance of grade-crossings, less likelihood of intrusion of foreign objects on to the guideway, and less disruption of surface activities than at-grade guideways. Future testing of SVS systems at the High Speed Ground Test Center at Pueblo, Colorado, will be conducted if current SVS studies described below continue to show promise and will provide a basis for evaluating system performance and costs. Both will play an important role in reaching a decision as to whether to proceed with a public demonstration program and subsequent incorporation of an SVS into the national transportation system. The SVS appears as a promising contender for public demonstration as an alternative to a surface rail vehicle and the TACV operating over short-stage lengths.

OHSGT became interested in the SVS on the results of a 1967 systems engineering study. The study compared performance characteristics for existing and proposed high-speed ground transportation systems and showed the advantage of the SVS, given the land use constraints. Also, a study of current state-of-the-art suspended vehicle dynamics, completed in December 1969, showed the system could be operated at speeds in excess of 100 mph (161 km/hr) while maintaining excellent ride comfort. Several additional studies of dynamic interaction between vehicle and elevated guideway, employing simply-supported and continuous beams, were completed in FY71 providing parametric designs and providing cost estimates.

Existing suspended vehicle systems for the most part have been designed and operated at moderate speeds of 50 to 70 mph (80 to 113 km/hr). The French have been the forerunners in suspended vehicle technology with two types currently undergoing testing, the "Safege" and "Urba", both of which operate beneath guideways supported by pylons that are approximately 100 feet (30.5m) apart. The Safege vehicle, the first to be developed, hangs from rubber wheels running inside a slotted box-beam guideway. Dynamic analyses indicated potential speeds up to 150 mph (241 km/hr). The Urba system makes use of suction air cushions for vehicle suspension and uses a linear induction



**Suspended Vehicle System (SVS)--Artist's Conception.**

**FIGURE 14**

motor for propulsion. Like the Safege, the Urba vehicle uses a slotted box guideway. Although Urba was designed with the urban (intracity) market in mind, the negative air cushion technology (less than atmospheric pressure) is applicable to higher speeds and intercity transportation as well.

A system definition study completed in June 1971 established the feasibility of 125 mph (201 km/hr) SVS synthesized from state-of-the-art components and judiciously uprated subsystems. The system definition has been carried to a level of detail sufficient to allow an estimation of performance characteristics and assess general operational requirements of an SVS. Such an SVS could find applications as a high-speed airport access from city centers or on short-state-length intercity routes.

Figure 14 shows an artist's conception of the synthesized SVS vehicle and guideway. Power is to be supplied to the vehicle by wayside distribution lines mounted inside the guideway beam. This SVS vehicle could carry between 36 and 48 passengers in a passenger compartment suspended from two electrically-powered overhead bogies. The bogies, based on the same basic principles as the French Safege, contain propulsion, suspension, and braking equipment, and are enclosed within the guideway and hence are insensitive to weather conditions. Connection linkages between the bogies and the passenger compartment pass through a slot in the bottom of the guideway beam. A long-stroke, verticle airspring suspension allows the employment of an exceptionally light weight steel guideway structure, designed for stress rather than deflection for light weight and low cost considerations. A passive roll stabilization

system will limit the vehicle's response to side winds while permitting desired banking of the passenger cabin in turns. Hence no guideway superelevation is required.

In addition to the above state-of-the-art SVS study, OHSGT has contracted for an investigation of an advanced system having speeds in excess of 150 mph (241 km/hr) and utilizing improved technologies and innovative concepts for meeting future transportation requirements. This analysis will fully explore guideway design (including cable-assisted configurations), advanced roll stabilization, linear induction motor propulsion, and noncontact vehicle suspension. The resulting study will include:

- Performance description of operating characteristics and capabilities such as cruise speed, acceleration, braking rates, ride comfort, all-weather operation, and noise levels.

- Trade-offs such as overall vehicle and guideway space envelopes, bogie arrangement, location of power distribution lines, cabin roll and lateral displacements, minimum and maximum acceptable guideway span lengths, recommended guideway beam support techniques, and vehicle/guideway interface.

Tube Vehicle Systems (TVS). A major consideration in the design of future transportation systems is the need to avoid social and physical environmental conflicts. Prospective systems must operate safely at high speed under all-weather conditions and not contribute to current concerns relative to the quality of the environment. Tube vehicle systems show promise of satisfying these demands and an artist's concept of this type of system is shown in Figure 15.

The three primary technical areas of consideration in designing tube vehicle systems are: vehicle aerodynamics, vehicle suspension, and propulsion.

While the science of aerodynamics for free flight has been exhaustively investigated and is, therefore, well developed, such is not the case for vehicles moving in enclosed tubes. Therefore, when studies of tube systems were begun several years ago it was recognized that an analytical and experimental research program in the aerodynamics of the tube vehicles had to be initiated. Accordingly, projects were funded with Renssalear Polytechnic, Carnegie-Mellon, Massachusetts Institute of Technology, Ohio State, Oceanics Inc., General Applied Science Lab, MITRE, and TRW Systems to develop analytical and experimental data on vehicle drag, vehicle stability, and near-and-far-field effects. The experimental work has included the launching of small-scale models at high speed in tubes.

During the past year a computer program has been developed by MITRE Corportion which simulates the aerodynamics of a vehicle moving through a tube. Initial results of the simulation show good correlation with the data obtained from the earlier small-scale laboratory experiments. The data obtained are for "unchoked" flow in the space between the vehicle and the tube wall. When speed increases to the point where a combination of blockage and speed causes the flow to "choke," the drag rises abruptly to much larger values. The next experimental phase is intended to supply information to permit the simulator to include choked flow conditions.

Since it is projected that tube systems may be capable of speeds up to

**Tubed Vehicle System (TVS)--Artist's Conception.**

**FIGURE 15**

500 mph (805 km/hr), there is some limiting speed below this where steel wheels on steel rails will not be able to provide a satisfactory method of suspension. At the present time, an insufficient amount of research has been conducted on the performance of wheels rotating at very high speeds. Work of this nature is planned for the Rail Dynamics Laboratory to be constructed at the High Speed Ground Test Center. Furthermore, it may not be practical to install and maintain rails in tubes to the extremely close tolerances which will be required for very high tube vehicle speeds. Alternatively, consideration is being given to both air cushion suspension in an evacuated tube and magnetic suspension. Separate research projects are proceeding in these areas.

A logical choice of a propulsion system for tube vehicles is the linear induction motor because of its low noise and freedom from pollutant emission. Results of the LIM studies will provide sufficient data for design of the propulsion system for the experimental tube system.

Advanced Technology

The OHSGT advanced technology R&D program includes projects to develop or improve the performance of subsystems which have been identified by systems engineering analysis as those which are not fully developed, but which have been found to have the greatest potential for operational use (see the Tracked Vehicle Development Tree Figure 9). To obtain maximum cost effectiveness, the OHSGT program consists of subsystems which are common to several systems. This section will discuss the status of those projects.

Linear Induction Motor (LIM). Several support systems under investigation for possible use in future high speed ground systems, such as air, magnetic, and vacuum cushions, preclude propulsion by rotary electric motors as there are no wheels or axles which can provide traction. Propulsion for systems with these kinds of support must be through reaction or thrust. Jet engines or rockets are clearly unacceptable because of noise, and there are questions of safety because of the high-temperature and air-polluting exhausts. Linear electric motors, however, can provide thrust with none of these disadvantages. After trade-off studies were made between various configurations of linear motors, the doublesided induction type with the primary in the vehicle was selected for development while studies were continued on the single-sided linear motor.

As reported in the Fourth Report, a full-scale LIM has been designed and fabricated by Garrett Corporation and is installed in a steel-wheeled research vehicle. A year of low-speed testing was completed on the LIMRV at the Garrett plant in Torrance, California, before it was shipped to the High Speed Ground Test Center. During the year the vehicle, instrumentation, and data processing equipment successfully passed the acceptance tests. In addition, enough low-speed data was collected to show good correlation with predicted results, although data for speeds up to 35 mph (56 km/hr) cannot be called conclusive. Figure 16 illustrates the good match of experimental data to the theoretical values for LIM slip (a measure of the relative velocity between the traveling wave of the magnetic field and the vehicle) versus current and thrust. Also the data processing computer programs were de-bugged so that high-speed testing will not be interrupted by the need to re-write computer routines.

The telemetry system, which transmits data from the LIMRV to the data processing van, operated satisfactorily at the Torrance test track. The operating frequencies had to be changed to 217 MHz because of interference with aircraft flight testing in the original frequencies. Although the terrain at the Test Center is relatively flat and favorable for line-of-sight transmission, a 140-ft. (43 m) antenna has been erected in anticipation of extension at the LIMRV test track beyond the present length.

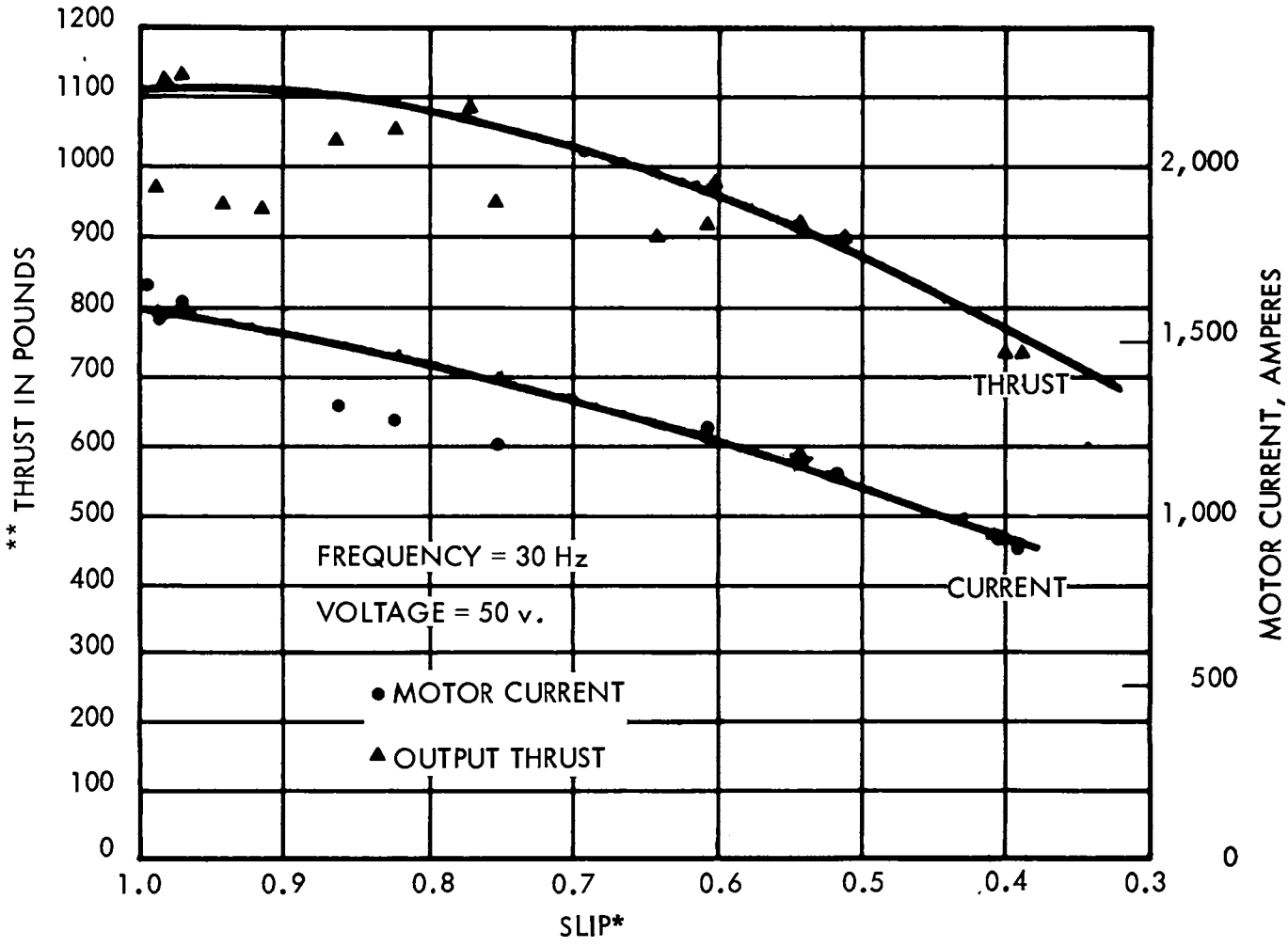
The LIMRV arrived at the Test Center in early May and attained a speed of 95 mph (153 km/hr) in a test run which Secretary Volpe was aboard during a Transportation Week ceremony on May 19, 1971. Additional test validation of the LIM was accomplished, however, testing was terminated for a period of time for repairs when the LIMRV, while being backed up at the conclusion of an operating run, struck the rear wall of the maintenance building. The vehicle came off the end of the rails and damaged the Linear Induction Motor. Analysis of the accidents revealed the cause to be improper operating procedure.

The LIM in the wheeled research vehicle is shown in Figure 17. The LIM is air-cooled by separate blowers for each of the two primary windings with a stack height of 10 inches (25.4 cm) and core length of 150 inches (381 cm). The design point rating is 2500 hp (1860 kW) or 3750 lb. (16.7 kN) continuous thrust at 250 mph (402 km/hr). The speed is controlled by varying the frequency and voltage of the power supplied to the LIM. Since the power is generated on board by a turbine driving an alternator, the frequency is varied by simply changing the speed of the turbine.

The design and low-speed testing of this LIM provided sufficient experi-

$$* \text{ SLIP} = \frac{\text{Velocity}_{\text{traveling wave}} - \text{Velocity}_{\text{vehicle}}}{\text{Velocity}_{\text{traveling wave}}}$$

**Metric Conversion 1 lb. thrust = 4.448 Newtons



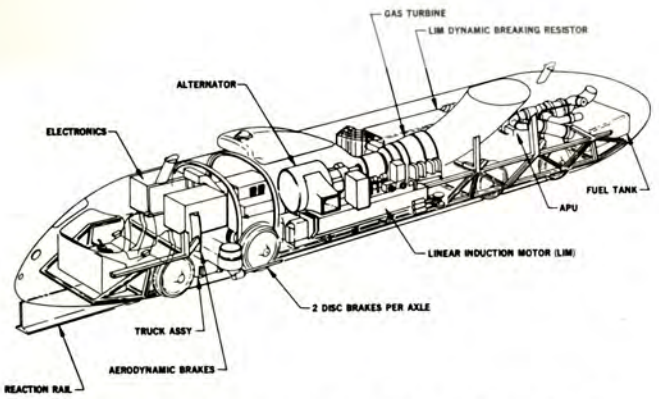

**Comparison of Theoretical and Experimental LIM Performance for 2.375 inch (6.04 cm) Gap.**

**FIGURE 16**

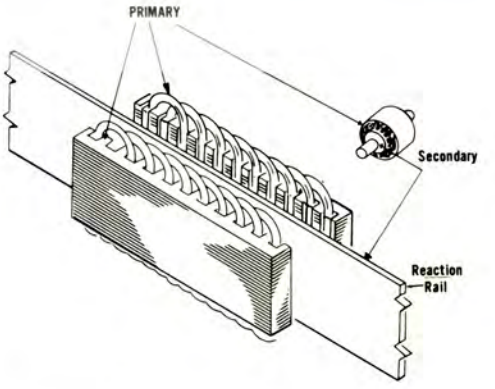
ence to design an advanced LIM for use in the Tracked Air Cushion Research Vehicle (TACRV).

The electrical propulsion system designed for the TACRV, as shown in Figure 18 will consist of two identical power conditioning units and two identical LIM propulsion subsystems or thrust modules, each sized to provide 50 percent of the propulsion system's total thrust. Each half-system is independent of the other with respect to thrust, power conditioning, control, sup-

## LIM Research Vehicle (LIMRV)




LINEAR INDUCTION MOTOR RESEARCH VEHICLE



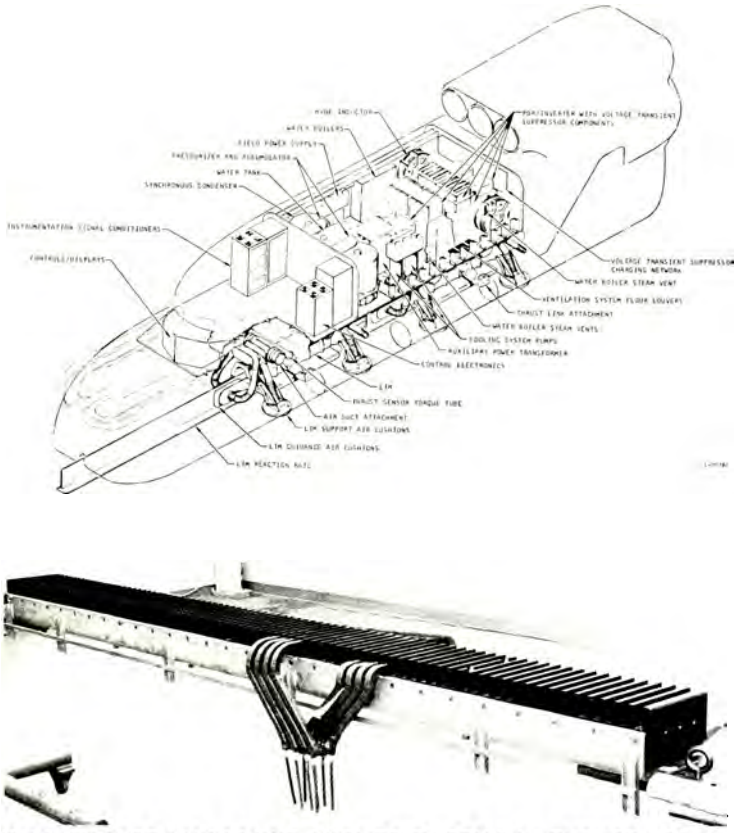

**WHAT IS A LINEAR INDUCTION MOTOR?**

A linear motor is a simple rearrangement of the classic asynchronous motor. It can be considered as a conventional rotary motor cut along a radius, unrolled and laid out flat. A small air gap between the primary and secondary remains, permitting relative linear motion between the two. One of the members must be lenghtened in the direction of travel so that motion can continue.

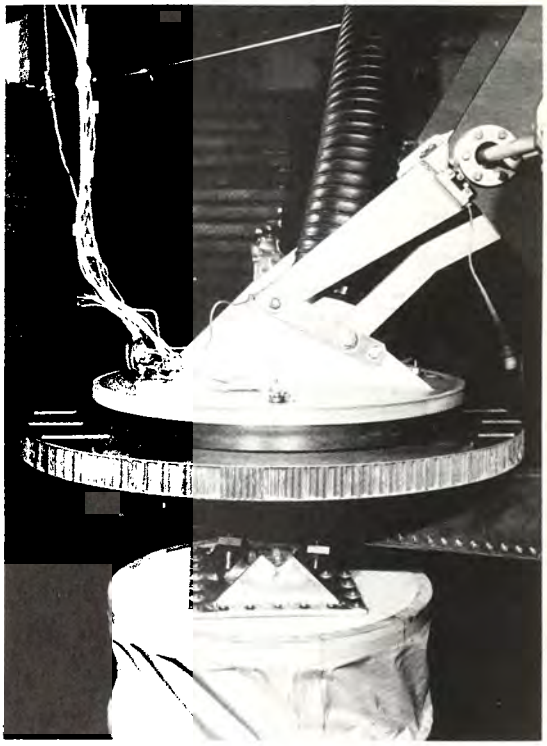
**FIGURE 17**

port, and guidance. Shared by the two half-systems are a liquid cooling and heat rejection system. Single systems are also used for fire protection, grounding, and lightning protection.

All components of the propulsion system are carried on board and supported by the TACRV itself, except for the two LIM thrust modules. The LIMs are each self-supported above the guideway by four levitated air cushions of their own. Guidance of each LIM along the reaction rail is accomplished through a leading and a trailing air cushion on each side of the rail. In all, there are eight air cushions on each LIM. Air for the LIM cushions is drawn from the TACRV main air ducts through a flexible coupling. Flexible connections for cooling water and electrical power are also used since the underslung LIMs



ONE HALF OF ONE LIQUID COOLED TACRV/LIM THRUST MODULE, WITH PARTIALLY WOUND COILS



TACRV/LIM VERTICAL SUPPORT AIR CUSHION (EIGHT ARE USED FOR BOTH LIM'S)

**TACRV Linear Induction Motor and LIM Air Cushion.**

**FIGURE 18**

are free to move about in five degrees of freedom independent of the TACRV. Thrust is transferred from each LIM to the TACRV through thrust assembly linkages that connect the LIMs to the TACRV chassis. The Garrett Corporation TACRV/LIM design was completed in April 1971 and fabrication began soon after. Each of the two TACRV motors is double sided, similar to that in the LIMRV, and is rated at 5,000 lbs. (22.24 kn) of thrust continuous and 7,500 lbs. (33.36 kn) of thrust for acceleration. They are designed to accelerate the TACRV to speeds of 300 mph (483 km/hr). In order to reach the higher thrust and speed without unduly increasing the weight, the operating voltage is 8,250 volts and water cooling is utilized. The water cooling is pushing the state-of-the-art of hollow conductors and it is a development in itself.

A high-speed wayside power collector system will afford access to 15 megawatts of 8,250 volt electrical power. Without a turbine on board, control of the LIM speed cannot be similar to the LIMRV; frequency and voltage will be controlled by a power-conditioning unit, which includes a synchronous condenser and solid-state circuitry. (See Power Conditioning subsection.)

The experience gained in the LIM design for the LIMRV and the TACRV programs provides the basis for the Urban TACV propulsion. Since the Urban

TACV is designed for speeds of only up to 150 mph (241 km/hr), the controls can be simplified more than those for the TACRV. Speed can be changed by varying voltage rather than frequency. However, the LIM itself--the thrust module--is very similar for the LIMRV and TACRV.

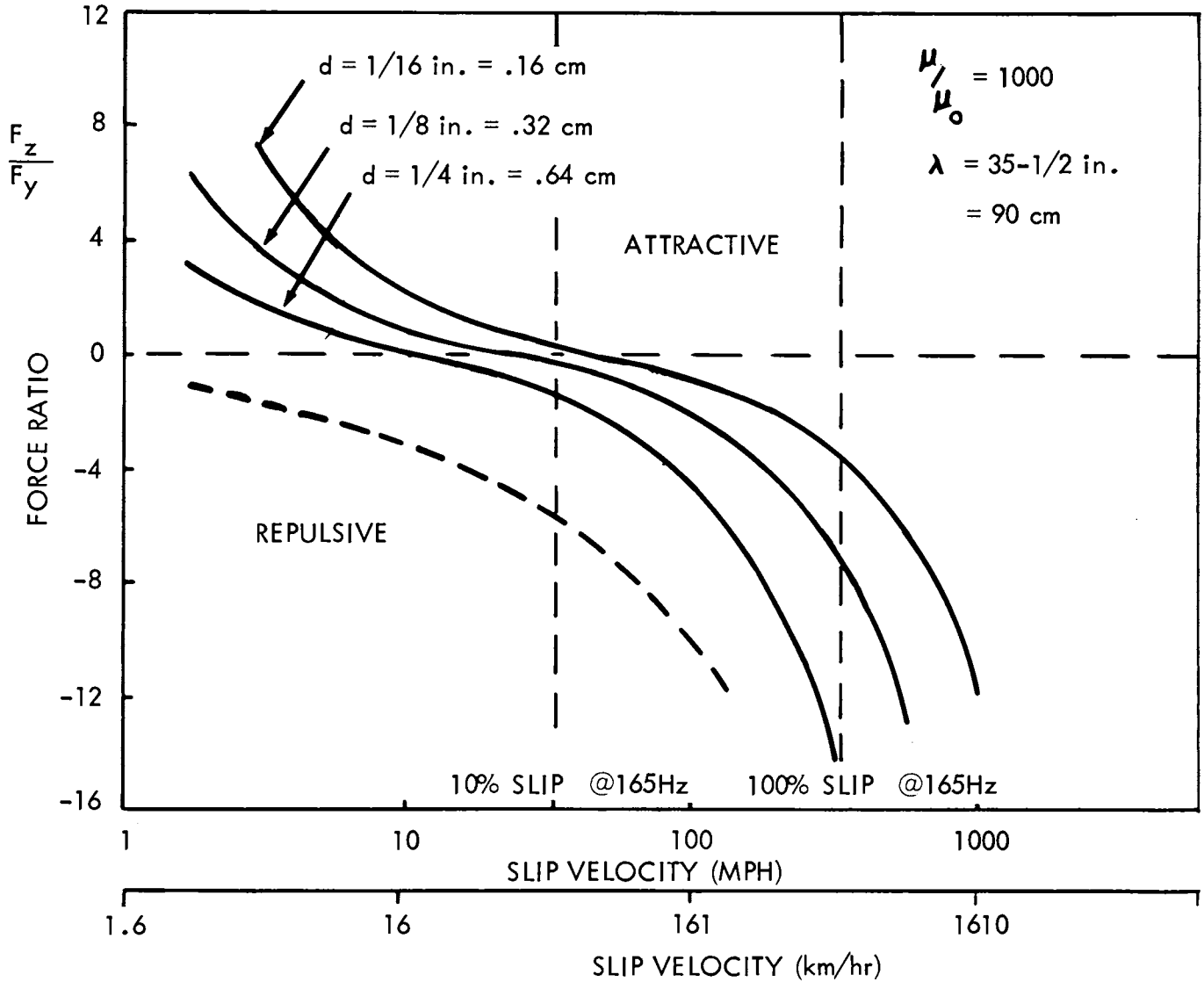
A comparison of LIM characteristics for the TACRV and LIMRV follows:

Comparison of the LIMs for the LIMRV and TACRV

| | Single LIM for TACRV |
|---|---|
| Thrust | 5000 lb. (22.24 kN) continuous<br>7500 lb. (33.36 kN) overload |
| Voltage | 8250 volts, 3-phase, grounded neutral |
| Frequency | Variable to 165 Hz at 300 mph (483 km/hr) |
| Primary Current | 530 amp at rated thrust and speed |
| Power Factor | 57.5 percent at rated thrust and speed |
| Efficiency | 80.5 percent at rated thrust and speed |

| | LIM for LIMRV |
|---|---|
| Thrust | 3750 lb. (16.68 kN) continuous<br>6400 lb. (28.47 kN) overload |
| Voltage | 1000 volts, 3-phase |
| Frequency | Variable to 173 Hz |
| Primary Current | 2000 amp at rated thrust and speed |
| Power Factor | 61 percent at rated thrust and speed |
| Efficiency | 85 percent at rated thrust and speed |

Studies have been completed by TRW and MITRE on single-sided LIMs. A single-sided LIM has one set of windings and the reaction rail is horizontal. These studies have shown that the popularly held notion that single-sided motors are impractical because of the large attractive forces between




**Force Ratio For Aluminum Over Laminated Steel**

**FIGURE 19**

the two halves of the motor is not correct. See Figure 19. Information exchanges with Tracked Hovercraft Ltd. in England confirm these findings. Although at some design points there are large attractive forces which would cause a heavy unwieldy vehicle structure, in the desirable range of operating conditions, the forces range from small attractive to repulsive forces. Planning has been started for future testing of a single-sided motor at the Test Center.

Wayside Power Distribution and Collection. The Garrett Corporation is under contract to OHSGT to develop a wayside power distribution and collection method for the TACRV system. Up to 15 megawatts of three-phase power at 8.25 kilovolts must be delivered to the vehicle while traveling at 300 mph (483 km/hr). A captive sliding contact system was designed in 1971 with the power rails arranged in a triangular array. The collector, which slides inside the three power rails, is a slotted plug as shown in Figure 20, and is supported and guided by the rails and towed by an arm extending from the

ASSEMBLED MODEL

POWER DISTRIBUTION SYSTEM

SLOTTED PLUG POWER COLLECTOR

**Power Collection and Distribution System**

**FIGURE 20**

vehicle. The advantages of this arrangement are compactness and the elimination of any need for active control to maintain contact. Voltage breakdown tests have been performed to determine the minimum rail spacing needed to avoid arcing.

Maintaining uninterrupted contact at high speeds is expected to be a very critical problem. Accordingly, two significant efforts are in progress in collector dynamics. An analog computer simulation has provided data on inertia, stiffness, and damping requirements to aid in the design of collector and distribution components. The same program will be used to interpret the behavior of the system during the full-scale high-speed tests of the collector. A rocket-sled test track at China Lake, California, is being made available by the Naval Weapons Center for testing the complete system in 1972. The high acceleration possible with a rocket sled permits the collector to achieve full speed with a minimum installation of power rails. Upon successful completion of these tests, the system will be installed on the TACRV guideway at the HSG Test Center.

While the Garrett program is specifically concerned with the TACRV,

power collection is involved in all advanced high-speed ground transportation systems. A more general investigation of power collection problems, therefore, has been assigned to the Transportation Systems Center (TSC), including contact and noncontact methods of transferring power. Brush materials for making sliding contact are being evaluated for maximum life. TSC has contracted manufacturers of brushes for railroad pantographs to obtain test samples. A combination of computer simulations and hardware testing will be used to evaluate geometries other than the design for the TACRV. No electrical problems are expected to be encountered in the China Lake rocket-sled tests; the uncertainty lies entirely with the mechanical dynamics of the collector plug/conductor rail interaction.

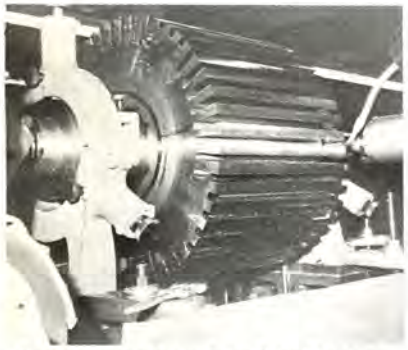
Power Conditioning. As discussed earlier, power must be conditioned for LIMs because the thrust and speed of the motor are controlled by changing the frequency and/or voltage characteristics of the power supply. Although this could be done on the wayside before the power is picked up by the vehicle, the higher frequency requirement would tend to require short distances between substations and, thus, many substations. Therefore, R&D has been concentrated towards onboard conditioning. This is accomplished by assemblying a number of components into a Power Conditioning Unit (PCU) as shown in Figure 21.

For lower-speed LIM-propelled vehicles, up to 150 mph (241 km/hr), control can be exercised by varying voltage, which is relatively easy to accomplish. The best technique developed so far for speeds above 150 mph (241 km/hr) involves varying the voltage and frequency, as was discussed in the section on Linear Induction Motors. The best approach to date for supplying variable voltage/frequency power is that of using a rotating machine (Synchronous Condenser) with solid state components as shown in Figure 21 which has been chosen by the Garrett Corporation for TACRV propulsion system.

Although the Garrett system is presently the least bulky and heavy in this power range, it still weighs more than the LIM itself. Therefore, in an effort to bind a smaller, lighter-weight power-conditioning unit, the DOT Transportation Systems Center (TSC) has undertaken a long-range research program for power conditioning. A particularly promising technique is one developed for the NASA space programs: this is a natural commutation technique that is a static all solid state device without a rotating machine component.

Onboard Power Sources for Propulsion and Levitation. A continuing search for ultra-low polluting onboard power sources which will lead to R&D for the high speed ground transportation has been carried on since 1968. The aim is to eliminate the appreciable systems installation and maintenance cost which characterizes the use of wayside electrical power for vehicle propulsion. The onboard engine would also provide power for levitation, whether air cushion or magnetic, and for auxillary equipment.

The search has brought to light several types of external combustion engines which show sufficient promise to warrant an R&D program. These engines will not only emit minimal pollution, but also operate quite silently and at very low rates of fuel consumption as the attributes listed below indicate.



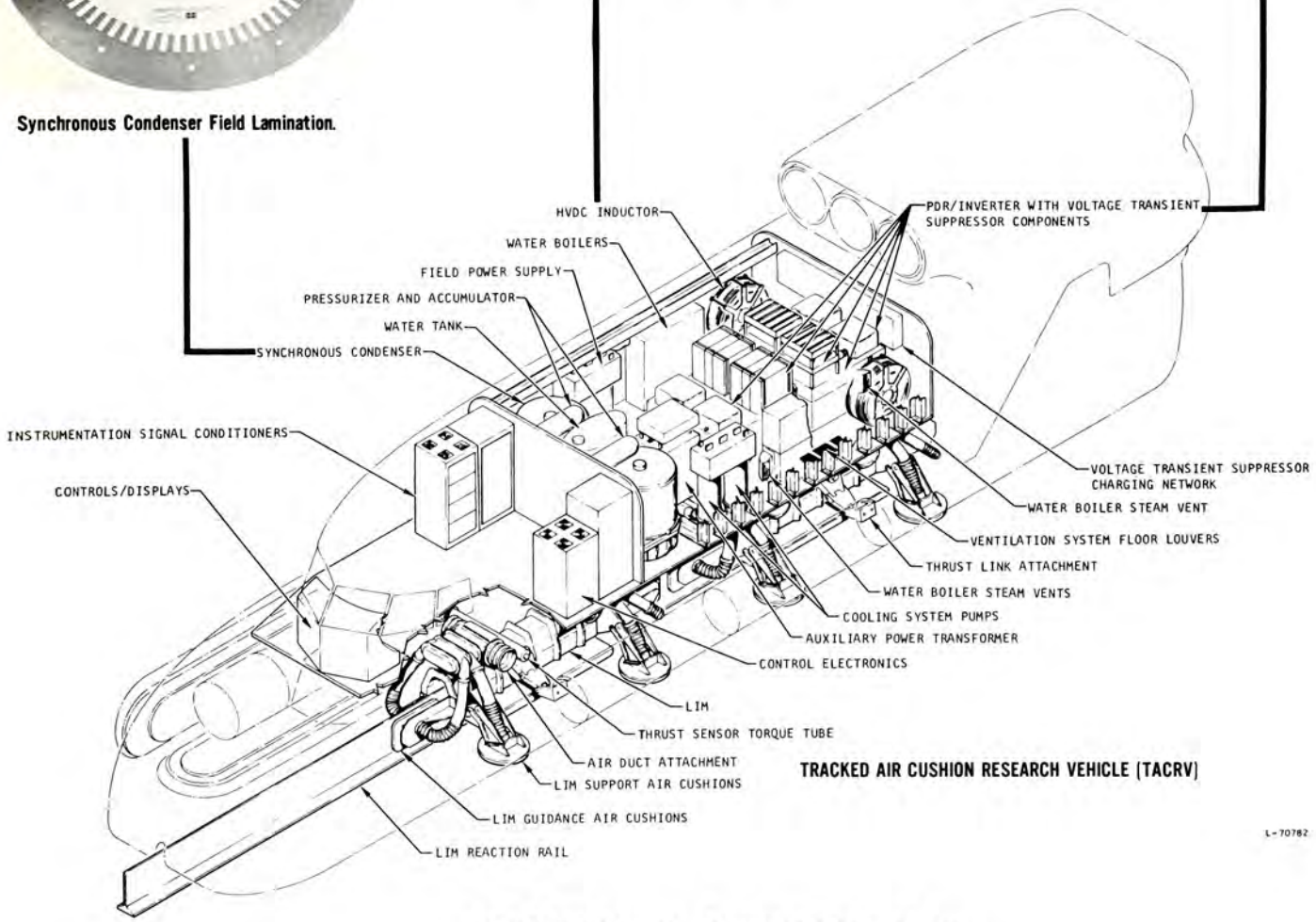
Sychronous Condenser Rotor Being Machined.

Laboratory Model of Inductor.

Phase Delay Rectafier/Inverter Prototype.

Module of PDR/Inverter.

Synchronous Condenser Field Lamination.




# TACRV Power Conditioning Unit
## FIGURE 21

CLOSED GAS CYCLE EXTERNAL COMBUSTION ENGINE ATTRIBUTES

| | |
|---|---|
| Pollution | Unburned hydrocarbons and CO--each less than 1/5 of the 1976 auto standards. |
| | $NO_x$--less than 1/3 of 1976 auto standards and less than 1/10 of diesel. |
| Fuel Consumption | Less than 2/3 of internal combustion engine in stop and go operations. Less than internal combustion engine in full-load continuous operations. |
| Noise | Quiet. Much quieter than internal combustion engine and open cycle gas turbine. |

Reliability higher than diesel and should be higher even than aircraft gas turbine. Of the closed cycle class, the Rankine cycle engine--both turbine and reciprocating--is best known. The more advanced closed gas cycle engines, also both turbine and reciprocating, are less well known and these appear to show greater promise of control simplicity and low fuel consumption. The remarkably efficient Stirling cycle engines and closed Brayton cycle engines are two examples. The gas serving as the working fluid can be helium or air and does not change phase during the cycle as does the steam or organic working fluid in the Rankine cycle.

The external combustion, as opposed to internal combustion, permits precise control and stability of the combustion process, hence the exceedingly low pollution levels. It also permits use of a wide variety of fuels: diesel oil, natural gas, propane, and hydrogen, for example.

This new technology for low pollution power appears to have unusual promise for a range of transportation applications, including the automobile and large and small stationary applications.

Magnetic Suspension. The search for a suspension system for very high-speed vehicles traveling in evacuated tubes has led to studies of magnetic suspension. Developments during the past year, however, have opened the possibility that magnetic suspension can be used for vehicles traveling in the open and may well be a competitor for air cushions.

Although research has not proceeded far enough to obtain conclusive results, there are indications that the power required to support vehicles is less for magnetic suspension than air cushion; and even more importantly, the guideway could be cheaper to construct. Further, the combination of magnetic suspension and linear electric motors may offer some additional efficiences through use of common components. Efficiencies of the magnetic suspension systems must be improved and high-reliability control systems must be developed. To this end, the FY71 effort was structured to study and define the requirements and limitations of magnetic suspension systems.

Ford Motor Company and Stanford Research Institute were awarded contracts in February 1971 to investigate the use of magnetic fields as a noncontact means of supporting and guiding high-speed ground vehicles. Three different

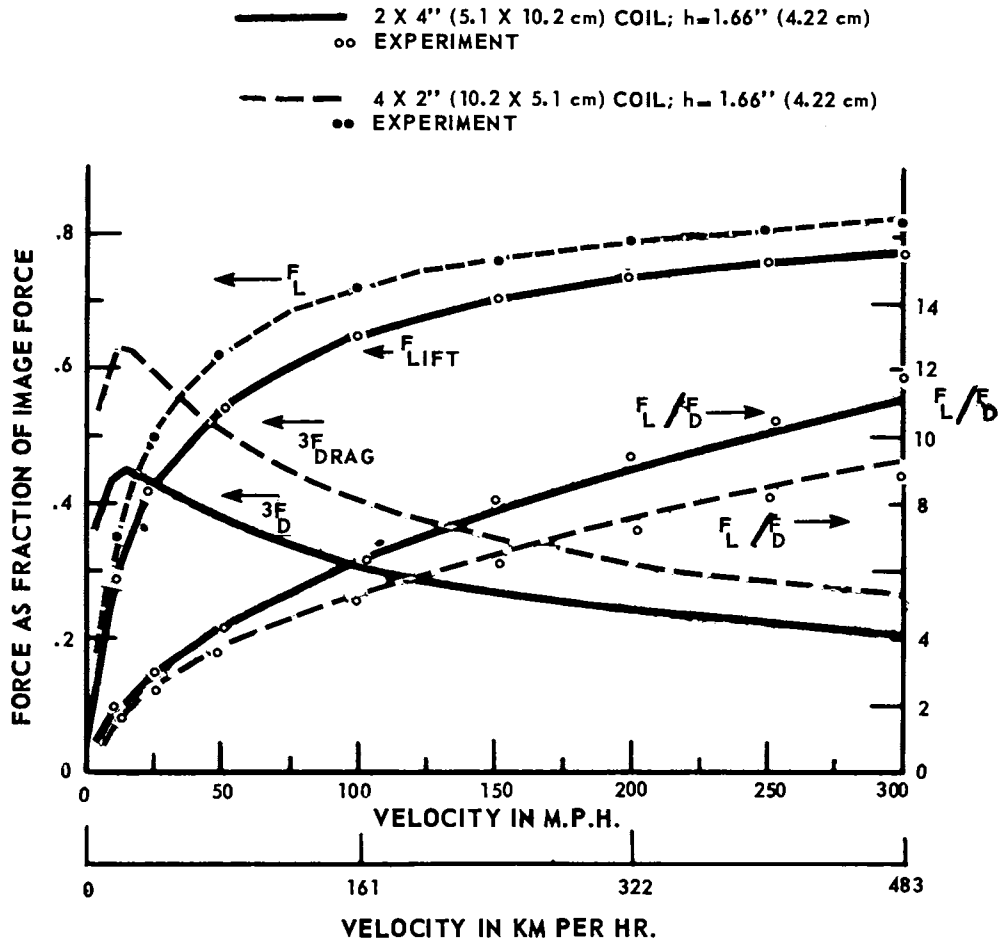
concepts are under active consideration by both companies: servo-controlled electromagnets, superconducting coils, and permanent magnets in the vehicle and guideway.

The first of these concepts is the servo-controlled electromagnet riding under a steel rail with a clearance of perhaps 10 mm. This concept was used in Germany by Messerschmitt-Bolkow-Blohm and Krauss-Maffei to construct large-scale experimental vehicles now in test. Current required for the coils are within the capabilities of conventional (non-cryogenic) electromagnets, and the guide rails require no more steel than conventional railroad tracks. The Germans have demonstrated excellent ride quality at low speeds with this concept; however, attaining acceptable ride quality at speeds over 200 mph (322 km/hr) may require a precision of rail alignment which is impractical to maintain.

If a larger clearance can be provided between the vehicle and the guideway, the magnetic suspension system becomes more tolerant of guideway irregularities. This requires magnets which can produce large fields over an extended region. Only superconducting coils, the second magnetic suspension system concept, can generate such fields without excessive consumption of electrical power. The major process in the OHSGT program to date has been in the analysis of superconducting coils moving over variously configured conductors in the guideway. Lift is obtained from the repulsive forces between the vehicle magnet and the eddy currents induced in conductors by the passage of the alternating magnetic field. It has been discovered that aluminum plates may be used on the guideway in place of the coils originally thought necessary with little or no sacrifice in lift-to-drag ratio. The case of a rectangular coil moving over a horizontal conducting sheet has been analyzed, and relationships derived for the lift and drag forces as a function of coil dimensions, clearance, and thickness of guideway conductors. The contribution to the forces on the guidance due to the side wall has also been approximately determined. It has been shown that the ratio of total drag to the arithmetic sum of lift and guidance forces is no greater than the drag-to-lift ratio when guidance is absent. A study of the dynamic response for this suspension reveals a readily controllable, weak instability, resulting from the curious behavior of the electromagnetic drag force which actually decreases with increasing speed, hence there is apparently no speed limitation in this type of suspension due to the suspension system itself.

An experimental program was conducted at Ford measuring lift, guidance, and drag forces on small superconducting coils held over a rotating aluminum wheel. Figure 22 is a comparison of experimental and theoretical results for a 2 x 4 inch (5.1x10.2 cm) rectangular superconducting coil held 1.66 inches (4.22 cm) over the curved surface of the wheel. The solid line results when the coil has its long dimension parallel to the direction of motion.When the coil is rotated 90 degrees the dashed curve is obtained. The image force is the value the lift would attain at infinite speeds. Much higher life-to-drag ratios result from larger coils at greater heights. A ratio of 40 is obtainable at 300 mph (483 km/hr) with 3.3 x 6.6 feet (1x2 m) coil riding 11.8 inches (0.3 m) above 0.6 inch (1.52 cm) thick plate of aluminum.

A miniature model of a magnetically-suspended vehicle has been constructed by Ford and is shown in Figure 23. Samarium cobalt permanent magnets are used on the four corners of the vehicle. The guideway is simulated by a 2 foot (.61 m) diameter, 6 inch (15.2 cm) wide aluminum wheel with 1.44 inch (3.66 cm)

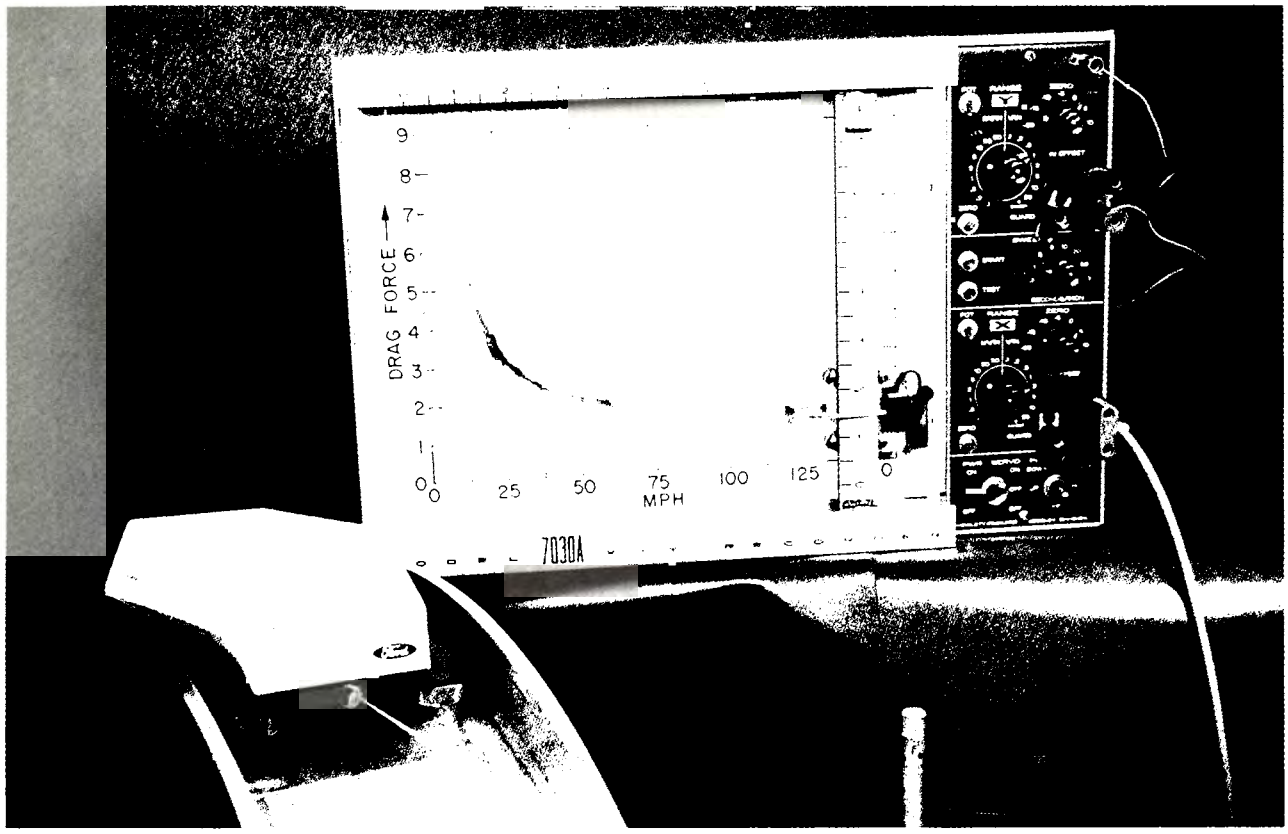



**Lift, Drag, and Lift to Drag Ratio for a Small Rectangular Superconducting Coil.**
**FIGURE 22**

flanges. Relative motion is obtained by rotating the wheel while tethering the vehicle by a string which resists the drag force. The drag force is recorded by measuring the pull on the string as a function of speed. Despite its simplicity this vehicle is able to recover from severe equilibrium displacements without contacting the guideway. The system possesses very little natural damping so that return to equilibrium requires many seconds. Even for full-scale vehicles, permanent magnets over a conductive guideway result in very high drag and provide clearances of only one to two inches. To obtain much larger clearances, superconducting magnets are required on board the vehicle.

The Stanford Research Institute has constructed a 300 foot (91.4 m) long, 18 x 6 inch (45.7&15.2 cm) channel-shaped aluminum guideway as shown in Figure 24. A flat rectangular 10 x 7 1/2 inch (25.4x19.0 cm) superconducting coil is transported along the guideway as a wheeled vehicle. Measurements of lift and drag for this coil have illustrated the decreasing drag as the velocity is increased.

The third magnetic levitation concept makes use of the repulsive force




**A miniature magnetically levitated vehicle. One inch diameter X 3/8 inch (2.54 cm X .95 cm) thick samarium-cobalt permanent magnets at each corner provide lift and guidance.**

**FIGURE 23**

between permanent magnets on the vehicle and permanent magnets embedded in the guideway. Because of the high cost per pound of permanent magnets, such a guideway appears very expensive and difficult to keep free of ferromagnetic debris. Each of these three concepts will be evaluated further in FY72.

Obstacle Detection. Safety of high-speed ground vehicles requires detection of any foreign objects on the guideway far in advance of the moving vehicle because of the long distances (one to several miles) required to stop the fast moving vehicle. Forward looking sensors on vehicles do not have the range required because of the long stopping distance and because of the guideway curvature. Therefore, research has been concentrated on wayside sensors which keep the entire length of the guideway under surveillance at all times.

After studying various sensors, a nonlasing diode proposed by Applied Metro Technology, Inc was selected and development has been concentrated on it in the last year. A unique feature of the system is that it is unaffected by changing environmental conditions. Field tests have been conducted in hot weather and the nonlasing diode has been found to be less affected by heat rising from the surface than are laser beams.

This project has produced the first nontransportation technology spin-off

**Stanford Research Institute's (SRI) "Maglev" Experimental Guideway**

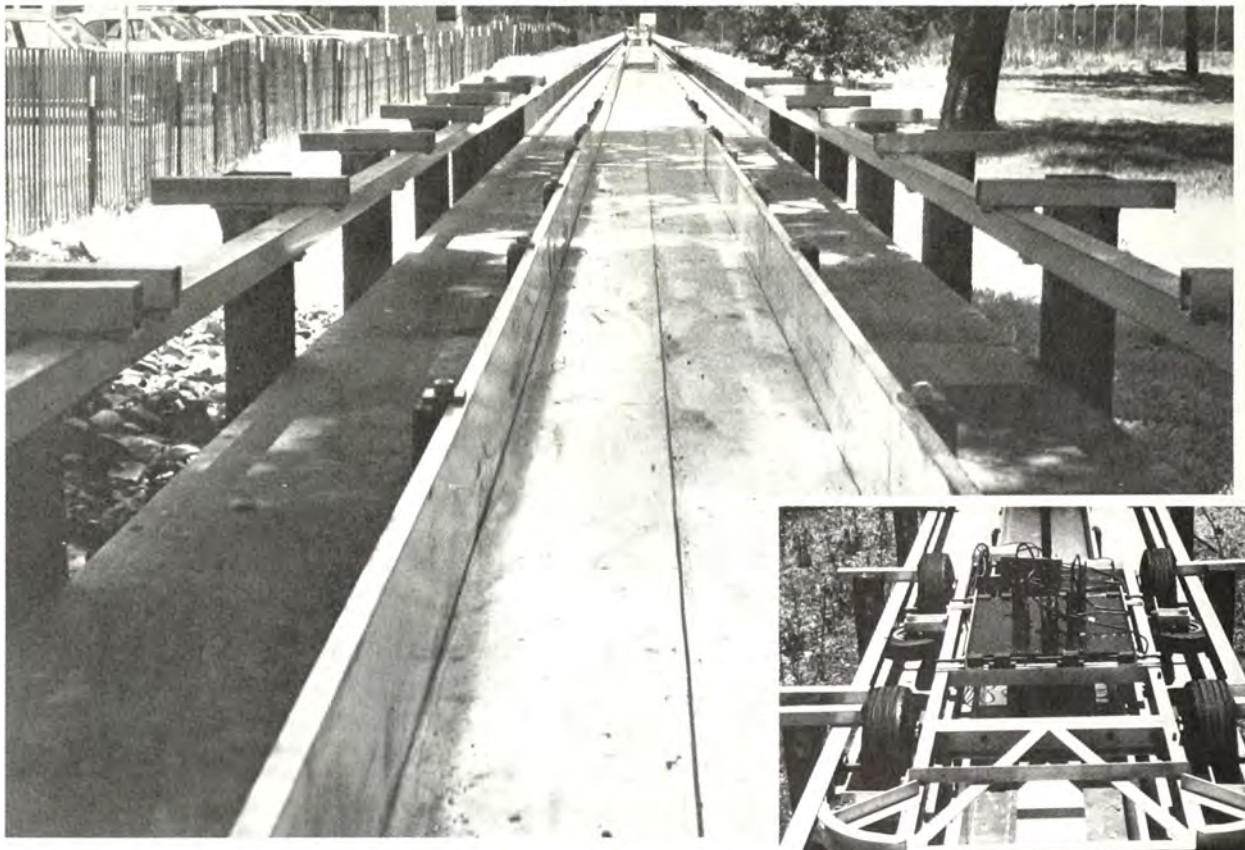


FIGURE 24



EXPERIMENTAL "MAGLEV" VEHICLE TO MEASURE LIFT AND DRAG

of the HSGT program in its adaptation to security systems. An example is the nonlasing diode security installation around the Governor's mansion in Madison, Wisconsin. This installation has provided cold-weather tests and has shown good reliability in snow and cold. The next step in the development cycle will be to install the sensors along a section of test track at the High Speed Ground Test Center for operational and long-term reliability tests.

Communications. Experience with telephone service on the Metroliner trains between Washington and New York has clearly demonstrated the usefulness of telephones to passengers. A sample telephone usage rate of the Metroliner running between New York and Washington is 4,244 calls per month. This mobile telephone demonstration shows an active and useful service for future surface transportation systems. Consequently, planning for future high-speed ground transportation systems will include requirements for adequate telephone service for passengers.

Also, higher vehicle speeds require improved communications between vehicles and various locations along the wayside for safety and operational control. A broad band of frequencies is needed for control signals, reporting location of vehicles, guideway surveillance and crew communications. If video (sight and sound) phone and TV were to be provided for passengers, bandwidth


**Dielectric Waveguide Laboratory Experiment for Communication Systems.**

**FIGURE 25**

requirements would be an order of magnitude larger. The added cost to provide all types of communications mentioned could probably be justified only if point-to-point communication could also be provided. The transportation system operator could use the link for business communications, including reservations information, and there still would be excess capacity which might be used to provide common carrier transmission services. Studies are being conducted to make cost/benefit comparisons between large-capacity waveguides and smaller-capacity devices to help select the communication system to be recommended for operational use on a future demonstration.

Because of the unavailability of additional frequency allocations by the Federal Communications Commission, no R&D has been undertaken on radio communication links. All effort has been directed to techniques which utilize transmission lines or waveguides along the right-of-way which produce very limited radiation patterns and thus do not require a frequency allocation. Antennas mounted on the vehicles must be designed to effectively operate within the relatively small radiation field near the transmission line for two-way communication to and from vehicles.

As reported in the Fourth Report, a number of large-capacity configurations have been analyzed and tested in the laboratory. From these studies a di-electric wave guide developed by General Applied Science Laboratories, as shown in Figure 25, was chosen for more extensive laboratory evaluation. This evaluation demonstrated that the system worked as predicted at the frequency range of 4 gigahertz (i.e., 4 billion cycles per second). Dielectric shrink-

age was noted during this test and further development work may be undertaken to remedy this condition. Further work may also be undertaken to determine the design required to environmentally protect the waveguide.

During FY71 Transportation Systems Center investigated several aspects of the proposed communication system including:

- Mechanical problems involved with the installation and operation of long transmission lines. These problems include periodic and random misalignments, such as sag between supports and installation defects. Since the lines may be aluminum, thermal expansion must be accounted for in the design.

- Losses caused by bends in transmission lines.

- Consideration of a rectangular dielectric in a trough as an alternative to the surface wave dielectric waveguide proposed by GASL (disadvantages were found to outweigh advantages).

The Physical Science Laboratory of New Mexico University has been continuing its computer simulation of the transmission line to determine the effect of impedance mismatches at the repeated junctions and the effect of the moving coupler on transmission quality.

Network Controls. If high-speed ground vehicles are to operate with short headways, the vehicles must be operated under an automated control system with far greater capability than even the most modern railroad controls. An examination of all proposed systems made it clear that the concept which has the greatest chance of success is one which utilizes an electronic signal transmitted along the vehicle path with sensors on the vehicle in a synchronous system. Since 1968, TRW has been supported in studies of such a system, which has been named Synchronous Longitudinal Guidance (SLG).

The SLG subsystems include the vehicle longitudinal control system (used for propulsion and braking control), the safety assurance system (used to prevent rear-end collisions), the merge control system, and the traffic management system. The main elements of the SLG approach are as follows:

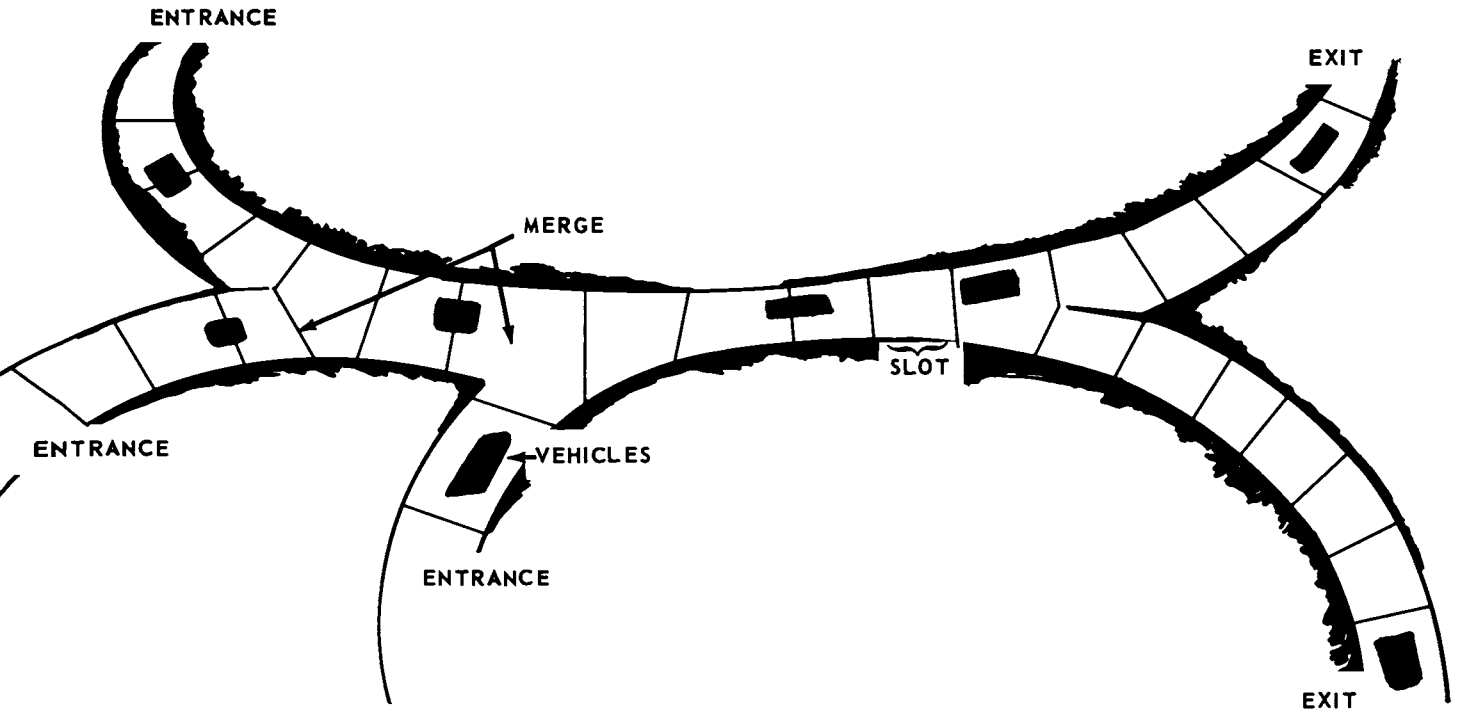
- Vehicles are required to follow deterministic position-time profiles in their travel through the transportation network.

- Headways between vehicles are restricted so as to be integral multiples of a chosen unit of headway; the moving space defined by the headway unit can be viewed as a moving slot or cell in the network.

- The arrival of slots at network nodes such as merges and diverges is synchronized.

- Occupancy of the slots by vehicles is controlled by a central computer in such a way that a vehicle which is located in its assigned slot travels through the network without interfering with other vehicles. Slot assignments are made by controlling vehicle departure times and itineraries.

- In large networks, slots may be grouped into reservation units called cycles. A vehicle then obtains a reservation for one slot (but not a par-




**Simple Synchronous Longitudinal Guidance (SLG) Network Of Space Allocation Slots With Vehicles Merging And Diverging**

**FIGURE 26**

ticular slot) in a cycle. The central computer controls these reservations to insure that the number of vehicles which occupy a cycle will never exceed the number of slots in the cycle. However, it does not keep track of individual slot reservations; these are assigned at each merge point by a local controller called an organizing section controller.

Figure 26 illustrates the space allocation slots and the merging and diverging of these slots in a simple representative network. The slots are generated at the entrances to the network, and travel to the various exits. The two synchronisms required in SLG are:

- Control of the vehicle in its slot.
- Control of corresponding slots at a merge.

Vehicles at the entrances are placed in these slots appropriately so as to insure that the internal capacity of the network is not overloaded. This eliminates traffic jams from forming in the network and allows the maximum number of vehicles to travel through the system.

TRW received a study contract to develop the necessary analytical space allocation expressions. The effectiveness of these expressions have now been verified through computer simulation as being very high. A standard "deal" utilization of a generalized transportation network was established.The actual utilization of the network by these expressions was then compared with

the ideal, and a measure of effectiveness based upon a comparison of the two was derived. The process of directing the flow of traffic in the network involves a combination of centralized and local control. The design specifications of the controllers has been started and the basic logic flow diagrams are being written.

A synchronous control system can also be used for urban transportation systems and is being studied under a DOT-wide project for use in a Dual Mode Vehicle (DMV) system. DMV is a system in which the same vehicles can be operated manually (as today's automobiles are) on conventional highways and also operated automatically on properly equipped guideways.

Tradeoff studies have also been made in preparation for design of the equipment which must be installed along the guideway for communication to, and control of, the vehicle. The results indicate that an integrated design will be possible which will provide for all normal necessary voice and data communications in a single enclosure installed in the guideway. Tests are planned at the High Speed Ground Test Center.

Guideways. High speed ground transportation system guideways may be located on, above, or below the surface. Surface guideways represent the least costly alternative when considering only construction costs, but real estate acquisition costs are higher than for either subsurface or elevated systems. Social costs,in terms of interference with surface activities, noise, and other environmental considerations, make surface guideways less desirable for future systems in highly populated areas. Conventional rail, tracked air cushion, and magnetic levitation vehicle systems appear to be the most appropriate for surface guideways.

Elevated guideways may be used by suspended, tracked air cushion, or magnetically-levitated vehicle systems. Elevated guideways have for many years been used by conventional rail systems to take advantage of clearance over cross traffic, doubling up on existing rights-of-way, and conservation of surface space for other purposes.

Construction costs for guideways must be reduced in order to make capitalization costs for new systems more attractive, especially for the tracked air cushion and magnetic levitation vehicles. Present costs estimates for a tracked air cushion single track electrified guideway are $900,000 per mile (1.61 km) on the surface, and $1.5 million if elevated.

In order to establish guideway design criteria, several studies have been undertaken by TRW, Duke University, and MIT to examine the dynamics of guideway-vehicle interaction. TRW prepared a computer program that determines the dynamic response of a simply supported elevated guideway to the passage of a high-speed train. Duke University and MIT have developed similar models and computer programs for vehicles, which place distributed rather than concentrated loads on elevated spans such as TACV.

Guideway design tolerances play an important part in determining costs. When greater design tolerances can be allowed and still provide satisfactory ride quality, lower construction costs generally result. Guideway maintenance costs are also a function of design tolerances, depending upon the specific vehicle/guideway system. The smaller the tolerances required the higher

the construction cost. Studies will be continued to find means of lowering guideway costs.

Tunneling. Tunnel systems appear to be the most logical option for future ground transportation if speeds above 300 mph (483 km/hr) are required. Operation in tunnels at these higher speeds makes environmental control more attainable and assures greater safety than surface or elevated guideways. Technological problems must yet be solved prior to the design of an operational high-speed tunnel system, and construction costs must be significantly reduced to be more competitive with those of surface and elevated systems.

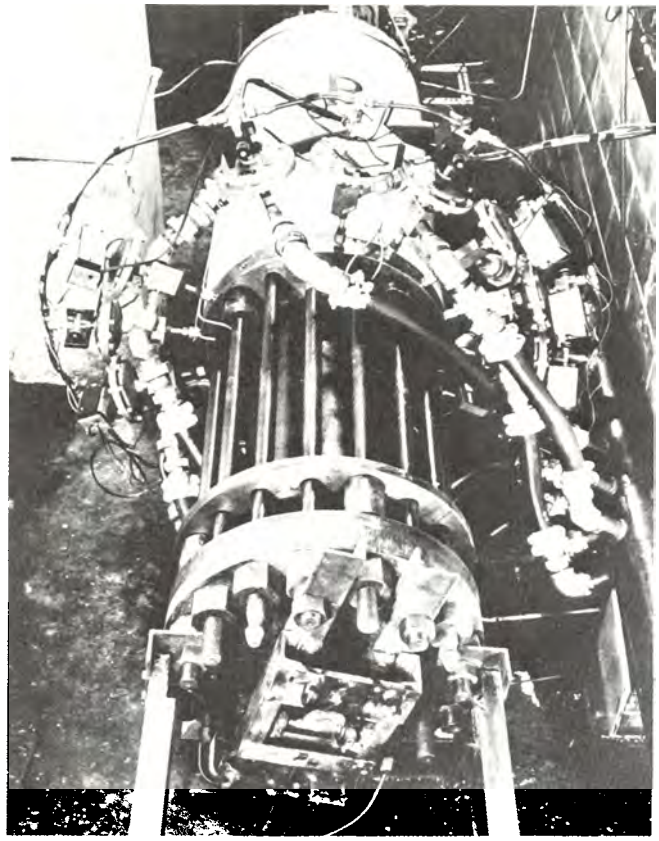
Tunnels will, of course, be needed on many potential new ground transportation systems because of the need to go through land masses or provide routes under rivers and harbors. Furthermore, new surface routes are almost impossible to obtain through city centers, and lower tunneling costs could provide a viable alternative. Therefore, tunneling R&D is important for all modes of ground transportation.

