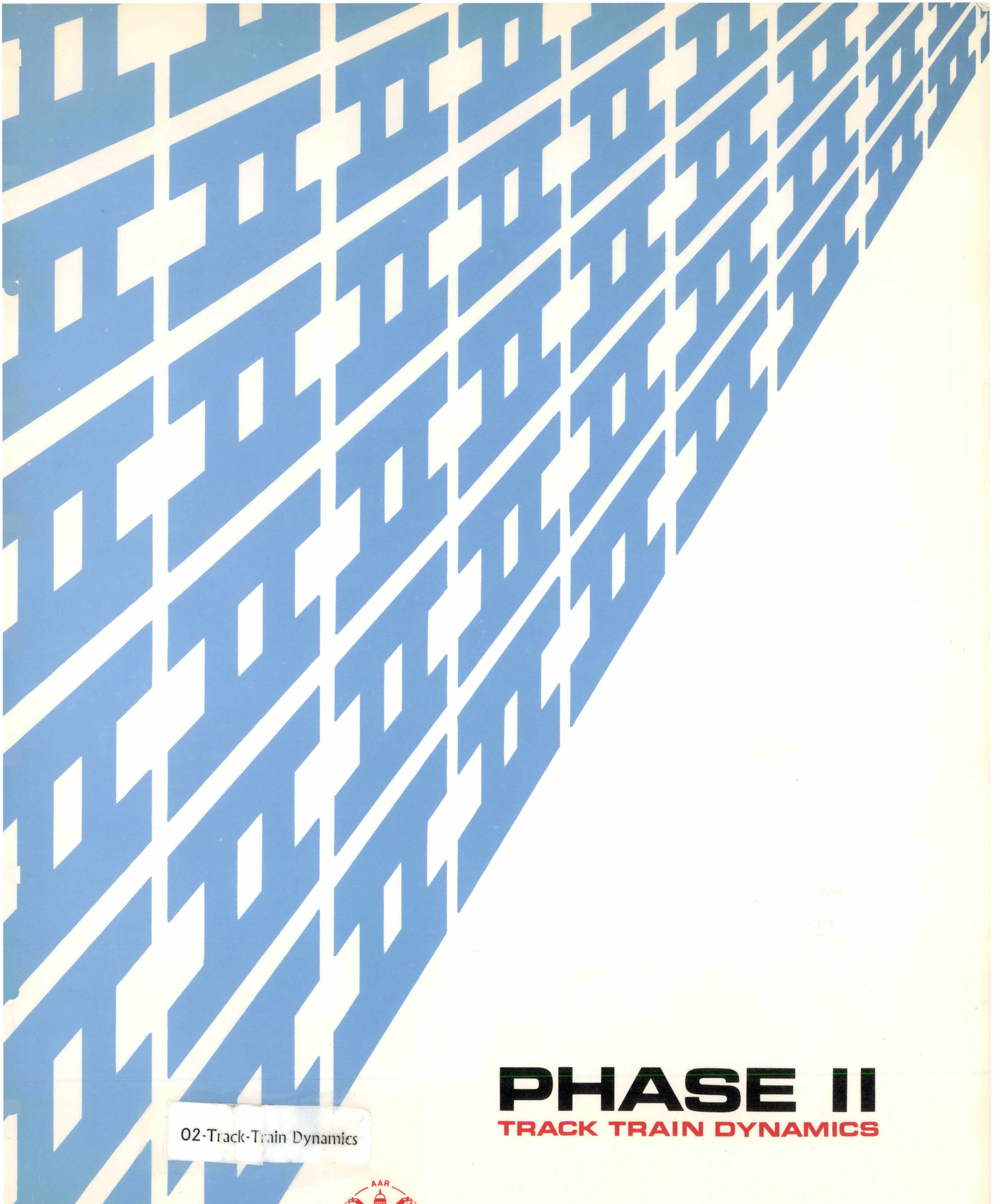

PHASE II
TRACK TRAIN DYNAMICS

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AN INTERNATIONAL GOVERNMENT - INDUSTRY RESEARCH PROGRAM ON TRACK - TRAIN DYNAMICS

R-380

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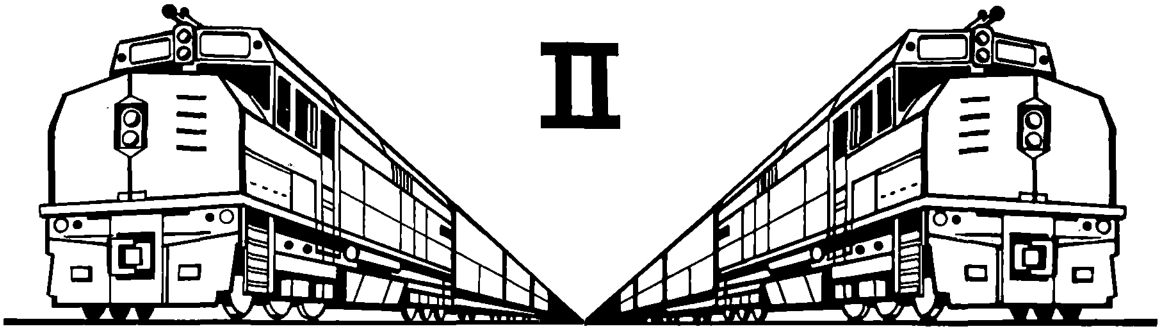
PHASE



II

TRACK TRAIN DYNAMICS

THE TRACK/TRAIN DYNAMICS PROGRAM

Research and planning carry large price tags in money, time, and the opportunities forgone by the people undertaking the projects. But if these costs are high, the costs of failure to plan and conduct research are exorbitant, possibly insurmountable.

Such was the decision faced in 1972, when the Southern Pacific Transportation Co. delivered its proposal for a joint, government/industry research effort on track/train dynamics.

The Association of American Railroads had commissioned the railroad in 1971 to prepare a proposal for a major research effort that would have long-term benefits--encompassing railroad operations, equipment design and materials specifications--bringing increased efficiency and profitability to railroad operations.

When the Southern Pacific delivered its report on March 31, 1972, it was clear the proposed program was too large and complex for any one railroad to undertake.

In his preface to the report, Southern Pacific's project leader, E. F. Lind, noted that railroad freight traffic volume was expected to exceed one-trillion ton miles annually by 1980--a one-third increase over the 1971 level. Increasingly specialized equipment, greater demands for cars, greater maintenance costs--all represented substantial investments for the railroads. The need to ensure that new equipment performed well, that operations continued safely, that freight operations were efficient and profitable, was pre-eminent. And that need was shared by all railroads.

Fulfilling the needs of the industry was a massive task. In the third quarter of this century, the complexity of railroad operations had increased greatly. Specialized cars, longer trains, heavier cars and more powerful locomotives were all moving at higher speeds than before, over track and roadbeds not designed with such conditions in mind.

New train makeup and higher speeds, plus the teaming of locomotives for greater tractive force, caused dynamic interactions to be heightened between cars, wheels and rail, individual car parts, and locomotives and train, track, and roadbed. Equipment design could not, at that time, account for these problems or mitigate them. In fact, many, if not most of the newly troublesome interactions, had not been studied in depth.

That was in 1972. Southern Pacific's proposal called for a ten-year research effort into track/train dynamics, an effort now approximately 50% complete.

Southern Pacific's proposal called for three phases of study, lasting two, three, and five years, respectively. The first phase would be directed at developing a data base and improving train handling techniques for the short term. Development of models also was viewed as crucial. In the second phase, specifications were to be established for rolling stock and track design, building on the information obtained through Phase I studies. The third phase effort was intended to utilize advanced technology in improving major train and track systems. It was anticipated that Phase III might be extended into a permanent program of monitoring and updating such systems.

The costs of such a far-reaching program, the Southern Pacific noted, would be acceptable if spread among railroads, interested suppliers, industry groups and government agencies, all of which might be called upon to lend expertise, equipment or labor to the study effort. The benefits to be obtained would make the study a most profitable venture--in the long run.

