ADVANCED SYSTEMS
and
ADVANCED TECHNOLOGY

A SUMMARY OF TEN YEARS OF ADVANCED RESEARCH AND DEVELOPMENT BY THE FEDERAL RAILROAD ADMINISTRATION

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Advanced Systems

A question facing OHSGT in 1965 was: "How fast is high-speed ground transportation?" OHSGT researchers developed an answer based on power requirements and energy consumption. A plot of the power required vs. speed for propulsion of various vehicles in Figure 1 shows the region of 300 mph (483 km/h) was a reasonable range because power requirements above that limit increase to where increased fuel expenditure for marginal time savings make higher speeds unattractive, at least in open air. In evacuated tubes, the lower air pressure presents less drag, and speeds of 600 mph (966 km/h) might be practical.

Systems Engineering

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

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

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

Tracked Air Cushion Vehicles (TACV)

As noted in the Systems Engineering section, one of the technologies chosen for detailed systems analysis was TACV. A TACV is supported and guided by cushions of air, formed by a flow of pressurized air from on-board compressors and controlled by a small leakage gap between the vehicle and the guideway. The vehicle weight is distributed over a large area without contact and resulting friction. (See Figure 2 for schematic representations of various air cushion designs.)

TACVs evolved from development of marine air cushion vehicles (ACV) and their land-based versions, called Ground Effect Machines. The British invented the marine ACV and later pursued development of TACVs through the organization of Tracked Hovercraft Ltd. The French built the first large-scale TACV. The Societe d' Aerotrain built a half-scale propeller-driven model and a 4.4-mile (7 km) test track in 1965. The half-scale vehicle made hundreds of runs, carrying a crew of two and up to four passengers. These demonstrations gathered data on ride quality and aerodynamic forces. With rocket boosters and a jet engine substituted for the turbo prop engine, the Aerotrain reached speeds of up to 215 mph (346 km/h). A second Aerotrain, carrying 80 passengers on an 11-mile (17 km) elevated guideway, went into operation in 1968. The 80-passenger vehicle ran a reliability test of 15,538 miles (25,000 km) with good performance. Aerotrain proposed several routes from Paris to nearby cities, but the French government did not provide the necessary funds. Testing continues with the vehicle and guideway, See Figure 3.

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

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

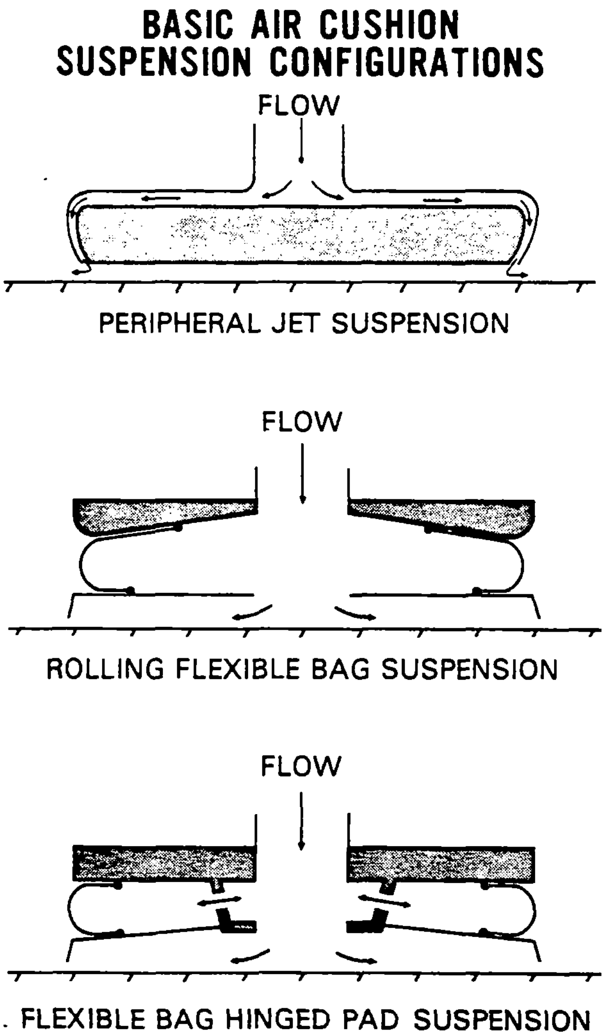


Figure 2. Different Designs of Air Cushion

design is technically quite simple and could use the Tracked Levitated Research Vehicle (TLRV) channel guideway or minor modifications of it. Figure 4 shows a ram air cushion vehicle model on the Princeton guideway. The ducting around the fan along with the walls of the channel guideway provide sufficient attenuation of the propeller noise to overcome this objection to a propeller.