Since 1965, tunnel research projects in the HSGT R&D programs have had a primary objective of reducing tunneling costs. Areas of tunneling research include:

- Development of new methods for hard rock and soft ground tunneling.
- Development of new materials and designs for tunnel liners and supports.
- Improving the handling of excavated soil and construction material.
- Computerizing methods for route selection.

The most outstanding advance in tunnel construction during the past decade has been the development of the full-face boring machine, or mole. These machines have significantly improved the speed of construction. On occasion, they have achieved boring rates of over 400 feet per day (122 m) in rock of soft-to-medium hardness. However, they are not able to economically penetrate very hard rock formations. The major limiting features of moles are their cutters and bearings. While the machine manufacturers are continually improving bearings, metallurgy, and design of cutters, it does not appear that any radical breakthrough in these well-established technologies will soon be forthcoming. OHSGT has, therefore, been seeking means by which the strength of hard rock could be reduced to within the range of mole capabilities.

It is a well-known phenomenon that rock can be permanently weakened by heat. Since the laser is an excellent source of concentrated heat, several years ago the Massachusetts Institute of Technology (MIT), under an OHSGT contract, conducted laboratory experimentation on the effects of laser heating on rock. In addition to the weakening effects of laser heat on rock, melting and spallation on rock were also investigated and documented. The MIT work loomed extremely promising, and a system study was undertaken in 1970 by the United Aircraft Research Laboratories to consider the use of lasers to heat-weaken rock directly ahead of mole cutters. Based on this work, a de-



**Water Pressure Intensifier to Eject a Continuous Stream of Water.**

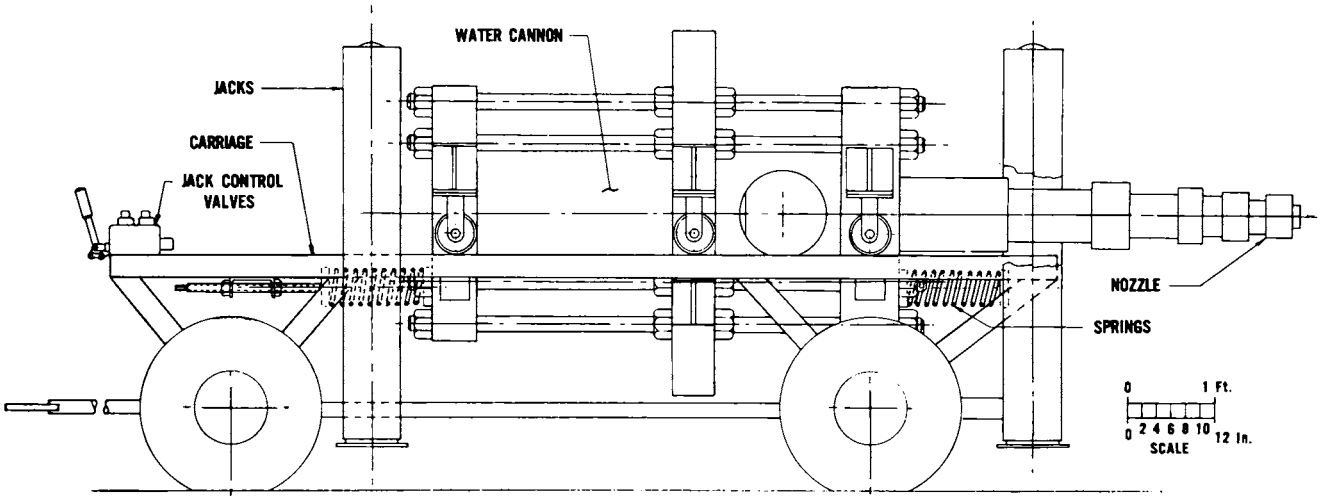
**FIGURE 27**

sign concept was developed whereby a laser beam can be deflected by mirrors through slits in a boring machine head so as to heat-weaken the rock immediately ahead of the cutters. However, it was concluded that current laser costs are too high to make the concept economically feasible, and that the power required to heat-weaken an entire tunnel face would be far in excess of the capability of any present commercial lasers.

Since the outer cutters on a boring machine wear much more rapidly than the inner ones, a new study to be initiated in FY72 will investigate the feasibility of heat-weakening only the rock ahead of the gauge cutters. This procedure should result in reduced power requirements, and significantly lower costs.

The Russians have been leaders in developing a technique for excavating rock by high pressure jets of water. The OHSGT personnel have visited and collaborated with Russian scientific personnel in investigating this approach. Research conducted by IIT Research Institute and others for OHSGT in which liquid and solid projectiles have been fired at rock at speeds up to 35,000 ft/sec (10.7 km/sec) have determined the magnitude of pressures needed to fracture rock. Figure 27 shows a pressure intensifier which was used by IITRI in this research to eject continuous streams of water at pressures up to 180,000 psi (1240 $MN/m^2$).

As a result of these investigations, the fracture of rock by high-pressure water jets looked so promising that a decision was made to design and build an experimental water cannon for laboratory and field tests in a quarry. In January 1971, Terraspace Inc. completed a design for a water cannon using




**Water Cannon And Carriage Assembly**

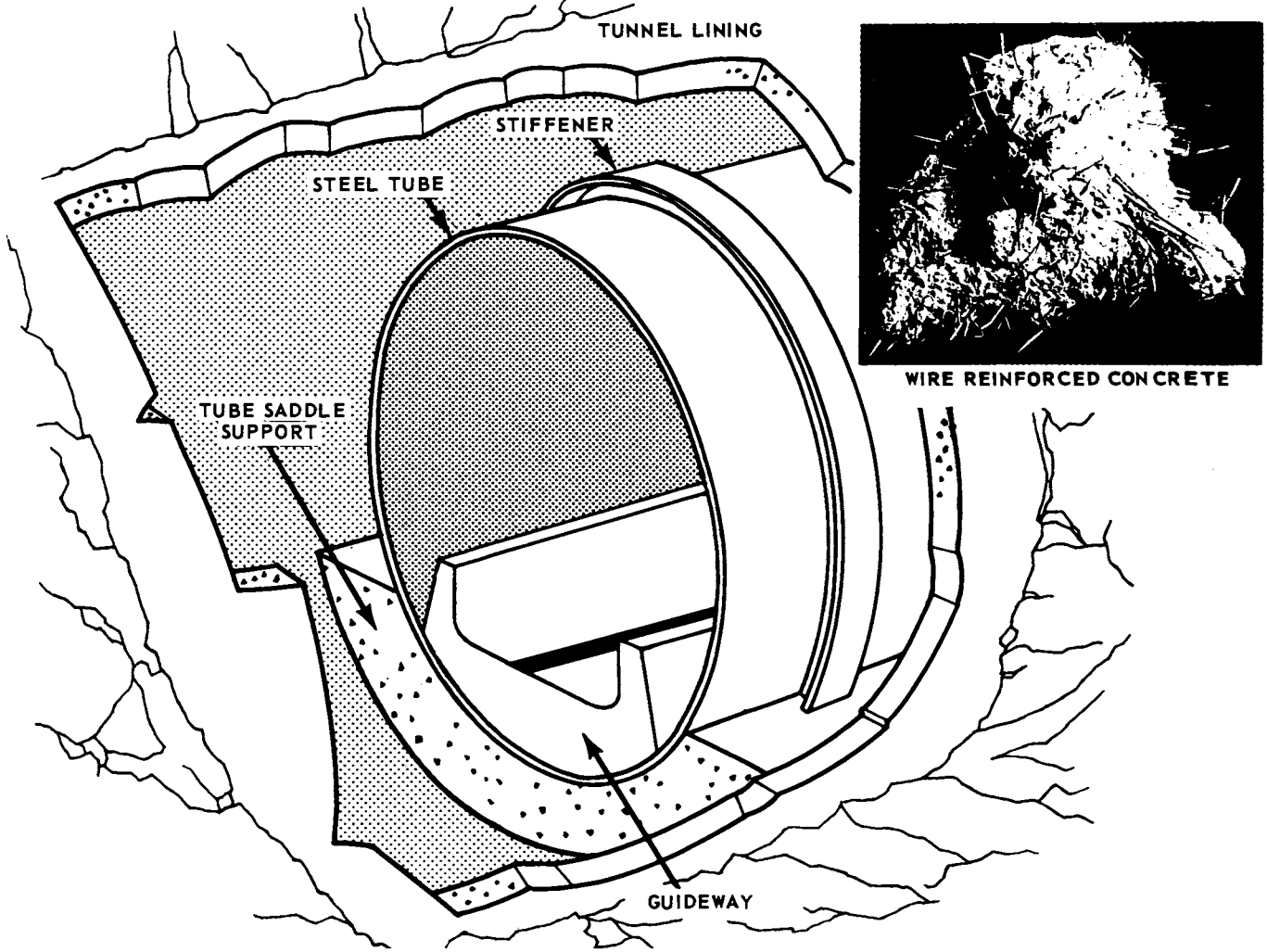
**FIGURE 28**

a patented Soviet nozzle which will eject pulsed jets or "slugs" of water at impact pressures up to 1 million psi (6.9GN/$m^2$) with energy values of 93,000 foot pounds (126 kJ). Proposals have been solicited to fabricate and test such a device as illustrated in Figure 28. The cannon uses a pneumatic-hydraulic actuator ("thumper") developed for seismic investigations to produce the high pressures.

The actuator provides a means for hydraulically cocking a piston which is released and fired pneumatically by compressed nitrogen. The piston weighs 140 lbs. (63.5 kg) and reaches a velocity of 207 ft/sec (63 m/sec) upon impact with a package of water in a plastic container. The force of the piston extrudes the water through a five-foot-long nozzle having an exponential bore. It is calculated that on exit from the nozzle the water will reach a velocity of over 12,000 ft/sec (3660 m/sec) and a pressure of 1,000,000 psi (6.9 $GNm^2$).

Initial testing of the cannon will be done in a laboratory to analyze its performance characteristics and to make any necessary design modifications. The cannon with controls will be mounted on a two-wheeled chassis so that it can then be transported to a field location (probably a rock quarry) where it can be tested against rock.

Liners and supports, which constitute as much as 30 to 40 percent of tunnel costs, also offer fruitful areas for innovation and cost reduction. For the past several years, the University of Illinois has been exploring new materials, designs, and construction techniques. Increasing the rate of speed for liner installation is particularly urgent in boring through soft ground. Under favorable soil conditions advances of perhaps 1,500 feet per day (457 m) are possible, providing liner operations can keep up with excavation. Present lining technology is inadequate, however, to support advances of this magnitude, and slip-forming and jacking against wet concrete are techniques currently being studied to increase liner installation speeds.




**Wire Reinforced Concrete For Tunnel Lining**

**FIGURE 29**

New liner materials are also being explored. Some of the test materials are: regulated-set concrete, wire-reinforced concrete, fiberglass-reinforced plastics, and polymer concrete. Wire-reinforcement of concrete looks particularly promising. A sample of wire-reinforced concrete is shown in Figure 29. While wire reinforcement has been used in other types of construction, it has not been used in the lining of tunnels. The wires, which are 1 inch long (2.54 cm) and about 10 mils (.25 mm) in diameter, are simply added during dry mixing. Cylinder tests have shown tensile strengths of 200 psi (1.38 $MN/m^2$) in one hour, and 1,600 psi (11.03 $MN/m^2$) in 28 days, which are several times greater than regular concrete.

The University of Illinois has also been studying new and unique structural shapes for steel sets. Preliminary results indicate that circular and rectangular boxes may be superior to the commonly used "H" sections since they are considerably stronger than torsion. An intensive laboratory test program is planned for FY72.

The Harza Engineering Company, under contract with OHSGT, has completed a computer program for rapidly estimating the cost of tunneling in hard rock. This program makes it possible to quickly analyze the cost implications of alternative routes, depths, and sizes of proposed tunnels under varying types of geology. It is currently being used successfully by several agencies involved in the planning and design of water tunnels, vehicular tunnels, and similar projects. Proposals have been solicited to extend the program's capability to include soft ground conditions.

The OHSGT has been most active in professional organizations which are interested in tunneling technology, such as the American Society of Civil Engineers and the American Institute of Mining Engineers. The Office is also participating actively in the new Interagency Committee on Excavation Technology which was recently established by the Federal Council on Science and Technology to coordinate Federal programs in tunneling research and in the formation of a National Committee on tunneling technology which is being established under the National Academy of Sciences and National Academy of Engineering.

Safety Design Analysis. Prepartion of a safety manual on advanced high speed ground transportation systems was started in December 1970, the purpose of which is to develop and assemble new safety standards and requirements for each separate vehicle design . Applicable portions will be included in RFP's and construction contracts of OHSGT. The initial effort included only the vehicles, with similar safety standards for their guideways and operations planned to follow.

The many variations in the types of vehicles, their higher operating speeds, and the many advanced and unique technologies involved in most projects (i.e., tracked air cushion vehicles, linear induction motors, evacuated tube systems, magnetic suspensions, etc.) require new and unique safety requirements, which in some cases go beyond any established set of standards for existing ground vehicles. It is for this reason that safety manuals of other agencies cannot be completely adopted, although most all of these including military and civil aerospace manuals, are being used in part to provide applicable inputs.

During FY71 the report was outlined, and as a result of numerous discussions with other agencies, such as FAA, NASA, Air Force, Coast Guard and Bureau of Railroad Safety, a substantial amount of material was obtained for this manual. Additional coordination, refinement, critiques, and experimental use of the manual will follow in FY72 to produce an effective safety manual that is consistent with DOT safety policies.

# 4.0 RAIL TECHNOLOGY

OHSGT Rail Technology efforts are devoted to improving the efficiency, safety, and capability of today's conventional freight and passenger trains as well as anticipating the inclusion of these characteristics in advanced high speed rail systems. The scope of the effort includes: measuring and assessing existing rail and track conditions; designing, developing, and testing new track systems; conducting and correlating analytical evaluations, laboratory tests, and field demonstrations of suspension system and vehicle dynamics; and improving rail, wheel, and car safety.

Through close work with operators and manufacturers, a base for the modernization of railroad research and engineering is being developed.

## Railroad Track Structures

Track Stability. A stable train support system in the form of rails, cross ties, ballast, and foundation is clearly necessary if the rail transportation industry is to function dependably and profitably. From the last decade's growth rate of train accident frequency and severity, it is apparent that desirable track stability does not prevail everywhere. Of the many reasons for this situation, the more important ones are:

- Contemporary route alignment and foundation conditions represent economic and technical constraints operative seventy-five or more years ago;
- Design of railroad track structures has evolved along a path placing total reliance on incremental improvement to the original concept of steel rails on wooden ties;
- Adverse financial trends severely affecting carrier maintenance resources.

Contemporary railroad track offers some interesting and challenging analytical problems. A moving train involves a distribution of stresses through a several-layered support medium exhibiting elastic variability in a way that is difficult to predict. Furthermore, the actual application of stress of load on track by a train occurs by random combination in three directions: vertical, lateral, and longitudinal. These forces are superimposed on static stresses already present in the track.

The Federal Railroad Administration is taking action to reverse the alarming accident growth rate and, at the same time, contribute to the identification of more economical track maintenance procedures that can be utilized by the rail industry. In compliance with the Federal Railroad Safety Act of 1970, FRA has issued initial track safety standards which are discussed later in this section. In order to improve performance of railroad track, OHSGT has undertaken the development of a generalized analytical method to determine the stability of track systems.

In recognition of foreign accomplishments, OHSGT contracted in 1971 with New York University for a review of the nature and validity of present track

stability analysis theories. This effort will be accomplished in the following steps:

- Identification of track-stability analysis models used by overseas researchers.
- Evaluation of the technical sufficiency of these models and related field experiments.
- Modification and adaptation to the U.S. conditions of suitable theories.
- Recommendation of new areas of investigation that will complement work already done, thus avoiding duplication.

This program on track-stability-analysis theories is half completed. It is already apparent that this work will lead to a more comprehensive general theory of railroad track stability than has been available in the past in either the U.S. or foreign countries.

Coupled with this theoretical effort, various testing projects have been and will be conducted in order to provide qualified data with which to validate and calibrate the formulas which result. All of the track measurement efforts discussed herein, plus future laboratory and field experiments now in the planning stage, will contribute to this data base.

Track Structures. The Atchison, Topeka, and Santa Fe Railway Company (AT&SF) and OHSGT are jointly sponsoring cost-benefit investigations into methods of providing more stable railroad track structures for present and future operating conditions with high speed trains as well as heavily loaded freight cars. The site selection between Aikman and Chelsea, Kansas, was influenced by the presence of abundant rail traffic, a long straight section, and uniform and relatively flat grades. The site's track structure was also considered to be reasonably typical of that existing on many of this country's railroads.

The AT&SF and OHSGT, along with the associated contractors, seek to provide sufficient instrumentation for the performance study of nine different track structures and to compare performance, maintenance, and economy. Construction is nearing completion, with operations scheduled to start in March 1972. A continuing analysis is expected for at least three years and possibly five.

Some of the main cost and benefit parameters to be investigated are as follows:

Cost Parameters:

- Initial Investment
- Track Maintenance Costs
- Projected Life of Structures

Benefit Parameters:

- Inspection and Maintenance Frequency Reduction
- Avoidance of Differential Structural Settlement
- Improved Structural Dynamic Response to Loads
- Reduction of Rail Stress
- Improved Ride Quality of Vehicles
- Increased Capacity

The physical layout of the project consists of an embankment and track structures located adjacent to, and offset 30 feet (9.1 m) from, the existing AT&SF main line as shown in Figure 30. The completed test embankment is nearly two miles (3.2 km) long on a slight grade. Transition sections at each end will divert main line traffic onto the test track and then back to the main line. The nine test sections include 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 conventional AT&SF construction. Each test section will have identical embankment instrumentation, as shown being installed in Figure 30. An access road adjacent to the test embankment will be used for periodic reading of the instrumentation and observing the test track.

Shannon and Wilson, Inc., of Seattle was engaged to design the embankment to provide soils data for evaluation of embankment behavior under the various test track structures. The firm of Westerhoff and Novick, Inc., of Chicago is responsible for the design, the preparation of specifications and plans, and the quality control during construction of concrete beams and slabs designated for three of the nine test sections. The Fastex Division of Illinois Tool Company at Chicago will redesign, test, and fabricate their "Fastall" rail fastener for incorporation into the slab and beam designs. Instrumentation design, data collection, and data reduction for all test track structures above the embankment support will be performed by the Cement and Concrete Research Institute. Concrete ties will be provided by the Ben C. Gerwick Co., of San Francisco. The fasteners associated with these ties will be the True Temper "Clip Lock" design.

This study is not intended as a demonstration of particular products or specific design details. All components represent a functional concept which might be provided elsewhere by several alternative products addressing the same performance objectives.

The studies will also be correlated with geometry and ride quality measurements made simultaneously through the use of the DOT instrumented Rail Research Cars, operated by ENSCO, Inc.

The various designs used in the Kansas test track are not necessarily new in concept. Some of these designs have physically existed in the United States in the past, but what has been lacking is continuous data collected over a period of time sufficient to determine performance of different types of track structures. An evaluation of the data should provide suitable criteria from

ENBANKMENT HORIZONTAL DISPLACEMENT TRANSDUCER REFERENCE TUBE INSTALLED PRIOR TO BACKFILLING.

NULL INDICATOR USED FOR FINAL INSTALLATION CALIBRATION OF ALL ENBANKMENT DISPLACEMENT TRANSDUCERS

INSTALLATION OF VERTICAL DISPLACEMENT TRANSDUCERS AT ONE OF NINE MAIN ARRAY INSTRUMENTATION LOCATIONS.

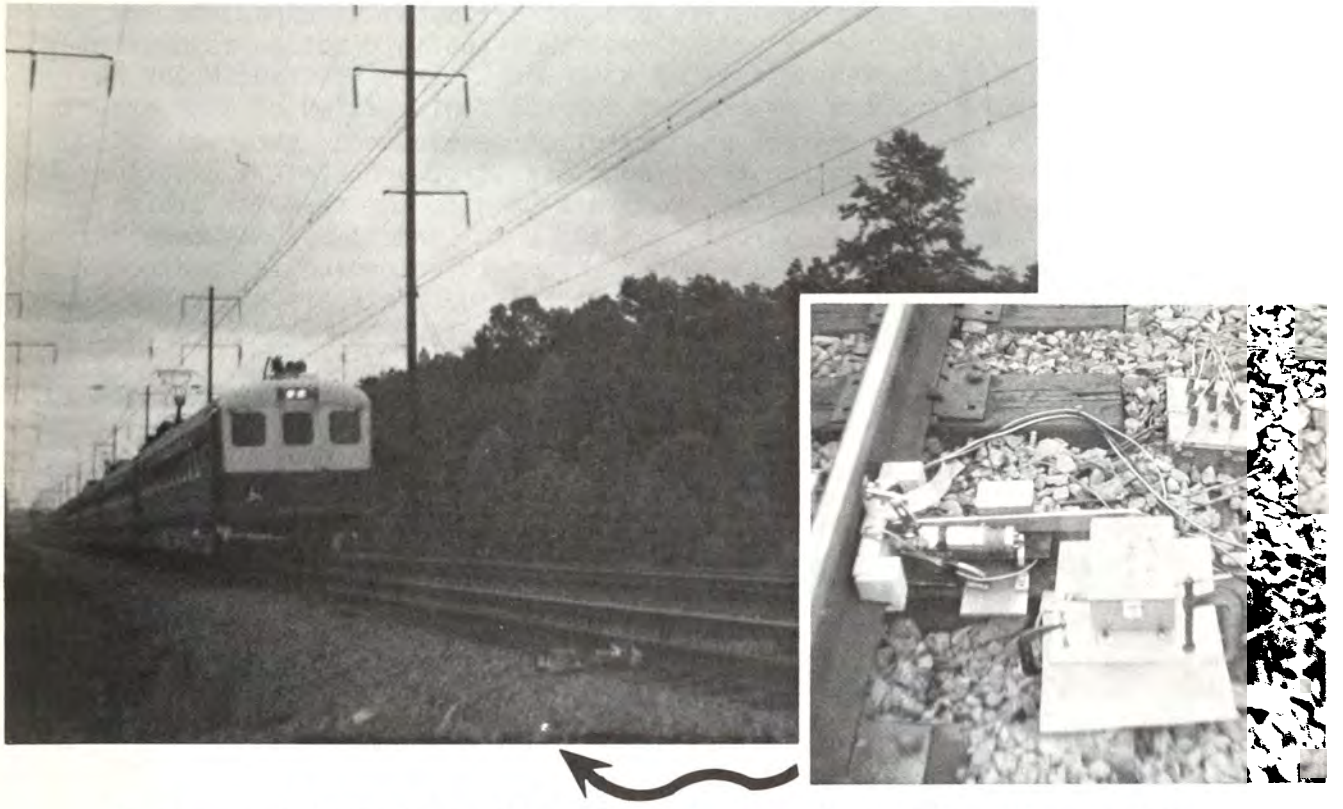
**Track Structures Embankment Experiment and Instrumentation, Next to Atchison, Topeka, and Santa Fe Railway Tracks Near Aikman, Kansas.**

**FIGURE 30**

which to select the proper track structure for an intended use, both in terms of economics and performance benefits. Past efforts were to put a concept into service and see what happened without establishing why it did or did not succeed.

The Europeans and Japanese have explored many of the same problems, yet their solutions apply to specific environments in terms of cost and design parameters directly associated with government-owned systems and with vehicles of relatively low axle-load capacity. However, available foreign track technology has been taken into consideration in this program because many of their approaches to problems in track stability are applicable.

Future plans for track structure research will be dependent on the results of this initial program. The most desirable designs in this effort will be selected for a second series of test observations related to track structure characteristics on high-speed, heavy-tonnage, and curved trackage. As the program progresses, significant results will be integrated with those of rail



**Instrumented Track Section at Bowie, Maryland Being Measured to Determine the Dynamic Track Response and Changes in Track Moduli and Geometry That Occurred Since Installation of Instrument 18 Months Earlier. Pressure Cells in Ballast are Not Visible.**

**FIGURE 31**

studies at the DOT High Speed Ground Test Center in Colorado and elsewhere.

Track Stress Measurements. Data collection on track stress measurements was completed in June 1971 at the Bowie, Maryland, Penn Central track-site installation as shown in Figure 31. These tests were made to determine the dynamic track structure response changes in track moduli and geometry that had occurred since December 1969 when similar data had been collected under a variety of train passages. These data are now being analyzed by Battelle Memorial Institute to define changes in moduli and geometry and their eventual effect on track and vehicle responses, just as they may occur in the Kansas test track.

Ballast Studies. The ballast plays an important role as an intermediate layer in the foundation support of track structures. Until now, this medium has not had the benefit of extensive investigation. Lacking comprehensive study of the interrelated effects of ballast gradation, void ratio, particle angularity, surface texture, and durability, the limits of resistance for an applied load cannot be predicted for any specific disposition of in-track ballast. As part of the track structure program, European and U.S. experts have held seminars for OHSGT to develop understanding of key elements and

parameters of material characteristics and properties with respect to the role of ballast within track structure systems. The information is now being utilized in specific studies associated with the Linear Induction Motor Research Vehicle track and the Kansas test track. Continuation of such efforts will aid OHSGT in keeping current with material developments and evaluation techniques as they may apply to improving track structure systems. Concurrent with the above efforts the OHSGT, in conjunction with the research staffs of the Association of American Railroads and the British Railways, is considering proposals for laboratory and field test programs to determine performance characteristics of all types of ballast material and their associated influence on stability of loaded track.

LIM Research Vehicle (LIMRV) Track. The initial 6.2 miles (10 km) of LIMRV track has been completed as discussed in Section 2.0. This short section of track provides the test bed for LIMRV experiments at speeds up to 165 mph (266 km/hr). If lengthened sufficiently the quality and geometry of the track will allow the vehicle to be tested at speeds up to 250 mph (402 km/hr).

The test track, as shown in Figure 32, is of standard gauge--56-1/2 inches (143.5 cm)--with conventional wood-tie and stone-ballast construction, but is unique in several aspects. The foundation ballast course is deeper, the ties are more closely spaced, and the steel rails are shimmed to provide a means for fine adjustment and alignment to meet the small tolerances required for high-speed operation.

Deviations from normal railroad construction practices include the following:

- The 0°26' curve (0.0076 rad), a 3-mile (4.8 km) portion of the track, is superelevated to 8° (0.14 rad) representing equilibrium speeds to the LIMRV of 167 mph (269 km/hr) permitting speeds to 200 mph (322 km/hr). For the 250-mph (402 km/hr) operation, this superelevation will be raised to 10° (0.17 rad) as the trackage is extended.

- Rigorous tolerances governing longitudinal profile and alignment, cross level, and gauge relationships of the 119-lb (54 kg) running rails have improved techniques for straightening rails.

- The first application of full ballast section consolidation during construction was introduced by use of equipment designed specifically for the purpose. Consolidation of railroad ballast normally takes place through traffic-induced loads and vibrations, whereas the LIMRV trackage would not see such traffic in the usual sense. The design of the rail fastener system permits fine realignments of both steel and aluminum reaction rails, without disturbance of ballast, through metal shims readily applied in association with standard track components.

- During installation, stress levels of the steel running rails were monitored with a mechanical strain gauge at 133 locations throughout the trackage to insure uniform final rail assembly at 80° F (27° C) regardless of ambient temperatures.

**View of LIMRV Test Track Showing Aluminum Reaction Rail Installed Mid-Way Between the 119 lb. Conventional Running Rails. Location is on 0°-26' Curve Having 8° of Superelevation.**

**FIGURE 32**

- The steel running rails were polished to remove excess mill scale and facets left by weld grinding. This provided an immediate smooth surface for the rail/wheel interface.

- Radiography was used for quality control of the field welds in the steel running rails. The X-ray records proved to be accurate. When sub-zero weather caused pull-aparts, the records showed some porosity in the welds affected. Without established standards for reference, the inspectors had passed those particular welds as marginal. This project has definitely advanced the state-of-the-art in quality control of field welds.

The existing LIMRV track is being monitored periodically to maintain proper tolerances and stress level conditions, and to provide documentation for future track behavior studies. Present measurements are made by FHWA survey teams using a transit and level. A Track Survey Device, currently being fabricated by General Applied Science Laboratories, is expected to be in operation at the HSGTC in early 1972 and will provide rapid track geometry data for operation and maintenance information relative to the LIMRV trackage.

The Track Survey Device is mounted on a rail car and consists of laser beams to detect deviations from straight lines. The data are recorded on magnetic tape for analysis.

The LIMRV retains many characteristics associated with railroad vehicles; i.e., it has two trucks (Figure 17) each with two axles and four steel wheels to support and guide the vehicle. Although the primary objective of the equipment is a performance test of the LIM propulsion system, an important secondary objective is the conduct of exploratory studies for defining the maximum capabilities of steel wheel/rail support and guidance systems.

It was evident early in designing the LIMRV that the supporting steel wheel/rail system would adequately provide the first stage technological expansion necessary for designing and constructing advanced passenger rail vehicles. Experts in the field generally agree that to date the surface of this technology has only been scratched. Brief moments of speed explorations above 200 mph with rail tracked vehicles have provided information that is limited and, therefore, inconclusive.

Through accelerometers and displacement transducers applied at specific locations on the LIMRV truck members, critical forcing functions and frequencies can be established through all speed ranges. Equally important variables associated with the LIMRV track will also be measured to determine spring rates, critical velocities, and dynamic track moduli. Once the basic variables and constants associated with LIMRV trucks and track are established, then already available computer models will provide a more exacting result. This analytical model will be useful, under varying parameters such as mass and speed, for designing other rail vehicle systems.

High-Speed Conventional Test Tracks. The Federal Highway Administration is currently engaged in location and design of the FRA Railroad Test Tracks as shown in Figure 4.

Approximately 20 miles (32 km) of conventional trackage will provide the facilities for testing total train dynamics, rock and roll characteristics of all classes of equipment, destructive and impact effects on equipment and lading, behavior of variable track, and vehicle conditions for both higher (160 mph) (258 km/hr) and lower speed train operations. The OHSGT and Association of American Railroads (AAR) staffs are working together to define the immediate and future needs associated with this test track.

The test track system will provide the means by which problems associated with the following considerations may be studied:

- Vehicle-track interaction
- Braking and train action
- Track stability
- Derailment prevention
- Controls and communications

- Crossing protection
- Switching
- Vehicle component checkout
- Train systems experiments
- Minimization of post-derailment effects
- Optimum vehicle impact resistance

Primary track studies will be integrated with the Rail Dynamics Laboratory in an effort to define and categorize all types of rail vehicle behaviors which occur when subjected to different car suspension, track geometry, and roadbed stiffness conditions.

Rail Research Test Car Program and Measurements. Analysis of track and roadbed conditions is essential for analytical studies of vehicle dynamics and for proper track maintenance planning. As part of a broader track research program for improved transportation systems, the four DOT Rail Research Test Cars shown in Figure 33 are essential tools for Government-sponsored railroad research. Extensive instrumentation has been installed on board these modified electric railroad cars, which are capable of a speed of 150 mph (241 km/hr). With the newly installed digital acquisition system, their capabilities of gathering data on track conditions and ride quality are in the forefront of the emerging field of mechanized track testing.

During the past year, the track measurement and data collection systems, parts of which are shown in Figure 33, were improved and refined to bring the Test Cars to an even more effective operational status.

These Test Cars have been used to measure approximately 6,000 miles (9660 km) of track geometry. Although they are self-propelled and operate independently in electrified territory, system improvements now permit extended data collection tests over non-electrified track, with the cars towed as part of special train consists. Approximately 2,000 miles (3220 km) of track were surveyed in this way during the past year on railroads such as the Santa Fe, Illinois Central, Bessemer and Lake Erie, and Denver and Rio Grande. These tests were performed to display the capabilities of such automated track measurement equipment to potential industrial users. Railroad managements were provided with analog recordings and digital printouts which could be used for maintenance planning and management evaluation of track conditions.

The benefits derived from the data developed by FRA track measuring cars will be demonstrated in a long-range program with one or two railroads. The purpose of this program will be to refine present techniques for translating the data so that useful information can be made available to several tiers of management and supervision.

The Test Cars have been employed in a variety of other track geometry tests that have satisfied different test objectives. Some of these tests were carried out periodically in the Northeast Corridor on the Penn Central Railroad in compliance with the Metroliner Demonstration. These surveys pro-

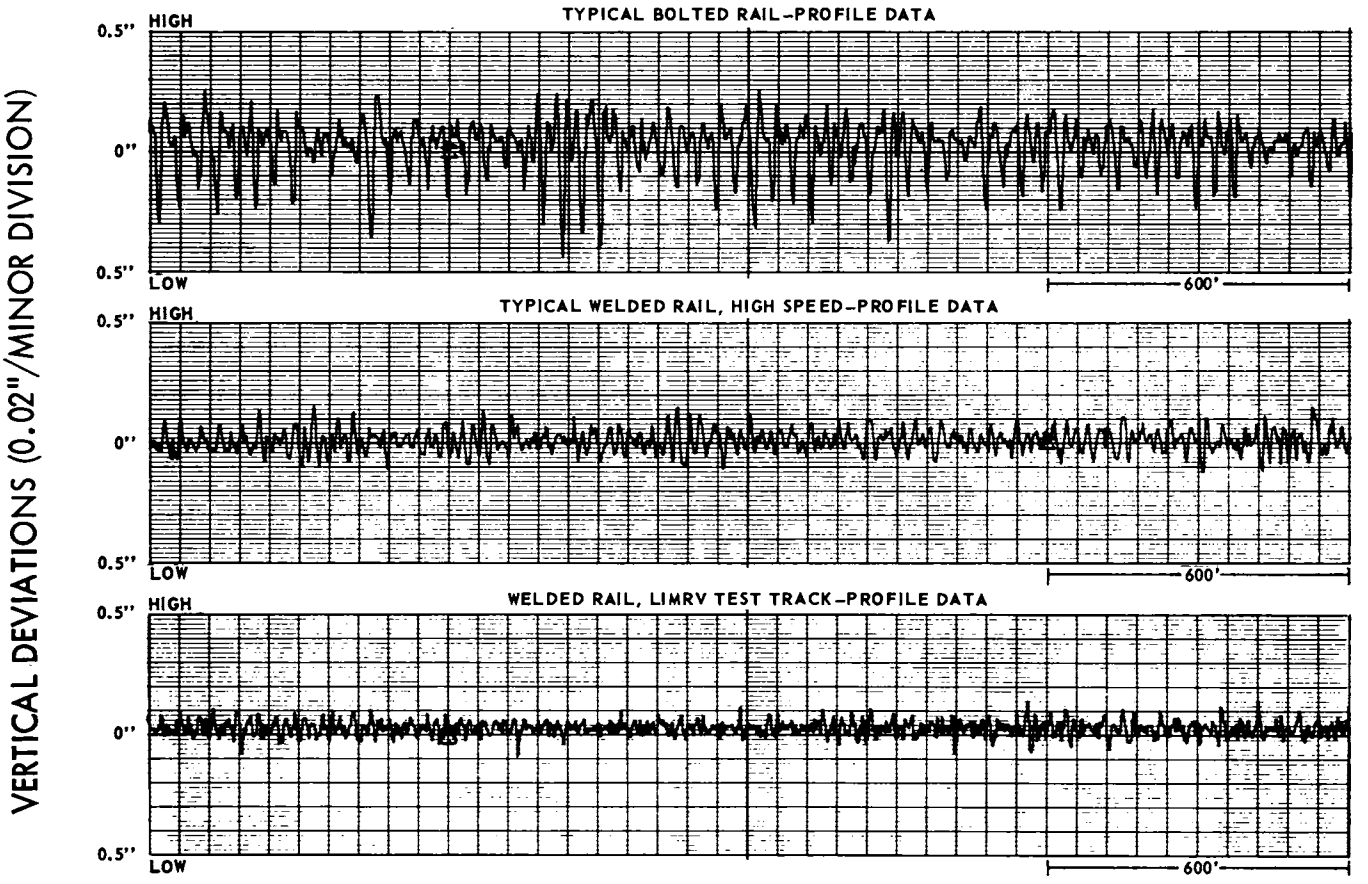
**DOT Rail Research Test Cars.**
**FIGURE 33**

TRACK MEASUREMENT DATA RECORDING SYSTEM IN ONE OF THE RAIL RESEARCH TEST CARS

vide the Penn Central Railroad and the Federal Railroad Administration with information for maintenance planning in an effort to provide the best track and Metroliner ride possible with the funds available.

At the DOT High Speed Ground Test Center in Pueblo, Colorado, track geometry measurements were made on the access spur and 6.2 miles (10 km) of the LIMRV track to determine the degree to which the contractor met the requirements of construction. Measurements were made during the consolidation of ballast on the LIM track to determine if there was any shift in the newly laid track. The access spur was remeasured some months later to examine possible degradation from its original condition. An example of one parameter that was measured under load--vertical rail roughness--is illustrated in Figure 34. This compares two types of standard tracks: the older bolted track and the newer welded continuous track.

The test cars have also been used to collect wheel/rail interaction data and are currently being modified to support increased attention to the force spectrum of railroad operation in concert with the track geometry aspect. The data acquired will provide criteria for speed limits on particular types of track. Much of the data is being used as input to other OHSGT programs such as




**Sample Oscillogram Data Taken with Track Geometry Measuring Car T-2.**

**FIGURE 34**

the Rail Dynamics Laboratory. In conjunction with computer models of car suspensions, the data is also used to analyze Metroliner ride quality phenomena.

In the coming year, the test cars will be utilized to study degradation of the experimental track structures being installed on the Santa Fe Railroad near Aikman, Kansas. Continued development of this equipment as a prototype inspection car will insure that FRA and the industry have tools available for monitoring track conditions.

Future test car activities will include development of a self-propelled capability for non-electrified operation. New data processing techniques and programs will be devised to determine the correlation between train dynamics and track characteristics. The instrumentation inventory will be expanded to include devices to sense track stiffness and structrual integrity. The cars will also continue to be used as test beds for prototype vehicle inspection devices and, when suitable, to test new rail equipment components.

Rail Dynamics Laboratory. The Rail Dynamics Laboratory, on which the progress was mentioned earlier in Section 2.0, The High Speed Ground Test Center, will be a major testing tool to advance rail technology. Hardware designs will be evaluated in the safe, fully-controlled, and repeatable laboratory environment. Close visual inspection, together with complete computer-controlled

data acquisition systems, will allow the economical performance of a variety of tests with minimal risk to equipment or personnel. It is a general-purpose, high-force test facility with full flexibility to support train or component excitation by reconfiguring the basic machinery, instruments, and controls as required. Both industry and Government-sponsored work will be accomplished in this laboratory.

The concept of a Wheel/Rail Dynamic Simulator, more commonly called "roller rig," originated in the early locomotive dynamometer installations where wheeled vehicles were positioned over rollers that incorporated energy absorbing devices. These facilities provided a means for "loading" the engines to determine their performance. This concept has been expanded upon in railroad research facilities in England, France, Germany, and Japan in the last five to ten years. Provisions have been incorporated in the Simulator for moving the rollers (which represent the track) up-and-down and sideways to simulate track irregularities. The resulting dynamic excitation is studied to evaluate the performance of vehicle suspension systems and the mechanics of rolling contact, as well as propulsion and braking.

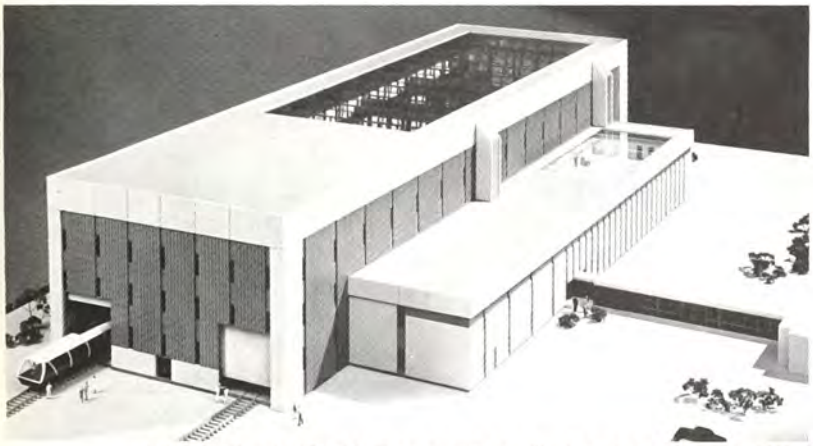
The Simulator planned for installation at the High Speed Ground Test Center will be an advancement in the state-of-the-art inasmuch as it will make possible the simultaneous simulation of all the various track irregularities experienced in the field, including track displacements under moving loads. The force, displacement, and operational frequencies of the roller motion system, together with the motors, flywheels, and other elements of the rotational system, will allow this unique railroad research machine to test today's vehicles under current track conditions as well as tomorrow's vehicles at much higher speeds under improved track conditions. Many of the unusual features of the machine owe their origin to developments made in simulation facilities designed and installed under Government sponsorship for aircraft, missile, and space programs.

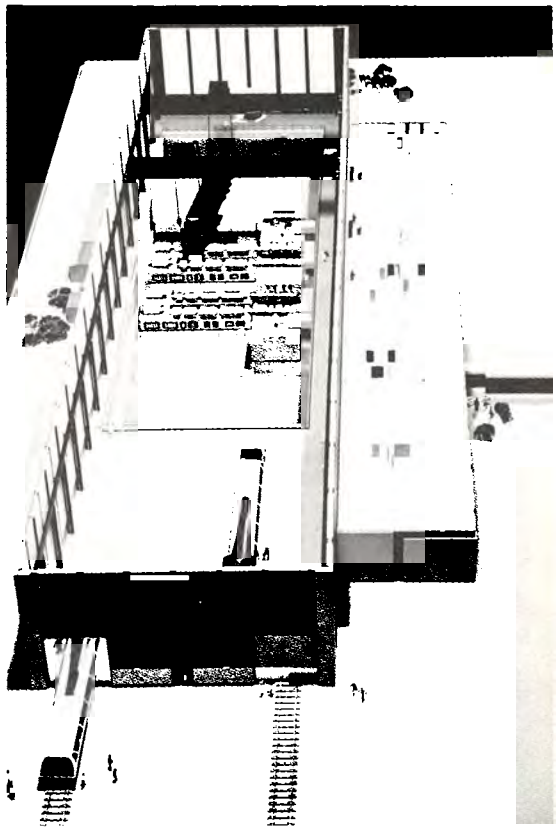
Notable features of the Rail Dynamics Laboratory are noted below, and Figure 35 illustrates the Wheel/Rail Dynamics Simulator and the building in which it will be housed.

FEATURES OF THE DYNAMICS LABORATORY:

- Principal dimensions:
- High Bay: 330 feet long, 112 feet wide, 60 feet high (101x34x18 m)
- Instrumentation, controls, office etc: 230 feet long, 50 feet wide, 30 feet high (70x15x9 m)
- Vehicle accommodated size: Up to 180 feet (55 m) long, 20 feet (6 m) high, weight to 400,000 lbs. (181 440 kg) under special conditions
- Truck spacing: From 20 feet to 180 feet (6 m to 55 m)
- Axle spacing: From 54 inches to 180 feet (137 cm to 55 m)


SCALE MODEL OF THE WHEEL-RAIL DYNAMICS SIMULATOR





**Model of Rail Dynamics Laboratory at High Speed Ground Test Center.**

**FIGURE 35**

- Gauge: From 4 feet 8-1/2 inches to 8 feet (143.5 cm to 2.4 m)
- Number of axles: Expandable to 8
- Axle load: Up to 80,000 (36 300 kg)
- Superelevation: Up to 8 degrees (0.14 rad)
- Curve simulation: 100 foot (30.5 m) radius minimum
- Horsepower: 7,200 (5370 kW) continuous, 12,000 (8950 kW) short time
- Speed: Up to 300 mph (483 km/hr)
- Crane capacities: two 100 ton (91 tonne)
- Component or subassembly test capabilities provisions have been incorporated in the design of the building for the concurrent performance of component or subassembly tests. Special setups may include a cab motion simulator and a track stress test bed.

- Vehicle test preparation:

  Area assignments and special service equipment will be available so that vehicles to be tested on the various Test Center tracks as well as Simulator test vehicles can be prepared for testing.

- Planning for the Future:

  Provisions have been made for converting test areas and equipment to accommodate rubber-tired vehicles, air-cushioned vehicles, or other future vehicle configurations as necessity dictates.

Improved Passenger Equipment

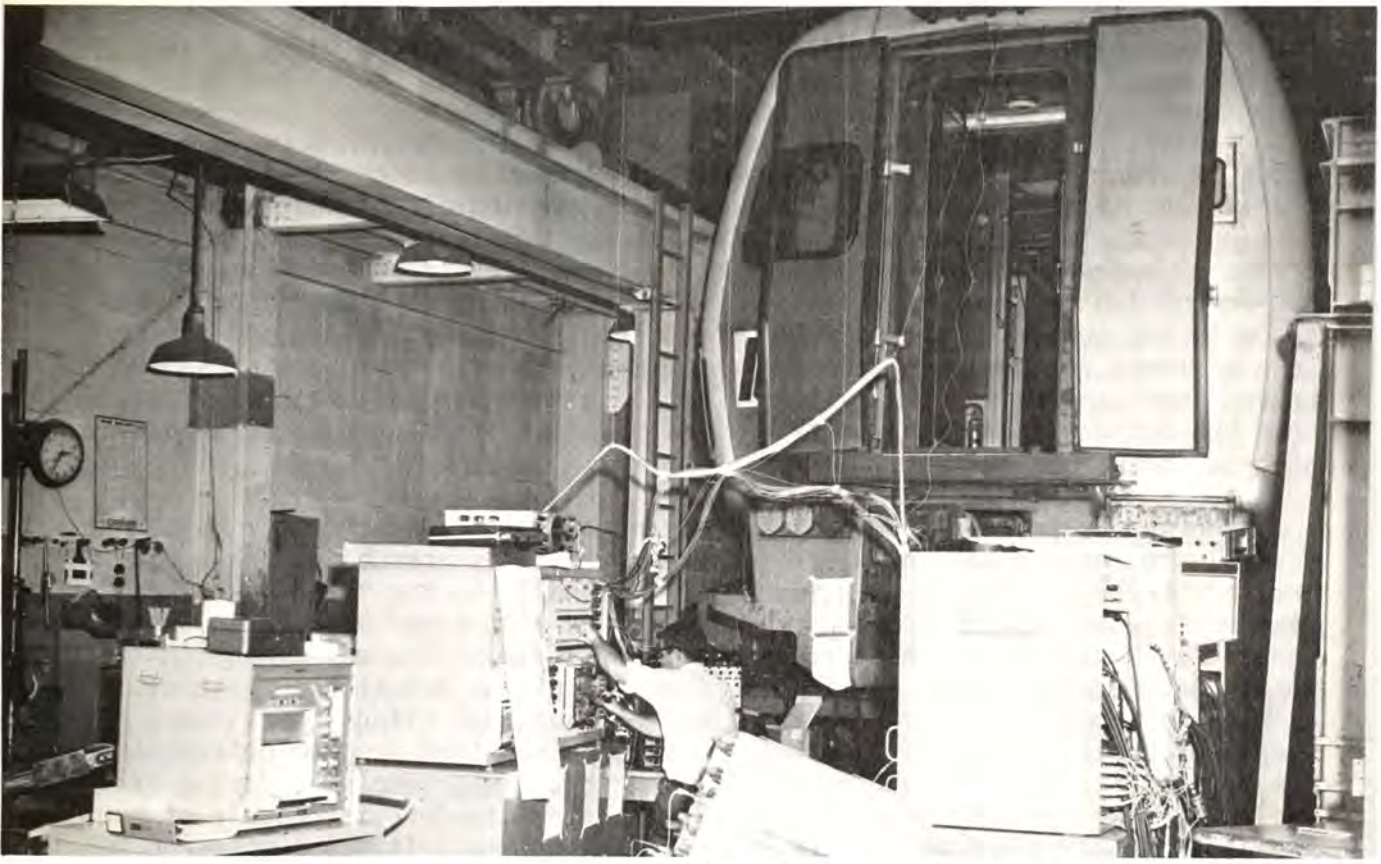
Metroliner Improvement Program. The riding qualities of present high-speed passenger trains show need for improvements. OHSGT plans to demonstrate improvements which are possible for high-speed vehicles using the Metroliners and DOT test cars. The Metroliner, because of its large public use in the heavily traveled Northeast Corridor, is an ideal candidate for improvement.

Toward that end, in FY71 OHSGT began a program with a two-fold approach to the ride problem of the Metroliners; first, a project leading to the modification of the existing truck, and second, a project leading to competitive procurement of a new truck for this application. This program includes field testing, laboratory testing as shown in Figure 36, computer modeling, and analysis, all of which were begun during the fiscal year. This program is expected to produce improvements which can be demonstrated early FY73.

Based on initial results, both the new truck program and the improved existing truck program should result in a better ride for the benefit of passengers on both Metroliners and improved passenger trains of the future. Also, the specification development technique should be very useful in attacking the ride-quality problems of freight cars and locomotives.

Ride Comfort Specifications and Measurement. During FY71 the OHSGT continued its experimental work in the ride-quality area. Perhaps the most important development during the year was a specification for the riding quality of advanced surface vehicles, such as the TACV or Magnetic Levitated vehicle. This specification was formed by analyzing the response of well-maintained railcars on excellent portions of roadbed. The responses under these conditions are known to be relatively comfortable. An added feature of the developed specification is that it is tied to a system measurement so that there can be no misunderstanding regarding the meaning of the numerical comfort limits. This improvement has been well-received by the industry and has been incorporated in a number of DOT requests for proposals as a ride-quality standard.

The ride quality of the Metroliners in operation was continually monitored during the past year. Also, OHSGT cooperated with Auto-Liner Corporation in making tests of the ride quality of automobiles carried aboard specially-modified railcars. The results of this test further bore out the conclusions of OHSGT's test program in 1967 on the Auto-Train concept; namely, that acceptable



**Laboratory Measurement of Metroliner Suspension Characteristics.**
**FIGURE 36**

levels of riding quality could be provided in this type of service.

Adhesion and Creep. During the past year, basic research in the area of the mechanics of rolling contact was continued. Among the factors examined for their influence on adhesion were surface roughness, surface vibration, surface contamination, dynamic loading, and velocity. The experimental and analytic studies concluded that surface vibration and contamination resulted in significant decreases in friction, whereas surface roughness and dynamic loads did not appear to have as great an influence. Decreases in friction at higher rolling velocities appeared to be due to increased surface vibrations.

This research is being undertaken to provide fundamental data required for the design of truck wheel assemblies for future high-speed trains. Further studies now underway are examining in greater detail the effects of surface vibration and roughness as well as temperature and contact resonance.

AMTRAK Support. OHSGT played an important role in the establishment of the National Railroad Passenger Corporation. The computer route models, which were responsible for the development of the final AMTRAK track network, were refined and run by OHSGT. In addition, a large part of FRA's "Briefing Manual for the Incorporators of the National Railroad Passenger Corporation" was prepared by the

Office. This document was intended to provide the initial directors of the Corporation with guidance in broad areas prior to the selection of a full staff.

Presently, the Office is in close coordination with AMTRAK on equipment needs in order to plan future programs for improved passenger trains. This involvement is also bolstered by a continuing examination of the best of foreign technology. Numerous countries are now developing advanced passenger trains or speeding up operations through right-of-way improvements. OHSGT has an ongoing program of evaluation of the techniques developed around the globe in the subsystem areas of braking, propulsion, suspension, and control. Some of these features will probably be compatible with the needs of an improved American train. The synthesis of these technological possibilities into the design of an improved train configuration is planned to be a major program in the near future.

Nonrubbing Brakes. An example of advanced vehicular technology which is possible to incorporate in future passenger trains is nonrubbing braking. Ordinary braking forces are introduced frictionally on the tread of the railroad car's wheels. The temperatures created by high-speed braking in this manner may be at levels which raise the possibility of thermal damage to the wheels and require a high level of replacement of the frictional material. Although a program has begun to test the metallurgical effect on railway wheels of braking loads of this nature, a more important program determining the feasibility of a nonrubbing hydrodynamic brake was completed during FY71. This promising new development, utilizing an air retarder, is capable of high levels of energy dissipation without thermal input to critical suspension elements, such as the wheels, and reduces the amount of required maintenance of frictional surfaces as compared to coventional brakes. This device is now undergoing detailed design prior to a prototype test.

Safety

Surveillance and Flaw Detection. A development effort was initiated during FY71 with the Naval Ordnance Laboratory to apply the spin-off of weapons systems technology to the problems of flaw detection and safety systems. This work is a continuation of rail technology begun several years ago with the design and development of a vehicle surveillance system now operating on the Rail Research Test Cars. The development of a simple, reliable, and inexpensive system to detect incipient failure of journal bearings, axles, or wheels would have widespread application to the Nation's freight fleet, rather than restricted application to high-speed passenger equipment. A final report is due during FY72.

The program of nonfriction braking and metallurgical examination of railroad wheels previously described is another example of a program in the safety area, overlapping somewhat with improved passenger train technology.

Railroad Safety Standards. On October 16, 1970, Public Law 91-548 was enacted by Congress. This legislation, entitled the "Federal Railroad Safety Act of 1970," directed the Secretary of Transportation to prescribe "...rules, regulations, orders, and standards for all areas of railroad safety..." The Secretary was required to issue initial railroad safety rules not later than one year following the enactment of this Law. Consequently, a task force was organized from several different functional groups within the Federal Railroad Administration

Statistically, the incidence of railroad accidents falls into four causal classifications of roughly equal frequency: track defects, equipment failures, operating practices, and human factors. Consequently, effective regulatory standards must address the factors identified as major causative agents within this broad classification.

A decision was made to attack the track and roadway aspect of the accident-cause matrix first. In anticipation of imminent legislative action, work on this commenced in the summer of 1970. OHSGT contributed to this effort by virtue of the research orientation of its personnel assigned to the task force, attempting to combine practical experience with the thoughtful approach of research. Even though the railroad industry has grown and functioned in this country for the last 140 years, much of its understanding of train-track interactive phenomena is purely empirical. A theoretical foundation to enable the industry to establish its track maintenance priorities and FRA to define useful standards in a scientific manner is clearly desirable. But, at the same time, the imperative of a single-year interval to promulgation of initial standards was dominant.

The task force was able to put together a body of initial track standards, as often as not omitting certain aspects in the initial set due to a limited base. These regulations are less than comprehensive at this point due to time constraint. Moreover, work on the standards served to sharpen the recognition of areas requiring further analysis and test so that the standards can be refined and further developed logically.

Grade Crossings. OHSGT is responsible for the technical grade crossing protection research. Increased work in this area was assigned to the DOT Transportation Systems Center during the past year, searching for economical approaches to protecting more of the 200,000 plus crossings in the U.S.

Tank Cars. A concerted program to reduce hazardous material tank car risks by defining methods to improve their ability to survive accidents without violent rupture is included in the safety related activities of the OHSGT staff. Working with the Bureau of Railroad Safety, a series of study and evaluation projects on penetration prevention, fire protection, controlled pressure relief, and structural integrity was initiated during the past year and will intensify in the coming year.

Naval Ordnance fireproofing expertise and Bureau of Standards metallurgical skills are included in the program. Close coordination with concurrent industry work is preventing unnecessary duplication and reducing overall cost by virtue of collaboration on expensive proof-testing work.

Future Rail Passenger and Freight Possibilities. The Office of High Speed Ground Transportation has been participating in a DOT study to examine the feasibility of establishing a high-speed train system along the eastern seaboard in conjunction with the 1976 Bicentennial Celebration. The concept originated with a plan called POLIS '76, which called for a multi-city fair to be held along the entire east coast.

The study concluded that a system of high-speed passenger trains, auto trains, and container freight trains running from Boston to Atlanta and Miami

would be economically viable and could be built by 1976 if financing could be arranged. The system would use existing rights-of-way, but the track would have to be substantially upgraded, all grade crossings would be eliminated or protected, and the line would be completely fenced. New trains incorporating the best aspects of the Metroliners and Turbo trains would be able to run as fast as 150 mph (241 km/hr) in the region north of Washington, and 120 mph (193 km/hr) south. Running times between Boston and New York would be 2-3/4 hours nonstop (instead of the present 3 hours and 40 minutes); between New York and Washington, 2 hours (instead of the present 3 hours); and between New York and Miami, 16-1/2 hours (instead of 26 hours). The study recommended half-hourly service between Washington and Boston, additional trains to provide quarter-hourly service between New Haven and Philadelphia, and eight trains per day south of Washington.

The study was based in part on the recommendations contained in the Northeast Corridor Report. Because of the limited number of potential train riders south of Washington (compared to the Northeast Corridor), a container freight system was introduced both to provide the necessary revenues to pay for the roadway investments south of Washington and to serve as a test-bed for a type of operation that could eventually be expanded across the country.

This concept is being studied further and no decision has yet been made on it.

# 5.0 RAIL PASSENGER SERVICE DEMONSTRATIONS

The rail passenger service demonstrations conducted by OHSGT are designed to meet specific objectives of the High Speed Ground Transportation Act of 1965 and its extensions. These objectives call for measurement and evaluation of public response to such factors in transportation service as "... new equipment, higher speeds, variations in fares, improved comfort and convenience and more frequent service...".

The two demonstrations currently in progress are coordinated with AMTRAK's* intercity operations on the Penn Central Railroad. One is with the Metroliners, which are operated in the Northeast Corridor between Washington and New York, a distance of 226 miles (364 km). On this demonstration, the Government provides financial participation and management guidance, and the Metroliner cars are a part of the Penn Central/AMTRAK fleet.

The other demonstration in the Northeast Corridor is with the Turbo train which operates between Boston and New York, a distance of 229 miles (369 km). In contrast to the Metroliner cars, the two three-car Turbo trains are leased by the Department of Transportation from United Aircraft Corporation, and made available to Penn Central for operation on a daily basis. UAC maintains them at an independent shop.

In two and one half years of scheduled service, the Metroliners and Turbo trains have demonstrated that there is a continuing market for rail passenger service. Travelers will respond with increases in rail patronage when given service improvements. Such improvements have been and can be made in rail services, facilities, and equipment that are technically and economically feasible.

Experience has led to the anticipation of further opportunities for service and equipment improvements, and has encouraged extensions of the demonstrations as a continuing part of the High Speed Ground Transportation Program. Technical problems that accompanied initiation of demonstration services have now been isolated. Both the Metroliners and Turbo trains are being modified to improve reliability and to produce finished products that can serve as prototypes for meeting new equipment requirements of AMTRAK. In addition, each Turbo trainset will have two cars added to make a total of five in order to have an economically viable passenger carrying capability.

Patronage at the Capital Beltway Station in Lanham, Maryland, northeast of Washington, D.C., at the intersection of the Penn Central line and Route I-495 Capital Beltway, continues to increase with suburbanites taking advantage of convenient parking for their cars at a fringe station. Another suburban station, in the Metropark Station in Woodbridge, New Jersey, is located near the junctions of the Garden State Parkway and the New Jersey Turnpike.

Two preliminary airport access studies were completed during the year. Studies have also begun on other city pairs for possible future demonstrations.

* National Railroad Passenger Corporation

## Washington--New York Demonstration

The Washington--New York Demonstration consists of all Penn Central/ AMTRAK conventional trains and Metroliner passenger service between those two cities. The initial Metroliner service was started by Penn Central on January 16, 1969, with one round trip daily. The official demonstration began on October 1, 1970, and will continue for a period of two years, with an option to renew for one year. Service by the Metroliner equipment has been progressively increased to the present level of twelve round trips on weekdays.

The Metroliners have continued to attract an increasing number of passengers from other transportation modes (air, bus, and automobile) and from conventional train service, due in part to replacements of some conventional trains by Metroliners, as detailed in Appendix C, Rail Passenger Data. On July 29, 1971, a significant event occurred when the three-millionth passenger boarded a Metroliner since the start of this service some 30 months earlier. Figure 37 shows a six-car Metroliner on a typical Washington-to-New York trip.

Fare and food service experiments were conducted during the past year to determine the effect on patronage and rider reactions. On April 1, 1971, a surcharge was added to the Metroliners' first-class fare in the Metroclub car: $2.00 for distances up to 175 miles (282 km) and $4.00 for longer distances. At the same time, first-class passengers received a reduction in food prices. Dinners went from $3.50 to $2.00, luncheons from $2.50 to $1.50, and a full breakfast from $1.75 to $1.35. Menus for the snack bar in the Metroliner coach cars were expanded with at least two hot-dish selections.

Although the Metroliner service has obtained favorable public response, the trains have proven more costly to maintain and less reliable than conventional electric locomotive-hauled passenger trains operating between New York and Washington. To correct this situation, General Electric Company and Westinghouse Electric Corporation, the builders of the propulsion equipment, contracted to review the causes of equipment problems and to recommend solutions. These studies have been completed and each company is now preparing to modify a Metroliner car, which in effect will be prototype cars. Work on the two cars is expected to be completed during the fall of 1972.

The Metroliner improvements will include modifying the propulsion systems to reduce thermal loading on electrical equipment, and collecting clean air from the car roof to cool undercar electrical equipment. Also, the dynamic braking resistor grids will be moved to the top of the car to reduce further the heat under the car. Many of the control systems will be modified to minimize false signals in the circuits; improve control cards, switches and interlocks; and provide a modular changeout of electronic tubes. A car-monitoring system will also be installed to assist in determining equipment difficulties prior to failure.

Concurrently with the modification program, an analysis is being made to determine what may be done to improve the ride quality of Metroliner cars. When the study has been completed, an improved suspension

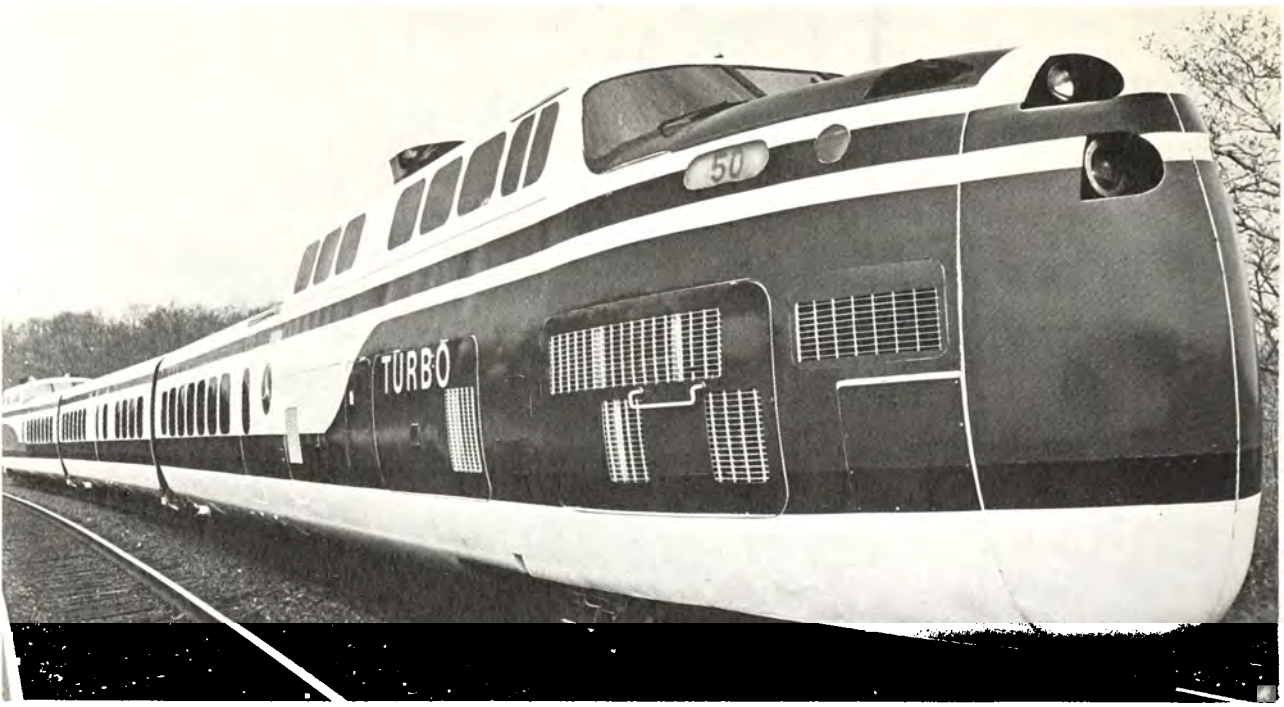
**Metroliner, Washington - New York Demonstration.**
**FIGURE 37**

and trucks will be placed on the two prototype cars by the fall of 1972.

The Penn Central-DOT contract provides that at the end of the test period the Government will share any test period revenues which exceed revenues of the corresponding period in the base year of 1968 by an amount greater than the increased cost of the service. During the first six months of the test period, revenues did not exceed the increased costs, but at the end of the first nine months there was $791,160 in excess revenue.

Metroliner train revenues have been increasing and now slightly exceed fully allocated costs. For example, revenues for the fourth quarter of 1970 were $4,701,887, while costs totalled $4,154,621. This small profitability is due in large part to the high maintenance costs mentioned previously.

As stated in the OHSGT Fourth Report, the experimental feeder bus services between the Lanham Station, Maryland, and Annapolis and Rockville were discontinued due to lack of patronage. Another experimental shuttle bus service started on September 14, 1970. It operated between the Washington, D.C., Union Station (the rail station in the city center) and a circuit of selected hotels and Government buildings within the city. Although considerable publicity was given to the experiment, with information signs located in the station and in the hotels and with a wide distribution of informative leaflets made to Government employees, monthly ridership reached only 2,063 by March 1971. The Washington D.C. Transit Company had estimated that approximately 14,000 riders a month would be required to make this a profitable operation; consequently, the experiment was discontinued on May 28, 1971.




**Turbo Train, Boston - New York Demonstration**

**FIGURE 38**

Boston-New York Demonstration

The Turbo train shown in Figure 38 is a train leased by DOT from United Aircraft Corporation (UAC). This demonstration covers only Turbo train service superimposed on existing conventional service, over which DOT has no contract authority.