At about the time the Southern Pacific was distributing its proposal, the Federal Railroad Administration (FRA) was completing plans for a major test facility--a track loop for train dynamics research--at the Department of Transportation test facility at Pueblo, Colorado.

The Railway Progress Institute (RPI) offered to supply industry expertise and manpower, equipment and data for the study; the FRA offered financial assistance; the Transportation Development Center, a branch of the Canadian government, agreed to commit itself to the study; and an exchange of information was arranged with the Office de Recherches et D'Essais, the research arm of the Union Internationale des Chemins.

With coordination by the AAR Research and Test Department and funds and staffing from the AAR, RPI, FRA, and TDC, the Track/Train Dynamics program was begun in July, 1972.

A 16-member steering committee, with members from all participating groups, took responsibility for choosing staff and study group members for the project and handling of funds.

For the first Phase, E. F. Lind, Southern Pacific's project leader in the planning of the program, was appointed director. Dr. G. C. Martin of the AAR became deputy director.

PHASE I

Phase I of the Track/Train Dynamics program was carried out by 13 separate task groups. Key to the effort was the establishment of authoritative guidelines for improved operating practices, thus providing improved performance which in turn increased the time reliability of rail freight transportation. Such results enabled the railroads to use Track/Train Dynamics Program outputs directly in a timely manner and instilled the necessary confidence to continue supporting this effort with dollars and manpower.

Some of the main achievements of the Phase I effort are described briefly below.

Bibliography and Accident Reporting

Several studies had been conducted prior to 1972 in the areas with which the Track/Train Dynamics Program was concerned. The project's goal was to determine what ongoing or completed research was applicable to the effort in order to minimize unnecessary duplication. To the Bibliography task group fell the responsibility for collecting and cataloging information on such studies, for reference use in the Track/Train Dynamics Program and beyond. The group analyzed and cross-referenced 600 articles in its 763-page bibliography, which also included a thesaurus as an aid to persons using the text. The bibliography has been incorporated and updated as part of the FRA's Railroad Research Information Service of the Transportation Research Board.

Additional activities were underway to collect detailed information on the causes of train accidents. A task group was organized on this problem. It designed new forms for reporting of derailments and other accidents and providing instructions on ways to determine the likely causes of accidents. The Accident Investigations Manual produced by this group is a highly effective document in guiding railroad personnel to better understand the mechanisms responsible for train accidents. Through these efforts, corrective steps have been initiated by the railroad to minimize the recurrence of derailments.

Train Makeup and Handling

Ten years would pass before completion of the Track/Train Dynamics Program. Dozens of years would elapse before improved equipment had replaced then current equipment, on a widespread basis, on the railroads of the United States and Canada. In the interim, it was believed, railroads could improve efficiency of operations through changes in train makeup and handling, employee training, and other means already at their disposal. To this end a group of knowledgeable railroad operating and engineering personnel was organized to develop such a document. Primary among these was the Operating Policies group, which was assigned to research train handling and makeup practices at various railroads and develop industry guidelines. The Interim Guidelines book included both fundamental and advanced instructions for train operations under various conditions, recommendations for safe train makeup, proposals for track maintenance and suggestions for engineer education. Meanwhile, the Engineer Performance group was studying the effects that training, experience and other characteristics had on the abilities of engineers to recognize the forces acting on a train. Knowledge of proper operating responses is useless if the engineer is not aware that the problem exists. In addition to studying the factors that influence an engineer's ability to respond to various situations, the study group considered various displays and equipment improvements that could increase the engineer's sensitivity to these stimuli. The group also developed a new evaluation form and a special locomotive performance report for engineers.

Although the Guidelines represent the best techniques available, they might not under certain conditions represent the optimum. After mathematical models of train performance were developed, the Train Handling Techniques task group further investigated the interim guidelines by performing parametric studies using computer models, which produced a matrix of outputs under varying conditions. The 295-page matrix allowed individual railroads to modify operating techniques put forth in the interim guidelines to fit their own particular circumstances, before adopting those techniques.

Models and Testing

To further design improvements and to optimize train handling techniques, several task groups worked on the creation of models of train behavior and on tests to obtain data and validate these models. Toward this end, the Acceptable Dynamic Train Performance Criteria group worked to determine safety limits for train operation. The group sought to determine the maximum forces that would be permissible under any train handling situation, so that when techniques were tested through the models, their safety could be measured. The Train Performance group considered nine adverse situations that can result from improper handling or makeup. The group then set limits designed to avoid such problems as centerplate separation, wheel lift, train separation, loss or damage to car contents, fatigue damage to components, widening of gage, rail rollover, track shift and wheel climb.

The Mathematical Modeling group developed sophisticated models of the nearly countless number and magnitude of interactions and forces created by train operations. Picturing the train consist as a complex series of springs, shock absorbers, pivot points and bars, the group produced detailed models of individual component interactions present in an entire train. The computerized models permit fast and relatively inexpensive study of situations that could prove dangerous in real-world tests and permit the testing of design changes without costly manufacturing efforts.

The modeling group developed separate models for locomotives; vehicles; locomotive trucks; the three-piece, standard, freight car truck; brakes; cushioning devices; curve entry forces; lateral vertical force ratios; and simulations of lateral and vertical train operations. The group developed several models for train actions and stability, and developed a processing system through which several models could be combined.

Of course, real-world comparisons were required for validation of these computer models, or else their predictability would be questionable. The Component Performance group was assigned the task of testing coupler forces, car and truck components and other train parts. With the use of instrumented trains, the group conducted studies of draft gears, trucks, car and wheel interactions, and oversaw several studies that provided the raw data for model validation.

The Engineering Test Requirements group designed equipment and testing procedures with which to collect field data. Some of the interactions that were to be studied had never been previously explored, nor had equipment been designed that could adequately measure the component and system responses. The result of these efforts led to the validation of a series of models that would be used to enhance equipment design, create new procedures for train makeup and handling, and provide engineering diagnostic capabilities taking into consideration economic factors.

Wide Gage and Harmonic Roll

Two major problems that had been plaguing the railroad industry--widening of gage and harmonic roll--were given special attention by a Special Problems task group. Wide gage and harmonic roll both are major causes of derailments. Even though derailments are not involved, harmonic roll can cause severe damage to components and cargo, and wide gage can cause extreme rail and wheel wear.

The Harmonic Roll sub-group produced a three-volume document which contained instructions for railroad employees on how to recognize evidence of harmonic roll, recommendations for train handling techniques to lessen the severity of the problem and for track maintenance and design standards that lessen the likelihood of harmonic roll occurring. The Wide Gage sub-group issued recommendations on how to avoid the problems found to be inherent in certain types of equipment and handling procedures.

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ILLUSTRATIONS

FOREWORD

Track/train dynamics has been a matter of continuing concern to the railroad industry for many years. The organized, coordinated international research program known as the Track/Train Dynamics Research Program took form in 1971 when the Southern Pacific Transportation Company and the Association of American Railroads, through its Research and Test Department, began preparation of a plan for an orderly scientific examination of these dynamic processes.

Upon completion of the plan in 1972, action was immediately taken to initiate a program. Suppliers, the academic community, and the railroads have participated. Funding has been provided by the Federal Railroad Administration, the Transportation Development Agency of Canada, several supply companies, many railroads, and the Association of American Railroads. Without extensive cooperation, progress could not have been made in many fields and would not have been made as rapidly in any.

The Track/Train Dynamics program has demonstrated the effectiveness of applied research. As a result of these activities, much is now known about the conditions that must exist to ensure stable and safe train operations. Guidelines for train handling have been extensively distributed. Analyses of potentially troublesome car and track have been adopted. Performance standards that can lead to the improvement of new equipment are in the process of being established.