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

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

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

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

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

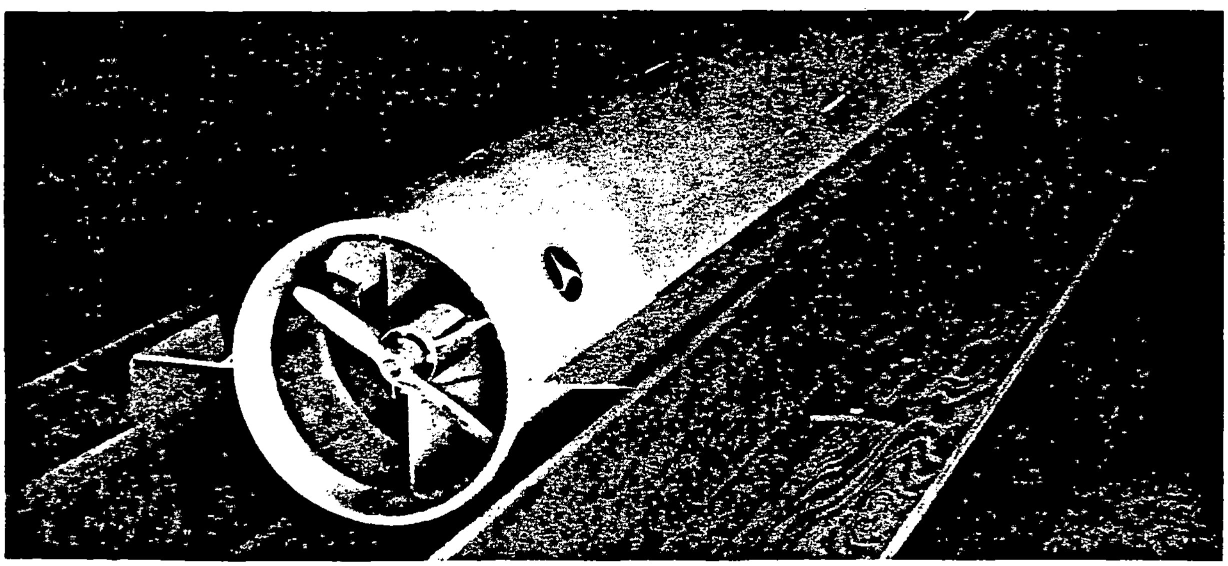


Figure 4. Model of Ram Air Cushion Vehicle.

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

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

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

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

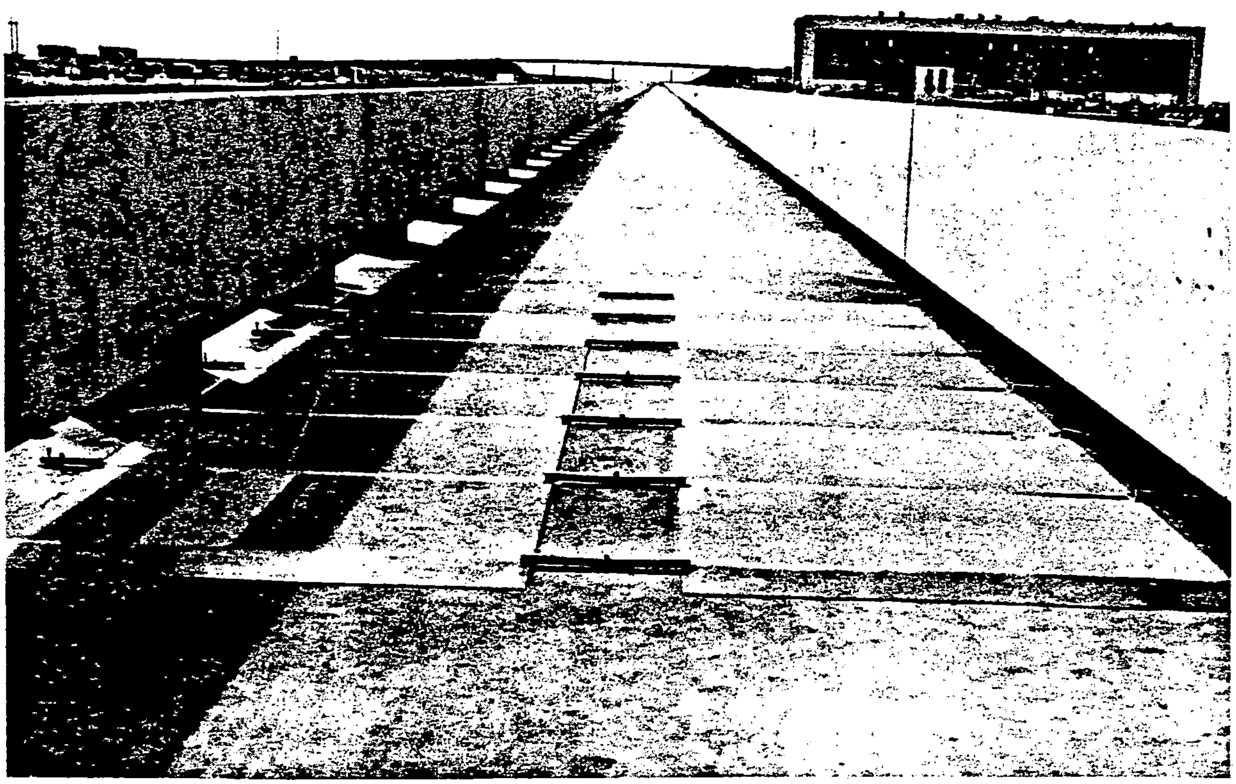


Figure 6. Surface Irregularities in TLRV Guideway to Study Vehicle Response and Behavior.

The Rohr Corp. fabricated a 60-passenger, 150 mph (241 km/h) all-electric vehicle, based on the French Aerotrain design, propelled by a linear electric motor, with cushion air supplied from electric air compressors, and power picked up from the wayside. See Figure 7 . The PTACV cushions applied low pressure uniformly over the entire area of each cushion—a plenum chamber. Air cushions for the TLRV were of quite different design—high pressure air blown through a narrow nozzle running around the periphery of each cushion—a peripheral jet. The two cushion designs offered a chance for comparison of their performances during the test programs.