From the start of the demonstration on April 8, 1969, to January 22, 1971, seven round trips were operated weekly, with two additional round trips on weekends in peak periods. The new two-year contract starting January 23, 1971, does not require a change in the operating agreement with Penn Central and provides for limited maintenance support for five trips weekly for 15 months. It also provides for equipment refurbishment and modification to improve ride quality and equipment reliability; reduction of noise, maintenance time, and costs; and expansion of the two trainsets from three cars to five cars with seating capacity increased from 144 passengers to 240. These additional two cars, for each of the two trains, as shown in Figure 39, which are being built by UAC, are expected to make the Turbo trainset a more viable economic unit.

Until the five-car trains are available, one of the existing two trains will be out of service and the other will be operated the five week days, with one round trip daily between Boston and New York.

Since the two Turbo trainsets started service, they have been continuously improved for greater reliability, as regular daily service proved necessary, largely by the replacement components which were more efficient, more accessible, or longer-lasting. These changes include:

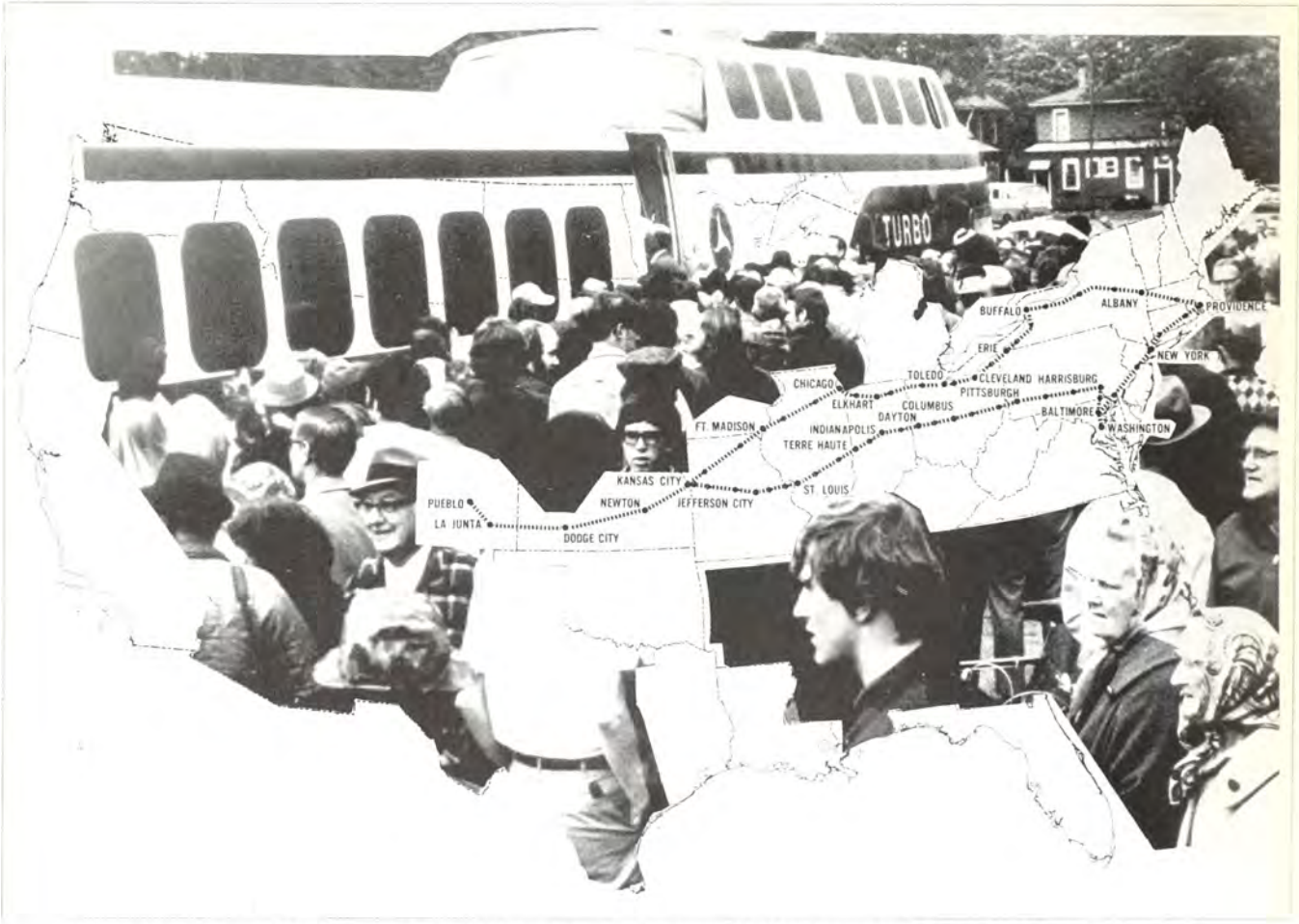
**New Turbo Train Intermediate Cars Being Manufactured at United Aircraft Corporation (Two to be added to each trainset).**

FIGURE 39

- Teflon bearing surfaces at most locations, in substitution for original bronze, or bronze-related, surfaces.
- Improved linkage for air-suspension-system filler valves.
- Improved type rubber springs on suspension members.
- Improved universal joint on guidance arms for single-axle trucks.
- More reliable gear shift device and sensing mechanism.
- Modified design of right-axle gearbox which cuts replacement time from four or more days, to one work shift.
- More reliable oil distribution.

The period in which the expanded five-car Turbos are to be operated in the renewed demonstration is limited to nine months because two years is the limit of DOT's option to renew its lease on the modified trainsets. The time is considered sufficient, however, to obtain a reasonably complete experience on the effect that increased seating capacity will have on the operating economics of the equipment, as well as on the share of total traffic that larger and more intensively utilized Turbos can attract.

Modification and refurbishment of one three-car trainset was completed on May 12, 1971. Three days later it departed on a 4,600-mile (7400 km)




**Tour of the Turbo - Providence, R. I. to High Speed Ground Test Center, Pueblo, Colo. - May 1971**

**FIGURE 40**

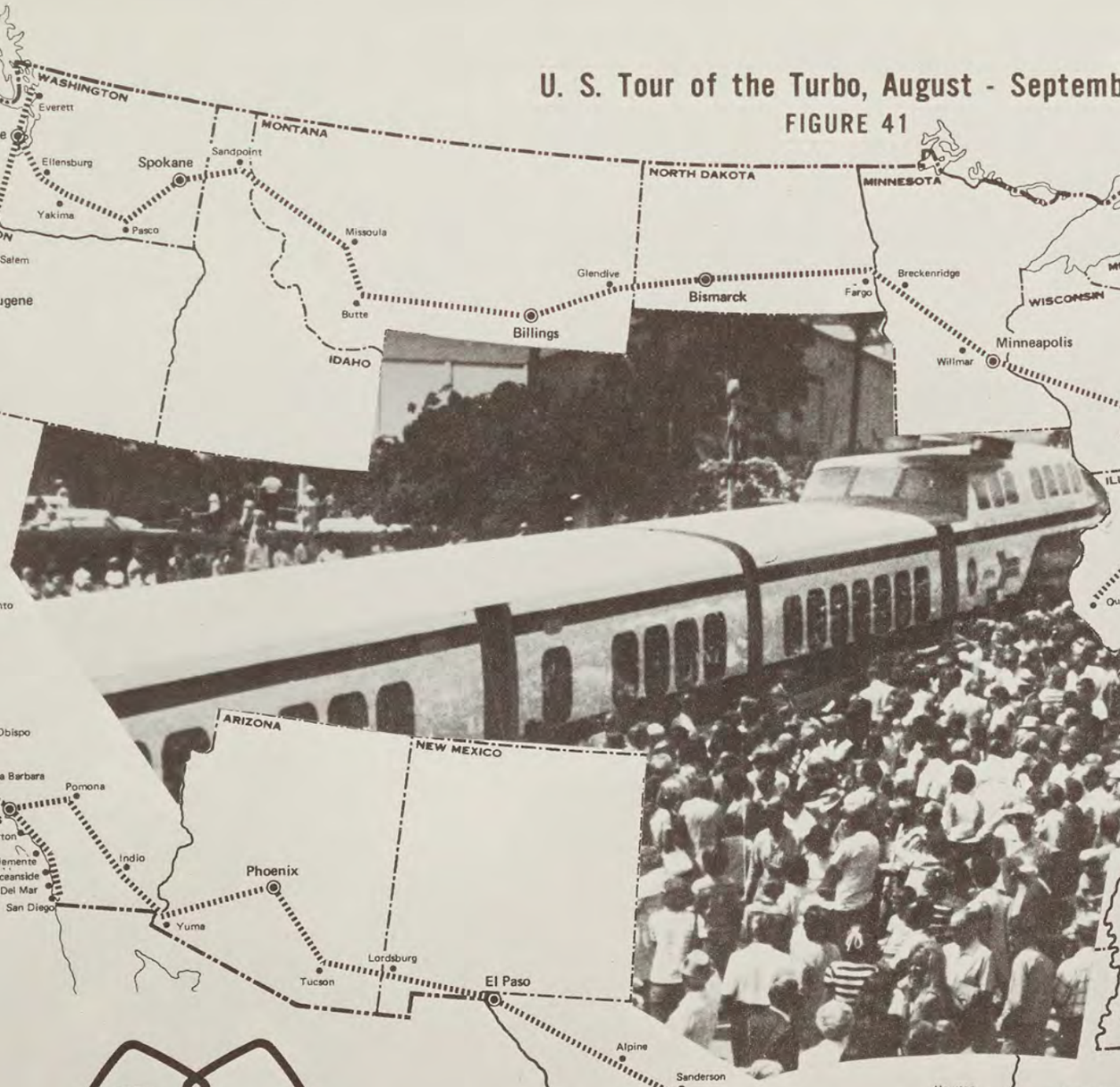
special trip as shown in Figure 40 from Providence, Rhode Island, to Pueblo, Colorado, and return, in connection with National Transportation Week and a ceremony at the new High Speed Ground Transportation Test Center near Pueblo. The self-propelled Turbo averaged 575 miles (925 km) daily for eight operating days, over a wide range of terrain, grade, and curvature conditions. Only one delay--10 minutes due to low oil pressure--could be attributed to the equipment.

The Turbo train attracted large crowds and widespread publicity. The return trip was routed to accommodate a limited number of exhibition stops, most of which were well attended by the public and news media.

The broad public interest and acceptance of the Turbo train on the Pueblo trip prompted plans for a country-wide tour of the Turbo, sponsored jointly by the Department of Transportation, United Aircraft Corporation and AMTRAK. The Turbo left Providence, Rhode Island, on August 11, bound for a 30-day, 31-state trip as shown in Figure 41 to test the capability of the train and to obtain public reaction. Meanwhile the second trainset, which was scheduled to be out-of-service for modifications at the time, remained in service until the tour ended.

## U. S. Tour of the Turbo, August - September 1971.

FIGURE 41






# Tour of the TURBO

SUMMER - 1971

The 12,000-mile (19,300 km) trip was highly successful. All who participated in the tour considered that the Turbo train was received with overwhelming enthusiasm. On five sections of the trip, the equipment was used in revenue service to augment regular AMTRAK runs. Most of the time, however, it was not in revenue service and, when feasible, people were permitted to ride to the next stop at no cost, and an estimated 7,000 persons took these rides. Approximately 250,000 people viewed the train, with some 125,000 walking through it.

Questionnaires were distributed to 2,040 of those who rode the train. As to their overall opinion of the Turbo train, 1,519 considered it excellent, 433 rated it as good, and the remainder, 118, rated it fair. Following are some of the other ratings: lighting--1,147 excellent, 600 good; attractiveness--1,348 excellent, 506 good; comfort of the low-section seats--1,208 excellent, 512 good; comfort of the dome seats--676 excellent, 416 good.

Even though a majority of the passengers voted the riding quality as excellent to good, few really had an opportunity to judge this quality at its optimum since the Turbo train achieves better riding comfort at higher speeds than were attainable on most of the tour.

As a consequence of the pending sale or lease of the Penn Central route and local service between New Haven, Connecticut, and New York City, effective January 1, 1971, all intercity service on the Boston-New York route was routed to Pennsylvania Station in New York City. Turbo service was transferred from Grand Central Terminal, effective February 1, and rescheduled to permit a cross-platform transfer connection to and from a connecting Metroliner in Washington-New York service.

Since completion of their manufacture in Chicago, Illinois, in May 1967, the two Turbos have traveled more than 525,000 miles (845 000 km)--478,000 (769 000 km) in revenue service, and 47,000 (76 000 km) in testing, shipment and special demonstrations, and they have operated in 34 of the 48 domestic states.

Of a total 1,686 revenue trips scheduled between the start of service on April 8, 1969, and July 26, 1971, 1,623 were completed, for a 97% average. Of significance is the fact that since January 23, 1971, with only one train available to run, 247 of 256 trips have been completed, for a 97% average. Of the 247 completed trips, only seven delays exceeding five minutes were attributed to the equipment.

## Station Experiments

The Capital Beltway Station at Lanham, Maryland, opened for use of Corridor travelers on March 16, 1970, has almost doubled in usage from 2,352 in June 1970 (the first month that complete records were available) to 4,306 in June 1971. The station's purpose is to provide easy access for suburbanites and to offer ample parking facilities, which were not readily available near Union Station in Washington. The loading platform at the Capital Beltway Station for northbound passengers is shown in Figure 42.

A survey of those using the station revealed the facility's importance in choosing a mode of travel. One question read, "If the Capital Beltway Station had not been opened, which of the following would you have done


**Metroliner Capital Beltway Station, Lanham, Maryland. The 16 Acre Site Will Accomodate 200 Automobiles for Travelers to Points North to New York on the Metroliner. The Station Includes a Waiting Area, with Seats, Rest Rooms, and a Ticketing Office.**

**FIGURE 42**

today?" Thirty percent said they would have taken a train from either Washington or Baltimore, 51 percent stated they would have taken a plane, 11 percent indicated that the bus would have been their travel mode, and 8 percent would have driven their autos. In other words, 70 percent of those interviewed would have chosen a mode other than rail because of the inconvenience in reaching the midcity location. In addition, 82 percent stated that there was a need for more departures from the station.

In relation to access, 62 percent parked their cars at the station, 30 percent had someone drive then there, 7 percent arrived by taxi, and 1 percent came by bus. Fifty-four percent said the main purpose of their trip was for business, with 33 percent stating it was for personal reasons and 13 percent mixing both.

The Beltway Station travelers were, for the most part, traveling long distances. Seventy percent were destined for either New York or Newark, 19 percent for Philadelphia, 8 percent for Trenton, and 1 percent each for Baltimore, Wilmington, and other points.


**Metroliner and Commuter Train Garden State Metropark Station, Woodbridge, New Jersey. The 12.4 Acre Site Will Accomodate 820 Automobiles for Travelers to Washington and New York. The Station Includes a Waiting Area, with Seats, Rest Rooms, and a Ticketing Office.**

**FIGURE 43**

A second new suburban station at Woodbridge, New Jersey, is shown in Figure 43. Officials anticipate that the Garden State Metropark Station, located near the junction of the Garden State Parkway and the New Jersey Turnpike, will be as successful as the Capital Beltway Station. Unlike the

Capital Beltway Station, the new Metropark Station will eventually handle local commuter trains as well as Washington--New York intercity trains.

Telephone information and reservations services have been particularly plaguing problems not only to those who wish to obtain tickets, but also to the ticketing organizations themselves. The OHSGT conducted a study of telephone procedures at the Baltimore, Wilmington, Philadelphia, Trenton, Newark and New York stations. As a result, the OHSGT recommended to AMTRAK specific improvements involving the use of additional lines and rotary numbers which would help relieve the problems.

Surveys to Determine Potential for New Corridors

The two Northeast Corridor demonstrations being conducted between Washington, D.C., New York, and Boston are providing traveler data in a densely populated area. Since the Northeast Corridor may not be typical of the traffic flow or volume in the rest of the country, the OHSGT has contracted for surveys to be made to develop estimates of traveler potential for improved rail service in four other corridor-type areas: Chicago-St. Louis; Chicago-Minneapolis/St. Paul; Seattle-Portland; and New York-Miami/Tampa/St. Petersburg. Results of the studies, which should be completed by early FY73, will identify areas where it will assist in transportation planning and for actual near-term demonstrations would be most fruitful and will provide data to determine the best combination of equipment and service for the potential demonstrations. The Department of Transportation of the States of New York and Florida are conducting similar surveys, respectively, in the New York City-Buffalo and Orlando-Tampa corridors, and the data exchange will prove most beneficial to all concerned.

Data Collection and Surveys

Data Collection has been a continuing project in the Demonstration Program since 1966 when the introduction of machine-readable seat tags began to provide the OHSGT with a count of passengers using the trains between city pairs on the demonstration routes. In addition, since 1967 self-administered onboard survey questionnaires have been used to evaluate passenger preferences and to determine the socio-economic characteristics of the patrons.

The results are summarized here and an extract of the yearly report is in Appendix C. Rail travel in the Northeast Corridor declined markedly in FY71. Passengers on the New York-Washington route dropped 10%, from 7.3 million to 6.4 million. A notable statistic, however, is that the number of Metroliner passengers increased 44 percent, from 983,000 to 1,411,000 during FY71, which was aided by the addition of one round trip on August 24, 1970, and two more on May 1, 1971. The latter two replaced conventional trains. As of June 30, 1971, there were nine Metroliner round trips per day and a total of two conventional trains were replaced during FY71.

New York-Boston rail passenger traffic in FY71 declined 31 percent, from 1.4 million to .9 million. The limited Turbo traffic between these two points slipped 8 percent, but this was due primarily to the fact that the number of weekly round trips was reduced from nine to five in the middle of January. The reduction was caused by taking one of the two trainsets out of service for modification work.

The onboard survey has indicated that Metroliner passengers have socio-economic characteristics which more closely resemble air passengers than conventional train patrons. On the average, Metroliner riders are slightly older, have higher incomes, travel more frequently, and are more likely to be on a business trip than their conventional train counterparts. The innovative Metroliner features and onboard services won overwhelming approval, but the terminals and terminal facilities fared no better among Metroliner passengers than they did among conventional train riders.

Eighty-one percent of the Metroliner patrons surveyed said they were going to use it for their next trip between the same points. Eighteen percent distributed their next mode usage preferences equally between autos, planes, and conventional trains, while one percent chose buses. Important concerns to those switching to air are speed, terminal facilities, and terminal services. Those passengers who plan to use the auto on their next trip are concerned chiefly with costs, terminal surroundings, and parking facilities. Those planning to ride a conventional train next time are most cost-conscious since almost half of them rated Metroliner ticket prices as fair-to-poor.

In addition to the onboard survey, the OHSGT receives similar data from the U.S. Department of Commerce Census Bureau concerning the travel characteristics of people residing in the metropolitan areas of the Northeast Corridor. A noticeable change in the three years this Corridor travel survey has been conducted is that, as a percentage of three travel modes--auto, rail, and air--auto usage has continued to climb, even among the middle to upper income families, while rails have held their relative share and air patronage has been on a constant decline in the Corridor.

## Airport Ground Access Studies

OHSGT sponsored an engineering study to assess alternative methods of providing transportation from Friendship International Airport, Maryland, to Washington and Baltimore. The study analyzed three alternative transportation combinations: (A) combined Penn Central and Baltimore and Ohio routes with a direct rail link built to the Airport; (B) the same combination but with a rail/bus transfer for bus transportation from existing tracks to the Airport instead of the rail link; and (C) an exclusive Baltimore and Ohio route with the rail link to the Airport.

For purposes of cost analysis, one-car to four-car train systems were considered in this study, with each one-car train system having the capacity to handle 7,000 passengers every 18-hour day. There would be 20 minutes between trains and a trip time of 24 to 31 minutes from Washington and 14 to 21 minutes from Baltimore.

The total capital costs for Alternative A range from $71,580,000 for a one-car system to $80,930,000 for a four-car system. The same figures for Alternative C are $61,140,000 and $71,040,000. Alternative B was limited to two-car trains to avoid the greater bus facilities which would otherwise be required to handle the number of people who would be transferring from three or four-car trains. The capital costs would be $51,000,000 for the one-car system and $54,130,000 for the two car system.

Annual costs by service, including capital, operating, and maintenance

costs, vary from $11,855,000 for a one-car system to $20,710,000 for the four-car system under Alternative A; $13,130,000 to $25,500,000 for Alternative C; and $10,640,000 and $13,725,000 for Alternative B.

Alternative B has the lowest total annual cost for each system, but is limited in its capacity. Alternative A and C were found equally acceptable with respect to capacity, but Alternative A was chosen for further study because it was less expensive on an annual cost basis.

A cost-benefit study will now be made which will include engineering costs and predicted revenue to determine the desirability of the project.

In compliance with Public Law No. 91-143, passed on December 9, 1969, entitled "National Capital Transportation Act of 1969", a $142,932 contract was awarded last year to the Washington Metropolitan Area Transit Authority for a feasibility study of extending the regional rapid transit system to Dulles Airport, Virginia. The study was conducted by Day and Zimmerman Consulting Services and the findings were submitted to the office of the Secretary on July 1, 1971. The following five service alternatives from the Airport were considered:

1. Express shuttle service to a transfer station on Metro Route K (Nutley Road Line).

2. Local shuttle service to the transfer station with two intermediate stops.

3. Integrated express service to downtown Washington.

4. Integrated local service (two intermediate stops) to downtown Washington.

5. Express service to a transportation center in Rosslyn.

An exclusive express line between downtown Washington and Dulles Airport was not considered because of the prohibitive costs.

There are three constant factors in each alternative: use of identical electrically-powered trains as planned for the Metro System; use of the Dulles Access Highway median; and a subway approach to the Airport with an underground station.

According to the study, Alternative 4 would be capable of handling the largest number of passengers in a 24-hour period--30,174. Trains would operate 15 minutes apart and have an overall trip time of 35 minutes at a one-way fare of $1.35 (present dollars). The total cost would be $90 million, with a predicted return on investment in 1990 of 8-1/2 percent.

## Personnel

The Office of High Speed Ground Transportation of the Federal Railroad Administration is divided into two divisions: the Engineering, Research and Development Division, including the administration of the expanding High Speed Ground Test Center; and the Demonstrations Division. During FY71, the Washington OHSGT staff increased by seven (four engineers and three clerical) and a Test Center staff of five (four engineers and one clerical) was recruited. At the end of FY71, the OHSGT staff consisted of 31 professionals and 17 clericals, for a total of 48.

## Program Management

The broader scope of the technological progress contained in this Fifth Report reflects in part the expanded capability of the OHSGT in R&D and demonstrations. The reported activity is also in response to the needs of the Northeast Corridor and other city pairs; the added capability that is being utilized at the Transportation Systems Center in Cambridge, Massachusetts; and a fully coordinated program with the Office of the Assistant Secretary for Systems Development and Technology.

On the basis of transportation studies, priorities have been determined for current and future needs of high speed ground transportation. Many of the research projects initiated early in the High Speed Ground Transportation program have moved into the engineering development phase, and thereby required the High Speed Ground Test Center in Colorado, the involvement and expertise of the Transportation Systems Center in Massachusetts, and the expanded utilization of contractor-performed R&D.

The two demonstration programs with the Metroliner and the Turbo train are both providing useful data that fulfill their respective program objectives, and the information obtained will help in planning future demonstrations of the new systems that complete the R&D phase.

With the advent of the National Railroad Passenger Corporation (AMTRAK) in FY71, an additional responsibility of close coordination has been required of OHSGT.

## HSGT Act Compliance And Extensions

The High Speed Ground Transportation Act of 1965 was originally enacted for a period of three years and has been extended for periods of two years and one year, respectively. The Act and its extensions are shown in Appendix A. The Department's request for permanent high speed ground transportation legislation is still pending in Congress.

This Fifth Report fulfills the requirements of Section 10.(a) that the Secretary of Transportation report annually to the President and the Congress with respect to activities carried out under the HSGT Act.

## Funding

Through FY71, appropriations totaling $94 million have been received

for six fiscal years. An additional appropriation of $25 million has been approved by Congress for FY72.

The table below shows the allocation of funds for fiscal year 1966 through 1971. Also, Appendix D contains OHSGT FY71 Contract Obligations by name, amount, organization, and the contractor's location.

HIGH SPEED GROUND TRANSPORTATION

Program Allocation of Funds-Fiscal Years 1966-1971
($ in thousands)

| Program Category | Obligations FY 1966-70 | Obligations FY 1971 | 6 Year Total FY 1966-71 |
|---|---|---|---|
| Research and Development | | | |
| Systems Engineering | $10,232 | 370 | 10,602 |
| Test Center | 1,738 | 3,847 | 5,585 |
| High Speed Rail Research | 8,019 | 2,462 | 10,481 |
| Advanced Systems | 7,793 | 7,792 | 15,585 |
| Advanced Technology | 10,743 | 2,061 | 12,804 |
| Totals | 38,525 | 16,532 | 55,057 |
| Demonstrations | | | |
| Washington to New York | 12,308 | 2,384 | 14,692 |
| New York to Boston | 6,813 | 3,139 | 9,952 |
| Data Collection | 3,006 | 714 | 3,720 |
| Other Potential Demonstrations and Studies | 3,287 | 166 | 3,453 |
| Totals | 25,414 | 6,403 | 31,817 |
| Administration | 3,316 | 1,178 | 4,494 |
| Totals | 67,255 | 24,113 | 91,368* |

* Against $94 million in appropriations.

# A P P E N D I X (A)

HSGT Act and Extensions

1965

1968

1970

APPENDIX A

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.

*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.

High-speed ground transportation study.

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.

Demonstration program.

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.

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.

Transportation data, collection.

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.

Advisory committee, establishment.

(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.

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 demonstration 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)

Common carrier employees. Protective arrangements.

79 STAT. 893.
79 STAT. 894.

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.

54 Stat. 905.

Labor standards.

(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).

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

63 Stat. 108.

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.

(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.

79 STAT. 894.
79 STAT. 895.

(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.

60 Stat. 810.

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.

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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



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.**

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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

84 STAT. 915

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.

*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.".

High-speed ground transportation. Research extension. 82 Stat. 424.

(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".

Termination date.

Approved October 13, 1970.

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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.

# A P P E N D I X (B)

OHSGT Published Reports Bibliography

# PUBLISHED REPORTS

by the

Office of High Speed Ground Transportation

Federal Railroad Administration

Department of Transportation

November 1971

This bibliography presents and abstracts 328 major research reports published by the Office of High Speed Ground Transportation in the Federal Railroad Administration, Department of Transportation. Also included are selected reports by the Office of Policy Planning, Federal Railroad Administration, and by the Northeast Corridor Transportation Project in the Office of the Assistant Secretary of Transportation for Policy and International Affairs. These reports represent results of contracted research and development, systems engineering, transportation surveys, and model development, along with intramural research reports and program summaries.

The abstracts have been arranged according to the technical categories listed below.

## Corporate Author Index

Each report may be found under the name of the firm which produced it. Firms are listed alphabetically. The numbers one through twenty-seven, beside each entry, refer to the technical categories as listed above.

## Personal Author Index

Each report can be found under the name of the principal scientific investigator(s) on the specific project. Investigators/authors are listed alphabetically. The numbers one through 27 refer to the technical categories as listed above.

## Accession/Report Number Index

The accession number (PB prefix) is assigned by the National Technical Information Service (NTIS), U.S. Department of Commerce, which prepared the bibliography for OHSGT. Prefixes other than PB refer to individual contractor reporting systems. Technical category field numbers are listed for reference.


NTIS

National Technical Information Service
U.S. DEPARTMENT OF COMMERCE
Springfield, Virginia 22151

"Published Reports" was prepared by the National Technical Information Service for the Office of High Speed Ground Transportation.

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Documents listed in this bibliography are generally available from NTIS and priced at $3.00 in paper copy and 95 cents in microfiche. However, prices for paper copy are subject to change. Should the document you order cost more than $3.00, the NTIS will ship your order and bill the difference. Please order by accession number and title.

## 01. RAIL TECHNOLOGY: TRACK AND STRUCTURES

**ANALYSIS OF STRESS DISTRIBUTION BENEATH EMBANKMENTS.**
Final research rept.,
Massachusetts Inst. of Tech., Cambridge. Soil Mechanics Div.
T. W. Lambe, R. C. Hirschfeld, and J. T. Christian. 1 Nov 66, 57p R66-53
Contract C-85-65
Northeast Corridor Transportation Project.

A mathematical analysis adapted to computer calculation is used to calculate stresses and displacements for complicated soil movements and for a large class of boundary conditions. Vertical stresses are found to be insensitive to variation in material properties and some boundary conditions, but marked changes in horizontal stresses suggest that elastic theory may be inaccurate. Additional work is suggested, to include further computer runs on a systematic basis, some improvements in the programs, and an extension of the work to study consolidation (the time-dependent dissipation of pore pressures), which is a major unsolved theoretical problem. (Author)
PB-173 637

**STUDY OF METHODS OF STABILIZING CONVENTIONAL BALLAST USING POLYMERS. FINAL REPORT ON CONTRACT MODIFICATION NO. 3.**
Materials Research and Development, Inc., Oakland, Calif.
F. S. Rostler, and J. W. Newton. Jul 68, 47p
Contract C-352-66

The report presents the results of the work performed in continuation of the research study on stabilized railroad ballast. The purpose of the continuation was to test the feasibility of applying the elastomeric cementing composition in the form of an emulsion. The principal advantage of this is that most of the agent is concentrated at the contact points of the rocks. Included are the testing procedures for the large-scale tests at the A.A.R.
PB-179 220

**STUDY OF NEW TRACK STRUCTURE DESIGNS,**
Carnegie-Mellon Univ., Pittsburgh, Pa. Transportation Research Inst.
Gurbachan S. Bhatia, James P. Romualdi, and Gerald R. Thiers. Mar 68, 103p*
Contract C-222-66

The effect of an abrupt change elastic foundation properties upon the motion of a high speed vehicle is investigated in detail in this study. Limiting allowable accelerations are chosen as the criteria for riding quality. The study indicates that there is a likelihood of encountering a variety of elastic soil combinations which can seriously deteriorate the riding qualities of a rail vehicle on conventional track. As remedial measures, two alternatives are considered to improve the quality of ride; one by improving the rigidity of the track structure by means of providing a track structure utilizing narrow vertical walls embedded in the subsoil, and the other by carefully compacting the foundation soil to minimize local variations. A study is also made to evaluate the relative economics of the alternatives. (Author)
PB-179 401

**STUDY OF METHODS OF STABILIZING CONVENTIONAL BALLAST USING POLYMERS.**
Final rept.,
Materials Research and Development, Inc., Oakland, Calif.
F. S. Rostler, R. M. White, K. Nair, R. G. Hicks, and J. W. Newton. 8 Dec 66, 219p*
Contract C-352-66
See also PB-179 220.

An elastomer compound based on a thermoplastic polymer has been developed which when applied to ballast rock as constituting conventional ballast, provides a continuous structure of high strength, good load distribution, and effective damping characteristics. Experiments were performed testing the properties of ballast treated with this compound as compared to non-treated ballast. The preparation was applied in form of a solution of the polymer compound in volatile solvents. One rate of application was explored in detail. (Author)
PB-179 466

**TRAIN ELEVATED GUIDEWAY INTERACTIONS,**
TRW Systems Group, Washington, D.C. Washington Operations.
A. Kaplan, N. Lipner, F. B. Roberts, and R. O. Strom. Feb 70, 141p 06818-6036-RO-00 FRA-RT-70-23
Contract DOT-C-353-66
Report on High - Speed Ground Transportation Systems Engineering Study.

The report describes a computer program modeling the response of an elevated guideway to the passing of a high-speed train. The train is modeled by a lumped parameter dynamic system. Specifically, the model consists of a two-vehicle train, traveling at constant velocity, over a series of similar, simply-supported bridges which may have initial camber. The response of the bridge is represented as the sum of normal mode responses. These are coupled to the equations of motion governing the response of the vehicles. The resultant system of equations is numerically integrated from arbitrary initial conditions. For evenly-spaced time intervals, depending on the size of the integration step chosen, the program calculates and prints out the displacement of centers of gravity of the cars, the wheel displacements, and the displacements of the truck masses, as well as the first and second time derivatives of these motion parameters. The output also includes the wheel loads and beam deflections as functions of time. The program has a plotting capability and a restart capability. It also has several options with respect to the modeling of the vehicles. (Author)
PB-190 635

**STABILIZED BALLAST INVESTIGATION.**
Final rept.,
Association of American Railroads, Chicago, Ill., Research Center.
G. M. Magee, et. al. Aug 69, 89p*
Contract DOT-FR-3-0254

The purpose of the investigation was to evaluate the ability of a compound to enhance the load resistant characteristics of conventional stone ballast. This compound, an emulsion based on a new butadiene-styrene block copolymer, was sprayed on the stone ballast of a short section of railroad track. A second section of track, similar but untreated, provided the sample of conventional construction. In the conduct of the investigation pulsating, single point, vertical loads varying from 5000 lbs. to 50,000 lbs. (and to 75,000 lbs. in some cases) were applied to, first, the untreated track and, then, the treated specimen in a uniform manner for 4,000,000 cycles. The treated ballast was finally subjected to 11,000,000 vertical stress cycles. Static lateral stress was also applied to each section. Comparisons established through this study are, conservatively stated, that the permanent settlement of ties supported on the untreated ballast was 10 times that recorded for the ties of the treated ballast test phase. Resistance to lateral displacement was, at least, five times greater for the treated specimen than for its companion. (Author)
PB-192 720

**STUDIES FOR RAIL VEHICLE TRACK STRUCTURES.**
Final rept. Sep 66-Apr 70,
Battelle Memorial Inst., Columbus, Ohio.
H. C. Meacham, R. H. Prause, D. R. Ahlbeck, and J. A. Kasuba. 30 Apr 70, 208p FRA-RT-71-45
Contract DOT-FR-9-0021

Conventional (tie-type) and non-conventional rail vehicle track structures were studied, with the restriction that standard gage and rail-head contour be used. Computer programs were developed and used to analyze track response to both static and dynamic vehicle loading. The models of conventional track were validated by track, and on the Penn-Central high-speed track near Bowie, Maryland. The DOT research cars were used to obtain a series of controlled-speed passes at speeds up to 125 mph. Track response under Metroliner and regular freight traffic was also recorded, both at a joint and away from a joint. The measurements showed the lack of consistency of track characteristics at different locations and at different times, and indicated the computer results to be as accurate as the degree to which track parameters could be defined. The predicted presence of individual pressure pulses for individual axles on trucks with wheelbases exceeding 6' was verified by measured subgrade pressures 3' beneath the tie base, at speeds up to 125 mph. A major philosophy in the development of improved track structures was to reduce the magnitude and number of pressure cycles transmitted into the roadbed, with the number of cycles reduced by using beam and slab type rail supports having substantial longitudinal bending stiffness. Following the analysis, performance specifications were written for rail fasteners and three types of reinforced concrete structures recommended for further evaluation in field tests: cast-in-place slab, cast-in-place twin beams, and precast twin beams. (Author)
PB-194 139

**HEAT-ASSISTED TUNNEL BORING MACHINES.**
Final rept. Feb 69-Apr 70,
United Aircraft Corp., East Hartford, Conn. Research Labs.
Jeffrey P. Carstens, W. Richard Davison, Choate A. Brown, Frederick J. McGarry, and Alan R. Smith. Sep 70, 335p UARL-J970802-12 FRA-RT-71-63
Contract DOT-FR-9-0035
Prepared in cooperation with Massachusetts Inst. of Tech., Cambridge, and Fenix and Scisson, Inc.

A study was performed to determine: the increase in tunneling machine performance in hard rock resulting from heat weakening of the rock in advance of the tunneling machine, the increase in hourly cost incurred by the heating system, and the net effect of the increased performance and the increased hourly cost on the cost of the finished tunnel. Rock-cutting experiments were performed on Barre granite using a 1-kw CO2-N2-He gas laser for rock heating and disc-type cutters of various diameters. Analytical work included the preparation of specific heat-assisted tunneler designs and their expected performance and economics. An alternative form of using heat for tunneling was also investigated in which slots were melted in the rock instead of merely heating it. The study concludes that the operation of tunneling machines incorporating lasers to provide the heat weakening is technically feasible but economically unattractive. Radiant heaters have insufficient power density to effectively heat the rock, and high-temperature jets create serious environmental problems. However, the test program indicated that a more effective way to assist mechanical cutters would be to use concentrated thermal energy to melt shallow slots in the rock between cutter paths. (DOT)
PB-197 243

**ROCK FRACTURE BY HIGH SPEED WATER JET.**
Final rept. Dec 68-Dec 70,
IIT Research Inst., Chicago, Ill.
Peter J. Huck, and Madan M. Singh. Dec 70, 98p
IITRI-D6009-11 FRA-RT-71-58
Contract DOT-FR-9-0031

The report discusses a study of rock breakage phenomena by high speed water jets. The water jets were 1 mm (0.039 in.) in diameter, traveling at 1200 m/sec (4000 fps) and had a duration of nearly 1.5 secs. Six rock types, viz. French Creek gabbro, Milford Pink granite, Connecticut brownstone, Minnesota dolomite, Indiana limestone and Massillon sandstone, ranging in compressive strength from 390 MN/ (sq m) to 30 MN/ (sq m) (56,900 psi to 4,400 psi) were used for the experiments. Only single shot tests were conducted. A number of the French Creek gabbro and Connecticut brownstone specimens split apart; the others were penetrated by a narrow hole. The depth of the hole varied from 3.2 cm to 16.7 cm (1.2 in. to 6.6 in.) depending on the rock type and experimental conditions. The specific energy consumption for these tests varied between 4000 j/cc and 340000 j/cc, but these values can be lowered one or two orders of magnitude by traversing the jet or using multiple shots. The specific energy was found to decrease with an increase in the specific pressure (stagnation pressure/compressive strength), up to specific pressures of nearly thirty-five (35). The mechanical properties of the various rocks were determined and correlated with the damage incurred by water jet impingement. (Author)
PB-197 651

**DESIGN OF A WATER CANNON FOR ROCK TUNNELING EXPERIMENTS.**
Final rept. May 70-Jan 71,
Terraspace, Inc., Bethesda, Md.
William C. Cooley, Franklin L. Beck, and Daniel L. Jaffe. 15 Jan 71, 76p* TR-2 FRA-RT-71-70
Contract DOT-FR-0-0017

A detailed design is presented for manufacturing a high pressure pulsed water cannon for rock-breaking experiments in a tunnel or quarry at jet pressures up to 1,000,000 psi. The test system includes a trailer for carrying the water cannon, and a separate dolly for the power system and controls. The water cannon incorporates components of a Terrapak hydro-pneumatic actuator and is designed to fire one pulse every 5 minutes, but can be modified to fire 20 pulses per minute with a pulse energy of 93,500 ft. lbs. This report covers the system analysis, design studies and detailed design of the water cannon system and discusses fabrication, operation and test procedures. (Author)
PB-198 050

**EXPLORATORY SOIL BORINGS AT TWO LOCATIONS FOR THE U.S. DEPARTMENT OF TRANSPORTATION. DESIGN STUDIES.**
Final rept.,
Hemphill Corp., Tulsa, Okla.
John T. Eidt, B. D. Marks, and Jack F. Stewart.
Aug 71, 75p FRA-RT-72-13

Exploratory borings and soil classification studies are reported on for two locations; southeast Kansas and northeast New Mexico. The objective of the work was the revelation of sufficient sub-soil information to enable a decision on the part of the sponsoring agency as to where to most appropriately install a railroad test track. Duplication of physical conditions most representative of present railroad track support conditions and economics of construction were important considerations. (Author)
PB-202 271

**STUDY OF NEW TRACK STRUCTURE DESIGN. PHASE I.**
Preliminary rept.,
Battelle Memorial Inst., Columbus, Ohio.
H. C. Meacham, J. E. Voorhees, and J. G. Eggert.
Sep 66, 146p FRA-RT-71-12
See also report on Phase 2, PB-202 273 and Final rept., PB-194 139.

Conventional (tie-type) and non-conventional rail vehicle track structures were studied with the constraint that standard gage and rail head contour not be varied from current practices. Computer programs were developed and used to analyze track response to both static and dynamic vehicle loading. A major philosophy in the development of improved track structures was to reduce the magnitude and number of pressure cycles transmitted to the foundation by passing rail vehicles. The report contains detailed discussion of material summarized in: 'Studies For Rail Vehicle Track Structures,' PB-194 139, and is a reference source cited in that document. (Author)
PB-202 272

**STUDY OF NEW TRACK STRUCTURE DESIGN. PHASE II.**
Summary rept.,
Battelle Memorial Inst., Columbus, Ohio.
H. C. Meacham, J. E. Voorhees, J. G. Eggert, and J. J. Enright. Aug 68, 64p FRA-RT-72-15
See also report on Phase 1, PB-202 272 and Final rept., PB-194 139.

Phase 1 of this research investigation was undertaken in September, 1966, for the Office of High Speed Ground Transportation (OHSGT) of the Department of Commerce by Battelle Memorial Institute for the purpose of conceiving new and improved track structures for high-speed trains. As a result of the Phase 1 program, a number of track structures and fasteners were devised which met the specified requirements. Following the conclusion of the Phase 1 program, the OHSGT requested additional studies and computer analyses of track structures and rail fasteners. The additional track structures of interest were chosen by OHSGT from many designs which had been submitted to them. In addition to the analysis of the track structures, they were interested in a more detailed analysis of rail fasteners, particularly any analysis which was amendable to computer techniques. This project (which was then designated as Phase 2) was then conducted, and the results are summarized in this report. The report contains detailed discussion of material summarized in: 'Studies For Rail Vehicle Track Structures,' PB-194 139, and is a reference source sited in that document. (Author)
PB-202 273

**EMBANKMENT SUPPORT FOR A RAILROAD TEST TRACK. DESIGN STUDIES.**
Final rept.,
Shannon and Wilson, Seattle, Wash.
R. J. Dietrich, and J. R. Salley. Aug 71, 167p FRA-RT-72-07

The events and considerations leading up to the production of an embankment design for the support of the Kansas test track are described. Included are discussion of site description, field investigations, laboratory investigations, sub-surface conditions, embankment design, and instrumentation. (Author)
PB-202 808

**COMPACTION OF THE CRIB AND SHOULDER AREAS OF THE BALLAST SECTION SUPPORTING THE LINEAR INDUCTION MOTOR RESEARCH VEHICLE TEST TRACT IN PUEBLO, COLORADO.**
Final rept.,
Ecole Polytechnique Federale de Lausanne (Switzerland). Institut de Technique des Transports.
David-Louis Genton. Aug 71, 38p IT-712 FRA-RT-72-09
Contract DOT-PR-10191

Observations concerning the problem of modifying a specifically identified unit of railroad ballast compacting equipment to achieve optimal working efficiency in one location are presented. The theories associated with the in-track compaction of railroad ballast are discussed and certain performance tests described. A comprehensive list of references is contained as an appendix. (Author)
PB-203 184

## 02. RAIL TECHNOLOGY: WHEEL/RAIL INTERACTION

**STRESS AND STRAIN IN ROLLING BODIES IN CONTACT,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Igor L. Paul, and P. Ranganath Nayak. 1 Nov 66, 43p
Contract C-85-65

The three-dimensional solution of the stresses and strains in the contact region of a rolling wheel which carries normal, lateral and tangential loads is sought. Because of the complexity of the general problem a preliminary step has been to seek the solution for two spheres of similar material rolling on each other. The approach has been to divide the 'locked' region into a grid of n cells formed by fixed circular grid lines and variable grid lines which have a shape similar to an assumed shape for the boundary between the 'locked' and 'slipped' regions. The equations and boundary conditions were formulated and a computer program solves 2n simultaneous equations to find the stress distributions. If all boundary conditions are not satisfied by the solution the computer program shifts the grid points according to an error criterion and reiterates the solution. The results were encouraging although the final solution is not yet available. The results for the two spheres can be extended to the case of a wheel rolling on a surface of dissimilar material. This solution is of considerable importance for high speed rail travel because forward and sidewise creep (which are vital parameters in stability calculations) and rolling stresses (fatigue, etc.) can be calculated from the complete picture of stresses and strains in the region. (Author)
PB-173 651

**A CALCULATION OF THE LATERAL HUNTING MOTION OF A TRACKED VEHICLE,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Masakazu Iguchi. 1 Nov 66, 27p DSR-76109-5
Contract C-85-65

The lateral hunting motion of a vehicle running on tracks is not only prejudicial to riding comfort, but may also cause dangerous derailment. The initial step in the design of a safe high-speed train is a theoretical and experimental investigation of this lateral hunting motion and a practical method of preventing it. The usual railroad train may be idealized as a system consisting of a number of cars connected end to end like links of a chain. The transfer-matrix technique purports to be applicable to such a system, whereby once the transfer matrices of each component (car) are derived, it is only necessary to perform successive matrix multiplications to fit the entire system. It is demonstrated that the transfer matrix method may be applied successfully in a study of lateral hunting motion. The stability problem associated with this motion, and forced vibrations caused by irregularities and lateral distortions in the rails may also be investigated by the use of the transfer-matrix technique. (Author)
PB-173 652

**A NEW THEORY OF ROLLING CONTACT.**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
P. Ranganath Nayak, and Igor L. Paul. Apr 68, 156p
Contract C-85-65

The report proposes an entirely new theory of rolling contact. Surfaces are modeled as rough (although rough in this context applies even to ball bearing smooth surfaces which are rough on the micro-scale) and are described statistically. When two rough surfaces are pressed together, their peaks (known as asperities) press against each other and form junctions. Friction in the interface is caused by the shearing of these junctions. An

important result of this model is that the relationship between the dimensionless friction force and the dimensionless lateral slip velocity depends on the surface roughness of the wheel and track. This surface roughness is described by a roughness (or smoothness) parameter. The influence of the roughness on the friction is postulated and described. Finally, experimental results are presented which support the conclusions that surface roughness is a relevant parameter in rolling contact and that the force-slip relationship is strongly dependent on surface roughness. (Author)
PB-179 433

**SOME PROBLEMS OF WHEEL/RAIL INTERACTION ASSOCIATED WITH HIGH-SPEED TRAINS.**
TRW Systems Group, Washington, D.C. Washington Operations.
Mar 69, 57p 06818-W318-R0-00
Contract C-353-66

The objective of the study is to identify and evaluate potential problems involving wheel-rail interaction which could limit the speed of a high speed rail (HSR) system. The study is based upon a survey of existing knowledge in the areas pertinent to wheel-rail interaction; no extensive analytical work is presented, but several approximate calculations are given. An attempt has been made to investigate possible wheel-rail speed limitations and to set aside some of the 'non-problems' which may at first appear to constitute a serious constraint upon rolling HSR concepts. The results and discussion are concentrated in four main areas; estimation of the dynamic loads; wheel behavior and structural integrity; rail dynamics and structural integrity; adhesion, hunting, and related problems. (Author)
PB-183 846

**A STUDY OF THE STABILITY AND DYNAMIC RESPONSE OF THE LINEAR INDUCTION MOTOR TEST VEHICLE.**
Final rept. Jun 68-Jun 69,
British Railways Board Research Dept., Derby (England). Advanced Project Div.
T. G. Pearce, and B. J. May. Sep 69, 86p* FRA-RT-70-25
Contract DOT-FR-3-0261

The results of extreme dynamical analyses of the suspension system of the linear induction motor (LIM) test vehicles are presented. Suspension stiffness and damper rates are selected on the basis of computations of lateral dynamic stability, curving and response, which should enable the vehicle to travel at speeds up to 250 mph with satisfactory riding characteristics. The influence of variations in suspension parameters is also discussed in relation to possible experimental studies on high speed, wheel supported and guided vehicles, using the LIM vehicle.
PB-192 718

**FRICTION AND CREEP IN ROLLING CONTACT,**
Bolt Beranek and Newman, Inc., Cambridge, Mass.
P. R. Nayak, S. Hariharan, Raya Stern, R. Abilock, and P. A. March. Nov 70, 273p FRA-RT-71-64

Experimental and analytical studies of friction and creep in rolling contact are reported. Factors examined for their influence on friction (adhesion) and creep are surface roughness, surface vibration, surface contamination, dynamic loading due to irregular track, and rolling velocity. The following conclusions are reached: surface roughness does not influence the creep coefficients at operating loads. However, surface roughness influences the tractive capacity when the wheel and rail surfaces are either very clean or flooded with a contaminant, surface vibrations affect wheel-rail friction considerably, surface contamination decreases both friction and creep coefficients. The magnitude of the change in these coefficients depends on the oil viscosity temperature and pressure coefficients, the normal load on the wheel and the surface roughness, dynamic loads due to suspension resonances do not appear to influence the friction or creep coefficients significantly, observed decreases in the friction coefficient at increased rolling velocities are probably due to increased surface vibrations, decreased time for the formation of friction junctions, and elastohydrodynamic effects. (OHGTR abstract)
PB-196 707

## 03. RAIL TECHNOLOGY: VEHICLE DYNAMICS

**BUFFETING TESTS ON THE HUDSON TUBE.**
Final rept.,
Stanford Research Inst., Menlo Park, Calif.
E. G. Chilton. 4 Jun 65, 30p
Contract C-209-65 (neg)

Buffeting tests were made on a two-car train of the Pennsylvania Railroad as it entered the Hudson tube. The pressure outside the train was measured at its head and at two locations along its side. The pressure inside the car was also measured. Tests were made at speeds between 55 and 70 mph. Results of these tests show that the pressure at the head rises abruptly when the nose of the train enters the tunnel, and gradually to a maximum of about 6 inches of water when the tail of the train enters. Beyond that time the pressure decreases. At the sides the initial abrupt rise is apparent only near the front of the first car and even there its severity is much smaller than at the head. Halfway along the first car the abrupt jump could not be detected. The subsequent gradual pressure rise is observed on all gages and is about equally steep everywhere. The pressure inside the car, which is the pressure experienced by a passenger, rises to a maximum of about 2.5 inches of water at a rate of about 1.5 inches of water per second. This pressure rise was noticeable but not painful. Since the maximum pressure increases as velocity squared and the rate of rise increases as velocity cubed, it seems clear that buffeting will be an important problem whenever speeds are significantly increased. (Author)
PB-168 647

**INVESTIGATION OF CAR FERRY SERVICE FOR HIGH SPEED GROUND TRANSPORTATION.**
Association of American Railroads, Chicago, Ill. Research Center.
Jul 66, 72p
Contract C-240-66- (N)

The report presents the results of an over-the-road investigation for determining the ride characteristics of automobiles and passengers on railroad cars incorporating three different truck suspension systems. The three rail cars used for this investigation are as follows: a tri-level auto rack car loaded with four automobiles on a freight type suspension, an end-door baggage car loaded with two automobiles on a six-wheel semi-soft suspension and a passenger coach on a four-wheel soft suspension system. One test auto on each car was instrumented and carried an instrumented simulated passenger in the drivers seat, also, a simulated passenger was placed in the coach. Test results show the tri-level rack car experienced the highest loadings and that the acceleration frequency range (0.85 to 5.00 cps) falls in the same bandwidth of 0.55 to 5.00 cps in all measured planes for the other two cars. In general, acceleration frequency appears to increase slightly with train speed, but did not exceed 5.00 cps. To design a car for its intended purpose, the truck suspension system, car body structural characteristics, and height of center of gravity of the loaded car, appear to be the areas for main consideration.
PB-173 513

**ACTIVE VIBRATION ISOLATION AND ACTIVE VEHICLE SUSPENSION,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Igor L. Paul, and Erich K. Bender. 1 Nov 66, 73p DSR-76109-1
Contract C-85-65

The feasibility of using 'active' elements in suspension systems for high speed ground vehicles to improve vibration isolation characteristics is considered. The characteristics of vehicle excitations (to the suspensions and to the vehicle body) are discussed and a mathematical expression for the suspension input is obtained. Based on data of human tolerance to vertical vibrations a comfort criterion (to vibrations) is established. The problem of vibration isolation to best satisfy this criterion is considered in terms of optimizing the parameters of a given suspension configuration and in terms of finding an optimum tranfer function for an unspecified suspension configuration. The methodology for obtaining these optimum solutions for a given comfort criterion is developed and solutions are obtained for the case of vertical vibrations of a two-degree-of-freedom system in which the root mean square acceleration of the vehicle is to be minimized for a given permissible suspension excursion. The optimum suspension transfer function for this case indicates that feedback of both vehicle and unsprung mass acceleration is required.
PB-173 648

**PARTIAL BIBLIOGRAPHY ON SUBJECTS RELATED TO ACTIVE VIBRATION ISOLATION AND ACTIVE VEHICLE SUSPENSIONS,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Igor L. Paul, and Erich K. Bender. 1 Nov 66, 35p DSR-76109-2
Contract C-85-65

The report represents a partial compilation of references on subjects related to active vibration isolation and active vehicle suspensions which have been collected during the past year in connection with active vehicle suspension research. The bibliography is categorized into a number of subject headings which reveal the diversity and scope of published work in general area of vibration isolation, ranging from purely mathematical techniques for optimum vibration filter calculations to the most practical aspects of suspension hardware design. No attempt has been made to sort or classify the reference with respect to the quality, scope, or usefulness of their contents. (Author)
PB-173 649

**GENERAL VEHICLE DYNAMIC MODEL,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Igor L. Paul, Hariharan Sankaran, and James L. Jackson. Nov 66, 189p DSR-76109-3
Contract C-85-65

Two computer programs were developed to calculate the three-dimensional dynamics of a rigid high-speed ground-vehicle supported vertically and laterally by an arbitrary number of suspensions and excited by arbitrary inputs (acting on the suspensions or on the vehicle body). The first program models each suspension by a linear spring and damper in parallel connected to the unsprung mass and another linear spring and damper in parallel joining the unsprung mass and the vehicle. This model is applicable to a limited class of suspensions over their linear operating range. The second, much more comprehensive program permits non-linear and/or 'active' suspension elements. Each suspension can consist of masses connected (in series or parallel) by elements with force characteristics which can be any function of time or of the relative or absolute displacements, velocities or accelerations of any of the masses (including the vehicle mass). Both programs accept sinusoidal, step, ramp or arbitrary function

inputs to the suspensions and print out any or all of the following vehicle response parameters as a function of time: vertical and lateral displacement, velocity and acceleration of the vehicle center of mass; vehicle roll, pitch and yaw (and their first and second derivatives); suspension forces on the vehicle and on the guideway. (Author)
PB-173 650

**A CALCULATION OF THE LATERAL HUNTING MOTION OF A TRACKED VEHICLE,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Masakazu Iguchi. 1 Nov 66, 27p DSR-76109-5
Contract C-85-65

The lateral hunting motion of a vehicle running on tracks is not only prejudicial to riding comfort, but may also cause dangerous derailment. The initial step in the design of a safe high-speed train is a theoretical and experimental investigation of this lateral hunting motion and a practical method of preventing it. The usual railroad train may be idealized as a system consisting of a number of cars connected end to end like links of a chain. The transfer-matrix technique purports to be applicable to such a system, whereby once the transfer matrices of each component (car) are derived, it is only necessary to perform successive matrix multiplications to fit the entire system. It is demonstrated that the transfer matrix method may be applied successfully in a study of lateral hunting motion. The stability problem associated with this motion, and forced vibrations caused by irregularities and lateral distortions in the rails may also be investigated by the use of the transfer-matrix technique. (Author)
PB-173 652

**AN INVESTIGATION OF THE RIDE QUALITY OF AUTO-TRAIN SERVICE,**
Office of High-Speed Ground Transportation, Washington, D.C.
Kenneth B. Ullman. Nov 67, 51p

The ride quality in automobiles carried aboard enclosed, airsprung railcars traveling over conventional rail roadbeds was determined. Evaluation of the data indicates that railcars transporting automobiles with their passengers could be built with minimal securement systems and could provide a ride of good quality. Two test automobiles were inserted inside an air-sprung railcar, equipped with instrumented dummies, and transported a total of 2200 rail miles during which ride vibrations and passenger reactions were recorded. The testing included alterations to the automobiles' suspension systems and different types of trackwork. Ride quality was also determined on highways using the same instrumentation. The data was analyzed by a combination of manual and automated methods. Acceleration distribution functions and frequency spectra were generated with a digital computer. (Author)
PB-176 044

**ANALYSIS OF OPTIMUM AND PREVIEW CONTROL OF ACTIVE VEHICLE SUSPENSIONS,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Erich K. Bender, and Igor L. Paul. 1 Sep 67, 75p
DSR-76109-6
Contract C-85-65

The analysis leading to the optimum transfer function for an active suspension excited by a random guideway input is briefly reviewed and a design chart is presented. A parameter sensitivity study of the stability is performed and shows excellent system stability. The wheel-guideway contact problem is considered and a design chart is developed to check wheel-guideway relative displacement (wheel hop) for active suspensions. The equations for the rms force required to prevent wheel hop are derived and a design chart showing the minimum rms vehicle acceleration which can be obtained while applying this force is presented. The improved vibration isolation characteristics of active suspensions using preview control are investigated for infinite and finite preview distances. It is found that for a simple model infinite preview can reduce the rms vehicle acceleration by a factor of 16 and that a preview time of .4-.5 seconds is sufficient to provide almost the same improvement as infinite preview. It is concluded that active suspension development for vehicle heave, roll and pitch control, particularly for use with preview control is warranted. (Author)
PB-176 137

**DYNAMIC SIMULATION OF AUTO AND PASSENGER RAIL TRANSPORTS.**
Final rept. 8 Sep 66-22 Mar 67,
IIT Research Inst., Chicago, Ill.
R. R. Robinson. Jan 68, 179p*
Contract DT-7-35086

A method of analysis and computer program was developed to generate dynamic response solutions for a bilevel auto ferry rail transport car. The analysis views the auto ferry as a system of rigid bodies interconnected by suspension system components, which include linear and nonlinear springs and rubber bumbers, bilinear rotary shock absorbers, etc. The rigid bodies consist of the rail car structure, front and rear trucks, each automobile carried (from 0 to 8) and a front and rear seat passenger in each auto. The rail suspension system is based on an air sprung truck system. The auto suspension system is based on a representative late model automobile. Five degrees of freedom are considered for the majority of the rigid bodies. The sixth degree of freedom is a prescribed function of time, equal to the current train velocity. Initially, the rail car and its contents are assumed to be traveling at constant longitudinal velocity in the equilibrium configuration. A Runge-Kutta numerical integration technique has been employed for the solution of this initial value rigid body system. (Author)
PB-180 132

**WIND TUNNEL TESTS OF A SCALE MODEL RAILROAD AUTOMOBILE RACK CAR,**
Office of High-Speed Ground Transportation, Washington, D. C.
John T. Matthews, and William F. Barnett. Jun 68, 36p*
Sponsored in part by Naval Ship Research and Development Center, Washington, D. C.

The document covers wind tunnel tests of scaled models of a representative automobile rack car. Various car configurations and arrangements were investigated to determine axial, normal, and side force coefficients for a single car with and without the interference effects of a leading, a trailing, and both a leading and a trailing car. Basic configurations were also tested through a range of sideslip angles. The interference effects from the leading and trailing cars caused notable differences between the coefficients for the one, two, and three car combinations of the configurations tested. (Author)
PB-180 198

**ECONOMICS OF RAILROAD AUTOMOBILE RACK CAR AERODYNAMIC DRAG,**
Office of High-Speed Ground Transportation, Washington, D.C.
Robert W. Luebke. Mar 69, 25p
Prepared in cooperation with C and O and B and O Railroads.

A program was established to evaluate in detail the causes of the excessive aerodynamic drag of automobile rack cars discovered by the New York Central System (now the Penn Central) and the economics of drag-reducing design modifications. The program consisted of a series of wind tunnel investigations conducted by the Naval Ship Research and Development Center, full scale aerodynamic drag tests conducted by the C and O/B and O Railroads, an analysis of the costs associated with excessive aerodynamic resistance, and an analysis of the savings that could be generated by design modifications to existing railroad auto rack cars. The first part of the program is covered in PB 180 198. The remainder is the subject matter of this report. The full-scale tests confirmed the wind tunnel test results. The economic analysis showed savings could be obtained by the addition of side and end curtains and the removal of the bridge plates. However, these savings are rather low and are quite dependent upon the actual train make up and movements involved. Consequently, the decision to modify car design must be based on the particulars of a railroad's operation and their cost of making modifications. (Author)
PB-183 845

**ENGINEERING DESIGN STUDY OF ACTIVE RIDE STABILIZER FOR THE DEPARTMENT OF TRANSPORTATION'S HIGH-SPEED TEST CARS,**
Westinghouse Research Labs., Pittsburgh, Pa.
W. O. Osbon, and T. H. Putman. Jun 69, 149p*
Contract DOT-3-0267

This report describes an engineering design study of the application of an active suspension to one of the U.S. Department of Transportation's high-speed test cars. The objective was to establish quantitatively the ride improvement which can be expected from the stabilizer as well as to determine power requirements, vehicle modifications, and the basic equipment design parameters. Quantitative assessment of expected ride improvement was carried out through computer simulation of the vehicle and the stabilization equipment for simulated sub-grade disturbances. These results are discussed in detail with computer records for the stabilized and unstabilized vehicle. To equip a test car with the proposed Active Stabilization System involves modification of the car suspension. These modifications are listed and detailed descriptions are given. (Author)
PB-185 008

**DYNAMIC RAILCAR SIMULATION PROGRAM.**
Melpar Inc., Falls Church, Va.
Mar 70, 293p* FRA-RT-20-24
Contract DOT-C-111-66

A generalized digital simulation has been programmed in the basic FORTRAN language for calculating the motions and forces during operation of a multi-membered railcar. The railcar is driven at selected speeds along a pair of rails represented by recorded numerical measurements. All massive components of the railcar are treated as general mechanical members with six degrees of freedom, coupled to each other by an arbitrary set of linear elements or a programmed set of nonlinear functions having given spring rates, damping constants, etc. The model includes simulation of truck hunting phenomena with cylindrical or taped wheel treads and simulation of the compliance properties of the rail roadbed. (FRA abstract)
PB-192 886

**INVESTIGATIONS OF BOXCAR VIBRATIONS.**
Final rept.,
Chesapeake and Ohio/Baltimore and Ohio Railroad, Baltimore, Md.
Robert W. Luebke. Aug 70, 186p FRA-RT-70-26
Contract DOT-FR-9-0038

The vibration environment within a 50 Foot - 70 ton boxcar and its running gear was measured by accelerometers and recorded on magnetic tape. The accelerometers were mounted on the car body floor over the center plate and on the unsprung mass of the trucks. The test consisted of operating a train over specially prepared track at speeds

between 10 and 60 mph. The boxcar was run empty, with half load, and finally with a full 70-ton load for each series. The full test program included evaluations designed to determine the effect of load, speed, track irregularities, flat wheels, friction damping, variable rate springs, spring travel, and truck design, on the vibration environment within the car body. The results of these tests are presented in the form of vibration spectrograms, Power Spectral Density Curves, Transmissibility Curves, and plots of acceleration versus speed. It was concluded that an increase in load and spring travel reduced the vibration levels in the car body. All of the new truck designs tested produced reductions in the car body vibration levels. Friction damping levels presently used in freight car trucks were found to be nearly optimum. Flat Wheels produced a tremendous increase in truck vibrations and a smaller increase in car body vibrations. (DOT abstract)
PB-195 341

**OPTIMIZATION OF A SIMPLE DYNAMIC MODEL OF A RAILROAD CAR UNDER RANDOM AND SINUOSOIDAL INPUTS,**
National Aeronautics and Space Administration, Langley Station, Va. Langley Research Center.
John S. Mixson, and Roy Steiner. Nov 69, 40p
FRA-RT-72-04
Presented at the ASME Annual Meeting - Symposium on Random Processes in Dynamical Problems, Los Angeles, Calif. 16-21 November 1969.

The investigation was concerned with techniques for determining values of damping and spring constants that would minimize the vibrations transmitted from irregular railroad track to passenger positions. Results developed for a three-degree-of-freedom model using a simplified representation of measured track roughness illustrate the influence on the minimizing values of the type of input used, the minimization criteria adopted, and the position at which vibrations were minimized. The results were sensitive to variations of the spectrum of the input, suggesting the importance of measuring actual track irregularities and of using the measured data in optimization studies. Different results were obtained when the rms acceleration was minimized than when peak value of spectral density was minimized, suggesting that the effects on passenger comfort of overall acceleration level be compared with the effect of vibrations that are concentrated near a single frequency. Results obtained by varying the suspension stiffness of a heavy electrical transformer suspended beneath the center of the particular type of railroad car suggest that such heavy components can be tuned to improve the vibration transmission characteristics of the system. (Author)
PB-201 620

**RAIL VEHICLE DYNAMIC STUDIES,**
National Aeronautics and Space Administration, Langley Station, Va. Langley Research Center.
John L. Sewall, Russell V. Parrish, and Barbara J. Durling. Oct 69, 21p FRA-RT-72-0318
Presented at the Shock and Vibration Symposium (40th), Hampton, Virginia. 21-23 October 1969.

The paper deals with the application of simplified dynamic models to the problem of a ride comfort in tracked vehicles for high-speed passenger travel. The studies reported are aimed at the adequate simulation of significant degrees of freedom in a railroad car in order that optimum stiffness and damping characteristics of the car and its truck suspension may be found for improved ride quality. The mathematical model used for this purpose are a four-degree-of-freedom vertical model and a 10-degree-of-freedom lateral model. The vertical model is subject to vertical inputs applied simultaneously to both trucks, and the lateral model is subject to lateral and/or rocking (or cross-level) displacements from the rails. Responses to these inputs, which may be deterministic or random, are obtained in acceleration units for various parts of the system. More emphasis is given to the lateral than to the vertical model and also to responses in the car than in other parts of the system. Nonlinear spring characteristics are simulated in two parts of the lateral truck suspension system. Interaction of railbed flexibility is not included. Results of this study show that car bending flexibility and the stiffness and damping characteristics of vertical and lateral transformer mountings play significant roles in the search for optimum stiffness and damping properties of the model. Optimum damping coefficients for the car bolsters due to sinusoidal inputs were significantly changed for certain nonsinusoidal deterministic and random inputs. (Author)
PB-201 622

**A TECHNIQUE FOR EVALUATING TRACK CONDITION USING RAILCAR VIBRATIONS,**
National Aeronautics and Space Administration, Langley Station, Va. Langley Research Center.
Sherman A. Clevenson, and Kenneth B. Ullman.
Apr 71, 7p FRA-RT-72-05
Presented at the AIAA/ASME Structures, Structural Dynamics, and Materials Conference (12th), Anaheim, California. 19-21 April 1971.

