IMPROVING TRANSPORTATION THROUGH RAILROAD RESEARCH

(Period Covered 1988 - 1991)

U.S. Department
of Transportation
Federal Railroad Administration

Office of Research
and Development

July 1992
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13. ABSTRACT (Maximum 200 words)

The Office of Research and Development (R&D) of the Federal Railroad Administration (FRA) conducts research, development, test, and evaluation projects to directly support the FRA's safety responsibility and to enhance the railroad system as a significant national transportation resource.

This report summarizes the FRA's research and development (R&D) activities conducted from 1988 through 1991. A report published in January 1988 covered the preceding seven years. This report does not include all of the R&D activities undertaken; instead, it is representative of the work done.

Many projects were undertaken in conjunction with the railroad industry. Where required by the FRA's public safety responsibility, the work was done independently. The Office of Research and Development has relied on cooperative and coordinated programs with other research organizations, other Government agencies, industry associations, individual railroads, and railroad suppliers. Organizations participating in cooperative research include the Association of American Railroads, the Railway Progress Institute, the American Railway Engineering Association, the Brotherhood of Locomotive Engineers, the United Transportation Union, individual U.S. railroads and their suppliers, and the Canadian Government and railroads.

This report consists of an Introduction, four major sections, and three appendices. Each section describes the R&D activities of one of the FRA's four functional research programs: (1) the Track, Structures, and Train Control Program, including related areas of bridges, switches, signals, and controls; (2) the Equipment Operations and Hazardous Materials Research Program; (3) the High Speed Guided Ground Transportation Safety Program; and (4) the National Maglev Initiative Program.

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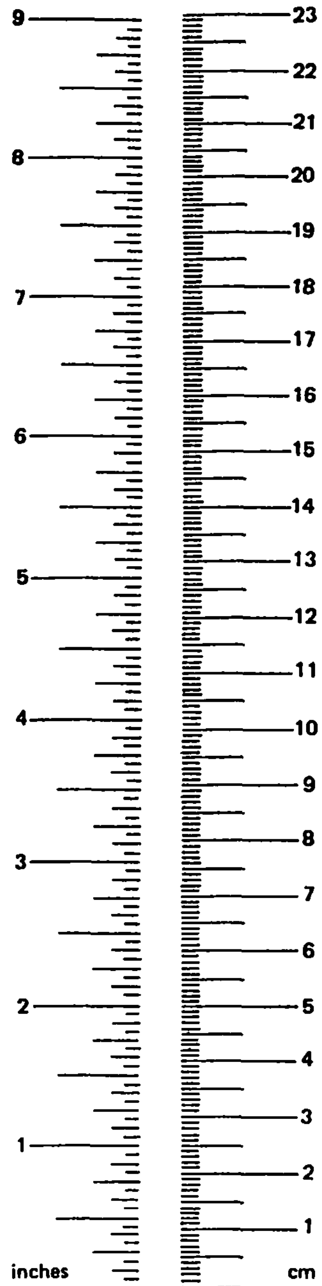
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

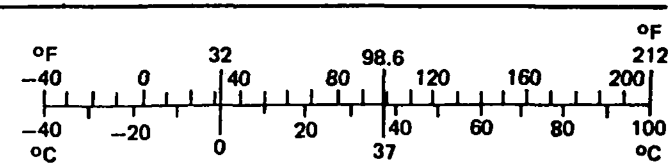
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2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

*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



Preface

The Federal Railroad Administration's (FRA) present involvement in research and development (R&D) began as a result of the High Speed Ground Transportation Act of 1965 in the Office of High Speed Ground Transportation at the Department of Commerce. In 1967, that office was reassigned to the then-new Department of Transportation and the FRA. The first ten years saw emphasis placed on development of such advanced high speed passenger systems as the Tracked Air Cushion Research Vehicle and the Linear Induction Motor Research Vehicle, and on research on magnetic levitation (maglev). During that time, the FRA also designed, constructed, and operated the facility now known as the Transportation Test Center, near Pueblo, Colorado.

In 1975, as the technical feasibility of the high speed ground systems was being demonstrated, congressional and executive branch direction shifted the research emphasis to support the then-troubled conventional railroad system. The research thrust was directed to stimulation of the economic recovery of the nation's railroads through application of advanced technologies to improve productivity, while providing for protection of the public's safety. Early in 1981, in another policy shift, the resources of the FRA R&D program began to be applied solely to railroad safety research, leaving economic research to private sector initiatives.

In 1989, in recognition of the renewed interest in high speed ground passenger transportation by the private sector, local and state governments, the U.S. Congress, and the Executive Branch, the emphasis of the FRA's R&D was expanded to include research on the safety of the new high speed systems being considered and evaluation of the technical and economic feasibility of maglev transportation systems. In addition, as a result of significant downsizing of the nation's large railroads, the number of short line and regional railroads increased significantly. The FRA Office of Research and Development increased its efforts to ensure that the results of the research were in a form that ensures the viability and safety of these smaller railroads.

Late in 1991, the Intermodal Surface Transportation Efficiency Act was passed. This act established several additional requirements which could affect the FRA's R&D activities in the future. Among the provisions is the requirement to develop and test a U.S. designed high-speed maglev system, technology demonstrations of high speed ground transportation systems, and a high speed ground transportation system R&D program.

This report is a summary of the FRA's R&D activities conducted from 1988 through 1991. A report published in January 1988 covered the preceding seven years. This report does not include all of the R&D activities undertaken; instead, it is representative of the work done. Many projects were undertaken in conjunction with the railroad industry. Where required by the FRA's public safety responsibility, the work was done independently. Organizations participating in cooperative research include the Association of American Railroads, the Railway Progress Institute, the American Railway Engineering Association, the Brotherhood of Locomotive Engineers, the United Transportation Union, individual U.S. railroads and their suppliers, and the Canadian

Government and railroads. The FRA Office of Research and Development is grateful to these organizations for the support they have provided over the years to the research achievements described in this report. Finally, the work on the high speed ground transportation systems received considerable support from other U.S. agencies including the U.S. Army Corps of Engineers and the Department of Energy, and from the governments and industry of Germany, France, and Sweden. The FRA Office of Research and Development appreciates all of their contributions.

Robert L. Krick

Deputy Associate Administrator
for Technology Development
Federal Railroad Administration

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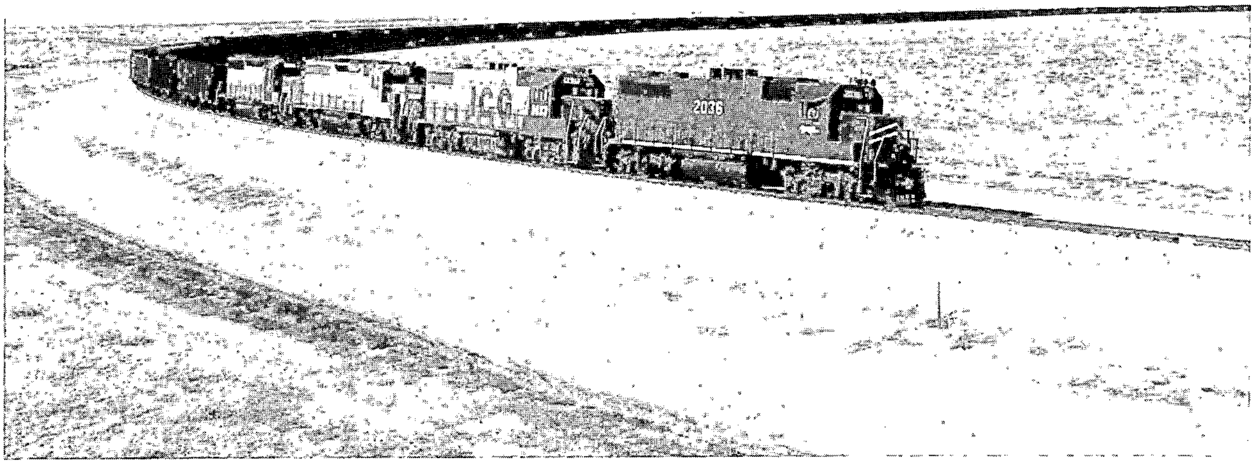
IMPROVING TRANSPORTATION THROUGH RAILROAD RESEARCH



Introduction

An effective research program is essential to the Federal Railroad Administration's (FRA) safety assurance and regulatory responsibilities, and its efforts to ensure a continuing viable and safe railroad transportation system for movement of people and freight. To this end, the FRA Office of Research and Development conducts research, development, test, and evaluation projects to directly support the Agency's safety responsibility and to enhance the railroad system as a significant national transportation resource.

To achieve the goal of improved safety, the research and development (R&D) projects support the development or revision of safety standards for regulatory action, or for voluntary industry implementation and use. Every attempt is made in R&D planning to anticipate and prevent potential safety threats. Inevitably, however, requests for spontaneous or reactive research arise. These requests may be to support a major accident investigation or to provide a technical explanation for unusual, unexplained, or potentially unsafe conditions found by FRA field safety inspectors. In either case, anticipatory or reactive research, the emphasis is on producing technically and economically sound countermeasures to ensure the continuing and enhanced safety and efficiency of railroad transportation.

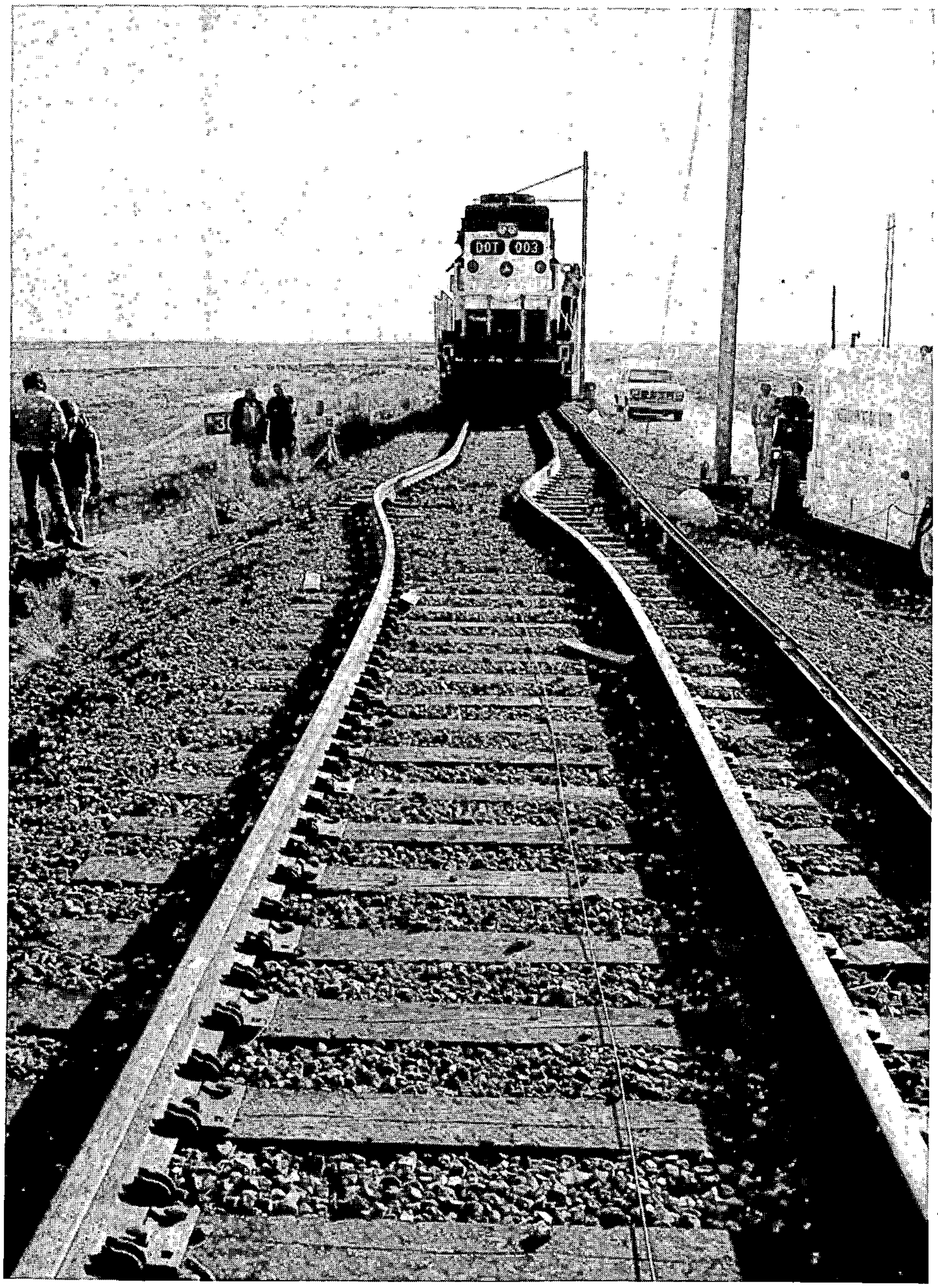
Throughout the years, while achieving FRA research goals, the Office of Research and Development has relied on cooperative and coordinated programs with other research organizations, other Government agencies, industry associations, individual railroads, and railroad suppliers. Key examples of government-industry cooperation exist in the Vehicle Track Systems Program and at the Facility for Accelerated Service Testing (FAST) at the Transportation Test Center (TTC), near Pueblo, Colorado. In both programs, all parties in the railroad community are involved. The interest of the FRA in these programs stems from its preference to fulfill its mission in a way which establishes cooperative interaction early in the industry's design process. There are obvious benefits to the industry, the public, and the FRA in attaining a status wherein the new concepts being introduced are consistently both cost effective and safe in actual service. One of the best ways to accomplish this is to imbed safety assurance in the routine analytical and testing phases of development. Safety research sponsored by the FRA looks toward the kind of up-front cooperative ventures which will maximize the likelihood that new railroad products and procedures will not inadvertently introduce unacceptable safety hazards.

Within accepted criteria for Federal involvement, FRA research seeks to avoid introduction of systems with basic incompatibilities between track, vehicles, and operations, and to prevent sudden track, equipment, or human failures which may cause major derailments or collisions. It is important that changes of the magnitude now underway in the railroad industry be thoroughly analyzed and that any potential safety implications be explored prior to widespread implementation. Several of the FRA's cooperative programs with industry reflect that approach. Recognizing that complete elimination of derailments is unrealistic, FRA research attempts to ensure that employees, passengers, and persons close to hazardous materials carried in trains are protected--even in the event of an accident.

Essential testing and simulations are carried out at two major facilities: TTC and the Research and Locomotive Evaluator/Simulator (RALES) facility, at the Illinois Institute of Technology Research Institute (IITRI) in Chicago, Illinois. Both facilities were built and are owned by the FRA, but are currently operated by the private sector under contract to the FRA. TTC is managed by the Association of American Railroads (AAR), and is used for most testing of track and train equipment. The RALES facility is managed and operated by IITRI for the FRA and consists of a computer controlled, motion-based locomotive cab which is capable of training locomotive engineers and conducting research projects.

FRA research is organized into four functional areas: (1) the Track, Structures, and Train Control Program, including related areas of bridges, switches, signals, and controls; (2) the Equipment Operations and Hazardous Materials Research Program; (3) the High Speed Guided Ground Transportation Safety Program; and (4) the National Maglev Initiative Program. These programs are discussed in the following sections, respectively.

TRACK, STRUCTURES, AND TRAIN CONTROL PROGRAM



Track, Structures, and Train Control Program

This research program directly supports the FRA's rail safety responsibility and authority under several specific acts. While much has already been accomplished in studies of track structures, much more is left to be done. In a practical sense, no appreciable quantity of work has been undertaken in the study of complex signal and train control systems or in the behavior of bridge structures under modern traffic loadings. Additional track research must continue to keep abreast of the many changes taking place in the industry. Recent improvements in the economic health and physical condition of the railroad industry has resulted in higher train speeds, heavier freight cars, and higher traffic densities. Train accidents today have potentially more severe consequences than ever before.

The design and maintenance of track, structures, signals, and train control systems are undergoing innovative changes necessitated by the increasing demands of competition. The benefits or consequences of these changes must be evaluated and predicted before their extensive adoption. The long-term effects of these changes on public safety must be determined by the FRA and considered in the conduct of railroad safety programs. In particular, safety standards for track, structures, and signal systems must be adapted to the state-of-the-art in those fields to permit innovation, but must also protect the safety of the public.

This research program is structured to directly support the Department of Transportation's (DOT) "Statement of National Transportation Policy" (NTP), particularly in ensuring that the rail transportation system supports public safety and national security. Secondarily, this research is directed toward advancing U.S. rail transportation technology and expertise, to keep the rail industry strong and competitive. In addition, elements of this program support all of the major themes of the NTP.

A description of the major ongoing program areas provides an overview of research objectives and preliminary results obtained to date. In each of these programs, technical reports have been published or will be published when major accomplishments occur. Research results are also disseminated through presentation at various technical conferences.

Track Buckling Prevention

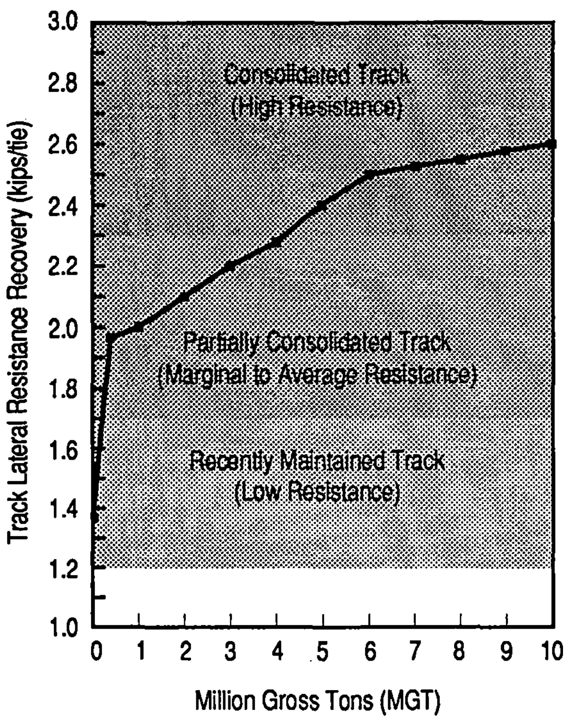
The increased use of continuous welded rail (CWR) by North American railroads has increased the risk of derailments caused by thermal buckling of railroad tracks. The FRA is attempting to reduce this risk by conducting several research efforts to investigate track lateral stability under thermal and dynamic loads.

Track buckling is the formation of large lateral misalignments caused by a combination of high compressive forces, weakened track conditions, and vehicle loads. Compressive forces are generated by thermal and mechanical loads. Weakened track conditions most typically include inadequate ballast resistivity, track alignment deviations, or deteriorated track materials.

High compressive forces may result from improper CWR installation or maintenance practices, and are indicated by low rail neutral temperature, i.e., the temperature at which the rails experience zero longitudinal force. This force-free state constitutes the reference condition from which longitudinal force buildup is measured. Vehicle loads entail longitudinal acceleration and braking forces, vertical wheel loads causing dynamic uplift (i.e. the lifting of rails/ties vertically out of the ballast resulting in a loss of ballast resistance under the ties), and lateral loads caused by curving and truck hunting. These loads play a large role in the mechanics of track buckling and hence in establishing the track's buckling potential.

Dynamic Buckling Tests for Buckling Safety Evaluations

Track buckling is a serious problem because incipient buckles are difficult to predict and detect. They often occur as trains pass over the track, creating a potential for catastrophic derailments. Prediction and detection are complicated by the fact that buckling can occur on otherwise well maintained track, under conditions for which track degradation is not suspected as a cause of impending failure.



Track Lateral Resistance Tests to Determine Consolidation Influence

The methods currently used by the railroads to minimize the risk of track buckling when laying CWR are largely empirical. The only guideline available in the United States is the American Railway Engineering Association recommended practice, which specifies a laying temperature range around the expected mean temperature. Unfortunately, this laying temperature often is not the same as stress free (or neutral) temperature, which itself can vary as a function of rail/track kinematics and CWR maintenance practices. A large reduction in the rail's neutral temperature can lead to high compressive forces, the primary factor in track buckling.

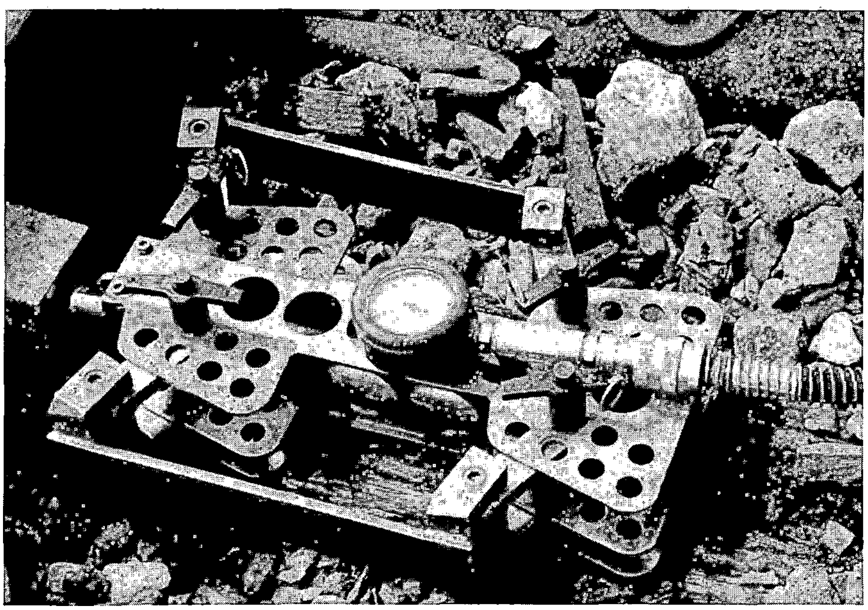
Track maintenance-of-way engineers need simple instructions, guidelines, and procedures to assess neutral temperature variations and to develop economic methods to increase the buckling strength of CWR tracks. Research efforts are underway to develop these guidelines, methods, and strategies for preventing buckling.

Accomplishments to date include the following:

- ➤ Development of analytical models to evaluate track buckling phenomena and tests to validate the models
- ➤ Use of the validated analytical models to assess and quantify the influence of the many variables involved in determining potential buckling conditions
- ➤ Determination of the force, caused by constrained thermal expansion, required to buckle typical track, and evaluation of the effects of vehicle dynamics on the buckling response
- ➤ Characterization of a variety of track construction and operating conditions in terms of restraint parameters (such as track lateral resistance), and establishment of standard methodologies for their measurement
- ➤ Preliminary characterization of rail neutral temperature shift behavior, and identification of governing causes and mechanisms
- ➤ Development of methods to nondestructively measure the internal longitudinal rail force
- ➤ Revenue service/field tests on CWR tracks to assess buckling strength characteristics and buckling potential

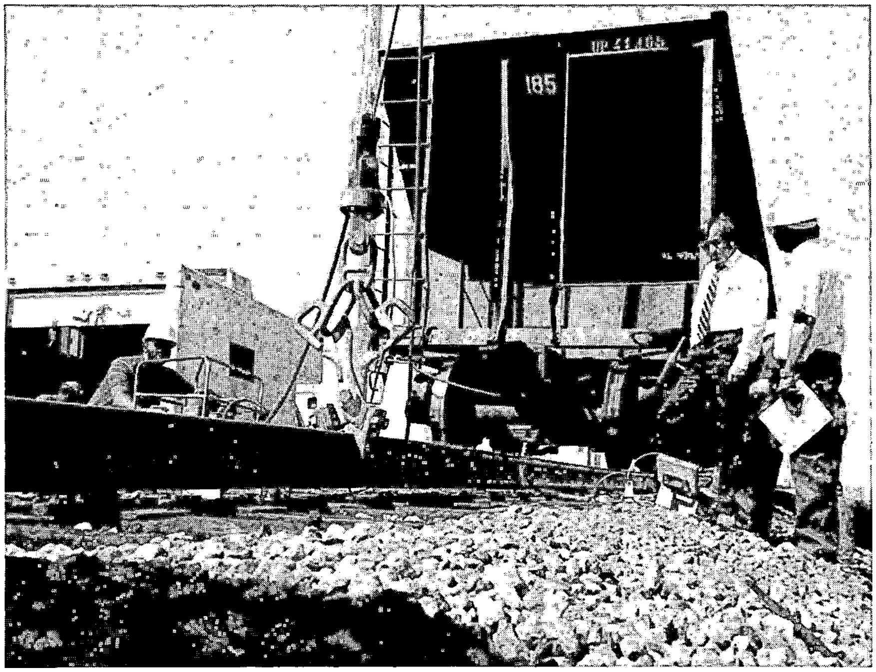
Results to date have produced prototype guidelines and criteria for buckling prevention. These criteria are based on the relationship between required track lateral strength and permissible rail longitudinal force or rail temperature increase values. The application of these criteria depends largely on an ability to determine track lateral resistance and rail longitudinal forces. Consistent with this requirement, the FRA is developing techniques and devices to measure track lateral resistance and rail longitudinal force.