During PTACV fabrication, Rohr constructed a 500-foot (152 m) track at their plant. Due to late delivery of the motor controls low-speed testing was conducted by connecting the LIM directly to the power supply with an on/off control. The controls were installed before the PTACV left the Rohr plant for the Test Center. Building an inverted-T guideway for the PTACV began at the TTC in May 1973. The vertical member in the center of the guideway slab (the leg of the inverted-T) guides the vehicle and also acts as the reaction rail for the linear motor. See Figure 8. The PTACV acceptance test program testing included one day of demonstration rides in 1976. The Department acknowledges that if transit authorities do display sufficient interest additional testing will be needed before deployment.

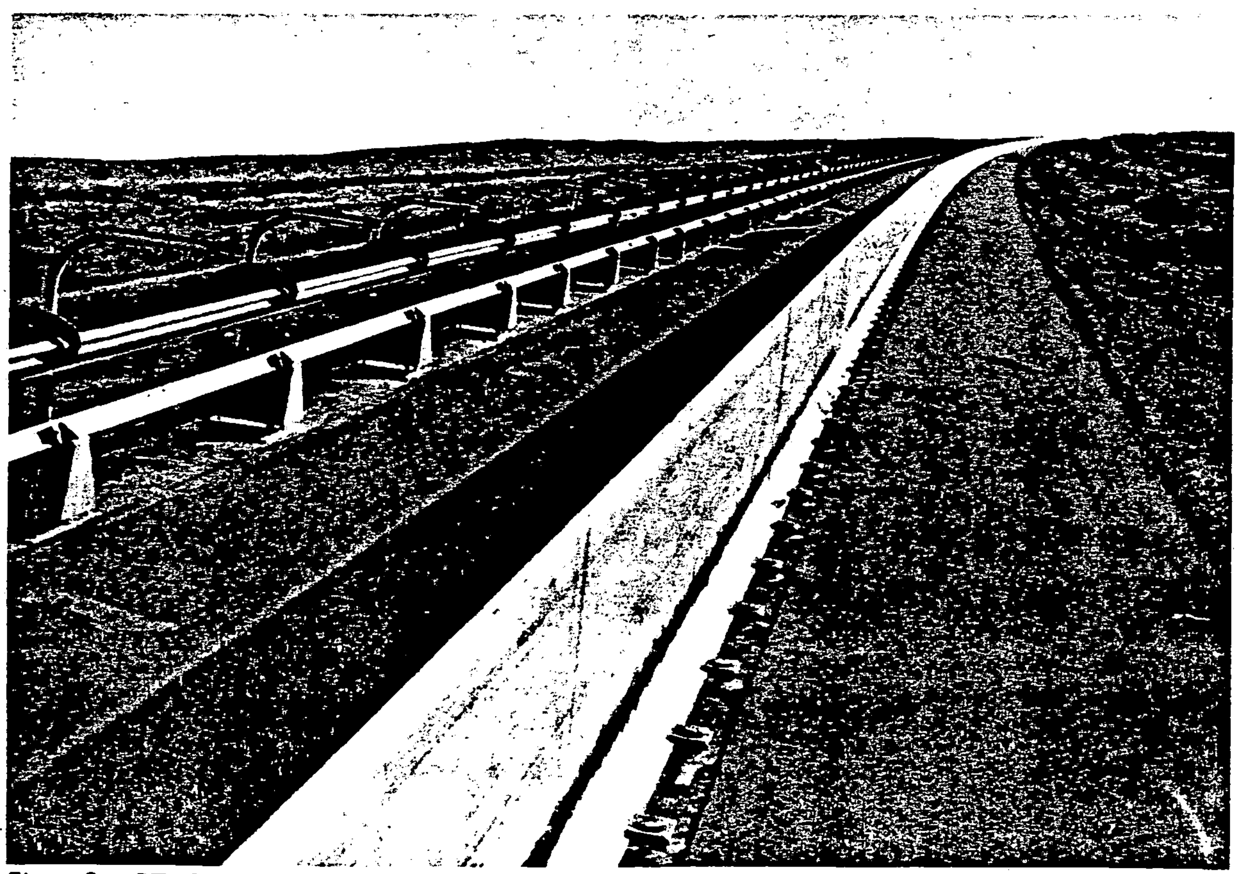


Figure 8. PTACV Guideway at Transportation Test Center. Reaction Rail in Center and Power Distribution Rails on Left.