A technique for evaluating rail track roughness and irregularities using vibration measurements in the railcar is discussed. The technique has been applied to a demonstration train route now operated under DOT contract and has been used in establishing priority for track maintenance. Specific attention is placed on the portable, low-frequency, low-amplitude, acceleration measuring/recording system. The data reduction and computer programs are described. Sample vibration measurements are given and the rating system is described. The project was a joint DOT-NASA effort. (Author)
PB-201 623

## 04. RAIL TECHNOLOGY: EQUIPMENT DESIGN

**UNITED STATES DEPARTMENT OF COMMERCE AUTO-ON-TRAIN PROJECT EQUIPMENT PREVIEW.**
Klauder (Louis T.) and Associates, Philadelphia, Pa.
2 Aug 66, 33p

The train will be designed to offer passenger train comfort, conveniences, and speed to the occupants of any of the common types of automobiles, including sedans, the various coupe models, and station wagons (except Volkswagen's 'Microbus'). Van and camper models in general cannot be accomodated on account of their height. In effect, the passenger brings his own seat aboard when he drives on and no other general seating is proposed. The situation is analogous to a drive-in theater.
PB-174 307

**HIGH-SPEED RAIL: PROBLEMS AND PROSPECTS,**
Office of High-Speed Ground Transportation, Washington, D.C.
Kenneth B. Ullman. 1968, 11p
Presented at conference on Transportation Engineering, Washington, D.C., 28-30 Oct 68.

A projection of demand for the current 'high-speed' mode - air - illustrates the importance of developing ground transportation systems of high capability. Presented in this context are the attributes both of the present generation of high speed rail (HSR) equipment and of future HSR systems. The potential of HSR embodies four distinct features: (1) Ability to compete with air transportation on a door-to-door travel time basis; (2) Greater passenger comfort, convenience, and safety; (3) Greater acceptability due to more efficient land use and less noise and air pollution; (4) Allows more rational use to be made of limited airport capacity and possesses very high limiting capacity. (Author)
PB-183 363

**ECONOMICS OF RAILROAD AUTOMOBILE RACK CAR AERODYNAMIC DRAG,**
Office of High-Speed Ground Transportation, Washington, D.C.
Robert W. Luebke. Mar 69, 25p
Prepared in cooperation with C and O and B and O Railroads.

A program was established to evaluate in detail the causes of the excessive aerodynamic drag of automobile rack cars discovered by the New York Central System (now the Penn Central) and the economics of drag-reducing design modifications. The program consisted of a series of wind tunnel investigations conducted by the Naval Ship Research and Development Center, full scale aerodynamic drag tests conducted by the C and O/B and O Railroads, an analysis of the costs associated with excessive aerodynamic resistance, and an analysis of the savings that could be generated by design modifications to existing railroad auto rack cars. The first part of the program is covered in PB 180 198. The remainder is the subject matter of this report. The full-scale tests confirmed the wind tunnel test results. The economic analysis showed savings could be obtained by the addition of side and end curtains and the removal of the bridge plates. However, these savings are rather low and are quite dependent upon the actual train make up and movements involved. Consequently, the decision to modify car design must be based on the particulars of a railroad's operation and their cost of making modifications. (Author)
PB-183 845

**ECONOMICS OF RAILROAD AUTOMOBILE RACK CAR AERODYNAMIC DRAG,**
Office of High-Speed Ground Transportation, Washington, D.C.
Robert W. Luebke. Mar 69, 25p*
Prepared in cooperation with C and O and B and O Railroads.

A program was established to evaluate in detail the causes of the excessive aerodynamic drag of automobile rack cars discovered by the New York Central System (now the Penn Central) and the economics of drag-reducing design modifications. The program consisted of a series of wind tunnel investigations conducted by the Naval Ship Research and Development Center, full scale aerodynamic drag tests conducted by the C and O/B and O Railroads, an analysis of the costs associated with excessive aerodynamic resistance, and an analysis of the savings that could be generated by design modifications to existing railroad auto rack cars. The first part of the program is covered in PB 180 198. The remainder is the subject matter of this report. The full-scale tests confirmed the wind tunnel test results. The economic analysis showed savings could be obtained by the addition of side and end curtains and the removal of the bridge plates. However, these savings are rather low and are quite dependent upon the actual train make up and movements involved. Consequently, the decision to modify car design must be based on the particulars of a railroad's operation and their cost of making modifications. (Author)
PB-183 845

**A STUDY TO REDUCE THE HAZARDS OF TANK CAR TRANSPORTATION.**
Final rept.,
Cornell Aeronautical Lab., Inc., Buffalo, N.Y.
W. A. Bullerdiek, F. A. Vassallo, D. E. Adams, and C. W. Matheis. Nov 70, 177p* FRA-RT-71-74
Contract DOT-FR-00028

The report details the findings of a 4-month study contract directed at reducing the hazards of tank car transportation. A number of shortcomings with existing safety-relief specifications were indicated. A key finding was that the controlling condition in sizing for propane relief should be the liquid feed, or 'upset' car condition, and not vapor feed per the current criterion. The net result is a significant undersizing of relief area considering the existing heat flux criterion to be accurate. Analytical studies and review of test data indicate the existing heat flux criterion to be significantly low--further increasing the possibilities of overpressure. A staged safety relief system was recommended for cars with liquefied compressed gas ladings. The primary relief element would be a pressure-maintaining system sized for handling abnormal operating conditions other than severe fire exposure. The secondary relief system would be a 'dump' type to drop system pressures to levels preventing catastrophic rupture and 'rocketing' under severe fire exposure conditions. Both model and full scale test programs are recommended. (Author)
PB-199 154

**FLAW DETECTION IN MODEL RAILWAY WHEELS.**
Final rept.,
Houston Univ., Tex. Dept. of Mechanical Engineering.
D. E. Bray, and R. D. Finch. Feb 71, 234p FRA-RT-71-75

The purpose of the report is to present the results of a theoretical and experimental study of acoustic pulses propagating within a model railway wheel. The ultimate goal is the development of a method, using either ultrasound or audible sound, for detecting flaws in wheels that are moving. Ultrasonic pulses have been produced on the tread of each model wheel and an experimental investigation has been made of the propagation in the plate and on the tread surface. Echos from artificial plate flaws are identified, and, using pulse-echo and attenuation techniques, thermal flaws on the tread have been located. Records of pulse arrivals are made by photographing the oscilloscope trace with a Polaroid camera. The behavior of these pulses is shown to be in accordance with the predicted propagation of Lamb waves in the plate region of the wheel, Morse waves in the rim and surface waves on the curved tread surface. Artificial plate flws have also been detected by differences in the spectrum of audio sound radiated into the air by a wheel excited with a random noise input. (Author)
PB-199 956

**HAZARDOUS MATERIAL TANK CARS - TANK HEAD PROTECTIVE 'SHIELD' OR 'BUMPER' DESIGN.**
Final rept.,
Association of American Railroads, Chicago, Ill.
J. E. Everett, and E. A. Phillips. Aug 71, 187p*
FRA-RP-72-01
Contract DOT-FR-00035

The objective of the study program is to design a railroad tank car head protective device which will reduce the frequency of head punctures in accidents. Accident data were reviewed in detail for the years 1965 through 1970 to correlate head damage frequency and severity with various types of tank cars, to determine distribution patterns of damage over tank car head surfaces, and to assess the costs to the railroad shipping industry of head punctures. Full scale head impact tests, previously run were also reviewed. From these two reviews, design criteria were established and used to reduce an initial compilation of 74 concepts to a group of 15, which when applied to various classes of cars, comprised a semi-final total of 42 combinations, or schemes, as referred to in this report. Designs for these 42 schemes were then detailed and cost estimated. Next, a comprehensive cost/benefit analysis was applied. Three schemes appear attractive for the non-insulated pressure cars of the DOT 112A or 114A type. A recommended test program is outlined, and a preliminary estimate of its cost is given. (Author)
PB-202 624

## 05. RAIL TECHNOLOGY: PROPULSION

**NONFRICTIONAL POWER COLLECTION FOR GUIDED HIGH-SPEED GROUND VEHICLES.**
Final rept. (Part 2).
General Electric Co., Schenectady, N.Y. Research and Development Center.
12 Apr 68, 147p* S-68-1056
Contract C-7-35121

The report is a preliminary evaluation of four basic noncontacting methods of transferring motive electrical power to high-speed trains (up to 300 miles per hour). The four methods considered are: Gaseous Conduction by a Controlled Electric Arc; Magnetic Induction Using Lenz's Law of Flux Linkage; Capacitive Coupling by Displacement Currents Between Parallel Plates; Electromagnetic Directional Wave-guide Coupling. Examination and calculation of several configurations of the four methods considered established data for comparison. The evaluations include the system functions of power conditioning, power transmission, noncontacting coupling, and onboard power conversion; however, emphasis is on the equipment directly associated with the coupling. (Author)
PB-178 228

**FEASIBILITY STUDY OF LINEAR INDUCTION MOTOR THRUST BOOSTERS FOR DIESEL-ELECTRIC LOCOMOTIVES.**
Rept. for 1 Nov-31 Dec 68,
Garrett Corp., Los Angeles, Calif. AiResearch Mfg. Div.
G. P. Kalman, and B. W. Hafele. 21 Mar 69, 51p
69-4862
Contract DOT-FR-9-0014

Both the technical and economic feasibility of utilizing surplus power available from the diesel engine, by adhesion-independent thrust boosters were reviewed. First the power available for thrust boosting was determined. Then several linear motor reaction rail configurations were considered. A preferred thrust booster configuration (Figure 1-1) which utilized the running rails as the secondary member, was described. It was found that 6000-lb force per locomotive, at 12 to 13 mph train speed can be delivered by such a thrust booster. (Author)
PB-184 252

**POWER COLLECTION BY SLIDING CONTACT METHODS FOR HIGH SPEED GUIDED VEHICLES. PHASE I. ANALYZE TECHNIQUES AND DESIGN CONCEPTS.**
Final rept.
General Electric Co., Erie, Pa. Transportation Systems Div.
Aug 69, 166p
Contract DOD-FR-9-0023
Systems Design and Materials Studies.

As a result of the high speed (300 mph) power collection research, specific recommendations are developed for power collection system design, candidate materials and further analysis and testing. Each of these areas is covered in detail. A power collection system based on the use of multiple contacts mounted on a servo driven support is recommended. Techniques for material selection are developed and used for the selection of preferred candidate materials for both the distributor and collector. Recommendations are presented for evaluation and verification of both collector system design and materials selection with laboratory-type equipment. (Author)
PB-185 449

**POWER COLLECTION. CATENARY/PANTOGRAPH DYNAMICS: DEVELOPMENT OF COMPUTER PROGRAM; VERIFICATION; RESULTS.**
Final rept.
General Electric Co., Erie, Pa. Transportation Systems Div.
Sep 69, 74p
Contract DOT-7-35121
Errata sheet inserted.

This report describes a mathematical model and digital computer program to simulate the dynamics of one or more pantographs in contact with and traversing an overhead catenary system. The computer program was written in the Fortran IV compiler language for a GE-635 computer, but it has been adapted to other computers and is generally available to others interested in this subject through the DOT. The report describes the computer program briefly, the work completed to validate the program, and general conclusions about the program's usefulness. The validation of the program included comparison of computed results with data measured on the four car DOT test train at speeds up to about 130 mph.
PB-186 230

**ELECTRIC POWER SYSTEMS FOR HIGH SPEED GROUND TRANSPORTATION.**
Final rept.
Westinghouse Electric Corp., Pittsburgh, Pa. Transportation Div.
25 Aug 69, 352p*
Contract DOT-9-0025

This study investigates the power needs of four classes of systems: (1) 300 mph Tracked Air Cushion Vehicle (TACV); (2) 250 mph Linear Induction Motor (LIM)-driven rail vehicle; (3) 250 mph wheel-driven vehicle; (4) 200 mph wheel-driven rail vehicle. Task areas for the study are: (1) Power systems; (2) Power distribution; (3) Power collection; (4) Power conditioning.
PB-186 232

**EVALUATION OF THE PLASMA TORCH. STUDY OF OPERATIONAL TESTING AND EVALUATION OF AN ARC PLASMA GENERATOR AS A MEANS TO IMPROVE WHEEL-RAIL ADHESION.**
Final rept. Jun 68-Jun 69,
British Railways Board Research Dept., Derby (England). Electrical Research Div.
D. J. Dobbs. Jan 70, 59p* FRA-RT-70-27
Contract DOT-FR-9-0009

Effectiveness of the d.c. are plasma generator as a tool for improving wheelrail adhesion was measured. Two torches per rail were found very effective in eliminating low adhesion areas. Generally, adhesion values of 0.1 to 0.2 were increased to nearly 0.3. More specifically, adhesion corresponding to the 2% slip risk level, averaged over all tests in the speed range up to 30 mph, was increased from 0.19 to 0.29. Significant improvement of adhesion was found up to six hours after treatment with the plasma torch even though climatic changes had brought about changes in the adhesion of both control and test sections. Over longer periods, large numbers of freight and passenger trains distribute fresh contamination over the test and control sections thereby changing the identity of the sites. The power used was increased with the square root of speed up to 15 mph when it totalled 60 kw for both rails. Above 15 mph the power was held approximately constant at 66 kw. Constant power operation results in adhesion increases which are significant but less than would have been obtained if power had been increased. The power level used in all the trials was such that no damage could occur to the rails. Experiments in the laboratory have shown that even with much greater plasma powers the mechanical properties of rail steel were unaffected; this provides a high level of operational safety should the power control system malfunction. With this equipment the problem of wheel slip on starting, for heavily laden

freight and passenger trains, can be confidently said to be overcome.
PB-192 885

## 06. RAIL TECHNOLOGY: BRAKING

**DEVELOPMENT OF NONFRICTION BRAKING SYSTEMS FOR HIGH SPEED TRAINS.**
Final rept. 19 May 69-4 Apr 70,
Cornell Aeronautical Lab., Inc., Buffalo, N.Y. Vehicle Research Dept.
R. J. Cassidy, R. L. Pleuthner, and F. K. Schenkel.
Apr 70, 204p CAL-YM-2811-K-3 FRA-RT-70-40
Contract DOT-FR-9-0040

Performance potential and approximate cost estimate for three nonfriction braking systems are obtained. The systems are: the air retarder, the hydraulic retarder, and aerodynamic braking. It is shown that the air retarder and the hydraulic retarder have potential to develop full braking deceleration in a speed range from 250 MPH to 25 MPH. Because of its advantage over the hydraulic retarder in system weight, simplicity and cost, it is recommended that development of the air retarder be undertaken. Aerodynamic braking deceleration is highly dependent on projected braking area. Maximum frontal envelope considered was car frontal area plus an area enclosed by car width and extending three ft. above the roof. For this area, most of the energy of a 250 MPH train can be absorbed by aerodynamic braking. At speeds below 100 MPH (very approximately) aerodynamic braking must be supplemented by friction braking to obtain sufficient deceleration rates. Existing aerodynamic test data for longitudinally spaced braking surfaces are not sufficient to obtain accurate predictions of the friction braking crossover point and the aerodynamic braking deceleration rate. Therefore a wind tunnel test program is recommended. The report includes an extensive bibliography and references covering related aerodynamic material. (Author)
PB-192 454

## 07. RAIL TECHNOLOGY: CONTROL AND COMMUNICATION

**OBSTRUCTION DETECTION PROGRAM.**
Final rept.
RCA Corp., Princeton, N.J.
15 Mar 69, 162p
Contract DT-7-35509

An obstacle detection system comprised of transmitters and collocated receivers spaced alongside railroad tracks and scanning across the tracks to a continuous retroreflective fence was studied, tested, and demonstrated. The transmitters emit a very narrow beam of collimated coherent light from a galium arsenide laser. The retroreflector establishes a narrow region with reflectivity substantially higher than the normal surroundings. An object located between the laser transmitter and the retroreflector will prevent the laser beam from impinging upon the retroreflector and will, therefore, cause a variation in the return energy normally observed by the receiver. This variation is then reported to a central control station for further action. An engineering model of a laser scanner was designed and built. In combination with an engineering model of a retroreflective fence, the scanner engineering model was used to successfully demonstrate the feasibility of the system concepts. (Author)
PB-182 996

**A PROGRAM DEFINITION STUDY FOR RAIL-HIGHWAY GRADE CROSSING IMPROVEMENT.**
Final rept.,
Voorhees (Alan M.) and Associates, Inc., McLean, Va.
David W. Schoppert. Oct 69, 171p AMV-R-71-1028 FRA-RP-70-2
Contract DOT-FR-9-0028

The report describes in general terms the present status of grade crossing inventories, improvement programs and other significant considerations. It identifies available information with respect to the cost of accidents and motor vehicle operations, as well as the preparation of estimates of the number of crossings in classes related to the volume of train movements and the volume of vehicle traffic. From these estimates, the number of crossings at which improvements would yield benefits in excess of costs was estimated, together with the reduction in accidents which those improvements could be expected to bring. It develops a five-year program of study related to policy formulation, program administration and research; also, it identifies and describes projects which can be initiated as action programs, research and special studies. This includes a recommended program to correct data deficiencies and develop a comprehensive information system. (Author)
PB-190 401

**TRAIN CONTROL AND OPERATIONS.**
Final rept.,
Department of Transportation, Cambridge, Mass. Transportation Systems Center.
K. Hergenrother. Jun 71, 34p DOT-TSC-FRA-71-5

ATO (automatic train operation) and ATC (automatic train control) systems are evaluated relative to available technology and cost-benefit. The technological evaluation shows that suitable mathematical models of the dynamics of long trains are required before substantial improvements can be made to ATO systems, and the present ATC systems are presently near optimum. The cost-benefit analysis concludes that only railroads which find CTC (centralized traffic control) economically desirable will also find that ATC offers improved operating economies. ATO does not seem economically or politically practical in the general railroad environment. A brief evaluation is made of both the contribution of the railroad locomotive to air pollution and the possible means of controlling this pollution. (DOT abstract)
PB-202 623

## 08. RAIL TECHNOLOGY: SYSTEMS AND TRAINS

**POSSIBLE IMPROVEMENTS TO RAILROAD PASSENGER SERVICE BETWEEN NEW YORK AND WASHINGTON.**
Preliminary engineering rept.,
Klauder (Louis T.) and Associates, Philadelphia, Pa.
Louis T. Klauder. 1 Jun 64, 135p
Contract Cc6238
Rept. on Washington-Boston Corridor Research Proj.

Studies are made of the possible service improvements on the Pennsylvania Railroad between Washington, D. C. and New York, N. Y. to provide in greater depth an analysis of the operational aspects of such service, the required alterations to existing facilities, and the equipment design features, as well as calculations of the cost of improvements and improved operations between these two cities.
PB-166 879

**POSSIBLE IMPROVEMENTS TO RAILROAD PASSENGER SERVICE BETWEEN NEW YORK AND WASHINGTON.**
Supplemental engineering rept.
Klauder (Louis T.) and Associates, Philadelphia, Pa.
12 Jun 64, 123p
Contract Cc6238
Rept. on Washington-Boston Corridor Research Proj. Supplemental rept. to preliminary rept. dated 1 Jan 64.

The possibility and the cost of establishing two and one-half hour passenger service between New York and Washington was studied, using the tracks of the Pennsylvania Railroad. The results of that study were presented in a 'Preliminary Engineering Report on Possible Improvements to Railroad Passenger Service Between New York and Washington,' dated June 1, 1964 (PB-166 879). In this report the possibility and cost of establishing two and one-quarter and two-hour service between these same two cities are studied.
PB-166 880

**DEMAND FOR INTERCITY PASSENGER TRAVEL IN THE WASHINGTON-BOSTON CORRIDOR.**
Systems Analysis and Research Corp., Boston, Mass.
1963, 288P

The study has four main objectives: (1) Identification and measurement of the principal factors influencing intercity passenger demand; (2) identification and measurement of the principal factors influencing the division of intercity passenger demand by mode; (3) projection of intercity passenger demand in the corridor through 1980, and (4) delineation of further study requirements.
PB-166 884

**INTERCITY FREIGHT TRANSPORTATION REQUIREMENTS OF THE WASHINGTON-BOSTON CORRIDOR IN 1980.**
Final rept.
United Research, Inc., Cambridge, Mass.
Nov 63, 243p
Contract Cc6224

The purpose of this research is to study the intercity freight transportation requirements of the Washington-Boston Corridor in 1980, and the improvements required in transporting commodities through and within the corridor by land, water and air. The study objectives are (1) to estimate in terms of traffic flows, the current total demand for intercity freight commodity transportation existing in the corridor; (2) to describe in qualitative terms the commodities making up these traffic flows; (3) to show how the current demand for commodity freight transportation is being met today; (4) to identify and establish a relationship between significant economic and sociological factors and levels of transportation demand; (5) to identify significant changes in these relationships which may occur in the future as a result of technological innovation; (6) to project the economic and sociological demand factors in 1980; (7) to forecast for 1980, total intercity freight transportation demand (as expressed in terms of traffic flows); (8) to allocate this total commodity flow to the various modes on the basis of foreseeable intermodal competitive relationships; (9) to identify and describe the economic and technical characteristics of the various ways and vehicles which may be made available to freight carriers by 1980; and (10) to describe the methodology by which the cost and technical characteristics of ways and vehicles could be related to possible future demand characteristics.
PB-166 885

**WASHINGTON-BOSTON TRANSPORTATION STUDY. PART B. FEASIBILITY AND COST OF IMPROVED RAILROAD SERVICE.**
Final rept.,
General American Transportation Corp., Niles, Ill. MRD Div.
Andrew A. Arentz, Jr., Fred W. Sander, and Richard E. Pages. Nov 63, 228p
Contract Cc6207

Conclusions: A large portion of the total intercity passenger market in 1980 in the Washington-

Boston corridor can be effectively and economically served by improved railroad service. To serve the 1980 market, major improvement of existing rail systems does not appear to be economically feasible. The most promising long-range solution to the 1980 corridor problem is a new high-speed high-frequency railriding auto ferry. An immediate improvement of the present rail systems in the corridor should be made with the object of achieving efficient, dependable, and economical operations. This improvement should be in the lower improved-speed ranges contemplated in the study and should be compatible with the structures of the railroads as they already exist. It should also be predicted on new comfortable equipment that will be consonant with future local and commuter requirements.
PB-166 886

**PRELIMINARY ENGINEERING REPORT ON POSSIBLE IMPROVEMENTS TO RAILROAD PASSENGER SERVICE BETWEEN NEW YORK AND BOSTON.**
Klauder (Louis T.) and Associates, Philadelphia, Pa.
15 Nov 65, 191p
Rept. on US Dept. of Commerce Northeast Corridor Transportation Proj.

The purpose of this report is to set forth the changes and additions which might be made in order to reduce the travel time between New York and Boston to 2-1/2 hours, 2-3/4 hours, or 3 hours. In the study of 3-hour travel time top speeds of both 125 mph and 150 mph are considered. In studies of 2-3/4 hour travel time two possiblilities are considered: first that the improvements to the right-of-way necessary to reduce the travel time to 2-3/4 hours might be made between New Haven and Providence where the costs are relatively modest, and, second, that these improvements might be made between New York and New Haven where the costs are considerably higher.
PB-169 907

**TRAIN AUTO FERRY OPERATIONS.--A SUMMARY OF PRESENT AND PROPOSED CONCEPTS AND RECOMMENDATIONS FOR A DEMONSTRATION PROJECT.**
Final rept.,
Whitten (Herbert O.) and Associates, Washington, D.C.
Herbert O. Whitten. Apr 66, 158p
Availability: Original document in color until exhausted.

The idea of moving passengers and their automobiles by train from a point of origin to a common destination is examined. This report discusses past and present attempts to put this idea into practice; analyzes potential costs and prices for such service if operated in this country; and makes recommendations for a proposed demonstration project of such service.
PB-170 798

**TRANSIM -- GENERAL PURPOSE TRANSPORTATION SYSTEM SIMULATOR -- USER'S MANUAL.**
California Univ., Los Angeles. Dept. of Engineering.
May 66, 231p Rept. no. 66-6
Contract Cc-6220
See PB-173 017 for the IBM-1401 and 7090/7094 punched cards.

The TRANSIM transportation simulator was developed at the University of California, Los Angeles, to fill the need for a general-purpose computer simulation method which is simple and economical to use for a wide variety of problems in transportation; these may concern different modes, traffic types, firm sizes, or system situations. The User's Manual describes the simulator and delineates the procedures for its use. The User's Manual also discusses topics of more general interest, such as the concept of the systems approach, and the difference between mathematical models and computer simulators such as TRANSIM.
PB-173 016

**STUDIES IN TRAVEL DEMAND.**
Mathematica, Princeton, N.J.
Sep 65, 188p
Contract C-247-65

Contents: Methodological problems - A survey of demand for travel studies, by Ronald E. Miller; Some problems in forecasting transportation demand, by Henry M. Peskin; Some perspectives of gravity models, by Richard E. Quandt. Modal studies - The demand for air travel, by Roger E. Alcaly; The demand for bus travel, by John Kissin; The demand for rail travel, by Solita C. Monsod; The demand for automobile travel, by Frank Vannerson.
PB-173 499

**STUDIES IN TRAVEL DEMAND. VOLUME II,**
Mathematica, Princeton, N.J.
Richard E. Quandt, and William J. Baumol. 30 Sep 66, 231p
Contract C-187-66
See also VOLUME I-PB-173 499.

Contents: Estimation and testing in abstract mode models - The abstract mode model; theory and measurement; Tests of the abstract mode model; A non-linear model of passenger demand; A probabilistic abstract mode model; Some considerations on the choice among forecasting formulas; Alternative approaches and special problems - Some problems and prospects in collecting data on travel demand; A cross-sectional model of the demand for rail passenger service in the Northeast Corridor; Time patterns of traffic volume; An optimization model for Corridor transportation planning.
PB-176 114

**STUDIES ON THE DEMAND FOR FREIGHT TRANSPORTATION, VOL. 1.**
Mathematica, Princeton, N.J.
Aug 67, 263p
Contract DC-7-35120

The volume is devoted to the estimation of freight demand in the Northeast Corridor. It is argued that a mode of freight transportation should be considered in terms of its abstract attributes, and the demand for freight transportation is analyzed in inventory theoretic terms. A macro-economic approach to the matter provides a more complete micro-model designed for descriptive, as well as forecasting, purposes. The grand total demand for freight transportation at the macro-level is estimated at the first stage on the basis of the values of exogeneous variables; then, at the second stage, the total is sub-divided with the aid of some specifically pertinent variables. In the third stage, the second stage sub-totals are again sub-divided with the aid of still other specific variables, etc. The interdependence of macro-totals on sub-totals is exploited as a part of the estimation technique. The data requirements provided can be useful in developing data banks or future statistical system for the Department of Transportation. A more current data requirements list is also provided. A novel technique for estimation of origin-destination data on freight movements using incomplete information is presented.
PB-176 479

**STUDIES IN TRAVEL DEMAND. VOLUME III.**
Mathematica, Princeton, N.J.
Jul 67, 416p
Contract C-187-66
See also Volume 2, PB-176 114.

The document covers a mathematical means of estimating travel demand in New England and the Middle Atlantic states.
PB-177 610

**A FEASIBILITY ANALYSIS FOR AUTO-ON-TRAIN SERVICE BETWEEN WASHINGTON, D.C. AND JACKSONVILLE, FLORIDA,**
Center for Advanced Administrative Research, Inc., Boca Raton, Fla.
George Horton. 1967, 96p

The study examines the potential market for automobile-on-train passenger service between Washington, D. C. and Jacksonville, Florida. The methodology employed in gaining information is discussed in detail. Indications are that the number of those willing to pay $100 or more per one-way trip between Washington, D. C. and Jacksonville, Florida, is about 14 times the capacity of a 10-car (78 autos) train making 2 round trips each 3 days.
PB-182 122

**SYSTEM FOR SURVEYING REGIONAL TRAVEL. VOLUME I: PROPOSED METHOD FOR SELECTION OF SURVEY SITES FOR A COORDINATED AIR, AUTO, BUS AND RAIL TRAVELER SURVEY IN THE NORTHEAST CORRIDOR.**
Peat, Marwick, Livingston and Co., Washington, D.C.
Jun 67, 58p
Contract DT-7-35215
See also Volume 2, PB-182 218.

The understanding of travel choices, investment opportunities, and community impact continues to be a distinctive challenge to planning research. A system for surveying regional travel could reasonably serve several objectives, some of which are: to provide statistical data; to establish travel preferences; to determine travel motives and patterns; to establish transportation needs or demand; to produce costs and other financial information; and to forecast future travel. (Author)
PB-182 217

**SYSTEM FOR SURVEYING REGIONAL TRAVEL. VOLUME II: PROPOSED SAMPLE DESIGN AND SURVEY PROCEDURES FOR A COORDINATED AIR, AUTO, BUS AND RAIL TRAVELER SURVEY IN THE NORTHEAST CORRIDOR.**
Abt Associates, Inc., Cambridge, Mass.
Apr 68, 116p
Contract DT-T8-054
See also Volume 1, PB-182 217. Limited number of copies containing color other than black and white are available until stock is exhausted. Reproductions will be made in black and white only.

The survey plan covered in the document is complete with respect to presenting the methodology for accomplishing the stated objectives. It covers the mathematical design and definitions of the survey population; the survey procedures and reasons for their selection; the overall plan for implementation; and guidelines for controlling the fieldwork. Costs documentation, and control requirements necessary to implement a survey of this magnitude are also discussed. (Author)
PB-182 218

**RAIL PASSENGER STATISTICS IN THE NORTHEAST CORRIDOR.**
Office of High-Speed Ground Transportation, Washington, D.C.
Feb 69, 22p

Using the results of surveys taken on Penn Central trains between Washington, New York, and Boston, this report discusses passengers' origins, destinations, socio-economic characteristics, purposes of travel, frequency of travel, and attitudes toward the service.

PB-183 365

**STUDIES IN TRAVEL DEMAND. VOLUME V,**
Mathematica, Princeton, N.J.
Michel R. Pinton. Mar 69, 288p*
Contract DOT-3-0009
See also Volume 4, PB-185 003.

Contents: Estimation and testing in long-range demand models (An abstract model approach to the demand for travel, Relative shares model, Estimation of the behavioral model, Tests and comparisons on demand models); Time-series analysis (An empirical study of the fluctuations in passenger traffic, The time patterns of train passenger traffic in the Northeast Corridor, A regression analysis of hourly traffic patterns in the Northeast Corridor).
PB-184 995

**ENGINEERING DESIGN STUDY OF ACTIVE RIDE STABILIZER FOR THE DEPARTMENT OF TRANSPORTATION'S HIGH-SPEED TEST CARS,**
Westinghouse Research Labs., Pittsburgh, Pa.
W. O. Osbon, and T. H. Putman. Jun 69, 149p*
Contract DOT-3-0267

This report describes an engineering design study of the application of an active suspension to one of the U.S. Department of Transportation's high-speed test cars. The objective was to establish quantitatively the ride improvement which can be expected from the stabilizer as well as to determine power requirements, vehicle modifications, and the basic equipment design parameters. Quantitative assessment of expected ride improvement was carried out through computer simulation of the vehicle and the stabilization equipment for simulated sub-grade disturbances. These results are discussed in detail with computer records for the stabilized and unstabilized vehicle. To equip a test car with the proposed Active Stabilization System involves modification of the car suspension. These modifications are listed and detailed descriptions are given. (Author)
PB-185 008

**NORTHEAST CORRIDOR TRANSPORTATION PROJECT REPORT,**
Office of High-Speed Ground Transportation, Washington, D.C.
Robert A. Nelson, Paul W. Shuldiner, Myron Miller, and Robert L. Winestone. Apr 70, 242p*
NECTP-209
Limited number of copies containing color other than black and white are available until stock is exhausted. Reproductions will be made in black and white only.

The Northeast Corridor Transportation Project was charged to determine the inter-city transportation facility requirements of the Northeast Corridor through 1980. This report contains the following: A comparative analysis of the transportation alternatives as to their technical feasibility, economic costs and benefits and other impacts in the year 1975; A discussion of the actions required to implement the transportation alternatives; An examination of possible financing and management of new modes included in the alternatives; Advantages and disadvantages of various organizational alternatives; Population growth patterns and the Corridor transportation system; Methodology; Description of the alternative systems; and exploratory studies and sensitivity tests. (Author)
PB-190 929

**NORTHEAST CORRIDOR TRANSPORTATION: PROBLEMS AND PROSPECTS.**
Peat, Marwick, Livingston and Co., Washington, D.C.
Dec 69, 109p* NECTP-210
Contract DOT-FR-9-0017
Limited number of copies containing color other than black and white are available until stock is exhausted. Reproductions will be made in black and white only.

The report contains four parts, each based on a region within the Corridor. New York is examined first because of its impact on the remainder of the region. The other three regions covered are Delaware Valley, Baltimore-Washington and New England. Each region is examined on the basis of four central points: Historic growth patterns; Demand for transportation; Level of service; and Anticipated deficiencies and prospects.
PB-190 930

**STATUS OF THE TRANSPORTATION SYSTEM AND PLANS FOR IMPROVING INTERCITY TRANSPORTATION IN THE NORTHEAST CORRIDOR.**
Peat, Marwick, Livingston and Co., Washington, D.C.
Dec 69, 189p NECTP-211
Contract DOT-FR-9-0017
Limited number of copies containing color other than black and white are available until stock is exhausted. Reproductions will be made in black and white only.

The report provides background information on the Northeast Corridor, its geographic and demographic characteristics in general, and the characteristics of its travelers, in particular. Also it describes the existing Corridor highway system, the rail passenger system, and the scheduled air transportation system. (Author)
PB-190 931

**NORTHEAST CORRIDOR TRANSPORTATION FACTS AND STATISTICS,**
Peat, Marwick, Livingston and Co., Washington, D.C.
M. J. Rothenberg. Dec 69, 155p* NECTP-212
Contract FR-9-0017

The material presented in the document is meant to provide basic information on the intercity transportation system and other select regional characteristics of the Northeast Corridor. Primary attention is given to the status of the existing transportation system and the magnitude and characteristics of system usage. (Author)
PB-190 932

**THE NEEDS AND DESIRES OF TRAVELERS IN THE NORTHEAST CORRIDOR. A SURVEY OF THE DYNAMICS OF MODE CHOICE DECISIONS.**
National Analysts, Inc., Philadelphia, Pa.
Feb 70, 306p*
Contract DOT-FR-9-0048

Most mode choices are the results of routines, not actual decisions. When decisions are made, they usually involve choices between only two modes, or three at most. From the individual traveler's point of view, the mode to use appears to be given by the nature of the trip, since he seldom subjects his needs and desires to conscious examination. For all three reasons, conceptualizing a simple four-way decision process, with the pluses and minuses of using each of the four modes weighed against one another simultaneously, is inaccurate. Mode selections are usually better conceptualized as routines that form around different kinds of trips, codifying the traveler's value considerations and mode evaluations. As a result of a series of carefully structured interviews of travelers, this report analyzes the process of mode selection. It finds that current rail service has a distinctly unpleasant image to most users and non-users, and that feelings about poor train service are bitter.
PB-191 027

**SYSTEMS SIMULATION STUDIES.**
Final rept.
TRW Systems Group, Redondo Beach, Calif.
Dec 69, 229p 06818-W008-RO00 FRA-RT-70-34
Contract DOT-C-353-66
Report on High-Speed Ground Transportation Systems Engineering Study.

The report describes a computer program developed to simulate the operation of a high speed ground transportation mode within the U. S. Northeast Corridor. The program utilizes the TRANSIM user language for the simulation in conjunction with an output processor program written specifically to improve the basic TRANSIM output format. This conversion allows quicker accessibility to critical analysis variables. As a demonstration of the program, a simulation was performed of a 150-mph new rail facility within the Northeast Corridor. The results of this simulation and the documentation of the program are included. (Author)
PB-191 411

**HIGH SPEED RAIL SYSTEMS.**
TRW Systems Group, Redondo Beach, Calif.
Feb 70, 608p* 06818-6037-RO00 FRA-RT-70-36
Contract DOT-C-353-66
Report on High-Speed Ground Transportation Systems Engineering Study.

The application of steel-wheel-on-steel rail trained vehicles to intercity passenger transportation at speeds of 200 to 300 mph is examined. The physical and human constraints, and the framework of ground-rules within which the study is constructed are described. Primary system elements are singled out and considered in the light of the higher speed requirements. The elements are the vehicle, propulsion and power, braking, suspension, guideway, control and communications and terminals. Present-day state-of-the-art operating systems are used as a point of departure. A baseline high-speed rail system is synthesized, and its performance and service characteristics are described parametrically, as a function of such independent variables as seating capacity and design cruise speed. Research and development, investment and operating costs are given. (Author)
PB-192 506

**DULLES AIRPORT RAPID TRANSIT SERVICE. A FEASIBILITY STUDY.**
Washington Metropolitan Area Transit Authority.
Jul 71, 169p FRA-RT-72-01
Prepared in cooperation with Day and Zimmermann Consulting Services, Philadelphia, Pa.

The study investigates the feasibility of extending a rapid transit line, in the median of the Dulles access highway from its projected junction with Interstate 66 to the Dulles International Airport, to be operated in conjunction with the Washington Metro System. The report encompasses requirements for right-of-way, fixed facilities and vehicles, and alternative methods and schedules of operation. Estimated capital and operating costs related to these factors have also been developed. Forecasts have been made for various time frames to estimate the numbers of travellers who would make use of this service, and revenues generated by this traffic have been projected. (DOT abstract)
PB-201 619

**OBSERVATIONS ON THE COST, PRESENT AND ANTICIPATED, ASSOCIATED WITH HIGH SPEED RAIL TRANSPORTATION.**
Rept. on assignment no. 9,
Federal Railroad Administration, Washington, D.C.
W. B. O'Sullivan. Sep 70, 104p FRA-RT-72-19
Also pub. in Bull-629, Sep-Oct 70, of the American Railway Engineering Association and in AREA Proceedings, v72.

The report is a synthesis of data, published and otherwise, commenting on costs related primarily to the construction and maintenance of present high speed train routes or those envisioned for

near and longer term future. Some of the social factors supporting the concept of high speed train service are explored. Results of recent model studies of a region's transportation demands for the next two decades are reviewed and the anticipated role of the rail mode described. (DOT abstract)
PB-202 573

## 09. RAIL TECHNOLOGY: HUMAN FACTORS

**LITERATURE SURVEY OF PASSENGER COMFORT LIMITATIONS OF HIGH-SPEED GROUND TRANSPORTS,**
United Aircraft Corp., East Hartford, Conn. Research Labs.
J. P. Carstens, and D. Kresge. 26 Jul 65, 60p Rept. no. D-910353-1
Research supported by Department of Commerce, Washington, DC.

A literature survey was made of passenger comfort criteria applicable to high-speed ground transports. Factors considered include acceleration vibration, pressure changes, atmospheric contamination, visual disturbances, and noise. Literature examined includes engineering data pertinent to the analysis of riding comfort in trains, automobiles, and airplanes, as well as aerospace medical and other medical sources. The results of the survey are presented in figures and tables. A summary of recommended values of the pertinent variables is also provided. (Author)
PB-168 171

**AN INVESTIGATION OF THE RIDE QUALITY OF AUTO-TRAIN SERVICE,**
Office of High-Speed Ground Transportation, Washington, D.C.
Kenneth B. Ullman. Nov 67, 51p

The ride quality in automobiles carried aboard enclosed, airsprung railcars traveling over conventional rail roadbeds was determined. Evaluation of the data indicates that railcars transporting automobiles with their passengers could be built with minimal securement systems and could provide a ride of good quality. Two test automobiles were inserted inside an air-sprung railcar, equipped with instrumented dummies, and transported a total of 2200 rail miles during which ride vibrations and passenger reactions were recorded. The testing included alterations to the automobiles' suspension systems and different types of trackwork. Ride quality was also determined on highways using the same instrumentation. The data was analyzed by a combination of manual and automated methods. Acceleration distribution functions and frequency spectra were generated with a digital computer. (Author)
PB-176 044

**HIGH SPEED GROUND TRANSPORTATION: NOISE SOURCES,**
Bolt Beranek and Newman, Inc., Cambridge, Mass.
C. W. Dietrich, Erich K. Bender, R. D. Bruce, H. H. Heller, and P. Ranganath Nayak. 6 Oct 68, 52p
BBN-1741

Analyzing the noise problem in high-speed ground transportation passenger spaces, this report identifies: (a) sources, (b) paths, and (c) receivers. It examines ways of establishing noise-level criteria for HSGT vehicles.
PB-182 752

**THE NEEDS AND DESIRES OF TRAVELERS IN THE NORTHEAST CORRIDOR. A SURVEY OF THE DYNAMICS OF MODE CHOICE DECISIONS.**
National Analysts, Inc., Philadelphia, Pa.
Feb 70, 306p*
Contract DOT-FR-9-0048

Most mode choices are the results of routines, not actual decisions. When decisions are made, they usually involve choices between only two modes, or three at most. From the individual traveler's point of view, the mode to use appears to be given by the nature of the trip, since he seldom subjects his needs and desires to conscious examination. For all three reasons, conceptualizing a simple four-way decision process, with the pluses and minuses of using each of the four modes weighed against one another simultaneously, is inaccurate. Mode selections are usually better conceptualized as routines that form around different kinds of trips, codifying the traveler's value considerations and mode evaluations. As a result of a series of carefully structured interviews of travelers, this report analyzes the process of mode selection. It finds that current rail service has a distinctly unpleasant image to most users and non-users, and that feelings about poor train service are bitter.
PB-191 027

## 10. RAIL TECHNOLOGY: DATA ACQUISITION AND ANALYSIS

**RAILROAD RESEARCH FIELD TESTING PROGRAM.**
Progress rept. no. 1,
Melpar, Inc., Falls Church, Va.
F. J. Hurley, J. N. Goeser, B. R. Koch, and P. J. McConnell. Dec 68, 215p
Contract C-111-66

The primary purpose of this project is to assist in defining the operational characteristics and constraints of conventional rail systems at speeds of the order of 150 miles per hour. Four electric, multiple-unit commuter-type cars, modified to facilitate instrumentation and to achieve full-power balancing speed in excess of 150 miles per hour, were built and heavily instrumented. High-speed tests are being conducted on an improved 21 mile section of the Penn-Central Railroad between Trenton and New Brunswick, New Jersey, and track geometry measurements reflecting track conditions are being made between Washington, D. C., and Boston. Of particular interest are the evaluation of ride quality, truck and suspension performance and vibration, track geometry measurements, pantograph performance, catenary profile and dynamic response, track-roadbed characteristics, and interaction between trains. An initial part of the original contract was the formulation of a general purpose mathematical model of car motion suitable for evaluating the performance of new or proposed vehicles or vehicle components in response to rail excitation at high speeds. The parameters and characteristics of the research cars and statistics of track geometry are being used to validate the mathematical model with actual measurements. This dynamic railcar simulation program will be the subject of a separate comprehensive report. The purpose of this report is to present in summary form the progress achieved thus far on this program.
PB-182 470

**FEASIBILITY STUDY FOR A WHEEL-RAIL DYNAMICS RESEARCH FACILITY,**
General American Transportation Corp., Niles, Ill. General American Research Div.
V. Milenkovic, and J. J. Poczatck. Dec 68, 180p
Contract DT-7-35363

The principal objective of the program is to determine the most suitable form of laboratory apparatus required to significantly advance the current knowledge of wheel-rail dynamics, and to establish the safe upper-limit speed for those wheel-rail combinations which hold promise of achieving speeds up to 300 mph. What is sought here is a versatile piece of equipment or equipments capable of accommodating as many of the rail vehicles, suspension systems, mating tracks and/or models or components thereof, as might reasonably be of interest, and being able to evaluate their merits or deficiencies either in component fashion, in scale-model fashion, or in full-scale systems fashion. Such equipment must be both technically feasible and practical, and economically justifiable. (Author)
PB-182 472

**SUPPLEMENTARY REPORT TO FEASIBILITY STUDY FOR A WHEEL-RAIL DYNAMICS RESEARCH FACILITY.**
General American Transportation Corp., Niles, Ill. General American Research Div.
Oct 69, 146p
Contract DT-7-35363
Supplement to report dated Dec 68, PB-182 472.

This supplement to PB 182 472 deals with: (1) the trade-off considerations in extending the simulation capability of the wheel-on-roller design to lower speeds and sharper curves, and to more precise simulation of general system behavior; (2) the methods of implementation of the various simulation schemes and/or the method of compensation and constraint in lieu of such simulation; (3) the relative merit of electromechanical drive versus hydraulic drive systems, and some considerations in tractive and braking performance associated with the electromechanical dirve-system selected; and (4) stress and deflection considerations of the diaphragm-coupler and the roller systems, their compliances, and how they relate to total system compliance and system performance.
PB-189 096

**LIGHT-MODULATED ACCELEROMETER FOR PANTOGRAPH MEASUREMENTS.**
Final rept. Aug 69-Mar 70,
General Applied Science Labs., Inc., Westbury, N.Y.
Hector Medecki, and Daniel E. Magnus. Mar 70, 31p GASL-TR-739, FRA-RT-70-41
Contract DOT-FR-9-00010

An instrument was developed to measure the accelerations of a pantograph shoe for power collection on railway vehicles. The basic problems of high operating voltages and severe electromagnetic interference are solved using optical methods. The intensity of a light source is modulated in proportion to the acceleration of the shoe. These signals are transmitted through fiber optics. The accelerometer was tested in field service on the DOT test cars. (Author)
PB-193 452

**TEST CAR PROGRAM.**
Progress rept. no. 2,
Melpar, Inc., Falls Church, Va.
F. J. Hurley, J. N. Goeser, B. R. Koch, and P. J. McConnell. Sep 70, 179p FRA-RT-71-48
Contract C-111-66
See also Progress rept. no. 1, PB-182 470.

During the period covered by the report, much of the developmental effort was devoted to improving and refining the existing systems. Developments such as a new signal conditioner for the gage sensors, a magnetic pulser for improved speed and distance measurement, and new sensor configurations were aimed at increasing the accuracy and reliability of track measurements. Improvements in overall system performance resulted from the development of special-purpose calibration devices, modifications to existing electronic circuitry, a more extensive use of selective filtering, and use of accelerometers which withstood the hostile environment. Data processing techniques and displays were also modified to make better use of the data being collected and to present it in a convenient form for operating personnel. (Author)
PB-195 400

**AUTOMATED TRACK INSPECTION INFORMATION AND ITS USE,**
Federal Railroad Administration, Washington, D.C.
Thomas P. Woll. 29 Sep 70, 39p FRA-RT-72-02
Presented at the Roadmasters and Maintenance of Way Convention, Chicago, Illinois. 29 September 1970.

The paper describes the type of track inspection information provided by the Department of Transportation test cars (railroad) and the way it is to be used. The D.O.T. track inspection car program and a computer program from which gage data is produced are discussed. The basic principle discussed apply to all track parameters. The concepts for data processing described and the resulting preferred formats for the presentation of track geometry data resulted from discussions with knowledgable people within the railroad industry. In particular track maintenance personnel were consulted regarding their preferred form for data presentation from the viewpoint of track maintenance. (Author)
PB-201 621

**A TECHNIQUE FOR EVALUATING TRACK CONDITION USING RAILCAR VIBRATIONS,**
National Aeronautics and Space Administration, Langley Station, Va. Langley Research Center.
Sherman A. Clevenson, and Kenneth B. Ullman.
Apr 71, 7p FRA-RT-72-05
Presented at the AIAA/ASME Structures, Structural Dynamics, and Materials Conference (12th), Anaheim, California. 19-21 April 1971.

A technique for evaluating rail track roughness and irregularities using vibration measurements in the railcar is discussed. The technique has been applied to a demonstration train route now operated under DOT contract and has been used in establishing priority for track maintenance. Specific attention is placed on the portable, low-frequency, low-amplitude, acceleration measuring/recording system. The data reduction and computer programs are described. Sample vibration measurements are given and the rating system is described. The project was a joint DOT-NASA effort. (Author)
PB-201 623

## 11. RAIL TECHNOLOGY: GRADE CROSSING

**TECHNOLOGICAL INNOVATION IN GRADE CROSSING PROTECTIVE SYSTEMS.**
Technical rept.,
Department of Transportation, Cambridge, Mass. Transportation Systems Center.
John B. Hopkins, and Morrin E. Hazel. Jun 71, 89p* DOT-TSC-FRA-71-3

The constraints on innovative grade crossing protective systems are delineated and guidelines for development indicated. Inventory data has been arranged to permit an estimate of the classes of systems needed, the allowable costs, and contribution of various types of crossings to accidents. A number of approaches are discussed for the intermediate cost classes, based on use of conventional signals with low-cost activation systems. Use of similar elements, singly or in combination, is suggested to improve effectiveness of more expensive systems. The very high cost locations may well benefit from interconnection of train and vehicle detectors and small computers. Extensive analysis and laboratory investigation has been carried out relating to a microwave telemetry alternative to conventional track circuits and possible crossing-located radar and impedance train detection systems. (Author)
PB-201 624

**THE VISIBILITY AND AUDIBILITY OF TRAINS APPROACHING RAIL - HIGHWAY GRADE CROSSINGS.**
Final rept.,
Systems Consultants, Inc., New York.
John P. Aurelius, and Norman Korobow. May 71, 163p* FRA-RP-71-2
Contract DOT-FR-00006
See also Addendum Rept. dated Jul 71, PB-202 669.

The study investigates devices and color schemes, proposed or in use on locomotives, which serve to make the train visible or audible to motorists approaching grade crossings. A color scheme using two contrasting colors, each color at least 3 1/2 x 5 feet in area, is recommended for visibility at 1000 feet. One color should be very bright, such as fluorescent or bright yellow. Two high-output xenon strobe lamps are recommended, one on each side of the cab roof, to flash alternately whenever the train is moving. At night, lighted panels are recommended as supplements to the strobe lamps. The sound level required to reliably alert a motorist was found to be 105 dB just outside the vehicle. In high speed encounters, present horns cannot reliably warn motorists early enough. A horn with enough output to be totally effective would not be an unacceptable nuisance. The report includes a bibliography and tables of required ranges. (Author)
PB-202 668

**THE SOUND ENVIRONMENT IN LOCOMOTIVE CABS,**
Systems Consultants, Inc., New York.
John P. Aurelius. Jul 71, 33p* FRA-RP-71-2A
Contract DOT-FR-00006
Addendum to Rept. No. 2, dated May 71, PB-202 668.

Measurements of the sound environment in locomotive cabs including audible warnings perceived by crew members are described. Data was collected during two different test runs under diverse conditions, one on the Long Island R.R. and the other on the St. Louis-San Francisco Railway. The crew's working environment was found to approach the exposure limits set in the Walsh-Healey Public Contract Service Act. Tape recordings from each run indicate the following elements as significant: engine noise, horn sounds and air brake application noise. Data indicate sound level readings taken under various operating conditions in the cab. The study does not include a definition of legal exposure in the cabs, but the noise survey forms presented are useful to compute approximate exposure from observed data. The study suggests that because measurements of noise level in a typical locomotive cab approach the limits allowed in the Walsh-Healey Act, a more detailed survey would be desirable to determine whether exposures do exceed legal limits, and if so under what conditions. Forms of frequency analysis used in the study are also explained. (Author)
PB-202 669

## 12. RAIL TECHNOLOGY: BIBLIOGRAPHIES

**BIBLIOGRAPHY OF HIGH SPEED GROUND TRANSPORT. PART IA.**
Massachusetts Inst. of Tech., Cambridge.
15 Oct 65, 86p
Contract C-85-65
See also PB-168 648, -169 121.
PB-170 581

**SYSTEM INSTRUMENTATION MANUAL. DOT TEST TRAIN PROGRAM.**
Annual rept. Jun-Dec 70,
ENSCO, Inc., Springfield, Va.
Charles L. Gerhardt, and Joe T. May. Jan 71, 176p
DOT-FR-71-1

The report describes current instrumentation installed aboard the Department of Transportation Test Train. The instrumentation is designed to gather research data on various rail research projects. The major discussion in this report covers the Track Geometry System aboard the test train, and the operation and calibration of this system. (Author)
PB-203 110

## 13. RAIL TECHNOLOGY: PROGRAM PLANNING AND ANALYSIS

**RESEARCH AND DEVELOPMENT FOR HIGH SPEED GROUND TRANSPORTATION.**
Department of Commerce, Washington, D.C. Panel on High Speed Ground Transportation.
Mar 67, 40p
Rept. of Panel on High Speed Ground Transportation.

Contents: Research recommendations for prepototype studies; Roster of Panel and Subpanels; Presentations to the Panel and Subpanels; Report of the Subpanel on Guideways, Suspensions and Aerodynamics; Report of the Subpanel on Propulsion, Energy and Braking; Report of the Subpanel on Communication and Control; Report of the Subpanel on Terminals and Interfaces; Report of the Subpanel on Passenger and Freight Factors; Current HSGT R and D Contract, Office of High Speed Ground Transportation.
PB-173 911

**THE HIGH SPEED GROUND TRANSPORTATION ACT OF 1965. 2ND REPORT.**
Department of Transportation, Washington, D.C.
Sep 67, 55p

The report complies with Section 10 (a) of the High Speed Ground Transportation Act of 1965 as amended by the Department of Transportation Act of October 15, 1966, requiring the Secretary of Transportation to report to the President and the Congress, not less often than annually, with respect to activities carried out under the Act. The first report covered the fiscal year ending June 1966 and was submitted in September 1966. The three basic activities authorized by the Act are: Research and development in high speed ground transportation; Demonstration projects to determine the contributions that high speed ground transportation could make to more efficient and economical intercity transportation systems; A national program to improve the scope and availability of transportation statistics. (Author)
PB-176 115

**THE HIGH SPEED GROUND TRANSPORTATION ACT OF 1965. 3RD REPORT.**
Department of Transportation, Washington, D.C.
Jul 69, 132p*
See also Rept. no. 2, PB-176 115.

The Northeast Corridor simulation model was assembled and exercised; a comprehensive inventory of technology options was prepared; two rail passenger service demonstrations are beginning and the first system for broad, regional transportation analysis was established. A national capability in R and D and transportation analysis was established in universities and in private industry across the country. The impact of the HSGT program is depicted. (Author)
PB-185 702

**A RECOMMENDED RAIL SAFETY RESEARCH PLAN FOR FISCAL YEARS 1971-1975.**
Melpar, Inc., Falls Church, Va.
Oct 69, 115p* FRA-RP-70-1
Contract DOT-FR-9-0047

The document is concerned with the initial picture of railroad safety, configured research projects which address specific needs as expressed by industry, labor and government, an estimation of the resources (in time and dollars) required to accomplish each project, and 3 alternative 5-year safety research program plans for the fiscal years 1971-1975. (Author)
PB-188 967

**A PROGRAM DEFINITION STUDY FOR RAIL-HIGHWAY GRADE CROSSING IMPROVEMENT.**
Final rept.,
Voorhees (Alan M.) and Associates, Inc., McLean, Va.
David W. Schoppert. Oct 69, 171p AMV-R-71-1028 FRA-RP-70-2
Contract DOT-FR-9-0028

The report describes in general terms the present status of grade crossing inventories, improvement programs and other significant considerations. It identifies available information with respect to the cost of accidents and motor vehicle operations, as well as the preparation of estimates of the number of crossings in classes related to the volume of train movements and the volume of vehicle traffic. From these estimates, the number of crossings at which improvements would yield benefits in excess of costs was estimated, together with the reduction in accidents which those improvements could be expected to bring. It develops a five-year program of study related to policy formulation, program administration and research; also, it identifies and describes projects which can be initiated as action programs, research and special studies. This includes a recommended program to correct data deficiencies and develop a comprehensive information system. (Author)
PB-190 401

**THE HIGH SPEED GROUND TRANSPORTATION ACT OF 1965. 4TH REPORT.**
Rept. no. 4.
Department of Transportation, Washington, D.C.
1970, 159p*
See also Rept. no. 3, PB-185 702.

Coupled with the Northeast Corridor Transportation Project, the high speed program was sought to: determine transportation demand in a most heavily populated and industrialized intercity corridor region; analyze engineering systems alternatives for meeting that demand; demonstrate traveller response to selected transportation improvements; and undertake research and development in fields of entirely new systems as well as stimulating that in existing systems. (Author)
PB-196 799

## 14. RAIL TECHNOLOGY: PASSENGER DEMONSTRATIONS

**TRAIN AUTO FERRY OPERATIONS.--A SUMMARY OF PRESENT AND PROPOSED CONCEPTS AND RECOMMENDATIONS FOR A DEMONSTRATION PROJECT.**
Final rept.,
Whitten (Herbert O.) and Associates, Washington, D.C.
Herbert O. Whitten. Apr 66, 158p
Availability: Original document in color until exhausted.

The idea of moving passengers and their automobiles by train from a point of origin to a common destination is examined. This report discusses past and present attempts to put this idea into practice; analyzes potential costs and prices for such service if operated in this country; and makes recommendations for a proposed demonstration project of such service.
PB-170 798

**INVESTIGATION OF CAR FERRY SERVICE FOR HIGH SPEED GROUND TRANSPORTATION.**
Association of American Railroads, Chicago, Ill. Research Center.
Jul 66, 72p
Contract C-240-66- (N)

The report presents the results of an over-the-road investigation for determining the ride characteristics of automobiles and passengers on railroad cars incorporating three different truck suspension systems. The three rail cars used for this investigation are as follows: a tri-level auto rack car loaded with four automobiles on a freight type suspension, an end-door baggage car loaded with two automobiles on a six-wheel semi-soft suspension and a passenger coach on a four-wheel soft suspension system. One test auto on each car was instrumented and carried an instrumented simulated passenger in the drivers seat, also, a simulated passenger was placed in the coach. Test results show the tri-level rack car experienced the highest loadings and that the acceleration frequency range (0.85 to 5.00 cps) falls in the same bandwidth of 0.55 to 5.00 cps in all measured planes for the other two cars. In general, acceleration frequency appears to increase slightly with train speed, but did not exceed 5.00 cps. To design a car for its intended purpose, the truck suspension system, car body structural characteristics, and height of center of gravity of the loaded car, appear to be the areas for main consideration.
PB-173 513

**RAIL SHUTTLE SERVICE BETWEEN WASHINGTON, D. C. AND BALTIMORE, MARYLAND VIA FRIENDSHIP INTERNATIONAL AIRPORT. AN ECONOMIC FEASIBILITY STUDY FOR 1972,**
Economic Sciences Corp., Inc., Washington, D.C.
Samuel Ewer Eastman. 31 Mar 69, 55p ES1-0169
Contract DOT-3-0166

This is an economic feasibility study of a rail shuttle service between Penn Central Railroad (PCRR) Terminals in Washington and Baltimore making a single intermediate stop at Friendship International Airport (FIA). The time period of the study is 1972. Three rail transportation systems are considered. Budd Company RDC-2. United Aircraft Corporation Turbo Train, and a rail-bus car. All three transportation producing systems are found to be economically feasible if costs are lower than the 'high' estimate; for the systems to be feasible costs need not be as low as the 'low' estimate. Feasibility depends on load factor and headway (time between service). The rail-bus service is feasible at headways of 15 minutes, 30 minutes and 60 minutes; the RDC-2 at headways of 30 minutes and 60 minutes; and the Turbo Train at headways of 60 minutes. (Author)
PB-184 265

## 25. ADVANCED SYSTEMS: TRACKED AIR CUSHION VEHICLE

**SUPPLEMENT TO SURVEY OF TECHNOLOGY IN FLUID SUSPENSIONS: PATENT SEARCH AND EFFECTS OF FORWARD SPEED,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
H. H. Richardson, and W. A. Ribich. 1 Nov 66, 68p
DSR-76110-1
Contract C-85-65
See also PB-168 648.

Supplementary information to that given in Part I, Survey of Technology for High Speed Ground Transport, Ref. 1, is presented for fluid suspensions and fluid-supported vehicle systems. Representative patent literature is described which shows that the existing basic concepts and configurations for fluid suspensions and associated vehicles are very old; however, many recent patents have been issued covering variations, improvements and applications to transport vehicles. Published information and experimental facilities and techniques relative to the influence of forward speeds on fluid suspension data are reviewed. Available data are limited to forward speeds less than 150 mph, to ambient pressures of one atmosphere and to low cushion-pressure levels. An adequate theoretical approach to forward speed effects is lacking. No experimental facilities entirely satisfactory for the investigation of the behavior of dynamically similar scale models of HSGT vehicles and guideways were found to exist in the world. (Author)
PB-173 653

**A TWO-DIMENSIONAL FLUID-SUSPENSION TEST APPARATUS FOR INVESTIGATION OF PRESSURE RATIO, MACH NUMBER AND REYNOLDS NUMBER EFFECTS,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
H. H. Richardson, and W. A. Ribich. 1 Nov 66, 53p
DSR-76110-2
Contract C-85-65

The design, instrumentation and evaluation of a small scale two-dimensional test apparatus for investigating the equilibrium and nonequilibrium pressure-displacement-flow characteristics of fluid suspension sealing regions are described. The apparatus is versatile and adaptable to a wide variety of suspension configurations. Dynamic similarity to large scale devices is maintained by varying the ambient pressure level. Ambient pressures from 0.1 psia to 150 psia can be employed in the present apparatus. The system is transparent and permits flow visualization through injection of smoke into the supply flow. Data reduction is automated via direct input of raw data into an IBM 7094 digital computer. Test results are presented for equilibrium and nonequilibrium conditions for tests run at one atmosphere ambient pressure for a peripheral jet suspension. Nonequilibrium cushion flow versus cushion pressure ratio did not show the discontinuity of slope near equilibrium predicted by all inviscid theories. The slopes of the pressure-flow curves were found to be predicted reasonably well by the inviscid underfed jet theory but predictions of actual magnitudes were in error by large factors. (Author)
PB-173 654

**DYNAMICS OF SIMPLE AIR-SUPPORTED VEHICLES OPERATING OVER IRREGULAR GUIDEWAYS,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
H. H. Richardson, K. M. Captain, and W. A. Ribich. Jun 67, 55p DSR-76110-4
Contract C-85-65

The simplest appropriate dynamic model for fluid suspensions, a dynamic spring with lead and lag, is used to study the vertical displacement and acceleration of a vehicle moving over a guideway containing deterministic and random irregularities. The analysis is limited to heave motion and to irregularity wavelengths long relative to the suspension length. For any value of lead time constant an optimum lag time constant is shown to exist which minimizes vehicle acceleration and which may be achieved by adjusting the dead volumes in the fluid suspension. The general results are applied to a simple rigid-walled plenum. Relations for acceleration, relative displacement, mass flow and pumping power are presented as functions of cushion geometry, loading, and hover height. The dynamic lead is shown to depend primarily on the vehicle weight and area and to be a primary factor determining maximum acceleration. For typical vehicle weights and sizes it is shown that optimum dynamic lead cannot be physically realized in a simple plenum suspension. Further the results obtained in this simple analysis suggest that it will be very difficult to achieve adequate passenger comfort at HSGT speeds over realistic guideways through use of only primary rigid simple plenum suspensions. (Author)
PB-173 655

**STATIC AND DYNAMIC BEHAVIOR OF A FLEXIBLE BASE FLUID SUSPENSION.**
Master's thesis,
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Barry L. Casey. 1 Nov 66, 111p DSR-76110-5
Contract C-85-65

The object of the thesis is to uncover a set of analytical expressions which will adequately permit the design of a flexible base air bearing and to verify these expressions experimentally. Simplifying assumptions include adiabatic flow through the inlet orifices and in the plenum beneath the diaphragm. Bending and shear stresses in the diaphragm are assumed to be negligible compared to tensile stresses. In the steady-state analysis, an equation is developed which predicts the platform height as a function of plenum pressure and also yields the bearing float limit condition. By averaging and linearizing, a limited amount of dynamic theory is developed which yields the bearing stability limit and completes the analysis. Experimental correlation of the theory is presented as well as a Fortran computer program which performs the necessary computations. (Author)
PB-173 656

**DYNAMIC ANALYSIS OF HEAVE MOTION FOR A TRANSPORT VEHICLE FLUID SUSPENSION,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
W. A. Ribich, and H. H. Richardson. 15 Jan 57, 90p DSR-76110-3
Contract C-85-65

A general lumped-parameter technique for the dynamic analysis of vehicle fluid suspensions operating in the heave mode (translational motion along an axis normal to the mean surface of the vehicle guideway) is presented. The analysis includes the effects of sealing region characteristics, of the fluid source, of the internal geometry, and of base flexibility. A linearization of the general system equations is given which is useful in the study of vehicle-suspension stability and dynamic behavior when the variations in support force are small compared with the average force. The analytical technique described is applied to formulate simple dynamic models for plenum, peripheral-jet, and flexible-base fluid suspensions. The parameters appearing in the dynamic equations can all be determined from computations or measurements of only the static characteristics of the suspensions. Analytical and graphical methods of finding these static parameters are discussed. (Author)
PB-173 685

**AN ANALYSIS OF THE EFFECTS OF FINITE FLUID-SUSPENSION PAD LENGTH ON THE DYNAMICS OF A VEHICLE ON AN IRREGULAR GUIDEWAY,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
W. A. Ribich, K. M. Captain, and H. H. Richardson. Sep 67, 46p
Contract C-85-65

An analysis is presented which describes the heave motion of a fluid-suspended vehicle moving over a guideway in which the irregularity wavelengths may be shorter than the suspension pad length. The analytical model is applied and exact solutions obtained for the cases of plenum and peripheral jet suspensions traversing sinusoidal and pure step irregularities. The technique is shown to be applicable to general irregularity profiles and numerical procedures for the general case are briefly discussed. It is found that compared to predictions based on zero suspension pad length (uniform guideway-suspension clearance) peak acceleration and relative displacements are generally reduced by the effects of finite pad length. Thus a conservative estimate of performance will usually be obtained if pad length effects are ignored. For most vehicle configurations and speeds, however, the attenuation due to finite pad length will be insignificant near the point of maximum vehicle response (near the natural frequency). Vehicle step responses are smoothed and a slight time delay appears compared with behavior predicted from the zero pad length theory. This work suggests that design criteria based on deterministic irregularities and peak dynamic response of the vehicle system can reasonably neglect the effects of finite suspension pad length. Further work is needed to evaluate these effects for statistically described irregularities. (Author)
PB-176 135

**PRESSURE-FLOW-DISPLACEMENT CHARACTERISTICS OF A PERIPHERAL JET FLUID SUSPENSION,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
H. H. Richardson, W. A. Ribich, and Y. Ercan. 1 Jun 68, 68p*
Contract C-85-65

An experimental investigation of the pressure-flow-displacement characteristics of a peripheral jet fluid suspension is summarized. The effects of nozzle pressure ratio, Reynolds number, base recess and jet nozzle size on equilibrium and nonequilibrium characteristics are presented for a 30 deg. nozzle angle. It is shown experimentally that the effects of geometric scaling can be studied adequately by varying ambient pressure level. Inviscid performance theories were found to overestimate equilibrium cushion pressures from 40% at low jet thicknesses, low Reynolds numbers and high hover heights to less than 5% at opposite conditions. Mass flow rates and power requirements were found to be within 15% of the inviscid Barratt theory for the larger jet widths tested. Theories for non-equilibrium jet behavior were found to be inadequate for predicting pressure-flow and displacement-flow sensitivities needed in dynamic models of peripheral jet devices. Predicted discontinuities in these parameters were not observed experimentally. Experimental values of pressure-flow-displacement sensitivities derived from non-equilibrium performance data are presented. These results suggest that for comparable conditions the peripheral jet suspensions will experience higher maximum heave accelerations than corresponding plenum configurations. (Author)
PB-176 136

**STUDY OF THE POTENTIAL OF HOVAIR FOR HIGH-SPEED GROUND TRANSPORTATION.**
Final rept.,
General Motors Research Labs., Warren, Mich.
Frederick Jindra. Mar 68, 131p
Contract C-197-66

The object of the program was to study the potential of the air bearing as a support system for high-speed ground vehicles. The tasks required included analytical investigations of performance characteristics of air bearings, analytical investigations of ride characteristics of vehicles with such support, development of dimensional analysis for experiments, and outlining future research and development requirements. (Author)
PB-177 523

**SIMPLIFIED STATIC PERFORMANCE CHARACTERISTICS OF LOW-PRESSURE PLENUM AND PERIPHERAL JET FLUID SUSPENSIONS,**
Massachusettes Inst. of Tech., Cambridge. Engineering Projects Lab.
H. H. Richardson, and K. M. Captain. Jan 68, 55p
Contract C-85-65

Simplified relationships and approximate design curves and nomograms are presented which permit the power, mass flow and stiffness of simple plenum and peripheral jet fluid suspensions to be estimated. Both gravity-loaded and transverse suspensions are considered. The incremental load capacity divided by the design load (force increment) is shown to be a major design parameter for fluid suspensions. Compared with simple orifice-restricted plenums, peripheral jet suspensions are shown to require less power and mass flow and to possess lower stiffness for comparable operating conditions. The advantage in power and flow increases as the force increment increases. A comparison is made between the inviscid peripheral jet performance theory used and experimental data which indicates that the theory gives useful estimates of performance which become more accurate as flow Reynolds number increases. (Author)
PB-177 668

**THE AEROTRAIN SYSTEM: AIR CUSHION GUIDED GROUND TRANSPORTATION: DESCRIPTION AND PERFORMANCE OF THE EXPERIMENTAL VEHICLE.**
Final rept.,
Aeroglide Systems, Inc., New York.
Francois L. Giraud. 1968, 204p*
Contract DT-7-35337

The report presents selected results of testing the experimental Aerotrain vehicle on the Gometz-laVille to Limours test track, including technical data on the vehicle and guideway, generalized performance and economic models, and technical specifications for a specific site for application of a full-scale Aerotrain system as an airport link. (Author)
PB-178 961

**MOVING GROUND-PLANE WIND-TUNNEL TESTS ON SEVERAL TRACKED AIR CUSHION VEHICLE (TACV) MODELS.**
Interim rept.
TRW Systems Group, Washington, D.C. Washington Operations.
1 Sep 68, 101p 06818-6029-R0-00
Contract C-353-66

An experimental wind-tunnel test program conducted jointly by TRW and NASA-Langley has provided supporting air cushion and body aerodynamic data for ongoing analytical and design studies at TRW and elsewhere. Selected results for two of the TACV models tested are presented in this report. Tests were conducted on a 30-inch-diameter circular air-cushion model and on an elongated model approximately 11 inches wide and 67 inches long. Each model's air-cushion base area was 5 square feet. The models' air-cushions were capable of operating in a peripheral-jet or hybrid-plenum mode. Circular model test results for both the forward-speed and hover state and the peripheral-jet and hybrid-plenum modes are reported. Results for the hover state and peripheral-jet mode are reported only for the elongated mode.
PB-179 893

**TRACKED AIR CUSHION VEHICLE DEVELOPMENT.**
Status rept.,
Mitre Corp., McLean, Va.
Warren L. McCabe, Carl G. Swanson, and Kenneth K. Tang. Oct 68, 16p
Prepared in cooperation with TRW Systems Group, Washington, D.C. Presented at Transport Engineering Conference, Washington, D.C. 28-30 Oct 68.