Track lateral resistance can be measured by a Single Tie Push Test (STPT) device, which enables determination of the nonlinear response characteristics of the ballast. This is a key parameter for evaluation of buckling strength. The STPT device has also been used to monitor recovery of track lateral resistance after the track has been disturbed by maintenance operations, thereby improving requirements for temporary speed restrictions.



Single Tie Push Test Device for Lateral Resistance Measurement

Measurement of in-situ rail longitudinal force is extremely difficult because of complexities in quantifying and resolving the influences of internal residual stresses, rail microstructure variations, and an apriori unknown reference (i.e., stress free) condition. Researchers at RSPA/Volpe National Transportation Systems Center are developing a technique for overcoming these difficulties. This technique, based on a car-mounted rail uplift device, measures the rail's beam-column bending response characteristics.



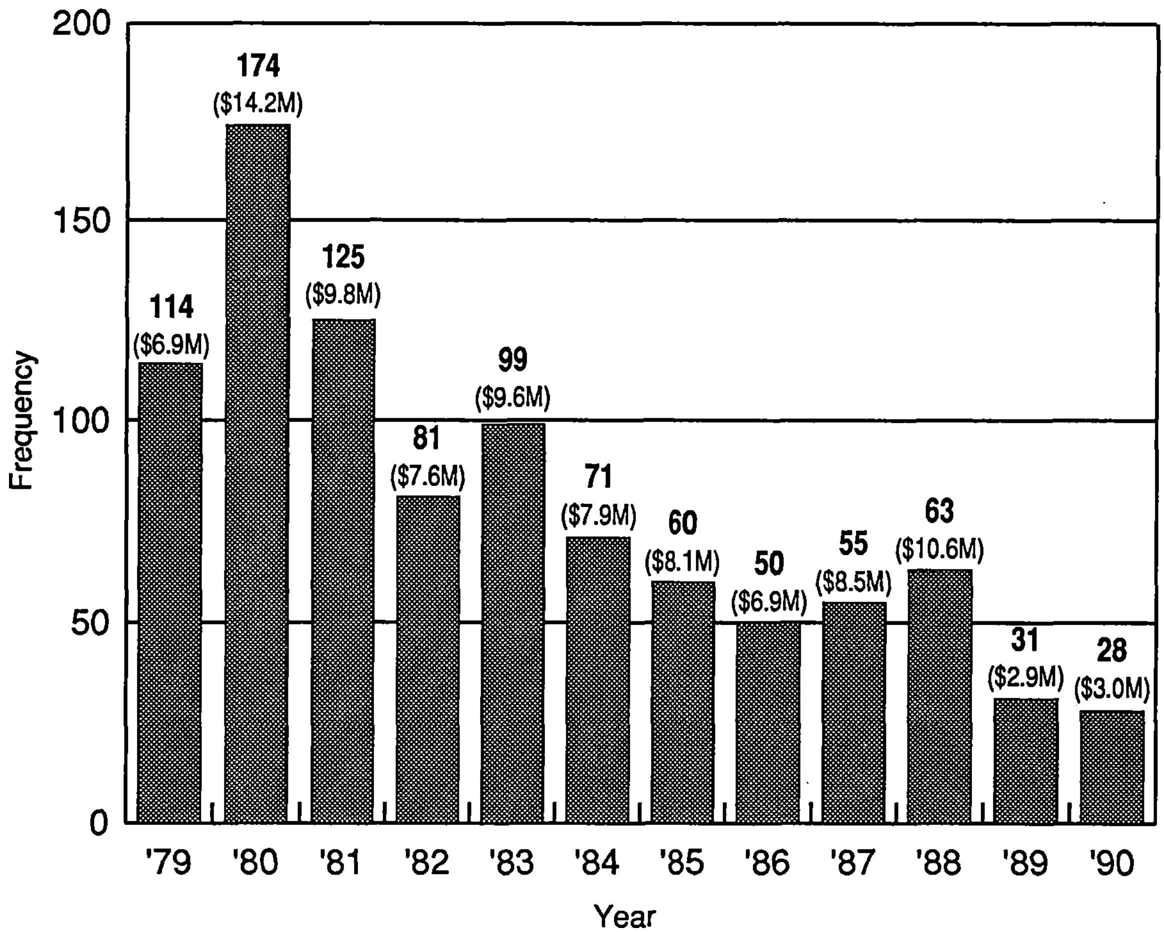
Prototype Rail Uplift Tests for Rail Longitudinal Force Measurement

This rail uplift concept/prototype device has been evaluated to establish accuracy and sensitivity limits and overall feasibility. The successful results of these studies are being extended to prototype revenue service pilot tests. The objective is to evaluate in-situ rail force and neutral temperature behavior, to improve prediction of critical buckling prone conditions.

Car-Mounted Longitudinal Force Measurement System Development

The results of the track buckling research will be used to develop guidelines and recommendations for preventing buckling in CWR tracks. The guidelines are expected to encompass performance-based instructions, as well as maintenance/design requirements which can be used by the FRA and the railroad industry to prevent buckling.

The results of this research are expected to substantially reduce the number of catastrophic accidents caused by track buckling. According to railroad industry sources, research results to date have already played a significant role in reducing the number of derailments caused by track buckling during the past ten years. The number of train accidents have decreased from 174 with $14.2 million in incurred damages in 1980 (at the inception of this research program) to only 28 and $3 million in damages in 1990. This trend is expected to continue with the new developments in buckling safety enhancement techniques as part of research efforts planned for the next five years.



Frequency Distribution of Buckled Track Derailments

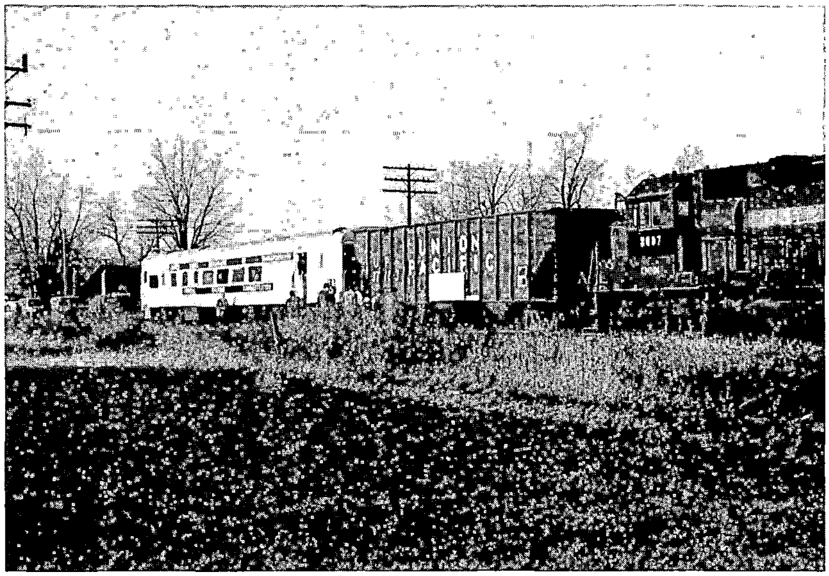
These efforts are expected to focus on:

- Continued development of rational safety criteria and specifications for preventing buckling in CWR track
- Extension of current buckling analyses and prevention techniques to CWR concrete tie track
- Continued development of concepts, techniques, and hardware for measuring rail longitudinal force and track lateral resistance, and development of guidelines for inspection methodologies and buckling prevention diagnostics
- Evaluation of high axle load and high speed influences on track stability and buckling

Rail Restraint

Failure of track to maintain gauge caused by missing or defective ties and fasteners remains the number one cause of track-related derailments in the United States. The railroads spend approximately $1 billion per year on track inspection and tie replacement to combat this problem. A research goal of the rail restraint task under the FRA's Track Research Program has been to develop a continuous inspection technique which can identify critically weak track.

Track inspections are currently performed visually, on foot or from highway-rail vehicles, and mechanically, using track geometry-measuring vehicles. Visual inspections of cross ties are largely subjective, and different competent inspectors may reach widely different conclusions concerning the condition of any group of cross ties, depending on their individual training and experiences.

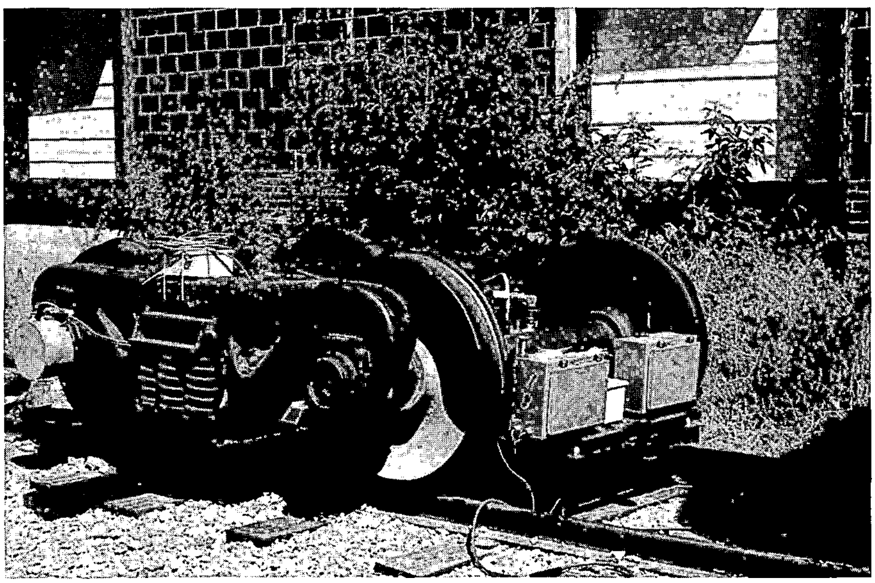


Gauge Restraint Measurement System (GRMS) in Operation

Track geometry cars measure track under loading conditions which are a function of the mass of the car, its velocities, and several random factors influenced by the geometry itself. Categorically, these cars cannot measure the ability of the track to maintain gauge under controlled lateral loads.

The FRA has developed the Gauge Restraint Measurement System (GRMS), the first continuous tie inspection system that automatically detects locations where rail restraint is inadequate. The GRMS provides a performance-based evaluation of rail restraint capacity by directly applying a lateral test load between the rails and measuring the resulting widening of gauge. The test load is kept to a sufficiently low level that the track is not damaged by the process.

Extrapolations from the gauge measurements under the test load project the potential gauge widening under severe lateral loads that could occur under a train. The GRMS locates and marks locations at which the potential widening of gauge could be sufficient to allow the wheels of a locomotive or car to drop between the rails.



Split-Axle Equipment for Loaded Gauge Measurement

The GRMS measures continuously, except through turnouts, at speeds up to 40 km/h (25 mph). The FRA, in cooperation with several of the largest railroad systems and many regional and short line carriers, has tested over 6,400 km (4,000 mi) of track while developing and refining the GRMS.

The present GRMS is an engineering prototype system.

It consists of a half-loaded 90,718-kg (100-ton) hopper car on loan from the Union Pacific Railroad, and an instrumentation car pulled by a locomotive. The hopper car is equipped with two gauge measuring systems. The special telescoping axle, used to measure loaded gauge, is mounted in a standard three-piece freight truck which fits under the hopper car or any conventional 90,718-kg (100-ton) capacity freight car. The instrumentation car carries all the computer, signal processing, power supply, and support systems equipment.

The GRMS first measures track gauge in its unloaded state using a conventional contact gauge system similar to that used on many track geometry cars. The seven-ton gauge widening load is then applied by a wheelset on a telescoping axle installed as the first axle of the trailing truck of the hopper car. The loaded gauge is measured directly from the displacement of the telescoping wheelset. Loaded and unloaded gauge measurements are taken once every foot, and are compared to provide calculated indications of track strength against gauge widening loads.

Two significant indications are provided. The projected loaded gauge is the calculated reserve of gauge remaining before widening to a critical level under predicted heavy lateral loads and normal vertical loads. The second indication, deflection rate, shows the relative stiffness of the track, and predicts locations of possible future weakness.

The quantitative measurements of track strength performed by the GRMS provide a continuous record of track condition and comparisons against defined thresholds. Comparing the measurements obtained from two or a sequential series of surveys will permit evaluation of overall track quality, the location of present and potential future problems, and the effects of time, traffic, and maintenance work on the strength of the track.

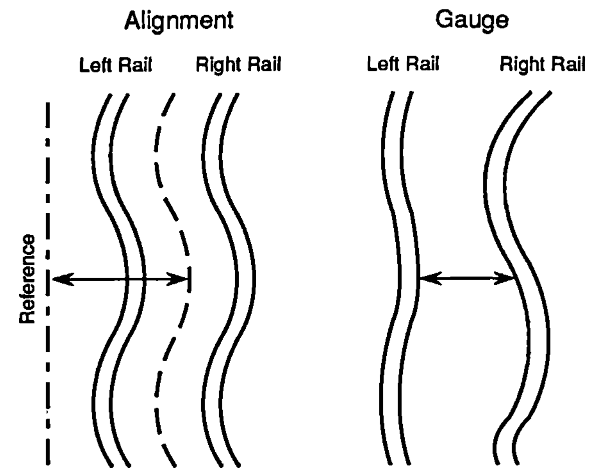
In addition to the obvious advantages of the GRMS for safety inspections, a railroad can incorporate this information into a maintenance planning program to provide a rational method of allocating cross tie renewal resources to maximize safety and economic benefits. The information is also valuable to railroads that are monitoring the quality control of cross tie renewal operations through the ultimate quality criterion of track strength improvement.

Research planned for the next few years includes the following topics:

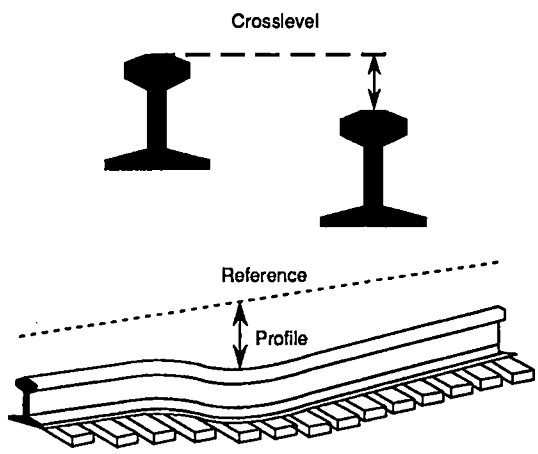
- Continued revenue track surveys of U.S. railroads
- Alternative tie inspection standards
- Rates of tie degradation
- Prototype tie maintenance planning procedures

Vehicle/Track Interaction

The FRA's Vehicle/Track Interaction Program conducts studies of vehicle response to track geometry. The objectives are to develop improved approaches to track geometry inspection and track maintenance that are both cost effective and safety effective, to develop modifications to vehicles susceptible to derailment, and to develop methodologies for evaluating new vehicle designs for safe dynamic behavior. In addition, some of the results of these efforts are used in studies of gauge restraint, track buckling,



Track Alignment and Track Crosslevel



Gauge Geometry and Profile Geometry

and rail fatigue. This program is being conducted through cooperative research efforts with the industry and has promoted information exchange among members of the industry and the Government.

Railroad track geometry is the geometric relationship between the two rails of the track and the position of the track relative to a fixed reference. Track geometry can be described by four characteristics: crosslevel, profile, alignment, and gauge. Gauge is the distance between the left and right rails, while track alignment is the location of the track center line relative to a reference. Profile is the elevation of each rail, and crosslevel is the difference in elevation between the left and right rails. All four of these characteristics vary with distance along the track. Because of the nature of track construction, track geometry variations can be repetitive or can be isolated single events.

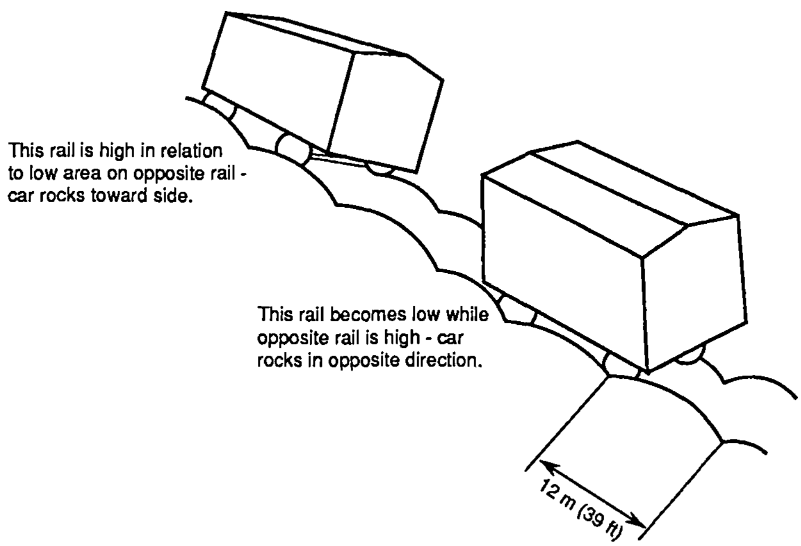
Excessive variations in any of the four track geometry characteristics can lead to a derailment. In addition, track geometry variations can cause large lateral rolling and vertical bounce motions of vehicles, and can induce large lateral and vertical forces between the wheel and the rail. These motions and forces can be oscillatory. The motions and forces might vary as the vehicle travels on the track, causing buildup of resonant motions of the vehicle, or they might be single events, occurring only once at a particular track location as each vehicle passes.

Over the last ten years, approximately one-third of all accidents involving freight trains have been attributed to defects in the track, with track geometry being attributed as the primary cause of approximately one-third of those accidents. Accidents attributed to track geometry defects have caused $162 million of damage from 1984 to 1990, ranging from $19 million to $29 million per year. It is likely that track geometry contributes to derailments even when another factor is cited as the primary cause. For example, poor track geometry can cause large forces to be imparted by the vehicle to the track, causing the gauge to spread wider and wider under successive vehicles until the gauge is too wide to support the next vehicle. Thus, track geometry contributes to derailments that are attributed to wide gauge. High forces, repeated with each passing vehicle, can contribute to rail fatigue and fracture. The forces generated by the vehicle response to track geometry can also trigger a track buckling failure, if other conditions which promote track buckling are present. Poor track geometry can also cause large vehicle motions, which can make the vehicle more prone to derailing if the locomotive engineer must brake or accelerate at an inopportune time. Train accidents attributed to human factors or miscellaneous causes can, in fact, be initiated by track geometry irregularities and are subjects of study under this research program.

The FRA has developed guidelines on the safe limits of track geometry based on rail vehicle response to track geometry variations. Statistical analyses of the freight car fleet and railroad track in the United States have shown that derailments are extremely rare statistically. Consequently, scenario analyses have been used extensively. A scenario is defined as a set of vehicle and track conditions under which the vehicle is expected to derail. After the general characteristics of the vehicle and track in the scenario have been established, the sensitivity of the vehicle's behavior to variations in these characteristics is investigated.

With the scenario approach, the safe limits of track geometry are determined through engineering analyses and tests. The analyses are used to extrapolate test results, to predict the response of the rail vehicles to different track geometries, and to determine the effect of vehicle characteristics, such as vehicle weight and the wear of vehicle components, on vehicle behavior. Testing is done to ensure that the analytical model can truly predict the behavior of the vehicle. When possible, tests are conducted close to derailment conditions. Tests are also conducted to demonstrate that vehicles are safe at the track geometry limits recommended for standards.

Harmonic roll is caused by variations in track crosslevel which cause vehicles to roll from side to side. Rails are manufactured in 12-m (39-ft) and 24-m (78-ft) lengths, which are then bolted or welded together. The joints on one rail are often laid opposite the rail length mid-points of the other rail to make the track structurally sound. The joints tend to settle lower than the mid-point of the rail, causing crosslevel variation at the joint location.



Rail Vehicle Rolling Caused by Reported Crosslevel Variations

For vehicles of a particular length, the wheels on one side of the vehicle will be near the low joints, while the wheels on the opposite side will be near the rail length mid-points. As such, as a vehicle moves down the track, the wheels which were at the low joints move to the high mid-points, while the opposite wheels move from the high mid-points to the low joints and the vehicle rolls from side to side.

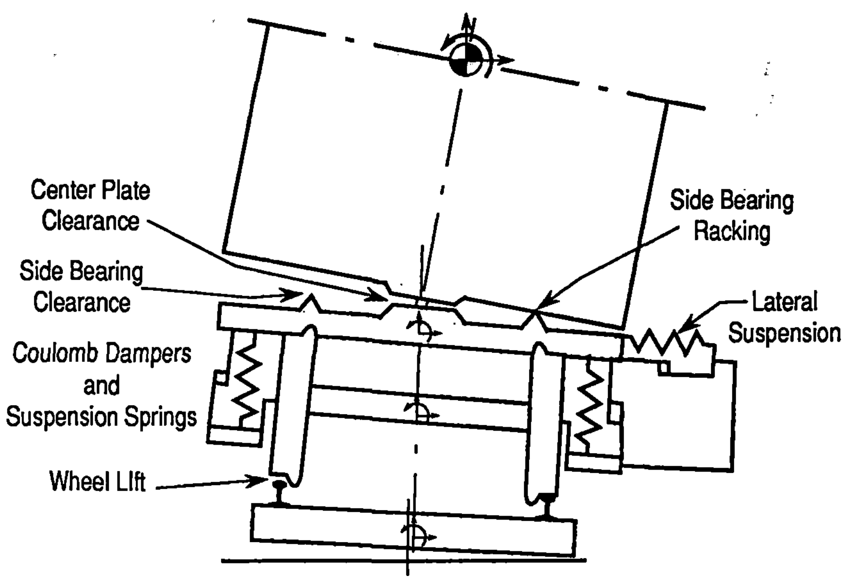
If a vehicle with a particular wheel placement encounters track with a sufficiently long series of consecutive low joints while moving near its critical speed, the amplitude of the roll response of the vehicle will increase, meaning that the vehicle will roll more and more at each low joint. This scenario is often referred to as the harmonic roll of freight vehicles.

High capacity vehicles for carrying grain, coal, and similar commodities came into increasing use in the 1970s. These vehicles tended to have high centers of gravity, because of their high capacity, and to have lengths near the suitable length for harmonic roll. The harmonic roll response of such vehicles to repeated crosslevel irregularities can build up sufficiently to literally roll the vehicle over and off the track.

The number of derailments attributed to this scenario, and the hazard and loss associated with these derailments, provided the impetus for a major research effort by the FRA to understand the track and vehicle conditions which allow harmonic roll to occur. Analytical models were developed and carefully controlled tests were conducted to better understand the vehicle and track characteristics which affect the harmonic response of freight vehicles. The analytical models, supported by the test data, have been used in studies to determine the effects of vehicle and track characteristics on the harmonic roll behavior of rail vehicles. These studies have been used as the basis for proposed specifications for maintaining crosslevel within acceptable levels to prevent excessive harmonic roll response for the fleet of North American vehicles.

Because of the complexity of the equations which describe the behavior of rail vehicles, such models often must be solved numerically on a computer. This model has been used to extensively analyze the harmonic roll behavior of rail vehicles. A number of harmonic roll response tests have been run, both at TTC and on revenue-service railroads.

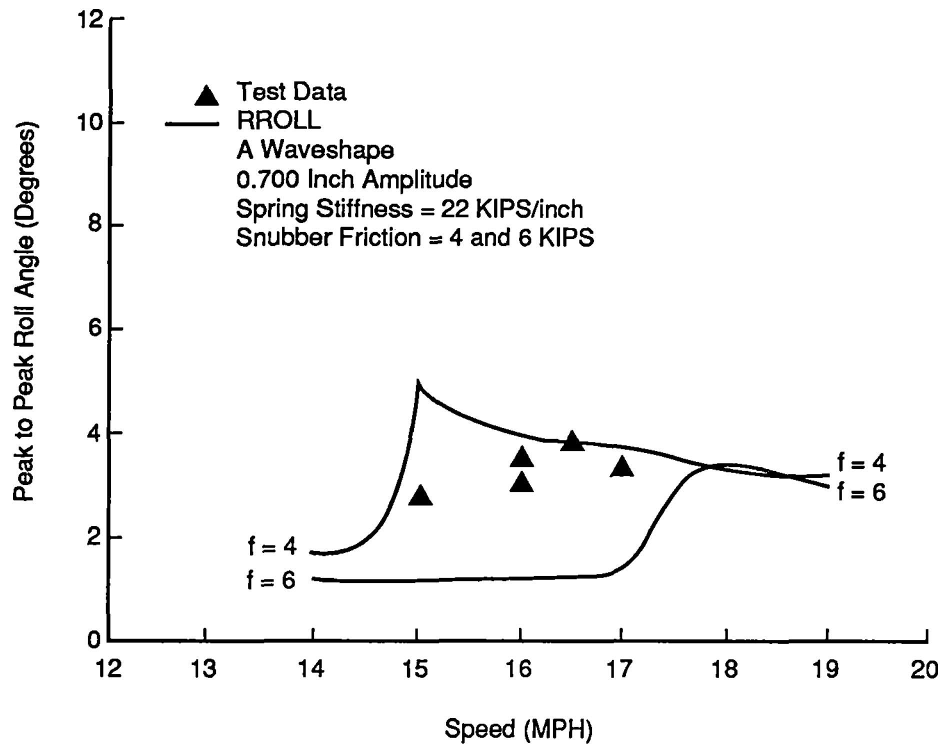
A comparison of analysis predictions with test results from the Vibration Test Unit at TTC revealed close agreement. The analytical predictions were made for different amounts of damping in the suspension system and actually bound the measured response of the vehicle.