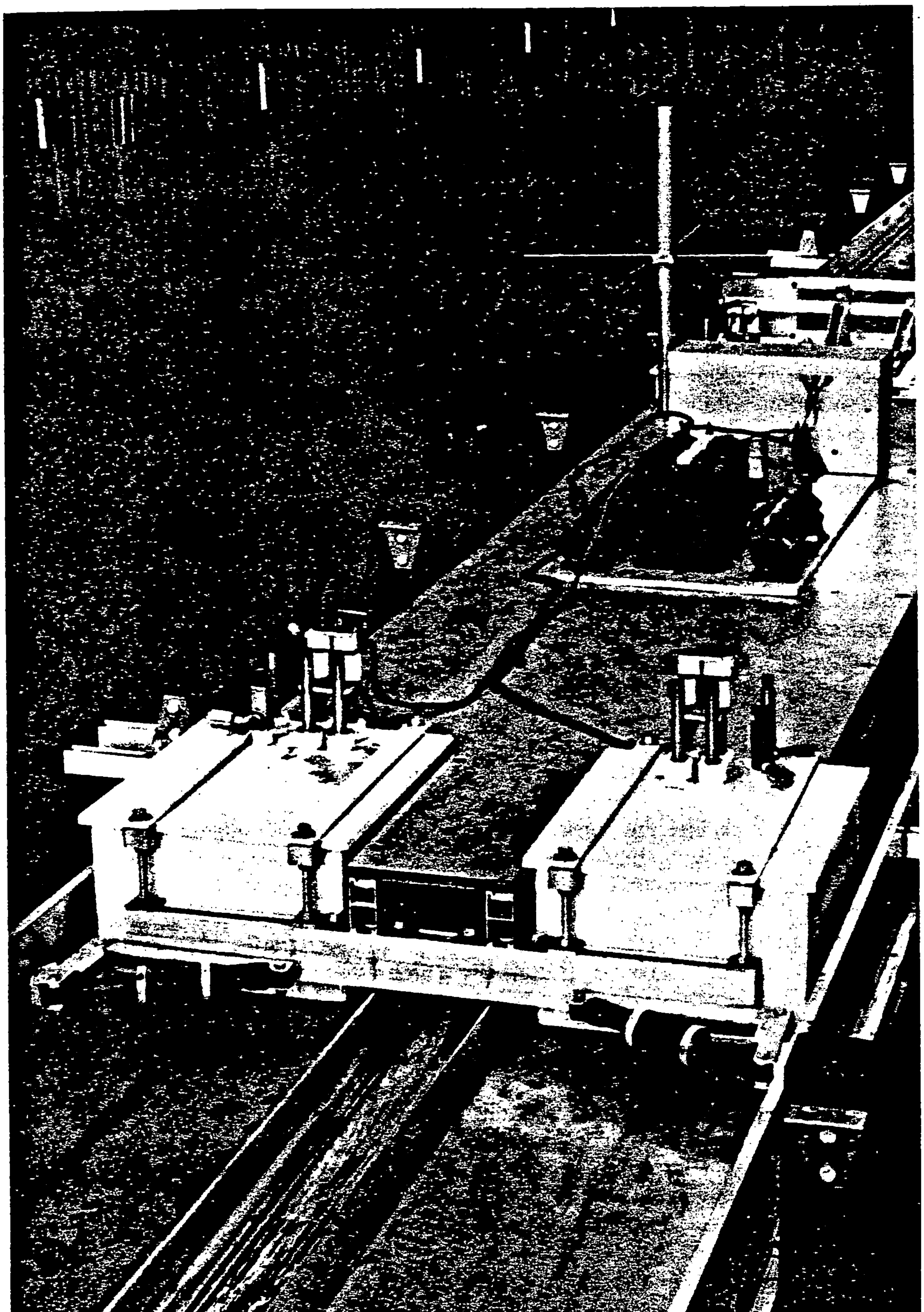


Figure 9. Magnetically Levitated Test Vehicle on Aluminum Guideway (Repulsive System).

velopment and Technology has continued a small cooperative maglev project with the Germans, including participation in the KOMET testing.

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

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

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

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

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

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

Tube Vehicles

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

Theoretical analyses and water tunnel tests reduce drag and power consumed by freight trains.

Multimodal

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

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

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

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

Suspended Vehicles

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

An experimental suspended vehicle and a one-kilometer test track were constructed by the Safege Company in France in the

Advanced Technology

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

Linear Electric Motors

The 1965 survey by MIT revealed that linear electric motors were a promising means of propelling levitated vehicles. Systems engineering studies by TRW confirmed the potential of linear motors. The concept of a linear motor had been known for almost half a century (see Figure 10), but little research or development had been done prior to 1965. An experimental aircraft launcher employing a linear motor had been built for the U.S. Navy in 1946, but the project was dropped when the Royal Navy developed the steam catapult. In the early 1960s, Professor Eric Laithwaite of Imperial College, University of London, undertook a number of laboratory experiments with several linear electric motor designs, which revived interest.

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

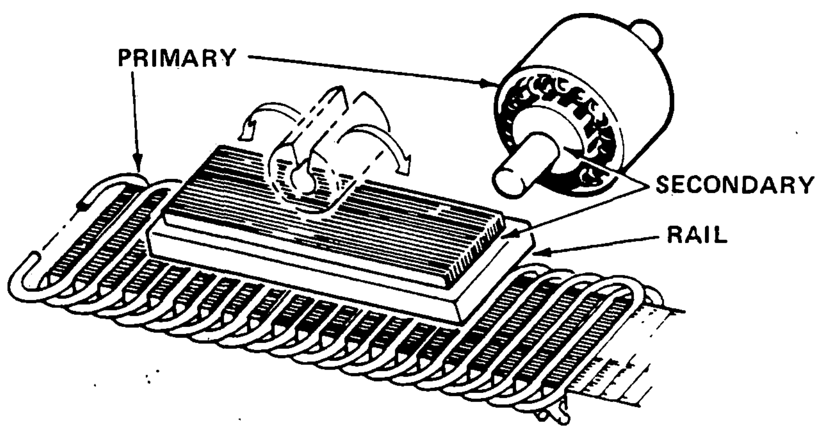


Figure 10. Principle of Single-Sided Linear Electric Motor

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

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

The LIMRV track is standard gauge with 119 lb/yard (49.4 kg/m) rail laid on wood crossties with crushed stone ballast, but the construction tolerances are tighter and the control of geometry is more precise than any track ever built. Precise alignment is made possible by the use of shims in the tie plates. An additional feature is a vertical aluminum rail—T-shaped, hollow, 22 in. (559 mm) high, ⅝ in. (16 mm) thick, with a 5 in. (12.7 mm) wide base fastened to the crossties and centered between the rails. This reaction rail acts as the secondary side of the linear motor and can be seen in Figure 11.