The dissemination of information on this subject requires continuing attention because of the extensive nature of the programs and their relationship to the ongoing railroad operations. Nevertheless, through the intensive efforts of a great many people, railroads and others are utilizing information derived from Track/Train Dynamics research. More can be expected in the future as the research findings are translated into improved practices, equipment and track.

Phase I of the original plans for the Track/Train Dynamics Program was completed. Phase II is mostly completed. Phase III is in progress. Overall, the program is demonstrating the capability of science to provide a strong foundation for safe and effective railroad operations.

Track/Train Dynamics has been a unique demonstration of the power that can be brought to bear on difficult problems through the coordinated and cooperative effort of government and industry.

INTERNATIONAL RESEARCH PROGRAM
ON
TRACK/TRAIN DYNAMICS

PHASE TWO REPORT

Prepared for the Federal Railroad Administration, Railway Progress Institute, Transportation Development Agency of Canada and Association of American Railroads as a summary of the second phase of a ten-year program.

Detailed in this report are the plans and progress of a joint government/industry program which seeks to identify and solve the dynamic problems confronting railroads in North America.

EXECUTIVE SUMMARY
FOR
TRACK TRAIN DYNAMICS
PHASE II OVERVIEW REPORT

The major objective of Phase II of Track/Train Dynamics was to perform research which would lead toward the development of performance specifications. This report reviews some of this research to promote a better understanding of how the various elements were to be incorporated into performance requirements for track and equipment.

To establish performance requirements, certain basic information was needed, e.g.:

1. Load environment
2. Definition of analytical prediction method or test method
3. Items 1 and 2 are used to establish ranges of performance (parametric study)
4. Performance criteria defined and applied to results of parametric study to establish performance specifications

Phase II was organized into eleven tasks, as follows:

1. Track Structures
2. Wheel/Rail Systems
3. Track and Suspension
4. Car Structures
5. Couplers, Yokes, Draft Gear and Cushion Units
6. Brake System

7. Test Management
8. Program Analysis
9. Advanced Analytical Techniques
10. Special Project - Locomotives
11. FAST Project

Track Structures

The Track Structures Task conducted research in areas primarily related to safety of operation, i.e. avoidance of conditions related to derailment. For example, experiments conducted early in the program revealed that build-up of rail longitudinal forces due to temperature changes could significantly reduce the amount of force required to overturn the rail. The data thus supported what many investigators had concluded from intuition.

Conditions which could lead to yard derailments at slow speed were revealed through the Quasi-Static Lateral Train Stability "QLTS" study. Here it was found that certain practical car combinations could not safely negotiate reverse curves of 14 degrees or greater regardless of tangent length between those curves. Also, it was found that some extreme long car/short car combinations should not be run over reverse curves of 10 degrees or greater.

Wheel/Rail Systems

The Wheel/Rail Task expended a considerable amount of effort in developing a means for assessing the effects of rail flaws. This resulted in development of a fracture mechanics model for transverse railhead defects such as detail fractures from shell. The model shows strong agreement between calculated and measured failure loads for loads of less than 200,000 lbs. and crack depths of more than 0.35 inches. The model was then used to predict stress intensity factors for a variety of stress states. A follow-on to this latter effort allows the development of a strategy for reducing rail defects and subsequent failure through selective use of special rail, control of stress in operations, improved inspection, and improved maintenance.

Rail metallurgy studies via a joint AISI/AAR/ARRA study were directed toward ways to improve strength and toughness. Results showed that a few basic, non-drastic changes in composition and microstructure can allow producers to manufacture superior and more reliable rail products.

The wheel research portion of Task II was concerned primarily with developing tools for optimizing wheel designs. Making the basic assumption that reduction of elastic stresses due to changes in loads and temperatures reflects an improvement in performance, a linear elastic finite element computer model was developed. This model is available for the user through the Association of American Railroads.

Trucks and Suspension

The Trucks and Suspension effort had three basic areas of research: bolster fatigue test through the Truck Safety Project, development of truck hunting computer models, and evaluation of rock and roll issues. The Truck Safety Project was successful in developing a test procedure, after having first conducted several thousand miles of tests to determine the load environment. The hunting effort was successful in development of a multi-degree-of-freedom non-linear truck hunting model, with validation data available from tests conducted on the U.P.

The rock-and-roll and bounce investigation involved a very comprehensive parametric study wherein hundreds of various conditions were studied. As an example of the output, for one of the cars used in the study, a truck with D-7 springs and a snubbing force of 4500 lbs. provided optimum performance with standard suspension components. Among other conclusions were: the critical roll speed increases and peak roll angle decreases as track stiffness increases, and reduction of center of gravity height has a very significant effect on roll angle. The comprehensiveness of the parametric study allows an investigator to review almost every combination of car/truck/spring/snubber combination.

Car Structures

The Car Structures area successfully concluded the development of Interim Guidelines on Freight Car Fatigue. The use of the approach outlined in the Interim Guidelines allows prediction of the life of the critical areas of the structure.

Couplers, Yokes, Draft Gear and Cushion Units

The Couplers, Yokes, Draft Gear and Cushion Units Task, through the Coupler Safety Project, developed recommendations for the mileage at which F-butts cast prior to 1970 should be removed from service. Service tests run to determine load environment covered more than 30,000 miles. Data was used to develop the coupler load environment.

On the cushion unit area, tests conducted with a special car subjected to impacts allowed for dynamic characterization of such units in both buff and draft. These data were then used in conjunction with the Detailed Train Action Model to analytically study unit train handling issues.

Special Project - Locomotives

Locomotive Research was predominantly involved with mathematical model development and testing necessary to validate such models. Testing also was conducted on 4 and 6-axle locomotives owned by AMTRAK to determine their respective sensitivities to track conditions. As might be expected, lateral forces were higher during steady state curving for the 6-axle unit. The several thousand miles of tests did reveal that for certain combinations of lateral and vertical rail irregularities, the 6-axle unit did apply more forces on the rail, although not necessarily to an unsafe degree for properly maintained track.

FAST Project

Experience with the FAST Project at Pueblo revealed a number of facts which are only now becoming available. However, early experience with a particular steel tie revealed unsatisfactory service life. Certain types of rail/tie fasteners were shown to be superior to others. The bearing seal tests provided results which allowed a supplier to upgrade his product. The rail metallurgy experiment provided data on performance characteristics of various types of improved rail.

Tasks 1 through 6 related to specific physical components. Tasks 7, 8 and 9 were support functions. Task 10, Special Project--Locomotives, was added in late 1976 to provide a mechanism within Track/Train Dynamics for investigating the comparative tracking performance of four and six-axle locomotives. The study concentrated on investigating the dynamic performance of the E8 and SDP 40 locomotives.

The FAST Project was added in 1977, to allow the Track/Train Dynamics Steering Committee to oversee the research at Pueblo. FAST (Facility for Accelerated Service Testing) was designed as a cooperative project to be conducted at the DOT Transportation Test Center at Pueblo, Colorado.

Also incorporated into the Phase II effort were two existing cooperative research programs. The Coupler Safety Project was incorporated into Task V (Couplers, Yokes, Draft Gear and Cushion Units). The Truck Safety Project was brought within the Trucks and Suspension Task.

The results of Phase II can be measured in several ways. Since the charter for TTD-II was the development of specifications, it is logical initially to look to this area for results. However, it should be understood that the AAR Mechanical Division, through its standing committee process, has the responsibility for issuing AAR freight car specifications. The Track/Train Dynamics Project, through association with the AAR Research and Test Department, developed "Guidelines" for review and possible adoption as AAR freight car specifications. To date, four "Guidelines" (or proposed revisions of existing specifications) have been developed. These are concerned with:

a. Coupler and Yokes Test Guidelines
b. Truck Bolster Test Guideline
c. Wheel Design Qualification Guideline
d. Freight Car Fatigue Analysis Guideline

Reference to the list of Track/Train Dynamics publications, available through the AAR Chicago Technical Center, will allow the interested reader to learn more about particular areas.