Model for Analyzing Rail Vehicle Response to Crosslevel Variations

Curved track is usually superelevated, with the outside rail higher than the inside rail. On tangent (straight) track, the two rails are maintained at the same elevation. A transition is usually placed between the level tangent track and the superelevated curved track. At this transition, the outside rail is gradually raised to obtain the superelevation required in the curve, thereby "warping" or "twisting" the track. In addition to the design features of the track, unintended twist can occur as a defect in the track. In addition to causing a crosslevel irregularity, a single low joint causes the track to be twisted. Irregularities in the track can also cause the twist at the entry and exit of a curve to be greater than the designed twist.

When a vehicle in good condition is on level track, all the wheels equally share the load. When the same vehicle is on twisted track, the wheel loads are redistributed. The situation is somewhat analogous to a table on a warped floor, which has a tendency to rock between diagonally opposite legs. The suspension of rail vehicles allows them to negotiate some amount of track twist without excessive changes in the load supported by the wheels.

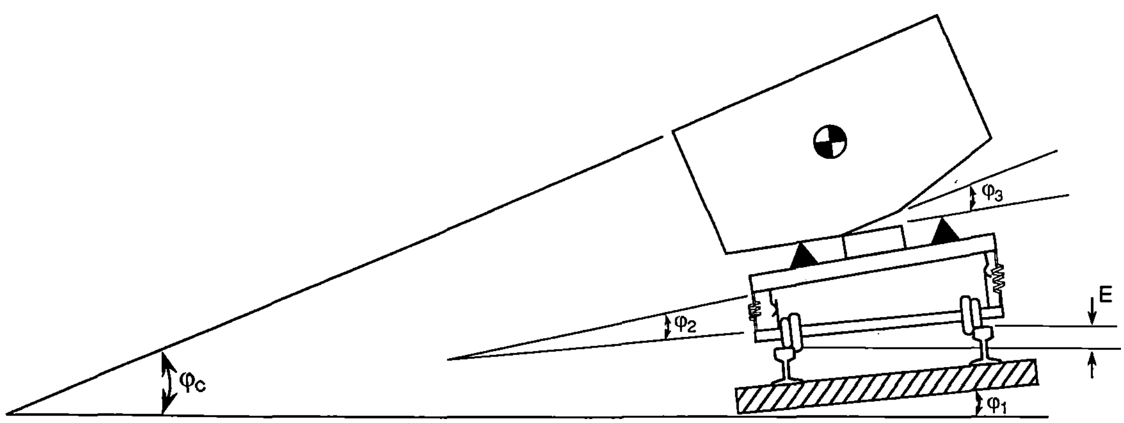


Comparison of Model Prediction and Test Measurements of Rail Vehicle Harmonic Roll Behavior

In addition to carrying the weight of the vehicle, the wheels must also transmit the lateral loads required for the vehicle to negotiate the curve. These lateral loads for curve negotiation can be quite high, even at low vehicle speeds. A wheel with insufficient vertical load and a high lateral load can be forced up and over the top of the rail, thus derailing.

Analytical modeling and testing of rail vehicle harmonic roll response to various track configurations and anomalies have improved understanding of rail vehicle behavior. An analytical model is used to study rail vehicle response to track twist. This model was compared to test results from the twist test part of the vehicle/track interaction tests conducted at TTC in 1984.

A comparison of the predicted with measured vertical wheel load on the left front wheel of an empty hopper car revealed relatively close agreement, but the test measurement indicated a lower minimum wheel load than the analysis predicted. This discrepancy is difficult to account for with the model, but the vehicle/track interaction twist test has only been run on tangent track. It is therefore necessary to run additional tests on curved track.

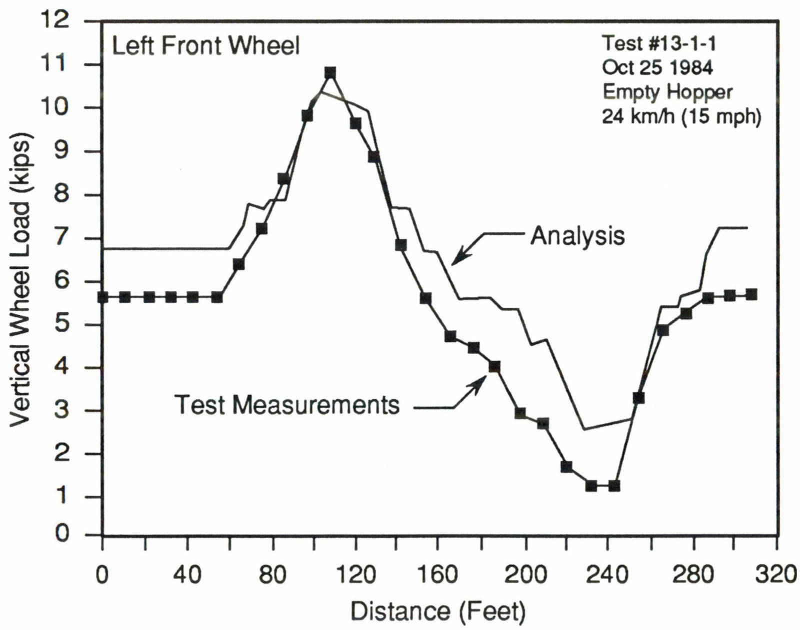


Model for Analyzing Rail Vehicle Response to Track Twist

The FRA has formulated a plan for testing three vehicles which are prone to derailment caused by track twist. This test will be performed on curved track under conditions which are expected to be close to derailment. The test plan calls for extensive instrumentation of the vehicle to closely observe vehicle response to twist. The results of this test will be used to augment the analytical basis for the twist part of the proposed specification for maintaining track twist within safe limits.

In addition to harmonic roll and twist, rail vehicle response to profile variations and rail vehicle curving behavior have also been studied with tests and analyses. From these tests and analyses, a safe envelope of crosslevel and profile geometry has been derived. A specification for crosslevel and profile geometry has been developed which is based on this safe envelope. The proposed safety specification seeks to prevent all causes of derailment other than failure of a structural or mechanical component of the vehicle or track. The safety criteria for the specification are limited to the conditions which cause:

- Excessive unloading
- Vehicle motions leading to coupler separation
- Vehicle motion which can led to separation between the car body and the truck centerplate
- Excess lateral forces and/or vertical load reductions which could lead to wheel climb in curved track



Comparison of Model Prediction and Test Measurements of Rail Vehicle Response to Track Twist

The proposed crosslevel and alignment geometry specification has been implemented in a computer program and applied to typical track geometry car data. This program has been used to analyze data taken with the FRA's T-10 inspection car, as well as with railroad track geometry cars.

The FRA has made considerable effort to understand rail vehicle response to track alignment geometry and gauge geometry, although the work has not yet progressed to the point where a specification for alignment and gauge can be developed. Efforts are being made to develop a sufficient base of knowledge for such a specification. The FRA has conducted extensive research on modelling the wheel/rail interface. Adequate modelling of this interface is essential to developing detailed models for analyzing rail vehicle response to alignment variations. With an accurate model of the wheel/rail interface, the FRA has been able to develop a detailed computer simulation model of a rail freight vehicle which can predict the vehicle response to any combination of track geometry variations.

The results of FRA research into vehicle modelling have been applied in a number of studies. Currently, efforts are being made to determine the limits of track alignment variations in curves. The effects of variations of length and amplitude on vehicle behavior are being studied. In curves, a long length variation with a relatively small amplitude may not represent a substantial change in the track alignment geometry. For a range of alignment variations in curves, it may be possible to traverse the track at slow speed without derailment. This study is directed toward determining the safe speeds at which alignment variations can be traversed as a function of alignment length and amplitude.

The FRA has also conducted a number of tests of rail vehicle response to alignment and gauge variations, including the vehicle/track interaction tests conducted at TTC, and the test conducted on the Boston and Maine railroad in Bennington, New Hampshire.

Combinations of track geometry irregularities, such as an alignment variation and a crosslevel variation, can cause a greater vehicle response than caused by a single irregularity. The FRA has started work to determine the influence of alignment variations on the harmonic roll response of a rail vehicle. A general effort is being made to determine the influence of alignment variations on vehicle response to track crosslevel, including the influence of alignment variations on vehicle response to track twist.

Currently, FRA efforts in vehicle/track interaction are primarily directed toward completing the experimental basis for the proposed twist specification, developing a basis for track alignment and gauge specifications, and developing an understanding of how alignment variations can influence rail vehicle response to crosslevel variations. The research to be conducted in the next five years is expected to include:

- Testing to experimentally determine the safe limits of track twist
- Implementation of the proposed specification on a track geometry vehicle
- Determination of the safe envelope for gauge and track alignment geometry
- Formulation of a specification which bounds limits of the safe envelope for gauge and track alignment geometry
- Determination of the influence of gauge and track alignment variations on vehicle response to profile and crosslevel variations

Facility for Accelerated Service Testing (FAST)

Located at TTC, FAST is the only full-scale railroad testing facility in North America dedicated to evaluating the behavior of track and equipment under actual service loads. FAST is a 4.3-km (2.7-mi) loop track.

FAST is capable of moving one million gross tons of railroad traffic per operating day over a given point in the track, under tightly controlled and monitored research conditions.

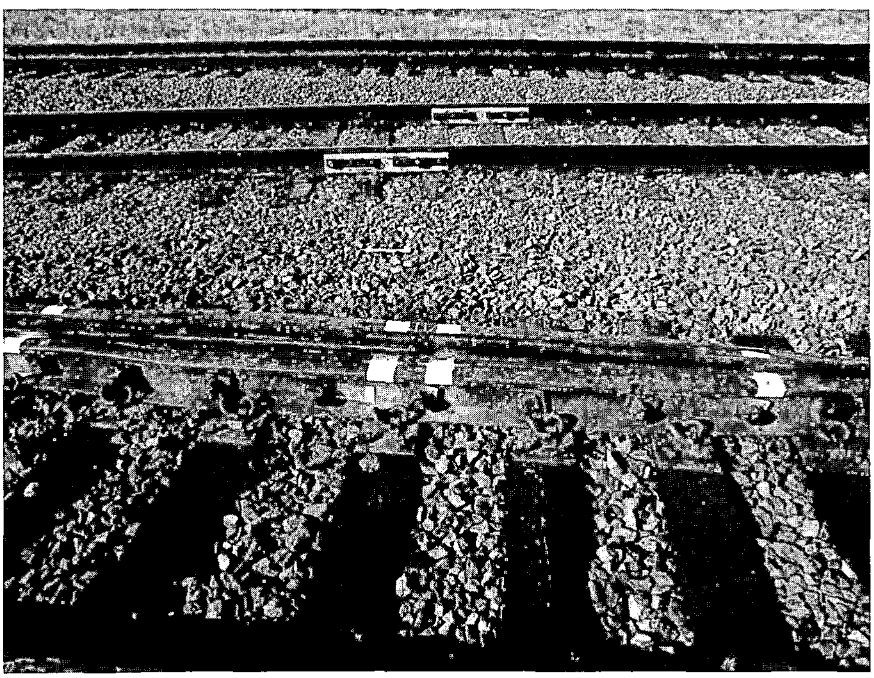
Since its inauguration in 1976, FAST has provided the FRA, the railroad industry, and railroad suppliers with a means to evaluate the performance of track and rolling stock designs and components under the rigors of actual service but during a greatly compressed time period.

FAST projects are sponsored jointly by the FRA and the railroad industry, which includes the railroads and railroad suppliers. The railroads participate both individually and through AAR. The FRA provides partial funding and program direction. AAR provides partial funding and program management and execution. The individual railroads provide material, rolling stock, and expertise of their personnel. The railroad suppliers provide material, equipment, and advice.

The Heavy Axle Load (HAL) project was initiated at FAST in 1988. The objective is to evaluate the performance of track that carries 108,862-kg (120-ton) to 113,398-kg (125-ton) freight cars loaded to 35,380 kg (39 tons) per axle. This project produced 145.15 x 10^6 Mg (160 x 10^6 tons) of traffic on each point on the FAST track by 1990. A rigorous comparison between the HAL project and earlier tests using 29,937-kg- (33-ton) per-axle cars has provided the FRA and the railroad industry with the most extensive body of information available on the safety, operating, and economic factors involved in the operation of these heavier cars.

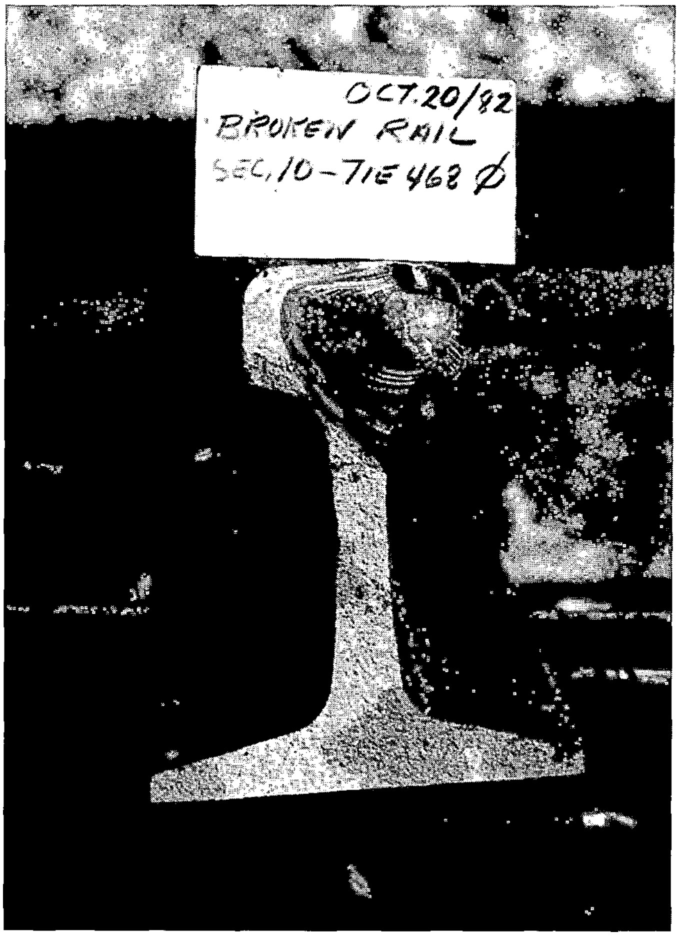
In 1991, the HAL project added half of the 90.7 x 10^6 Mg (100 x 10^6 ton) extension needed to further evaluate improved track components and to conduct more extensive subgrade testing. This 90.7 x 10^6 Mg (100 x 10^6 ton) phase is scheduled for completion in 1992. This phase will be followed by a series of tests of still further improved track and equipment components under heavy axle loads. Improvements in track and rolling stock are becoming available at an increasing rate, largely because of the information coming from FAST. These developments result, in turn, in increasing needs for evaluation that is only available in North America at FAST.

Initial Operation of the FAST Heavy Axle Load Experiment

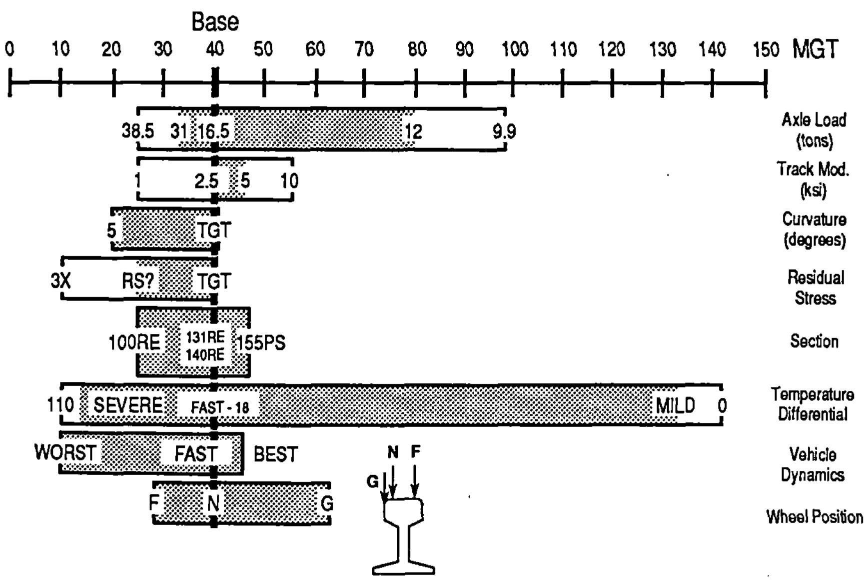


Test Frog Under Evaluation in the FAST Experiment

Rail Integrity



Detail Fracture Life Sensitivity



Detail Fracture in Rail Head

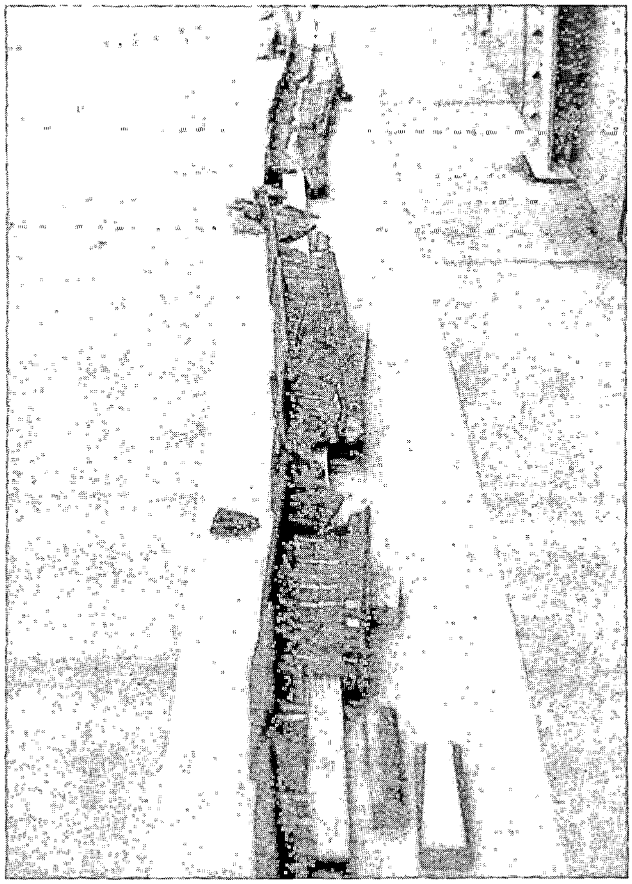
The nation's railroads are placing ever increasing demands on their tracks by operating heavier and heavier vehicles at increasing frequencies over a concentrated route structure. These increased demands on the track require a rationale for rail inspection that will provide for the timely detection and removal of internal rail defects and thus reduce the risk of train accidents caused by rail failure. An improved rail inspection methodology can potentially save much of the $20 million in annual costs associated with derailments caused by rail failures and with unplanned or emergency rail replacements.

Study of this problem has concentrated on the control of fatigue and fracture failures in rail through application of the principles of fracture mechanics to the synthesis of a rational strategy for inspection for and detection of internal rail flaws prior to service failure.

Rail defects can be found in three broad categories: (1) rolling contact fatigue, (2) manufacturing defects, and (3) maintenance- or service-induced defects. Rolling contact fatigue defects, also known as detail fractures and vertical or horizontal split heads, have long formation periods. Understanding this fatigue defect has been the focus and principal thrust of the research to date.

Field experiments conducted at FAST have provided the only actual accurate measurements of detail fracture growth and correlation with .907 x 10^6 Mg (10^6 tons) of exposure. Detail fractures which were allowed to grow to 80 percent of the rail head area were evaluated during the first field experiment, which involved rails in tangent track. In a later experiment, rails containing detail fractures were tested in curved track with similar results.

The study of detail fracture life sensitivity illustrates the variables involved and their potential impact on defect growth as measured in .907 x 10^6 Mg (10^6 tons) of traffic. The shaded area on each bar represents the typical range of the variable in revenue track throughout the nation. These results were produced using a fracture mechanics model, which was calibrated to the results of the first field experiment. The model has been validated by a demonstration that correlates the results of the second experiment.



Remains of Shattered Rail

A guideline has been developed for adjusting the frequency of rail inspection, based on defect occurrence and growth characteristics. In a field trial, one railroad saved $70,000 annually after decreasing inspection frequency on one line, based on application of the principles in the guide. The railroad was able to maintain the established level of safe performance on this line, and the resources saved were made available for other lines which might benefit from more frequent inspection. The guide includes a provision for fine tuning inspection frequency to account for changes in the performance of rail inspection equipment. Such changes are reflected by changes in the rate of unscheduled rail replacements, relative to the rate of defect detection in scheduled inspections. The guideline provides a minimum suggested frequency of testing which is consistent with the current scheduling practices followed by major railroads for track with medium-to-high traffic density.

Investigation of a 1983 derailment of an Amtrak train revealed the role of residual stress as a potential threat to rail integrity. The rail which caused this derailment failed in a highly unusual manner, shattering into hundreds of small pieces. The principal factor contributing to this rail failure was later identified as the residual stress left by a cold rolling process which manufacturers commonly use to bring rails within the straightness tolerances required for installation in modern track.

In response to the accident investigation finding, research was undertaken to develop procedures for measuring straightening stress at the rail mill. Work is now underway, in cooperation with the railroad industry, to develop non-destructive evaluation procedures based on ultrasonic measurement of metal under stress.

Residual stress caused by the action of vehicle wheels was identified earlier as a factor in reduced rail economic life, as well as reduced resistance to defect growth and rail failure. As a consequence of these conclusions and similar conclusions reached by technical committees of the International Union of Railways, a joint American-European research program is now in progress to improve understanding of the causes and effects of rail residual stress. Technical information developed from American and

European research projects is regularly exchanged between the Office of Research and Development of the FRA and the Office for Research and Experiments of the International Union of Railways. Joint work sponsored by the FRA includes a series of full-scale laboratory experiments and the development of stress analysis procedures to model the formation of residual stress.

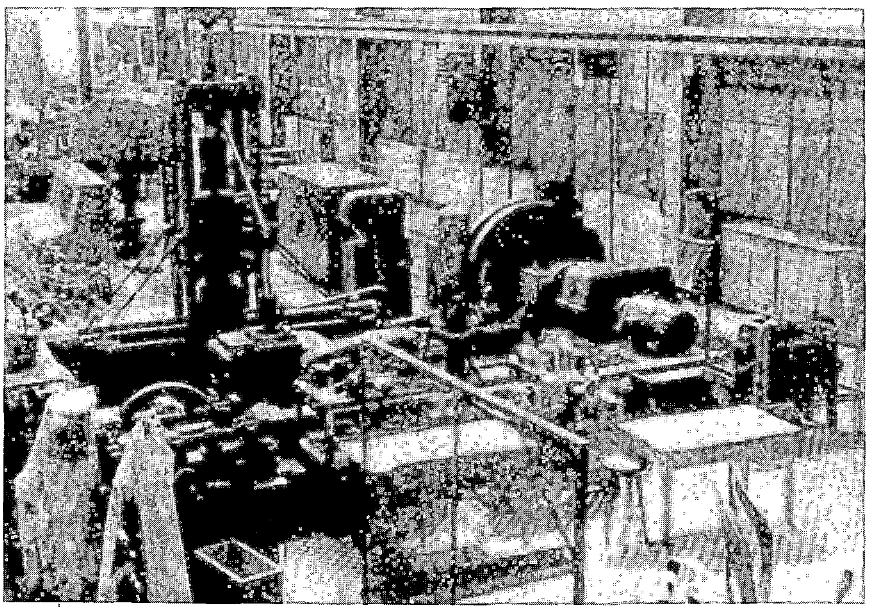
The laboratory experiments are being conducted at the Central Research Institute of the Polish State Railways, in Warsaw, Poland. The Institute has designed special fixtures and procedures for adaptation of its EMS-60 rail fatigue testing machine to simulate wheel/rail contact on both tangent and curved track, with the lateral position of the wheel precisely controlled. These tests will soon provide key results for understanding service load effects on rail stress and for validation of residual stress analysis procedures.

The stress analysis procedures are being developed by faculty and staff of the Cracow Institute of Technology, in Cracow, Poland.

The residual stress research program has already led to improvements in rail safety. Rail manufacturing mills in North America and Europe have now recognized that straightening stresses must be minimized to eliminate the risk of rail failure by shattering. Guidelines for improved roller straightening practice were developed as a part of the research program and have been furnished to the mills on both continents as technical information. Quality control engineers in several mills are now working on practical procedures to implement these guidelines. The visibility given to the significance of straightening stress has also motivated one mill to invest in R&D on an innovative process which may allow rail to be straightened without causing residual stress.

The research is now continuing with the main emphasis on the behavior of rails under typical service conditions. The next objective is to evaluate the effects of different grinding practices used on heavy haul freight lines and braking action of high speed trains on dedicated passenger lines.