Program results to date, current activities and plans for future work are discussed. System engineering studies performed so far have identified and examined the major alternatives available for a TACV system, and significant R and D requirements. Factors which will strongly affect the design and cost of an operational TACV system include the vehicle-guideway configuration, the effects of cross winds, the relationship between cushion pressure and the free stream dynamic pressure, and the type of propulsion subsystem used. Research activities to advance the state of the art of TACV systems are briefly described. These include the NASA/TRW wind tunnel tests, the suspension and dynamics studies at MIT and NASA, and the experimental French Aerotrain tests. The objective, approach and requirements of the recently contracted design studies for a Tracked Air Cushion Research Vehicle are presented. (Author)
PB-182 290

**TRACKED AIR CUSHION RESEARCH VEHICLE. VOLUME I. RESEARCH VEHICLE PRELIMINARY DESIGN.**
Final rept.
Grumman Aircraft Engineering Corp., Bethpage, N.Y.
Mar 69, 230p FSR-ST-4
Contract DOT-FR-9-0003
See also Volume 2, Pt 1, PB-183 173.

The report contains a preliminary design and development plan for a research tool to validate tracked air cushion vehicle technology.
PB-183 172

**TRACKED AIR CUSHION RESEARCH VEHICLE. VOLUME II. RESEARCH VEHICLE DEVELOPMENT PLAN. PART I-TECHNICAL PLANS.**
Final rept.
Grumman Aircraft Engineering Corp., Bethpage, N.Y.
Mar 69, 31p FSR-ST-5A
Contract DOT-FR-9-0003
See also Volume 3, PB-183 174.

Three major subsystem development tasks are required: (a) Design, build, and test a cushion air control valve; (b) Develop friction and wear data for friction brake facing and skid materials at high speeds; (c) Develop a suitable flexible peripheral jet material. Manufacturing facilities required are 8000 sq ft of shop area with access to detail parts manufacturing, processing, and inspection areas. The GFE required includes a JT8D-9 turbofan, a PLF1A-2 turbofan, the LIM, its turbo-alternator package and power pickups and/or power conditioning equipment. A minimum qualification program has been generated which uses qualified hardware and/or conservative design, reducing the need for testing. Qualification testing is therefore categorized as functional, performance verification, and/or calibration.
PB-183 173

**TRACKED AIR CUSHION RESEARCH VEHICLE. VOLUME III. RESEARCH VEHICLE RESEARCH PLAN.**
Final rept.
Grumman Aircraft Engineering Corp., Bethpage, N.Y.
Mar 69, 106p FSR-ST-6
Contract DOT-FR-9-0003
See also Volume 1, PB-183 172.

The TACRV program will provide test data on ride comfort, performance, efficiency, and level of noise in operation, for use in the final design of a public demonstration system. The TACRV will be used to obtain test operation data, under actual forward speed conditions, in the areas of air cushion performance, suspension system dynamics, vehicle stability and control dynamics, vehicle/guideway dynamic interactions, linear induction motor (LIM)/vehicle performance and internal cabin and far field acoustics. (Author)
PB-183 174

**TRACKED AIR CUSHION RESEARCH VEHICLE DEVELOPMENT PLAN STUDY REPORT.**
General Electric Co., Philadelphia, Pa. Transportation Systems Div.
17 Mar 69, 72p 69AT-1003
Contract DOT-FR-9-0004
See also PB-183 178, PB-183 179 and PB-183 180.

The objectives of this R/V Development Plan are to indicate the schedules for, and to describe the efforts necessary to accomplish the refinement of the vehicle design details, development of subsystems, fabrication and assembly of the research vehicle, and the performance of suitable component and vehicle qualification and performance tests. Its further objective is to include schedule estimates for the production of all ground support equipment, checkout systems, and spares necessary to implement the proposed research use of the vehicle. (Author)
PB-183 177

**TRACKED AIR CUSHION RESEARCH VEHICLE RESEARCH PROGRAM STUDY REPORT.**
General Electric Co., Philadelphia, Pa. Transportation Systems Div.
17 Mar 69, 83p 69AT-1004
Contract DOT-FR-9-0004
See also PB-183 177, PB-183 179 and PB-183 180.

The system test program discussed in this report is to provide engineering data, verified analytical tools, and design guidelines for an attractive, high-performance public demonstration TACV and guideway system. The report examines the general qualities required of a commercial TACV system; the translation of these qualities into technology requirements; and the assessment of the state-of-the-art in regard to these requirements. In each deficient area, several alternative ways of advancing the state-of-the-art are examined. This basic work culminates in a clearer definition of the specific role of the TACRV. This role is then translated into specific experiment areas and instrumentation requirements.
PB-183 178

**TRACKED AIR CUSHION RESEARCH VEHICLE PRELIMINARY DESIGN STUDY REPORT.**
General Electric Co., Philadelphia, Pa. Transportation Systems Div.
17 Mar 69, 204p 69AT-1002
Contract DOT-FR-9-0004
See also PB-183 177, PB-183 178 and PB-183 180.

This report presents a preliminary design for a Tracked Air Cushion Research Vehicle (TACRV). The proposed design meets performance, design, and test requirements prescribed by the OHSGT. The research program test requirements emphasize air cushion and suspension research. Additional research program investigations include subsystem interactions, aerodynamics, propulsion, noise, and vehicle/guideway interactions, especially as they affect ride quality and operational guideway design requirements. The experimental program is to provide engineering data and verification of analyses that will be applicable to the design of public demonstration TACV systems. (Author)
PB-183 179

**TRACKED AIR CUSHION RESEARCH VEHICLE PRELIMINARY DESIGN STUDY REPORT: APPENDICES.**
General Electric Co., Philadelphia, Pa. Transportation Systems Div.
17 Mar 69, 473p 69AT-1007
Contract DOT-FR--9-0004
See also PB-183 177, PB-183 178 and PB-183 179.

These appendices deal with (a) requirements, (b) aerodynamics, (c) braking, (d) loads and structural design criteria, (e) structural analysis, (f) weight analysis, (g) personnel accommodations, (h) linear induction motor, (j) ground support equipment, (k) electrical system, (m) guideway requirements, (n) suspension dynamics, (p) special sensors and measurement techniques, (q) drawings and specifications, (r) noise, and (s) instrumentation and data handling system.
PB-183 180

**A PRELIMINARY DESIGN STUDY OF A TRACKED AIR CUSHION RESEARCH VEHICLE. VOLUME I: GENERAL REPORT.**
Final rept.,
Aeroglide Systems, Inc., New York.
Francois L. Giraud. Feb 69, 262p
Contract DT-7-35337
See also Volume 2, PB-183 320.

The first part of this study compares different configurations of high speed air cushion vehicles and guideways. Economical and functional comparisons of the guideway functional cross section favor the double 'L' and inverted 'T'. A comparison of 3 types of suspensions points to the suspended lip as the most suitable design to achieve the comfort requirement, since it allows a simple means of activation. A comparison of different means of propulsion focuses on aerodynamic propulsion with a by-pass ratio of 5 combined with a propulsive exhaust into the track gap. The second part of this study aims at describing a vehicle and track to perform a test program. A common vehicle frame equipped with a fan jet can accommodate the existing linear induction motor. Tests of the most interesting track form and structure, tests of all suspensions and trials of alternate means of aerodynamic propulsion with their noise attenuation systems can be performed.
PB-183 319

**A PRELIMINARY DESIGN STUDY OF A TRACKED AIR CUSHION RESEARCH VEHICLE. VOLUME II. GUIDEWAY STUDY REPORT.**
Aeroglide Systems, Inc., New York.
Dec 68, 112p
Contract DT-7-35337
Prepared in cooperation with Parsons, Brinckerhoff, Quade and Douglas, Inc., New York. See also Volume 1, PB-183 319.

This report describes the development of preliminary design tradeoff studies for a single vehicle aerial guideway to accommodate a vehicle traveling on air cushions at speeds up to 300 miles per hour. Three guideway structure types were studied: (1) the Inverted Tee, (2) the Double L (or Channel), and (3) the Box (or Inverted Channel). Each of these structural types was analyzed for the purpose of determining the most economical construction material, the optimum span length, the tolerance requirements, construction methods and maintenance procedures. (Author)
PB-183 320

**MOVING GROUND PLANE WIND TUNNEL TESTS ON SEVERAL TRACKED AIR CUSHION VEHICLE (TACV) MODELS.**
TRW Systems Group, Washington, D.C. Washington Operations.
1 Mar 69, 220p 06818-6032-RO-00
Contract C-353-66
Report on High Speed Ground Transportation Systems Engineering Study.

Test results are presented for four models. Briefly, the objectives of the program were: (a) Determination of whether a moving ground plane simulation is necessary for valid TACV wind tunnel test results. (b) Determination of the aerodynamic characteristics of air cushions. (c) Determination of the aerodynamic characteristics of TACV bodies. (Author)
PB-183 857

**HEAVE DYNAMICS OF FLEXIBLE-BASE FLUID SUSPENSIONS,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
K. M. Captain, and H. H. Richardson. 15 Jan 69, 111p
Contract DOT-C-85-65

The report presents the results of an analytical and experimental study of the heave dynamics of externally pressurized flexible base fluid suspensions operating over guideways containing either deterministic or random irregularities whose wave lengths are large compared to the suspension pad length. The effects of base flexibility and damping, but not of base mass, on the dynamic behavior of suspended vehicles are investigated and relationships are derived between the critical fluid and mechanical parameters which will maximize ride quality for a given vehicle and guideway characteristic. The suspension is modeled as a dynamic lead-lag spring and it is shown that for any value of lead time constant -- as determined by the vehicle weight and size -- there exists an optimum value for the lag time constant (or cushion volume) which minimizes the peak vertical vehicle acceleration. (Author)
PB-183 987

**INVESTIGATION OF SEAL MATERIALS AND CONFIGURATIONS FOR HIGH SPEED AIR CUSHION VEHICLES,**
Johns-Manville Research and Engineering Center, Manville, N.J.
H. John Reynolds, Jr. 1 Oct 69, 84p*
Contract DOT-3-0268

Air flow characteristics through openings provided by single and multiple metal or rubber skirts (labyrinths) situated above a bed surface were established for low pressure systems up to one psig. Single skirting of both types exhibits the standard theoretical discharge coefficient of 0.61 for sharp-edged skirting. Reduced coefficient values are obtained with multiple skirting with rapidly declining benefit over five skirts. For metal skirts, coefficients are asymptotically low at skirt spacing/opening ratios in excess of 60 for two skirts, 45 for three skirts, and 30 for five skirts. The test results indicate that rubber skirting in multiple configurations is more efficient than metal with respect to coefficient values and pressure retention between skirt spacings. This is contrary to what might be expected, and the reason for this difference is not understood at this time. Pressure retention between skirts in all multiple skirt configurations is at an asymptotically high value when skirt spacing/opening ratios are at least 60. The relative efficiency of air cushions using multiple skirt configurations is very dependent upon specific plenum shape factor, skirt spacing, and operational skirt opening. When properly designed, multiple skirt air cushions can be appreciably more efficient than single skirt cushions. (Author)
PB-186 414

**A VISCOUS-FLOW ANALYSIS FOR THE QUASI-STATIC PRESSURE-FLOW-DISPLACEMENT CHARACTERISTICS OF PERIPHERAL JET FLUID SUSPENSIONS,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Y. Ercan, and H. H. Richardson. 1 Feb 69, 111p
DSR-76110-10
Contract DOT-C-85-65

A viscous-flow analysis is presented which is capable of predicting the static and quasi-static behavior of peripheral jet fluid suspensions operating in the incompressible flow regime. The theory accounts for the observed discrepancies between experiment and inviscid flow analyses by including entrainment and turbulent mixing in the jet and wall boundary layer effects. Equilibrium cushion pressure is predicted within 3 to 4 percent compared with errors up to 40% which occur in even the most conservative inviscid theories. The analysis is used to develop solutions for the non-equilibrium pressure-flow-displacement characteristics required in dynamic analyis of heave motion. Comparison of theory and experiment indicates the slopes of these characteristics (the sensitivities) can be predicted within about 10 percent over the range of jet Reynolds numbers of interest for vehicle suspensions. Curves and digital computer programs are included which permit peripheral jet performance to be determined as a function of geometry, supply pressure and Reynolds number. (Author)
PB-188 358

**PRELIMINARY STUDY OF AN AUGMENTED RAM-WING VEHICLE CONCEPT.**
Final rept. 1 Aug 67-18 May 68,
IIT Research Inst., Chicago, Ill.
Imants Reba. Jan 70, 126p* IITRI-J6128-FR
Contract DOT-7-33512

The report describes a wind-tunnel study of a ram-wing-type vehicle with various blowing arrangements. Two models were studied. One model represented a thick vehicle configuration with a blunted rear end. The second had a streamlined chord section. Blowing arrangements consisted of two two-dimensional Coanda nozzles, one placed near the leading edge and one near the midchord. Upward, downward, and mixed blowing arrangements were investigated. The results indicate that the downward blowing near the leading edge and upward blowing at midspan constitute the most promising of those arrangements investigated. With this arrangement the vehicle has high lift capability at zero forward speed and low drag characteristics at all forward speeds. A range of blowing and pressure coefficients at which a considerable increase in lift-to-horsepower ratio takes place (as compared with a case without blowing) also exists. Similarly, blowing arrangements and blowing coefficients that detrimentally affect power economy also exist. In most cases, blowing permits increasing the wing loading efficiency (weight carried per unit area), independently of forward speed or ground clearance. (Author)
PB-189 425

**HIGH-SPEED JETPORT ACCESS.**
Final rept.
TRW Systems Group, Redondo Beach, Calif.
Dec 69, 580p* 06818-6044-RO00 FRA-RT-70-38
Contract DOT-C-353-66
Feasibility Study of a Demonstration Project in Southern Florida.

The feasibility of a high speed access system as a transportation demonstration project to a new Southern Florida Jetport was determined. Several candidate systems were considered and included vertical-takeoff (VTOL) and short-takeoff (STOL) airborne vehicles, in addition to high speed rail (HSR), monorail systems (MRS) and tracked air cushion vehicles (TACV) ground vehicles. The evaluation of the perspective alternatives was made using technical performance and cost considerations over similar routes connecting a jetport to the main population centers in Southern Florida. Several jetport locations were postulated and considered in the evaluation of the routes and terminal requirements. A Tracked Air Cusion Vehicle (TACV) system capable of a cruise speed of approximately 150 mph is recommended as the initial jetport high speed access system. This system provides economic transportation for the projected airport access demands and for growth

to the high speeds desired for future interurban service. A performance description, preliminary implementation plan, and cost estimates are provided for the recommended system from a jetport to Miami. A general description of the expanded network is also presented with data for long-range planning and the development of programs for financing and enabling legislation included. (Author)
PB-192 842

**HIGH-SPEED GROUND TRANSPORTATION SYSTEMS ENGINEERING STUDY. TRACKED AIR CUSHION VEHICLE SYSTEMS.**
Final rept.
TRW Systems Group, Redondo Beach, Calif.
May 70, 623p* 06818-6039-RO-00 FRA-RT-71-59
Contract DOT-C-353-66

The tracked air cushion vehicle is one of several advanced ground transportation systems being studied by TRW Systems Group for the Department of Transportation as a possible means of providing safe, high-speed, high-capacity transportation along densely populated areas such as the Northeast Corridor. Based on requirements and constraints chosen for an operational system, subsystem alternatives are evaluated and the selected subsystems are synthesized into a TACV system. Cost and performance are estimated over a range of parameters, such as design cruise speed (150 to 350 mph) and vehicle capacity (50 to 150 passengers per vehicle). The configuration defined consists of trainable, electrically powered TACV's which collect power from trackside power rails mounted on the side of a channel guideway. Propulsion is by linear induction motors with variable frequency speed control. Control of the vehicles, singly or in trains, is automated and centralized. The vehicles are supported on and guided by peripheral jet air cushions with high pressure air provided by electrically driven axial flow compressors. (Author)
PB-195 030

**A PRELIMINARY STUDY OF ACTIVELY CONTROLLED AIR CUSHION VEHICLE SUSPENSIONS.**
Technical summary rept.,
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
David A. Hullender, David N. Wormley, and Herbert H. Richardson. 15 Jun 70, 161p EPL-70-76110-11, DSR-76110-11 FRA-RT-71-61
Contract C-85-65

The primitive vehicle suspension system coupling a simple vehicle model in point contact with a two-dimensional guideway having random irregularities is defined. The optimum linear suspension which minimizes a linear combination of vehicle heave acceleration (passenger comfort) and suspension-guideway displacement (suspension excursion) is synthesized using Weiner-Hopf filter theory. The mechanics of flexible base externally pressurized air cushion vehicle suspensions are discussed, including the use of a feedback control flow into the cushion region. The required form of control law to make the fluid suspension dynamically identical to the primitive optimum suspension is determined and the corresponding mean square control flow calculated. By properly selecting the suspension capacitance the control flow can be limited to a moderate fraction of the suspension equilibrium flow. Compared with optimized flexible base suspensions, heave accelerations are lowered by about 2.7 times through the use of optimum feedback control. An exploratory experimental program using a small scale rigid plenum suspension with electropneumatic valve modulated control flow is described. The results show that significant improvements in system dynamic response are possible with control flows of only 15 per cent of the equilibrium suspension flow. In a design example several suspension systems are designed for a full-scale hypothetical vehicle for 300 mph operation and comparison made between rigid plenum and flexible base suspensions with and without active control. (Author)
PB-196 465

**BRITISH AND AMERICAN TACV SYSTEM DEVELOPMENTS: TECHNICAL AND ENVIRONMENTAL FACTORS,**
Mitre Corp., McLean, Va.
C. G. Swanson, G. J. Easton, and A. F. Lampros.
Sep 70, 78p* M70-47
Contract OHSGT-7-35248
Prepared in cooperation with Tracked Hovercraft Ltd. (England).

The paper describes programs directed toward the development of tracked air cushion vehicle systems of Tracked Hovercraft Ltd. in Great Britain and by the Department of Transportation in the United States. The research programs are outlined and the results of transportation planning studies are presented. The environmental effects and the future prospects for this new transportation system are also discussed. (Author)
PB-196 980

**THE USE OF AERODYNAMIC LIFT FOR APPLICATION TO HIGH SPEED GROUND TRANSPORTATION.**
Interim rept. Sep 69-Jun 70,
Massachusetts Inst. of Tech., Cambridge. Fluid Dynamics Research Lab.
Timothy M. Barrows, Sheila E. Widnall, and Herbert H. Richardson. Jun 70, 162p* T70-3 FRA-RT-71-56
Contract DOT-C-85-65

The problem of a wing flying in very close proximity to a solid boundary, the so-called 'ram wing,' is reviewed and a new solution is found using the method of matched asymptotic expansions. The effect of the wing upper and lower surface coordinates on the resulting pressure distribution is shown explicitly for the case of a two-dimensional airfoil. It is shown that for very small clearance ratios a very simple expression is valid for the lift coefficient. On the basis of this simplification on analytic solution is obtained for the case of a flat-plate airfoil operating above a sinusoidal ground plane, which gives the forces and moments due to ground bumps. The longitudinal dynamics of a tracked vehicle designed to utilize aerodynamic lift are then investigated. Attention is focused on the case in which the vehicle body is a lifting surface operating in a rectangular guideway. It is found that, as with an airplane, a single wing gives unacceptable stability characteristics and some kind of stabilizing surface is required. Sample calculations are made for the case of a vehicle with a canard which show that adequate ride quality may be obtained with a reasonably smooth guideway. Some of these ideas are extended to three dimensions. An analytic solution is obtained for the case of a flat elliptical wing with a straight trailing edge which has the minimum induced drag for a given lift. A similar solution is obtained for the case of a wing in a tube. (Author)
PB-197 242

**HEAT-ASSISTED TUNNEL BORING MACHINES.**
Final rept. Feb 69-Apr 70,
United Aircraft Corp., East Hartford, Conn. Research Labs.
Jeffrey P. Carstens, W. Richard Davison, Choate A. Brown, Frederick J. McGarry, and Alan R. Smith. Sep 70, 335p UARL-J970802-12 FRA-RT-71-63
Contract DOT-FR-9-0035
Prepared in cooperation with Massachusetts Inst. of Tech., Cambridge, and Fenix and Scisson, Inc.

A study was performed to determine: the increase in tunneling machine performance in hard rock resulting from heat weakening of the rock in advance of the tunneling machine, the increase in hourly cost incurred by the heating system, and the net effect of the increased performance and the increased hourly cost on the cost of the finished tunnel. Rock-cutting experiments were performed on Barre granite using a 1-kw CO2-N2-He gas laser for rock heating and disc-type cutters of various diameters. Analytical work included the preparation of specific heat-assisted tunneler designs and their expected performance and economics. An alternative form of using heat for tunneling was also investigated in which slots were melted in the rock instead of merely heating it. The study concludes that the operation of tunneling machines incorporating lasers to provide the heat weakening is technically feasible but economically unattractive. Radiant heaters have insufficient power density to effectively heat the rock, and high-temperature jets create serious environmental problems. However, the test program indicated that a more effective way to assist mechanical cutters would be to use concentrated thermal energy to melt shallow slots in the rock between cutter paths. (DOT)
PB-197 243

**A COST COMPARISON OF THREE TRACKED AIR CUSHION VEHICLE CONFIGURATIONS.**
Final rept.
Tracked Hovercraft Ltd., London (England).
Jul 70, 370p* FRA-RT-71-68
Contract DOT-FR-9-0032

A comparison is made of three different types of Tracked Air Cushion Vehicle systems, using box, inverted-tee and channel cross section tracks. Each system is adapted from previously published schemes to meet a common specification, which required 100 passenger, electrically powered, vehicles operating at 250 mph on an elevated guideway. The comparison is divided into sections; guideway assessment; vehicle design and performance; total system performance; and an essay on the T.H.L. concept of single-sided linear induction motors. Vehicle power requirements are based on a simple form of peripheral jet air-cushion suspension system which can be expected to be improved upon. Even with this assumption it is shown the box track system would have the lowest total annual cost to an operator, due to the substantially lower costs of the box guideway compared to either of the alternatives. (Author)
PB-197 501

## 26. ADVANCED SYSTEMS: TUBE VEHICLE

**AERODYNAMIC DRAG ON VEHICLES IN ENCLOSED GUIDEWAYS.**
Rept. for Sep 64-Sep 66,
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
S. William Gouse, Jr., and Joseph Nwude. 6 Dec 66, 59p DSR-76108-1
Contract C85-65
Rept. on Proj. Transport. See also PB-173 647.

The purpose of this study was to investigate the aerodynamic drag on vehicles moving in enclosed guideways. The reason for the study was, and is, that several potential high-speed ground-transport system concepts involve high-speed motion of vehicles in enclosed guideways for significant portions of their travel time. Both analytical and experimental studies have been carried out. The analytical studies commenced by developing a solution for the aerodynamic drag on a vehicle in an enclosed guideway in laminar flow. This analysis was based on an analogy, first suggested by Rayleigh, that exists between the governing equations for unsteady flow resulting when an infinite body is started impulsively from rest and for the steady flow that results from steady motion of a semi-infinite body. The results of this analysis for laminar flow provided a base from which to begin, and were then used in an attempt to predict the drag that would result in turbulent flow. The turbu-

lent flow analytical estimate was based on another approximation or analogy which assumes that for any turbulent flow there exists a laminar flow in which corresponding streamlines in the laminar flow can be found to enclose the turbulent wake in the turbulent flow, and that by making use of an effective eddy viscosity in the laminar flow solution, one can predict the drag coefficient in the corresponding turbulent flow. Experimental studies were carried out using 8 spherical models and 16 cylindrical models in tubes of various diameters. (Author)
PB-173 646

**A FEASIBILITY STUDY OF THE CRYOPUMPED TUBE TRAIN CONCEPT,**
Celestial Research Corp., South Pasadena, Calif.
Raymond L. Chuan, Kenneth W. Rogers, Paul C. Wilbur, P. R. Choudhury, and N. V. Peterson. 11 Oct 66, 136p Celesco-388-101
Contract C279-66

The thermodynamic and gasdynamic characteristics of a saturated vapor in a tube enclosing a high speed train have been analyzed to assess the aerodynamic resistance to motion and possible means of propulsion using the same vapor. It is found that the piston action of the train causes condensation of the vapor ahead of and re-evaporation behind the train, these mechanisms thus providing the equivalent of by-passing the atmosphere in the tube around the train without any significant gap between the train and the tube. The term Cryopumped Tube Train is applied to the concept, since it is the heat sink capacity of the earth which effects the pumping of the vapor in the tube by condensation. The results of the analysis indicate that the total aerodynamic resistance to motion of a train at speeds around 400 mph in a close-fitting subterranean tube, evacuated free of air but filled with saturated water vapor at 13 mm pressure, is about two orders of magnitude below the resistance of a conventional flanged wheel-rail suspension system. Use of the same vapor for cruise mode jet propulsion is found to be feasible, though with very low efficiency. An effective and economical acceleration system to bring a train rapidly to cruising speed by means of low pressure steam catapult is found to be feasible and compatible with the cryopumped tube concept. These theoretical results have yet to be verified experimentally. (Author)
PB-173 982

**THE AERODYNAMIC CHARACTERISTICS OF A SLENDER BODY TRAVELING IN A TUBE.**
Technical rept.,
Oceanics, Inc., Plainview, N.Y.
Theodore R. Goodman. Jan 67, 50p TR-66-31
Contract C-265-66

Slender-body theory is applied to determine the flow about a slender body of revolution traveling in a tube. A formula for the pressure distribution on an ellipsoid centered in the tube is derived and it is shown that for a body whose diameter is a large percent of the tube diameter the pressures are an order of magnitude greater than they would be for the same body traveling in free air. It follows that a body which passes from a wide to a narrow passage will experience a large impact loading. Formulas for all the static and dynamic stability derivatives are then derived for an arbitrary body of revolution in terms of its cross-sectional area distribution. These formulas are specialized to an ellipsoid of revolution as an illustrative example, and plots of the results are presented as a function of the ratio of the maximum cross-sectional area of the body to the area of the tube. For the body whose diameter is a large percent of the tube diameter the stability derivatives also become an order of magnitude greater than they would be for the same body in free air. Furthermore, a statically unstable force of attraction to the wall due to proximity to the wall is present which does not exist at all for the body in free air. The inherent aerodynamic instability of a body in free air without controls is thus exaggerated by the presence of the tube walls, and the walls may be said to exert a large effect on the aerodynamic characteristics of the body. (Author)
PB-173 997

**PROJECT TUBEFLIGHT. PHASE I. FEASIBILITY STUDY.**
Final rept., 10 Dec 65-9 Sep 66.
Rensselaer Polytechnic Inst., Troy, N.Y.
Sep 66, 194p
Contract C-117-66
High speed ground transportation project.

Project Tubeflight is a study of a transportation mode in which aerodynamically supported and propelled vehicles travel at high speed in non-evacuated tubes. The feasibility of a mode of propulsion is studied in which thrust is generated by a continuous transfer of air in the tube from immediately in front of the vehicle to its rear. The use of bladeless fans as thrust generators for propulsion is examined. A study is made of the feasibility of powering the vehicle by high frequency electrical energy. The problems of radiating, propagating through the tube, receiving and rectifying this energy are covered. The inherent stability of a vehicle supported by a ram wing or a jet-flapped wing operating in close proximity to the tube wall is studied. A theoretical analysis of augmented stability and control is made, particularly in relation to the vehicle's roll. A small scale test facility was constructed consisting of an instrumented 12 inch diameter tube 2000 feet long. (Author)
PB-174 085

**PLANE-FLAME SIMULATION OF THE WAKE BEHIND AN INTERNALLY PROPELLED VEHICLE - PART I - SIMULATION OF A SUPERSONIC VEHICLE BY A DETONATION.**
Doctoral thesis,
Rensselaer Polytechnic Inst., Troy, N.Y. Dept. of Aeronautical Engineering and Astronautics.
John H. Skinner, Jr. Mar 67, 44p TR-AE-6701-Pt-1
Contract C-117-66
Rept. on Proj. Tubeflight.

The development of the flow field behind an internally-propelled vehicle in steady motion at supersonic speed is analyzed by the method of characteristics. The vehicle is simulated by a Chapman-Jouguet detonation propagating in an infinite duct. Friction and heat transfer are accounted for, and the friction factor is related to the heat transfer coefficient through the Reynolds analogy. The characteristic equations are integrated numerically employing a high-speed computer. In the inviscid adiabatic case the flow is nonsteady in all frames of reference. On the other hand, when the effects of friction and heat transfer are included, a region of flow is found to develop which is steady in a frame of reference moving with the detonation front. The steady-flow region starts directly behind the detonation and gradually grows to fill the entire flow field. The flow conditions far downsteam from the detonation return asymptotically to their ambient values. (Author)
PB-174 730

**UNSTEADY FLOW IN TUNNELS,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Forbes T. Brown, and Rasik P. Shah. 30 Sep 67, 108p
Contract C-85-65

Theoretical predictions are made for attenuation, dispersion, and characteristic impedance of long-wavelength small-amplitude waves in turbulent flow in cylindrical lines or tunnels. A lower limit for attenuation and dispersion results from assuming a turbulent viscosity profile across the tube which remains constant throughout the cycle. An upper limit results from assuming a turbulent viscosity profile which fluctuates during the cycle, maintaining the steady-flow values. An experimental apparatus was nearly completed to check the theory and resolve the transition from upper limit to lower limit. The theory indicates that a relatively simple constant-inertance-resistance model is useful at much higher frequencies than in laminar flow, including most problems of normal vehicle acceleration and deceleration in tunnels, but is totally unacceptable at very high frequencies such as those which result when a vehicle passes rapidly through a sharp or gradual change in the tunnel area. (Author)
PB-176 138

**THE AERODYNAMICS OF TUBE TRAVEL: EFFECTS OF COMPRESSIBILITY AND THE RESISTANCE OF SLENDER CYLINDERS TRAVELING IN A TUBE.**
Technical repts.,
Oceanics, Inc., Plainview, N.Y.
Theodore R. Goodman. Nov 67, 48p TR-67-36, TR-67-21
Contract C-265-66

Slender-body theory is used to determine the flow about a slender body of revolution traveling inside a tube at subcritical speed in a compressible fluid. It is shown that if the tube diameter is a small percent of the body length and the body is centered in the tube then the axial component of the flow in the annular region between the body and the tube can be approximated by one-dimensional compressible channel flow. Formulas for all the static and dynamic stability derivatives are derived for an arbitrary body of revolution in terms of its cross-sectional area distribution. The dynamic derivatives are shown to be identical with their incompressible counterparts. The static derivatives, on the other hand, are Mach number dependent and, as an illustrative example, these are calculated for an ellipsoid, and the results are normalized with respect to their incompressible counterparts. The resulting compressibility rise is presented graphically as a function of the ratio of the maximum cross-sectional area of the body to the area of the tube for various free-stream Mach numbers. The augmentation factor due to the presence of the tube walls, which had previously been calculated for incompressible flow, is shown to be augmented still further by the effect of compressibility. (Author)
PB-176 204

**ROLL CONTROL OF A FLUID-SUPPORTED VEHICLE MOVING IN A NON-EVACUATED TUBE,**
Rensselaer Polytechnic Inst., Troy, N.Y. School of Engineering.
Dean K. Frederick, and Imsong Lee. Sep 67, 35p TR-CISD-101
Contract C-117-66
Presented at the Sequicentennial Forum on Transportation Engineering, New York, NY, Aug 29 1967, ASME paper 67-Tran-8.

The problem of controlling the roll angle of a high-speed vehicle moving through a tube was investigated, both for straight portions of the tube and around curves. The dynamics of the vehicle with 6 degrees of freedom were studied by postulating reasonable force characteristics for the support pads and the aerodynamic forces on the fuselage. It was shown that de-stabilizing coupling exists between the roll and lateral modes, wheras the heave, pitch, and yaw modes are essentially uncoupled and are well-damped. However, the vehicle model studied can be stabilized by the use of a feedback torque about the roll axis proportional to the derivative of the roll-angle error. During a curve, the roll-angle error can be sensed by using a pendulum mounted in the vehicle in conjunction with a rate gyro. For straight portions of the tube only the rate gyro measurement is required. In addition to the feedback torque, the vehicle's roll angle is varied by an appropriately chosen open-loop torque as it passes through a

curve. The results of digital and and analog simulations are presented. (Author)
PB-176 375

**STEADY-STATE SIMULATION STUDY OF THE FLOW INDUCED BY AN INTERNALLY PROPELLED VEHICLE IN AN INFINITE TUBE: SUPERSONIC VEHICLE,**
Rensselaer Polytechnic Inst., Troy, N.Y. Dept. of Aeronautical Engineering and Astronautics.
Duane E. Cromack. Jun 67, 30p TR-AE-6704
Contract C-117-66

The flow induced in the wake of an internally-propelled supersonic vehicle or of a disturbance moving supersonically through an infinite tube is analyzed as a steady one-dimensional flow in the frame of reference of the vehicle or disturbance, with full amount of heat transfer and dispative effects. The governing equations are solved numerically. The results confirm that the flow can be steady if it is everywhere supersonic relative to the vehicle or disturbance. (Author)
PB-176 410

**PLANE-FLAME SIMULATION OF THE WAKE BEHIND AN INTERNALLY PROPELLED VEHICLE. PART III. EXPERIMENTAL SIMULATION OF A SUPERSONIC VEHICLE BY A DETONATION.**
Doctoral thesis,
Rensselaer Polytechnic Inst., Troy, N.Y. Dept. of Aeronautical Engineering and Astronautics.
John H. Skinner, Jr. Nov 67, 41p TR-AE-6708-Pt-3
Contract C-117-66
Rept. on Proj. TUBEFLIGHT. See also Part 2, PB-177 141.

The flow field induced by an internally-propelled vehicle traveling through a tube at a supersonic speed is simulated experimentally by the flow field induced by a detonation. The results indicate that as the vehicle continues to travel at a constant velocity, the effects of friction and heat transfer cause a region of flow to develop which is steady in the frame of reference of the vehicle. This steady-flow region starts directly behind the vehicle and gradually grows to fill the entire flow field as time progresses. (Author)
PB-176 924

**PLANE-FLAME SIMULATION OF THE WAKE BEHIND AN INTERNALLY PROPELLED VEHICLE. PART 2. SIMULATION OF A SUBSONIC VEHICLE BY A HEAT SOURCE.**
Doctoral thesis,
Rensselaer Polytechnic Inst., Troy, N.Y. Dept. of Aeronautical Engineering and Astronautics.
John H. Skinner, Jr. Jul 67, 34p TR-AE-6705
Contract C-117-66 (Neg.)
Rept. on Proj. Tubeflight. See also Part 1, PB-174 730.

The development of the flow field about an internally-propelled vehicle in steady motion at subsonic speed in a tube is analyzed by the method of characteristics. The vehicle is simulated by a heat source releasing heat at a constant rate and moving through an infinite duct at a constant subsonic velocity. Friction and heat transfer are accounted for, and the characteristic equations are integrated numerically employing a high-speed computer. In a vehicle-fixed frame of reference the induced flow field is initially steady, but friction and heat transfer soon cause it to become nonsteady. As time progresses, the nonsteady effects slowly decay and the flow field asymptotically approaches a steady state. (Author)
PB-177 141

**AERODYNAMIC DRAG ON A BODY TRAVELING IN A TUBE,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
S. William Gouse, Jr., B. S. Noyes, and Michael C. Swarden. Oct 67, 94p
Contract C-85-65

The purpose of the study is to continue the investigation of the aerodynamic drag on vehicles moving in guideways of varying degrees of enclosure. The reason for the study is that several potential high-speed ground transport system concepts involve high-speed motion of vehicles in enclosed guideways for significant portions of their travel time. Both analytical and experimental investigations were carried out. The analytical studies continued the development of the solution for the aerodynamic drag on a vehicle in an enclosed guideway in laminar flow. Experimental studies were carried out using cylindrical models in circular tunnels of various length and various degrees of wall porosity. A drop testing apparatus was employed in which water was the only test fluid and results were obtained for Reynolds numbers of the order of 100,000. Results to date indicate that for vehicle length-diameter ratios of the order of 15 and above, with tunnel to vehicle diameter ratios of 1.5 and greater, a drag coefficient based on the wetted surface area of the vehicle is independent of the vehicle length-diameter ratio for incompressible flow. Results also indicate that, for incompressible flow, employing a tunnel model with a closed end simulates a tunnel length-diameter ratio of infinity. Tunnel wall porosity, assuming relatively unobstructed motion of fluid outside the porous wall, has a marked effect on decreasing the aerodynamic drag on vehicles moving in enclosed guideways and for the range of variable investigated (clearance ratio as low as 1.4) tunnel wall porosity of 20 per cent is adequate for all the significant drag reduction that is possible. (Author)
PB-177 211

**SUMMARY OF RESEARCH AT RPI ON TUBEFLIGHT, SEPTEMBER 1966--9 NOVEMBER 1967.**
Rensselaer Polytechnic Inst., Troy, N.Y.
Jan 68, 34p TR-PT-6801
Contract C-117-66

This report is a summary of the researches performed during the period 9 September 1966 - 9 November 1967 under contract with the Office of High-Speed Ground Transportation of the United States Department of Transportation. Studies under this program focussed on the areas of Propulsion (Chapter I), inherent stability (Chapter II), stability augmentation (Chapter III), electrical power supply (Chapter IV), and small-scale experimentation (Chapter V). Specific problems within each of these areas are discussed in detail in the technical reports which are listed in the Appendix.
PB-177 518

**STUDIES ON THE ACTIVE CONTROL OF HIGH SPEED TUBE VEHICLE,**
Rensselaer Polytechnic Inst., Troy, N.Y. School of Engineering.
Imsong Lee, Dean k. Frederick, N. Josephy, and F. Treiber. Jan 68, 126p
Contract C-117-66

This document consists of two reports: (A) Stability analysis of a tube vehicle with flexible suspension; (B) A digital computer program for simulation of nonlinear tube vehicle dynamics with six degrees of freedom.
PB-177 519

**THREE NOTES ON PROPULSION AND BRAKING OF TUBEFLIGHT VEHICLES,**
Rensselaer Polytechnic Inst., Troy, N.Y.
Joseph V. Foa. Mar 68, 110p* TR-AE-6707, TR-AE-6802
Contract C-177-66
Rept. on Proj. TUBEFLIGHT.

This report consists of the following articles: Tubeflight propulsion by bladeless fans; Power demands of tubeflight vehicles; Preliminary evaluation of the braking capabilities of tubeflight vehicles.
PB-177 520

**AERODYNAMIC CHARACTERISTICS OF GROUND SUPPORT SYSTEMS,**
Rensselaer Polytechnic Inst., Troy, N.Y.
Robert E. Duffy, and George C. Cooke, IV. Jan 68, 119p* TR-AE-6801, TR-AE-6804
Contract C-117-66, Grant NSF-GK-618
Report on Proj. TUBEFLIGHT.

Two reports dealing with the aerodynamic characteristics of ground support systems are presented. The first report 'Aerodynamic Characteristics of a Tubeflight Vehicle Support System' by Robert E. Duffy presents experimental data on an aerodynamic ground-support-system obtained in a moving-wall wind tunnel. The second report 'Jet-Flapped Airfoils in Ground Proximity' by George C. Cooke concerns a study of the subsonic lift characteristics of airfoils in ground proximity with and without trailing-edge jet flaps. This study was restricted to supercritical flow analysis. (Author)
PB-177 521

**FLOW PROPERTIES OF A SLENDER BODY TRAVELING CENTERED IN A PERFORATED TUBE,**
Oceanics, Inc., Plainview, N.Y.
Theodore R. Goodman. Apr 68, 29p* TR-68-43
Contract C-265-66

The previously derived boundary condition which states the law governing the flow through a perforated wall (see PB-177 766) is applied to solve the title problem for a body of revolution. It is shown that even a moderate amount of perforations can cause the axial perturbation velocity in the annular region to be reduced by an order of magnitude in comparison with the closed wall case. It may be inferred from this that all aerodynamic forces, including drag, can be reduced considerably by perforating the walls. Thus, from the point of view of the body aerodynamics, tube wall perforations will have a beneficial effect on a tube transportation system. (Author)
PB-177 524

**STATIC AERODYNAMIC FORCE MEASUREMENTS OF BODIES IN TUBES,**
Oceanics, Inc., Plainview, N.Y.
Theodore R. Goodman, and August F. Lehman. Apr 68, 46p* TR-68-45
Contract C-265-66

Experiments were performed in a water tunnel to measure the lift, drag, and pitching moment on models intended to simulate a vehicle traveling in a tube. Bodies of three different thickness ratios were tested, and the heave displacement and angle of incidence was varied. In one series of tests the body alone was tested in a tube. In another series a propeller was placed near the rear of the body in the tube and the thrust of the propeller was made equal to the drag of the body, thereby simulating the condition of self-propulsion. The slopes of the measured lift-displacement and moment-displacement curves at zero displacement, for both heave and incidence displacements, were found to give good agreement with a theory previously derived by one of the authors. These curves remained virtually unaltered when self-propulsion was simulated. (Author)
PB-177 671

**AERODYNAMIC PROPERTIES OF PERFORATED WALLS FOR USE IN A TUBE TRANSPORTATION SYSTEM,**
Oceanics, Inc., Plainview, N.Y.
Theodore R. Goodman. Apr 68, 26p* TR-67-39
Contract C-265-66

For flow in a closed wall tube the boundary condition at the tube wall is the kinematic one of no normal flow. When the tube is perforated it is shown that the average effect of many small perforations may be calculated. From a theoretically derived formula it is shown that many small holes are more effective than a few large ones. It is then shown that there exists an analogy between a body traveling in a perforated tube and a geometrically similar body tested in a tunnel test facility having longitudinal slots. Furthermore, a relationship between the geometry of the holes of the perforated tube and the geometry of the slots of the tunnel test facility is established. (Author)
PB-177 766

**AERODYNAMIC ANALYSIS OF VEHICLES IN TUBES.**
TRW Systems Group, Washington, D.C. Washington Operations.
15 Apr 68, 35p* 06818-6026-R000
Contract C-353-66
Report on High Speed Ground Transportation System Engineering Studies Program.

The aerodynamic characteristics of a vehicle traveling in a tube are an important consideration in the analysis of high speed ground transportation systems. This report presents a list of the important aerodynamic parameters; an analysis of the various flow assumptions available to the researcher; a breakdown of the problem into two regimes, near field and far field; and a detailed description of the numerical analysis of the one-dimensional unsteady flow problem. (Author)
PB-178 796

**SCATTERING OF TE (0)SUB01 MODE ENERGY FROM A CENTERED METAL RING (WITH APPLICATION TO ANTENNA ARRAYS),**
Rensselaer Polytechnic Inst., Troy, N. Y. Div. of Electrophysics.
John A. Bradshaw. Jan 68, 19p TR-EP-6801
Contract C-117-66
Report on Project Tubeflight. See also PB-179 465 and PB-174 085.

A variational expression for the fields scattered by a metal ring, centered in round waveguide, is obtained for excitation by circularly symmetric TE modes. An example is worked out and the method supported by application to a rectangular iris for which data are available. An antenna array for launching TE01 or TE02 fields in round waveguide is described, based on current rings, and measurements of its performance given. It is capable of launching rather pure fields in highly over-moded guide, but its efficiency is not high. (Author)
PB-179 464

**HIGH FREQUENCY SOLID-STATE POWER RECTIFICATION,**
Rensselaer Polytechnic Inst., Troy, N.Y. Div. of Electrophysics.
K. E. Mortenson, P. E. Bakeman, Jr., and W. C. Taft. Dec 67, 42p TR-EP-6803
Contract C-117-66
Report on Project Tubeflight. See also PB-179 464.

This report covers the progress made on high frequency power rectification from September 1966 to September 1967. The requirements for a high frequency rectifying diode are reviewed. The germanium-gallium arsenide p-n heterojunction diode is presented and its material requirements, fabrication technology, and packaging are discussed. The circuit requirements for high frequency rectification are considered, and a new lumped circuit test jig was designed and built. The development of a 220 MHz one kilowatt rectification test facility is reported. Finally, a continuous rectified DC output power of 28 watts was obtained from a 220 MHz source using a single germanium-gallium arsenide heterojunction diode. The overall rectification efficiency of a similar heterojunction diode including circuit losses was 72%. (Author)
PB-179 465

**AERODYNAMIC STABILITY DERIVATIVES OF A SLENDER BODY TRAVELING IN A PERFORATED TUBE.**
Technical rept.,
Oceanics, Inc., Plainview, N.Y.
Theodore R. Goodman. Oct 68, 33p* TR-68-48
Contract C-265-66

The incompressible potential flow is determined for a slender body traveling off center in a perforated tube. From this, formulas are derived for the stability derivatives of a body having an arbitrary cross-sectional area distribution. These results may be compared with results previously derived for the stability derivatives of a slender body traveling in a tube with a closed wall. In the latter case the stability derivatives could become a large multiple of their free air values, and the more the body filled the tube the greater the multiple. When the wall is perforated, on the other hand, it is found to be always possible to design the perforations in such a way that the stability derivatives take on their free air values regardless of the size or shape of the body. Thus, it becomes possible to make the ratio of the body cross-sectional area to the tube cross-sectional area very close to unity without paying any aerodynamic penalty. (Author)
PB-180 091

**A PRELIMINARY STUDY OF THE COANDA NOZZLE PRINCIPLE FOR PROPULSION OF TUBE VEHICLES.**
Final rept. 1 Aug 67-18 May 68,
IIT Research Inst., Chicago, Ill.
Imants Reba. Oct 68, 92p*
Contract DT-7-35512

The report describes experimental studies to determine the feasibility of a new type of mass transportation, called the IITRI Passive-Vehicle Tube Transport System. This system (1) uses propulsive guideway concepts based on solely fluid dynamical propulsion principles (the Coanda effect). (2) has the utmost mechanical simplicity, with no moving parts other than vehicles. (3) uses small, inexpensive vehicles providing a personalized mode of mass transportation. (4) is suitable for transportation of goods and passengers. The qualitative and quantitative results of the study provide an insight into various problem areas. The following features were demonstrated: (1) High subsonic speed potential (in the experimental mode, speeds up to 320 fps were reached). (2) Capability of high vehicular frequency. (3) High load-to-power ratios at speeds above 120 mph and at high vehicular frequencies. (4) System efficiency increases with increasing tube diameter. (Author)
PB-180 156

**A STUDY OF THE RIBLET COUPLER (FOR RECEPTION OF TE (O)01 MODE ENERGY BY A VEHICLE IN A TUBE),**
Rensselaer Polytechnic Inst., Troy, N.Y. Div. of Electrophysics.
John A. Bradshaw. Jan 68, 24p* TR-EP-6802
Contract C-117-66
Report on Project Tubeflight.

The operation of the Riblet coupler in multi-mode round waveguide is described analytically, for the case where three TE (o)01 modes propagate in the coupling gap. A model of the coupling structure, for a vehicle flying in a tube, was built and tested, using this Riblet coupling as a basis. The coupler collected 96% of the power incident on the vehicle; however, the gap length and centering of the vehicle were more critical than expected. Details of the model and measurements are given, as well as a method for subdividing the power collected into 'packages' suitable for rectification. (Author)
PB-180 278

**THE CALCULATION OF PROPAGATION CONSTANTS OF A PERIODICALLY LOADED MULTIMODE CIRCULAR WAVEGUIDE,**
Rensselaer Polytechnic Inst., Troy, N.Y. Div. of Systems Engineering.
Dean Arden, and John Riganati. Jul 68, 93p* TR-DSF-6801
Contract C-117-66
Report on Project Tubeflight.

Operation of a circular waveguide at frequencies considerably above cutoff in order to obtain a low attenuation for the circularly symmetric transverse electric modes results in a system capable of propagating many modes. The stability of the launched TE sub 01 energy is a function of both the deviations of the guide from a true right circular cylinder and the mode structure. Guide modifications based on the natural dichotomy between the desired and spurious mode forms may be designed to increase this stability by modifying the mode structure. One way to determine the effect of any periodic modifications is to compute the scattering matrix for each junction and to apply Floquent's theorem. For a modification consisting of a narrow circumferential gap, coupled to either free space or an off resonance coaxial cavity, the scattering matrix may be found if the field in the gap is known. A field equivalence theorem is presented and used to formulate equations for the solution of the electromagnetic boundary value problem for this field. (Author)
PB-180 279

**FAR-FIELD AERODYNAMICS OF TUBEFLIGHT PROPULSION,**
Rensselaer Polytechnic Inst., Troy, N.Y. Project Tubeflight.
Joseph V. Foa. Jan 69, 36p TR-PT-6903
Contract C-117-66

Tubeflight is a high-speed tube transport scheme in which the vehicle derives its propulsion from the fore-to-aft transfer of air within the tube. The power required for tubeflight propulsion depends not only on the gasdynamics of the transfer flow but also on the amplitude of the disturbances that are generated by the vehicle in the far field, and these in turn depend on the energy conversion efficiency of the propulsion mechanism. A method is developed for the coupling and solution of the equations governing the flow field for the case of a tubeflight vehicle in steady motion in a very long tube. The method produces useful information on the interrelationships between the speed of travel, the drag of the vehicle, the amplitude of the flow disturbances in the far field, the energy conversion efficiency of the thrust generator, and the power demands. (Author)
PB-183 866

**SUMMARY OF RESEARCH AT RPI ON TUBEFLIGHT, 15 FEBRUARY 1968 - 15 JANUARY 1969.**
Rensselaer Polytechnic Inst., Troy, N.Y.
Jan 69, 24p TR-PT-6904
Contract DOT-C-117-66
See also PB-177 518.

Project Tubeflight deals with an intercity high-speed ground-transportation scheme in which air-cushion-supported vehicles propel themselves in a novel way in nonevacuated tubes. The report covers effort aimed primarily at the objective of obtaining realistic predictions of the power demands and attainable speeds of full-scale tubeflight vehicles. (Author)
PB-184 317

**STABILITY OF A SLENDER ELASTIC BODY TRAVELING IN A TUBE,**
Oceanics, Inc., Plainview, N.Y.
D. P. Wang. Feb 69, 54p TR-68-54
Contract DOT-FR-9-0020

The stability of a slender, axisymmetric, elastic body, supported by two simple spring systems, travelling in a cylindrical tube filled with air is studied. Slender-body theory is used to evaluate the aerodymanic force acting on the body. Under this aerodynamic loading the elastic body is assumed to obey the equation of motion of a simple beam. A method of solution of the equation of motion is presented for a slender ogive cylinder. It is found that at a given travelling speed instability occurs when the length of the body exceeds a critical value. This critical length is found to be approximately proportional to the inverse of the travelling speed, and to the square-root of the difference of the characteristic cross-sectional areas of the tube and of the body to the third power. (Author)
PB-184 319

**TUBEFLIGHT POWER-DEMAND TESTS AND INITIAL VALIDATION OF THEORY: 1. ESTIMATED PERFORMANCE OF WHEEL-SUPPORTED VEHICLES TO BE TESTED IN FACILITY T-2. 2. INTERPRETATION OF INITIAL TUBEFLIGHT PROPULSION TEST RESULTS, AND COMPARISON WITH THEORY. 3. TESTS OF WHEEL-SUPPORTED VEHICLES IN THE T-2 FACILITY,**
Rensselaer Polytechnic Inst., Troy, N.Y.
Joseph V. Foa, N. A. Messina, P. A. Graham, and W. B. Brower, Jr. Feb 69, 116p TN-PT-6802, TR-PT-6905
Contract C-117-66
Also includes Report TN-PT-6901.

To permit correlation between the predictions of PB-177 520 and the results of the small-scale model tests that are to be conducted in facility T-2, the power demands of these models are calculated by a procedure that is essentially the same as that of PB-177 520, except for such changes in the analytical model as are suggested or called for by the conditions of the tests. Experimental power demand data are presented for tests of the RPI MK IIc scale-model tubeflight vehicle in test facility T-2. This is done by use of propeller efficiency data generated through testing in the tubeflight wind tunnel, facility T-3. A description of the Mark IIc (wheel-supported) tubeflight vehicle is given. A series of test runs in the T-2 Facility is reported in which the top speed was about 76 feet per second. This result checks very closely with theoretical predictions for this vehicle. (Author)
PB-184 435

**EXPERIMENTAL EVALUATION OF VEHICLE DRAG IN LONG TUBES.**
Final rept.,
General Applied Science Labs., Inc., Westbury, N.Y.
Daniel E. Magnus, Sergio Panunzio, and Hector Medecki. May 69, 128p
Contract FR-9-0011

The report describes experimental results for aerodynamic phenomena in high speed tube-vehicle transportation systems. The data is obtained from a scaled facility which is suitable for a broad range of operating conditions and vehicle configurations. Seven vehicle configurations were used to measure vehicle drag force and the histories of static and dynamic pressure. The results correspond to full-scale vehicles approximately 8 to 13 feet in diameter operating in an evacuated tube (p=.0056 atm) 7 miles long. The history of static wall pressure in the far field is analyzed and related to the propagation of disturbances along the tube. Also, the pressure was measured in the region of the near field, and the results compared for various geometries of the vehicle. (Author)
PB-185 707

**FLUID DYNAMIC DRAG ON VEHICLES TRAVELLING THROUGH TUBES,**
Carnegie-Mellon Univ., Pittsburgh, Pa. Dept. of Mechanical Engineering.
Robert G. Hoppe, and S. William Gouse, Jr. 11 Aug 69, 187p CMU-1-59076-1
Contract DOT-3-1058

The document presents the results of an investigation of the fluid dynamic drag force exerted on externally propelled vehicles moving axially through guideways of varying lengths, degrees of enclosure, and percentage of wall perforation area. The conditions differ from most wind or water tunnel studies because the models are moving relative to the tunnel walls and occupy a large percentage of the tunnel cross section. Experimental studies were conducted by measuring the terminal velocity of small scale models falling through transparent, vertical and inclined guide tubes filled with water. The models were cylindrical with an ogive nose and a blunt conical tail. They varied in length from 3 to 36 diameters and occupied between 7 and 93 per cent of the tunnel cross section. Reynolds number based on model terminal velocity and diameter ranged from 3000 to 2,500,000. The experimental results indicated a smooth transition from free environment flow, with little or no wall interference, to fully developed confined flow, with no unusual phenomena or discontinuities occurring.
PB-188 451

**ANALYSIS OF THE NEAR FLOW FIELD FOR TUBE-VEHICLE SYSTEMS.**
Final rept.,
General Applied Science Labs., Inc., Westbury, N.Y.
Sergio Panunzio, and Daniel E. Magnus. Sep 69, 58p GASL-TR-732
Contract DOT-FR-9-0011, Modification 1

Results are presented from the investigation of vehicle drag in tube transportation systems. The report emphasizes the analysis of the aerodynamic phenomena in tube vehicle systems. A simplified one-dimensional analysis is formulated for the near flow field. The analysis is applied to several model vehicles, and the results compared with existing data from 19 different experiments. The correlation between the experimental and analytical drag coefficients is good. Also, the dependence of the drag coefficient on various flow parameters is examined and tentative conclusions presented. (Author)
PB-188 847

**AN EXPERIMENTAL STUDY OF THE AERODYNAMIC RESISTANCE OF VEHICLES MOVING THROUGH TUBES,**
Ohio State Univ., Columbus. Aeronautical and Astronautical Research Lab.
G. M. Gregorek. Apr 69, 43p
Contract DOT-3-0298

The aerodynamic resistance of solid rocket propelled, tube-vehicle models was examined at speeds up to 400 ft/sec. During the traverse of a 250-foot-long, 2.89 in. I.D. stainless steel tube, model trajectory, tube air static pressure and tube air velocity data were recorded. At low speeds, a pipe friction theory was found to correlate both the drag coefficients inferred from model deceleration, and the air pressure drop across the models. At high speed, the models induced significant air motions in the tube which, when coupled with tube end reflections, precluded data reduction to coefficient form. Application of the one-dimensional, unsteady method of characteristics, modified to account for mass flow past the models, is shown to produce reasonable agreement between the measured and predicted values of the induced air velocity. (Author)
PB-188 848

**THE AERODYNAMIC CHARACTERISTICS OF A SLENDER BODY TRAVELING CHOKED IN A TUBE.**
Technical rept.,
Oceanics, Inc., Plainview, N.Y.
Theodore R. Goodman. Jan 70, 112p TR-69-67
Contract DOT-FR-9-0020
See also PB-173 997.

In order that a tube vehicle system (TVS) be economically feasible it is necessary that the vehicle fill the tube as much as possible because tunneling costs are very high. Under these circumstances the body-tube ratio may be so large that the flow in the annular passageway between the body and the tube will choke. The paper is concerned with analyzing the flow and determining the aerodynamic forces acting on a vehicle under these circumstances. When the flow is choked a shock wave appears downstream of the throat and the flow never expends to upstream ambient conditions. This unsymmetrical flow situation creates a wave drag and increases the lift and moment substantially above the values they have in subcritical flow. All the stability derivatives are calculated for choked as well as subcritical flow conditions for a vehicle shaped in the form of an ellipsoid and also for a family of vehicles shaped in the form of ogive-cylinders. Using the results for one of the ogive-cylinders it is shown that when the flow is choked the aerodynamic forces can become comparable with the weight of a TVS vehicle. (Author)
PB-190 395

**TRAVEL TIME REDUCTIONS AND ENERGY SAVINGS FOR GRAVITY-AUGMENTED, EVACUATED TUBE VEHICLE SYSTEMS,**
TRW Systems Group, Washington, D.C. Washington Operations.
M. King, R. Simms, and J. W. Smylie. Jan 70, 41p 06818-6035-RO-00
Contract DOT-C-353-66
Report on High-Speed Ground Transportation Systems Engineering Study.

The use of gravity augmentation to accelerate an evacuated TVS affects the travel time, speed, and energy requirements for the system. For stage lengths of 3 to 10 miles characteristic of urban links, savings in travel time can be achieved by gravity augmentation over that for conventional systems operating on the surface. Savings in travel time are achieved however at the expense of higher vehicle speeds which lead to a more complex technological system. For stage lengths up to 100 miles characteristic of a regional transportation system, gravity augmentation results in a savings in travel time at the expense of greater tunnel depth and train speed. A reduction in energy per train trip can also be attained. However, the technological requirements depend largely on the maximum train speed which is sensitive to the propulsion mode of operation selected.
PB-190 396

**SERVICE ANALYSIS OF TUBE VEHICLE SYSTEMS.**
Final rept.
TRW Systems Group, Redondo Beach, Calif.
Dec 69, 73p 06818-W006-RO00 FRA-RT-70-33
Contract DOT-C-353-66
Report on High-Speed Ground Transportation Systems Engineering Study.

The report describes an analysis of the service characteristics, cost and performance of Tube Vehicle Systems operating within the Northeast Corridor of the United States in the 1975 to 1985 time frame. The basis of the study is the TRANSOP computer program which, as described, searches for optimal service policies for high speed ground transportation modes in competition with automobile, bus, conventional air and new technology air modes. Included in the report is a description of the TVS model used in the program, the mathematical basis for the optimization, and the results of the applications of the program to the TVS service design. The results indicate that, with the assumptions and approximations employed in the model, the improved travel opportunities attendant with the introduction of the TVS technology in the Northeast Corridor do not provide sufficient revenue to cover the costs of implementing TVS. (Author)
PB-191 412

**SUPPORTING STUDIES FOR HSGT SYSTEM REPORT (TVS).**
Final rept.
TRW Systems Group, Redondo Beach, Calif.
Jun 70, 120p* 06818-6041-RO00
Contract DOT-C-353-66
Report on High-Speed Ground Transportation Systems Engineering Study. See also PB-193 144.

The document, a supporting studies volume, contains appendices covering various detailed analyses which are referenced in a report on tube vehicle systems.
PB-193 145

**STATE-OF-THE-ART TUBE VEHICLE SYSTEM.**
Final rept.,
TRW Systems Group, Redondo Beach, Calif.
M. King, and I. W. Smylie. Jun 70, 56p* 06818-6042-RO00
Contract DOT-C-353-66
Report on High-Speed Ground Transportation Systems Engineering Study.

A train utilizing state-of-the-art equipment operating in a low pressure (3.5 psia) underground tunnel is analyzed. The tunnel is smaller (13.75 feet in diameter) than conventional subway tunnels (16 to 18 feet in diameter). The tunnel is deeper (200 to 500 feet) than most subways. The additional depth provides assistance to the propulsion system during acceleration and to the braking system during deceleration. The reduction in tunnel size and cost offsets the additional cost of vacuum pumps of conventional urban systems, while at the same time energy costs are reduced. The system speed is great enough to provide high capacity as a shuttle service utilizing a single tube, which may have application in an airport access link.
PB-193 273

**TUBE VEHICLE SYSTEM PARAMETRIC INVESTIGATION.**
Final rept.,
TRW Systems Group, Redondo Beach, Calif.
M. King, and J. W. Smylie. 15 Jun 70, 79p* 06818-6050-RO00
Contract DOT-C-353-66
Report on High-Speed Ground Transportation Systems Engineering Study.