PHASE II

PROGRAM PLANNING

Task Organization

Detailed program planning for Phase II was begun in the fall of 1974. Dr. D. R. Sutliff, on loan to the AAR from the AMCAR Division of ACF Industries Incorporated, was appointed director. Dr. G. C. Martin and K. L. Hawthorne, the AAR's managers of dynamics research and safety research, respectively, were assigned as deputy directors. Later, Dr. V. K. Garg and J. R. Lundgren, the AAR's managers of dynamics research and track structures, respectively, also were appointed Deputy Directors.

Planning for the Phase II program was directed at identifying issues pertinent to development of performance specifications for track structures, rolling stock, and components. As the various areas of research were determined, detailed task descriptions were developed in the form of flow charts for each task. These charts were then used to prioritize the various activities of each task.

Figure 1 shows the general task organization for Phase II. Note that the tasks were grouped into those which were directed at hardware issues and those whose purpose was to provide technical support.

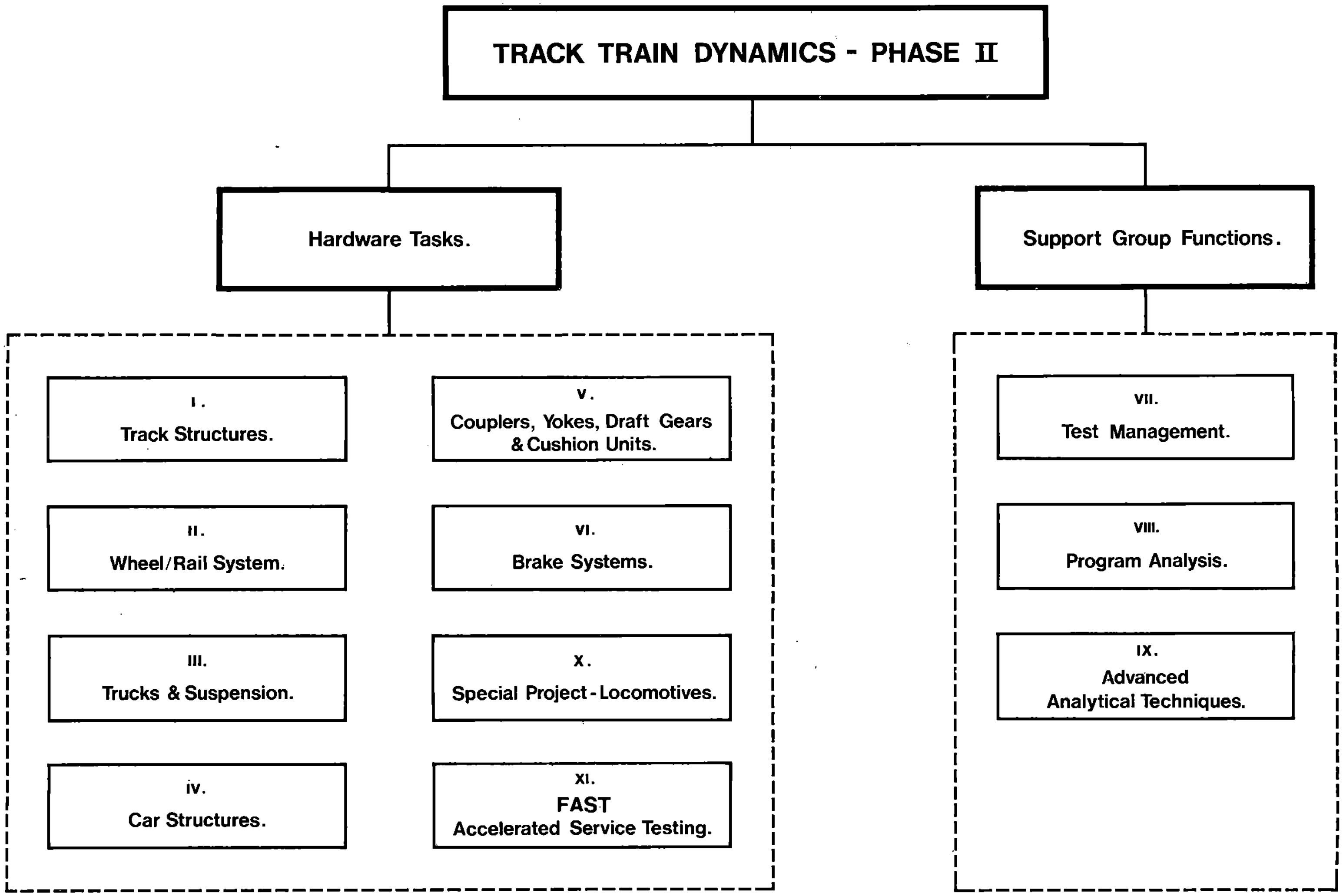


FIG. 1

TASK ORGANIZATION

Figure 2 is a further breakdown into key research elements of the various tasks. It should be noted that tasks X and XI were added to the project in 1975 and 1976, respectively.

Having developed the detailed descriptions of the various tasks, descriptions of the necessary personnel and man-months required were completed.

Further Task Description

The Phase I effort, completed early in 1976, provided methods of study for succeeding tasks and recommended interim guidelines for operations with existing equipment. The Phase II effort included development of performance specifications for new equipment, with priority given to the component systems having the highest failure rates.

That equipment specifications must constantly be improved need not be explained. Train handling and makeup techniques can only ameliorate the interactions that produce wear, damage and accidents, but cannot completely eliminate those problems that are inherent in specific system designs.

The need for new equipment design is particularly intense when considered in light of changing patterns within the railroad industry. Trains are longer and heavier than in years past and changes in the type of freight carried have spurred development of new types of cars. Speeds and