The LIMRV and its associated data acquisition system were delivered to the Test Center in the spring of 1971, and testing began in May. The system obtains data as voltages from sensors located on the vehicle. These signals are transmitted via telemetry to a trailer, where they are recorded on magnetic tape. Several channels of telemetered data can be displayed on a cathode ray tube (CRT) during a run for control or safety purposes. The trailer also contains remote control equipment for unmanned test runs (See Figure 12).

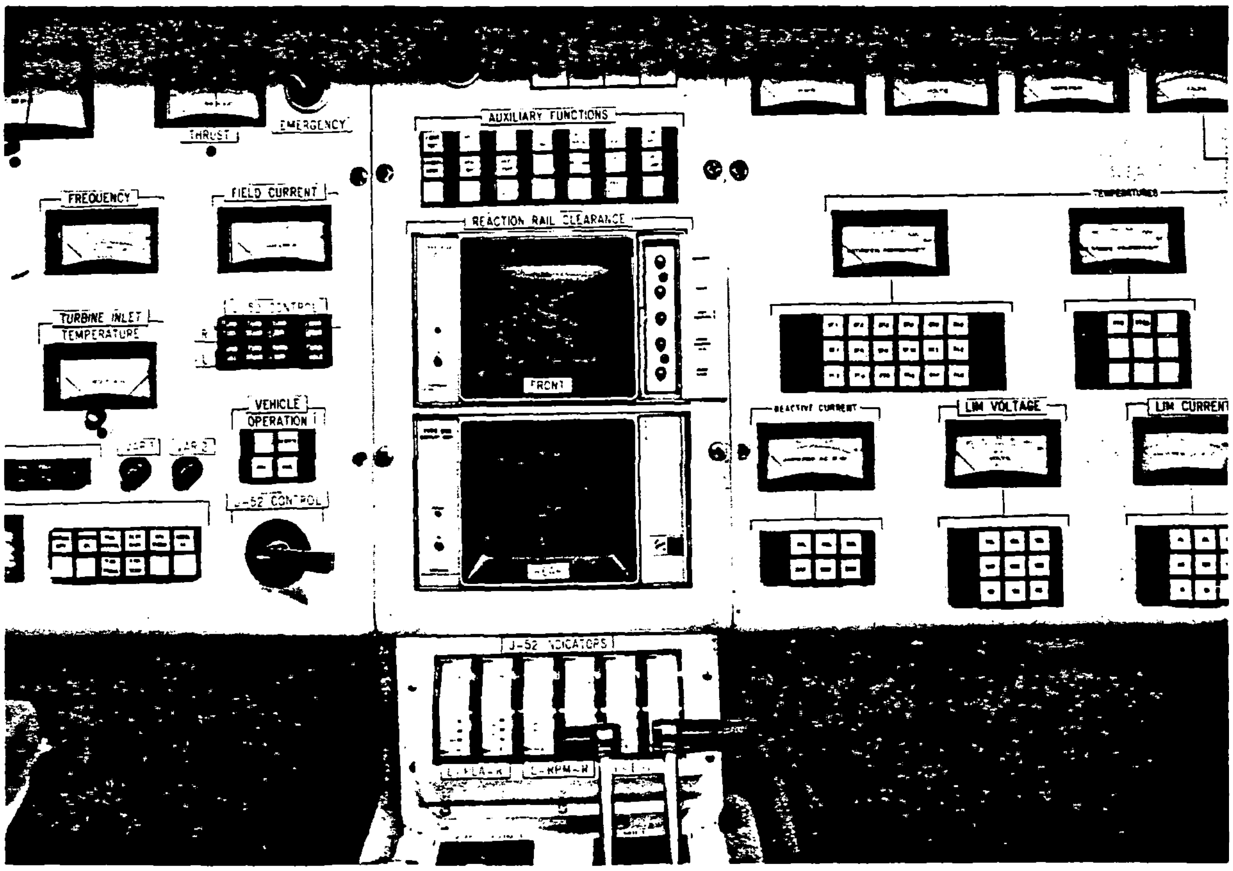


Figure 12. LIMRV Instrument Van Remote Control Panel.

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

Mathematical Models. The Jet Propulsion Laboratory (JPL) at the California Institute of Technology developed a mathematical model to predict linear motor performance, which could be used for design of linear motors. FRA contacted other researchers throughout the world who had also been working on models of linear motors. Three of these models were programmed for a computer by the Transportation Systems Center (TSC) and compared with the JPL model. The predictions of the four models agree closely (see Figure 13), giving designers confidence that new designs will perform as expected.

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

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

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

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

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

The LIM program has produced good motor designs that have performed about as predicted. Large LIMs could be operated successfully; the feasibility of linear motor propulsion for high-speed tracked vehicles has been proven. Linear motors are rugged and reliable and have potential application in railroads as well as in advanced high-speed ground systems. The Japanese National Railways have in operation a classification yard using linear motors to replace