The report extends previous results by investigating the effects of tube pressure level and alternate propulsion modes for a 300-mph TVS system. The ventilation system relationship to the tunnel size and quantitative assessment of the requirements for repressurization of the guideway tube are presented. The results of the analyses are integrated to provide the overall system requirements which can serve as a basis for the preliminary design of a 300-mph TVS. (Author)
PB-193 274

**TUBE VEHICLE SYSTEM (TVS) TECHNOLOGY REVIEW.**
Interim rept. 1966-69,
Mitre Corp., McLean, Va.
Walter P. Trzaskoma. Jul 70, 65p* M70-4, FRA-RT-71-44
Contract DOT-7-35248

Contents: Description of tube vehicle systems; OHSGT research to date; Research not sponsored by OHSGT.
PB-193 451

**TUBE VEHICLE SYSTEMS.**
Final rept.
TRW Systems Group, Redondo Beach, Calif.
May 70, 759p* 06818-6038-RO-00 FRA-RT-71-65
Contract DOT-C-353-66
Report on High-Speed Ground Transportation Systems Engineering Study.

The tube vehicle class is one of several advanced transportation concepts studies by TRW Systems Group for the Department of Transportation as a possible means of providing safe high speed intercity transportation along densely populated areas such as the Northeast Corridor. The tube vehicle class consists of those systems requiring a complete enclosure such as a tube or tunnel surrounding the train during operation. The enclosure requirement may come from the need for a reduced pressure or a need for a continuous support for the vehicle suspension. Tunneling to avoid unfavorable terrain or unfavorable community reaction, or to provide all-weather capability does not classify a transportation concept as a tube vehicle system (TVS) although these attributes are characteristic of the class. The TVS class is able to achieve ultra-high speeds (300 to 450 mph) without enormous power plants or large expenditure of energy. Preliminary subsystem elements are considered in the light of the high speed requirements and the TVS class characteristics. A baseline representative TVS is defined evaluating the design characteristics and relative investment and operating costs for alternate combinations of subsystems. The baseline system consists of electrically propelled, mechanically suspended steel wheels on steel rails and travels through an underground guideway which is at reduced pressure. Design solutions for propulsion, braking and suspension are suggested, and R and D requirements are identified. (Author)
PB-195 875

**THE AERODYNAMIC CHARACTERISTICS OF A VEHICLE TRAVELING IN A TUNNEL OF FINITE LENGTH.**
Final rept., Oct 69-Oct 70,
Carnegie-Mellon Univ., Pittsburgh, Pa. Dept. of Mechanical Engineering.
S. William Gouse, Jr., and Ezzatt Wali. Oct 70, 93p
CMU-59095-1
Contract DOT-FR-0007

The experimental study investigates the dependence of the drag coefficient of a vehicle, moving coaxially with uniform linear velocity through a solid wall tube of finite length, on the ratio of the relative velocity of the induced fluid pushed ahead of the vehicle to the absolute velocity of the vehicle. An apparatus was built with a vertical acrylic test tube, 25 ft. high and 1.732 in. inside diameter. The tube was provided with water flow of different negative and positive pressure gradients. Drop tests were conducted using models with smooth surface, in the form of cylinders with a streamlined nose and conical tail. The mode of variation of the drag coefficient with the velocity ratio at model Reynolds number of 100,000 was experimentally established for the test parameters. (Author)
PB-197 871

**EXPERIMENTAL INVESTIGATION OF THE NEAR FLOW FIELD FOR TUBE VEHICLES.**
Final rept.,
General Applied Science Labs., Inc., Westbury, N.Y.
Sergio Panunzio, and Daniel E. Magnus. Nov 70, 96p GASL-TR-70-749 FRA-RT-71-72
Contract DOT-FR-0039

The experimental results from an investigation of the near flow field for tube-vehicle systems are reported. The data were obtained from a tube-vehicle test facility which is 200 feet long and instrumented to measure vehicle drag, history of static wall pressure and dynamic pressure. Emphasis is on the accurate measurement of the dynamic pressure to determine the flow velocity in front of the vehicle. With this data and drag force, a drag coefficient is defined and related to the relative Mach number and the ratio of relative flow velocity to vehicle velocity. The experimental results are correlated with an analysis of the near flow field and results from other studies. (Author)
PB-198 205

# 27. ADVANCED SYSTEMS: AUTOMOBILE RELATED

**STUDY OF SYNCHRONOUS LONGITUDINAL GUIDANCE AS APPLIED TO INTERCITY AUTOMATED HIGHWAY NETWORKS.**
Final rept.
TRW Systems Group, Washington, D.C. Washington Operations.
15 Sep 69, 103p* 06818-W666-RO-00
Contract C-353-66 (Neg)

The report documents the results of the Synchronous Longitudinal Guidance (SLG) Study as applied to automated highway networks. Section 1 of the report contains a background of the SLG projects, an introduction to the basic concepts used in SLG, objectives and methods of the study, and conclusions reached as a result of the study. Sections 2 and 3 discuss results of analytical work done to verify various properties of the algorithms used for local vehicle control and for interfacing highway elements within the network. Work done in simulating the allocation algorithm for three networks is summarized in Section 4. A brief comparison between SLG and manual highway design is drawn in Section 5. Finally, Section 6 contains recommendations for further study of the SLG concept. (Author)
PB-188 582

**AUTOMATED HIGHWAY SYSTEMS.**
Final rept.
TRW Systems Group, Redondo Beach, Calif.
Dec 69, 572p* 06818-W006-RO00 FRA-RT-70-30
Contract DOT-C-353-66
Report on High-Speed Ground Transportation Systems Engineering Study. Sponsored in part by Office of High Speed Ground Transportation, Washington, D.C.

The report provides an examination of the status of automated highway systems evolution and the applicability of this class of transportation to high-speed, intercity service. The report deals with the problem in two principal ways. The first is from an evolutionary point of view; what has been done to date, where can we go in the future, and how do we get there. The second effort involves the hypothecation of a system which would be representative of an AHS if it were actually developed for service. The purpose of this effort was to determine the technological feasibility of a total AHS. Although a few areas of critical research have been identified, AHS is a technically feasible transportation alternative to existing systems. (Author)
PB-191 696

**MULTIMODAL SYSTEMS.**
Final rept.
TRW Systems Group, Redondo Beach, Calif.
Feb 70, 370p* 06818-6040-RO00 FRA-RT-70-39
Contract DOT-C-353-66
Report on High-Speed Ground Transportation Systems Engineering Study.

The multimodal system is one of several advanced ground transportation concepts being studied as a possible means of providing safe high speed intercity transportation along densely populated areas such as the Northeast Corridor. Subsystem alternatives are evaluated and a representative multimodal system is synthesized. Cost and performance are estimated over a range of parameters such as design cruise speed (75 to 150 mph) and system capacities. The multimodal configuration defined consists of pallet vehicles which carry automobiles completely enclosed on an elevated guideway. DC traction motors which pick up power from trackside power rails are used for propulsion. Steel wheels on steel rails provide support and guidance for the pallet vehicle. Control of the pallet vehicle is completely automated and centralized. (Author)
PB-192 507

## 28. ADVANCED SYSTEMS: SUSPENDED VEHICLE

**SUSPENDED VEHICLE SYSTEMS (SVS). VOLUME I. SYSTEM DEFINITION.**
Final rept.,
TRW Systems Group, McLean, Va. Washington Operations.
R. Y. Pei. Jun 71, 168p* 06818-W031-R0-00 FRA-RT-72-16
Contract C-353-66 (Neg)
See also Volume 2, PB-202 608.

A first-generation Suspended Vehicle System (SVS), to be synthesized from state-of-the-art components, is described. The configuration is based on a comprehensive selection logic supported by quantitative analyses. A 125-mph state-of-the-art SVS appears to be entirely feasible, and higher speeds seem readily attainable with slightly more advanced subsystems whose development requirements do not appear excessive. (Author)
PB-202 607

**SUSPENDED VEHICLE SYSTEMS (SVS). VOLUME II. SUPPORTING ANALYSES.**
Final rept.,
TRW Systems Group, McLean, Va. Washington Operations.
R. Y. Pei. Jun 71, 182p* 06818-W031-R0-00 FRA-RT-72-16A
Contract C-353-66 (Neg)
See also Volume 1, PB-202 607.

The volume contains the following appendices: An evaluation of the pneumatic tire for application to suspended vehicle systems (SVS); Acousta-flex wheel; Roll dynamics; Vehicle-guideway interaction dynamics; Structural design tradeoffs; Electromagnetic suspension for suspended vehicle system; Air suction and air cushion suspension. (Author)
PB-202 608

## 29. ADVANCED SYSTEMS: GUIDEWAYS AND STRUCTURES

**GEOLOGIC SKETCH OF THE PROPOSED NORTHEAST CORRIDOR HIGH-SPEED GROUND TRANSPORT SYSTEM,**
Geological Survey, Washington, D.C.
C. F. Withington. May 66, 3~p

From a geologic viewpoint, it can be concluded that the rocks of the Crystalline terrain are most suited for underground or surface construction, followed by the rocks of the Triassic terrain. Underground and surface construction in the Appalachian terrain can be recommended with limitation; extensive tunneling in sediments of the Coastal Plain terrain is not recommended because of difficulty of tunneling, but can be effected in underlying crystalline rocks. Subsurface and surface geologic mapping utilizing drilling and geophysical methods is strongly urged before a final route selection is made. Highly detailed engineering geologic studies will be required of the actual route selected before design and construction can begin; feasibility studies and preliminary route selection will require extensive compilation of existing geologic data and mapping at adequate scales. (Author)
PB-173 511

**ANALYSIS OF STRESS DISTRIBUTION BENEATH EMBANKMENTS.**
Final research rept.,
Massachusetts Inst. of Tech., Cambridge. Soil Mechanics Div.
T. W. Lambe, R. C. Hirschfeld, and J. T. Christian. 1 Nov 66, 57p R66-53
Contract C-85-65
Northeast Corridor Transportation Project.

A mathematical analysis adapted to computer calculation is used to calculate stresses and displacements for complicated soil movements and for a large class of boundary conditions. Vertical stresses are found to be insensitive to variation in material properties and some boundary conditions, but marked changes in horizontal stresses suggest that elastic theory may be inaccurate. Additional work is suggested, to include further computer runs on a systematic basis, some improvements in the programs, and an extension of the work to study consolidation (the time-dependent dissipation of pore pressures), which is a major unsolved theoretical problem. (Author)
PB-173 637

**A PRELIMINARY DESIGN STUDY OF A TRACKED AIR CUSHION RESEARCH VEHICLE. VOLUME II. GUIDEWAY STUDY REPORT.**
Aeroglide Systems, Inc., New York.
Dec 68, 112p
Contract DT-7-35337
Prepared in cooperation with Parsons, Brinckerhoff, Quade and Douglas, Inc., New York. See also Volume 1, PB-183 319.

This report describes the development of preliminary design tradeoff studies for a single vehicle aerial guideway to accommodate a vehicle traveling on air cushions at speeds up to 300 miles per hour. Three guideway structure types were studied: (1) the Inverted Tee, (2) the Double L (or Channel), and (3) the Box (or Inverted Channel). Each of these structural types was analyzed for the purpose of determining the most economical construction material, the optimum span length, the tolerance requirements, construction methods and maintenance procedures. (Author)
PB-183 320

**PLANE STRAIN CONSOLIDATION BY FINITE ELEMENTS.**
Research rept.,
Massachusetts Inst. of Tech., Cambridge. Dept. of Civil Engineering.
Jan Willem Boehmer, and J. T. Christian. Aug 69, 183p R69-60, Soil Mechanics Pub-243
Contract DOT-C-85-65

The report describes the application of the finite element technique to plane strain consolidation problems, dealing with primary consolidation only. A description is given of three-dimensional consolidation in order to explain three-dimensional effects in the consolidation process and to discuss similarities in the finite element formulation, Biot's and Terzaghi's formulation. The main points of a finite element formulation for the consolidation process are summarized, and the resulting computer program, CONSOL, is described. The complete element formulation is given in an appendix. An investigation is made on one- and two- dimensional problems, which show the effects discussed in the chapter on consolidation theory. A choice is made of problems which are of practical importance. (Author)
PB-188 023

**TRAIN ELEVATED GUIDEWAY INTERACTIONS,**
TRW Systems Group, Washington, D.C. Washington Operations.
A. Kaplan, N. Lipner, F. B. Roberts, and R. O. Strom. Feb 70, 141p 06818-6036-RO-00 FRA-RT-70-23
Contract DOT-C-353-66
Report on High - Speed Ground Transportation Systems Engineering Study.

The report describes a computer program modeling the response of an elevated guideway to the passing of a high-speed train. The train is modeled by a lumped parameter dynamic system. Specifically, the model consists of a two-vehicle train, traveling at constant velocity, over a series of similar, simply-supported bridges which may have initial camber. The response of the bridge is represented as the sum of normal mode responses. These are coupled to the equations of motion governing the response of the vehicles. The resultant system of equations is numerically integrated from arbitrary initial conditions. For evenly-spaced time intervals, depending on the size of the integration step chosen, the program calculates and prints out the displacement of centers of gravity of the cars, the wheel displacements, and the displacements of the truck masses, as well as the first and second time derivatives of these motion parameters. The output also includes the wheel loads and beam deflections as functions of time. The program has a plotting capability and a restart capability. It also has several options with respect to the modeling of the vehicles. (Author)
PB-190 635

**ELEVATED GUIDEWAY STRUCTURES.**
Final rept.
TRW Systems Group, Redondo Beach, Calif.
Dec 69, 131p 06818-W005-RO00 FRA-RT-70-35
Contract DOT-C-353-66
Report on High-Speed Ground Transportation Systems Engineering Study. Sponsored in part by Office of High Speed Ground Transportation, Washington, D.C.

The report addresses the problem of elevated guideway structures employing simply-supported beams and spread footing. Various structural materials and components are considered. On the basis of static analysis, practical information about the design requirements has been generated. Cost data are also provided. Results are displayed in convenient graphical form, for span length up to 100 feet and maximum deflection up to 0.1 foot. (Author)
PB-191 670

**TRAIN/ELEVATED GUIDEWAY PARAMETRIC INVESTIGATION.**
Final rept.,
TRW Systems Group, Washington, D.C. Washington Operations.
A. L. Soux. Jul 70, 133p 06818-W018-RO-00
Contract DOT-C-353-66
Report on High-Speed Ground Transportation Systems Engineering Study. See also report dated Feb 70, PB-190 635.

The report contains the results of a parametric investigation of train/elevated guideway interaction to establish the dynamic criticality in the design of simply-supported elevated guideways for multi-vehicle trains traveling at high speeds. The study is based on a digital simulation model developed for this purpose. Results of the study are presented in graphical form. (Author)
PB-194 039

**DYNAMIC RESPONSE OF CONTINUOUS BEAM ELEVATED GUIDEWAYS. VOLUME I - ANALYSIS.**
Final rept.,
TRW Systems Group, Redondo Beach, Calif.
N. Lipner, D. A. Evensen, and A. Kaplan. Jul 70, 104p 06818-6046-RO00 FRA-RT-71-42-Vol-1
Contract DOT-C-353-66
See also Volume 2, PB-194 138.

The report describes a Train-Elevated Guideway Interaction (TEGI-2) program. TEGI-2 considers a two-vehicle train traveling at constant velocity over a series of uniform, simply-supported, continuous span bridges. A technique for considering nonuniform guideway beams is developed and discussed. The equations governing the train and guideway responses are numerically integrated from arbitrary initial conditions. The bridges can have initial camber or roadway roughness conditions. As part of the program formulations, the dynamic response of a semi-infinite uniform and periodically supported beam load by end moments is derived. The program calculates motion parame-

ter, wheel loads, and bending moments in the spans as a function of time. Maximum values of these quantities are also determined. As options, the program can consider a one-car train or a single spring mass damper system moving across the bridges. A sample case is run with the program developed using the same vehicle parameters as those for the sample case presented in TRW Systems Group Report, 'Train Elevated Guideway Interactions' (PB-190 635) for the simply-supported spans. It is shown that even with a reduced beam cross section, the response is improved. (Author)
PB-194 137

**DYNAMIC RESPONSE OF CONTINUOUS BEAM ELEVATED GUIDEWAYS. VOLUME II - COMPUTER PROGRAM.**
Final rept.,
TRW Systems Group, Redondo Beach, Calif.
F. B. Roberts, N. Lipner, D. A. Evensen, and A. Kaplan. Jul 70, 172p 06818-6047-RO00 FRA-RT-71-42-Vol-2
Contract DOT-C-353-66
See also Volume 1, PB-194 137.

The report describes a Train-Elevated Guideway Interaction (TEGI-2) program. TEGI-2 considers a two vehicle train traveling at constant velocity over a series of uniform simply supported continuous span bridges. A technique for considering non-uniform guideway beams is developed and discussed. The equations governing the train and guideway responses are numerically integrated from arbitrary initial conditions. The bridges can have initial camber or roadway roughness conditions. As part of the program formulations the dynamic response of a semi-infinite uniform and periodically supported beam load by end moments is derived. The program calculates motion parameters, wheel loads, and bending moments in the spans as a function of time. Maximum values of these quantities are also determined. As options, the program can consider a one car train or a single spring mass damper system moving across the bridges. (Author)
PB-194 138

**ELEVATED STRUCTURES - CONTINUOUS BEAMS.**
Final rept.,
TRW Systems Group, Washington, D.C. Washington Operations.
C. H. Wang. Jul 70, 80p* 06818-W017-RO-00 FRA-RT-71-54
Contract C-353-66
Report on High-Speed Ground Transportation Systems Engineering Study.

The report addresses the problem of elevated guideway structures employing continuous span beams and spread footing. Various structural materials and components are considered. On the basis of static analysis, practical information about the design requirements was generated. Results are displayed in convenient graphical form for span length up to 160 feet and maximum deflection up to .16 foot. (Author)
PB-194 371

**COUPLED DYNAMIC INTERACTIONS BETWEEN HIGH SPEED GROUND TRANSPORT VEHICLES AND DISCRETELY SUPPORTED GUIDEWAYS.**
Final rept.,
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Wen S. Chiu, David N. Wormley, Richard G. Smith, and Herbert H. Richardson. Jul 70, 130p
DSR-76115-1 FRA-RT-71-76
Contract DOT-C-85-65

The coupled dynamic interactions between high speed ground transport vehicles and discretely supported guideways is investigated using modal analysis techniques to determine the performance of vehicles traversing spans with distributed mass, flexibility and damping and which rest on rigid discrete supports. Results indicate that for typical advanced transportation systems span dynamic deflections at vehicle speeds of 100 - 300 mph may approach values which are twice the span static deflection due to the vehicle weight and that vehicle heave accelerations may substantially exceed the desired 0.05 g level unless very strong constraints are placed upon system parameters. Parametric design charts are presented which provide an initial basis for the selection of vehicle and guideway system parameters to meet a given specified limit on vehicle heave acceleration. A number of numerical design examples are described to illustrate the use of the design charts and to indicate specifically the influence of vehicle weight, and suspension damping and stiffness, and guideway span configuration and length upon span deflection per unit length, mass, and stress. Limited data are also presented for the multiple vehicle passage case. (Author)
PB-199 136

**THE EFFECTS OF SOIL PARAMETERS AND BOUNDARY CONDITIONS ON THE CONSOLIDATION OF AN ELASTIC LAYER.**
Final rept. Oct 68-Jan 70,
Massachusetts Inst. of Tech., Cambridge. Dept. of Civil Engineering.
John T. Christian, and Jan Willem Boehmer. Aug 70, 124p R70-50 FRA-RT-71-81
Contract C-85-65

The behavior of a linearly elastic layer consolidating under influence of a strip surface load is investigated by means of a previously developed finite element program. Several parameters affect the results of such calculations; included among these parameters are: the Poisson's Ratio, the ratio of horizontal to vertical permeability, boundary conditions with respect to displacement, boundary conditions with respect to drainage, and relative load width. The interaction of these is complex, but some have a larger effect than others. A smooth bottom boundary and bottom drainage cause considerable change in the pattern of pore pressure dissipation. Increased horizontal permeability speeds consolidation but not as much as would be expected intuitively. When the load width is narrow, the horizontal permeability has a larger effect. Poisson's ratio does not markedly affect the rate of consolidation provided scaling is done on the basis of the constrained modulus or the in-plane bulk modulus. (DOT abstract)
PB-201 550

## 30. ADVANCED SYSTEMS: TUNNELS AND TUNNELING

**BUFFETING TESTS ON THE HUDSON TUBE.**
Final rept.,
Stanford Research Inst., Menlo Park, Calif.
E. G. Chilton. 4 Jun 65, 30p
Contract C-209-65 (neg)

Buffeting tests were made on a two-car train of the Pennsylvania Railroad as it entered the Hudson tube. The pressure outside the train was measured at its head and at two locations along its side. The pressure inside the car was also measured. Tests were made at speeds between 55 and 70 mph. Results of these tests show that the pressure at the head rises abruptly when the nose of the train enters the tunnel, and gradually to a maximum of about 6 inches of water when the tail of the train enters. Beyond that time the pressure decreases. At the sides the initial abrupt rise is apparent only near the front of the first car and even there its severity is much smaller than at the head. Halfway along the first car the abrupt jump could not be detected. The subsequent gradual pressure rise is observed on all gages and is about equally steep everywhere. The pressure inside the car, which is the pressure experienced by a passenger, rises to a maximum of about 2.5 inches of water at a rate of about 1.5 inches of water per second. This pressure rise was noticeable but not painful. Since the maximum pressure increases as velocity squared and the rate of rise increases as velocity cubed, it seems clear that buffeting will be an important problem whenever speeds are significantly increased. (Author)
PB-168 647

**ROCK FRACTURE RESEARCH.**
Research rept. 1 Nov 65-1 Sep 66,
Massachusetts Inst. of Tech., Cambridge. Dept. of Civil Engineering.
F. Moavenzadeh, R. B. Williamson, and A. E. Z. Wissa. 1 Nov 66, 94p RR-R66-56
Contract C-85-65

The results of flexural tests on granite, marble, gneiss, and schist beams are presented in terms of the maximum stress and the work expended to cause failure. The extent of side cracking is measured by quantitative microscopy and is used to calculate a corrected fracture surface work. Thermal cycling of unnotched beams to 540C, 1280C, and 1800C is found to cause extensive cracking, and the resulting decrease of strength can be measured. The use of surface-active agents to reduce the work necessary to cause failure is found effective. A one percent water solution of aluminum chloride at 90C produces a fifty percent reduction in the fracture surface work value of granite, compared to the room temperature dry condition. A mechanism of stress-activated corrosion may be the principal cause of this reduction in strength.
PB-173 638

**DYNAMICS OF FLEXIBLY SUPPORTED TUNNELS AND OTHER ROADBEDS,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Forbes T. Brown. 1 Nov 66, 31p DSR-76107-1
Contract C-85-65

Vehicles supported by flexible roadbeds can exhibit violent vibrations near a particular critical velocity. This situation is idealized to a concentrated load traveling on a Bernoulli-Euler beam which rests on an elastic foundation. A floating tunnel design of the type proposed by Edwards is so modeled, and found to have a critical velocity of about 262 miles per hour and nearly negligible damping. Avoidance of excessive vibration by rapidly accelerating or deceleration through the critical frequency is studied with preliminary results. The tentative indication on the particular example is that an impractically high acceleration would be necessary unless changes are made. (Author)
PB-173 645

**HYDRAULIC ANALOGY STUDY OF WAVES IN TUNNELS.**
Final rept.,
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Mikio Suo, and Paul Jacobs. 1 Nov 66, 55p DSR-76111
Contract C-85-65

As a train enters a tunnel at high velocities, a pressure wave is built up ahead of it. The pressures involved may be so high as to cause the train to slow down and to cause damage to the train and the tunnel. In order that trains be used at high velocities, it is necessary to find a way to relieve these pressure waves. A study was made of a technique for measuring these pressure waves and of some data for a typical train configuration. The technique consists of making measurements on a free-surface water table of a model geometrically similar to actual trains. This gives information about the pressure waves around trains travelling on the ground through air. The results indicate that valid information can be obtained from the water table and that the water table can be ultimately used towards reducing the magnitude of the pressure waves. (Author)

PB-173 657

**LASER ASSISTED ROCK FRACTURE.**
Research rept.,
Massachusetts Inst. of Tech., Cambridge. Dept. of Civil Engineering.
F. Moavenzadeh, R. B. Williamson, and F. J. McGarry. 30 Jan 67, 63p R67-3
Contract C-85-65

The report presents information obtained from initial experiments involving the use of a laser to degrade and deteriorate hard rock samples. The work is being done within the context of a continuing search for more efficient means of excavation and tunnelling in hard rock. The techniques discussed herein should be considered in the context of making hard rock more easily removed by reducing its strength. The laser appears to have an unusual potential for this application. (Author)
PB-174 245

**UNSTEADY FLOW IN TUNNELS,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Forbes T. Brown, and Rasik P. Shah. 30 Sep 67, 108p
Contract C-85-65

Theoretical predictions are made for attenuation, dispersion, and characteristic impedance of long-wavelength small-amplitude waves in turbulent flow in cylindrical lines or tunnels. A lower limit for attenuation and dispersion results from assuming a turbulent viscosity profile across the tube which remains constant throughtout the cycle. An upper limit results from assuming a turbulent visocity profile which fluctuates during the cycle, maintaining the steady-flow values. An experimental apparatus was nearly completed to check the theory and resolve the transition from upper limit to lower limit. The theory indicates that a relatively simple constant-inertance-resistance model is useful at much higher frequencies than in laminar flow, including most problems of normal vehicle acceleration and deceleration in tunnels, but is totally unacceptable at very high frequencies such as those which result when a vehicle passes rapidly through a sharp or gradual change in the tunnel area. (Author)
PB-176 138

**STUDY BY HYDRAULIC ANALOGY OF THE PASSAGE OF HIGH-SPEED TRAINS THROUGH TUNNELS,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
J. M. Mills, and D. G. Wilson. 15 Dec 67, 52p
Contract C-85-65

When a train enters a tunnel, an unsteady flow of air occurs in the tunnel near the front end of the train, and this disturbance is propagated down the tunnel as a pressure wave. Accompanying this is a change of air pressure on the exterior of the train. In view of the proposal for a high-speed ground-transportation system in this country to operate in the speed range of 250 miles per hour, and faster, it is important to know what pressure fluctuations to expect when fast trains enter tunnels. In order to surmount experimental difficulties assocciated with high-speed models and transient phenomena, a series of experiments using a water table and two-dimensional train and tunnel models were begun. The work has now been extended to several tunnel-entry shapes, and to square and elliptical train section-models. Experiments included trains entering along the tunnel centerline, as well as trains entering near one wall of the tunnel, and traveling along that wall through the tunnel. (Author)
PB-176 922

**A STUDY OF EXTERNAL AUGMENTATION OF THE VELOCITY OF FLUID JETS.**
Bowles Engineering Corp., Silver Spring, Md.
1967, 40P BEC-R-12-21-67
Contract 7-35380

In order to make tunneling operations for future transportation systems economically feasible, a new method must be developed to provide a major step forward in tunneling speed and ease of operation. Attention was directed to tunneling by water jet techniques which promise to overcome the inherent slowness of conventional tunneling methods. Previous work indicates that at high velocities, water jets produce much the same effect on rock as do explosives. A major problem of hypervelocity jet production is dealt with in this effort, that being to provide hypervelocities without requiring extremely high pressures. A new technique involving the impacting of two relatively slow-moving slugs of water to produce a very small but effective fast jet was studied by analysis and very low pressure experiments. The analysis included the effect of slug profile, prediction of fast jet velocity as a function of the slug face impact angle, fast jet mass, optimum slug length, and time between slugs. Special test fixtures were built and tested to experimentally verify the theoretical results. These tests included the high speed photography of the collapse transient, impacting of wax targets and velocity measurement by streak photography. (Author)
PB-177 595

**FEASIBILITY OF FLAME-JET TUNNELING. VOLUME I. SUMMARY REPORT.**
United Aircraft Corp., East Hartford, Conn. Research Labs.
May 68, 52p* UACRL-G910560-10-Vol-1
Contract DC-7-35126
See also Volume 2, PB-178 199.

Analytical system studies were made to determine the configuration of a flame-jet tunneling system and its expected performance. These studies examined the flame-jet tunneler design, haulage system, power system, and shoring and lining problem areas. Similar studies considered in detail various aspects of the environmental control problem, including a determination of the environmental heat, fumes, and noise created by the flame jets, the design of air and water supplies to modify this environment, and possibilities for crew protection against a hostile environment. Three possible alternative modes for life support were designed and evaluated, and one was chosen as the recommended system. Studies were also made to determine the overall cost of flame-jet tunneling, based on the detailed cost estimates made in the component subsystem studies. Total costs of flame-jet tunneling are developed and compared with conventional methods. In an experimental program, a series of tests was made on two 'control rocks' to determine the effect of various burner parameters on spalling rate. For comparative purposes, information was developed on conventional tunneling methods. (Author)
PB-178 198

**FEASIBILITY OF FLAME-JET TUNNELING. VOLUME II. SYSTEMS ANALYSIS AND EXPERIMENTAL INVESTIGATIONS.**
Technical rept.
United Aircraft Corp., East Hartford, Conn. Research Labs.
May 68, 380p* UACRL-G910560-10-Vol-2
Contract C-7-35126
See also Volume 3, PB-178 200.

The feasibility of flame-jet tunneling is considered analytically from three points of view, namely technical (or operational), environmental, and economic. An experimental program was performed to provide cutting capabilities of flame-jets in rock types expected on the Northeast Corridor. (Author)
PB-178 199

**FEASIBILITY OF FLAME-JET TUNNELING. VOLUME III. CONVENTIONAL TUNNELING METHODS.**
Rept. for 1 May 67-15 Mar 68.
United Aircraft Corp., East Hartford, Conn. Research Labs.
May 68, 116p* UACRL-G910560-10
Contract DC-7-35126
Prepared in cooperation with Fenix and Scisson, Inc., Tulsa, Okla. See also Volume 1, PB-178 198.

The report has been divided into two sections: (1) Methods for Conventional Tunneling and Shaft Sinking; (2) Boring Methods for Tunneling and Shaft Sinking. (Author)
PB-178 200

**HIGH SPEED GROUND TRANSPORTATION TUNNEL DESIGN AND COST DATA.**
TRW Systems Group, Washington, D.C. Washington Operations.
Mar 68, 265p Rept. no. 06818-W454-R0-11
Contract C-353-66
Prepared in cooperation with Harza Engineering Co., Chicago, Ill.

Five important components of costs of tunneling, shafting and construction of terminals were identified. These cost components significant to tunneling, that is, those that account individually for more than approximately 5 percent of the total cost, are: (1) Excavation; (2) Muck loading, transport and disposal; (3) Tunnel supports; (4) Tunnel lining; and (5) Interface load supports. Similar cost components of shafting and terminal construction were identified. Five characteristics of the HSGT system and three groups of geologic conditions of the site that materially affect the cost components of tunneling, shafting and terminal construction were identified. These significant HSGT characteristics and site conditions are: (1) Tunnel and shaft diameter; (2) Terminal size; (3) Depth; (4) Shaft spacing; (5) Interface loads; and (6) Rock types grouped according to their excavation, supporting and water transmission characteristics. The rock types were delineated according to these groupings on maps of the project area. A study of the unit costs of work was made for each cost component, and the cost data were applied to determine the cost of an arbitrary tunnel system. (Author)
PB-178 201

**JET DELIVERY OPTIMIZATION.**
Final rept.
Bowles Engineering Corp., Silver Spring, Md.
Apr 68, 119p BEC-R-4-23-68
Contract 7-35381

The report investigates several ways of improving water jet delivery in order to increase the efficiency of hydraulic tunneling and mining. These approaches are directed toward the reduction of water jet velocity decay by suppressing pressure disturbances and turbulence which cause jet breakup, by such means as the use of turbulence suppressing chemical additives, the design of a minimum transverse turbulence nozzle, and the suppression of air shear on a free water jet by providing the jet with a moving air sheath. In addition, an investigation is made of the use of a Fluidic Jet Modulator to generate liquid slugs which would produce high pressure impulsive shocks when impacting upon a rock face. A survey is made of the various modes of rock fracture in order to relate the results of the investigation to the problems of tunneling or mining. An evaluation is made of each of the separate studies as to its applicability to tunneling and its technical and economic feasibility. Finally, a system is proposed which incorporates the most effective results of the investigation. (Author)
PB-178 437

**HYPERVELOCITY JET DRIVER STUDY.**
Final rept.,
Bowles Engineering Corp., Silver Spring, Md.
V. Neradka, W. Walston, and R. Turek. May 68, 87p* BEC-R-22-68
Contract 3-0055
See also PB-178 437.

This study investigates analytically a concept for accelerating liquid slugs to high velocities by the use of supersonic gas nozzles. This technique is of interest for developing economic methods for cutting rock during tunnel construction. The merits of this concept are based on the fact that only moderate gas pressures are required to accelerate liquid slugs to velocities which have been demonstrated as suitable for fracturing rock material. To obtain these velocities by liquid nozzles alone, very high hydraulic pressures would be required. This concept, therefore, amplifies the pressure which is used to accelerate the slug to a high value delivered to the face of the rock material. The concept for mechanizing this augmentation is a hypervelocity gun comprising of a constant area section tube for accelerating the slug to sonic speed and a diverging area tube for further accelerating the slug to supersonic gas speeds. Analyses are performed to evaluate the lengths and acceleration times for both sections of the gun under different conditions of supply pressure and temperature and slug sizes. An important aspect of this concept is the requirement to control the hypervelocity jet driver repetitively at a controlled frequency and slug size. The design considerations for such a jet driver control system are considered and a preliminary concept is presented. (Author)
PB-178 506

**CRACK INITIATION AND PROPAGATION IN ROCK.**
Research rept.,
Massachusetts Inst. of Tech., Cambridge. Dept. of Civil Engineering.
P. Forootan-Rad, and F. Moavenzadeh. May 68, 127p* R68-29
Contract C-85-65

Theories of crack initiation, propagation and bifurcation in perfect solids based on energy equilibrium criteria, elasticity theory considerations and particulate body mechanics are reviewed. Modifications of these and their applicability to rock are discussed. Different testing methods used to study the fracture characteristics of rock are reviewed; a bending method was chosen as most suitable for the purpose. A literature review on the effect of heat treatments on rock weakening are discussed. The principles of a continuous duty, high powered gas laser as a heat source are described. The values of the fracture surface energy were determined for four different geometries of a granite specimen; the results show that if a stable fracture is obtained, the value is independent of geometry. Results of the heat treatment and laser treatment studies on marble and granite show the thermal exposure causes a decrease in the value of ultimate flexural strength because of intergranular and transgranular cracks induced in the specimen. (Author)
PB-178 987

**REVIEW OF EFFECTS OF HYPERVELOCITY JETS AND PROJECTILES ON ROCK.**
Final rept.,
Missouri Univ., Rolla. Rock Mechanics and Explosives Research Center.
George B. Clark, Charles J. Haas, John W. Brown, and Clifford D. Muir. Jun 68, 415p*
Contract DC7-35511

New methods are being continuously sought which will radically increase the rates of tunnel excavation. Attention has turned to the use of hypervelocity impact as a means of cutting and breaking rock, as well as the use of lasers, electric current, explosive drilling, high frequency vibration, etc. The information in this report was assembled and analyzed to give a state of the art summary of hypervelocity techniques which show promise for use in cutting and breaking rock. These include the use of water jets, metallic jets and hypervelocity projectiles. (Author)
PB-179 022

**ROCK TUNNELING WITH HIGH SPEED WATER JETS UTILIZING CAVITATION DAMAGE.**
Final technical rept.,
Hydronautics, Inc., Laurel, Md.
R. E. Kohl. Jun 68, 52p* 713-1
Sponsored in part by Department of Transportation, Washington, D. C., Office of High Speed Ground Transportation.

A test apparatus, capable of producing a 1/4-inch diameter jet up to 500 ft/sec was designed and built. Initial tests with this facility produced erosion intensities of 37 watts/sq. meter. This value was encouraging and demonstrated that the technique had potential. As a result a three-month extension of the contract was granted so that the operating parameters could be optimized thereby maximizing the erosion intensity. During this period the erosion intensity was improved from 37 watts/sq. meter to 670 watts/sq. meter. In addition those relationships such as the time dependence of erosion intensity and its variation with jet velocity were determined. The information was obtained for both a 1/4-inch and 1/8-inch nozzle. Once the behavioral relationships were established attention was directed to means by which the erosion intensity produced could be efficiently used. As a result a nozzle to specimen distance adjustment technique and specimen rotation technique were developed which improved volume removal by two orders of magnitude. Finally, the effect of heat treatment on reducing the strength of rock was briefly examined. (Author)
PB-179 076

**THIN DISK TECHNIQUE FOR ANALYZING ROCK FRACTURES INDUCED BY LASER IRRADIATION.**
Research rept.,
Massachusetts Inst. of Tech., Cambridge. Dept. of Civil Engineering.
F. Moavenzadeh, R. B. Williamson, and F. J. McGarry. May 68, 91p R68-21, DSR-76103
Contract C-85-65

The report presents results to date in the study 'Laser Assisted Rock Fracture.' Thin disc samples of marble and granite have been irradiated for short intervals with unfocused 10.6 micron (infrared) radiation from a carbon dioxide-nitrogen-helium gas laser. The specimens were exposed to laser radiation of different power levels over various areas of one side. Thermo-sensitive paints applied to the face indicated the radial temperature distribution across the specimen, and the initiation of the crack was detected using electrically conductive silver paints on the other face. Good agreement was found between the experimental data obtained from the temperature at failure and the calculated thermal stresses developed in the specimens. The results indicated that failure occurred when the induced thermal stresses exceeded the tensile strength of the rock. (Author)
PB-179 205

**MODELING A JOINTED ROCK MASS.**
Research rept.,
Massachusetts Inst. of Tech., Cambridge. Dept. of Civil Engineering.
R. A. Nelson, and R. C. Hirschfeld. Sep 68, 233p* R68-70
Contract C-85-65

The ultimate goal of the study of jointed rock is to provide fundamental understanding of the mechanics of jointed rock, which is a crucial part of hard-rock tunnel design of the type that might be required for underground high-speed transport systems. The jointed-rock modeling material was selected to meet similitude requirements between the model and a typical field prototype rock and to ensure that it would be possible to make homogeneous, reproducible model specimens. A universal mold was designed for manufacturing specimens having different joint spacings and orientations. Strength tests were performed on the models in a triaxial cell. (Author)
PB-180 248

**DESIGN OF TUNNEL LINERS AND SUPPORT SYSTEMS.**
Final rept.,
Illinois, Univ., Urbana. Dept. of Civil Engineering.
D. U. Deere, R. B. Peck, J. E. Monsees, and B. Schmidt. Feb 69, 419p
Contract DOT-3-0152

Contents: Introduction; Fundamentals of tunnel support design; Existing theories, design methods, and practices; Tunnel support systems in soil and soft rocks; Tunnel support systems in rock--Factors influencing behavior; Tunnel support systems in rock--Design procedures; Potential developments of tunnel support systems; Shotcrete.
PB-183 799

**ROCK BREAKAGE BY LIGHT-GAS GUN PROJECTILES.**
Final rept. Feb 68-Jan 69,
IIT Research Inst., Chicago, Ill.
Victor G. Gregson, Jr., and Madan M. Singh. 22 Jan 69, 129p IITRI-D6000-FR-06
Contract DOT-3-0171

The report discusses hypervelocity impact on rock targets using a light-gas gun with Zelux projectiles (solid and water-filled). The specific energies for rock breakage range from 120 to 260 joules/cc (1,400 to 3,200 ft-lb/cu in.) for Indiana limestone, and from 80 to 120 joules/cc (900 to 1,500 ft-lb/cu in.) for Milford Pink granite. Rock descriptions and strength properties are included. Previous work on basalt by Gault (NASA) and Moore (USGS) is included. The specific energies compared to specific energies incurred by other potential drilling techniques indicates that high velocity solid impact is a potential method to increase drilling rates. A potential method is developed to calculate hydrodynamic crater volumes for given impact energies. The general problem is outlined whereby the strong shocks generating the hydrodynamic crater can be extended to include spall and fracture effects. (Author)
PB-184 191

**ROCK PROPERTIES RELATED TO RAPID EXCAVATION.**
Final rept.
Missouri Univ., Rolla. Rock Mechanics and Explosives Research Center.
Mar 69, 358p
Contract DOT-3-0143

The purpose of this report is to present an evaluation of rock property measurement in relation to the problems of rapid excavation, to summarize recent theory and representative data, to point out their usefulness and limitations, and finally to indicate some of the pressing needs for further research and development. In most cases the investigators in specific areas of research have presented complete analyses of their work. Where possible, further analysis has been made, primarily in terms of application of results of research. (Author)
PB-184 767

**EXTERNALLY AUGMENTED HYPERVELOCITY JET PROGRAM.**
Final rept.
Bowles Engineering Corp., Silver Spring, Md.
Dec 69, 147p* BEC-R-10-31-69
Contract DOT-FR-9-0015

The external velocity augmentation concept was demonstrated by striking a flat plate with a flat-faced slug of water to create a jet with a velocity eight times that of the slug. A generator capable of providing flat-faced slugs at a velocity of 1000 ft/sec was designed, built, instrumented, and tested. Experimental studies were made of interface devices capable of maintaining a 1/2 inch vertical face of water at the end of a horizontal chan-

nel. Pressure pulse characteristics at various points in the generator and slug velocity and form were analyzed to optimize slug generation techniques. Results showed superiority of flat impingement plate concept to the two slug concept as a method of achieving external velocity augmentation. (Author)
PB-188 452

**SOME DESIGN CONSIDERATIONS IN THE SELECTION OF UNDERGROUND SUPPORT SYSTEMS.**
Final rept. Feb-Nov 69,
Illinois Univ., Urbana. Dept. of Civil Engineering.
R. B. Peck, D. U. Deere, J. E. Monsees, H. W. Parker, and B. Schmidt. Nov 69, 179p*
Contract DOT-3-0152

Guidelines for the design of supports for underground openings in both soil and rock are presented and discussed for several specific situations. The design and construction of both shafts and tunnels are examined. The problems that may occur because of unusual or variable geologic conditions are outlined and the effects of these geologic anomalies on the construction scheme are indicated. Other situations considered include multiple parallel tunnels and crossed tunnels as well as intersections and enlargements of tunnels. Support systems and construction methods which can be easily modified to adapt to variable conditions and requirements are also discussed. The cost of tunnel support systems is evaluated and compared to the total cost of the tunnel. The cost relationships are illustrated by numerous detailed cost estimates of tunnels in both soil and rock. Finally, the problems of ground movements around soft ground tunnels are discussed and methods for predicting the magnitude of settlement over soft ground tunnels are presented. (Author)
PB-190 443

**VEHICLE-TUNNEL ENTRY AT SUBSONIC SPEEDS.**
Final rept., Part 1,
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Michael C. Swarden, and D. G. Wilson. Mar 70, 54p* DSR-76111-3 FRA-RT-70-28
Contract DOT-C-85-65

This is the first part of a two-part report on the problem of vehicle-tunnel interaction during the entering period. This part covers most of the analytical work done for the project and contains a description of the experimental apparatus to be used to investigate the phenomena.
PB-190 912

**ROCK BREAKAGE BY PELLET IMPACT.**
Final rept.,
IIT Research Inst., Chicago, Ill.
Madan M. Singh. 24 Dec 69, 92p FRA-RT-70-29
Contract DOT-3-0171

This report discusses a study of rock breakage effected by the use of high-speed pellets. A previous study had been conducted at IITRI in which two rock types were subjected to hypervelocity impact by solid Zelux pellets as well as hollow, water-filled capsules. In this extension to the above study six rock types, viz. French Creek gabbro, Milford Pink granite, Connecticut brownstone, Minnesota dolomite, Indiana limestone, and Massillon sandstone, were investigated. The compressive strengths of these rocks range from 390 MN/square meter to 30 MN/square meter (56,900 psi to 4,400 psi). Other mechanical properties of the rocks were also determined. The pellets used in this study were solid cylinders 5.6 mm in diameter and 1 cm long, weighing nearly 0.25 gm. Impact velocities of 1 to 7 km/sec were generated by means of a rifle and a light-gas gun. Craters with volumes ranging from almost negligible values to 52 cc were obtained. Regression equations for crater volume and crater depth in terms of the impact parameters and rock properties were determined. Impact pressures/compressive strength ratios of up to nearly 1000, with the weaker rocks, were obtained. It was found that specific energy consumptions of the order of 200 joules/cc were obtained when these ratios were near 100. For the stronger rocks this implied impact velocities above 5 km/sec. The dominant rock failure mechanism appears to be spalling. (Author)
PB-190 965

**A COMPUTER PROGRAM FOR ESTIMATING COSTS OF HARD ROCK TUNNELLING (COHART).**
Final rept.,
Harza Engineering Co., Chicago, Ill.
Frank T. Wheby, and Edward M. Cikanek. May 70, 242p*
Contract DOT-FR-9-00003

A computer performs all logic and computations customarily done by hand in preparation of engineer's estimates or contractor's bids on tunnel-shaft systems. The program described is based on construction methods, work forces and equipment selections corresponding to the current state of the art of tunnelling. The program contains logic to permit the estimate of costs of complicated tunnel-shaft systems. In any estimate, the program will accommodate a large number of values or changes in the values of the factors that affect cost, such as tunnel shape and size, shaft depth, rock characteristics, and construction method. To provide great flexibility, the user of the program is provided with the option of selecting lining type and thickness, profit and overhead margins, and other input data. Suggestions for selecting an appropriate value for these inputs are contained in the report. Complete operating instructions and an illustrative example are presented. (Author)
PB-193 272

**A SYSTEMS STUDY OF SOFT GROUND TUNNELING.**
Final rept. Feb 69-May 70,
Fenix and Scission, Inc., Tulsa, Okla.
C. T. Brandt, R. B. Stone, A. R. Smith, B. H. Willis, and Alex Pastuhof. May 70, 439p* DOT-FRA-OHSGT-231
Contract DOT-FR-9-0034
Prepared in cooperation with Little (Arthur D.), Inc., Cambridge, Mass.

A fundamental investigation of soft-ground tunneling operations was made to identify and assess the potential technical and economic feasibility of new tunneling system concepts. Quantitative estimates were made of costs and rate of advance of different candidate system concepts relative to an assumed set of tunneling conditions. The magnitude of R and D effort required to achieve cost reductions and performance improvements over the 1970 to 1985 time period was estimated. The study concludes that the major restraints to reducing costs and increasing performance in soft ground tunneling over the 1970 to 1985 time period will result from the lack of any effective method for handling bouldery ground and from the lack of a method for rapid installation of the permanent tunnel liner continuously and concurrently with the advance of the face. With a 15-year R and D effort of $35 to $70 million, these problems could be substantially overcome and current tunneling costs could be expected to decrease by 40-65% and advance rates could be expected to increase by a factor of from 4 to 8. Cost differences among the more promising alternative system concepts were found to be small relative to the range of uncertainty associated with the cost forecasts. (Author)
PB-194 769

**MECHANICS OF JOINTED ROCK: EXPERIMENTAL AND THEORETICAL STUDIES.**
Interim rept. Sep 68-Dec 69,
Massachusetts Inst. of Tech., Cambridge. Dept. of Civil Engineering.
H. H. Einstein, R. W. Bruhn, and R. C. Hirshfeld.
Aug 70, 122p R70-62 FRA-RT-71-62
Contract C-85-65
See also report dated Sep 68, PB-180 248.

The stress strain behavior of intact rock and the phenomena of friction along a single plane as well as the relation to the underlying mechanisms are reviewed. The behavior of the modeling material is consistent with that of most brittle rock. Results of the tests with jointed models which are also supported theoretically, show that the transition from brittle to ductile behavior coincides with the transition from sliding along a pre-existing joint to fracture through the intact material. Multiple joints have a systematic influence on strength and deformability depending on joint orientation, joint spacing and number of joint sets. The study of analytical methods shows that the finite element technique with the feature of special joint elements is well suited for the analysis of jointed rock masses. (Author)
PB-195 917

**HEAT-ASSISTED TUNNEL BORING MACHINES.**
Final rept. Feb 69-Apr 70,
United Aircraft Corp., East Hartford, Conn. Research Labs.
Jeffrey P. Carstens, W. Richard Davison, Choate A. Brown, Frederick J. McGarry, and Alan R. Smith. Sep 70, 335p UARL-J970802-12 FRA-RT-71-63
Contract DOT-FR-9-0035
Prepared in cooperation with Massachusetts Inst. of Tech., Cambridge, and Fenix and Scisson, Inc.

A study was performed to determine: the increase in tunneling machine performance in hard rock resulting from heat weakening of the rock in advance of the tunneling machine, the increase in hourly cost incurred by the heating system, and the net effect of the increased performance and the increased hourly cost on the cost of the finished tunnel. Rock-cutting experiments were performed on Barre granite using a 1-kw CO2-N2-He gas laser for rock heating and disc-type cutters of various diameters. Analytical work included the preparation of specific heat-assisted tunneler designs and their expected performance and economics. An alternative form of using heat for tunneling was also investigated in which slots were melted in the rock instead of merely heating it. The study concludes that the operation of tunneling machines incorporating lasers to provide the heat weakening is technically feasible but economically unattractive. Radiant heaters have insufficient power density to effectively heat the rock, and high-temperature jets create serious environmental problems. However, the test program indicated that a more effective way to assist mechanical cutters would be to use concentrated thermal energy to melt shallow slots in the rock between cutter paths. (DOT)
PB-197 243

**MATERIALS HANDLING FOR TUNNELING.**
Final rept.,
Holmes and Narver, Inc., Los Angeles, Calif. Advanced Technology Div.
J. M. Duncan, M. P. Tierney, and H. V. Schneider. Oct 70, 614p HN-8080 FRA-RT-71-57
Contract DOT-FR-00002

At the tunnel face advance rates anticipated for the future, material handling could become the critical factor in the tunneling project. All functional elements of the tunneling process require materials to be moved by the materials handling system. The characteristics, quantities, and flow of muck, ground support materials, materials for transport system extension, personnel, and other materials and equipment which must be transported between the surface and the work zones are defined. Candidate transport modes to meet the requirements of the future are classified as continuous flow systems or utilized transport systems. Conveyors, hydraulic pipelines, and pneumatic

pipelines are selected as representative of continuous flow systems. Conventional dual rail systems with locomotive drive, side-wheel drive and cable drive, siderail systems, monorail systems hoist, and truck systems are selected for evaluation in the unitized category. These ten transport modes are described, discussed, and analyzed through computerized mathematical models representing the cost/performance relationship for each system. Integrated systems including all elements of the total materials transport system throughout its total life cycle are conceived and analyzed. Based on the results of these evaluations and analyses, areas are identified for beneficial allocation of research and development resources to advance the state of the art of materials handling for tunneling. (Author)
PB-197 331

**ROCK FRACTURE BY HIGH SPEED WATER JET.**
Final rept. Dec 68-Dec 70,
IIT Research Inst., Chicago, Ill.
Peter J. Huck, and Madan M. Singh. Dec 70, 98p
IITRI-D6009-11 FRA-RT-71-58
Contract DOT-FR-9-0031

The report discusses a study of rock breakage phenomena by high speed water jets. The water jets were 1 mm (0.039 in.) in diameter, traveling at 1200 m/sec (4000 fps) and had a duration of nearly 1.5 secs. Six rock types, viz. French Creek gabbro, Milford Pink granite, Connecticut brownstone, Minnesota dolomite, Indiana limestone and Massillon sandstone, ranging in compressive strength from 390 MN/ (sq m) to 30 MN/ (sq m) (56,900 psi to 4,400 psi) were used for the experiments. Only single shot tests were conducted. A number of the French Creek gabbro and Connecticut brownstone specimens split apart; the others were penetrated by a narrow hole. The depth of the hole varied from 3.2 cm to 16.7 cm (1.2 in. to 6.6 in.) depending on the rock type and experimental conditions. The specific energy consumption for these tests varied between 4000 j/cc and 340000 j/cc, but these values can be lowered one or two orders of magnitude by traversing the jet or using multiple shots. The specific energy was found to decrease with an increase in the specific pressure (stagnation pressure/compressive strength), up to specific pressures of nearly thirty-five (35). The mechanical properties of the various rocks were determined and correlated with the damage incurred by water jet impingement. (Author)
PB-197 651

**DESIGN OF A WATER CANNON FOR ROCK TUNNELING EXPERIMENTS.**
Final rept. May 70-Jan 71,
Terraspace, Inc., Bethesda, Md.
William C. Cooley, Franklin L. Beck, and Daniel L. Jaffe. 15 Jan 71, 76p* TR-2 FRA-RT-71-70
Contract DOT-FR-0-0017

A detailed design is presented for manufacturing a high pressure pulsed water cannon for rock-breaking experiments in a tunnel or quarry at jet pressures up to 1,000,000 psi. The test system includes a trailer for carrying the water cannon, and a separate dolly for the power system and controls. The water cannon incorporates components of a Terrapak hydro-pneumatic actuator and is designed to fire one pulse every 5 minutes, but can be modified to fire 20 pulses per minute with a pulse energy of 93,500 ft. lbs. This report covers the system analysis, design studies and detailed design of the water cannon system and discusses fabrication, operation and test procedures. (Author)
PB-198 050

**TUNNELING COST ANALYSIS.**
Final rept.,
RMC, Inc., Bethesda, Md.
Louis A. Spittel, and James C. Willyard. Mar 71, 160p* RMC-UR-151 FRA-RT-71-73
Contract DOT-FR-0-0040

The report provides the Office of High Speed Ground Transportation with a review and analysis of tunnel construction costs. The data for all cost analyses in the report were obtained from historical records of tunnel owners, contractors, and equipment and material manufacturers throughout the United States. The report proper includes discussions regarding the data gathering process, the methods of analysis employed, and the tunneling cost estimating relationships. Also, included is a brief review of the cost impact of differences in tunnel design and construction policies. (Author)
PB-201 363

## 31. ADVANCED SYSTEMS: SUSPENSION

**ACTIVE VIBRATION ISOLATION AND ACTIVE VEHICLE SUSPENSION,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Igor L. Paul, and Erich K. Bender. 1 Nov 66, 73p
DSR-76109-1
Contract C-85-65

The feasibility of using 'active' elements in suspension systems for high speed ground vehicles to improve vibration isolation characteristics is considered. The characteristics of vehicle excitations (to the suspensions and to the vehicle body) are discussed and a mathematical expression for the suspension input is obtained. Based on data of human tolerance to vertical vibrations a comfort criterion (to vibrations) is established. The problem of vibration isolation to best satisfy this criterion is considered in terms of optimizing the parameters of a given suspension configuration and in terms of finding an optimum tranfer function for an unspecified suspension configuration. The methodology for obtaining these optimum solutions for a given comfort criterion is developed and solutions are obtained for the case of vertical vibrations of a two-degree-of-freedom system in which the root mean square acceleration of the vehicle is to be minimized for a given permissible suspension excursion. The optimum suspension transfer function for this case indicates that feedback of both vehicle and unsprung mass acceleration is required.
PB-173 648

**PARTIAL BIBLIOGRAPHY ON SUBJECTS RELATED TO ACTIVE VIBRATION ISOLATION AND ACTIVE VEHICLE SUSPENSIONS,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Igor L. Paul, and Erich K. Bender. 1 Nov 66, 35p
DSR-76109-2
Contract C-85-65

The report represents a partial compilation of references on subjects related to active vibration isolation and active vehicle suspensions which have been collected during the past year in connection with active vehicle suspension research. The bibliography is categorized into a number of subject headings which reveal the diversity and scope of published work in general area of vibration isolation, ranging from purely mathematical techniques for optimum vibration filter calculations to the most practical aspects of suspension hardware design. No attempt has been made to sort or classify the reference with respect to the quality, scope, or usefulness of their contents. (Author)
PB-173 649

**GENERAL VEHICLE DYNAMIC MODEL,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Igor L. Paul, Hariharan Sankaran, and James L. Jackson. Nov 66, 189p DSR-76109-3
Contract C-85-65

Two computer programs were developed to calculate the three-dimensional dynamics of a rigid high-speed ground-vehicle supported vertically and laterally by an arbitrary number of suspensions and excited by arbitrary inputs (acting on the suspensions or on the vehicle body). The first program models each suspension by a linear spring and damper in parallel connected to the unsprung mass and another linear spring and damper in parallel joining the unsprung mass and the vehicle. This model is applicable to a limited class of suspensions over their linear operating range. The second, much more comprehensive program permits non-linear and/or 'active' suspension elements. Each suspension can consist of masses connected (in series or parallel) by elements with force characteristics which can be any function of time or of the relative or absolute displacements, velocities or accelerations of any of the masses (including the vehicle mass). Both programs accept sinusoidal, step, ramp or arbitrary function inputs to the suspensions and print out any or all of the following vehicle response parameters as a function of time: vertical and lateral displacement, velocity and acceleration of the vehicle center of mass; vehicle roll, pitch and yaw (and their first and second derivatives); suspension forces on the vehicle and on the guideway. (Author)
PB-173 650

**STRESS AND STRAIN IN ROLLING BODIES IN CONTACT,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Igor L. Paul, and P. Ranganath Nayak. 1 Nov 66, 43p
Contract C-85-65

The three-dimensional solution of the stresses and strains in the contact region of a rolling wheel which carries normal, lateral and tangential loads is sought. Because of the complexity of the general problem a preliminary step has been to seek the solution for two spheres of similar material rolling on each other. The approach has been to divide the 'locked' region into a grid of n cells formed by fixed circular grid lines and variable grid lines which have a shape similar to an assumed shape for the boundary between the 'locked' and 'slipped' regions. The equations and boundary conditions were formulated and a computer program solves 2n simultaneous equations to find the stress distributions. If all boundary conditions are not satisfied by the solution the computer program shifts the grid points according to an error criterion and reiterates the solution. The results were encouraging although the final solution is not yet available. The results for the two spheres can be extended to the case of a wheel rolling on a surface of dissimilar material. This solution is of considerable importance for high speed rail travel because forward and sidewise creep (which are vital parameters in stability calculations) and rolling stresses (fatigue, etc.) can be calculated from the complete picture of stresses and strains in the region. (Author)
PB-173 651

**SUPPLEMENT TO SURVEY OF TECHNOLOGY IN FLUID SUSPENSIONS: PATENT SEARCH AND EFFECTS OF FORWARD SPEED,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
H. H. Richardson, and W. A. Ribich. 1 Nov 66, 68p
DSR-76110-1
Contract C-85-65
See also PB-168 648.

Supplementary information to that given in Part I, Survey of Technology for High Speed Ground Transport, Ref. 1, is presented for fluid suspensions and fluid-supported vehicle systems. Representative patent literature is described which shows that the existing basic concepts and configurations for fluid suspensions and associated vehicles are very old; however, many recent patents have been issued covering variations, improvements and applications to transport vehicles. Published information and experimental facilities

and techniques relative to the influence of forward speeds on fluid suspension data are reviewed. Available data are limited to forward speeds less than 150 mph, to ambient pressures of one atmosphere and to low cushion-pressure levels. An adequate theoretical approach to forward speed effects is lacking. No experimental facilities entirely satisfactory for the investigation of the behavior of dynamically similar scale models of HSGT vehicles and guideways were found to exist in the world. (Author)
PB-173 653

**A TWO-DIMENSIONAL FLUID-SUSPENSION TEST APPARATUS FOR INVESTIGATION OF PRESSURE RATIO, MACH NUMBER AND REYNOLDS NUMBER EFFECTS,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
H. H. Richardson, and W. A. Ribich. 1 Nov 66, 53p DSR-76110-2
Contract C-85-65

The design, instrumentation and evaluation of a small scale two-dimensional test apparatus for investigating the equilibrium and nonequilibrium pressure-displacement-flow characteristics of fluid suspension sealing regions are described. The apparatus is versatile and adaptable to a wide variety of suspension configurations. Dynamic similarity to large scale devices is maintained by varying the ambient pressure level. Ambient pressures from 0.1 psia to 150 psia can be employed in the present apparatus. The system is transparent and permits flow visualization through injection of smoke into the supply flow. Data reduction is automated via direct input of raw data into an IBM 7094 digital computer. Test results are presented for equilibrium and nonequilibrium conditions for tests run at one atmosphere ambient pressure for a peripheral jet suspension. Nonequilibrium cushion flow versus cushion pressure ratio did not show the discontinuity of slope near equilibrium predicted by all inviscid theories. The slopes of the pressure-flow curves were found to be predicted reasonably well by the inviscid underfed jet theory but predictions of actual magnitudes were in error by large factors. (Author)
PB-173 654

**STATIC AND DYNAMIC BEHAVIOR OF A FLEXIBLE BASE FLUID SUSPENSION.**
Master's thesis,
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Barry L. Casey. 1 Nov 66, 111p DSR-76110-5
Contract C-85-65

The object of the thesis is to uncover a set of analytical expressions which will adequately permit the design of a flexible base air bearing and to verify these expressions experimentally. Simplifying assumptions include adiabatic flow through the inlet orifices and in the plenum beneath the diaphragm. Bending and shear stresses in the diaphragm are assumed to be negligible compared to tensile stresses. In the steady-state analysis, an equation is developed which predicts the platform height as a function of plenum pressure and also yields the bearing float limit condition. By averaging and linearizing, a limited amount of dynamic theory is developed which yields the bearing stability limit and completes the analysis. Experimental correlation of the theory is presented as well as a Fortran computer program which performs the necessary computations. (Author)
PB-173 656

**DYNAMIC ANALYSIS OF HEAVE MOTION FOR A TRANSPORT VEHICLE FLUID SUSPENSION,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
W. A. Ribich, and H. H. Richardson. 15 Jan 57, 90p DSR-76110-3
Contract C-85-65

A general lumped-parameter technique for the dynamic analysis of vehicle fluid suspensions operating in the heave mode (translational motion along an axis normal to the mean surface of the vehicle guideway) is presented. The analysis includes the effects of sealing region characteristics, of the fluid source, of the internal geometry, and of base flexibility. A linearization of the general system equations is given which is useful in the study of vehicle-suspension stability and dynamic behavior when the variations in support force are small compared with the average force. The analytical technique described is applied to formulate simple dynamic models for plenum, peripheral-jet, and flexible-base fluid suspensions. The parameters appearing in the dynamic equations can all be determined from computations or measurements of only the static characteristics of the suspensions. Analytical and graphical methods of finding these static parameters are discussed. (Author)
PB-173 685

**PRELIMINARY DESIGN AND TEST OF LINEAR INDUCTION TRACTION MOTORS AND SUSPENSION SYSTEMS,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Dwight M. Baumann, and G. B. Kirby Meacham. 1 Nov 66, 47p* DSR-6106-3
Contract C-85-65

The report presents some very preliminary calculations and experiments investigating linear induction motors for high speed ground transportation. An iron field slotted rotor configuration is proposed for improved performance. The possibility of combined magnetic suspension and propulsion are discussed and found to require pole pieces that are on the order of weight of the vehicle. (Author)
PB-173 686

**AN ANALYSIS OF THE EFFECTS OF FINITE FLUID-SUSPENSION PAD LENGTH ON THE DYNAMICS OF A VEHICLE ON AN IRREGULAR GUIDEWAY,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
W. A. Ribich, K. M. Captain, and H. H. Richardson. Sep 67, 46p
Contract C-85-65

An analysis is presented which describes the heave motion of a fluid-suspended vehicle moving over a guideway in which the irregularity wavelengths may be shorter than the suspension pad length. The analytical model is applied and exact solutions obtained for the cases of plenum and peripheral jet suspensions traversing sinusoidal and pure step irregularities. The technique is shown to be applicable to general irregularity profiles and numerical procedures for the general case are briefly discussed. It is found that compared to predictions based on zero suspension pad length (uniform guideway-suspension clearance) peak acceleration and relative displacements are generally reduced by the effects of finite pad length. Thus a conservative estimate of performance will usually be obtained if pad length effects are ignored. For most vehicle configurations and speeds, however, the attenuation due to finite pad length will be insignificant near the point of maximum vehicle response (near the natural frequency). Vehicle step responses are smoothed and a slight time delay appears compared with behavior predicted from the zero pad length theory. This work suggests that design criteria based on deterministic irregularities and peak dynamic response of the vehicle system can reasonably neglect the effects of finite suspension pad length. Further work is needed to evaluate these effects for statistically described irregularities. (Author)
PB-176 135

**PRESSURE-FLOW-DISPLACEMENT CHARACTERISTICS OF A PERIPHERAL JET FLUID SUSPENSION,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
H. H. Richardson, W. A. Ribich, and Y. Ercan. 1 Jun 68, 68p*
Contract C-85-65

An experimental investigation of the pressure-flow-displacement characteristics of a peripheral jet fluid suspension is summarized. The effects of nozzle pressure ratio, Reynolds number, base recess and jet nozzle size on equilibrium and non-equilibrium characteristics are presented for a 30 deg. nozzle angle. It is shown experimentally that the effects of geometric scaling can be studied adequately by varying ambient pressure level. Inviscid performance theories were found to overestimate equilibrium cushion pressures from 40% at low jet thicknesses, low Reynolds numbers and high hover heights to less than 5% at opposite conditions. Mass flow rates and power requirements were found to be within 15% of the inviscid Barratt theory for the larger jet widths tested. Theories for non-equilibrium jet behavior were found to be inadequate for predicting pressure-flow and displacement-flow sensitivities needed in dynamic models of peripheral jet devices. Predicted discontinuities in these parameters were not observed experimentally. Experimental values of pressure-flow-displacement sensitivities derived from non-equilibrium performance data are presented. These results suggest that for comparable conditions the peripheral jet suspensions will experience higher maximum heave accelerations than corresponding plenum configurations. (Author)
PB-176 136

**ANALYSIS OF OPTIMUM AND PREVIEW CONTROL OF ACTIVE VEHICLE SUSPENSIONS,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Erich K. Bender, and Igor L. Paul. 1 Sep 67, 75p DSR-76109-6
Contract C-85-65

The analysis leading to the optimum transfer function for an active suspension excited by a random guideway input is briefly reviewed and a design chart is presented. A parameter sensitivity study of the stability is performed and shows excellent system stability. The wheel-guideway contact problem is considered and a design chart is developed to check wheel-guideway relative displacement (wheel hop) for active suspensions. The equations for the rms force required to prevent wheel hop are derived and a design chart showing the minimum rms vehicle acceleration which can be obtained while applying this force is presented. The improved vibration isolation characteristics of active suspensions using preview control are investigated for infinite and finite preview distances. It is found that for a simple model infinite preview can reduce the rms vehicle acceleration by a factor of 16 and that a preview time of .4-.5 seconds is sufficient to provide almost the same improvement as infinite preview. It is concluded that active suspension development for vehicle heave, roll and pitch control, particularly for use with preview control is warranted. (Author)
PB-176 137

**SIMPLIFIED STATIC PERFORMANCE CHARACTERISTICS OF LOW-PRESSURE PLENUM AND PERIPHERAL JET FLUID SUSPENSIONS,**
Massachusettes Inst. of Tech., Cambridge. Engineering Projects Lab.
H. H. Richardson, and K. M. Captain. Jan 68, 55p
Contract C-85-65

Simplified relationships and approximate design curves and nomograms are presented which permit the power, mass flow and stiffness of simple

plenum and peripheral jet fluid suspensions to be estimated. Both gravity-loaded and transverse suspensions are considered. The incremental load capacity divided by the design load (force increment) is shown to be a major design parameter for fluid suspensions. Compared with simple orifice-restricted plenums, peripheral jet suspensions are shown to require less power and mass flow and to possess lower stiffness for comparable operating conditions. The advantage in power and flow increases as the force increment increases. A comparison is made between the inviscid peripheral jet performance theory used and experimental data which indicates that the theory gives useful estimates of performance which become more accurate as flow Reynolds number increases. (Author)
PB-177 668

**TRENDS IN SUPERCONDUCTIVITY RELATED TO ELECTROMAGNETIC SUSPENSION OF HSGT VEHICLES.**
TRW Systems Group, Washington, D.C. Washington Operations.
6 Oct 67, 46p* 06818-6009-R000
Contract C-353-66
Report on High Speed Ground Transportation System Engineering Studies Program.