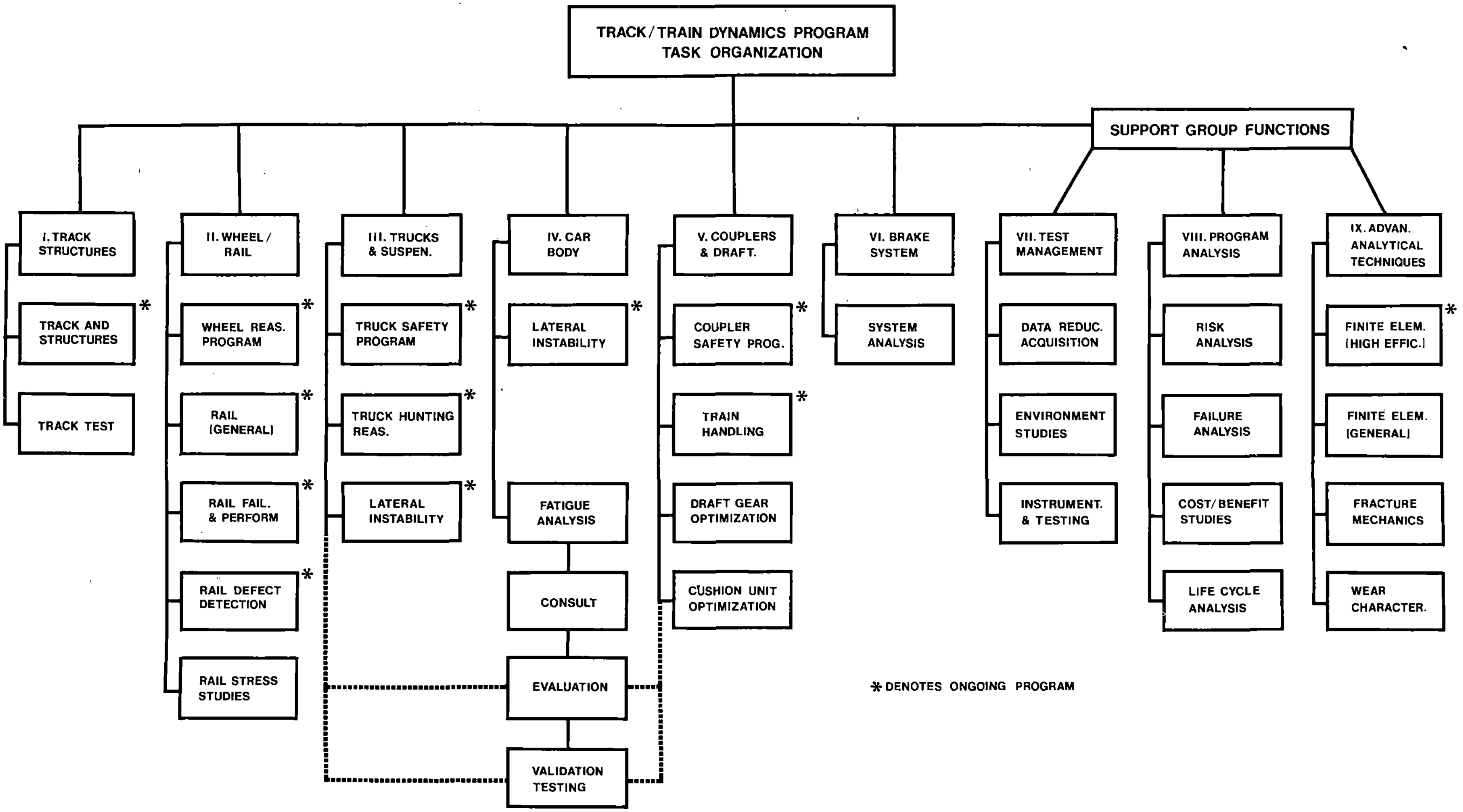


FIG. 2

BREAKDOWN OF TASK ORGANIZATION

axle loads have also increased.

New demands, new services, changing operating techniques, and other new factors all require that new equipment designs be developed. In Phase II, studies of key components and systems were conducted in an effort to develop specifications that must be met in future production if equipment is to fulfill the new demands being placed on the railroad industry.

As these new specifications are implemented into equipment design and the designs become part of rolling stock, savings can be expected in maintenance, damage to cargo, wear and damage of components, accidents and other areas.

The Phase II equipment studies were divided among eight "hardware" task groups, with three more task groups fulfilling support functions for the program. The result has been an intensive study of individual components and component systems that retained the perspective of the entire system.

Phase II included detailed studies of track structures, wheel/rail contact, trucks and suspension systems, car bodies, coupling systems, brake systems and locomotives. In addition, special wear and fatigue tests were planned and implemented at the new Facility for Accelerated Service Testing at the U.S. Department of Transportation's Test Center at Pueblo, Colorado.

The three support groups fulfilled the functions of test management, program analysis and development of analytical study techniques.

Each of the eleven tasks included in Phase II will be discussed in detail in later sections. But an overview is helpful to the understanding of the specific tasks and their relation to the total Phase II effort. The following are brief descriptions of the individual tasks, as they were designed, and their relationships with other studies.

HARDWARE TASKS

Task I. Track Structures

The track, like any foundation, is critical to the performance of the equipment operating on the structures. The best of equipment cannot operate very effectively on poor track, although well-designed and constructed track can help to alleviate the problems. The Track Structures group developed guidelines for track performance evaluation, designed to ensure that both the components and the track structures as a whole perform adequately. The research program was designed to ensure both structural integrity and acceptable track/vehicle behavior.

Task II. Wheel/Rail System

Increased train speeds and wheel loadings have intensified the dynamic interactions between wheel and rail, necessitating new performance standards for both wheels and rail. Because of the importance of this interrelationship, it was determined that the wheel/rail system merited special study.

Task III. Trucks and Suspension

In constructing the track/train system from the track structure to the wheel, the truck and suspension system is next in line for consideration. As with the track structures study, the truck study focused both on specifications for the individual truck components and on standards for the truck dynamic systems.

The RPI-AAR Truck Safety Project was included within this effort. This activity, directed by Robert A. Evans of American Steel Foundries, is a research program to develop means for improving truck bolster performance. It was brought within the Track/Train Dynamics effort, although it has continued to function as a self-contained research program.

Task IV. Car Body

The next major part to be added in the chain is the car body, an increasingly important structure in light of demands for new car design and current problems. The study of car bodies was designed to place greater emphasis on dynamic interactions between the truck and suspension system and lading, as opposed to the existing static standards. Thus, a Fatigue Analysis Guideline has been developed.

Task V. Couplers, Yokes, Draft Gears and Cushion Units

With research directed literally from the ground up, attention was also required to study the longitudinal environment. Cars interact both with the track and with each other, through coupler interface systems. The couplers and draft gears absorb and transmit longitudinal forces through the train, and act as links during curve negotiation. This task included two major efforts: development of metallurgical standards for couplers and yokes and generation of performance criteria for draft gears and cushioning units.

As in the case of the truck study, an already existing research project, called the RPI-AAR Coupler Safety Project, was absorbed by the Track/Train Dynamics Program. The Coupler Safety Project is an AAR/RPI joint effort to develop test performance guidelines for couplers and yokes. It is directed by Norman Morella of National Castings, Division of Midland-Ross Corp.

Task VI. Brake Systems

Like the coupler, the brake system is an integral function controlling the longitudinal environment. The Brake Systems group first determined the effects of various brake system parameters on train performance; then developed information on brake shoe characteristics and their effects on train performance.

Task X. Locomotive Study

Task X, the Locomotive Study, is mentioned out of sequence because, although it was added after the Phase II effort began, its proper place is with the other component system studies. The special study was designed to consider differences between the derailment tendencies of four-axle and six-axle locomotives. Extensive field tests were conducted to develop knowledge of locomotive/car/track interactions. Support also was given to FRA research in this area.

Task XI. Facility for Accelerated Service Testing

The need for real-world testing is crucial to implementation of any new design or technique, but testing in revenue service is neither an efficient nor a thoroughly reliable means of obtaining data. When the U. S. Department of Transportation was ready to develop a new "FAST" track at its Transportation Test Center at Pueblo, Colorado, planning and coordination of that project became an added task under Phase II. The FAST Track, dedicated in August, 1976, is providing detailed information on equipment and track wear through continued operations of a 10,000 ton train over the 4.8-mile test loop.

SUPPORT GROUPS

Task VII. Test Management

Massive testing efforts that were a part of various component studies were completed quickly and efficiently as a result of the Test Management group's activities. The management group helped individual task groups develop test procedures, defined test parameters for tests, analyzed data and coordinated task efforts.

Task VIII. Program Analysis

With a dynamic system as complex as a train, the number of possible studies is seemingly endless. Yet only a relatively small number of these studies can be undertaken economically. The Program Analysis group helped set the priorities for system studies and developed techniques. This task group also was responsible for ensuring statistical validity of field test programs. This activity was most evident in designing the Freight Equipment Environmental Sampling Test (FEEST) performed under Tasks IV and VII.

Task IX. Advanced Analytical Techniques

The Phase II study efforts touched upon a certain amount of virgin soil, which meant that better methods had yet to be devised. The Advanced Analytical Techniques group worked to consider new or more advanced types of analysis that might provide assistance to the other task groups.

Summary

Thus, the Phase II effort has produced design guidelines to improve the performance of individual components and component systems, while developing new study and analysis techniques. Phase II Program was also instrumental in implementing a test track loop that will be a constant source of data for future studies.

Individual guidelines for wheels, truck bolsters, couplers and car structures have been furnished to the AAR Mechanical Division for their incorporation into freight car specifications.

Program Cost Estimates

In budgeting for the project, a total dollar estimate of $5,350,000 was projected. Since the budget was to be made up of contributed personnel as well as donated funds, a value of $3,000 was assigned to the value of each contributed man-month. The cost of the effort originally was intended to be split roughly equally among the FRA, RPI, railroads and AAR.