Periodic grinding of rail surfaces has been widely adopted in the past five years as a maintenance practice to increase the useful economic life of rail stock on the nation's heavy haul freight lines. The main benefits of grinding are control of wear and elimination of surface defects. However, recent field experience suggests that these benefits have been negated in some cases because certain grinding schedules appear to promote formation of dangerous subsurface defects. To address this problem, the residual stress analysis procedures currently under development by the Cracow Institute of Technology will be applied to evaluate the effects of different grinding schedules on the level of residual stress in the rail head.



EMS-60 Testing Machine at Central Research Institute, Polish State Railways

The technical exchange program with the International Union of Railways has revealed that dangerous surface defects could form on rails on certain high speed passenger lines in Europe. These defects are a type not found on today's American freight lines and they seem to result from a combination of the light wheel loads and high braking or tractive effort associated with high speed vehicles. However, such defects are expected to occur on the routes now under development in various states to serve as dedicated high speed passenger lines. The United States is thus in a position to benefit from the European experience as inspection guidelines are developed for the nation's new passenger lines. Also, the residual stress analysis procedures will be applied to this problem in order to evaluate the effects of different brake application profiles on the level of residual stress in the rail head.

The fruits of the rail integrity research program will be applied over the next few years to improve the safety of railroad operations in several ways.

Better Guidelines for Remedial Action

Different kinds of rail defects react in different ways to external conditions. Thus, different kinds of remedial actions must be taken to prevent rail failure. The research on crack propagation behavior of rail defects is leading to a better understanding of how the external conditions influence the defect. (How fast does it grow? How big must it be to pose an imminent risk of rail failure?) The external conditions are to some extent controllable by means of remedial actions. The research results will provide better guidelines for remedial actions (urgency, slow orders, replacement versus repair, etc.) based on the known effects of these external conditions.

Improvement of Rail Production Quality

Both domestic and foreign mills now routinely finish rail with a roller straightening operation. The rail integrity research program has revealed that roller straightening can cause dangerously high levels of residual stress, if the operation is not carefully controlled. Guidelines for better control of roller straightening have been developed and will be disseminated to the industry in the near future. This will complete a major effort aimed at improving rail quality by means of more nearly uniform production.

One aspect of production quality remains to be addressed: can a maximum permissible level be established for residual stress due to fabrication? The answer may depend on the future trend in maximum axle loading allowed for interchange service. Axle loads transmitted to the rails also cause residual stress, and the two sources of stress may combine in ways that can make rail defects occur more often and/or grow more quickly. Study of the combination effects is required before a rational specification for production stress limits can be established.

Guidelines for Safe Rail Grinding Practices

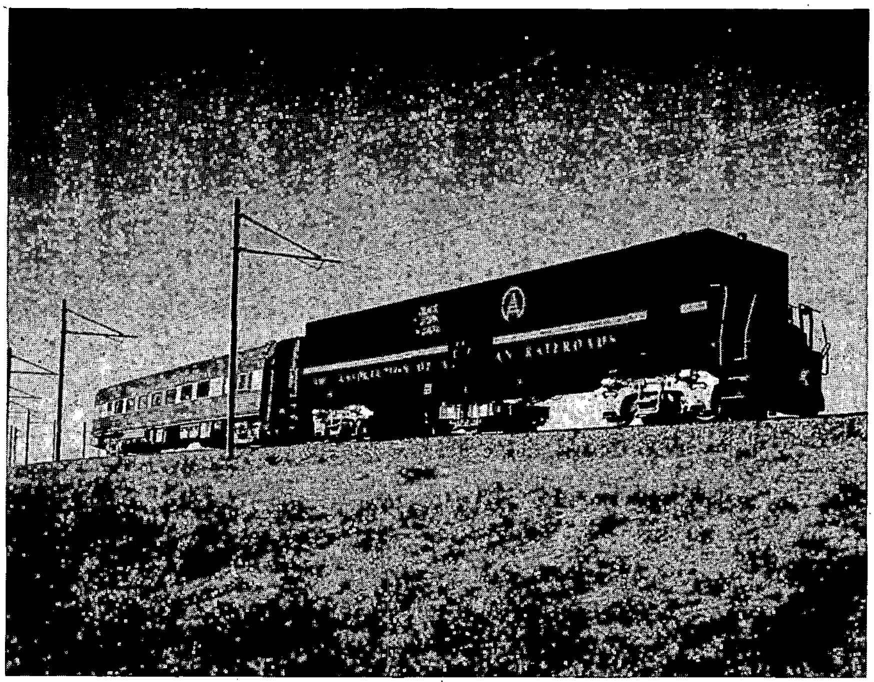
The rail on today's heavy haul freight lines is routinely ground to periodically change the shape of the running surface. This redistributes the axle loads in ways that extend the useful economic life of the rail. Rail grinding can either promote or detract from safety, depending on the way in which the redistributed loads affect the formation and growth of fatigue cracks. The research already completed suggests that crack behavior can be characterized by the residual stress associated with the combination of axle loads and grinding. The residual stress analysis software, now nearly completed, will be used to study the relation between axle loads, rail grinding, and stress. The results of this study will be used to provide guidelines for safe rail grinding practices (depth per pass, angle of cut, and frequency of application).

Standards for Rail Inspection on High Speed Lines

The Rail Integrity Research Program has already provided the technical basis for revised standards on frequency of inspection for the nation's heavy haul freight lines. Similar standards will be required in the future to ensure safe operations on the dedicated high speed passenger lines currently proposed or under construction in several areas. Based on the experience of European railways, rail fatigue cracks on these lines are expected to be of a fundamentally different from the cracks observed on heavy haul freight lines. European research on fatigue of rails in high speed service is already being shared with the FRA through existing technical exchange arrangements. After these research results have been adapted for North American conditions, they will be combined with other aspects of the rail integrity research program to formulate a new standard for frequency of rail inspection on dedicated high speed passenger lines in the United States.

Vehicle Track Systems Program

The Vehicle Track Systems Program began in 1986, jointly sponsored by the FRA and AAR with the support of the Railway Progress Institute, the Canadian Government, and the railroad industry. This program is intended to produce a wide range of railroad research in the areas of track structure systems, freight car systems, interaction of vehicle track systems, and advanced concepts evaluation. The research covers the specific areas of braking systems and car structure fatigue, derailment studies, bridge load testing, and safe performance features of the concept of high productivity integral trains. Research in these fields will increase the probability that freight car system design and car fatigue design result in the highest levels of operating safety. In addition, this research will permit development of new methodologies for evaluating derailment characteristics and track strength and for testing the safety characteristics of new train consist designs.



AAR Track Loading Vehicle Undergoing Preliminary Tests at TTC

Research plans were instituted in five major task areas: derailment phenomena studies, new train safety issues, freight car fatigue life, fatigue life of car components manufactured using futuristic materials, and the undesired application of emergency brakes. Through 1991, several significant accomplishments have been achieved.

Derailment Studies

A variety of unexplained derailments are typically associated with flange climbing, gauge widening, rail rollover, or panel shift. The common problem in these situations is the difficulty in quantifying the parameters that lead to excessive lateral forces and/or low vertical forces, the combination of which results in high lateral-to-vertical force ratios. Many theoretical and small-scale laboratory tests have produced a number of hypotheses concerning the value of these forces that will lead to a potential derailment. However, there is a significant lack of full-scale validation of the current derailment criteria.

To gain the knowledge of the actual forces and reactions occurring at the wheel/rail interface needed to reduce the number of derailments, a testing device, i.e., the track loading vehicle (TLV), has been developed by AAR. The TLV will identify, measure, and evaluate interface forces, displacement reactions, and other derailment contributors at the wheel/rail interface region. The TLV represents a significant step in the advancement of derailment analysis techniques. Previous activities in this project permitted review of existing concepts and study of known works discussing the wheel/rail interface as a basis for determination of safety limits and to validate mathematical modeling methodology for the interface technology to be studied. Needed data relative to heavy axle loads--to account for wheel loads up to 17,690 kg (39,000 lb)--have also been obtained to aid in the definition of parameters to be considered during test design stages. Static track tests were conducted to demonstrate the capabilities of the TLV in achieving goals necessary for measuring safe limits of track strength and interface conditions. Tests included determining the TLV's ability to maintain controlled loads over different operating and track conditions; determining the rolling integrity of the vehicle over regular and perturbed tangent and curved track and over both staggered and matched joint track at TTC; determining reactions at various vertical and lateral wheel loads; and initial bridge inspection/analysis. The TLV performed very well under all conditions, and more than met all planned goals and objectives.

Through a cooperative fund-sharing program with the FRA, AAR is conducting on-track tests to verify measurements made by the TLV in operating situations, while the vehicle is static or moving and under a variety of track conditions. The tests are also being conducted on a broad range of track types, to evaluate the test device and to develop limits of track performance under conditions of differing installation and operating criteria.

Deterioration of major railroad bridge structures over the years will ultimately result in substantial economic and safety problems associated with the aging railroad infrastructure. The TLV appears to have potential for use in the analyses of these structures. The objective is to identify problems in critical members and correct them prior to failure. Tests are currently being performed through this cooperative FRA/AAR program to evaluate the ability of the TLV or similar loading device to identify these problems.

New Train Safety Issues

The High Productivity Integral Train (HPIT) project was initiated to encourage the railroad supply industry to develop new train designs as complete systems. The main objective of any HPIT test program is to examine the major issues raised in the technical evaluation; to verify, where possible, the assumptions made in the economic evaluation; and to provide some assurance of overall safety of a new train design operating in everyday revenue service. A generic safety test plan has been developed to ensure safe performance of new train systems and consists as they are introduced into the nation's railroad system. The safety test plan is being evaluated through tests of prototype train consists manufactured in conjunction with the HPIT project and furnished by cooperating industry suppliers.

Using the safety test plan, one prototype train consist has been successfully tested. Results indicate that the prototype train consist, furnished by Transit America, Inc. (Budd Division), exhibits improved safety performance in the areas of curving, rock and roll, pitch and bounce, lateral track forces, and crosswinds.

Phase I testing of a second prototype consist furnished by the New York Air Brake Company has proven successful, and Phase II is scheduled to begin in 1992. Phase I was the evaluation of the stability of the suspension system. Phase II testing is to include a more detailed program using production cars and power equipment to fully evaluate the safety, reliability, and performance of the concept.

Freight Car Fatigue Life

A specific hopper car design with a known history of fatigue failure was selected for evaluation, and the design was analyzed to determine the most likely critical failure modes. A car of this design was equipped with instruments to record stresses contributing to fatigue, and operated in the same service environment where the fatigue failure originally occurred. The hopper car was then further tested on the Simuloader Test Unit at TTC to determine fatigue failure modes and to establish universal methods for estimating safe fatigue life to be expected from new railcar designs. Simuloader tests revealed that the car body dynamic response at critical strain gauge locations was very similar to that observed from actual over-the-road tests. During a short test encompassing 270 Simuloader hours, the freight car was subjected to fatigue damage equivalent to 965,606 km (600,000 mi) of revenue track testing. The test car developed fatigue cracks at locations where similar cracks had been experienced in earlier revenue service.

Fatigue Life of Car Components

Common freight car component shapes and sections were selected for determining fatigue life characteristics. In particular, an aluminum alloy construction material was selected, since it is anticipated to be used frequently in future car construction and the industry does not now have fatigue life estimation criteria available for this material. A contractor was selected to perform tests on the various shapes and sections of the selected aluminum material, and sources were found for sample shapes and sizes manufactured from this material. Tests are now ongoing at the University of Illinois and will permit development of needed safe life estimation criteria for this material and its use in the railroad environment.

Undesired Application of Emergency Brakes

Background data and information were gathered from a wide range of industry sources interested in eliminating undesired applications of emergency braking systems (UDEs). Braking system components, operating procedures, braking conditions, and other braking system variables were tested and the results analyzed. Many suspected causes for the problem were studied. The next step was to test an entire 36-car train, including cars furnished by participating railroads and suppliers, at TTC. The objective was to create extreme conditions of slack run-in and run-out and to study the rapid variations of brake pipe pressure under those conditions. Data have been analyzed to identify pressure changes that are critical to the onset of UDE. It was discovered that these pressure changes were very close to those necessary to produce UDEs. A possible cure is a 0.43-diameter choke placed between the pipe bracket and the emergency portion of the control valve. This method has shown promise for eliminating or greatly reducing UDEs resulting from these pressure differentials.

Proposed projects being considered for this important FRA/AAR/industry cooperative program are as follows:

- Develop procedures for estimating residual stresses in as-built tank cars.
- Develop viable methods for estimating stress concentrations in key structural elements of freight cars.
- Validate methodology for incorporating the effects of track geometry perturbations on dynamic load environments of freight cars, and incorporate the validated methodology into the specifications for new railroad freight car equipment.
- Test and evaluate operating capabilities of selected advanced braking systems on integral train prototypes, and develop guidelines and recommendations for safe, effective operations of advanced braking systems being developed for integral train prototypes, including fail-safe provisions for expected failure modes.
- Evaluate the appropriateness of several flange climb criteria using the AAR TLV to safely study conditions leading to derailment.
- Develop base fatigue life data for railway bridges, develop bridge safety criteria for modern freight operations, and identify non-destructive evaluation techniques for reliably predicting incipient bridge failures.
- Quantify track panel lateral shift resistance using the AAR TLV, and use the TLV to provide systematic measurements of track panel shift conditions.
- Determine the influence of track twist on wheel unloading and wheel climbing tendencies of stiff, light, and unloaded freight cars, as a function of speed and track curvature.
- Develop and validate a prototype methodology for automating evaluations of freight car design concepts and qualifications of prototype freight cars. (The initial prototype of this methodology will permit evaluation of a tank car design.)

This plan describes research specifically related to improving railroad safety and efficiency through an improved understanding of the elements of vehicle/track interaction.

Several areas are emphasized. Research will be conducted in the areas of track strength, bridge strength, and the reaction of various freight car load inputs.

Cooperative inputs will be made by AAR and the railway supply industry, with implementation coming through changes in industry mechanical and track standards.

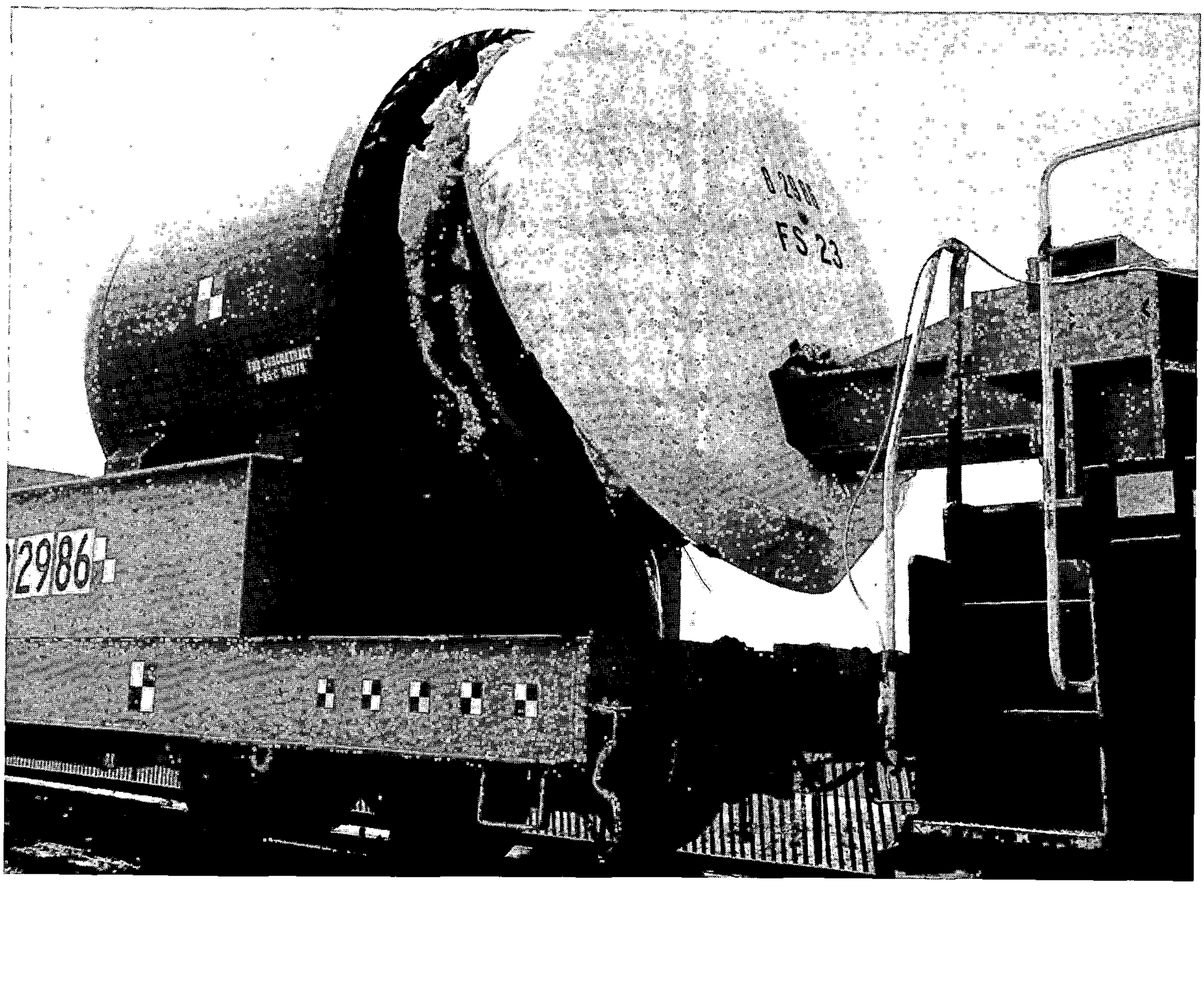
This program is structured around four basic areas of study: axle load economics, derailment prevention, vehicle/track standards, and transfer of vehicle track systems technology. The fundamental goal is development of specifications and guidelines for safe and efficient train operations.

The general approach is to use analytical techniques supplemented with laboratory and field test data. As the research progresses, significant findings will be reviewed through program reports and program reviews. Presentations will be made, and reports will be disseminated to all participants and interested parties. Further, various elements will be offered as papers in appropriate technical society and significant railroad technical conferences.

Success, as measured by implementation of results, will be enhanced by the close association and participation of industry and supplier officials. An indefinite time frame is projected for this program as this government- (U.S. and Canadian) industry-supplier program has, at this point, a continuous 19-year history. The plan will continue to be updated as necessary as new critical issues or significant findings identify the need for new project directions.

Benefits from this research can be expected at several levels. The most important benefit will be fewer unexplained derailments caused by adverse interaction of operations, vehicles, and track. A primary example is the expected reduction in derailments caused by undesired emergency brake applications. Changes in air brake valves and brake pipes suggested by the results of recently completed work on this project should substantially reduce this type of derailment. Several projects will provide information necessary to improve AAR specifications and recommended practices, as well as aiding the FRA Office of Safety in possible rulemaking activities. Further, appropriate results will also be the basis for updating AAR operation guidelines and derailment investigation manuals. Generally, this program will promote safer equipment, track, and operations.

EQUIPMENT, OPERATIONS, AND HAZARDOUS MATERIALS RESEARCH PROGRAM



Equipment, Operations, and Hazardous Materials Research Program

The Equipment, Operations, and Hazardous Materials Research Program directly supports the rail safety responsibility and authority specifically conferred in the Federal Railroad Safety, the Hazardous Materials Transportation, and the Occupational Safety Acts of 1970, as amended; the Rail Safety Improvement Act of 1988; and the Hazardous Materials Transportation Uniform Safety Act of 1990. The program focuses on research necessary to ensure safe operation of railroads by considering critical equipment, components, operating practices, and hazardous materials transport in the railroad environment. In general, this research program addresses rail vehicles and their operation and the hazardous materials transportation aspects unique to railroad operations.

This research program directly supports two key objectives of DOT's "Statement of National Transportation Policy" (NTP):

- Ensure that the transportation system supports public safety and national security.
- Advance U.S. transportation technology and expertise.

It also supports other key objectives: to foster a sound financial base for transportation by emphasizing cooperative research programs with the railroad industry, to keep the transportation industry strong and competitive by conducting research that may lead to reduced costs, and to protect the environment and quality of life.

This program is conducted in cooperation with and receives cost sharing from private sector organizations, including AAR's Research and Test Department, Mechanical Division, Hazardous Material Systems, Tank Car Committee, and Railroad Safety Officers Committee; the Railway Progress Institute; the Brotherhood of Locomotive Engineers; the United Transportation Union; and individual railroads.

Research programs include both short- and long-range projects. Some of the research is reactionary: it is conducted in response to specific accidents and/or recommendations of the National Transportation Safety Board (NTSB) or Congress. This research is usually conducted to support decisions on potential regulations. Other research is anticipatory: it is conducted to avoid the potential for safety problems with existing or proposed (new) equipment.

Results of the research projects are disseminated to the public by published reports and/or technical presentations at symposiums and conferences.

This program comprises three subprograms:

- Equipment and Components
- Operating Practices
- Hazardous Materials

Each subprogram is interrelated in a number of ways and has a common focus on conditions, events, and functions above the rail bed. Each is distinctive, however, in the research perspective applied to these situations.

The Equipment and Components subprogram deals with locomotives, cars, and the components and appurtenances necessary for their proper functioning, such as wheels, bearings, and brakes. It covers the full range of research activities, including analyses, tests, evaluations, and demonstrations where specific projects are defined. This subprogram may also include tests in support of other subprograms, such as tank car performance, train handling devices, or wheel-rail interfaces.

The Operating Practices subprogram addresses the human factor aspect of railroad research. Training, job aptitude and environment, safety guidelines, programs and management, and employee health and motivation affect every aspect of railroad operations, especially safety performance. Therefore, these aspects are examined in the railroad operating environment with the objective of developing demonstrated improvements in performance. The current emphasis is on operator performance and factors affecting performance such as stress and fatigue.

The Hazardous Materials subprogram examines the special considerations necessary for the safe handling and rail transport of hazardous materials. Puncture resistance, fire protection, pressure release mechanisms, and crashworthiness of the tank cars and other rail hazardous material containers are examined through analytical evaluations and tests. In addition, handling techniques, risk assessments, routing issues, and accident response procedures are examined to minimize the potentially catastrophic effects of a rail accident involving hazardous materials. Tank car design improvements are examined for recommendations to the FRA Office of Safety concerning potential regulations.

The remainder of this section discusses the major accomplishments in each of the subprograms of the Equipment, Operations, and Hazardous Materials Program between 1988 and 1991.

Equipment and Components

Past research includes safety assessment of freight cars, examination of wheel failure mechanisms, analysis of commuter car bearing failure, and development of a stuck brake detector. Current research is expanding on previous research in freight car standards, locomotive improvements, wheels, brakes, and bearings.

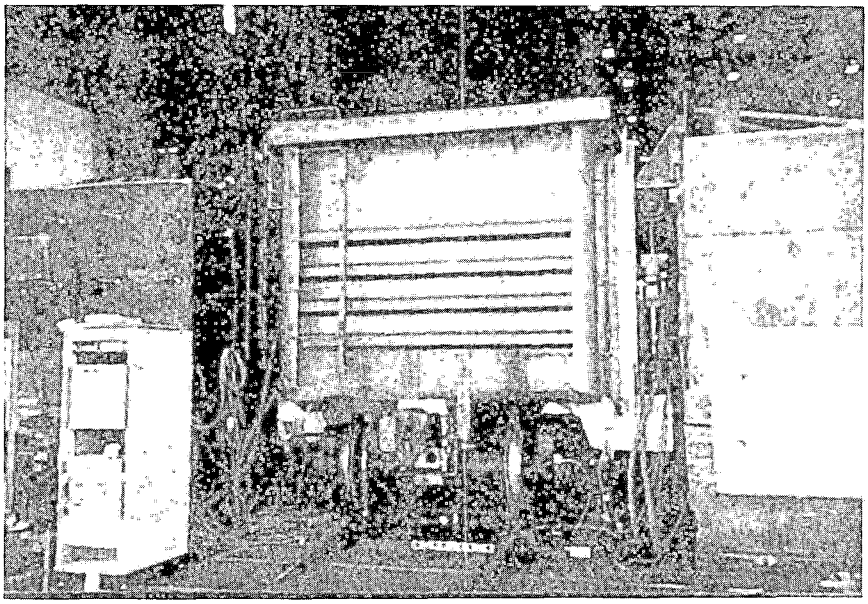
Safety Assurance for New and Untried Freight Cars

To meet demand for decreased vehicle tare weights, increased ease of loading and unloading, and increased compatibility with other transportation modes, new rail vehicle designs are being introduced at a rapid rate. To keep up with the recent influx of new car designs, the FRA has been working with the railroad industry to develop better methodologies and techniques for evaluating new and untried cars for safety performance. This combined effort has resulted in the proposed Chapter XI of the AAR's Manual of Standards and Recommended Practices. The project focus has been to develop and validate the appropriate analytical simulation models and test scenarios that will more efficiently and effectively evaluate new car or truck (suspension) systems, thereby facilitating their widespread use in revenue service. The current focus is to evaluate the completeness of the required tests and to validate the simulation model.