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

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

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

Power Conditioning

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

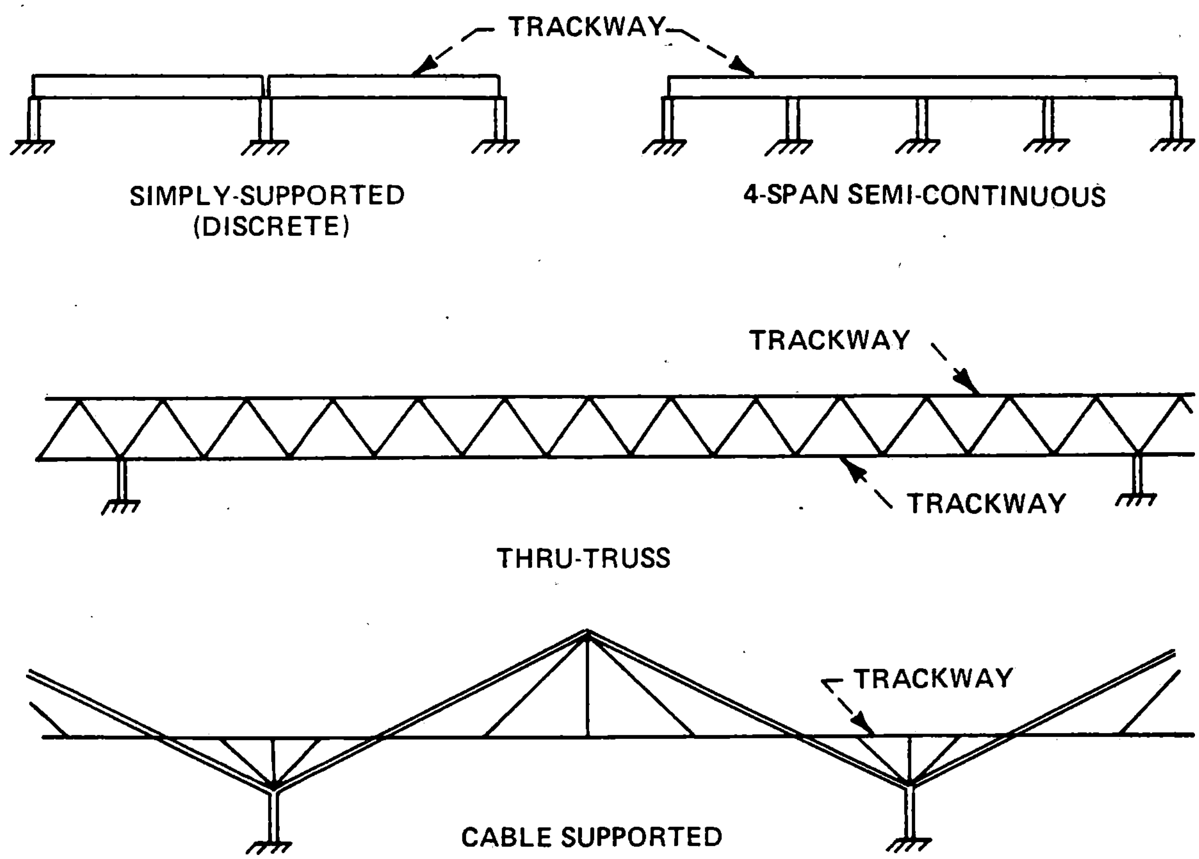


Figure 14. Elevated Guideway Design Concepts

road Technology section of this report two studies were run with the FRA test cars; one study found that power interruptions to Metroliner cars could be reduced by operating with one pantograph per pair of cars, and the other, study found that pantograph contact shoes made of sintered metal last longer than those of the carbon steel normally used.

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

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

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

Westinghouse Electric studied other possibilities for high-speed power distribution