Personnel

Having developed the task descriptions, flow charts, costs, and manpower estimates, detailed job descriptions were prepared to describe the types of people necessary to staff the various tasks. These descriptions were circulated within the industry.

Publications - Track/Train Dynamics

The following chapters describe the activities of the various tasks of Track/Train Dynamics, Phase II. Obviously, in this one book, the activities of eleven tasks cannot be described in detail. The interested reader can obtain further information on publications of the Track/Train Dynamics Program by writing Mr. J. G. Britton, Director of AAR Chicago Technical Center, 3140 South Federal, Chicago, Illinois 60616, and requesting a TTD Publications List.

PHASE II MANAGEMENT

DIRECTORS:

Dr. D. R. Sutliff ACF Industries	1974 -- 1977
K. L. Hawthorne AAR	1978 -- To present

DEPUTY DIRECTORS:

Dr. G. C. Martin AAR	1974 -- 1977
K. L. Hawthorne AAR	1974 -- 1977
V. K. Garg AAR	1975 -- 1978
J. R. Lundgren AAR	1975 -- 1978

TASK I -- TRACK STRUCTURES

Managers:

J. R. Lundgren Canadian National Railroad	1974 -- 1975
C. L. Gatton Louisville & Nashville R.R.	1975 -- 1977
Keith Bradley D & RGW R.R.	1977 -- 1978

Deputy Manager:

R. A. Abbott AAR	1976 -- 1978

TASK II -- WHEEL/RAIL SYSTEM

Managers:

W. J. Kucera Griffin Wheel Co.	1975 -- 1977
D. H. Stone AAR	1977 -- 1978

TASK III -- TRUCKS AND SUSPENSION

Managers:

F. Korpics ASF, Inc.	1975 -- 1976
R. B. Love ASF, Inc.	1976 -- 1978

TASK IV -- CAR STRUCTURES

Managers:

P. G. Pryzbylinski Pullman Standard	1975 -- 1976
S. P. Halcomb ACF Industries	1976 -- 1978

Deputy Manager:

Dr. A. L. Zarembski AAR	1976 -- 1978

TASK V -- COUPLERS, DRAFT GEAR, AND CUSHION UNITS

Managers:

Tom Brown McConway-Torley	1975 -- 1976
N. M. Morella National Castings	1975 -- 1976

Deputy Manager (Cushion Units):

Mark Scott WKM Valve, Inc.	1976 -- 1978

TASK VI -- BRAKE SYSTEMS

Manager:

Gerry Misner AAR	1975 -- 1978

TASK VII -- TEST MANAGEMENT

Manager:

N. J. Darien AAR	1975 -- 1978

TASK VIII -- PROGRAM ANALYSIS

Managers:

Raj Saroop AAR	1975 -- 1977
W. R. McGovern AAR	1977 -- 1978

TASK IX -- ADVANCED ANALYTICAL TECHNIQUES

Manager:

Dr. G. J. Moyar Brenco, Inc.	1975 -- 1978

TASK X -- SPECIAL PROJECT - LOCOMOTIVES

Managers:

E. C. Polk Penn Central Transportation Co.	1975 -- 1976
E. F. Lind Southern Pacific Transportation Co.	1976 -- 1978

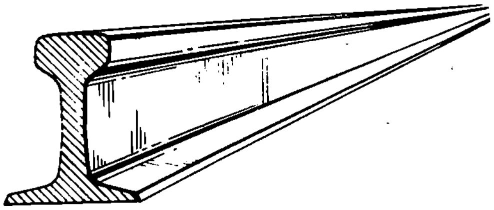
TASK XI -- FACILITY FOR ACCELERATED SERVICE TESTING (FAST)

Managers:

J. R. Lundgren AAR	1976 -- 1977
Sergei Guins AAR	1977 -- 1978

TASK I

TRACK STRUCTURES



The Phase II research effort was aimed at improving railroad performance and specifications literally from the ground up, beginning with the track structure itself.

The track is the first requirement of any railroad, the medium by which all goods are transported. It is the first component to be constructed, requires continual maintenance, and it affects every piece of equipment that passes over it.

Benefits to be derived from improving the quality of track structures will accrue in both the costs and time required to maintain the track itself and in the safety and performance of the equipment that negotiates that track.

The Track Structures task group was assigned to develop a program leading to improved or new performance specifications for individual track components and for the track structure as a system.

Because of economic considerations, this study was limited to conventional track component types and excluded any studies of such auxiliary items as trackside engineering facilities, signalling equipment, etc.

Track Geometry

Track may be straight or curved, superelevated or flat -- and the alignment of constructed track can provide specific problems for train performance.

The Track Structures study included a detailed evaluation of those track geometries which are compatible with common car combinations and operating conditions. The geometric study involved extensive use of a model developed during Phase I: the Quasi-Static Lateral Train Stability Model (QLTS).

The study group considered the entry of four car combinations into curves of varying degrees and with varying amounts of spiral footage and superelevation. Specifically, combinations of long car/long car, long car/medium-long car, long car/medium-short car, and long car/short car were run through five curves with and without spirals.

A report titled Minimum Tangent Length between Reverse Curves for Slow Speed Operation was finalized in October, 1976. This technical report utilized the QLTS model to evaluate the need for tangent between reverse curves in yard (involving slow speed without superelevation in curves) operations.

Prior to the completion of the QLTS model, both the Association of American Railroads and the Southern Railway had conducted their own studies of minimum tangent length requirements. The studies had utilized different equipment and had come up with varying, though not necessarily conflicting, results.

The QLTS model yielded recommendations for tangent lengths for slow speed operation. Figure 3 indicates the recommended tangent lengths between reverse curves for slow speed operation, without superelevation, as estimated by the AAR and Southern Railway, along with data on the equipment used and the environments in which the tests were conducted.

Briefly, the QLTS study concluded that certain car combinations could not safely negotiate reverse curves of 14 degrees or higher, regardless of tangent length, and that extreme long car/short car combinations should not be run over reverse curves of 10 degrees or more, although recommended tangent lengths could make such curves safe for less critical consists. For reverse curves of 6 degrees or less, no tangent was required, according to the QLTS study.

The QLTS model was modified to include a projection of the critical speed for train operations under given conditions. This addition became extremely valuable in studying track geometries related to high-speed operations.

In addition to the minimum tangent length study, the Track Geometry study included research into simple curve

FIG. 3

RECOMMENDED TANGENT LENGTH BETWEEN REVERSE CURVES

Degree of Reverse Curves	A. A. R. Study	Southern Railway Study
Under 6 degree	0′	0′
6 degree	0′	20′
7 degree	0′	30′
8 degree	10′	40′
9 degree	20′	60′
10 degree	30′	70′
11 degree	40′	70′
12 degree	50′	70′
13 degree	60′	70′
14 degree	70′	70′
15 degree	70′	70′

entries with and without spirals and superelevation, and reverse curve entry with both spirals and superelevation.

Track Irregularities

Curve entry is generally more demanding of equipment than negotiation of straight track, but irregularities of tangent track also can lead to serious difficulties, including severe harmonic roll. In a sub-study of the Track Structures research, the Flexible Body Vehicle Model (FBV) was used to evaluate the effects of several irregulatities on train operations.

Specifically, the group studied six levels of alignment error, six levels of profile error, four levels of gage error, and four levels of warp, as shown in Figure 4.

The Flexible Car Body Model (FCB) was modified to consider lateral and vertical track irregularities. After validation efforts provided confidence in the results of the revised model, the investigation of track irregularities continued.