The procedure for accepting a new car into interchange service, described in the proposed Chapter XI, is to test the vehicle over a number of track conditions, including geometry perturbations, and to extend the test results to other track conditions of potential concern using computer simulation analyses. Sections of track have been constructed or modified at TTC to test vehicles as required by the proposed Chapter XI procedure. A computer simulation program, New and Untried Cars Analytical Regime

Simulation (NUCARS), has been written for conducting analyses and extending the test results to a broad range of track and operating conditions.

The first railcar subjected to the newly developed acceptance process was a single-axle trailer-on-flatcar. In an elaborate series of dynamic characterization tests using TTC's Vibration Test Unit and other test facilities, the physical constants and variables to be used in the NUCARS model were obtained.



An Aluminum Coal Gondola Car with a Steel Underframe and a Conventional Three-Piece, Two-Axle Truck

The joint membership project committee established test conditions and acceptance procedures to be used in the trial process. The test conditions replicated the typical track conditions and resulting vehicle movements believed to represent the real-world behavior that a new and untried car experiences in regular service.

An aluminum coal gondola car with steel underframe and conventional three-piece, two-axle trucks was selected as the second car for evaluation using the NUCARS model and track testing. The objective was to determine whether truck suspension performance under the extremes of loaded-to-empty weight ratios can cause unstable riding conditions, particularly when empty. This program further refines and validates inexpensive test procedures that reduce the need for in-service testing and provide information for the modelling/ analysis methods used to assess the safety aspects of new and untried freight cars.

In further support of the program for accelerated acceptance of new equipment, a technique for buff and draft testing procedures is being developed. These procedures can be used to evaluate the performance of the equipment in a cost-effective and reliable manner. In addition, on-track tests and extensive analysis are being performed to further validate NUCARS model predictions. These efforts will extend the NUCARS safety assessment capability, allowing evaluation of the total safe performance envelope.

Technical reports on various phases of this project have been published, and others will be completed in 1992.

High Productivity Integral Train

The FRA, in conjunction with AAR, is analyzing a design of the High Productivity Integral Train. This train consists of trailer-on-flatcars on platforms with steerable single-axle trucks with independent rotating wheels. This vehicle design is significantly different from the equipment currently used on North American railroads, and has the potential to greatly reduce wheel and rail wear, as well as to ease interchange with highway transportation. The designer, with the help of other members of the industry, has provided a test consist for testing at TTC. The analyses and comparisons with the test data will help to further validate the NUCARS simulation model.

Locomotive Crashworthiness

Locomotive cab safety has been an area of concern for industry, labor, and government since the passage of the Railroad Safety Act of 1970, which gave the FRA broad powers to regulate in all matters affecting railroad safety. A particular area of concern has been fatalities caused by locomotive-to-locomotive collisions.

The Locomotive Control Compartment Committee, consisting of members from the FRA, AAR, the United Transportation Union, and the Brotherhood of Locomotive Engineers was established in 1971 to examine areas where locomotive cabs could be improved. A number of the committees's recommendations are now incorporated in the design of locomotives. The recommendations include the clean cab, which has non-skid floors, door closure bars, padded sun visors, and improved seats.

In September 1989, in response to an FRA Inquiry and the recommendations of the Locomotive Control Compartment Committee, AAR adopted Locomotive Crashworthiness Requirements for new road type locomotives built after August 1, 1990. The requirements include anti-climbers, collision posts, and stronger hoods on short-hood locomotives. The effectiveness of these new protection features have yet to be proven. An analytical program is being undertaken to evaluate the effectiveness of these new features and, in response to a request from Congress, to assist in determining whether additional rulemaking is necessary. A report on the study will be available in 1993.

Four-Axle Locomotive Evaluation Tests

In response to FRA efforts to improve the design of locomotives and to enhance the safety of cab occupants, AAR established standards for crashworthiness, which include anti-climb features, thicker hoods on short-hood locomotives, and stronger collision posts. These improvements add between 2,722 kg (6,000 lb) to 4,536 kg (10,000 lb) to the locomotive, thereby increasing the axle load beyond the limit normally considered as the maximum for four-axle locomotives. This project is assessing the potential for derailment created by these increased axle loads. Problems with the instrumented wheelset data have delayed the completion date for this project until 1993.

Passenger Equipment Cant Deficiency Testing

One inexpensive way to achieve shorter point-to-point passenger train trip time is to traverse the track curves at higher speeds. Present FRA regulations restrict speeds to 7.6 cm (3 in) of cant deficiency (unbalance) in curves. The FRA participated with Amtrak in conducting cant deficiency tests between Boston, Massachusetts, and New York City, to determine the safe limits of operation and potential impact on passenger safety at higher unbalance conditions. Five different passenger trains representing different coach designs were tested at higher than normal cant deficiencies by operating at higher than normal speeds: Amtrak's Amcoaches, the RTC (French-built Turbotrain), the RTL (U.S.-built Turbotrain), the Canadian LRC train, and the Spanish Railway's Talgo coaches. Safe operational limits were established, and passenger safety information was obtained. Amtrak will test the Swedish X-2000 train set on the Northeast Corridor between Washington, D.C. and Boston in 1992, and trial revenue service will follow. Full revenue service is expected by 1997.

Railroad Passenger Car Waste Retention Systems

In fiscal year (FY) 1989, the House Appropriations Committee (H.H. 3015) directed the FRA to analyze suitable toilet and waste retention technologies for use on future passenger cars and to report its findings to the appropriate committees. The results of the study revealed a thriving supply industry which can provide products for application to railcars. The FRA concluded that it is reasonable to include a toilet system with retention capability on all future passenger cars and that Amtrak should conduct a carefully structured evaluation program. A Report to Congress was published in August 1990.

Safety Aspects of Passenger Equipment

A special study was conducted to determine the end strength of cars operated by Port Authority Trans-Hudson Corporation (PATH). PATH requested authorization to operate trains weighing over 272,155 kg (600,000 lb) with cars which had not been tested to 362,874 kg (800,000 lb) as specified in Federal regulations. A computer analysis predicted no significant differences in the crush distances predicted for the principal structural elements of the new cars from the older cars. A detailed examination of the structural characteristics indicated that the cars would be able to meet the 362,874-kg (800,000-lb) requirement and, as a result of this supporting information, the FRA granted a waiver to PATH to operate the heavier vehicles.

Rail Rollover

Measurements at TTC have revealed high rail lateral deflections under 113,398-kg- (125-ton) car consists. These high lateral forces cause the rail to roll over and may result in gauge-widening derailments. Testing and analysis is being conducted to improve understanding of the effects of high truck turning moments. The data will be used to establish guidelines for track strength and equipment mechanical condition.

Air Flow Meter Evaluation

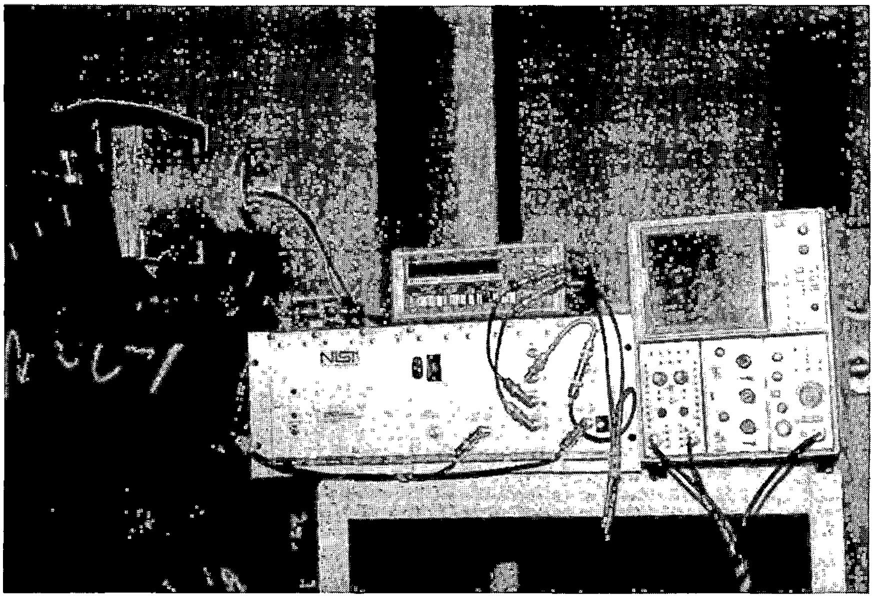
Several railroads requested authorization to use the air flow method in place of the air brake leakage tests. FRA regulations stipulate the maximum leakage rate permitted during the initial terminal test. The air flow method evaluates braking system leakage, not just the brake pipe leakage, and provides continuous monitoring of braking system functions during service. Studies were conducted to evaluate the air flow meter as an alternative method to the pipe leakage test. Results indicate no safety problems in allowing trains to operate using the air flow method in the prescribed manner.

Material Fatigue Properties

A joint government-industry program was established in 1988 to investigate the fatigue properties and fatigue life predictions of various proposed new freight car construction materials, including aluminum. A project was initiated to evaluate needs and trends concerning use of alternative materials (other than steel) for freight car construction and, through laboratory testing, to gather material properties fatigue data for one material type. Testing on aluminum alloy samples was initiated in 1990 and is continuing. A final report is expected in 1992.

Development of Railroad Wheel Inspection Systems

Although the total number of reported train accidents resulting from mechanical and electrical failures has decreased in recent years, over 1,400 accidents were caused by these types of failures over the past three years. Approximately one out of every five of these was caused by wheel failures, totaling more



Prototype Wheel Residual Stress Measuring System Under Development at NIST. (The system uses EMATs to obtain the necessary birefringence measurements. The EMAT sensor is shown in a typical measurement configuration: clamped to the wheel using a wheel-mount fixture which allows the sensors to be rotated 90°. Also shown are the associated electronics and cabling for this system.)

than $30 million in damages. Over half of the wheel-related accidents resulted from broken or thermally cracked wheels.

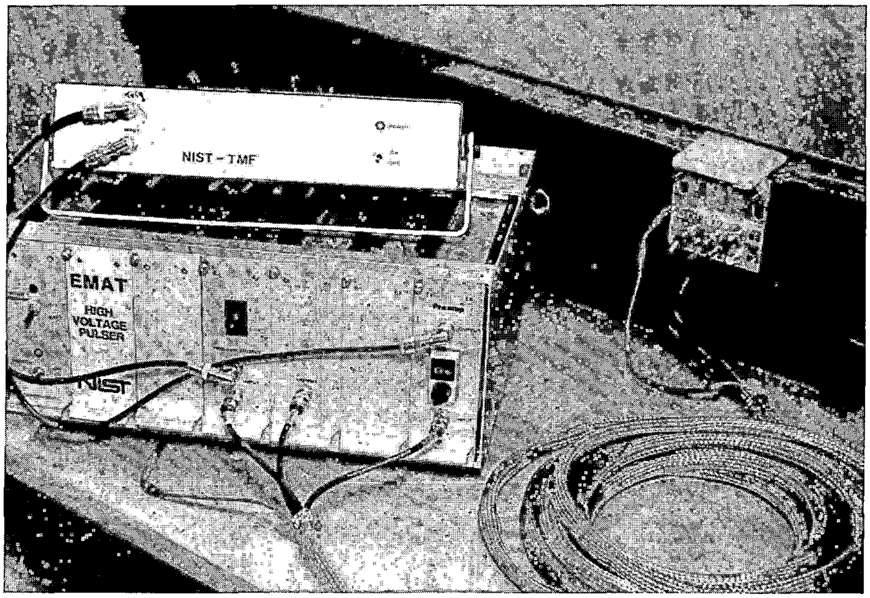
Typically, cracked or broken wheels result from the buildup of residual stress in the wheel coupled with the initiation of one or more small cracks. The presence of adverse stress gradients and crack initiations in the wheel rim occur from thermal or mechanical abuse caused by abnormal braking operations, faulty braking equipment, or damage from rail impact.

Currently, surface cracks in the treads of wheels are found mainly through visual means during normal car maintenance and spot inspections. FRA regulations require that wheels containing these cracks be removed. There are no means to reliably detect internal cracks or to assess the stress state of a wheel while in service. The existing FRA rule concerning internal cracks requires removal of freight car wheels exhibiting discoloration in the rim which extends more than 10.2 cm (4 in) into the plate. This rule can be costly to the railroads, as not all discolored wheels removed contain dangerous or adverse stress gradients. Additionally, it does not guarantee the removal of wheels with adverse stress gradients.

Therefore, both safety and economic benefits can be realized from the successful development of a reliable non-destructive method for detecting cracks and assessing the stress state of in-service railroad wheels which include:

- Reduction in the number of wheel failures and therefore the probability of catastrophic wheel-related accidents
- Establishment of a more effective and reliable method of identifying and removing potentially dangerous wheels prior to failure
- Significant reduction in the cost of wheel replacements

To achieve these benefits, a major FRA-directed development program is continuing through interagency, government-industry, and more recently, international cooperative research projects. The objective is to develop and evaluate field-operable detection systems, using non-contacting electromagnetic-acoustic and magneto- acoustic transducers (EMATs), which can reliably assess the stress state and detect and define cracks and other flaws in the treads of in-service railroad wheels.



Prototype Wheel Crack Detection Unit Including In-Rail EMAT Sensor and Associated Cables, Analog Generator, and Digital Analyzer

Research efforts to develop an operable residual stress measuring system under this program include two different approaches. First, the National Institute of Standards and Technology (NIST) is pursuing development of a birefringence measurement technique which uses EMATs to couple the acoustic energy into the wheel. Second, the National Aeronautics and Space Administration (NASA)-Langley Research Center, Hampton, Virginia, in cooperation with AAR, is exploring a technique that uses magneto-acoustic principles. Prototype systems employing both technical approaches are currently being evaluated at TTC. A recently proposed joint research project with the Central Research Institute of the Polish State Railways will provide the opportunity to examine the application of stress-measurement research being conducted in Poland. The Polish research has led to development of a prototype system known as the DEBRO-30. This hand-held unit employs more conventional piezoelectric transducers to obtain acoustic birefringence measurements on wheels.

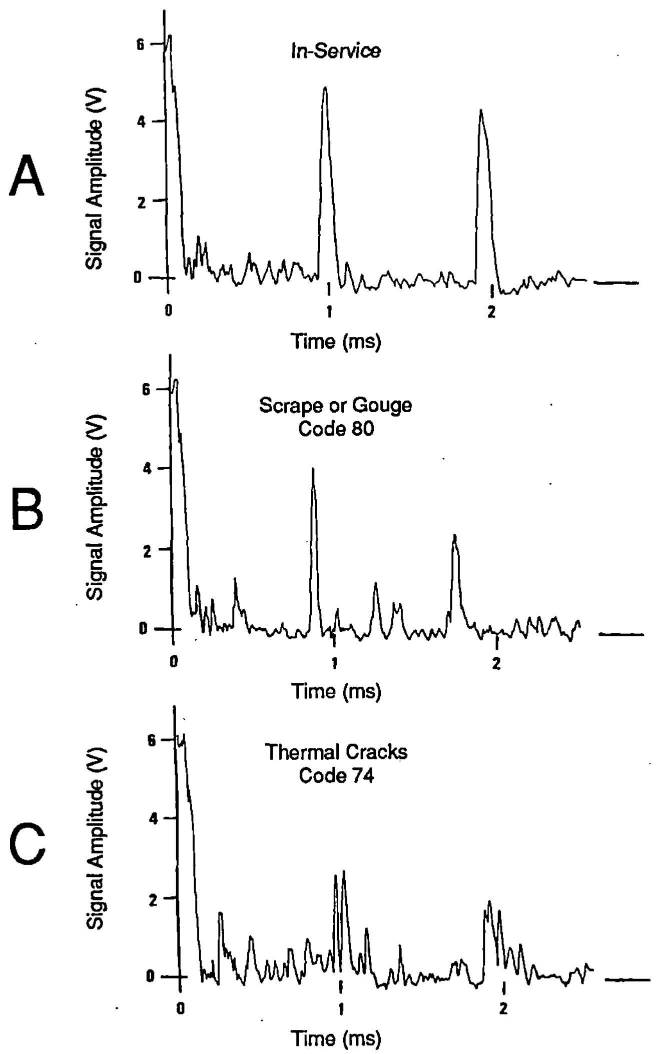
This development program is expected to continue until 1995 with technology transfer beginning in late 1994.

Research to date has produced a prototype field-operable crack detection unit, developed by NIST, in Boulder, Colorado, which employs EMATs in a rail-mounted unit to detect wheel cracks and other defects as the wheel rolls over the unit. Initial field evaluations have been completed at TTC.

The following figure shows typical output signals (analog oscilloscope traces) obtained during the field evaluations for three different wheel conditions. "A" depicts signals obtained for an in-service wheel in good condition without condemnable defects. The large signal near zero time is referred to as the main bang and merely indicates that the system is operating. The signals occurring at approximately 1 and 2 ms are the first and second echoes received from the main bang. "B" and "C" depict signals obtained for wheels containing condemnable defects for scrape/gouge and thermal cracks, respectively. The corresponding change in the echo signal arrival times and amplitudes, from those for a normal wheel, form the basis for characterizing these defects.

Freight Car Roller Bearing Failure Research

Freight car roller bearing failures are relatively infrequent in normal revenue service, but can lead to severe and costly accidents. Total bearing failures are known to occur quite rapidly, often providing insufficient time to detect changes in behavior prior to a derailment. Failures frequently lead to near total destruction of the bearing and axle components, making detailed post analysis of the causes of the failure almost impossible. Mechanisms suspected of causing total thermal bearing failure include



Typical Analog Signals Resulting from Initial Field Evaluations on the Prototype Wheel Crack Detection Unit, Train Speed: 8 km/h (5 mph)

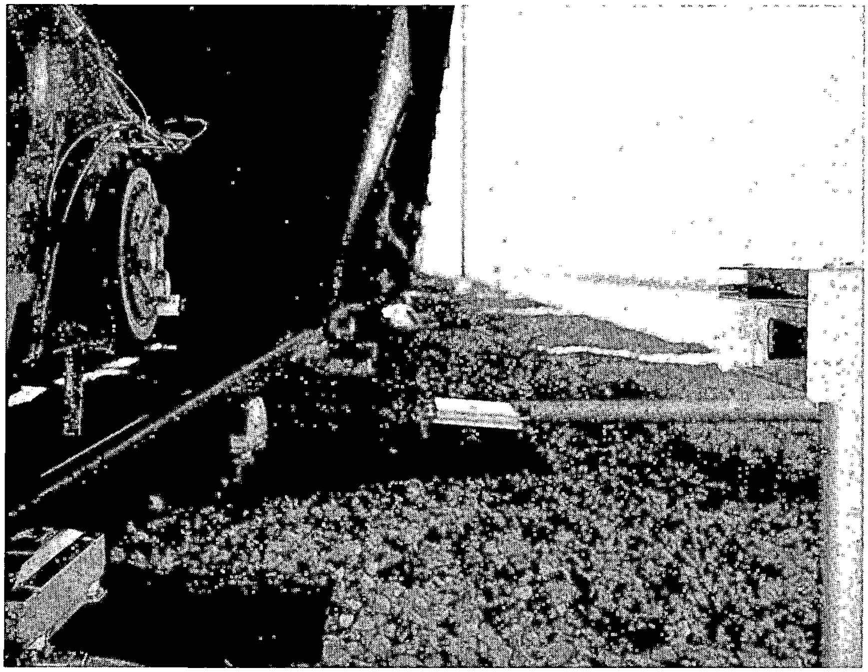
sudden fracture of bearing components, progressive spalling of rolling contact surfaces, loss of proper interference fits between bearing cone assemblies and the axle, loss of lateral clamping force allowing undesired relative motion of components within the bearing, lubrication failures leading to excessive wear, and impact damage to bearing components from damaged wheels and/or rail.

Both the FRA and the railroad industry are concerned that the number of bearing failures in recent years has not decreased significantly. Present hotbox detectors condemn a bearing only when severe overheating begins. Field experience and prior tests confirm that overheating may occur only minutes before total destruction of the bearing and the subsequent derailment of the car. Improved detection methods are sought which will reduce the incidence of derailments caused by bearing failures. Improved methods can be developed only if the actual mechanisms of failure are better understood and detectable failure characteristics are defined which allow removal of defective bearings prior to severe overheating.

The mechanisms which cause roller bearing overheating and ultimate failure are being investigated by AAR at TTC through a cooperative government-industry research program, funded by the FRA with the railroad and supply industries providing equipment and services. A group of AP Class F roller bearings are being evaluated in two phases: (1) a short-term test phase of 8,000 km (5,000 mi), which has already been completed and (2) a long-term phase, which has currently reached 32,000 km (20,000 mi) and is expected to reach 72,000 km (45,000 mi). The bearings under test include a range of axle journal/bearing cone interference fits and end clamp load conditions. Cone slippage is believed to cause the majority of bearing failures. It occurs when the initial bearing interference fit becomes degraded. Loss of end clamp load, caused by excessive bearing component wear, usually accompanies cone slippage.

Results obtained from the short-term test phase indicate that bearings with a grooved axle journal defect develop measurable temperature gradients across the cup surface, and that bearing cone slippage was detected on all bearings having less than 0.038 mm (0.0015 in) interference fit between the axle journal and the bearing cones. Additional results indicate that wayside detector alignment and scan location are critical factors for successful detection of an overheated bearing. Further, the performance of experimental low-friction seals during the short-term test was acceptable. The test bearings that survived the short-term test were also used for the long-term test.

Although no over-temperature events have occurred during the first 32,000 km (20,000 mi) of the long-term testing, cone slippage has resulted in measurable loss of material on the axle journals and cones of approximately one-third of the bearings. Additionally, a grooved axle condition has developed on one bearing. Test results indicate that bearings with a 0.127 mm (0.0050 in) interference fit and charged with 907 g (32 oz) of grease operate at higher temperatures and experience more cone bore growth than do bearings with a 0.0635 mm (0.0025 in) interference fit and charged with 680 g (24 oz) of grease.



One of Several Instrumented Test Bearings Operating over an Acoustic Bearing Defect Detector During the Long-Term Testing Phase of the Bearing Failure Research at TTC

This research program is expected to be completed in early 1994.

Freight Car Braking System Performance Evaluation

FRA-sponsored research conducted before 1988, under the Wheel Failure Mechanisms Program, revealed that the thermal input to freight car wheels, resulting from uneven braking action, can vary significantly from car to car in a train. These variations can cause reduced braking efficiency and severe wheel overheating which can lead to wheel failures and catastrophic accidents. Based on these findings, the FRA initiated a program to investigate the extent and causes of significant variations in braking thermal input to railcar wheels under a given set of braking conditions. This program included analytical and experimental studies of the effects of worn and distorted (bent) components on the distribution of brake forces for conventional brake rigging. The program also included tests to evaluate the effects of extreme shoe placement on wheel temperatures, friction characteristics of brake shoes during extended drag braking, and frictional characteristics of brake shoes with simulated metal pickup.

Results evaluated to date indicate the following:

- Worn brake rigging conditions decrease braking forces and therefore do not result in excessive wheel heating.
- Unequal-length bent truck levers can produce substantial wheel-to-wheel force variations during drag braking conditions.

- Levers with oversize pin holes and worn pins installed can increase the wheel-to-wheel variation in braking forces.
- Misaligned brake shoes wear at accelerated rates which can result in metal-to-metal contact as the shoe wears to the backing plate.
- During full service drag braking conditions, the wheel-to-wheel variations in brake shoe coefficient can be 30 percent.
- During drag braking conditions, the coefficient of friction of a given brake shoe decreases. The coefficient decreases as the brake shoe temperature rises, effectively defining an upper limit on the amount of thermal input to the wheel that can be sustained.

The final results of this research program are expected by the end of 1992.

Another joint program with AAR studied undesired emergency brake applications. A report covering the results of the undesired emergency tests has been published.

Operating Practices

Previous research in this area dealt mainly with development of the Research and Locomotive Evaluator/Simulator (RALES). Human factors as a cause of railroad accidents has been gaining importance in recent years, and current research has addressed this cause.

RALES: Operation and Maintenance

RALES was originally developed and constructed under contract to the FRA and is operated and maintained by the Illinois Institute of Technology Research Institute (IITRI), in Chicago, Illinois. All costs are covered by a user fee charged by IITRI. The FRA contract for the care, custody, and control of this facility provides for FRA issuance of task orders to conduct research as needed. This contract arrangement was used for all research projects using RALES between 1988 and 1991, and extends to early 1994.

RALES was upgraded in 1991 using state-of-the-art computer and laser disk technology to increase its versatility, flexibility, and capacity for future research. From initial use through calendar year 1990, nearly 8,000 hours of billable time were logged on RALES. Some of this time was devoted to research, but most was used by private railroads and the military services for training. As a result of this training experience, a RALES derivative simulator was developed to meet future training needs. The first RALES derivative was the TS-2, which has neither cab nor motion base. Later, the TS-3, a motion-base RALES derivative, was developed. U.S. railroads have bought or have on order three TS-3s and 15 TS-2s for use in their training programs. Two TS-3s and four TS-2s are being built for foreign countries. These spin-off simulators have significantly improved locomotive engineer training.