The technology of superconductive magnets was studied because of their potential application to electromagnetic suspension of high speed ground transportation vehicles. The technology was observed to be in the classical period of rapid growth which follows a technological breakthrough. The liquid helium technology was also investigated because it is presently the most feasible technique to maintain the low temperatures required for superconductivity. The electromagnetic suspension system which was proposed for HSGT usage was found to be within the present state of the art except possibly for the proposed current density. (Author)
PB-178 795

**A NEW THEORY OF ROLLING CONTACT.**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
P. Ranganath Nayak, and Igor L. Paul. Apr 68, 156p
Contract C-85-65

The report proposes an entirely new theory of rolling contact. Surfaces are modeled as rough (although rough in this context applies even to ball bearing smooth surfaces which are rough on the micro-scale) and are described statistically. When two rough surfaces are pressed together, their peaks (known as asperities) press against each other and form junctions. Friction in the interface is caused by the shearing of these junctions. An important result of this model is that the relationship between the dimensionless friction force and the dimensionless lateral slip velocity depends on the surface roughness of the wheel and track. This surface roughness is described by a roughness (or smoothness) parameter. The influence of the roughness on the friction is postulated and described. Finally, experimental results are presented which support the conclusions that surface roughness is a relevant parameter in rolling contact and that the force-slip relationship is strongly dependent on surface roughness. (Author)
PB-179 433

**HEAVE DYNAMICS OF FLEXIBLE-BASE FLUID SUSPENSIONS,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
K. M. Captain, and H. H. Richardson. 15 Jan 69, 111p
Contract DOT-C-85-65

The report presents the results of an analytical and experimental study of the heave dynamics of externally pressurized flexible base fluid suspensions operating over guideways containing either deterministic or random irregularities whose wave lengths are large compared to the suspension pad length. The effects of base flexibility and damping, but not of base mass, on the dynamic behavior of suspended vehicles are investigated and relationships are derived between the critical fluid and mechanical parameters which will maximize ride quality for a given vehicle and guideway characteristic. The suspension is modeled as a dynamic lead-lag spring and it is shown that for any value of lead time constant -- as determined by the vehicle weight and size -- there exists an optimum value for the lag time constant (or cushion volume) which minimizes the peak vertical vehicle acceleration. (Author)
PB-183 987

**A VISCOUS-FLOW ANALYSIS FOR THE QUASI-STATIC PRESSURE-FLOW-DISPLACEMENT CHARACTERISTICS OF PERIPHERAL JET FLUID SUSPENSIONS,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Y. Ercan, and H. H. Richardson. 1 Feb 69, 111p
DSR-76110-10
Contract DOT-C-85-65

A viscous-flow analysis is presented which is capable of predicting the static and quasi-static behavior of peripheral jet fluid suspensions operating in the incompressible flow regime. The theory accounts for the observed discrepancies between experiment and inviscid flow analyses by including entrainment and turbulent mixing in the jet and wall boundary layer effects. Equilibrium cushion pressure is predicted within 3 to 4 percent compared with errors up to 40% which occur in even the most conservative inviscid theories. The analysis is used to develop solutions for the non-equilibrium pressure-flow-displacement characteristics required in dynamic analyis of heave motion. Comparison of theory and experiment indicates the slopes of these characteristics (the sensitivities) can be predicted within about 10 percent over the range of jet Reynolds numbers of interest for vehicle suspensions. Curves and digital computer programs are included which permit peripheral jet performance to be determined as a function of geometry, supply pressure and Reynolds number. (Author)
PB-188 358

**PRELIMINARY STUDY OF AN AUGMENTED RAM-WING VEHICLE CONCEPT.**
Final rept. 1 Aug 67-18 May 68,
IIT Research Inst., Chicago, Ill.
Imants Reba. Jan 70, 126p* IITRI-J6128-FR
Contract DOT-7-33512

The report describes a wind-tunnel study of a ram-wing-type vehicle with various blowing arrangements. Two models were studied. One model represented a thick vehicle configuration with a blunted rear end. The second had a streamlined chord section. Blowing arrangements consisted of two two-dimensional Coanda nozzles, one placed near the leading edge and one near the midchord. Upward, downward, and mixed blowing arrangements were investigated. The results indicate that the downward blowing near the leading edge and upward blowing at midspan constitute the most promising of those arrangements investigated. With this arrangement the vehicle has high lift capability at zero forward speed and low drag characteristics at all forward speeds. A range of blowing and pressure coefficients at which a considerable increase in lift-to-horsepower ratio takes place (as compared with a case without blowing) also exists. Similarly, blowing arrangements and blowing coefficients that detrimentally affect power economy also exist. In most cases, blowing permits increasing the wing loading efficiency (weight carried per unit area), independently of forward speed or ground clearance. (Author)
PB-189 425

**A STUDY OF THE STABILITY AND DYNAMIC RESPONSE OF THE LINEAR INDUCTION MOTOR TEST VEHICLE.**
Final rept. Jun 68-Jun 69,
British Railways Board Research Dept., Derby (England). Advanced Project Div.
T. G. Pearce, and B. J. May. Sep 69, 86p* FRA-RT-70-25
Contract DOT-FR-3-0261

The results of extreme dynamical analyses of the suspension system of the linear induction motor (LIM) test vehicles are presented. Suspension stiffness and damper rates are selected on the basis of computations of lateral dynamic stability, curving and response, which should enable the vehicle to travel at speeds up to 250 mph with satisfactory riding characteristics. The influence of variations in suspension parameters is also discussed in relation to possible experimental studies on high speed, wheel supported and guided vehicles, using the LIM vehicle.
PB-192 718

**DYNAMICS OF INDEPENDENTLY ROTATING WHEEL SYSTEMS.**
Final rept.,
TRW Systems Group, Redondo Beach, Calif.
A. Kaplan, and S. A. Short. Jul 70, 74p 06818-6045-RO-00, FRA-RT-71-47
Contract DOT-C-353-66
High-Speed Ground Transportation Systems Engineering Study.

The report presents the results of an analysis of the dynamics of individually rotating wheel systems for use on high speed rail systems such as the Tube Vehicle System (TVS). The objective of this system is to remove the hunting stability problems of conventional rail-wheel systems and thus improve the vehicle ride comfort and safety. The analysis indicates that the use of independently rotating wheel systems eliminates the standard hunting instability, but it introduces a lightly damped but stable oscillation of its own. However, by increasing the yaw stiffness, the frequency of this oscillation can be moved beyond the low point in the human vibration tolerance limit. When this is done, the ride response is improved over that for a conventional integral wheel system. (Author)
PB-194 000

## 32. ADVANCED SYSTEMS: PROPULSION, POWER, AND ENERGY

**SOME PROBLEMS RELATED TO ELECTRIC PROPULSION,**
Massachusetts Inst. of Tech., Cambridge. Dept. of Electrical Engineering.
David C. White, Richard D. Thornton, Charles Kingsley, Jr., David H. Navon, and Sakutaro Nonaka. 1 Nov 66, 133p
Contract C-85-65

Content: Short-stator effects in linear-induction motor; Discussion of the Laithwaite goodness factor; Summary of double-sided linear induction motor design; Summary of the effect on induction motor performance non-sinusoidal excitation; Laithwaite semiconductor-switched motors; A linear induction power-transfer system for vehicles; Design of a double-sided linear induction motor for electric propulsion; Induction motor supplied by simple frequency inverter, producing rectangular voltage waveform.
PB-173 639

**ANALYSIS OF A FREE PISTON HYDRAULIC PUMP,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Dwight M. Baumann, Robert E. Oaklund, and Bruce T. Powell. 1 Nov 66, 83p DSR-6106-2
Contract C-85-65

Among the sets of attributes investigated in the Concepts-keeping, Evaluation, and Development report, were propulsion system reliability, compactness, efficiency and controllability for the family of on-board propulsion component concepts. The consideration of efficiency and compactness pointed to use of chemical fuel with as high a compression ratio as possible. The resulting free-piston-hydraulic pump, (FPHP) described here is a uniflow scavenged, supercharged diesel engine with potential compression ranges up to or exceeding 50:1. (Author)
PB-173 643

**UNIVERSAL DRAG LAW.**
Rept. for Sep 64-Sep 66.
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
S. William Gouse, Jr., and Michael C. Swarden. 6 Dec 66, 79p DSR-76108-2
Contract C85-65
Rept. on Proj. Transport. See also PB-173 646.

The purpose of this report is to present the results of a general examination of the propulsion power requirements of a variety of transport system vehicles in an effort to determine patterns of behavior that might be useful in the preliminary design of high-speed ground-transport systems. The propulsion system will be one of the major sub-systems of any high-speed ground-transport system, and there are several ways in which one can begin making estimates on the magnitude of the power requirements. One way is to extrapolate the performance of existing vehicles into higher speed regions. Another might be to make detailed designs of various HSGT systems. Still a third approach to the estimation of potential power requirements is to base it on the best performance attained by all classes of vehicles with existing technology. The last approach was based on the estimation of potential power requirements on the updating of the Gabrielli-von Karman technology limit line which first appeared in 1947. In addition to adding the performance of supersonic aircraft, supertankers, and missiles on a gross weight basis, we have examined the performance of a variety of transport systems on a payload basis and found a payload performance technology limit line similar to the gross weight performance technology limit line established by Gabrielli and von Karman in 1947. (Author)
PB-173 647

**PRELIMINARY DESIGN AND TEST OF LINEAR INDUCTION TRACTION MOTORS AND SUSPENSION SYSTEMS,**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Dwight M. Baumann, and G. B. Kirby Meacham. 1 Nov 66, 47p* DSR-6106-3
Contract C-85-65

The report presents some very preliminary calculations and experiments investigating linear induction motors for high speed ground transportation. An iron field slotted rotor configuration is proposed for improved performance. The possibility of combined magnetic suspension and propulsion are discussed and found to require pole pieces that are on the order of weight of the vehicle. (Author)
PB-173 686

**STUDY OF LINEAR INDUCTION MOTOR AND ITS FEASIBILITY FOR HIGH-SPEED GROUND TRANSPORTATION.**
Final rept.
Garrett Corp., Los Angeles, Calif. AiResearch Mfg. Div.
Jun 67, 322p Rept. no. 67-1948
Contract C-145-66 (Neg)

The report presents the results of a study program performed by AIResearch for the Office of High Speed Ground Transportation, U. S. Department of Transportation. This program is concerned with determining the feasibility and practicality of utilizing linear induction motors for high-speed ground transportation (HSGT) propulsion at speeds up to 500 mph. Detailed consideration is given to the electrical, thermal, and mechanical aspects of linear induction motor design. The electrical design analysis considers motor end effects, reaction rail design, and other motor design parameters influencing performance. The analytical models derived in the study for electrical design are verified in laboratory tests using small rotary motors designed to provide the desired data. Data on five reaction rail designs are reported. A composite reaction rail design is recommended for optimum motor performance, although other types are considered for special characteristics. The thermal studies indicate that the minimum motor size consistent with appropriate operating temperature levels for long motor life corresponds to specific continuous thrusts on the order of 1.2 to 2.4 lb per sq in. per side of motor area. The problems of air gap control, speed control, and power supply are analyzed to determine suitable provisions in the design of HSGT propulsion systems incorporating linear induction motors. Recommendations for future work include fabrication and testing of a full-scale (2500 hp) prototype linear induction motor. (Author)
PB-174 866

**APPLICATION OF HIGH POWER SOLID-STATE ELECTRONICS TO ELECTRIC PROPULSION,**
Massachusettes Inst. of Tech., Cambridge. Dept. of Electrical Engineering.
Richard D. Thornton, David H. Navon, J. Lichtenberger, C. Erdelyi, and E. Miller. 4 Oct 67, 67p
Contract C-85-65

The work reported here is concerned with the application of high power electronics to electric propulsion. During the last year the effort has been in two main areas: (1) development of improved high power semi-conductor switches and (2) the development of lightweight, low inductance machines which are well matched to semi-conductor device capabilities.
PB-176 920

**HIGH SPEED GROUND TRANSPORTATION. A PRELIMINARY STUDY OF THE LINEAR INDUCTION MOTOR FOR HIGH SPEED GROUND TRANSPORTATION.**
TRW Systems Group, Washington, D.C. Washington Operations.
Jan 68, 120p Rept. no. 06818-W454-R0-12
Contract C-353-66

A theoretical study was undertaken to describe the characteristics of a linear induction motor for High Speed Ground Transportation. A quasi-one-dimensional analysis is made of a linear induction motor without recourse to the usual idealization of the polyphase stator windings into current sheets. The analysis assumes that the stator windings and the induced currents inside the reaction rail (rotor) produce a resultant traveling wave magnetic field at the stator surfaces, and under the assumption of negligible end effect, the electromagnetic boundary conditions are applied to determine the attenuation of the magnetic field, both inside the reaction rail and at the air gap between the reaction rail and stator surfaces. Taking into account real machine effects, expressions based on classical AC machine theory are given for the required exciting current, the generated voltage, the net power output, and the electrical efficiency. Results are reduced into equivalent circuit form so comparisons can be made with conventional rotary induction motors. (Author)
PB-178 202

**NONFRICTIONAL POWER COLLECTION FOR GUIDED HIGH-SPEED GROUND VEHICLES.**
Final rept. (Part 2).
General Electric Co., Schenectady, N.Y. Research and Development Center.
12 Apr 68, 147p* S-68-1056
Contract C-7-35121

The report is a preliminary evaluation of four basic noncontacting methods of transferring motive electrical power to high-speed trains (up to 300 miles per hour). The four methods considered are: Gaseous Conduction by a Controlled Electric Arc; Magnetic Induction Using Lenz's Law of Flux Linkage; Capacitive Coupling by Displacement Currents Between Parallel Plates; Electromagnetic Directional Wave-guide Coupling. Examination and calculation of several configurations of the four methods considered established data for comparison. The evaluations include the system functions of power conditioning, power transmission, noncontacting coupling, and onboard power conversion; however, emphasis is on the equipment directly associated with the coupling. (Author)
PB-178 228

**SPECIFICATIONS FOR LINEAR INDUCTION MOTOR P/N 546230, TURBOALTERNATOR PACKAGE P/N 546798, AUXILIARY POWER UNIT P/N 928288, MANUAL CONTROL P/N 44290,**
Garrett Corp., Los Angeles, Calif. AiResearch Mfg. Div.
G. P. Kalman, and J. Chapa. 24 Mar 69, 44p 68-3400-1
Sponsored by Office of High Speed Ground Transportation, Washington, D.C.

The document describes the basic power systems supplied for the linear induction motor test vehicle. The alternator is matched to the turbine, and is capable of providing 3000KVA at 0.6 pf. at 173 Hz, which can be exceeded only by using military overload' of the gas turbine. The linear induction motor was designed to be compatible with the turboalternator and produce 3750 lb thrust, 0 to 250 mph, 2500hp. The linear induction motor, however, is also capable of much higher performance if suitable electrical power is supplied. (Author)
PB-183 362

**FEASIBILITY STUDY OF LINEAR INDUCTION MOTOR THRUST BOOSTERS FOR DIESEL-ELECTRIC LOCOMOTIVES.**
Rept. for 1 Nov-31 Dec 68,
Garrett Corp., Los Angeles, Calif. AiResearch Mfg. Div.
G. P. Kalman, and B. W. Hafele. 21 Mar 69, 51p 69-4862
Contract DOT-FR-9-0014

Both the technical and economic feasibility of utilizing surplus power available from the diesel engine, by adhesion-independent thrust boosters were reviewed. First the power available for thrust boosting was determined. Then several linear motor reaction rail configurations were considered. A preferred thrust booster configuration (Figure 1-1) which utilized the running rails as the secondary member, was described. It was found that 6000-lb force per locomotive, at 12 to 13 mph train speed can be delivered by such a thrust booster. (Author)
PB-184 252

**TUBEFLIGHT POWER-DEMAND TESTS AND INITIAL VALIDATION OF THEORY: 1. ESTIMATED PERFORMANCE OF WHEEL-SUPPORTED VEHICLES TO BE TESTED IN FACILITY T-2. 2. INTERPRETATION OF INITIAL TUBEFLIGHT PROPULSION TEST RESULTS, AND COMPARISON WITH THEORY. 3. TESTS OF WHEEL-SUPPORTED VEHICLES IN THE T-2 FACILITY,**
Rensselaer Polytechnic Inst., Troy, N.Y.

Joseph V. Foa, N. A. Messina, P. A. Graham, and W. B. Brower, Jr. Feb 69, 116p TN-PT-6802, TR-PT-6905
Contract C-117-66
Also includes Report TN-PT-6901.

To permit correlation between the predictions of PB-177 520 and the results of the small-scale model tests that are to be conducted in facility T-2, the power demands of these models are calculated by a procedure that is essentially the same as that of PB-177 520, except for such changes in the analytical model as are suggested or called for by the conditions of the tests. Experimental power demand data are presented for tests of the RPI MK IIc scale-model tubeflight vehicle in test facility T-2. This is done by use of propeller efficiency data generated through testing in the tubeflight wind tunnel, facility T-3. A description of the Mark IIc (wheel-supported) tubeflight vehicle is given. A series of test runs in the T-2 Facility is reported in which the top speed was about 76 feet per second. This result checks very closely with theoretical predictions for this vehicle. (Author)
PB-184 435

**POWER COLLECTION BY SLIDING CONTACT METHODS FOR HIGH SPEED GUIDED VEHICLES. PHASE I. ANALYZE TECHNIQUES AND DESIGN CONCEPTS.**
Final rept.
General Electric Co., Erie, Pa. Transportation Systems Div.
Aug 69, 166p
Contract DOD-FR-9-0023
Systems Design and Materials Studies.

As a result of the high speed (300 mph) power collection research, specific recommendations are developed for power collection system design, candidate materials and further analysis and testing. Each of these areas is covered in detail. A power collection system based on the use of multiple contacts mounted on a servo driven support is recommended. Techniques for material selection are developed and used for the selection of preferred candidate materials for both the distributor and collector. Recommendations are presented for evaluation and verification of both collector system design and materials selection with laboratory-type equipment. (Author)
PB-185 449

**PRELIMINARY STUDY OF A ROTOR DRIVEN BY LEADING-EDGE BLOWING.**
Final rept.,
IIT Research Inst., Chicago, Ill.
Imants Reba. Jan 69, 61p IITRI-J6128-FR
Contract DOT-7-35512

The report summarizes a preliminary experimental study of a new propeller concept. The propeller blades were symmetrical 33-percent-thick air foil sections. Rotational speed was provided by a sheet of air ejected through a spanwise slit cut near the leading edge (Coanda effect). The study was performed at static conditions (zero advance velocity) and at a velocity of advance of 28 fps. At static conditions the 21-in.-diameter rotor produced lift augmentation up to 2.6 and up to 7.95 lb thrust per air horsepower. Lift coefficients of the blades as high as seven were measured. The actual test data yielded a figure of merit of 0.218 max. Upgrading based on limited experimental data indicate that M approx.=0.6 may be attained. At dynamic conditions, this rotor produces higher thrust coefficients and operates at higher advance ratios than a conventional propeller. Thus, a blown foil propeller is capable of generating higher disk loadings while operating at lower rotational speeds. The presently encountered propulsive efficiencies are low, but an extrapolation of data indicates that at least in the range of low advance velocities (at low efficiency regime) the propulsive efficiency of a blown foil propeller may be comparable to that of conventional propeller. (Author)
PB-185 511

**PRELIMINARY DESIGN STUDY OF A LINEAR INDUCTION MOTOR WITH AN ALUMINUM BONDED TO STEEL REACTION RAIL.**
Final rept.
Westinghouse Electric Corp., Pittsburgh, Pa. Transportation Div.
25 Aug 69, 137p*
Contract DOT-9-0025

High speed ground transportation vehicles that are propelled by linear induction motors (LIM) may prove to be attractive alternatives for high speed inter-city transit. One concept for such a vehicle system employs a steel I-beam to guide the vehicle. The steel I-beam, onto which has been bonded some material of high conductivity, serves as the reaction rail for the LIM. The purpose of the study was to determine if a steel I-beam acting as the LIM reaction rail could be used to guide and support the LIM as well as guide the vehicle. If such an arrangement would prove practical, a large cost saving might be realized in guideway construction for the Tracked Air Cushion Vehicle (TACV). (Author)
PB-186 231

**ELECTRIC POWER SYSTEMS FOR HIGH SPEED GROUND TRANSPORTATION.**
Final rept.
Westinghouse Electric Corp., Pittsburgh, Pa. Transportation Div.
25 Aug 69, 352p*
Contract DOT-9-0025

This study investigates the power needs of four classes of systems: (1) 300 mph Tracked Air Cushion Vehicle (TACV); (2) 250 mph Linear Induction Motor (LIM)-driven rail vehicle; (3) 250 mph wheel-driven vehicle; (4) 200 mph wheel-driven rail vehicle. Task areas for the study are: (1) Power systems; (2) Power distribution; (3) Power collection; (4) Power conditioning.
PB-186 232

**LIM GUIDANCE CONTROL SYSTEMS,**
Mitre Corp., McLean, Va.
J. D. Muhlenberg. Jun 70, 175p MTR-4136-Rev-1, FRA-RT-71-46
Contract DOT-7-35248

The feasibility of control systems for positioning the LIM with respect to the reaction rail without physical contact is examined. Preliminary design analyses are made for several representative systems. Systems for use with both a ferrous or composite reaction rail and a nonferrous rail are examined and comparisons of system performance are made. A comprehensive performance criterion is developed. Recommendations for future investigations are made. (Author)
PB-193 933

**ATTRACTION/REPULSION FORCES IN A SINGLE-SIDED LINEAR INDUCTION MOTOR.**
Final rept.,
Mitre Corp., McLean, Va.
J. K. Dukowicz. Mar 71, 33p WP-7519 FRA-RT-71-78
Contract OHSGT-7-35248

Calculations of the normal force-to-thrust force ratio are made for some simple one-dimensional LIM secondary models, (i.e., effects of finite geometry are not considered). The principal result is the determination of the cross-over when the normal force changes from being attractive to being repulsive. At this point, one-sided LIMs begin aiding the guidance/support system instead of opposing it. The results indicate that for a single-sided LIM similar to the TACRV/ADLIM, the normal force is repulsive for almost the entire operating range. This is less true for a low-speed LIM. (DOT abstract)
PB-200 685

# 33. ADVANCED SYSTEMS: CONTROL AND COMMUNICATION

**LITERATURE SURVEY ON THE COMMAND AND CONTROL OF HIGH-SPEED GROUND ORIENTED TRANSPORTATION SYSTEMS.**
Hughes Aircraft Co., Fullerton, Calif. Transportation Research Project Office.
Mar 66, 56p FR-66-11-65
Revision of FR65-11-281.
PB-170 561

**OPTIMAL DISPATCHING POLICIES BY DYNAMIC PROGRAMMING.**
Research rept.,
Massachusetts Inst. of Tech., Cambridge. Dept. of Civil Engineering.
Donald Evan Ward. 1 Nov 66, 102p R66-55
Contract C-85-65

The paper describes methods of determining optimal vehicle dispatching schedules by the use of dynamic programming techniques. Using cost criteria based on minimizing a combination of passenger delay and system capacity, these techniques were applied to vehicle scheduling for three variations of linear networks of dispatching stations: point-to-point (one way), line of stations (one way), and two-station line (round trip). FORTRAN programs were written to aid in both the generation and analysis of the optimal schedules. Various dispatching policies are examined with respect to system parameters such as vehicle capacity, load factor, and fleet size. An analysis and comparison of the optimal schedules in terms of passenger delay and vehicle fleet size are made with some non-optimal schedules similar to those used in many present-day operations. Optimal schedules yielding minimum passenger delay are shown to be superior with respect to most other system variables. The value of dynamic programming in these and future scheduling studies is discussed. (Author)
PB-173 636

**ON THE OPTIMAL AND SUBOPTIMAL POSITION AND VELOCITY CONTROL OF A STRING OF HIGH-SPEED MOVING TRAINS,**
Massachusetts Inst. of Tech., Cambridge. Electronic Systems Lab.
Michael Athans, William S. Levine, and Alexander H. Levis. Nov 66, 73p
Contract C-85-65
Rept. on Project Transport.

The study was motivated by the interest in developing a high-speed ground-transport (HSGT) system for the Northeast Corridor. The report contains general methods for controlling the spacing, velocity, and acceleration of individual vehicles in a tightly-packed string of high-speed trains. The control of vehicles moving in a string can be divided into four functions: The control of the starting and stopping operations; The injection and ejection of vehicles from the main guideway; The normal operation of a string of vehicles (far from stations) at essentially constant velocity and separation; and the control in emergency situations. (Author)
PB-173 640

**ORGANIZATION OF SYSTEM CONTROL,**
Massachusetts Inst. of Tech., Cambridge. Electronic Systems Lab.
R. W. Brockett, and R. J. Canales. Nov 66, 25p
Contract C-85-65

In the report a general method of designing control laws for very complex systems is described. A particular multipoint scheduling problem which has potential application in the operation of a high-speed ground transportation system is given to illustrate the approach. The basic assumption made

is that the system to be controlled is so complex that mathematical optimization, even with the aid of a high-speed computer, is either impossible or too expensive--an assumption that holds even for relatively simple scheduling problems. Of course this assumption implies that the optimization problem must be divided into smaller parts and a sub-optimal solution sought. By the development of precise lower bounds on the performance of the system it is possible, however, to obtain an estimate of how close to optimal the system is. This leads to the definition of a performance ratio which characterizes the efficiency of the control system and provides what should be a very useful design parameter. (Author)
PB-173 641

**HEADWAY AND SWITCHING STRATEGIES FOR AUTOMATED VEHICULAR GROUND TRANSPORTATION SYSTEMS.**
Massachusetts Inst. of Tech., Cambridge. Engineering Projects Lab.
Michael Bick Godfrey. 1 Nov 66, 170p
Contract C-85-65

The report considers the distribution of headways throughout the vehicle flow on a one-lane guideway, the splitting of such a flow at a diverging switch, and the merging of two such flows at a converging switch. The focus of the investigation was on several vehicles near a single switch, rather than on the entire system as an integrated entity. The minimum headway separating two isolated vehicles or trains is shown to be a function of time delays in information transmission and processing, uncertainties in the measurement of, and errors in, kinematic variables, emergency stopping distance, and a cost criterion pertaining to reliability and expected damage. Several alternative headway distributions among vehicles in single-lane flow are presented, and maximum flow rates are computed as functions of these strategies and system performance parameters. The propagation of velocity transients is discussed in terms of responses to the probable inputs to a single-line of traffic. It is shown that controlling headways to a single-valued function of velocity leads to undesirable responses, and that headways must include some space in excess of the minimum safe headway. In addition to the minimum headway strategies, there is a presentation of several possible merging strategies for a converging switch and of queue disciplines to yield either maximum or minimum queue lengths. (Author)
PB-173 644

**OPTIMAL VEHICLE CONTROL FOR THE MERGING PROBLEM,**
Massachusetts Inst. of Tech., Cambridge. Electronic Systems Lab.
Michael Athans, and William S. Levine. Nov 67, 30p ESL-R-327
Contract C-85-65

The report deals with the problem of the control of high-speed vehicles so that safe merging from two guideways into a single one takes place. The theory of optimal control is used to analyze the problem. Two main results are obtained: first, the optimal control of the vehicles is obtained for any given merging sequence and second, the best possible merging sequence is obtained. (Author)
PB-176 921

**SAMPLED-DATA CONTROL OF HIGH-SPEED TRAINS,**
Massachusetts Inst. of Tech., Cambridge. Electronic Systems Lab.
Alexander H. Levis, and Michael Athans. Jan 68, 56p* ESL-R-339
Contract C-85-65

The report deals with the control of the positions and velocities of high-speed vehicles in a single guideway. It is assumed that each and every train measures its position and velocity every T seconds. The appropriate accelerations or decelerations to be applied to each vehicle are constrained to be constant during the sampling interval. Through the use of a control costs functional, which penalizes the system for any deviations from the desired headway and velocity, the required control accelerations and decelerations are obtained by deriving the system equations in discrete-time and, through the use of available results in the theory of discrete optimal control, the optimal linear time-invariant sampled-data feedback control system is determined. The general results, as well as the general purpose digital computer programs, are presented and are used to study the effect of changing the sampling time T upon the control-system performance. Since, in general, the cost of the communication system (in terms of required channel capacity, bandwidth, etc.) decreases with increasing values of the sampling time, the system designer has the capability of conducting trade-off studies involving the deterioration of the control system performance vs. the decrease in the cost of communication as the sampling time is increased. (Author)
PB-177 669

**USE OF SURFACE WAVES IN COMMUNICATING WITH HIGH SPEED VEHICLES.**
Technical rept.,
Institute for Telecommunication Sciences, Boulder, Colo.
R. L. Gallawa, W. M. Beery, T. M. Chu, K. R. Cook, and R. G. FitzGerrell. 15 Jun 68, 155p*
Prepared in cooperation with Department of Transportation, Washington, DC. Office of High Speed Ground Transportation.

The potential use of surface waves in communicating with and controlling high speed ground vehicles has been under study. Consideration was given to the Goubau line or G-line in particular, and it was found that it has many attractive features. The various facets considered include launching, line characteristics, coupling to the moving vehicle, and communication capacity. It appears that the use of surface waves shows great promise in providing the bandwidth and economy required to meet the communication demands of the high speed ground transportation problem. (Author)
PB-178 794

**FEASIBILITY STUDY OF COUPLED LEAKY WAVEGUIDE SYSTEM FOR COMMUNICATION IN HIGH SPEED GROUND TRANSPORTATION.**
Technical rept.,
Sumitomo Electric Industries Ltd., Osaka (Japan).
Tsuneo Nakahara, Taichiro Nagao, Noritaka Kurauchi, Ken-ichi Yoshida, and Hiroshi Kitani.
31 Oct 68, 77p
Contract DT-3-0212

The use of a coupled leaky waveguide system for high speed ground transportation communication was studied and found to be feasible. The coupled leaky waveguide system has leaky circular waveguides along the track and a coupling antenna on the trains. Basic properties of the leaky circular waveguides were determined theoretically. The coupling was estimated based on earlier experiments. The FDM-FM system was shown to be applicable to the modulation and multiplex requirement of the system. Basic structure and signal level diagrams were presented for the proposed coupled leaky waveguide system. The unwanted radiation levels were estimated in comparison with the FCC restrictions. The interference on this system was also estimated. (Author)
PB-180 750

**HIGH SPEED GROUND TRANSPORTATION COMMUNICATIONS SYSTEM.**
Final rept.,
Hughes Research Labs., Malibu, Calif. Electron Device Physics Dept.
R. E. Lundgren, and G. R. Nudd. Nov 69, 268p*
Contract DOT-FR-09-0007

The report contains the results of an investigation concerning the communication aspects of a high speed ground transportation (HSGT) system. The study was restricted to the portion of the frequency spectrum between 30 and 65 GHz. In contrast to communication systems which operate at lower frequencies, this millimeter-wave portion of the spectrum makes available to the system designer very large bandwidths, of the order of several gigahertz, and tehcniques for insuring system isolation and freedom from interference. The characteristics and feasibility of two types of communication system were considered. It is concluded that, on a performance basis, a system employing a leaky wavequide transmission medium is the better of the two; however, if cost is the overriding determinant, a communication system which employs atmospheric propagation should be considered. (Author)
PB-189 416

**DIELECTRIC WAVEGUIDE FOR COMMUNICATION WITH HIGH SPEED VEHICLES.**
Final rept.,
General Applied Science Labs., Inc., Westbury, N.Y.
Manlio Abele. 1 Aug 69, 154p* GASL-TR-729
Contract DOT-FR-9-0016

This report assesses the feasibility of a wireless, non-radiating communication system based on the use of a dielectric waveguide. The dielectric waveguide is composed of a dielectric rod attached to a metallic shield. The transfer of an electromagnetic signal to and from a vehicle moving parallel to the waveguide is accomplished by means of a coupler mounted on the vehicle itself without a physical contact with the dielectric waveguide. Both the waveguide and the moving coupler theoretically are non-radiating units. Consequently, no radiation is emitted by the system and conversely it does not couple with external electromagnetic signals which propagate in the surrounding environment. The feasibility study, conducted in the X-band or 8.8 to 9.0 GHz, has shown that the concept provides a reasonably simple and efficient communication system with a moving vehicle. In terms of radiation losses and rejection of external electromagnetic signals, the performance of the waveguide is good and consequently it can be used in regions of crowded electromagnetic environment. (Author)
PB-189 476

**VERIFICATION OF FEASIBILITY STUDY OF COUPLED LEAKY WAVEGUIDE SYSTEM FOR COMMUNICATION IN HIGH SPEED GROUND TRANSPORTATION.**
Final technical rept.,
Sumitomo Electric Industries Ltd., Osaka (Japan).
Tsuneo Nakahara, Ken-ichi Yoshida, Masataka Kuroda, Noritaka Kurauchi, and Kenji Takemura.
2 Jan 70, 141p*
Contract DOT-FR-9-0042
See also PB-180 750.

Laboratory-scale tests and extensive studies were carried out to verify the feasibility of a coupled leaky waveguide system. Aluminum waveguides with radiation holes and some components were fabricated for the test. The attenuation constants and coupling properties were measured, and these measurements agreed well with the theory. Installation of waveguides in a duct with plastic cover proved effective to eliminate foreign substances depositing thereon affecting transmission loss. Suppression of radiation was measured by use of various combinations of wall materials. Expected suppression radiation effects were obtained even with combinations of metal and concrete. The effect of rain on the attenuation and coupling were measured. Though phase distortion due to waveguide irregularity could not be measured, the theoretical limitation of phase distortion was obtained, which provided the data required to evaluate the waveguide properties employing the vari-

ous modulation and multiplex systems and also the channel band width capacities. Signal-to-noise ratios were calculated for voice channels in typical cases of the coupled leaky waveguide system with a 400 mile waveguide length with estimates for FDM-FM and PCM-PM systems including the thermal, intermodulation, and distortion noises.
PB-189 481

**REQUIREMENTS AND METHODOLOGY FOR EVALUATION OF THE WAYSIDE COMMUNICATION LINK.**
Final rept. 2 Dec 68-16 Jun 69.
New Mexico State Univ., Las Cruces. Physical Science Lab.
Sep 69, 72p* PSL-PR00651
Contract DOT-FR-9-0026

The study was devoted to formulating technical requirements for the HSGT wayside communications medium and to developing a methodology for determining the most suitable of the proposed media. (Author)
PB-189 778

**DEVELOPMENT AND DEMONSTRATION OF W-LINE COMMUNICATIONS WAVEGUIDE AND COMPONENTS FOR HIGH SPEED GROUND TRANSPORTATION.**
Final rept.,
Wheeler Labs., Inc., Smithtown, N.Y.
Irwin Koffman, Richard Lodwig, Henry Redlien, and Harold Wheeler. Dec 69, 78p* WL-1611A
Contract DOT-FR-9-0022

There have been developed and demonstrated, a continuous-access waveguide and accessory components for use in providing non-radiating communications with a high-speed vehicle on a track. The waveguide has the form of an open-sided TEM-mode transmission line; coupling to a vehicle is provided by a non-contacting directional coupler on board the vehicle. The waveguide assembly operates in the VHF range, giving channel capacity for several TV channels and other services with no appreciable distortion. The line has a square outer conductor with one side open but protected by a cover of dielectric sheet. It has a round inner conductor supported by beads of dielectric sheet. The line is intended to be self-supporting between posts. It may be assembled from sections with expansion joints as may be required. (Author)
PB-191 028

**EVALUATION OF FDM-FM MODULATION FOR USE ON WAYSIDE COMMUNICATION SYSTEMS.**
Final rept. 17 Jun 69-12 Jan 70.
New Mexico State Univ., Las Cruces. Physical Science Lab.
Mar 70, 128p PSL-PE00651 FRA-RT-70-37
Contract DOT-FR-9-0026

The frequency response of Long Transmission Line with multiplex reflection discontinuity is obtained by computer simulation. A criterion is derived for evaluating frequency division multiplex on a frequency modulation carrier for transmission over the simulated lines. (Author)
PB-191 788

**A SURFACE - WAVE TRANSMISSION LINE FOR VEHICULAR COMMUNICATIONS.**
Final technical rept.,
Institute for Telecommunication Sciences, Boulder, Colo.
R. G. FitzGerrell, L. L. Haidle, and J. E. Partch.
Feb 70, 147p

A year's study carried out by the ESSA/ITS Guided Wave Technology Group under contract from the OHSGT/DOT indicates that low cost, excellent coupling characteristics, and ability to serve vehicles on two closely spaced guideways make the Goubau surface-wave transmission line an attractive solution to the high-speed ground transportation communications problem. Further testing in a real environment should be undertaken to prove or disprove the encouraging results obtained experimentally with the 918-ft prototype line used in this study. (Author)
PB-194 146

**VP COMMUNICATIONS LINE PROJECT.**
Final rept.,
TRW Systems Group, Washington, D.C. Washington Operations.
D. L. Rebsch. Jul 70, 68p* 06818-W010-RO-00
FRA-RT-71-52
Contract C-353-66
Report on High-Speed Ground Transportation Systems Engineering Study.

The concept of a variable parameter (VP) communications line is introduced. The VP concept permits control of the location and amount of electromagnetic radiation escaping from a transmission line to a nearby receiver. A specific implementation of the VP concept, utilizing ferrite loaded apertures activated by an external magnetic field, is studies. A coupling ration (defined as the ration of the radiated power in the 'ON' or activated condition to the radiated power in the 'OFF' or unactivated condition) of 20 dB is observed in agreement with theoretical predictions. The incorporation of the VP concept in certain existing transmission lines is analyzed. (Author)
PB-194 370

**REPEATER STATION FOR A DIELECTRIC WAVEGUIDE COMMUNICATIONS SYSTEM.**
Final rept.,
General Applied Science Labs., Inc., Westbury, N.Y.
Manlio Abele. May 70, 41p GENAPPSL-70-743
Contract DOT-FR-9-0016-1

The research program was developed to study a new repeater station concept for a dielectric waveguide communication system. The recommendations and summary of the results are presented. For completeness the principles of operation of the dielectric waveguide communication system are summarized. The concept of the new repeater station and the experimental results are presented. (Author)
PB-194 373

**NETWORK CONTROL STUDY.**
Final rept.,
TRW Systems Group, Washington, D.C.
R. K. Boyd, L. R. Bogert, and I. F. Kan. Jul 70, 103p 06818-W019-RO00 FRA-RT-71-77
Contract DOT-C-353-66

The usefulness of a ground transportation system controlled by synchronous techniques would be severely limited if occurrences such as link blockage, reduced operating velocity or equipment failures could be accommodated only by loss of system-wide synchronism. Consequently, this study examined in depth the strategies and techniques which could accommodate a wide range of real life problems. It was found that excellent accommodations could be made for all types of problems, thus assuring the efficacy of the synchronous approach to traffic management. (Author)
PB-199 124

## 34. ADVANCED SYSTEMS: OBSTACLE DETECTION

**OBSTRUCTION DETECTION PROGRAM.**
Final rept.
RCA Corp., Princeton, N.J.
15 Mar 69, 162p
Contract DT-7-35509

An obstacle detection system comprised of transmitters and collocated receivers spaced alongside railroad tracks and scanning across the tracks to a continuous retroreflective fence was studied, tested, and demonstrated. The transmitters emit a very narrow beam of collimated coherent light from a galium arsenide laser. The retroreflector establishes a narrow region with reflectivity substantially higher than the normal surroundings. An object located between the laser transmitter and the retroreflector will prevent the laser beam from impinging upon the retroreflector and will, therefore, cause a variation in the return energy normally observed by the receiver. This variation is then reported to a central control station for further action. An engineering model of a laser scanner was designed and built. In combination with an engineering model of a retroreflective fence, the scanner engineering model was used to successfully demonstrate the feasibility of the system concepts. (Author)
PB-182 996

**OBSTACLE DETECTION FOR HIGH SPEED GROUND TRANSPORTATION.**
Final rept. Jun 69-Jun 70,
General Applied Science Labs., Inc., Westbury, N.Y.
Daniel E. Magnus, Hector Medecki, Sergio Panunzio, and Paul Sallustio. Jun 70, 121p
GENAPPSL-TR-745
Contract DOT-FR-0057

Results are presented from the investigation of optical sensors as a means for detecting obstacles on the guideway of a high speed transportation system. Operating characteristics for such sensors were investigated experimentally and analytically. Both approaches are described in the report. In addition, the kinematics of the optical sensor for scanning the guideway is reviewed. A scanner was designed and demonstrated in the laboratory. The performance of the optical sensor is dependent upon the extent of the ray bending which is caused by the solar heating of the air immediately above the guideway. The effect of ray bending is presented in terms of a relationship between obstacle size and length of the optical path. The sensor is investigated for deployment along a TACV guideway and estimates of cost per mile are included. (Author)
PB-194 374

## 35. ADVANCED SYSTEMS: HUMAN FACTORS AND SAFETY

**LITERATURE SURVEY OF PASSENGER COMFORT LIMITATIONS OF HIGH-SPEED GROUND TRANSPORTS,**
United Aircraft Corp., East Hartford, Conn. Research Labs.
J. P. Carstens, and D. Kresge. 26 Jul 65, 60p Rept. no. D-910353-1
Research supported by Department of Commerce, Washington, DC.

A literature survey was made of passenger comfort criteria applicable to high-speed ground transports. Factors considered include acceleration vibration, pressure changes, atmospheric contamination, visual disturbances, and noise. Literature examined includes engineering data pertinent to the analysis of riding comfort in trains, automobiles, and airplanes, as well as aerospace medical and other medical sources. The results of the survey are presented in figures and tables. A summary of recommended values of the pertinent variables is also provided. (Author)
PB-168 171

**HIGH SPEED GROUND TRANSPORTATION: NOISE SOURCES,**
Bolt Beranek and Newman, Inc., Cambridge, Mass.

C. W. Dietrich, Erich K. Bender, R. D. Bruce, H. H. Heller, and P. Ranganath Nayak. 6 Oct 68, 52p BBN-1741

Analyzing the noise problem in high-speed ground transportation passenger spaces, this report identifies: (a) sources, (b) paths, and (c) receivers. It examines ways of establishing noise-level criteria for HSGT vehicles.
PB-182 752

## 36. ADVANCED SYSTEMS: TRANSPORTATION SYSTEMS ANALYSIS

**DEMAND FOR INTERCITY PASSENGER TRAVEL IN THE WASHINGTON-BOSTON CORRIDOR.**
Systems Analysis and Research Corp., Boston, Mass.
1963, 288P

The study has four main objectives: (1) Identification and measurement of the principal factors influencing intercity passenger demand; (2) identification and measurement of the principal factors influencing the division of intercity passenger demand by mode; (3) projection of intercity passenger demand in the corridor through 1980, and (4) delineation of further study requirements.
PB-166 884

**TRANSIM -- GENERAL PURPOSE TRANSPORTATION SYSTEM SIMULATOR -- USER'S MANUAL.**
California Univ., Los Angeles. Dept. of Engineering.
May 66, 231p Rept. no. 66-6
Contract Cc-6220
See PB-173 017 for the IBM-1401 and 7090/7094 punched cards.

The TRANSIM transportation simulator was developed at the University of California, Los Angeles, to fill the need for a general-purpose computer simulation method which is simple and economical to use for a wide variety of problems in transportation; these may concern different modes, traffic types, firm sizes, or system situations. The User's Manual describes the simulator and delineates the procedures for its use. The User's Manual also discusses topics of more general interest, such as the concept of the systems approach, and the difference between mathematical models and computer simulators such as TRANSIM.
PB-173 016

**OPERATIONS ANALYSIS OF SYSTEM SPECIFICATIONS. PART I. PASSENGER SCHEDULING.**
Research rept.,
Massachusetts Inst. of Tech., Cambridge. Dept. of Civil Engineering.
E. F. Bisbee, J. W. Devanney, III, K. U. Bhatt, S. Kuroda, and Donald Evan, Ward. 1 Nov 66, 62p R-66-54
Contract C-85-65

In this report some service properties of a transport system that result from operating policies are formulated jointly with system costs. By varying major system design parameters such as vehicle size, allowable dispatching frequency, fleet size and so on, rather different operating practices are possible each of which yields a quantity of service at a given level and an associated cost. The model finds optimal operating policies with respect to a weighted function of system cost and traveller utility (service level). The resulting evaluations for each set of parameters can serve as a basis for comparison of competing systems which, though only a crude basis, contains generalizable components representing dominant measures of transport effectiveness, i.e., its cost and its apparent desirability. The fundamental assumption made is that all technological aspects of a possible system remain to be selected. The models developed here have further use after component choices are made. (Author)
PB-173 635

**OPTIMUM ALLOCATION OF TRANSPORTATION TERMINALS IN URBAN AREAS.**
Research rept.,
Massachusetts Inst. of Tech., Cambridge. Dept. of Civil Engineering.
Barton Emmet Cramer. 1 Nov 66, 63p RR66-60
Contract C-85-65

The report indicates a method of determining the location of a number of transportation terminals in an urban area in such a way that they were most accessible, and thus had the greatest utility from a system customer's point of view. By equating demand distribution with population distribution, and making some straightforward assumptions about travel velocity and path, a simple circular model was constructed. Subsequent theoretical and numerical analyses using a computer program which was developed from the model suggested several important results. There seems good reason to believe that the model, which is based on very modest assumptions and requires vastly less effort to parametrize than the network approach, will generate solutions which compare favorably with more complex models. (Author)
PB-173 684

**STUDIES ON THE DEMAND FOR FREIGHT TRANSPORTATION, VOL. 1.**
Mathematica, Princeton, N.J.
Aug 67, 263p
Contract DC-7-35120

The volume is devoted to the estimation of freight demand in the Northeast Corridor. It is argued that a mode of freight transportation should be considered in terms of its abstract attributes, and the demand for freight transportation is analyzed in inventory theoretic terms. A macro-economic approach to the matter provides a more complete micro-model designed for descriptive, as well as forecasting, purposes. The grand total demand for freight transportation at the macro-level is estimated at the first stage on the basis of the values of exogeneous variables; then, at the second stage, the total is sub-divided with the aid of some specifically pertinent variables. In the third stage, the second stage sub-totals are again sub-divided with the aid of still other specific variables, etc. The interdependence of macro-totals on sub-totals is exploited as a part of the estimation technique. The data requirements provided can be useful in developing data banks or future statistical system for the Department of Transportation. A more current data requirements list is also provided. A novel technique for estimation of origin-destination data on freight movements using incomplete information is presented.
PB-176 479

**THE RELATIONSHIP BETWEEN CARRIER CAPACITY AND MEAN PASSENGER WAITING TIME.**
Research rept.,
Massachusetts Inst. of Tech., Cambridge. Dept. of Civil Engineering.
Kent L. Groninger. Sep 67, 53p R67-74
Contract C-85-65

The study is addressed to the problem of determining the relationship between carrier capacity and the expected waiting time of a random passenger at various demand levels. (Passenger arrivals per time.) A passenger is assumed to be in a waiting state during the total time he is in his station of origin from the time he enters until he departs on a moving carrier. A mathematical model of the stochastic process resulting from a 'go-when-filled' carrier dispatching policy is formulated and analyzed. The model assumes that individual passenger arrivals to the station are Poisson and that a minimum headway must be enforced between successive carriers leaving the station. A carrier queueing situation of the form E sub K (absolute D)1 results which is solved for the mean waiting time in queue. A solution technique and computer program for obtaining the roots of a c (th) order, complex, transcendental equation (necessary for a numerical solution of the mean waiting time in queue) is also included. Numerical values of the mean waiting time for various carrier capacities and arrival rates are included to illustrate the relationships. (Author)
PB-176 919

**TRANSPORTATION SCHEDULING UNDER MULTI-DIMENSIONAL DEMANDS.**
Research rept.,
Massachusetts Inst. of Tech., Cambridge. Dept. of Civil Engineering.
J. W. Devanney, III. 16 Dec 67, 73p R67-72
Contract C-85-65

This report describes an algorithm for scheduling passenger transportation systems under the realization that travel demand will both vary with time of day and depend on the schedule. The control variables used are the number of departures per day on each link, the times of these departures, and the number of units dispatched at each departure. The algorithm uses a combination of dynamic programming and heuristic search to generate scheduling policies which attempt to balance the demand attracted and served against the costs of attracting and serving this demand in a manner consistent with the system's objective. The algorithm can accept a wide variety of demand models and objective functions and may be feasibly applied to networks containing several hundred links.
PB-177 527

**TRANSPORTATION SYSTEM OPTIMIZATION PROGRAM DEMONSTRATION PROBLEM.**
TRW Systems Group, Washington, D.C. Washington Operations.
1 Jun 68, 98p* 06818-W917-R000
Contract C-353-66
Report on High Speed Ground Transportation System Engineering Studies Program.

The report describes the application of a computerized methodology to the analysis of a representative ground transportation system. The preferred design and performance characteristics of a tracked air cushioned vehicle system were determined in order to minimize the cost per passenger mile. The vehicle-guideway system was mathematically represented by a set of simultaneous, non-linear, algebraic equations. This description was combined with a cost accounting model and structured for solution on a digital computer. Results were obtained for parametrically varied system performance levels. (Author)
PB-178 797

**SOME FLEET ROUTING AND SCHEDULING PROBLEMS FOR AIR TRANSPORTATION SYSTEMS,**
Massachusetts Inst. of Tech., Cambridge. Flight Transportation Lab.
Amos Levin. Jan 69, 130p FTL-R68-5
Contract C-136-66

The purpose of the work is to formulate and develop practicable solution methods to some important fleet routing, scheduling and fleet composition problems. These problems arise in the operation of air transportation systems like the operating domestic and international airlines. The minimal single fleet problem is extended to include some extraneous constraints on service frequencies between and at stations. Computational results with examples are provided. The problem of system design with and without a given fleet

size is formulated. The problem of decomposition of the system into subsystems, each consisting of a single vehicle type is also formulated in several ways for several considerations. (Author)
PB-183 014

**SIMULATION ANALYSIS OF A HIGH SPEED GROUND TRANSPORTATION SYSTEM.**
Thesis,
Massachusetts Inst. of Tech., Cambridge. Dept. of Naval Architecture and Marine Engineering.
Michael Allen Crane. Sep 68, 231p 68-20
Contract C-136-66
Sponsored in part by the National Science Foundation, Washington, D.C.

A ground transportation system is considered which includes as its proposed operating charactistics: real-time dispatching of trips according to passenger demand; travel from origin to destination without intermediate stops for the purpose of passenger exchange; travel through a network of links and nodes, with constant-speed travel on each link; minimum headway constraints for each link resulting in capacity limits and possible interference between trips; and the possible coupling of vehicles, for more efficient use of channel capacity and reduced propulsion costs. Quantitative measures of cost and utility are developed as criteria for a comparative analysis of operating policies and design parameters. Overall system utility is postulated as an approximate function of a worst-case level of passenger service and a partonage-weighted mean measure of service level. Cost impacts are characterized in terms of vehicle size and a measure reflecting fleet size and vehicle-hours of operation. An event-ordered simulation model representing the transportation system is described in some detail. It is used together with the cost-utility relationships in determining policies and parameters such as vehicle size, fleet size, dispatching policy and vehicle coupling policy. Some consideration is given also to the design of train formation policies and vehicle inventory control policies. (Author)
PB-183 156

**NORTHEAST CORRIDOR TRANSPORTATION PROJECT REPORT,**
Office of High-Speed Ground Transportation, Washington, D.C.
Robert A. Nelson, Paul W. Shuldiner, Myron Miller, and Robert L. Winestone. Apr 70, 242p* NECTP-209
Limited number of copies containing color other than black and white are available until stock is exhausted. Reproductions will be made in black and white only.

The Northeast Corridor Transportation Project was charged to determine the inter-city transportation facility requirements of the Northeast Corridor through 1980. This report contains the following: A comparative analysis of the transportation alternatives as to their technical feasibility, economic costs and benefits and other impacts in the year 1975; A discussion of the actions required to implement the transportation alternatives; An examination of possible financing and management of new modes included in the alternatives; Advantages and disadvantages of various organizational alternatives; Population growth patterns and the Corridor transportation system; Methodology; Description of the alternative systems; and exploratory studies and sensitivity tests. (Author)
PB-190 929

**HSGT MODE SERVICE ANALYSIS IN THE NORTHEAST CORRIDOR,**
TRW Systems Group, Washington, D.C. Washington Operations.
J. R. Vadeboncoeur, and T. W. Smith. Dec 69, 145p* 06818-W007-RO-00 NECTP-214
Contract DOT-C-353-66
See also Rept. no. TRW-06818-W917-RO-00, PB-178 979.

The report describes the analysis of High Speed Ground Transportation service in the U. S. Northeast Corridor. In the analysis, three HSGT systems were established: a 150-mph High Speed Rail system (HSRA), a 200-mph High Speed Rail system (HSRC), and a Tracked Air Cushion Vehicle system (TACV). Each of these was analyzed in competition with auto, bus, conventional air (C-TOL), short takeoff and landing (STOL), and vertical takeoff and landing (VTOL) modes. (Author)
PB-190 934

**TRANSOP MODEL METHODOLOGY,**
TRW Systems Group, Washington, D.C. Washington Operations.
J. R. Vadeboncoeur, T. W. Smith, and D. S. Adamson. Dec 69, 129p* 06818-W009-RO-00 NECTP-216
Contract DOT-C-353-66
See also Rept. no. NECTP-214, PB-190 934 and Rept. no. TRW-06817-RO-00, PB-178 797.

The TRANSOP computer program was developed in order to assist in the determination of transportation equilibrium supply and demand levels for the Northeast Corridor Transportation Project. The program is built upon a proprietary optimization and simultaneous equation-solving algorithm (SLANG) developed by TRW Systems Group. Applications of the TRANSOP program have included investigation of the competitive position of ground modes such as high speed rail, tracked air cushion vehicles, and tube vehicle systems. The program has also been utilized to examine similar systems in other U. S. corridors. (Author)
PB-190 936

**COST ANALYSES FOR NECTP. VOLUME I. HIGH SPEED GROUND MODES,**
Resource Management Corp., Bethesda, Md.
Paul F. Dienemann, and Joe P. Large. Dec 69, 77p* NECTP-222
Contract DOT-7-35297
See also Volume 2, PB-190 943.

The report documents the cost analysis of high speed ground transportation modes, including rail and tracked air cushion vehicles, performed for the Northeast Corridor Transportation Project of the U. S. Department of Transportation. It presents descriptions of each mode, the derivation of research and development, investment and operating costs, and an appraisal of results. (Author)
PB-190 942

**EXTERNAL COSTS AND BENEFITS ANALYSES, NECTP,**
Resource Management Corp., Bethesda, Md.
Paul F. Dienemann, and Armando M. Lago. Dec 69, 107p* NECTP-224
Contract DOT-7-35297

Rational decision-making in the transportation sector requires consideration of externalities third party effects. The study quantifies the incommensurable and imputed monetary values of costs and benefits of alternative NEC transportation system impacts on: noise, air pollution, aesthetics, safety, air and highway congestion, as well as the employment benefits from system construction. A final tableau of social costs and benefit impacts summarizes the monetary values of incremental impacts of new NECTP transportation modes--high-speed rail, tracked air cushion vehicles, STOL, and VTOL--over the social costs of a 1975 base case composed of auto, bus, conventional air, and the continuation of current NEC demonstration rail projects underway. (Author)
PB-190 944

**THEORY AND IMPLEMENTATION OF COST AND BENEFIT ANALYSIS OF TRANSPORTATION SYSTEMS: THE NECTP,**
Resource Management Corp., Bethesda, Md.
Luis Sanchez, Osker Morgenstern, Klaus-Peter Heiss, Kan-Hua Young, and Solita Monsod. Dec 69, 298p* NECTP-225
Contract DOT-FR-9-0044
Prepared in cooperation with Mathematica, Inc., Princeton, N.J.

The report presents the theory and application of transportation cost analysis methodology within a framework based on economic efficiency principles and on the application of welfare economics to decision-making in the transportation sector. The principles governing the efficient allocation of resources in transportation are set forth and adjustments required for market imperfections are discussed. Economic theory is applied to costing methods and techniques, and finally both transportation cost and productivity are brought together within a Pareto optimal framework for purposes of exploring the proper use of costs in decision-making. (Author)
PB-190 945

**A COMPUTER-ASSISTED METHOD FOR OPTIMIZING ROUTE PROFILES.**
Final rept.
TRW Systems Group, Redondo Beach, Calif.
Dec 69, 89p* 06818-W004-RO00 FRA-RT-70-31
Contract DOT-C-353-66
Report on High-Speed Ground Transportation Systems Engineering Study.

The report describes an heuristic approach to estimate the cost of constructing a route along a given path. Specifically, a computer program is developed to perform cost computation for a given road profile, taking into account the earthwork as well as elevated structures and tunnels. The user inputs the trial profiles, the constraints, and the changes. Use is made of a time-sharing remote terminal so that the user can interact with the computer to manually perform the optimization. The program performs all cost calculations, accepts data and modifications, edits road profiles and prints out diagnostics when necessary. (Author)
PB-191 118

**SYSTEM EFFECTIVENESS STUDIES.**
Final rept.
TRW Systems Group, Redondo Beach, Calif.
Nov 69, 71p 06818-W002-RO00 FRA-RT-70-32
Contract DOT-C-353-66
Report on High-Speed Ground Transportation Systems Engineering Study.

The report describes an investigation of the feasibility and appropriateness of system effectiveness techniques in the analysis and design of high speed ground transportation systems. A computerized model was constructed which employs selectable reliability and failure distributions to interrelate the performance of an HSGT system in terms of adherence to established schedule and the various reliability and failure parameters on the subsystem and component level. The model is based upon an analytic combination of the conditional reliability and failure distribution. Three train failure modes, distinguished by the limiting speed encountered for the various component failure contributions, are considered. These lead to the overall probability of reduced operating performance for a train and, finally, to the probability distribution of delays in a network. The computer output information is prepared so as to be compatible input to a TRANSIM simulation program developed under an associated system engineering support task. (Author)
PB-191 323

**SYSTEMS SIMULATION STUDIES.**
Final rept.
TRW Systems Group, Redondo Beach, Calif.
Dec 69, 229p 06818-W008-RO00 FRA-RT-70-34
Contract DOT-C-353-66
Report on High-Speed Ground Transportation Systems Engineering Study.

The report describes a computer program developed to simulate the operation of a high speed ground transportation mode within the U. S. Northeast Corridor. The program utilizes the TRANSIM user language for the simulation in conjunction with an output processor program written specifically to improve the basic TRANSIM output format. This conversion allows quicker accessibility to critical analysis variables. As a demonstration of the program, a simulation was performed of a 150-mph new rail facility within the Northeast Corridor. The results of this simulation and the documentation of the program are included. (Author)
PB-191 411

**SERVICE ANALYSIS OF TUBE VEHICLE SYSTEMS.**
Final rept.
TRW Systems Group, Redondo Beach, Calif.
Dec 69, 73p 06818-W006-RO00 FRA-RT-70-33
Contract DOT-C-353-66
Report on High-Speed Ground Transportation Systems Engineering Study.

The report describes an analysis of the service characteristics, cost and performance of Tube Vehicle Systems operating within the Northeast Corridor of the United States in the 1975 to 1985 time frame. The basis of the study is the TRANSOP computer program which, as described, searches for optimal service policies for high speed ground transportation modes in competition with automobile, bus, conventional air and new technology air modes. Included in the report is a description of the TVS model used in the program, the mathematical basis for the optimization, and the results of the applications of the program to the TVS service design. The results indicate that, with the assumptions and approximations employed in the model, the improved travel opportunities attendant with the introduction of the TVS technology in the Northeast Corridor do not provide sufficient revenue to cover the costs of implementing TVS. (Author)
PB-191 412

**HIGH-SPEED JETPORT ACCESS.**
Final rept.
TRW Systems Group, Redondo Beach, Calif.
Dec 69, 580p* 06818-6044-RO00 FRA-RT-70-38
Contract DOT-C-353-66
Feasibility Study of a Demonstration Project in Southern Florida.

The feasibility of a high speed access system as a transportation demonstration project to a new Southern Florida Jetport was determined. Several candidate systems were considered and included vertical-takeoff (VTOL) and short-takeoff (STOL) airborne vehicles, in addition to high speed rail (HSR), monorail systems (MRS) and tracked air cushion vehicles (TACV) ground vehicles. The evaluation of the perspective alternatives was made using technical performance and cost considerations over similar routes connecting a jetport to the main population centers in Southern Florida. Several jetport locations were postulated and considered in the evaluation of the routes and terminal requirements. A Tracked Air Cusion Vehicle (TACV) system capable of a cruise speed of approximately 150 mph is recommended as the initial jetport high speed access system. This system provides economic transportation for the projected airport access demands and for growth to the high speeds desired for future interurban service. A performance description, preliminary implementation plan, and cost estimates are provided for the recommended system from a jetport to Miami. A general description of the expanded network is also presented with data for long-range planning and the development of programs for financing and enabling legislation included. (Author)
PB-192 842

## 37. ADVANCED SYSTEMS: BIBLIOGRAPHIES

**BIBLIOGRAPHY OF HIGH SPEED GROUND TRANSPORT. PART IA.**
Massachusetts Inst. of Tech., Cambridge.
15 Oct 65, 86p
Contract C-85-65
See also PB-168 648, -169 121.
PB-170 581

## 38. ADVANCED SYSTEMS: PROGRAM PLANNING AND ANALYSIS

**SURVEY OF TECHNOLOGY FOR HIGH SPEED GROUND TRANSPORT, PART I.**
Massachusetts Inst. of Tech., Cambridge.
15 Jun 65, 484p
Contract C-85-65

This report presents the results of a research planning study initiated at MIT on September 16, 1964 in support of the Northeast Corridor Transportation Project of the United States Department of Commerce. The objective of the Northeast Corridor Transportation Project is to determine the facilities that will be needed to transport passengers and freight in the region extending roughly from Boston, Massachusetts to Washington, DC in the era of 1980 and thereafter. This includes study of both technological and nontechnological aspects of transportation; analysis of transportation needs and related demographic and economic forecasts for the region; and consideration of the interaction between transportation services and their impact on the development of the region as a whole and of its many urban centers. It includes studies of both existing and projected facilities for all modes of intercity transport, prospective technological improvements in each mode and alternative network configurations.
PB-168 648

**HIGH PRIORITY RESEARCH TASKS FOR HIGH SPEED GROUND TRANSPORT.**
Part 2.
Massachusetts Inst. of Tech., Cambridge.
15 Jun 65, 73p
Contract C-85-65

This volume represents Part II of a four part report prepared in partial fulfillment of a Contract initiated in September 1964 between the Massachusetts Institute of Technology and the United States Department of Commerce. The following proposals for additional research of high priority are divided into two groups: technological studies and design studies. The technological studies constitute applied research in various technical areas essential to the realization of a HSGT system. Their purpose is to establish the current state of the art, to determine which lines of attack are technically promising, to ascertain the practical and theoretical feasibility of various design alternatives, and to extend the state of present knowledge to the point where the design of an HSGT system will be a practical possiblity. The purpose of the design studies is to generate alternative ideas and proposals for network configuration, access methods, guideway structures, vehicle designs, propulsion, suspension, control, communication, and all other components of the system.
PB-169 121

**TECHNOLOGY FOR HIGH-SPEED GROUND TRANSPORT.**
Summary on research at MIT for 16 Sep 65-15 Sep 66,
Massachusetts Inst. of Tech., Cambridge.
William W. Seifert, and Robert J. Hansen. 31 Dec 66, 53p
Contract C-85-65

The report summarizes the research accomplished at the Massachusetts Institute of Technology during the period September 16, 1965 through September 15, 1966. The efforts were on networks and terminals, scheduling, vehicle flow control and switching problems, vehicle-suspension problems, propulsion problems, vehicle and tube aerodynamics, and guideway problems.
PB-173 658

**RESEARCH AND DEVELOPMENT FOR HIGH SPEED GROUND TRANSPORTATION.**
Department of Commerce, Washington, D.C. Panel on High Speed Ground Transportation.
Mar 67, 40p
Rept. of Panel on High Speed Ground Transportation.