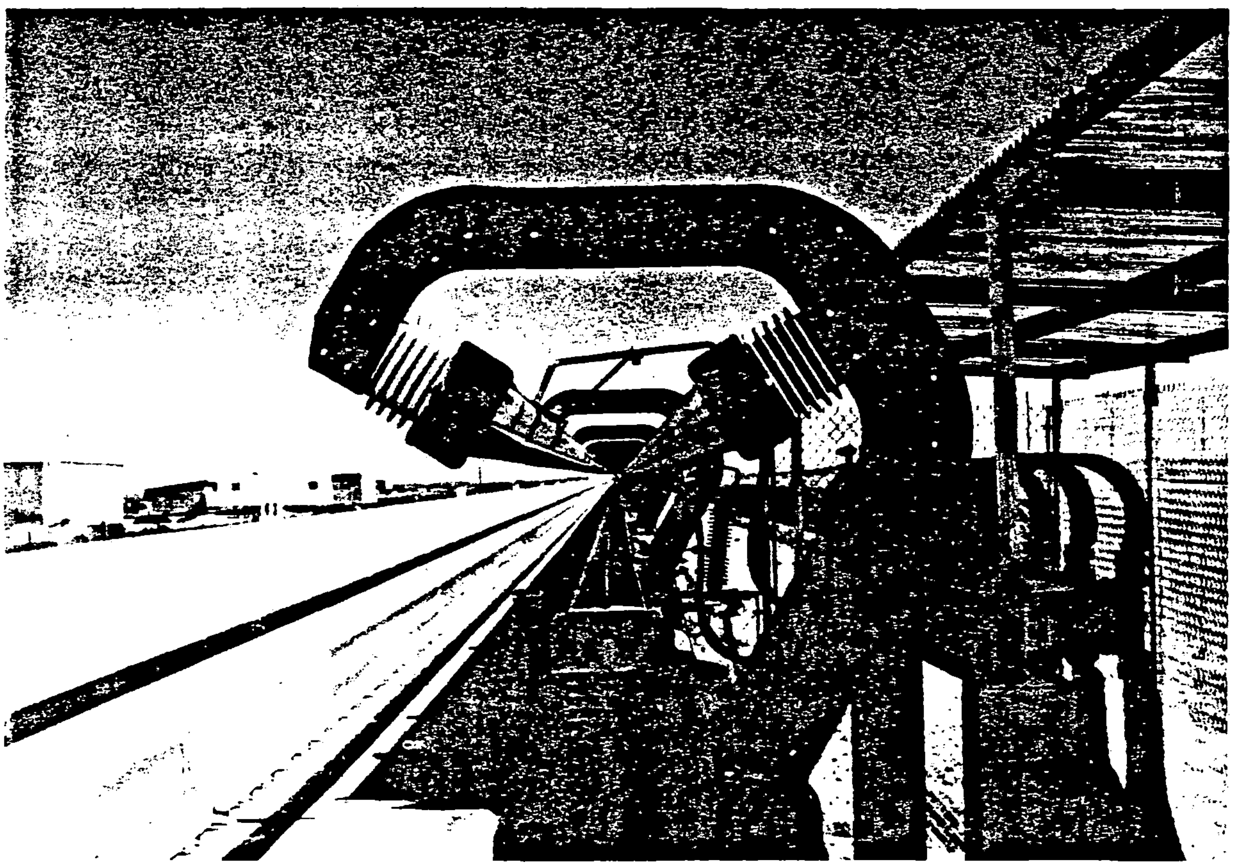


Figure 15. High-Speed Power Distribution Rails.

over to adjacent tracks or lanes. From this investigation emerged a concept designed to improve on wiggly wire—Synchronous Longitudinal Guidance (SLG).

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

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

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

Obstacle Detection

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

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

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

APPENDIX

ACTIVE FRA PROGRAMS

FRA's Advanced Systems and Advanced Technology program, as summarized in this brochure, was authorized in September 30, 1965 under the old High Speed Ground Transportation Act. Under the provisions of this Act, the R&D hardware developed was not restricted to rail, and included levitated systems and related technology as well. In 1976, however, funding under the old Act ceased and all hardware activities at FRA were restricted to wheel on rail; only analytical work in levitated systems is now authorized at FRA. Therefore, among all the projects listed in the Table of Contents of this brochure, linear electric motors and power conditioning are the only ones which have continued at the hardware level.

a. Advanced Systems

FRA is currently conducting a systems study to provide analytic insight into ways of maintaining or increasing the transportation mobility enjoyed today by the U.S. public, while at the same time employing energy conservation measures that would normally reduce mobility. This will be accomplished as a result of analyzing the projected demands for intercity transportation created by various energy assumptions, and conducting life-cycle cost/benefit studies of the various transportation technology alternatives in order to determine the most cost and energy effective solutions.

As a result, the Department of Transportation will be better able to respond to future national transportation needs, and in cooperation with the Department of Energy, make more viable the future national energy conservation policies which deal with transportation. This study will allow DOT to develop a logical integrated plan in cooperation with the Department of Energy, for developing the appropriate solutions in a timely and coordinated fashion to meet our national transportation and energy needs.

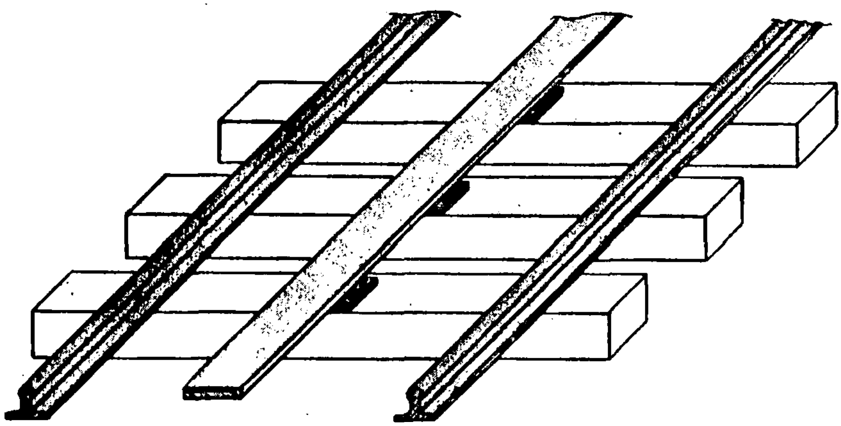
Based on the findings of the study, the areas of technology that provide the most cost and energy effective transportation will be used as the guide for directing further R&D in order to produce the most viable alternatives to the present automobile and petroleum consumption. The forecast of the approximate time for when the critical energy milestones will be reached, and the required time for developing the technology solutions, will then be used in pacing the R&D activities.

In July 1967, AiResearch completed all tests on the LIMRV linear motor in its present double-sided (vertical reaction rail) configuration. Data was acquired and is now being processed for LIM operation with a varying number of poles (out of ten) excited. This is to gain a better understanding of end-effect phenomena in the motors. The vehicle and half the present motor are now being modified to permit testing in a "single-sided" configuration which will be completely compatible with conventional railroad tracks. The reaction rail consists of .16" (4.1 mm) of 6061 aluminum laid on top of .88" (22 mm) of solid back iron. Thrust data similar to those obtained with the double-sided LIM are expected, except for effects produced by eddy currents and saturation in the back iron. Another important consideration, and perhaps the most important, is that the single-sided motor produces a substantial normal force on the reaction rail. This force can be attractive or repulsive, depending on vehicle speed and the excitation frequency of the motor windings. Also, saturation effects in the back iron may have a more pronounced effect on normal force than on thrust. The data produced by the testing will be the first with such a large machine and will reveal information which is extremely difficult to obtain by analytical means. The performance of double-sided LIMs can be predicted reasonably well using a number of published theories, but the same cannot be said for prediction of normal and lateral forces in a single-sided configuration. The normal force, especially, may significantly influence vehicle dynamics.