Selection of Locomotive Engineers

A battery of tests have been developed to screen candidates for training as locomotive engineers. Validation of this battery and the individual tests within it is expected to be completed by mid-1992. Tests within the battery assess the following individual characteristics: memory, reading comprehension, perception (of difference), listening, logical reasoning, and ability to concentrate. An analysis identifying critical skills and abilities required of locomotive engineers determined that these tests were the most useful tests for screening potential trainees. Locomotive engineers, trainers, and supervisory personnel from 14 railroads have participated in this project.

Rear End Marker Study

A 1977 FRA regulation established standards for luminance of train rear end marker lights in conjunction with testing procedures to ensure that lights approved by the FRA for this purpose would meet the set of standards. A series of field and laboratory tests was conducted to determine whether these standards and test procedures continue to be applicable to the newer lighting technology, such as xenon tubes and light emitting diode (LED) units. These tests were completed during 1990; it was concluded that the 1977 standards and test procedures remain applicable.

Hazardous Materials on Short Lines

Local and regional railroads generally have very limited resources to prepare for emergencies created by accidents involving hazardous materials. An FRA project was initiated to determine the level of preparedness these railroads should attain, to evaluate the level of preparedness that exists, and to identify the sources and resources available to assist in achieving the desired level of preparedness. Particular attention has been given to creating an awareness of the potential hazards presented by the materials transported, and the need for employee training and emergency response planning and coordination with local emergency response agencies. This work was essentially completed by the end of 1991.

Operation Lifesaver

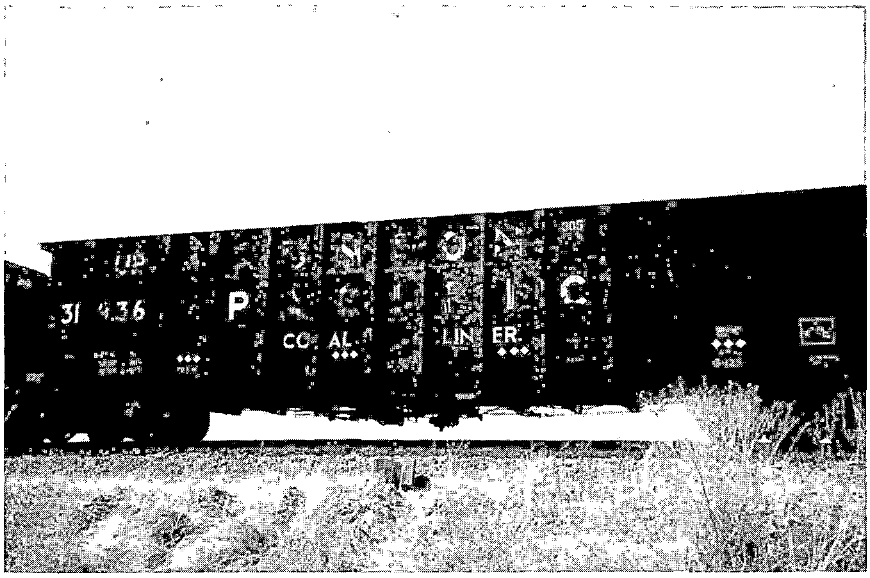
Educational materials designed to increase public awareness of the hazards present at highway-railroad grade crossings are developed, prepared, and distributed through the National Operation Lifesaver Program. In every state, grade crossing accidents have decreased significantly after the program was initiated. Volunteers distribute the materials and use them for presentations to a wide variety of organizations, such as schools and civic groups. The FRA has endorsed and encouraged this program since its inception in the early 1970s. The FRA is providing financial assistance to help support the joint Federal/state/industry cooperative program.

Grade Crossing Demonstration: Train Reflectorization

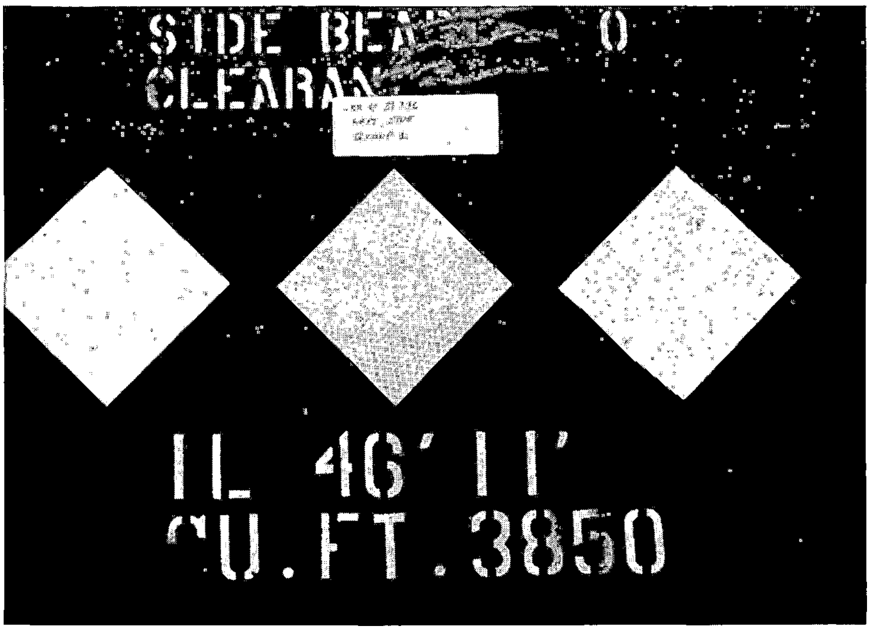
Annually, a substantial number of motor vehicles strike the sides of trains at highway-railroad grade crossings after dark. Most approaches to making trains more visible are too costly or are impractical, especially in rural and remote areas. Among the potentially least expensive solutions are use of retroreflective materials on the sides of train cars to reflect light from automotive headlights. A study published in 1982 concluded that the useful life of such materials then available was too short to be cost effective. In 1990, the FRA began to evaluate of materials introduced to the market since 1982 which may endure in the railroad environment for a satisfactory period of time. The results of this study are expected in 1992.

Advanced Train Control Evaluation

Advanced train control systems (ATCS) of various configurations and functions are being developed within the railroad industry. From a safety perspective, the train control features are of primary interest. From a human factors perspective, critical issues are the interface of the locomotive engineer with the in-cab computer and information display, the linkage between the train and dispatch center, and the



Open-Top Hopper Car at TTC Showing the Three Types of Retroreflective Material Being Tested

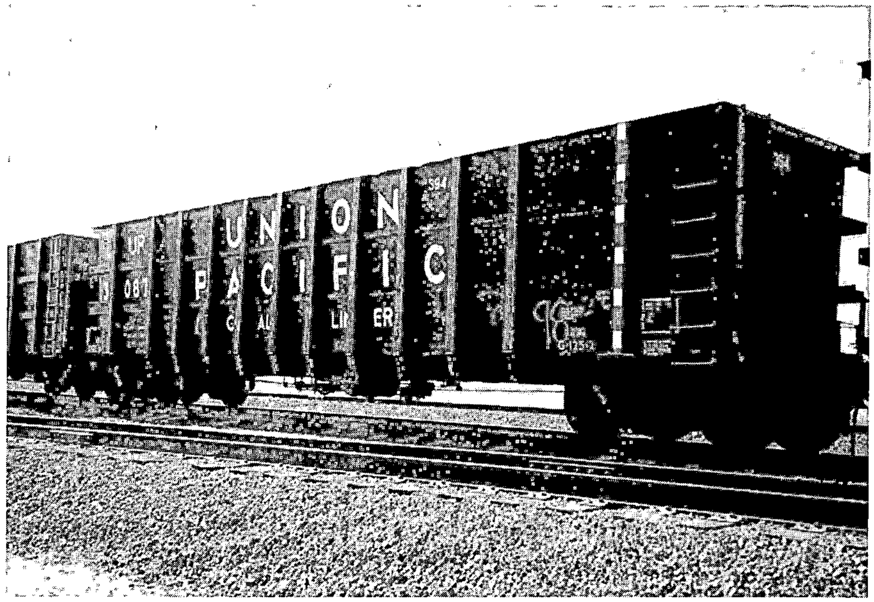


Closeup of an Open-Top Hopper Car at TTC Showing the Three Types of Retroreflective Materials Being Tested

compatibility of the dispatcher with the dispatch center computer, displays, and information. The FRA has been monitoring progress of performance specification development to ensure, as much as possible, that the resulting hardware and software will safely perform the train control functions for which they are intended. To date, there has been little hardware or software to actually test. In this context and as performance specifications were being developed, the Canadian National Railroad developed a simulation of a locomotive cab display operating in the ATCS environment. The format, information provided, and other features of this display generally conform to one of five performance specifications for locomotive cab displays. The FRA is conducting a subjective human factors evaluation of this display simulation to determine if it helps, hampers, or has no practical effect on the locomotive engineer's train handling responsibilities. These tests will be conducted using RALES. Results of this evaluation will be available in mid-1992.

Enginemen Stress and Fatigue

Fatigue of train crews, especially the locomotive engineer, has been cited by NTSB as a primary or contributing cause of a large number of train accidents with severe consequences during recent years. This is particularly true for collisions between trains resulting in loss of life. Several factors, including psychological stress, are believed to contribute to fatigue. Some factors seem intuitively obvious, but their effect on fatigue and engineer performance have not been measured, either individually or in various combinations. Fatigue cannot be directly measured, but engineer performance can be measured using RALES.



Alternative Placement of Prismatic Type Retroreflective Material Being Tested at TTC

This project is designed to function as a controlled laboratory experiment to measure the degradation of engineer performance as influenced by known variables. Data obtained from these tests are expected to provide a basis for determining the actions that should be taken to reduce the likelihood of on-duty fatigue that impairs engineer performance. The pilot test series will be completed in January 1992. It used four experienced locomotive engineers as test subjects and manipulated the variables of length of duty period, sleep deprivation, and circadian rhythm. Core body temperature and train handling performance were measured. Results from this pilot test will be available in mid-1992.

Tests involving additional variables and larger numbers of engineers will be started during 1992. To evaluate the range of variables believed to contribute most to fatigue and to acquire sufficient data to ensure that the study results are statistically significant and reliable will require an estimated three to four years. Human factors experts from the Volpe Center are assisting in this effort. Tests are being conducted using RALES at IITRI.

Impairment Testing

When operating personnel report for work, they are ordinarily considered fit for duty unless obvious actions or appearance or the smell of alcohol suggests otherwise. Therefore, they will usually go to work as scheduled. Accident investigations have concluded, too often, that the presumption of fitness for duty can be a dangerous one. Judgement, perception, reaction time, and other faculties may be impaired for a variety of reasons and may not be observed.

In 1990, the FRA initiated a project to develop a device or process for determining impairment, regardless of cause. The device was to be non-invasive, easy and fast to use, legally and socially acceptable, and relatively inexpensive. This project was initiated through DOT's Small Business Innovation Research (SBIR) Program. Phase I of this effort funded feasibility studies of three distinctly different technologies. Phase I results were reviewed in the summer of 1991.

The technology funded for further development, under Phase II, involves measurements of pupil reflex reactions of the eye and is believed to be the most likely approach to producing a single device that can reliably determine impairment, regardless of cause. Potential sources of impairment being studied include alcohol, drugs (legal and illegal), fatigue, and a variety of illnesses. Research results are anticipated late in 1993.

Dispatcher/Dispatch Center Evaluation

Based on the report "National Train Dispatcher Safety Assessment 1987-1988," prepared by the FRA Office of Safety, the following aspects of the dispatcher's job are to be evaluated:

- Workload
- Fatigue
- Occupational stress
- Training
- Selection for training
- Operating rules

Study designs for each of these facets of the dispatcher's job will be developed early in 1992. Actual studies are planned to begin in late 1992 and to continue for several years.

Locomotive Control Compartment Evaluation

In locomotive crashes, the severity of injury to occupants of the cab is often attributed to design features within the cab. New cab designs are now emerging which may, in part, reduce occupant injury severity. This project is expected to evaluate the ergonomics of these cab designs with the goal of making future versions even safer. It is anticipated that new cab designs from the following sources will be evaluated: General Motors, Electro-Motive Division; General Electric; Amtrak; Burlington Northern Railroad (rebuilt locomotives); and Santa Fe Railroad (express service locomotives). This analysis is planned to start in the spring of 1992.

Evaluation of Locomotive Engineer Training

Training of various types (classroom, simulator, on-the-job, etc.), testing, and experience are to be considered in certifying a locomotive engineer as qualified under the applicable rulemaking recently published. This project was proposed to evaluate railroad engineer training and testing programs to ensure they are sufficient to support certification. Where they are not, specific recommendations will be made to correct deficiencies. This evaluation is expected to begin during the summer of 1992.

Operating Rules Evaluation

Operating rules are written by the railroads and reviewed by the FRA for operations validity. In general, they have a high content of jargon and phraseology understood by the drafters, but not necessarily understood by other users. Testing for knowledge of operating rules varies greatly between railroads and between divisions of the same railroad. This project is intended to produce recommendations for preparation of operating rules that are commonly understood by all users and recommendations for tests for rules knowledge that demonstrates a working understanding. The outcome of this project is substantially related to the dispatcher/dispatch center evaluation discussed earlier, locomotive engineer certification, and the improved safety performance of other railroad crafts. Work is planned to begin in the spring or early summer of 1992.

Enginemen Driving Records/Train Handling

In accordance with the Rail Safety Improvement Act of 1988, one criterion to be considered in the certification of locomotive engineers is their motor vehicle driving records. This project was initiated in July 1991 to identify correlations between motor vehicle driving records and railroad discipline records of engineers. Such correlations or the lack of correlation will determine which elements of driving records are to be considered. These analyses are to be completed during the summer of 1992.

Evaluation of Human Factors in High Speed Train Operations

At train speeds exceeding 200 km/h (125 mph), what control functions can an operator be reasonably expected to perform safely and effectively? Should such an operator be on board or in a control center or both? How many continuous hours can an operator be reasonably expected to operate while remaining vigilant and efficient? How much rest is desirable between such work shifts? Assuming that operating control will or must be computer assisted, what mix, types and configuration of displays, audible signals, and printed information are most appropriate for operators to maintain safe train operations? These and other safety-related questions must be answered as high speed wheel-on-rail and magnetically levitated trains are placed in service in various corridors around the country. This project is intended to begin addressing these issues late in 1992.

Access For Disabled Americans

In support of the objectives of the Americans With Disabilities Act of 1990, a grant was provided to Amtrak in 1991 to identify and develop devices and programs for access to Amtrak trains and facilities helpful to those with vision, hearing, and mental impairments. A variety of prototype equipment and situations will be tested, such as improvements in lighting, signing, use of color, use of textures, and audible messages. Individuals with the targeted disabilities will be used as advisors and test subjects. Devices and programs determined to be useful and cost effective are expected to be identified and implemented within the schedule established by the statute.

Hazardous Materials

Major tank car safety research in the late 1970s resulted in the regulatory requirement for certain classes of DOT tank cars to be equipped with shelf couplers, head shields, and thermal protection systems. The FRA continued to study ways to improve the rail tank cars that carry hazardous materials. Research has focused on tank car structural integrity and residual stress, emergency response procedures and devices, and spent nuclear fuel transportation.

Hazardous Material Tank Car Accident Analysis

Accidents involving railroad tank cars were studied in an effort to improve rail transportation of hazardous materials. The characteristics of individual tank cars involved in accidents were examined for the years 1981 through 1985.

This study, completed in 1988, determined if a specific DOT class of tank cars is involved, disproportionally, in accidents and derailments. The study considered distance traveled, car type, capacity, derailment cause, and ambient temperature. In hazardous materials accidents, DOT Class 112 tank cars had the highest accident rate in all major cause codes. When broken down by capacity, DOT Class 111 tank cars, with a capacity of 119 m^3 (31,500 gal) and over, had a remarkably high accident rate for track-related causes and was very high in other causes. When taken as a percentage of the total number of tank cars in service, involvement of DOT Class 111 tank cars is in the normal range. The final report on this study was published in 1991.

Hazardous Material Car Placement in a Train Consist

The objectives of this study, completed in 1989, were to determine whether there was an incompatibility of hazardous materials that could potentially be mixed during a derailment and to examine separation distances and placement of hazmat cars. Analysis confirmed that the longer the train, or the higher the speed, the more cars derailed. The risk of car derailments is significantly less in the rear quarter or third of the train consist. The front section is the next safest location. The analysis of the hazardous commodities showed that oxidizing mineral acids and caustics dominated the list of incompatible commodities. However, the mixing of hazardous materials has not been cited in any NTSB accident reports as a specific problem. The final report was published in 1991.

Assessment of Emergency Response Procedures for Damaged Tank Cars

Based on a series of accidents that occurred in the early 1980s, it became apparent that several techniques exist for handling damaged hazardous materials cars at accident sites. It was determined that an evaluation of the methods for safe release of hazardous materials was necessary. A workshop of experts in tank car damage assessment and repair was held to prepare preliminary guidelines for handling damaged tank cars in accident situations. These guidelines have been reviewed and revised as a result of subsequent meetings and reviews. The current draft handbook deals with situations where a tank car has been damaged to the extent that it cannot be safely "re-railed" and moved to an unloading point. Appropriate unloading techniques at the derailment site are described. As a result of this study, it was recommended that another companion handbook be prepared to address tank car damage assessment; however, this work has not yet begun.

Hazardous Material Product Identification

In 1985, a Phase I SBIR Program project was begun to develop a tank car transponder system. The Phase I effort proved the concept was feasible. A Phase II SBIR program was initiated in 1988 to develop a transponder system for use on tank cars to identify the car and its contents during an accident. The system uses a passive transponder on the tank car and a hand-held interrogator to activate the transponder by emergency response personnel. Testing of the prototype system identified several problem areas. Further testing of the prototype device is suggested to determine its survivability in a rail accident. This project was completed in 1990.

Spent Nuclear Fuel Cask Rail Transportation Safety Analysis

In cooperation with the Department of Energy (DOE), the FRA has been conducting research involving the effects of a typical rail fire accident on a spent nuclear fuel cask. Sandia National Laboratory performed fully engulfing pool fire tests on cask-size calorimeters in 1983. Since then, other large and small cask-like articles have been tested in various thermal environments. An analysis of the results of small-article testing concluded that response to the thermal environment is highly dependent on the shape of the test article, as well as on its thermal mass.

In 1988, tests were conducted at Sandia National Laboratory for two different fire environments for spent nuclear fuel casks. These results were used to develop a model for analysis of the cask fire boundary conditions. In this experimental series, the response of a cask-like test article to three different thermal environments was investigated. An evaluation was conducted of thin walled versus thick walled, thermally massive objects. To compare test performance, the maximum and minimum heat input to the test article for each of the two fire scenarios was determined. Results show that the test article absorbed more energy in the 466°C (870°F), 100-minute radiant heat environment than in any other environment studied. A final report was published in 1990.

The primary fire safety regulations governing the rail transportation of spent nuclear fuel are embodied in the Nuclear Regulatory Commission's certification process for shipping container design. The FRA requested the Volpe Center to evaluate several realistic railroad accident scenarios in which a spent nuclear fuel cask, if it is in a train consist, is likely to be exposed to or engulfed in a large fire. The durations and temperatures of the fires postulated in the scenarios are realistic and are supported by accident and experimental data. While each of the postulated scenarios can occur, the total probability or frequency in a given year that any one of the scenarios will occur is extremely small. The final report is being reviewed.

The Hazardous Materials Transportation Uniform Safety Act of 1990 directed the Secretary of Transportation to conduct an analysis of the safety of transporting spent nuclear fuel and high-level radioactive waste by rail. The study is to address the use of dedicated or special trains for transporting this material versus transporting it in regular freight train consists. Only safety issues are to be considered. The Report to Congress is scheduled for early 1993.

Nondestructive Evaluation for Insulated Tank Cars

Under the SBIR Program, a Phase I effort was funded to conduct an analytical feasibility study of a concept to develop a device to detect cracks in damaged insulated tank cars. Detection techniques exist for non-insulated tank cars; however, their use on insulated tank cars is limited. Existing nondestructive evaluation techniques mostly rely on the use of induced stresses for detection of cracks. If a tank car is damaged, stresses induced in the tank car for identification and detection of cracks may cause the tank car to fail. The feasibility study suggested that the proposed concept was reasonable. A Phase II effort was begun, and completion of the feasibility analysis is expected early in 1993.

Stub Sill Tank Cars

The effect of welded attachments on tank car shells, especially the underside of the car, was studied to determine the need for post-weld heat treatment to relieve the residual stresses. This research led to the program to study tank car residual stresses. A squeeze test was conducted on an instrumented tank car to determine the stresses in the underbelly of the car. This information was used in subsequent analyses of tank cars.

An analysis of the problems of cracking in the weld area of the stub sill tank car attachment was conducted using a finite element model. These analyses were conducted for several tank car designs that had experienced this problem and had been repaired. An analysis of the repair was made to estimate fatigue life. The results of the study showed that the head brace repair procedure provides an effective means for redirecting the stub sill loads into the tank body. In conclusion, the redesigned cars, with the head brace properly installed, will exhibit significantly longer service lives before fatigue cracks form in the head brace area. A final report was published in 1989.

A project to evaluate the effects of over-the-road vibrations on the residual stress in tank car shells was completed in 1990. This project was begun because of problems identified in tank cars investigated by

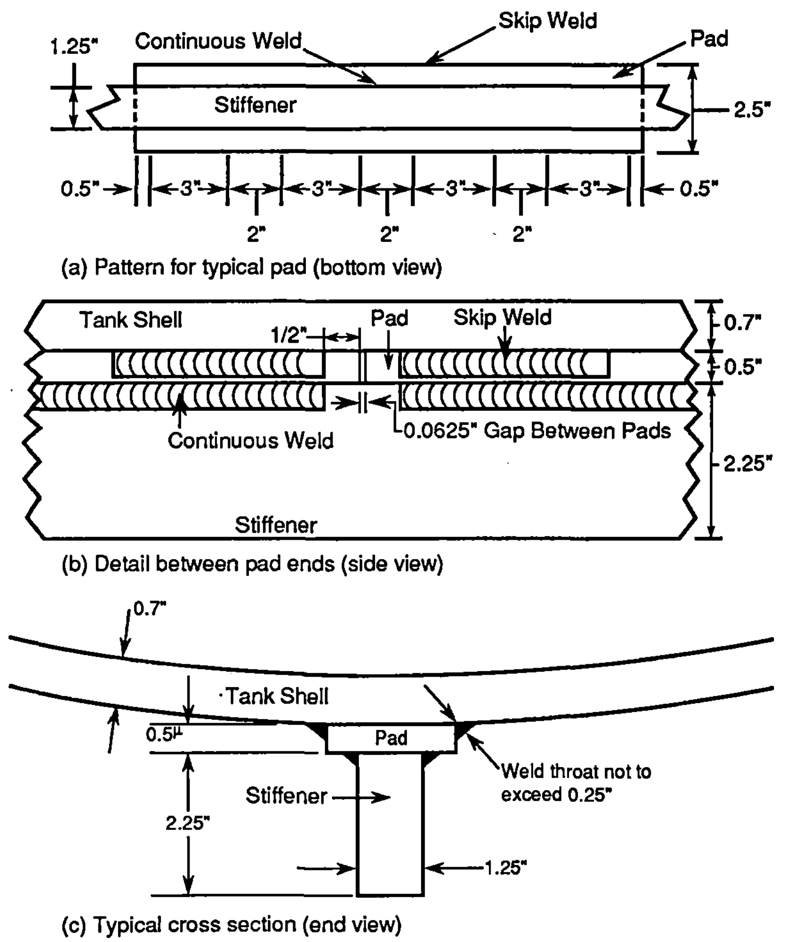
FRA inspectors. The cars in question were modified with attachments welded to the tank car that did not conform with the specifications. A finite element model of the area of concern was developed. A risk analysis of not post-weld heat treating the welded area was conducted. Based on the analysis, it was determined that the vibration stress loads are very low, and probably would not provide any significant amount of stress relief. The final report was published in 1991.

Work was completed on a materials engineering study to determine residual stress patterns associated with pad welds for tank car attachments. A draft technical report was prepared and is being reviewed.

Residual Stress/Fatigue Crack Growth

The FRA has been examining cracks in tank cars, especially in the weld area. This research led to several conclusions concerning stub sill tank cars. The design of the stub sill car allows impact forces to be carried through the tank. In addition, attachments welded to the tank shell produce additional stresses in the shell. These stresses are of concern to the safe performance of stub sill tank cars.