Three typical railway vehicles -- a 40-foot, 50-ton boxcar; a 50-foot, 70-ton boxcar; and an 89-foot, 70-ton flat car -- were selected for simulation studies. Figure 4 shows the various deviations investigated at various operating speeds. Also studied were several combinations of different types of track irregularities and their com-

FIG. 4

TRACK DEVIATION STUDY FOR VARIOUS SPEEDS

Track Geometry

Operating speed for freight trains for a given class of track as per FRA standards is as follows:

Class of Track	Operating Speed for Freight Trains
1	10 mph
2	25 mph
3	40 mph
4	60 mph
5	80 mph
6	110 mph

Track deviations (vertical and/or lateral) as per FRA track standards, TTD-Pase II - Task I 1.1.1 (b) and recommended study are as follows: —

(1) Profile deviation

Class of Track	Profile deviation			
1	3″	*	⊛	
2	2-3/4″	*	⊛	
3	2-1/4″	*	⊛	**
4	2″	*	⊛	**
5	1-1/4″	*	⊛	**
6	1/2″	*	⊛	**

---

* — suggested levels by FRA standards

⊛ — suggested levels by TTD-Phase II-Task I - 1.1.1. (b)

** — suggested levels for study

(2) Gage Deviation

Class of Track	Min.	Max.	Deviation (+)	Deviation (-)	
			(Standard Gage — 4' 8½")		
1	4' 8"	4'-9¾"	1¼"	½"	* ⊛ **
2	4' 8"	4'-9½"	1"	½"	*
3	4' 8"	4'-9½"	1"	½"	* ⊛ **
4	4' 8"	4'-9¼"	¾"	½"	* ⊛ **
5	4' 8"	4'-9"	½"	½"	* ⊛ **
6	4' 8"	4'-8¾"	¼"	½"	*

(3) Alignment deviation

Class of Track	Alignment deviation
1	5" * ⊛
2	3" * ⊛
3	1-¾" * ⊛ **
4	1-½" * ⊛ **
5	¾" * ⊛ **
6	½" * ⊛ **

(4) Warp Deviation

Class of Track	Warp Deviation
1	3" * 4" ⊛
2	2" *
3	1-¾" * 3" ⊛
4	1-¼" * 2" ⊛ **
5	1" * 1" ⊛ **
6	⅝" *

---

* — SUGGESTED LEVELS BY FRA STANDARDS

⊛ — SUGGESTED LEVELS BY TTD — PHASE II TASK I

** — SUGGESTED LEVELS FOR STUDY

Combination of errors:

(5) Profile and alignment errors

Class of Track	Profile	Alignment
1	3″	5″ ⊛
2	2¾″	3″ ⊛
3	2¼″	1¾″ ⊛ **

(6) Profile and Gage error

Class of Track	Profile	Gage
4	2″	¾″ **
5	1¼″	½″ **

(7) Profile, alignment and Gage error

Class of Track	Profile	Alignment	Gage
1	3″	5″	1¼″⊛
2	2-¾″	3″	1″ ⊛
—	2¼″	1¾″	1″ **

(8) Profile, alignment, gage and warp error

Class of Track	Profile	Alignment	Gage	Warp
3	2½″	1¾″	1″	2″

---

* — suggested levels by FRA standards

⊛— suggested levels by TTD — Phase-II Task-I, 1.1.1.(b)

**— suggested levels for study

bined effect on train performance.

Wayside Data Collection

The Wayside Data Collection program was developed to bring real world input and problems back to the laboratory. It was decided that information would be gathered by instrumenting several sections of revenue track in various parts of the continent and studying the track and vehicle behavior at those locations, through both the instrumented track and a test car. As will be discussed later, the data collection system proved a major stumbling block.

After the geographical areas to be studied were chosen, the Wayside Data Collection group contacted several railroads and received permission to conduct tests on their lines.

The sites chosen, as shown in Figure 5, were as follows:

1. A section of Louisville and Nashville Railroad track between Corbin, Kentucky, and Knoxville, Tennessee, on its main line between Cincinnati and Atlanta. This section, located near the bottom of an 8-mile, 1% compensated grade, contains several 10-degree reverse curves. At this location the L & N had experienced several cases of rapid gage widening. Annual tonnage was recorded as 39,600,000 tons.
2. A section of the Chessie System's main westbound track

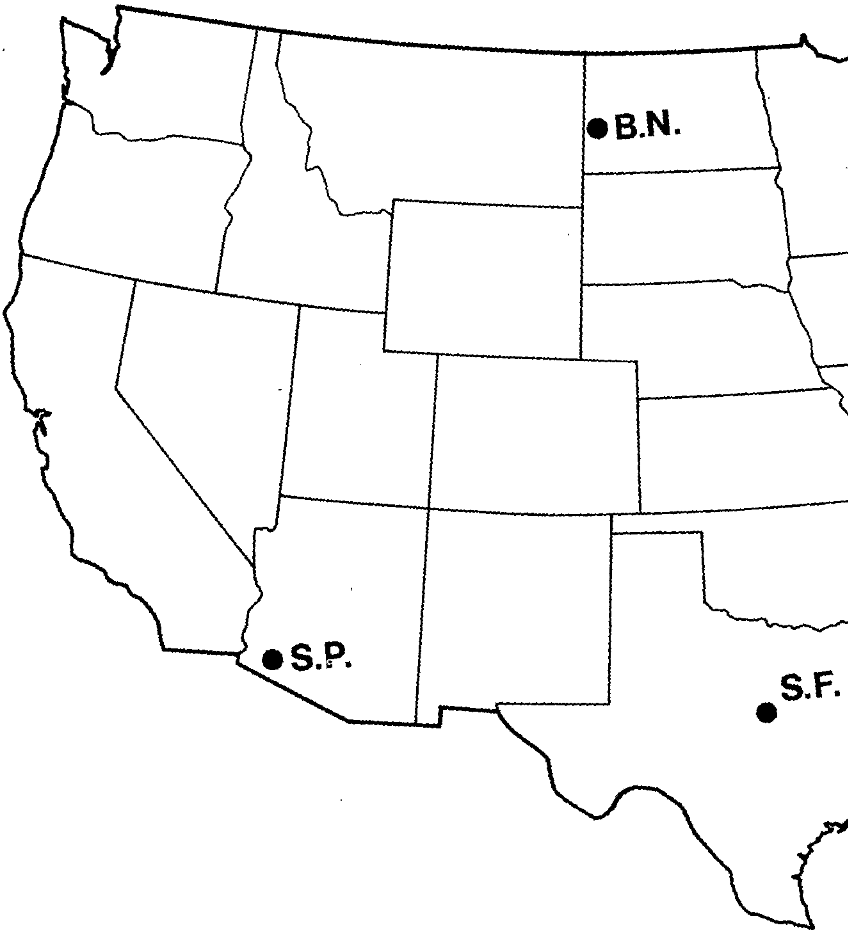
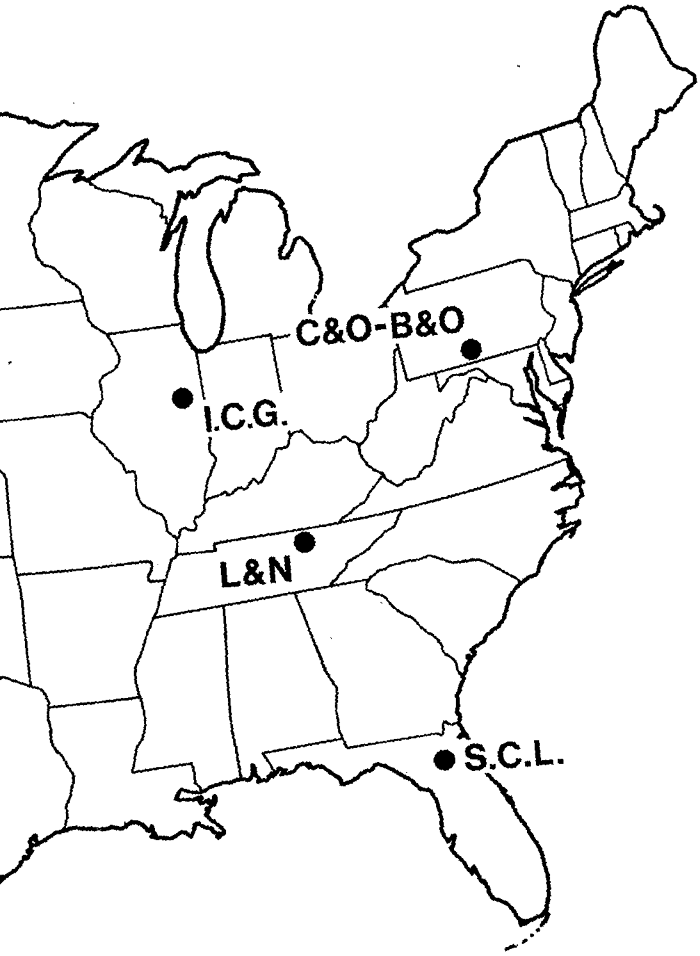


FIG. 5

TEST SITE LOCATION MAP


C&O-B&O
I.C.G.
L&N
S.C.L.

in southwest Pennsylvania, near the top of an 18-mile ascending grade, on an 8-degree curve along the east slope of the Allegheny Mountains between Cumberland, Maryland, and Pittsburgh was selected. Several different dynamic problems had been encountered on the track in this area.