Contents: Research recommendations for prepototype studies; Roster of Panel and Subpanels; Presentations to the Panel and Subpanels; Report of the Subpanel on Guideways, Suspensions and Aerodynamics; Report of the Subpanel on Propulsion, Energy and Braking; Report of the Subpanel on Communication and Control; Report of the Subpanel on Terminals and Interfaces; Report of the Subpanel on Passenger and Freight Factors; Current HSGT R and D Contract, Office of High Speed Ground Transportation.
PB-173 911

**THE HIGH SPEED GROUND TRANSPORTATION ACT OF 1965. 2ND REPORT.**
Department of Transportation, Washington, D.C.
Sep 67, 55p

The report complies with Section 10 (a) of the High Speed Ground Transportation Act of 1965 as amended by the Department of Transportation Act of October 15, 1966, requiring the Secretary of Transportation to report to the President and the Congress, not less often than annually, with respect to activities carried out under the Act. The first report covered the fiscal year ending June 1966 and was submitted in September 1966. The three basic activities authorized by the Act are: Research and development in high speed ground transportation; Demonstration projects to determine the contributions that high speed ground transportation could make to more efficient and economical intercity transportation systems; A national program to improve the scope and availability of transportation statistics. (Author)
PB-176 115

**TECHNOLOGY FOR HIGH SPEED GROUND TRANSPORT.**
Summary rept. 16 Sep 66-15 Nov 67,
Massachusetts Inst. of Tech., Cambridge.
Robert J. Hansen. 31 Dec 67, 67p
Contract C-85-65

This report contains highlights of research findings developed during the second year of research at M. I. T. on the technology of high speed ground transport (HSGT). The research topics are diverse but can be grouped roughly into areas relating to system operational performance, vehicles, including suspension, propulsion, and control; and the problems of the infrastructure of an HSGT system. The research is aimed at establishing a basis for design of HSGT and often treats problems not previously studied for conventional transportation systems. (Author)
PB-176 923

**THE HIGH SPEED GROUND TRANSPORTATION ACT OF 1965. 3RD REPORT.**
Department of Transportation, Washington, D.C.
Jul 69, 132p*
See also Rept. no. 2, PB-176 115.

The Northeast Corridor simulation model was assembled and exercised; a comprehensive inventory of technology options was prepared; two rail passenger service demonstrations are beginning and the first system for broad, regional transportation analysis was established. A national capability in R and D and transportation analysis was established in universities and in private industry across the country. The impact of the HSGT program is depicted. (Author)
PB-185 702

**THE HIGH SPEED GROUND TRANSPORTATION ACT OF 1965. 4TH REPORT.**
Rept. no. 4.
Department of Transportation, Washington, D.C.
1970, 159p*
See also Rept. no. 3, PB-185 702.

Coupled with the Northeast Corridor Transportation Project, the high speed program was sought to: determine transportation demand in a most heavily populated and industrialized intercity corridor region; analyze engineering systems alternatives for meeting that demand; demonstrate traveller response to selected transportation improvements; and undertake research and development in fields of entirely new systems as well as stimulating that in existing systems. (Author)
PB-196 799

## 39. ADVANCED SYSTEMS: MISCELLANEOUS

**SUPPORTING STUDIES FOR HSGT SYSTEM REPORTS.**
Final rept.
TRW Systems Group, Redondo Beach, Calif.
Jun 70, 522p* 06816-6041-RO00
Contract DOT-353-66
Report on High-Speed Ground Transportation Systems Engineering Study. See also PB-193 145.

The document is a supporting studies volume which contains appendices covering various detailed analyses which are referenced in reports on a high speed rail system, tracked air cushion vehicle systems, multimodal systems, and automated highway systems.
PB-193 144

**DYNAMIC ANALYSIS OF MULTIPLE CAR VEHICLES USING COMPONENT MODES. VOLUME I. ANALYSIS.**
Final rept.,
TRW Systems Group, Redondo Beach, Calif.
T. K. Hasselman, H. D. Riead, and A. Kaplan. Jul 70, 271p 06818-6048-RO00-Vol-1 FRA-RT-71-43
Contract DOT-C-353-66
Report on High-Speed Ground Transportation Systems Engineering Study.

The report documents the development of a computer program to predict the dynamic characteristics of multiple car trains. The approach, of analysis by subsystems forms the basis of this program. The method of component mode synthesis is then used to obtain an accurate approximate solution with a reduced number of coordinates and thus reduced computing time. Previously the method of component mode synthesis has been applied to undamped elastic structures. In this report the method is extended to general linear systems, that is, systems which include significant damping and asymmetric matrix coefficients. The modal coordinates to which the original equations of motion are thus transformed are no longer real but complex, and include velocity as well as displacement information. Included is a complete description of the program, a user's guide and a sample program. A limited amount of numerical results have been obtained and these are discussed. These preliminary results show that modal frequency and damping obtained by component mode synthesis after truncating half of the component modes agrees to within a couple of percent of exact solutions which include all of the modes. As expected, the mode shapes did not agree quite as well. (Author)
PB-193 545

**DYNAMIC ANALYSIS OF MULTIPLE CAR VEHICLES USING COMPONENT MODES. VOLUME II. PARAMETRIC STUDY.**
Final rept.,
TRW Systems Group, Redondo Beach, Calif.
T. K. Hasselman, and A. Kaplan. 27 Jul 70, 37p
06818-6049-RO00-Vol-2 FRA-TR-71-53
Contract DOT-C-353-66
Report on High Speed Ground Transportation Systems Engineering Study. See also Volume 1, PB-193 545.

The report documents the results of a parametric study made to assess the effects of inter-car coupling on the dynamic characteristics of high speed trains. In addition to shedding light on potential problems which may arise from the dynamic coupling of vehicle modes, the report includes a summary of the experience gained in application of the computer program developed for this purpose.
PB-194 375

**SUMMARY OF RESEARCH AT MIT ON TECHNOLOGY FOR HIGH SPEED GROUND TRANSPORT.**
Progress rept. 16 Nov 67-15 Sep 69,
Massachusetts Inst. of Tech., Cambridge.
William W. Seifert. 31 Aug 70, 85p 71-8 FRA-RT-71-71
Contract DOT-C-85-65

Contents: Systems analysis and vehicle control; Vehicle suspension systems; Propulsion; Vehicle and tube aerodynamics; Some guideway considerations.
PB-198 015

# CORPORATE AUTHOR INDEX

# PERSONAL AUTHOR INDEX

# ACCESSION/REPORT NUMBER INDEX

01274

# APPENDIX (C)

Rail Passenger Data

Extract of a Report on a

# STATISTICAL ANALYSIS OF THE NEW YORK - WASHINGTON, D. C. RAIL PASSENGER SERVICE 1970

U. S. DEPARTMENT OF TRANSPORTATION
OFFICE OF HIGH SPEED GROUND TRANSPORTATION
DEMONSTRATIONS DIVISION
OCTOBER 1971

Data collected thus far indicates that Metroliner has attracted riders with characteristics more similar to the Corridor airline passengers than to Corridor conventional train patrons.

On the average, Metroliner passengers are slightly older, have substantially higher incomes, travel more frequently, and are more likely to be on a business trip than are their conventional train counterparts.

Since there is this similarity between the airline and Metroliner passengers, it only follows that Metroliner patrons rate the equipment and services in comparison to the standards prevalent in the airline industry. For example, equipment innovations such as the new seats, seat spacing, indirect lighting, and improved air circulation all received overwhelming approval. Likewise, most of the onboard services won favor, including conductor courtesy, housekeeping, and trip time. Food quality and prices were the two most negative factors in this category.

Although the new features and improved services found success, the old ones did not. Baggage handling, terminal surroundings, and parking at the terminals received the preponderance of fair-to-poor ratings. Other terminal-related facilities fared somewhat better, but not by a large margin.

The drawing power of the Metroliner trains becomes apparent when considering that 81% of the riders surveyed said they were going to travel on the Metroliner next time. Of the remainder, 18% distributed their preferences equally between autos, planes, and conventional trains, while 1% chose buses.

Features which are of paramount importance to those switching to air are speed, terminal facilities, and terminal services. The auto-next passengers are concerned chiefly with costs, terminal surroundings, and parking facilities. Those planning to ride a conventional train next time are most cost

conscious since almost half of them rated cost on the Metroliner as fair-to-poor. The Metroliner coach fare between New York and Washington at the end of 1970 was $17 versus the conventional train fare of $13. The air shuttle between the same cities cost $24.

## PASSENGER PROFILES

The statistics below present an interesting analysis. The family incomes of conventional train passengers are rather equally distributed throughout the various levels, excluding the under-$5,000 group. And this distribution has remained constant, even for 1968. On the other hand, the Metroliner income levels rise dramatically. There are only one-third as many under $5,000 as on conventional trains. The correlation between Metroliner and Corridor airline passengers is revealed by the similarity of distributions within the income levels.

| | Conventional % | | Metroliner % | | Air* % |
|---|---|---|---|---|---|
| Family Income | 1970 | 1969 | 1970 | 1969 | '68-'67 |
| Under 5,000 | 11 | 12 | 4 | 4 | 2 |
| 5,000 - 9,999 | 25 | 24 | 12 | 13 | 11 |
| 10,000 - 14,999 | 22 | 22 | 18 | 19 | 18 |
| 15,000 - 24,999 | 23 | 23 | 30 | 30 | 31 |
| 25,000 and over | 19 | 19 | 36 | 34 | 38 |
| Age | | | | | |
| 20 and under | 12 | 11 | 6 | 6 | |
| 21 - 35 | 36 | 44 | 37 | 36 | |
| 36 - 50 | 30 | 26 | 35 | 34 | |
| 51 - 65 | 18 | 16 | 19 | 20 | |
| 66 and over | 4 | 3 | 3 | 4 | |
| Sex | | | | | |
| Male | 64 | 62 | 70 | 65 | |
| Female | 36 | 38 | 30 | 35 | |

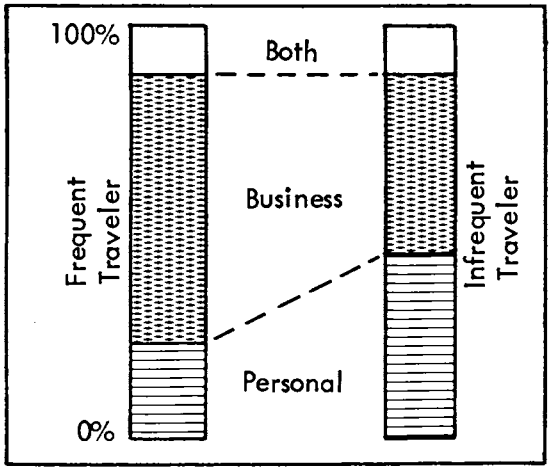
*Source - Port of New York Authority - Air Passengers originating in Manhattan 1967-1968, destined for Washington, D. C.

# PURPOSES AND FREQUENCIES OF TRIPS

| | CONVENTIONAL % | | METROLINER % | | AIR* % |
|---|---|---|---|---|---|
| | 1970 | 1969 | 1970 | 1969 | 1970 |
| PURPOSES | | | | | |
| Personal | 45 | 44 | 36 | 42 | 23 |
| Business | 42 | 45 | 52 | 47 | 67 |
| Some of both | 13 | 11 | 12 | 11 | 10 |
| TIMES MADE THIS SAME TRIP IN PAST YEARS BY ANY MODE | | | | | |
| None | 14 | 17 | 22 | 27 | |
| 1 - 5 | 26 | 28 | 35 | 37 | |
| 6 - 10 | 14 | 13 | 16 | 14 | |
| 11 - 20 | 13 | 13 | 13 | 11 | |
| 21 - 50 | 12 | 11 | 9 | 8 | |
| Over 50 | 21 | 18 | 5 | 3 | |

*Source - Port of New York Authority

Almost two-thirds of the Metroliner passengers traveled for business purposes in 1970 (including those in the "some of both" category), which is 13% less than on airlines and 9% more than on conventional trains. However, the air percentages are for those traveling only between the city pairs of New York and Washington. The train figures are for any city pairs within the Corridor, and approximately one-fifth of the conventional train riders use commutation tickets.




Of the Metroliner passengers, those who traveled most frequently (6-50 trips) between a city pair in the last year by any mode, did so less than one-quarter of the time on personal trips. As noted at left, the percentage of business travel by the frequent traveler is much higher than that of the infrequent one.

## CAR FEATURES

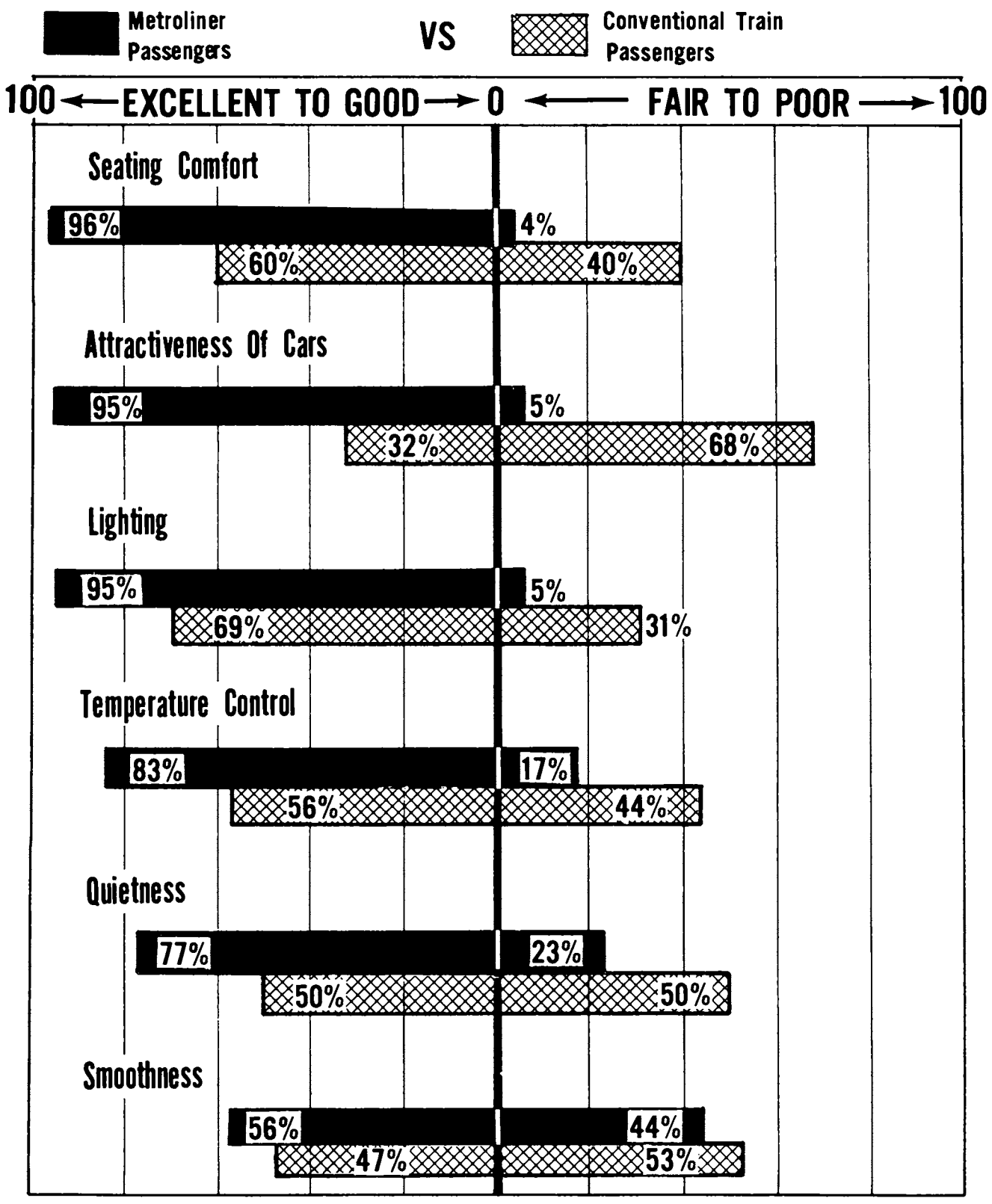
Each Metroliner train normally consists of two Metroclub cars, two coaches and two snack-bar coaches, with a total seating capacity of 340. They are not only streamlined on the outside, but the interior appointments and features are vastly superior in comparison to conventional trains. There is carpeting throughout, and a public address system which is used for announcements and music. The trains can boast of an especially designed continuous public telephone system, tinted windows, and doors between cars which slide open by a simple touch of the controls.

All this is not lost on the passengers, as evidenced by the fact that last year 95% rated the attractiveness of the cars as good-to-excellent. In comparison, the conventional Corridor trains received only a 32% rating in the same category by their passengers.

The aircraft-type seats and the indirect lighting also received high marks from the Metroliner passengers. They received good-to-excellent ratings from 96% and 95% of the riders respectively, as opposed to 60% and 69% from conventional train patrons.

A disappointing feature of the cars is the riding quality. Only 56% of the passengers rated the smoothness good-to-excellent. Suppliers are presently considering methods of improvement.

# 1970 PASSENGER RATINGS OF CAR FEATURES



## ON-BOARD SERVICE FEATURES

The only on-board service item which gained a high positive rating from conventional train passengers was conductor courtesy. Coupled with the 95% rating obtained by the Metroliner conductors, one might conclude that the customer relations training given to the crews of the demonstration trains by the Penn Central Railroad was effective.

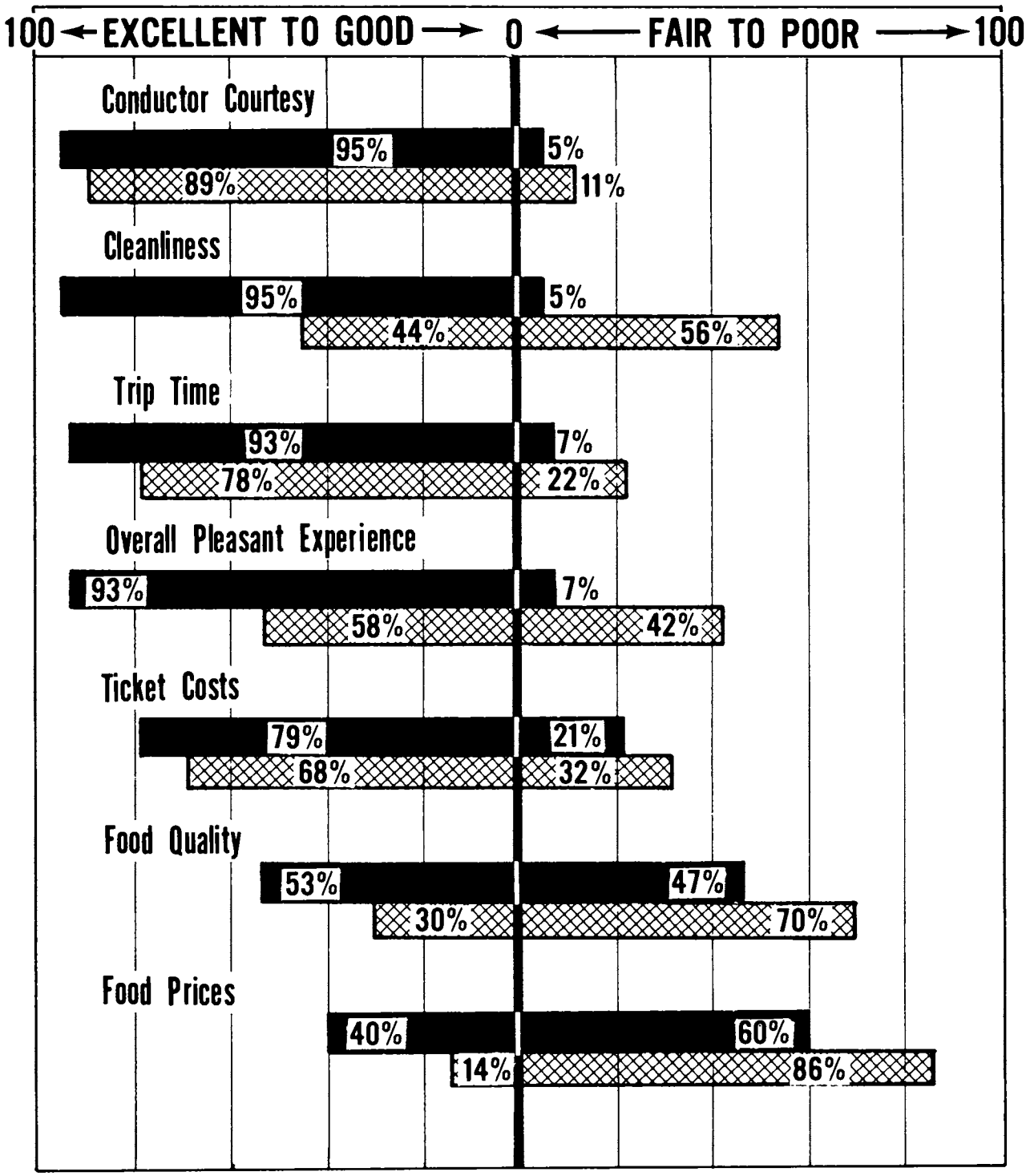
Train housekeeping functions, so often severely criticized, get an enthusiastic response by Metroliner passengers. But not so on conventional trains: 56% of those riders rated this service fair-to-poor.

The Metroliner schedule calls for a maximum trip time of three hours between Washington and New York City. Conventional demonstration trains take a minimum of 3 hours 50 minutes, so naturally the faster Metroliner speed receives a 93% favorable passenger response. However, the conventional train riders give trip time a relatively substantial 78% good-to-excellent rating, which indicates that many factors other than speed affect the choice as between Metroliner and conventional trains.

Percentages shown on the following chart are based upon the number of passengers who responded to the specific questions. In two cases there were a significant number of non-responses; the most probable reason being that the passengers did not use those particular services, "food quality" and "food prices" categories, and those who did not respond probably did not eat on the train and did not feel qualified to render an opinion.

# 1970 PASSENGER RATINGS OF SERVICE FEATURES

Metroliners VS Conventional Trains



Those who did respond, though, are getting their point across very vividly. Only a little better than half of the Metroliner patrons responding felt the food quality was good-to-excellent versus roughly one-quarter of the conventional riders. As far as food prices are concerned, both groups gave a resounding negative vote, especially the conventional train passengers. Experiments are currently being conducted to improve both these areas.

Below are the actual percentages of those who responded and those who did not respond in these two categories.

FOOD QUALITY

| | Metroliner | Conventional |
|---|---|---|
| Excellent-to-Good | 30% | 11% |
| Fair-to-Poor | 26 | 29 |
| No Response | 44 | 60 |
| | 100% | 100% |

FOOD PRICES

| | | |
|---|---|---|
| Excellent-to-Good | 25% | 7% |
| Fair-to-Poor | 34 | 36 |
| No Response | 41 | 57 |
| | 100% | 100% |

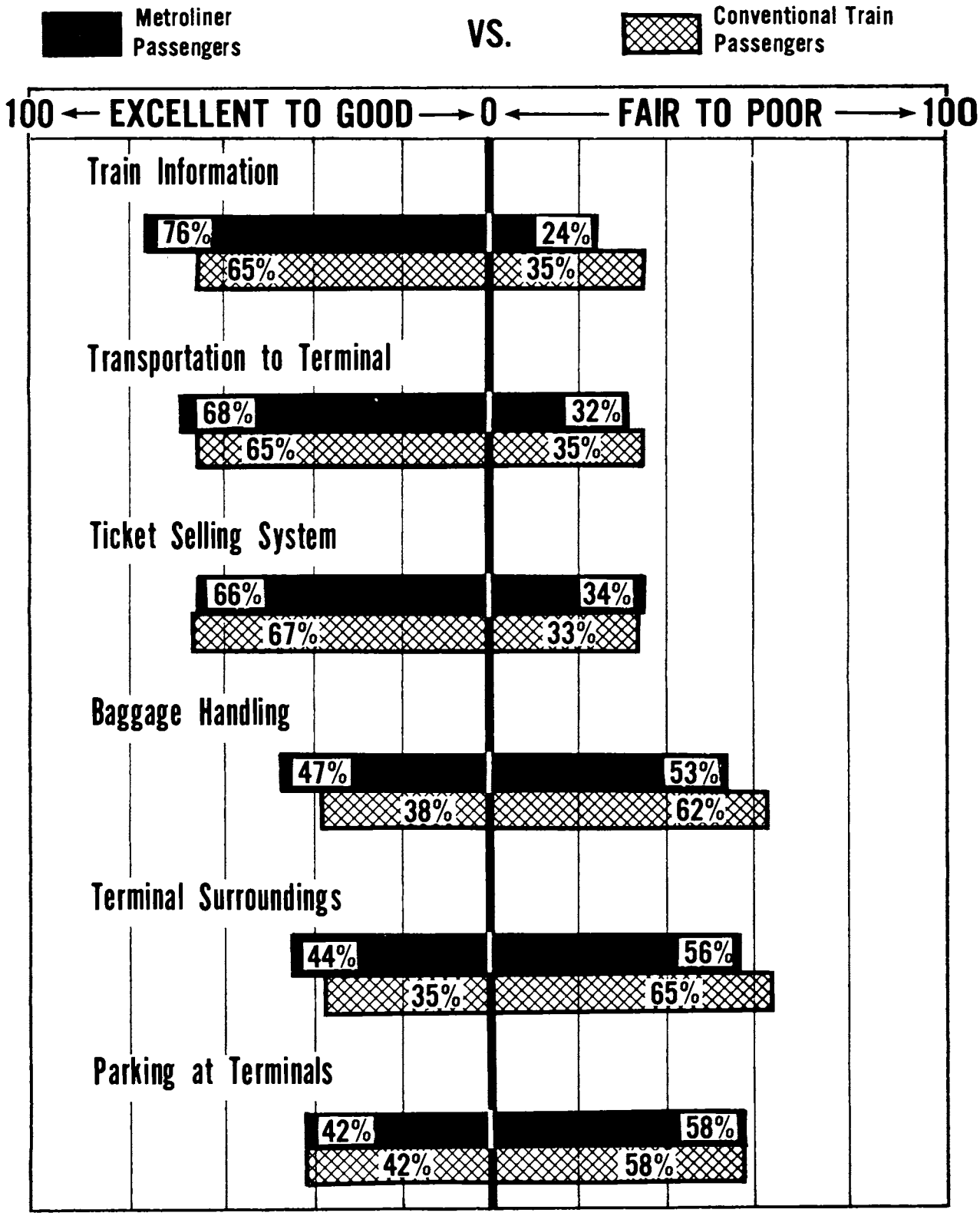
## TERMINAL FEATURES

Once outside the trains, the reactions of both groups converge to the same plateau: increased negative ratings. "Train Information" is the only category which received above 75% of good-to-excellent votes, either from Metroliner or conventional train passengers. From there on the ratings go downhill, which indicate clearly the need to improve the terminal surroundings and the terminal features. A reasonable assumption would be that ridership on all Corridor trains would be increased if the terminal features were improved.

"Parking At Or Near The Terminal" drew a large number of negative responses. This problem may be eased somewhat in the future by the use of two new suburban stations: the Capital Beltway Station near Washington, D.C., and the soon-to-open Metropark Station in Woodbridge, New Jersey. Both have adequate parking facilities, are located adjacent to high-speed highways and provide easy access to suburbanites. Even though not all trains stop there, the early success of Capital Beltway Station has been encouraging. Opened in March 1970, the station now handles approximately 11% of the metropolitan Washington Corridor rail travelers who ride the trains that stop at the Beltway.

As in the preceding section, there are some categories in this section with a large number of non-responses. "Parking At Or Near The Terminal" received no response from 38% of the Metroliner passengers and 40% of the conventional train riders.

# 1970 PASSENGER RATINGS OF TERMINAL FEATURES



Following are the actual percentages of responses and non-responses for these categories:

BAGGAGE HANDLING

| | Metroliner | Conventional |
|---|---|---|
| Excellent-to-Good | 25% | 17% |
| Fair-to-Poor | 31 | 43 |
| No Response | 44 | 40 |
| | 100% | 100% |

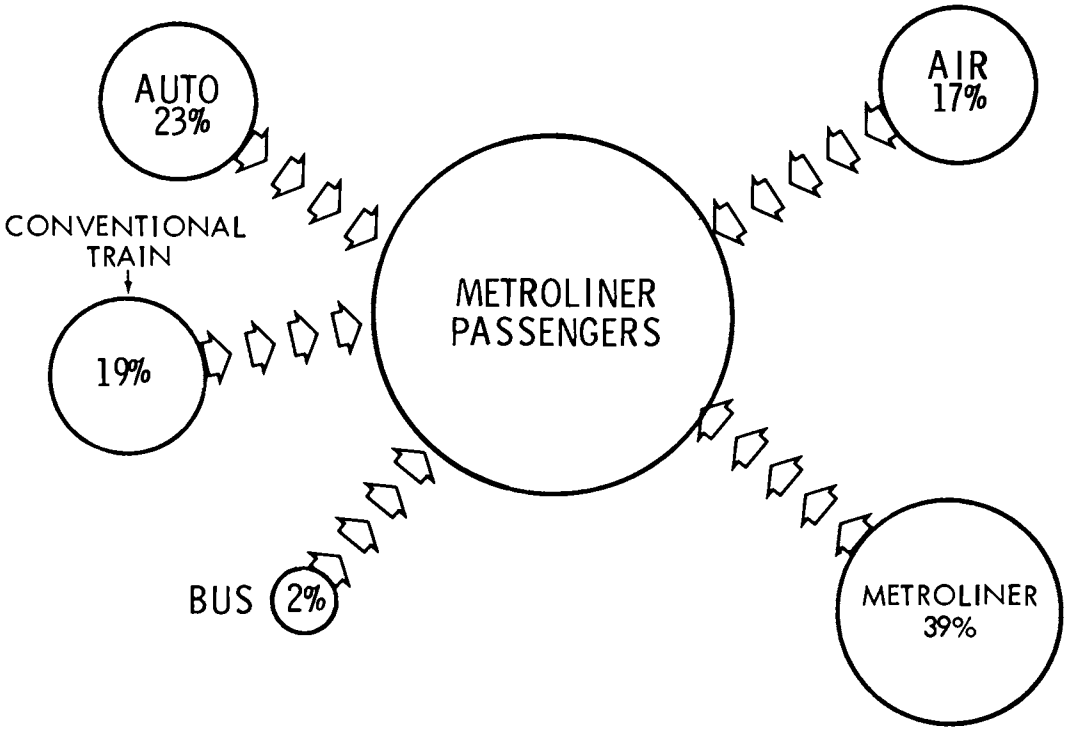
PARKING AT TERMINALS

| | | |
|---|---|---|
| Excellent-to-Good | 23% | 13% |
| Fair-to-Poor | 39 | 47 |
| No Response | 38 | 40 |
| | 100% | 100% |

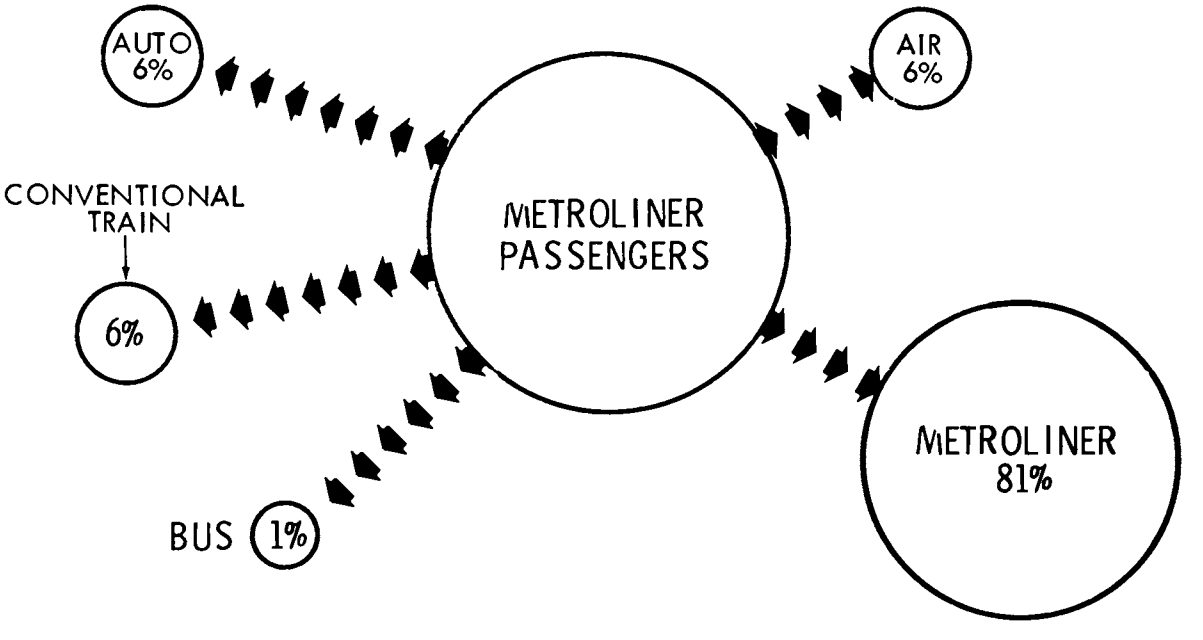
TERMINAL SURROUNDINGS

| | | |
|---|---|---|
| Excellent-to-Good | 36% | 24% |
| Fair-to-Poor | 50 | 51 |
| No Response | 14 | 25 |
| | 100% | 100% |

# HOW THE METROLINER RIDERS TRAVELED ON THEIR LAST CORRIDOR TRIP....




# AND HOW THEY'LL TRAVEL NEXT TIME!



## REACTIONS OF MODE SWITCHERS TO METROLINERS

A critical element of the Corridor experiment is to determine if the Metroliners are capable of attracting new riders from autos, planes and buses--and then retaining them for future travel. Figures indicate that the Metroliners are succeeding, as evidenced by the chart on the preceding page.

The new trains have had success in attracting about an equal number of passengers from autos, conventional trains, and airplanes, with each accounting for about one-third of the mode switching. Bus passengers constitute a negligible fraction. As far as repeat business from the new riders is concerned, 81% report they plan to use the Metroliner for their next trip.

The comparison of likes and dislikes between passengers of Metroliners and conventional trains was contrasted previously. This section will deal with the reactions of two groups of passengers: those who have decided to keep riding the Metroliner in the future, and those who have decided to switch to another mode.

Of the riders who said they would make their next trip by Metroliner, 20% were traveling in first-class accommodations and 80% were in coach. The percentage by class of tickets of those who said they were switching to another mode were: air - 21% first-class, 79% coach; auto - 13% versus 87%; conventional train - 7% versus 93%. During 1970, 16% of the Metroliner passengers rode in the first-class Metroclub cars.

Areas of positive reaction to the Metroliner are remarkably similar between the switchers and the non-switchers. The following table shows the most frequent positive response patterns of all passengers concerning Metroliner features.

ITEMS RATED GOOD-EXCELLENT MOST FREQUENTLY BY METROLINER PASSENGERS

| | Next Trip By | | | |
|---|---|---|---|---|
| Features | Metroliner | Air | Auto | Conventional |
| Seat Comfort | 96% | 90% | 91% | 94% |
| Attractiveness | 96 | 89 | 89 | 91 |
| Cleanliness | 95 | 98 | 96 | 93 |
| Lighting | 95 | 93 | 90 | 91 |
| Overall Experience | 95 | 76 | 81 | 88 |
| Conductor Courtesy | 95 | 91 | 90 | 92 |
| Trip Time | 94 | 61 | 86 | 91 |

The best responses are to the Metroliner onboard features, such as seating, housekeeping, lighting, and conductor courtesy. Speed seems more critical to those passengers who intend switching to air than to those planning to switch to auto or conventional train.

Dissatisfaction expressed by passengers who intend to switch modes is generally reflected in areas other than the equipment, as evidenced by the following table.

ITEMS RATED FAIR-POOR MOST FREQUENTLY BY METROLINER PASSENGERS

| | Next Trip By | | | |
|---|---|---|---|---|
| Features | Metroliner | Air | Auto | Conventional |
| Terminal Area | 55% | 67% | 60% | 49% |
| Smoothness | 43 | 71 | 53 | 58 |
| Parking | 40 | 49 | 52 | 33 |
| Food Prices | 37 | 46 | 45 | 45 |
| Ticket Sales | 36 | 48 | 33 | 36 |
| Baggage Handling | 31 | 47 | 40 | 37 |
| Cost | 14 | 26 | 47 | 46 |

Next Trip Air

Metroliner passengers who plan to fly next trip express only two strong objections to the equipment and onboard service: smoothness and food prices. The majority of the negative reaction centers around ancillary services, the strongest of which is the reaction to terminal areas. Fully two-thirds of these passengers rated the terminal areas fair-to-poor.

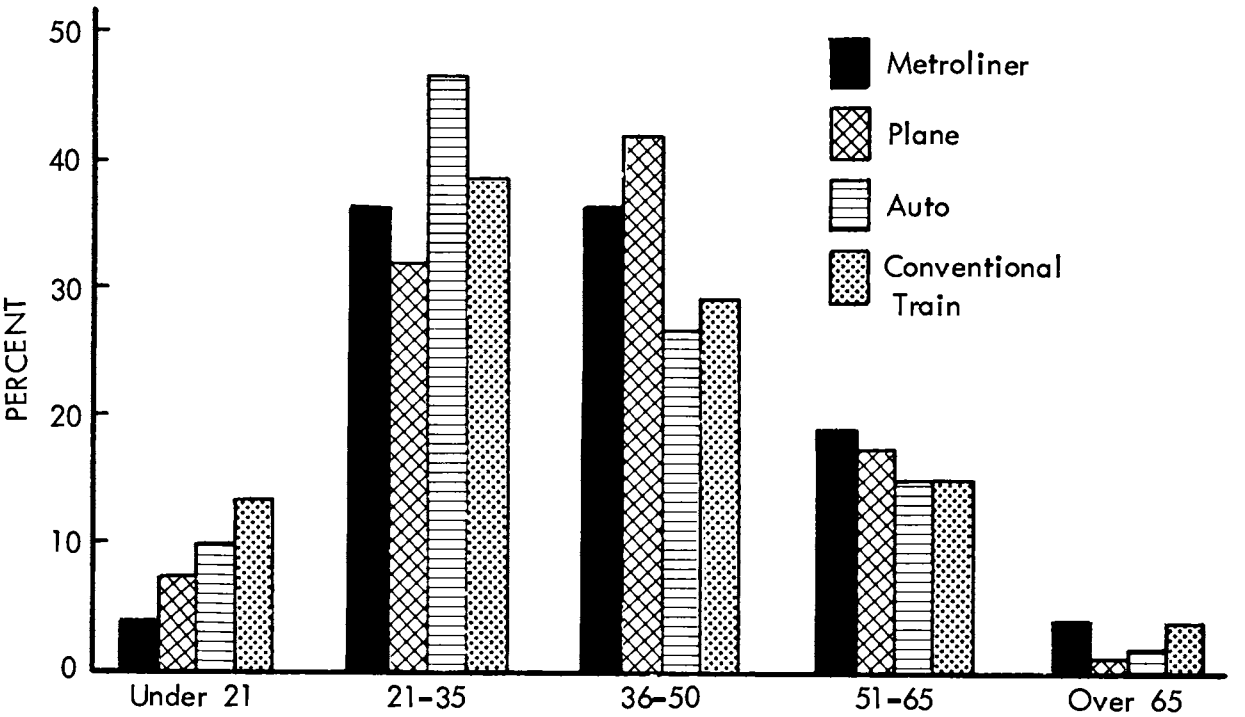
Another terminal function, automobile parking, was rated fair-to-poor by one-half of the total passengers planning to switch to air. Since one-third of these passengers did not respond to the question, it may be assumed that parking is not important to that segment. Stated another way, two-thirds of those passengers switching from Metroliner to air who had an opinion on the subject rated parking fair-to-poor.

Most of the rail terminals, of course, have mid-city locations with little, if any, parking facilities. This creates no problems for passengers whose origins and destinations are mid-city, but is undesirable from the standpoint of access for those who start or end their trips in a suburban location. The air mode generally suffers the opposite problem, with a location far from city center but close to the suburbs. Two attempts are being made to combine the best of both modes, in terms of access, by building two suburban stations, as mentioned previously. This will provide superior access from the suburbs to a station with adequate parking space on one end of a trip, and close proximity to a mid-city location at the other end.

Two additional terminal-related ancillary services objected to by people switching to air are the ticket-selling and baggage-handling systems. Many air carriers in the Corridor offer a multiplicity of baggage services. Most, for example, provide sky cap attendants to assist with luggage from curbside to check-in desk. Five of the eight current Metroliner stations provide similar red cap service, but with a limited number of men.

Metroliners have extra wide overhead racks because service was originally designed for the Corridor travelers who had carry-on baggage. However, one factor causing some passengers to switch to the air mode is the availability of better airline baggage-handling systems.

## PERCENTAGE DISTRIBUTION OF NEXT MODE CHOICE BY AGE GROUPS




The proportion of those choosing conventional train as the next mode is greater in the under-21 group than for each of the other mode choices. Similarly, the proportion of those choosing auto is greater in the 21 - 35 groups than for each of the other mode choices in that age group; the proportion of plan choice is greater in the 36 - 50 range; and the proportion of Metroliner choice is greater in the 51 and 65 group than for each of the other mode choices in that age bracket.

---

The final major area of dislike by those switching to air is the current ticket-selling system. The ticketing/reservation system is made up of many elements. Since the Metroliner ticketing hardware is among the most advanced of any transportation mode, one can assume that a portion of this displeasure stems from other aspects of the ticketing/reservations system.

The current Metroliner fare received a 26% fair-to-poor rating, which is the best of the negative reactions in this category. This indicates that those who switch from Metroliners to air do so primarily for

reasons other than dissatisfaction with the fare levels.

Next Trip Auto

The Metroliner passengers who have indicated that they plan to drive the next trip exhibit dislikes that are similar but generally less intense than the passengers who plan to fly next trip. They have strong objections to the terminal area, but generally favor the ticketing/reservation system and object slightly less to the baggage system. The passengers planning to switch to auto are disturbed by lack of parking at the terminals, and are very price conscious customers, with almost one-half objecting to the fares.

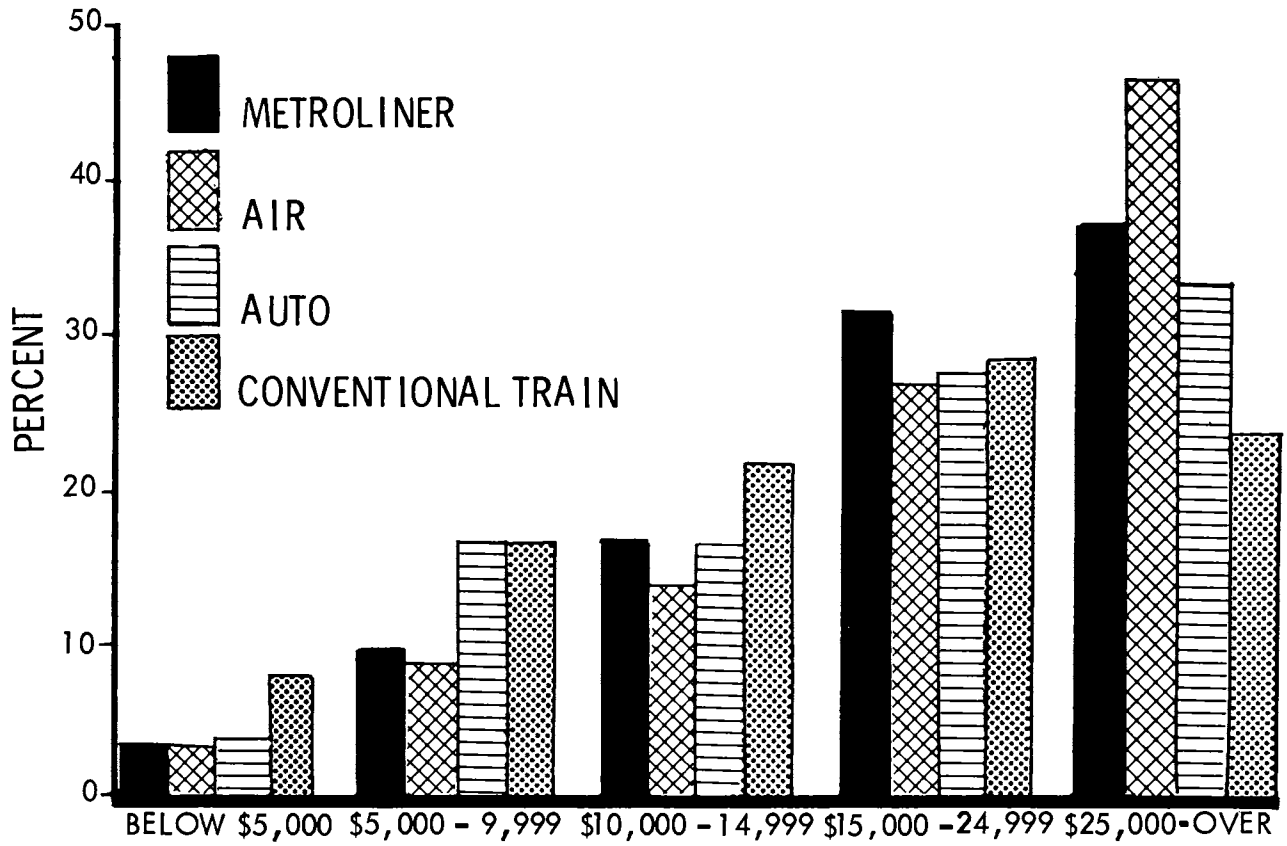
The demographics of the passengers planning to take Metroliners next trip and those planning to drive present an interesting contrast. Almost half of the auto-next passengers are traveling on business. By comparison, more than two-thirds of the Metroliner-next passengers are business travelers. The auto-next patrons have slightly lower incomes than the Metroliner-next riders, with 62% earning $15,000 and above versus 70% for Metroliner passengers. They are younger, with 57% of them under 35, compared to 41% of the Metroliner-next passengers.

In summary, the auto-next passengers might be characterized as young and budget-conscious, requiring better terminal surroundings and better parking facilities.

Next Trip Conventional Train

The Metroliner passengers who plan to take a conventional train on the next trip exhibit somewhat mixed characteristics compared to other mode switchers. They object to the terminal area, with half rating terminals fair-to-poor. But only one-third have intense feelings about the need for increased parking facilities, as opposed to half of the air-switch or auto-switch counterparts. The negative reaction of the conventional train

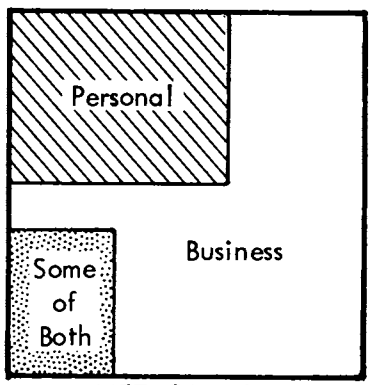
## Metroliner Passenger Views
## PERCENTAGE DISTRIBUTION OF NEXT MODE CHOICE BY INCOME GROUPS



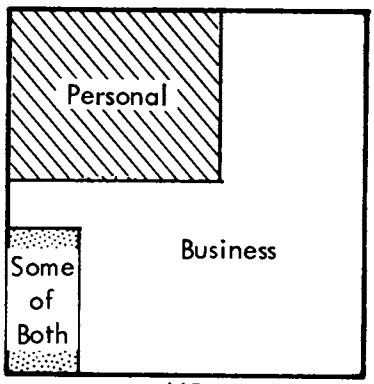

The proportion of those choosing conventional train as the next mode is greater in the below-$5,000 and $10,000 - $14,999 groups than for each of the other mode choices in those ranges. Similarly, the proportion of those choosing auto or conventional train is greater in the $5,000 - $9,999 group than for each of the other mode choices in that income range; the proportion of Metroliner choice is greater in the $15,000 - $24,999 classification; and the proportion of air choice is greater in the $25,000-and-over group than for each of the other mode choices in that income range.

switchers to the Metroliner food prices are about equal to the other mode switchers. Reactions to the ticketing/reservations systems are equivalent to those of the auto switchers and the passengers who choose Metroliners for the next trip. The lack of baggage service also seems to be somewhat important but not critical to their mode-switching decisions.

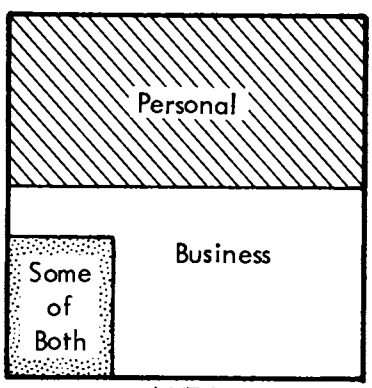
# NEXT MODE CHOICE OF TRIP PURPOSE GROUPS



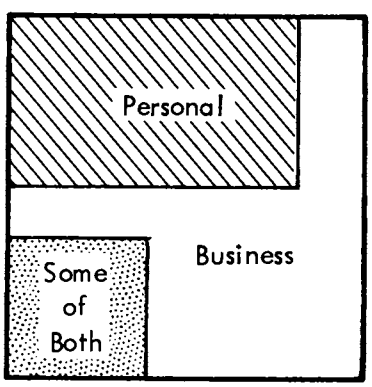
METROLINER



AIR



AUTO



CONVENTIONAL

A critical factor in the modal switch (since the other important factors including terminals and food prices are identical) is the fare differential between Metroliners and conventional trains. Between those Metroliner passengers who intend to switch to auto and those who are going to conventional trains, a substantial market would seem to exist for passengers who require good-quality, moderate-speed transportation at lower cost.

The income level of passengers who plan their next trip by conventional-

train substantiates the importance of fare levels to this market segment. Those earning over $15,000 annually constitute only 43% of the group as opposed to 70% of those riders who plan to use the Metroliner next time.

## HOUSEHOLD SURVEY RESULTS

In addition to the on-board surveys, which provide statistics on those people traveling by rail, the Office of High Speed Ground Transportation receives data from the U. S. Census Bureau concerning similar characteristics about households in the Northeast Corridor. This probability sampling, which has been conducted since 1968, provides information on the travel pattern of Northeast Corridor residents in metropolitan areas. There may be some differences between these Census Bureau figures and the ones obtained from train travelers because not all riders live in the metropolitan areas covered by the Census Survey.

As noted on the chart below, the family automobile dominates travel in the Corridor, and continues to climb at a gradual pace. Relative rail travel has held its own since 1968, with buses moving up 1 percentage point in 1970, and air travel dropping 4 percentage points in three years.

| Mode | Calendar Year 1970 | 1969 | 1968 |
|---|---|---|---|
| Rail | 10% | 11% | 10% |
| Auto | 77 | 75 | 74 |
| Bus | 6 | 5 | 5 |
| Commercial Air | 7 | 9 | 11 |
| | 100% | 100% | 100% |

Mode of travel as characterized by family income has undergone some significant changes. As indicated by the following chart, relative rail travel had dropped 8 percentage points among those passengers with a family income of under $4,000, while bus patronage has risen 6 points. The $4,000-to-$9,999 group has remained rather stable, with bus travel again having the greatest percentage increase.

Elsewhere in this report, Metroliner passengers are likened to those of air in that they have relatively higher family incomes than do those using conventional trains and autos. But those data were received from people riding the trains. The Household survey shows that families with incomes over $10,000 are continuing to use their cars at an accelerated rate, expecially in the $10,000-to-$14,000 group. At the same time, rails have lost 2 percentage points of their relative position in that group while air travel has been cut in hlaf. Air again lost heavily in the $15,000-and-over group, whereas rail travel increased considerably.

FAMILY INCOME

| Mode | Under $4,000 | | | $4,000-$9,999 | | | $10,000-$14,999 | | | $15,000 and over | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1970 | 1969 | 1968 | 1970 | 1969 | 1968 | 1970 | 1969 | 1968 | 1970 | 1969 | 1968 |
| Rail | 13% | 15% | 21% | 9% | 11% | 10% | 7% | 9% | 9% | 14% | 14% | 10% |
| Auto | 68 | 68 | 65 | 79 | 76 | 79 | 86 | 81 | 78 | 68 | 68 | 66 |
| Bus | 17 | 13 | 11 | 10 | 10 | 7 | 3 | 3 | 3 | 3 | 2 | 2 |
| Commercial Air | 2 | 4 | 3 | 2 | 3 | 4 | 4 | 7 | 10 | 15 | 16 | 22 |
| | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |

Although no detailed analysis has been undertaken to evaluate these mode switches, one can assume that economic reasons are causing residents to shift to the less expensive forms of transportation. Certainly highway congestion

in the Northeast Corridor has been alleviated to make road travel most desirable. And these statistics indicate that congestion will be worsening.

While the preceding figures in this section deal with the Household Census Survey of metropolitan areas in the entire Northeast Corridor, the following figures show Census Bureau travel patterns between city pairs in the New York-Washington Corridor only.

| Mode | N.Y.-Wash | | | N.Y.-Phila. | | | N.Y.-Baltimore | | | Phila.-Wash. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1970 | 1969 | 1968 | 1970 | 1969 | 1968 | 1970 | 1969 | 1968 | 1970 | 1969 | 1968 |
| Rail | 13% | 12% | 6% | 17% | 20% | 18% | 16% | 21% | 16% | 16% | 13% | 13% |
| Auto | 47 | 50 | 48 | 74 | 70 | 71 | 63 | 58 | 58 | 74 | 78 | 76 |
| Bus | 7 | 9 | 8 | 8 | 9 | 9 | 14 | 8 | 15 | 6 | 6 | 5 |
| Air | 33 | 29 | 38 | 1 | 1 | 2 | 7 | 13 | 11 | 4 | 4 | 6 |
| | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |

# A P P E N D I X (D)

FY 1971 Contract Obligations

As Of June 30,1971

OFFICE OF HIGH SPEED GROUND TRANSPORTATION
CONTRACT OBLIGATIONS FOR FISCAL YEAR 1971

ENGINEERING RESEARCH AND DEVELOPMENT

| Scope of Work | Contracted Amount | Contractor | Location |
|---|---|---|---|
| **Systems Engineering** | | | |
| Systems engineering for Suspended Vehicles | $ 285,962 | TRW Systems Group | Redondo Beach, CA |
| Social and environmental costs of HSGT | 7,000 | Resource Mgmt. | Bethesda, MD |
| Systems engineering | 148,000 | MITRE | McLean, VA |
| Total | $ 440,962 | | |
| **High Speed Railroad R&D** | | | |
| *Research Car Field Testing* | | | |
| Develop track survey device | $ 161,533 | General Applied Science Laboratory | Westbury, NY |
| Operate and maintain test cars | 78,334 | Penn Central | Philadelphia, PA |
| Technical rail research data | 773,000 | Ensco | Springfield, VA |
| Crosslevel data | 3,176 | Melpar | Falls Church, VA |
| Time-sharing computer services | 32,720 | Control Data | Falls Church, VA |
| Total | $1,048,763 | | |
| *Rail Vehicle Dynamics* | | | |
| Non-friction braking | $ 133,306 | Cornell Aeronautical Laboratory | Buffalo, NY |
| Experimental theory correlation | 65,265 | Bolt, Bernanek, Newman | Cambridge, MA |

| Scope of Work | Contracted Amount | Contractor | Location |
|---|---|---|---|
| Design wheel/rail lab and subcontracts | $ 694,928 | Wyle Labs | Huntsville, AL |
| Test car data acquisition | 45,805 | Melpar | Falls Church,VA |
| Consulting services | 10,000 | NBS | Washington, D.C |
| Total | $ 949,304 | | |
| **Track Structures** | | | |
| Perform rail track stress tests | $ 12,781 | Battelle Memorial Institute | Columbus, OH |
| Study response of supporting rails | 27,591 | New York University | New York, NY |
| Grinding of LIMRV test track | 19,856 | Minnix Construction | Minn., MN |
| Track Analyzer and roll Ordinator | 3,330 | American RR Curveling | Long Island, NY |
| Track and wheel profile engineering | 6,226 | Association of American Railroads | Chicago, IL |
| Test track rails, ties, etc. | 542,206 | AT & SFE Railroad | Chicago, IL |
| Total | $ 611,990 | | |
| **Traction Systems** | | | |
| Cost effect review | $ 99,965 | Pan-Technology Consulting | Washington, D.C. |
| Total | $ 99,965 | | |
| **Other Rail R&D** | | | |
| Study railroad operation of railbelt | $ 38,750 | MIT | Cambridge, MA |
| For locomotive at test center | 350,023 | General Electric | Erie, PA |

| Scope of Work | Contracted Amount | Contractor | Location |
|---|---|---|---|
| Metroliner Reliability review | $ 160,000 | Transportation Systems Center | Cambridge, MA |
| Total | $ 548,773 | | |

## Advanced Systems R&D

### Tracked Air Cushion Vehicle

| | | | |
|---|---|---|---|
| Wayside Power for the TACRV | $ 310,000 | AiResearch/ Garrett | Torrance, CA |
| Vehicle guideway and fluid suspension studies | 98,274 | MIT | Cambridge, MA |
| Turbofan engines for TACRV | 245,224 | UAC of Canada Ltd. | Montreal, Canada |
| TACRV fabrication | 3,555,545 | Grumman | Long Island, NY |
| Design of TACRV | 236,964 | Grumman | Long Island, NY |
| TACRV advanced LIM fabrication | 1,745,188 | AiResearch/ Garrett | Torrance, CA |
| Technical support | 49,500 | TRW Systems Group | Washington, D.C. |
| Tracked Air Cushion Vehicle studies | 235,000 | MITRE | McLean, VA |
| TACRV guideway engineering | 82,500 | FHWA | Denver, CO |
| LIMRV track grading | 575,000 | Colorado Constructors | Denver, CO |
| TACV ram wing studies | 66,250 | Transportation Systems Center | Cambridge, MA |
| TACV guideway | 657,500 | FHWA | Denver, CO |
| Computer services | 2,000 | Control Data | Falls Church, VA |
| Total | $7,858,945 | | |

### Tube Vehicle Systems

| | | | |
|---|---|---|---|
| Tube vehicle systems studies | $ 109,000 | MITRE | McLean, VA |

| Scope of Work | Contracted Amount | Contractor | Location |
|---|---|---|---|
| Computer services | $ 5,000 | Control Data | Falls Church, VA |
| Total | $ 114,000 | | |

Advanced Technology R&D

Communication and Control

| | | | |
|---|---|---|---|
| FM communication system model | $ 38,634 | New Mexico State Univ. | Las Cruces, NM |
| Dielectric wave guide experiments | 86,062 | General Applied Science Laboratory | Westbury, NY |
| Communications system systems studies | 83,750 | Transportation Systems Center | Cambridge, MA |
| Network control studies | 262,830 | TRW Systems Group | Washington, D.C. |
| Total | $ 471,276 | | |

Obstacle Detection

| | | | |
|---|---|---|---|
| Develop continuous surveillance system | $ 56,037 | Applied Metro Technology | Barrington, NJ |
| Total | $ 56,037 | | |

Linear Electric Motor

| | | | |
|---|---|---|---|
| Technical support | 106,000 | MITRE | McLean, VA |
| LIM modification | 38,468 | AiResearch/ Garrett | Torrance, CA |
| Test LIMRV truck components | 7,425 | Battele Memorial Inst. | Columbus, OH |
| LIMRV testing | 773,663 | AiResearch/ Garrett | Torrance, CA |
| Total | $ 925,556 | | |

Power Collection

| | | | |
|---|---|---|---|
| Electrical study | $ 100,000 | MITRE | McLean, VA |
| Power collection research | 329,250 | Transportation Systems Center | Cambridge, MA |

| Scope of Work | Contracted Amount | Contractor | Location |
|---|---|---|---|
| Wayside power distribution | $ 716,862 | AiResearch/ Garrett | Torrance, CA |
| Total | $1,146,112 | | |
| **Magnetic Suspension** | | | |
| Magnetic suspension | $ 121,337 | Stanford Research Inst. | Menlo Park, CA |
| Magnetic suspension | 130,000 | Ford Motor Company | Detroit, MI |
| Total | $ 251,337 | | |
| **Guideways** | | | |
| Tunnel liner study | $ 35,005 | University of Illinois | Urbana, IL |
| Research on mechanics of jointed rock | 22,000 | MIT | Cambridge, MA |
| Total | $ 57,005 | | |
| **HSGT Test Center (Pueblo, Colorado)** | | | |
| Office trailers | $ 16,951 | Boise Cascade | Texarkana, TX |
| Lease electrical generators | 17,532 | McCoy | Pueblo, CO |
| Reworking stabilized ballast | 25,839 | Materials R&D | Oakland, CA |
| Install power at test site | 3,565 | Main Electric | Pueblo, CO |
| Install septic tanks at test center | 3,041 | Dubbel's Sanitation | Pueblo, CO |
| Guard services | 22,293 | Haynes Guardian | Pueblo, CO |
| Rail ties | 4,554 | AT&SF RR | Chicago, IL |
| Spike dimension modification | 1,877 | Lewis Bolt & Nut | Minneapolis, MN |
| Track construction inspection | 28,230 | L.T. Klauder Associates | Philadelphia, PA |

| Scope of Work | Contracted Amount | Contractor | Location |
|---|---|---|---|
| Studies for test center master plan | $ 165,069 | MITRE | McLean, VA |
| Preparation specification plans for test center track construction | 57,320 | FHWA | Denver, CO |
| Construction at test center | 292,500 | FHWA | Denver, CO |
| Track construction inspection | 27,609 | U.S. Army Corps of Engineers | Seattle, WA |
| Boundary survey, monuments, etc. | 116,000 | Nat'l Oceanographic Survey | Rockville, MD |
| Plans and specifications LIMRV Maintenance Building | 6,149 | U.S. Army Corps of Engineers | Seattle, WA |
| A-E Program Management Bldg. | 26,680 | Bertrum Bruton Associates | Denver, CO |
| Inspect railroad ties | 3,917 | FAA | Washington, D.C. |
| LIMRV maintenance building | 51,800 | FAA & Schout Construction | Denver, CO |
| Program management building | 381,895 | Whitlock Construction | Denver, CO |
| Engineering of railroad test tracks | 10,000 | FHWA | Denver, CO |
| Miscellaneous support services | 150,000 | FHWA | Denver, CO |
| Inspection of Project management building | 11,800 | FHWA | Denver, CO |
| Support services | 165,000 | Pueblo Army Depot | Pueblo, CO |
| Total | $1,589,621 | | |

| Scope of Work | Contracted Amount | Contractor | Location |
|---|---|---|---|
| **Washington-New York Demonstrations** | | | |
| Engineering study of Metroliners | $ 50,000 | General Electric | Erie, PA |
| Engineering study of Metroliners | 48,453 | Westinghouse | Washington, D.C. |
| Basic ordering agreement | 14,388 | Pan-Technology Consulting | Washington, D.C. |
| Metroliner improvements | 121,299 | Budd | Fort Wash., PA |
| Metroliner improvements | 770,616 | Westinghouse | Washington, D.C. |
| Metroliner improvements | 1,067,233 | General Electric | Washington, D.C. |
| Metroliner improvements | 60,172 | Peat, Marwick, Mitchell | Philadelphia, PA |
| Bus service interface with Metroliner trains | 32,507 | D.C. Transit | Washington, D.C. |
| Engineering support | 135,000 | L.T.Klauder | Philadelphia, PA |
| Training services for Metroliner | 59,600 | Penn Central | Philadelphia, PA |
| Capital Beltway Suburban Station | 23,648 | Prince George's County | Upper Marlboro, MD |
| Inspection of Lanham Suburban Station | 1,037 | FAA | Washington, D.C. |
| Total | $2,383,953 | | |
| **Boston-New York Demonstrations** | | | |
| Turbo train operations | $2,795,011 | United Aircraft | Farmington, CT |
| Rental of Metroliner advertising | 1,000 | AMTRAK | Washington,D.C. |
| Turbo train lease | 141,519 | United Aircraft | Farmington, CT |

| Scope of Work | Contracted Amount | Contractor | Location |
|---|---|---|---|
| Installation of Transformer | $ 45,698 | Penn Central | Philadelphia,PA |
| Turbo train operations | 124,520 | Penn Central | Philadelphia,PA |
| Inspection services | 28,370 | Department of Navy | Norfolk, VA |
| Total | $3,136,118 | | |
| **Data Collection** | | | |
| Demonstrations planning data | $ 10,665 | MITRE | McLean, VA |
| Study of travelers in the Chicago to St. Louis and New York to Miami-Tampa, Florida routes | 35,876 | National Analysts | Washington, D.C |
| Passenger Data Retrieval | 139,300 | Kimball Systems | Washington, D.C |
| On board survey (NY-Wash.) | 96,000 | Opinion Research | Princeton, N.J. |
| Northeast Corridor travel survey | 355,000 | Bureau of Census | Washington,D.C. |
| Computer time | 2,580 | FHWA | Washington, D.C |
| Equipment rental (computers) | 72,099 | Honeywell | Arlington, VA |
| Programming services | 2,500 | Smithsonian Institute | Washington, D.C |
| ADP Rental | 12,314 | IBM | Washington, D.C |
| Rental of tick-o-meters | 3,360 | Pitney-Bowes | Stamford, CT |
| Total | $ 729,694 | | |
| **Auto-Train Demonstrations** | | | |
| Storage of materials | $ 14,856 | Pier Freight | Philadelphia,PA |
| Total | $ 14,856 | | |

| Scope of Work | Contracted Amount | Contractor | Location |
|---|---|---|---|
| **Airport Ground Access Study** | | | |
| Rapid transit study Dulles Airport | $ 142,932 | Wash. Metro Area Transit Authority | Washington, D.C |
| Total | $ 142,932 | | |
| **Other Studies** | | | |
| **Other (Washington-Miami) Demonstrations** | | | |
| Improve Wash.-Miami run | $ 7,500 | L.T. Klauder & Associates | Washington, D.C |
| Total | $ 7,500 | | |





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