The effects of static and dynamic loading on the tank shell needed to be analyzed. A test was conducted on the squeeze test fixture, at TTC, to determine the compressive loads applied to a tank car during impact. This test did not address the service stress environment, nor did it examine crack growth rates at locations where cracks might form in the tank shell. Therefore, a project was initiated in 1989 to characterize the service stress environment, to investigate crack growth rates, and to obtain dynamic measurements of the buff load concentration effects at the tank mid-span and near the stub sills. This project will continue into 1992. Over-the-road tests have been conducted to develop data for use on the Simuloader test of an actual tank car with cracks. The test car will be exposed to 482,800 km (300,000 mi) of simulated track geometry inputs on the Simuloader, to determine the rate of crack growth.



Stiffener Weld Layout

Tank Car Design Improvements

Leaks caused by fittings, valves, and closures were analyzed to determine if a design change is needed or if more stringent loading procedures are required. Tank car lining failures were also investigated. Most leaks occur on cars carrying corrosive materials and are caused by improperly secured openings.

This problem is most attributable to improper loading techniques coupled with insufficient inspection. Gasket failures involve deteriorated gaskets, improper gasket materials, and improper closure procedures. Improvements in the state-of-the-art in lining inspection are needed. A technical report has been prepared and will be published.

Tank Car Structural Integrity

The analysis of critical flaw size for tank car steels continues. This work, performed by NIST, is long term because of the need to study a variety of damaged tank car steels. Detailed metallurgical studies of deformed, dented, or otherwise stressed steels from tank cars involved in derailments will be conducted. This work includes deciding the material's metallurgical properties as a function of its loading rate and temperature. A report will be prepared at the conclusion of the program.

New Tank Car Steels

This project, begun in 1989, will continue into 1992. The purpose is to conduct metallurgical evaluations of the new steels proposed by the industry for use in future tank car construction. The new steels are high strength, micro-alloy steels, and some are made using inclusion shaped control practice. Because of problems with the manufacturing processes, the tank car industry has postponed development of standards for the new steels. Research is also being conducted on existing tank car steels to develop a database of material properties. A final report will be prepared at the conclusion of the project.

Tank Car Repair Facilities Handbook

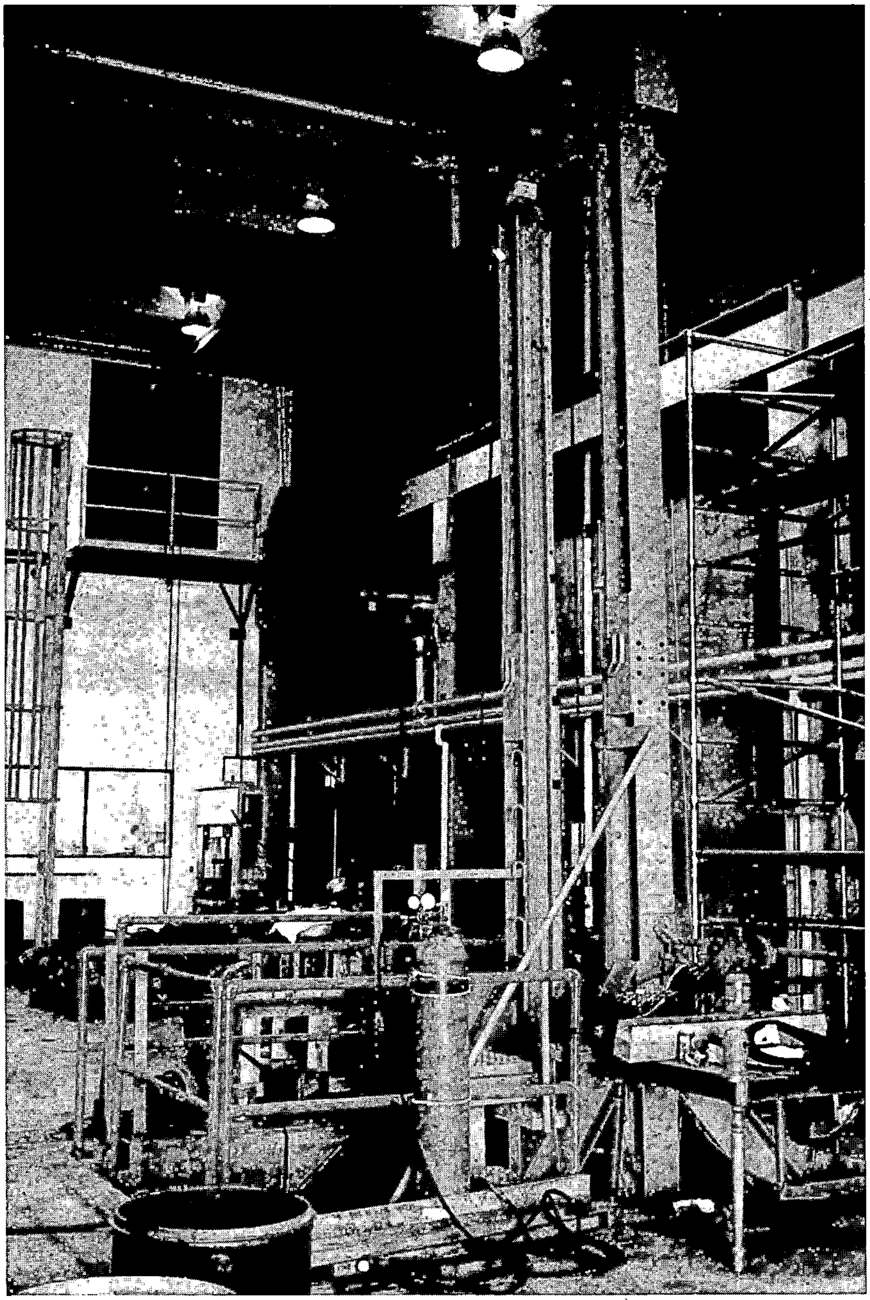
Research is being initiated to improve inspection procedures and reporting at tank car repair facilities. Many tank car failures are attributable to improper, incorrect, or poor repairs or improper, incorrect, or poor inspection. An inspection report that would show ongoing trends of poor workmanship or trends in apparent failures of repaired containers will be developed under this program.

Tank Car Puncture Resistance Testing

In 1976, full-scale tests were conducted at TTC to investigate the mechanism of coupler override. This mechanism was believed to cause several tank car puncture accidents during train makeup operations in switch yards. These tests showed that, under certain circumstances, the coupler on the adjacent car could override a tank car's coupler and strike the tank head with sufficient force to puncture the shell. These tests investigated the use of shelf couplers to reduce the potential for override and 1.3-cm (0.5-in) thick steel head shields to blunt the striking coupler. The results of these tests and other investigations were used to establish minimum safety standards requiring that DOT 112/114 tank cars designed to carry flammable liquids be equipped with shelf couplers and head protection sufficient to withstand a 26-km/h (18-mph) impact.

Because of incidents involving chlorine tank cars and general concern over the commodity, the FRA considered requiring that these cars show an ability to withstand impacts as described in the Code of Federal Regulations. To provide background data, a series of tests was conducted comparing the puncture resistance of DOT 112J340W tank cars used to carry liquified propane gas and DOT 105A500W tank cars that carry chlorine. One-fifth scale model, full-scale, and actual tank car tests were conducted. The puncture threshold for the propane car was above 37 km/h (23 mph). For the chlorine tank car, the puncture threshold is near 29 km/h (18 mph). It was concluded that adding thickness to the steel jacket on the chlorine tank car would be more effective than using a thicker tank head. A final report on this project will be published in 1992.

Because of continued concern for the safety of hazardous materials transported by rail, the study of the vulnerability of aluminum tank cars to puncture was extended. This program includes scale-model and full-scale testing and evaluation of the effectiveness of head shields to protect DOT Type 111 non-pressure aluminum tank cars from puncture. Part of the program included comparison with the propane and chlorine tank cars. The effort also included evaluation of the puncture resistance of tank cars subjected to ambient temperatures and to two specific cold temperatures: -29°C (-20°F) and 0°C (+32°F). A series of 1/5 scale and full-scale model tests were conducted from March 1989 to March 1990 at TTC, to provide data for this evaluation.



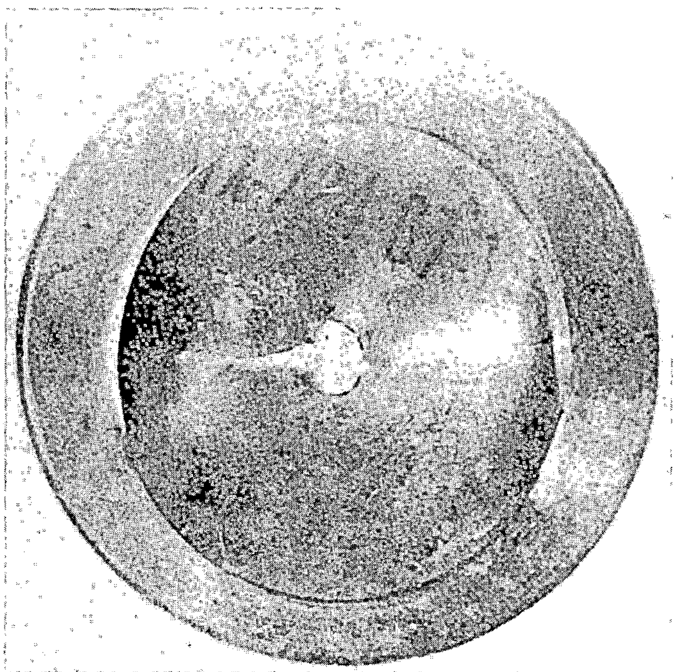
One-Fifth Scale Drop Test Fixture, Upper Section

Scale models of tank car head configurations were tested in a laboratory drop test fixture. Design parameters were varied to establish the sensitivity of puncture resistance to head and shield thickness, internal pressure, and temperature. Full-scale tests were conducted with a simulated tank car employing a pressurized tank fixture mounted on a railroad flatcar to establish the puncture resistance of a shielded head configuration and to investigate the relationship between the 1/5 scale and full-scale impact models.

The results of the 1/5 scale tests show that use of a head shield was very effective in increasing the puncture resistance of a tank car, tank head material and material thickness also affect puncture resistance, and cold temperatures and insulation have negligible effects. A final report is being reviewed and will be published in 1992.

One-Fifth Scale Head Assembly in Test Pit

Evaluation of Premature Failure of Frangible Discs

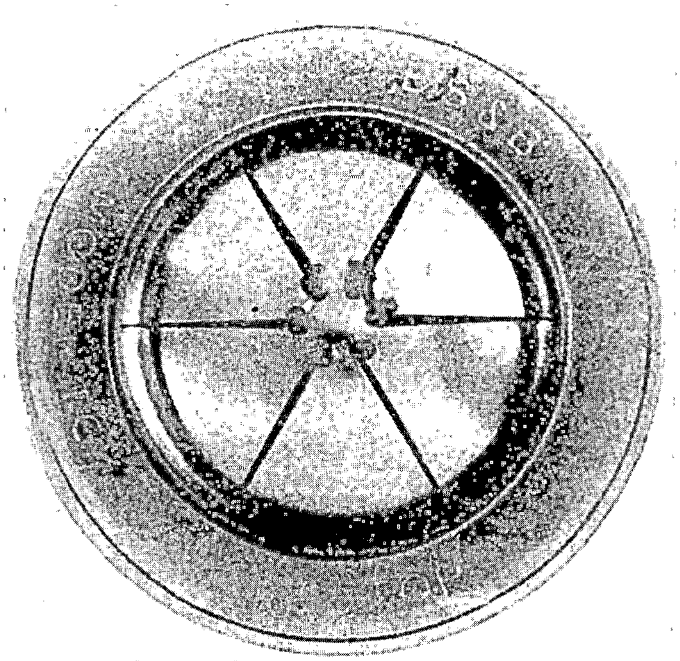


Failed Lead Disc with Breather Hole

A frangible disc, used in safety vents, acts as a one-time pressure release device. Non-pressure tank cars, carrying certain commodities, are often equipped with such a safety device. The disc separates the contents of the tank from the atmosphere and is designed to rupture at a prescribed internal pressure below the design burst pressure of the tank car.

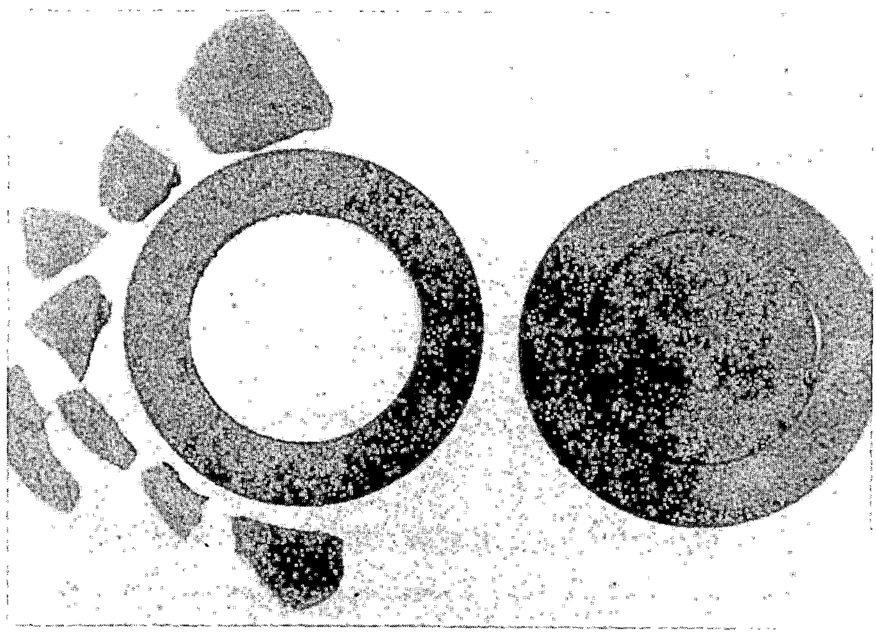
Laboratory tests were performed at TTC to evaluate the performance of various frangible disc designs with respect to AAR Specification A5.03. Tests were also performed to determine the range of burst pressures and the effect of temperature, creep, pressure surge, and corrosives on the burst pressure of one lot per disc design.

Premature frangible disc failure is an issue of major concern to shippers of hazardous materials. One possible cause of premature disc failure is high pressures caused by low-speed impacts in yards or longitudinal slack action in trains. Tests simulating the low-velocity impacts of tank cars in train yards were conducted in August 1989 at TTC, to evaluate the relationship between low-velocity impacts and undesired frangible disc failures. In addition, the tests evaluated the performance of several devices designed to mitigate the effects of large surge pressures resulting from yard impacts.



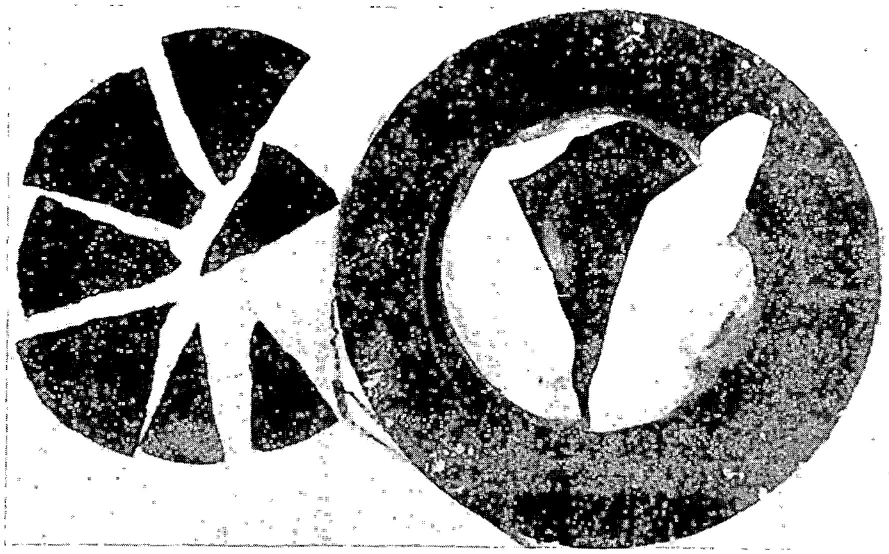
Failed Stainless Steel Disc

A tank car was instrumented to measure the coupler forces and accelerations generated during low-speed couplings, as well as the internal pressures at five locations along the top of the tank. The results were analyzed and presented as time histories of the pressure surges and as plots of peak pressures versus coupler force or impact velocity for various test conditions, such as commodity outage (amount of tank volume that is not filled with the commodity) or vent location. Outages tested were 0 percent, 1 percent, 2 percent, and 4 percent. The car was equipped with three vents of varying diameter: 6.4 cm (2.5 in), 10.2 cm (4 in), and 16.5 cm (6.5 in). The car was struck from both ends during the tests.



Composite Disc #1 Broken with Air (left) and Oil (right)

The tests showed that frangible disc ruptures occurred at speeds as low as 10 km/h (6 mph) for 0-percent outage and less than 13 km/h (8 mph) for all outages tested. The 0-percent outage is a much more severe condition than the 1-percent outage, and there was little variation in the pressures between the 1-percent outage series and the 2-percent and 4-percent outage series. During the test, several surge pressure reducer designs were evaluated. The baffle type surge pressure reducer was found to be very effective in reducing surge pressures well below the frangible disc rupture specification, both 413,700 Pa (60 psi) and 689,500 Pa (100 psi). A final report has been prepared and will be published in 1992.

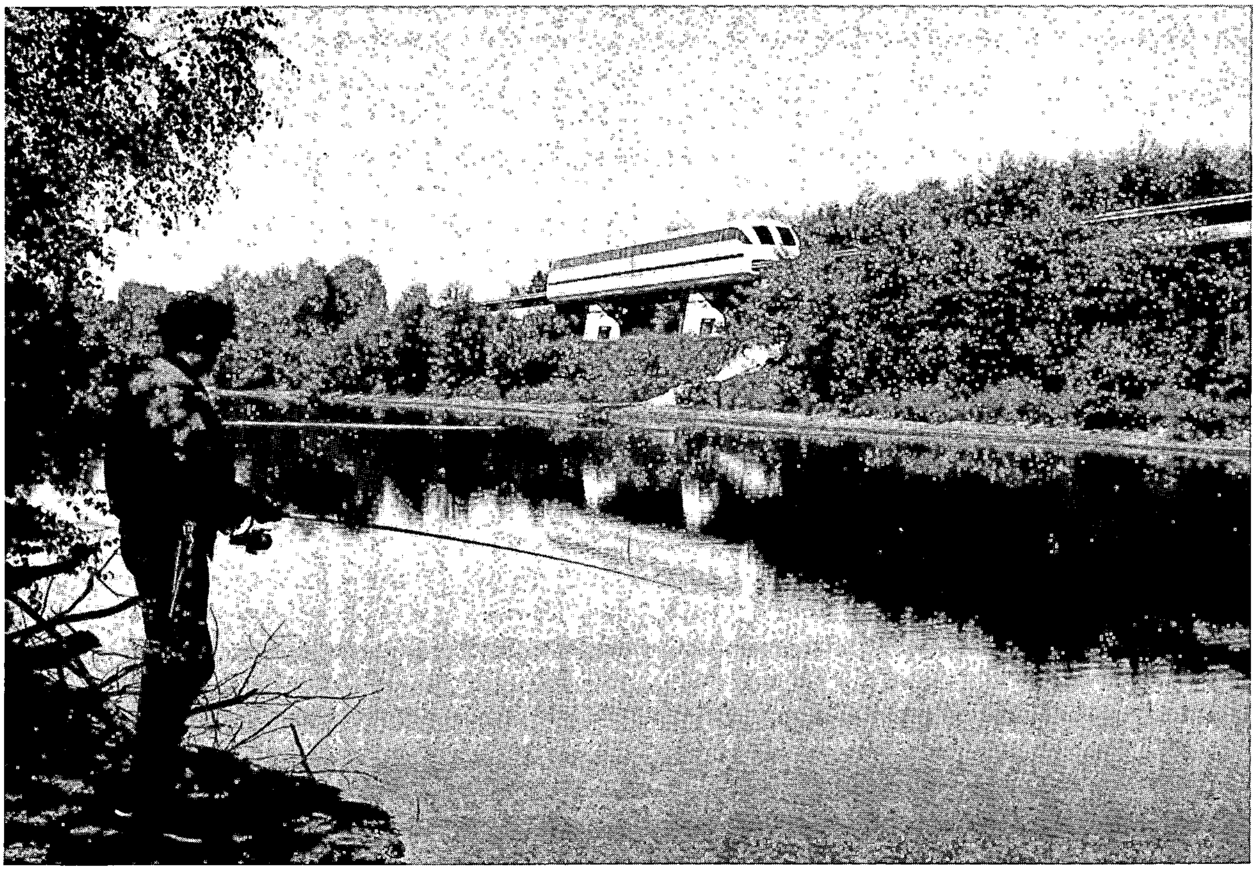


Fractured Graphite Disc

Tank Car Design Analysis

The Hazardous Materials Transportation Uniform Safety Act of 1990 required the Secretary of Transportation to conduct a study of the tank car design process and tank car design criteria, including the use of head shields on all cars that carry hazardous materials. The study will be initiated in 1992 with the Report to Congress to be submitted in 1993.

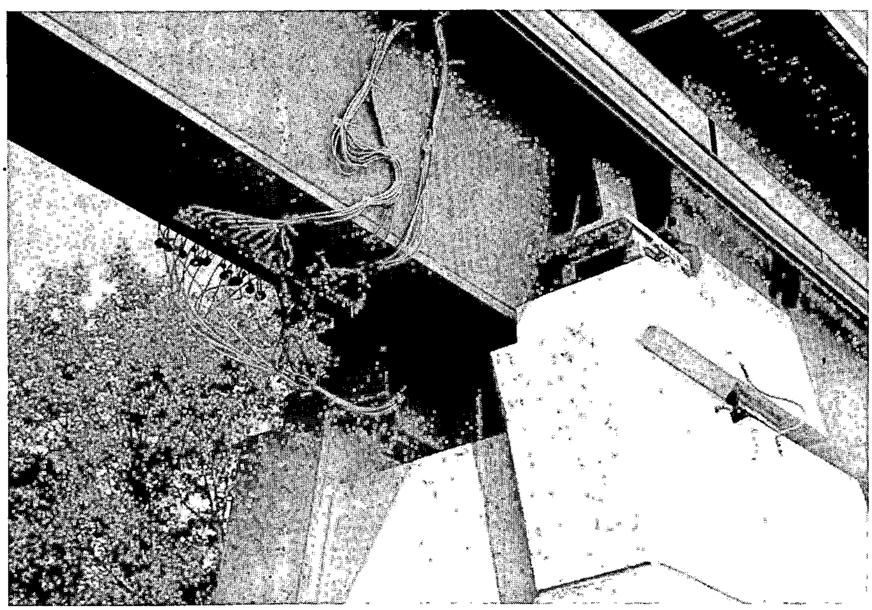
HIGH SPEED GUIDED GROUND TRANSPORTATION SAFETY PROGRAM



High Speed Guided Ground Transportation Safety Program

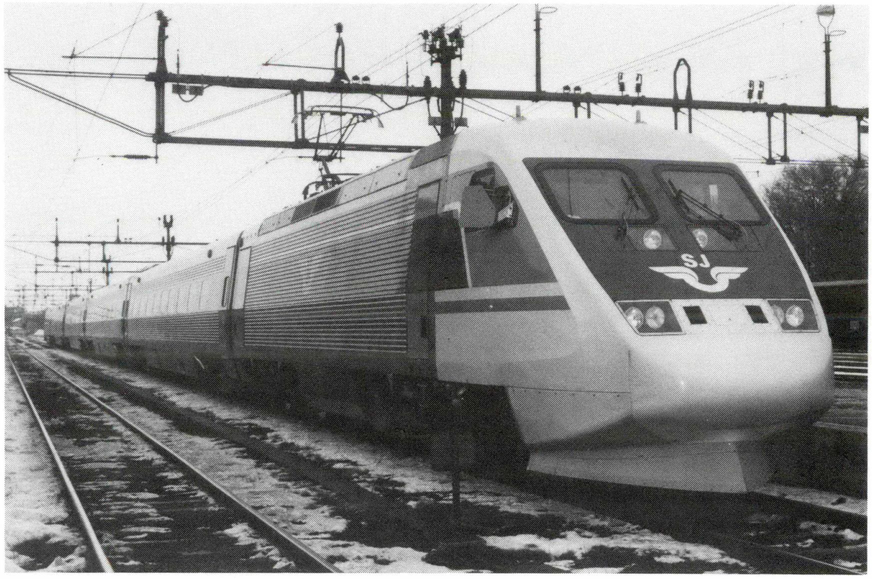
New intercity high speed rail technologies may become an operational reality in the United States in the next few years. As a result of the development of these advanced very high speed guided ground transportation systems, there is a need to re-examine existing Federal safety requirements for their appropriateness for application to these new technologies. It is also necessary to assess the relative safety of these high speed rail systems, for all of them are of foreign origin at the present time and may employ different equipment and operating procedures from those customarily seen in the United States. This responsibility rests with the FRA, which is charged with ensuring the safety of rail systems in the United States--under the Railroad Safety Act of 1970, as amended, including the Rail Safety Improvement Act of 1998, which clarified the definition of rail to include magnetically levitated (maglev) systems.