Experimental work on LIMs is also being done at General Electric using a rotating wheel. The wheel has a diameter of 54" (1.4 m) and is capable of tangential speeds to 400 km/hr. The wheel facility is well instrumented and a microprocessor is used to permit rapid and accurate acquisition of data. The 112 kW output linear induction motor being tested at GE has only 4 poles compared to the 10 in the megawatt-rated LIMRV/LIM. The GE LIM has a severe end effect, but is nevertheless very useful for gaining a full understanding of how LIMs function. A solid iron wheel with an eighth inch (3.2 mm) band of aluminum forms the reaction rail. The tests with this configuration, as well as those without the aluminum band are now complete. These tests will yield information that bears directly upon the oepration of a LIM over conventional running rail. A possible outcome of these tests is the eventual realization of improved non-contacting linear brakes for use on passenger trains.

The LIM testing at GE complements both the LIMRV/LIM testing and the exploratory development of the linear homopolar inductor synchronous motor. The latter type of motor will soon be tested by GE. The AC windings on both sides of the motor resemble the windings in a LIM. The apparatus consists of two AC windings and a DC excitation winding. The field winding acting in unison with the iron track bars produces a unidirectional (homopolar)

APPLICATIONS OF LINEAR MOTORS TO RAIL



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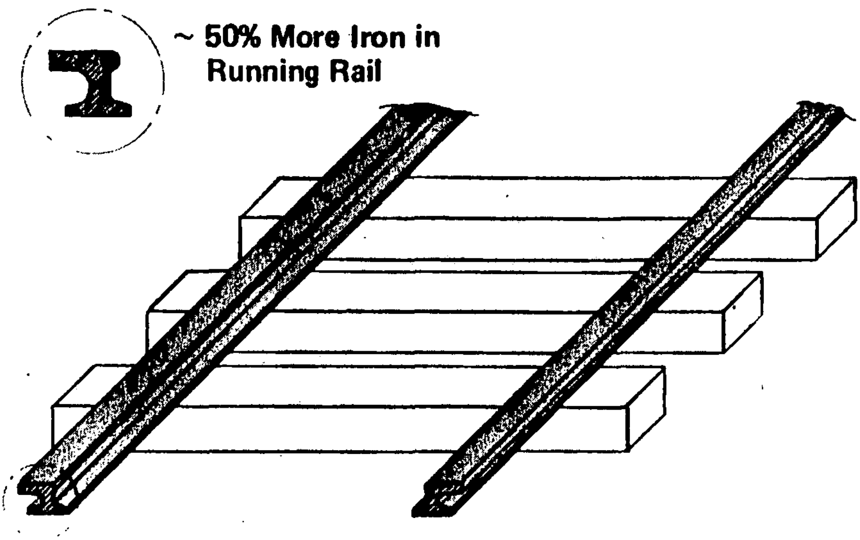
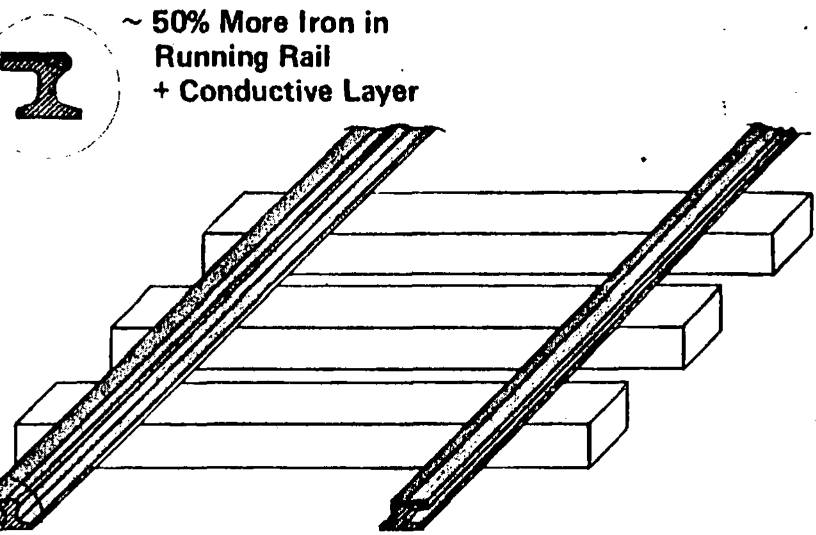


C

— FOUR BASIC CONFIGURATIONS



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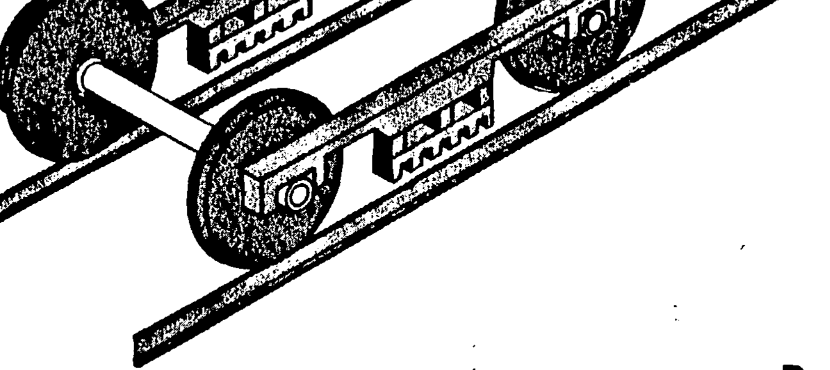

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