Inquiry into the Facts Concerning the Transrapid Levitation Magnets with the Vehicle Designer

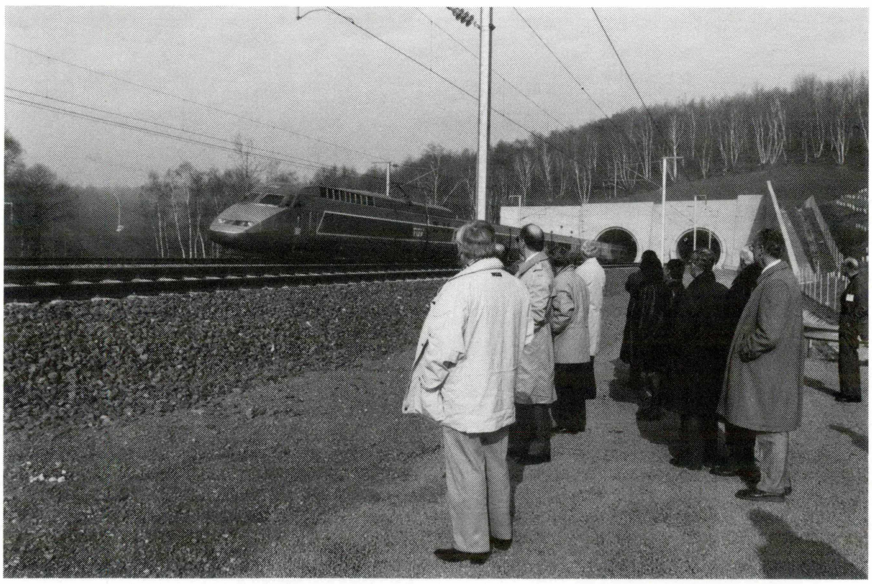


Instrumentation To Collect Information on the Behavior of the Transrapid Guideway at the TVE Test Facility, Emsland, Germany

As noted in the DOT's "Statement of National Transportation Policy" (NTP), "safety is the top priority for the Department of Transportation." The NTP further indicates that it is Federal transportation policy to "review new designs for transportation vehicles to detect any safety problems...," to "develop rules to require vehicle design improvements to increase occupant protection and improve crash avoidance capabilities . . .," and to "promote safety in public transportation by encouraging the development of industry safety standards, implementation of comprehensive system safety plans. . . ." The intent of the High Speed Guided Ground Transportation (HSGGT) Safety Program is to implement these policies through use of project accompanying safety assessments. This process permits the Government and the private sector to work together to ensure that system safety is built into all new developments. Early identification of safety concerns permits timely remediation and avoids unnecessary expense later in a system's development.



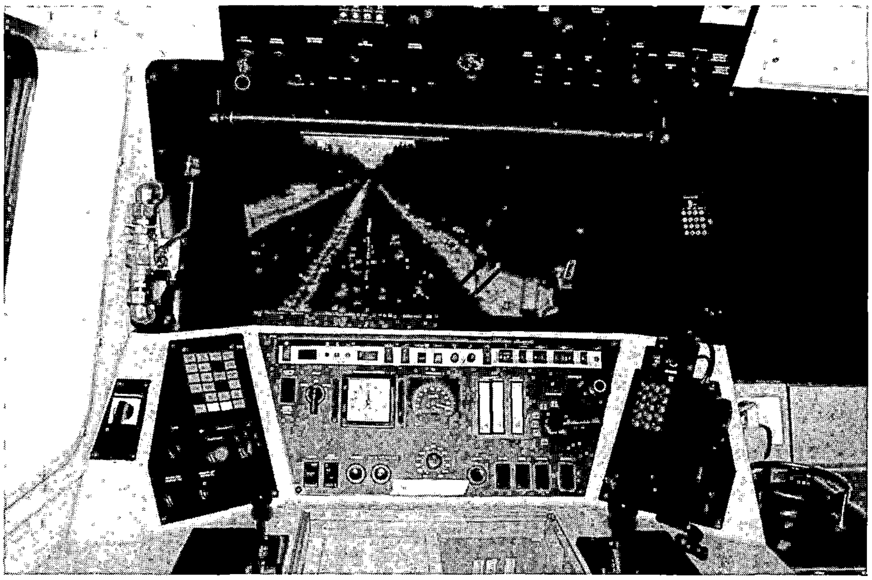
The X2000 Tilting Train: Cab-Car End Forward at a Stop in Sweden Where It Operates over Existing Mixed Traffic Lines at 200 km/h (125 mph)



U.S. Technical Delegation Observes TGV Atlantique Exiting a Tunnel Portal While Inspecting Right-of-Way Infrastructure and Wayside Operations

The overall HSGGT area of concern includes maglev vehicle systems and conventional wheel-on-rail with its various configurations, such as when equipped with articulated trucks or tilting mechanisms. All of these new systems are represented in the FRA/Volpe Center HSGGT Safety Task Force review and assessment of the maglev system's ability to comply with the existing Federal safety regulations. Thus far, safety-relevant observation reports have been prepared for the French Train ! Grande Vitesse (TGV), the German InterCity Express (ICE), and the Swedish X2000 Tilting Train. A preliminary safety review of the German Transrapid maglev system was completed and reported on in November 1990.

The German high speed maglev train safety requirements were reviewed to determine the suitability of the requirements for use in the United States. The review revealed that, while many of these requirements are directly transferable to the U.S. application of the Transrapid system, additional requirements are necessary to ensure safety of operations in the United States. In addition to preparing the requirements document, the German Federal Railway (DB) has conducted an exhaustive examination of all aspects of the Transrapid system, with system safety as a major objective. This process has determined the "readiness for application" of Transrapid. The DB final report is expected to produce considerable information that can be used in the development of the initial U.S. safety standards for electromagnetic maglev systems. A review of the documents supporting the "readiness for application" and the DB report itself will be the subject of a future report to be prepared by the HSGGT Safety Task Force.



Operator's View from the Cab of the X2000 Tilting Train

The level of effort devoted to the study of maglev safety is considerable compared to that applied to wheel-on-rail, simply because the Transrapid technology is much newer.

Effectiveness of X2000 Tilting Mechanism Passing Through a Curve

When a specific HSGGT system is planned for application in the United States, that system is studied in greater detail. Such is the case with the TGV, since it was approved for installation in Texas, between Dallas/Ft. Worth, Houston, and San Antonio. A more rigorous examination is now underway to evaluate the safety standards to which TGV is built and to compare them with accepted U.S. practice. Existing safety regulations may require modification to permit TGV operation at 320 km/h (200 mph), as envisioned. The HSGGT Safety Task Force will provide the technical bases for recommended rulemaking actions. The task is to maintain equivalent safety while not creating any unnecessary impediments to acceptance of this new technology. Initially, rules for particular applicability are

Discussion of the Construction Features of the InterCity Express (ICE) at the Manufacturers' Plant

expected to be issued on a project-by-project basis. Later, as operating experience with the new HSGGT systems accrues, rules of general applicability will be developed for the new technologies.

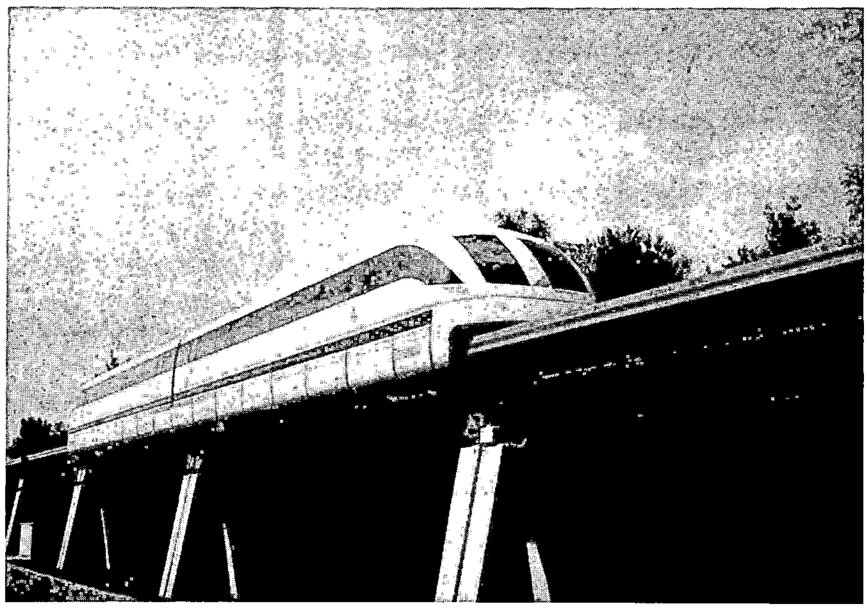
Specific research has been undertaken to provide further insight into some of the more sensitive issues that have arisen in the recent considerations for applying HSGGT systems in the United States. This research includes collision avoidance and accident survivability, safety issues surrounding HSGGT use of shared right-of-ways, convertability of foreign engineering standards to U.S. standards, and the measurement of electromagnetic fields and determination of the potential health effects. Additional research requirements were identified in a report of the Transportation Research Board (TRB). This report documented the results of a workshop, held, in 1991, by TRB at the request of the FRA, on safety factors related to high speed rail and maglev passenger systems.

NATIONAL MAGLEV INITIATIVE PROGRAM

National Maglev Initiative Program

In December 1989, an interagency maglev coordinating committee was formed to coordinate maglev efforts within the Federal Government. Membership included DOT, DOE, and the U.S. Army Corps of Engineers (USACE), together with other agencies, including the Environmental Protection Agency, the Department of Commerce, and NASA.

At the same time, DOT's "Statement of National Transportation Policy" (NTP), issued in February 1990, emphasized that in dense intercity corridors there is a need to develop new complementary transportation options, particularly to serve passenger trips in the 160-to-800-km (100-to-500-mi) range. Such options should take into account land use, energy, and environmental impacts, as well as transportation preferences. One of the options highlighted in the NTP, as well as in the National Energy Strategy, issued by DOE in March 1991, is magnetically levitated trains. Maglev is a potentially environmentally benign, energy efficient, high speed technology. It was supported in the United States in the 1970s, and is currently under development in Germany and Japan. In response to initiatives within the Administration and Congress, the National Maglev Initiative (NMI) was established in the spring of 1990 to coordinate the efforts of the three primary Federal agencies involved in maglev, the FRA, USACE, and DOE. NMI near-term goals are to evaluate the potential for maglev to improve intercity transportation and to develop the information necessary for the Administration and Congress to determine the appropriate role for the Federal Government in advancing this technology.



Transrapid Electromagnetic Maglev Under Test at 410 km/h (255 mph) on the 32-km (20-mi) Emsland Test Track in Northwestern Germany

To achieve these goals, NMI has embarked on an ambitious program of technical and economic analyses and market feasibility studies of maglev concepts, as well as research on associated energy, environmental, health and safety issues. An outreach program is underway to identify and involve industry and academic experts, state and local governments, and others interested in this technology.

In May 1990, NMI held a forum in Washington, D.C., which brought together more than 200 industry and government officials, as well as representatives of the academic community, to discuss NMI work programs. A nationwide survey was also conducted to obtain the views of major firms that were interested in involvement in maglev. In June 1990, the FRA's preliminary feasibility assessment report, "Assessment of the Potential for Magnetic Levitation Transportation Systems in the U.S.," and

USACE's draft program implementation report, "A Preliminary Implementation Plan," were submitted to Congress. These reports concluded that maglev appears to be technically and economically feasible, but considerable study is required to determine whether and how maglev should be integrated in the U.S. transportation system.

In July 1990, a workshop was held at the Argonne National Laboratory (near Chicago) to identify research needs and to refine maglev system parameters. Regional meetings with state Departments of Transportation and local officials were held in Sacramento, California in January 1991 and in Albany, New York in October 1991. A symposium for technology assessment and potential system concept definition contractors and other interested parties was held at the Volpe Center, in Cambridge, Massachusetts in September 1991. A second symposium was held at the Argonne National Laboratory in April 1992.

For FY 1991, Congress appropriated $8.2 million for the FRA and $2.0 million for the USACE, totalling $10.2 million for NMI research activities. This was in addition to $1.3 million for ongoing maglev safety research and $500,000 for high speed rail safety studies. In early 1991, an interagency program office was established at DOT Headquarters to conduct the NMI Program. This office is directed by Robert L. Krick, the FRA Deputy Associate Administrator for Technology Development.

Using FY 1991 NMI funding, the following studies are underway: (1) maglev technology assessment contracts totalling $4.3 million, to define the state-of-the-art and opportunities for improving operational performance and for reducing costs and risks of subsystems; (2) economic and market studies, including assessment of specific markets for maglev potential; (3) analyses of right-of-way and intermodal connectivity issues; and (4) analyses of public policy issues.

Contracts for system concept definition studies to evaluate possible maglev systems were negotiated in late FY 1991, and four 11-month contracts, totalling over $8.6 million, were awarded in late October 1991. Congress appropriated $16.0 million ($8.0 million to the FRA and $8.0 million to USACE) for FY 1992, to continue the maglev assessments initiated in FY 1991 and to advance the definition of concepts through simulation and some subsystem-level testing.

For further information on the progress of the NMI Program, refer to the National Maglev Initiative November 1991 Annual Report.

APPENDIX A
ACRONYMS

Acronyms

AAR	Association of American Railroads
ATCS	Advanced Train Control Systems
CWR	Continuous Welded Rail
DB	German Federal Railway
DOT	Department of Transportation
EMAT	Electromagnetic Acoustic Transducers
FAST	Facility for Accelerated Service Testing
FRA	Federal Railroad Administration
GRMS	Gauge Restraint Measurement System
HPIT	High Productivity Integral Train
HSGGT	High Speed Guided Ground Transportation
IITRI	Illinois Institute of Technical Research Center (Chicago, IL)
Maglev	Magnetic Levitation Vehicles
NIST	National Institute of Standards and Technology
NMI	National Maglev Initiative
NTP	National Transportation Policy
NUCARS	New and Untried Cars Analytical Regime Stimulation
PATH	Port Authority Trans-Hudson Corporation
RALES	Research and Locomotive Evaluator/Simulator
R&D	Research and Development
SBIR	Small Business Innovation Research Program
STPT	Single Tie Push Test
TGV	French Train Gránde Vitesse
TLV	Track Loading Vehicle
TTC	Transportation Test Center
UDE	Undesired Application of Emergency Braking Systems
USACE	U.S. Army Corps of Engineers

APPENDIX B
PUBLISHED REPORTS

Published Reports

Report Number	NTIS Number	Contractor	COTR	Report Title
FRA/ORD-88/01	---	AAR	Moody	Derailment at FAST July 1, 1986
FRA/ORD-88/02	88 179551	EG&G	Orth	Evaluation of Damaged Tank Car Structural Integrity
FRA/ORD-88/03	88 166582	OR&D	Bang	Recent Developments in Railroad Safety Research
FRA/ORD-88/04	88 241815	MITRE	Orth	Safety Testing of Intermodal Hazmat Configurations - Summary Reports
FRA/ORD-88/05				SUPERSEDED BY FRA/ORD-89/06
FRA/ORD-88/06	88 176268 Vol I 88 176276 Vol II	AAR/TTC	Gannett	Wheel Failure Mechanisms of Railroad Cars Volume I - Final Summary Report Volume II - Technical Tasks Summaries
FRA/ORD-88/07	---	AAR/TTC	Scharr	Safety Aspects of New and Untried Freight Cars, Car 1
FRA/ORD-88/08	88 214622	IITRI	Orth	Results from the Car Coupling Impact Tests of Intermodal Trailers and Containers
FRA/ORD-88/09	89 163091	Magna-sonics, Inc.	Bowers	Railroad Rail Flaw Detection System Based on Electromagnetic Acoustic Transducers
FRA/ORD-88/10	89 178032	AAR/TTC	Bowers	Laboratory Testing of Articulated Prototype Covered Hopper Car (Budd Hi-Cube HPIT Prototype)
FRA/ORD-88-88/12	88 219613	NBS	Orth	Dynamic Mechanical Properties of Two AAR M128 and One ASTM A212-B Steel Tank Car Head Plates (NBSIR-88-3690, June 1988)
FRA/ORD-88/13	90 113044	TSC	Paxton	Crack Propagation Life of Detailed Fractures in Rails
FRA/ORD-88/14	89 138929	Technology Management Systems, Inc.	Orth	A Risk Assessment Study on the Transportation of Hazardous Materials over the U.S. Railroads
FRA/ORD-88/15	---	ENSCO	Scharr	Roller Bearing Temperature Measurements on Double-Stack Container Cars

Published Reports (continued)

Report Number	NTIS Number	Contractor	COTR	Report Title
FRA/ORD-88/16	---	TSC/Univ. of WA	Gannett	Analysis of Residual Stresses in Railroad Car Wheels Based on Destructive Test Measurement THIS WAS NOT A REPORT - JOURNAL ARTICLE ONLY (per O. Orringer 6/6/89)
FRA/ORD-89/01	90 161456	Battelle Columbus Lab	Orth	Stub Sills on Tank Cars - Final Report
FRA/ORD-89/02	---	AAR	Moody	Vehicle Track Interaction Truck Hunting
FRA/ORD-89/03	89 190110	Battelle subcont- R&R Research	Thomas	A Survey of Railroad Industry Perceptions Regarding Needed Locomotive Cab Design Improvements
FRA/ORD-89/04	---	ENSCO	Scharr	Test Report of Bearing Drop Test Data Collected at Southern Research Laboratory
FRA/ORD-89/05	---	ENSCO	Scharr	Cant Deficiency Test Safety Monitoring Using Accelerometer Measurements
FRA/ORD-89/06	---	ENSCO	Scharr	Railroad Passenger Ride Safety
FRA/ORD-89/07	---	MIT/TSC	Scharr	A Comparison of Model and Field Test Dynamic Performance Data for a Two-Axle Freight Car
FRA/ORD-89/08	90 185471	TSC	Paxton	Analysis of Phase III Dynamic Buckling Tests
FRA/ORD-89/09	---	TTC/AAR	Orth	Stub Sill Tank Car Compression Test
FRA/ORD-90/01	90 207911	Sandia National Lab	Orth	Thermal Response of a Small Scale Cask-Like Test Article to Three Different High Temperature Environments
FRA/ORD-90/02	90 225319	TTC/AAR	Orth	Tank Car Frangible Disc Tests
FRA/ORD-90/03	---	IITRI	Schultz	Safety Aspects of High Speed Passenger Equipment
FRA/ORD-90/04	---	ADL	Paxton	An Assessment of High Speed Rail Safety Issues
FRA/ORD-90/05	90 266420	TSC- Orringer	Evans	Control of Rail Integrity by Self-Adaptive Scheduling of Rail Tests

Published Reports (continued)

Report Number	NTIS Number	Contractor	COTR	Report Title
FRA/ORD-90/06	90 268624	TSC	Evans	Evaluation of Elbers' Crack Closure Model as an Explanation of Train Load Sequence Effects on Crack Growth Rates
FRA/ORD-90/07	90 252305	ADL-Martin	Bang	An Industry Perspective of MAGLEV
FRA/ORD-90/08	---	---	Bang	Broad Agency Announcement MAGLEV Transportation System Technology Harding Assessment (September 1990)
FRA/ORD-90/09	91 129684	TSC	Bang	MAGLEV Transportation (Transrapid) Preliminary Safety Assessment
FRA/ORD-90/10	91 124552	IITRI	Thomas	Test of Alerter/Emergency Braking System
FRA/ORD-90/11	---	Battelle	Paxton	Rail Neutral Temperature Tests on CSX
FRA/ORD-90/12	92 129428	ENSCO	Gray	Performance of Degraded Roller Bearings (DOT-FRA-89-08)
FRA/ORD-90/13	91 173021	TSC	Paxton	Dynamic Buckling Test Analyses of High Degree CWR Track
FRA/ORD-90/--	91 104596	FRA	Harding	REPORT SUPPLEMENTAL (June 1990) Assessment of the Potential for Magnetic Levitation Transportation Systems in the U.S.
FRA/ORD-90/--	91 104588	FRA	Harding	A REPORT TO CONGRESS (June 1990) Assessment of the Potential for Magnetic Levitation Transportation Systems in the U.S.
FRA/ORD-90/14	91 129668	TSC	Bang	Safety Relevant Observations on the X2000 Train as Developed for the Swedish National Railways (November 1990)
FRA/ORD-91/01	---	ADL	Pena	HM Releases Due to Unsecured Openings and Lining Failures
FRA/ORD-91/02	---	ADL	Schultz	Waste Retention/Passenger Cars
FRA/ORD-91/03	92 102649	TSC	Bang	Safety Relevant Observations on the TGV Atlantique High Speed Train
FRA/ORD-91/04	92 119064	TSC	Bang	Safety Relevant Observations on the ICE High Speed Train
FRA/ORD-91/05	92 118843	TSC	Orth/Pena	Tank Car Accident Data Analysis (1981-1985)

APPENDIX C
PLANNED REPORTS

Planned Reports

Report Number	NTIS Number	Contractor	COTR	Report Title
FRA/ORD-91/06	---	Battelle	Orth/Pena	Hazardous Material Car Placement in a Train Consist, Volume I - Review and Analysis
FRA/ORD-91/07	---	Battelle	Orth/Pena	Hazardous Material Car Placement in a Train Consist, Volume II - Appendices
FRA/ORD-91/08	---	VNTSC Dorer		Safety of High Speed Magnetic Levitation Transportation Systems: Review of German High Speed Safety Requirements
FRA/ORD-91/09	---	TTC/AAR Florom	Davids	FAST/HAL Mechanical Performance Test
FRA/ORD-91/10	---	TTC/AAR Trevizo	Davids	FAST/HAL Ballast and Subgrade Experiments
FRA/ORD-91/11	---	TTC/AAR Laine Trevizo Kalb	Davids	FAST/HAL Ballast Gradation
FRA/ORD-91/12	---	TTC/AAR Read	Davids	Evaluation of Heavy Gauge Geotextiles at FAST
FRA/ORD-91/13	---	TTC/AAR Leary	Davids	Mechanical and Material Aspects of Wheel Wear at FAST
FRA/ORD-91/14	---	TTC/AAR Reiff	Davids	Correlating FAST Rail Wear Data with Revenue Service
FRA/ORD-91/15	---	TTC/AAR Rajkumar	Davids	Torsional Stick-Slip Phenomena Torsional Vibrations of Wheel Set and Wheel Corrugation
FRA/ORD-91/16	---	TTC/AAR Leary	Davids	Wheel/Truck Tolerance Experiment at FAST
FRA/ORD-91/17	---	TTC/AAR Brave	Davids	Gas-Spray Repair of Rail Surface Defects

Planned Reports (continued)

Report Number	NTIS Number	Contractor	COTR	Report Title
FRA/ORD-91/18	---	TTC/AAR Clayton Brave	Davids	Fatigue Defect Origination and Growth Experiment
FRA/ORD-91/19	---	TTC/AAR Larson	Pena	Aluminum/Cold Temperature Tank Car Puncture Resistance Tests
FRA/ORD-91/20	---	TTC/AAR Read Otter	Davids	Fast/HAL Track Loads Evaluation
FRA/ORD-91/22	---	VNTSC Coltman Hazel	Pena	Chlorine Tank Car Puncture Resistance Evaluation
FRA/ORD-91/23	---	TTC/AAR Read	Davids	FAST/HAL Tie and Fastener Experiment
FRA/ORD-91/24	---	TTC/AAR Brave Hannafrous Steele	Davids	FAST/HAL Rail Performance Experiment and Overview
FRA/ORD-91/25	---	TTC/AAR Read Hannafrous	Davids	FAST/HAL Turnout and Frog Performance Test
FRA/ORD-92/01	---	VNTSC Dorer	Bang	German High-Speed Maglev Train Safety Requirements (A Translation)
FRA/ORD-92/02	---	VNTSC Dorer		German High-Speed Maglev Train Safety Requirements--Potential for Use in the U.S.
FRA/ORD-92/03	---	VNTSC Dorer	ENSCO	Tilt Train Technology: State of the Art Assessment

Planned Reports (continued)

Report Number	NTIS Number	Contractor	COTR	Report Title
FRA/ORD-92/04	---	TTC/AAR Wilson	Schultz	Safety Aspects of New Trucks and Lightweight Cars, Car 2
FRA/ORD-92/05	---	TTC/AAR Larson Rajkumar	Orth Pena	Residual Stress Measurements of Weldments of Retrofitted Tank Cars
FRA/ORD-92/06	---	VNTSC Markos	Bang	Maglev Safety Requirements Safety Analysis
FRA/ORD-92/07	---	TTC/AAR Larson Florom Rajkumar	Gray	Field Testing of a Wayside Wheel Crack Detection System
FRA/ORD-92/08	---	TTC/AAR Florom Rajkumar	Gray	Roller Bearing Failure Mechanism Test and Wheel Anomaly Report
FRA/ORD-92/09	---	ERM Brecher	Bang	Magnetic Field Testing of TR07 Maglev Vehicle and Systems Volume I - Final Report Volume II - Appendices

APPENDIX D
LIST OF RESEARCH AND DEVELOPMENT CONTACTS

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