3. The Seaboard Coast Line Railroad gave its permission for study of a site near Hawthorne, Florida, between Baldwin and Wildwood. No unusual problems had been reported at the site, but it was a desirable test site because it consisted of high speed, level, tangent track. It was, basically, the control track for this study.

4. An extremely cold location also was sought for testing and the Burlington Northern agreed to allow testing on its track between Bismarck and Fryburg, North Dakota. It was the third curved section of track in the study.

5. The Santa Fe furnished a tangent track site on a 1.3% grade near Lampasas, Texas. This was also one of the two Santa Fe track sites utilized as part of the field testing program to help validate vehicle response models. As was the case with the Seaboard Coast Line track, this section was an example of tangent track, although the Santa Fe track was on a grade.

6. The Illinois Central-Gulf Railroad supplied a section of tangent track 35 miles south of Chicago, near Monee, Illinois. Because of differences in traffic mixes, densities

and climatic conditions, this site was compared with the Seaboard Coast Line section.

The Association of American Railroads purchased a motor home, shown in Figure 6, for transporting and housing a data collection system for the tests. An engineering position was established within the AAR to aid in the collection and analysis of the data obtained from the tests. A major area of interest in the Wayside Data Collection program was the effect of seasonal changes on track performance. The monitoring schedule was set up so that the track sites would be studied during each of the four seasons, keeping the mobile data van on the road continuously. (Because of limited climatic changes at the Seaboard Coast Line and Santa Fe sites, these sites were to be monitored only twice.)

The data van was equipped with a digital data collection system. This system was selected after reviewing several different approaches to recording the data. It consisted of a Data General 210 minicomputer, disc drive, digital tape recorder, and unique hardware and software proprietary to the manufacturer. Communication with the system was provided via a teletype terminal.

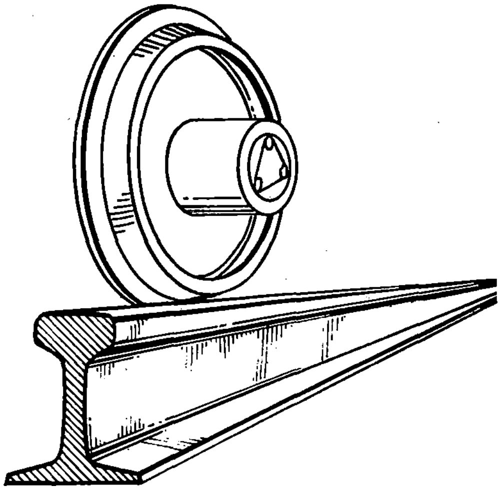
After trying to debug the basic system, attempts were made to use it at some track sites. The system proved very unreliable, to the extent that it was returned to the manu-

FIG. 6

MOBILE HOME DATA COLLECTION SYSTEM

facturer for modification of the problems. This proved unsatisfactory, and due to severe schedule disruptions, a decision was made by Track/Train Dynamics management in the fall of 1978 to cancel the effort.

A review of the overall track data collection effort showed that the basic techniques for Wayside instrumentation were reliable in the electronics sense. Nevertheless, some of the gaging approaches prove to be unreliable. In addition, the gages applied directly to the ties continued to work better than expected.



TASK II

WHEEL/RAIL RESEARCH

The most crucial dynamic interaction site in the operation of a train is the few square inches of contact between the rail and the wheels.

It is in that contact that conditions leading to wheel climb, rollover or wide gage are developed, and that track irregularities are transmitted into hunting, harmonic roll or bounce.

The trend toward heavier cars, longer trains and higher speeds places increased burdens on the wheel/rail contact, increasing the probability and severity of undesired interactions. Thus, the wheel and rail together make up a critical system of dynamic interactions. The Phase II effort included a major study of that system.

The goal of this study: to create performance standards for rail and performance standards for wheels that complement each other in such a way as to provide acceptable performance of the wheel/rail system.

Because of the importance of that system, it was not surprising that several studies were already on-going at the

AAR Technical Center. Those studies quickly became part of the Track/Train Dynamics program, under the coordination and direction of the Wheel/Rail Research team.

At the time the Phase II Wheel/Rail effort began, the Association of American Railroads already was involved in an effort called the Wheel Research Project. The project investigated problems which caused cracked and broken wheels.

Under the Wheel Research Project, the AAR reviewed Wheel failure problems and developed an analytical technique for calculating wheel stresses, using various vertical loads, brake application, changes in temperature and other conditions. The AAR study was concerned particularly with detecting heat damage in wheels and predicting thermal fatigue occurrences. It also involved development of methods to detect cracks and develop standards for the maximum crack size.

Under the Phase II research effort, the Wheel/Rail group was assigned the task of identifying the problems and criteria to be used to justify development of performance and design specifications and investigating solutions for wheel and rail failure and excessive wear.

Toward that end, the Wheel/Rail task group was directed to determine the service environment of the wheel/rail system and analyze the design and metallurgical properties of existing wheel and rail.

Resulting from this study were performance specifications and design guidelines for the wheel and a methodology which should eventually lead to a decrease in derailments through broken rails.

Wheel Research

The first step in wheel research was the study of existing data, to determine the key problems to be solved and to set priorities for the study.

After completing that effort, the wheel research team began studying wheel contours of various manufacturers to determine the stress levels experienced by different contours under similar conditions, studied the properties of the steel used in existing wheels, considered the impact of seasonal changes on wheel failure, determined the problem of loose wheels, and studied the metallurgical properties of wheels involved in various types of failure incidents.

A contract was given to Battelle Columbus Laboratories for development and validation of an elastic wheel stress model. The model developed under that contract has been incorporated into the AAR's computer system and also into a recommended performance guideline for specifications.

Battelle's model development study focused on the CH-36 wheel, but the elastic, finite-element stress model created is capable of analyzing any common railroad wheel configuration. Besides the CH-36, the model was used further to study H-36, J-36 and CJ-36 wheels. By comparing new and condemning profiles of those wheels and analyzing the stress distribution, the model helped determine the effect of rim thickness on the distribution of stresses throughout the wheel.

The knowledge of stress distribution patterns and intensity is crucial in the wheel research effort. The use of that knowledge makes it possible to predict the loads that can lead to initiation or propagation of flaws and cracks and the rim thicknesses that are unacceptable for future service use.

The Battelle report, Wheel Research Volume I, described studies of heat transfer, elastic finite-element stress and contact stress in rail car wheels.

The heat transfer study was concerned with the stresses of braking, when wheel/rail friction can raise temperature hundreds of degrees. Induction coil tests by Griffin Wheel Company and instrumented braking tests on the Santa Fe system were utilized to validate and adjust the model. The two-dimensional, axisymmetrical model predicts the temperatures reached in various sections of the wheel (heat transfer) during braking, acceleration, or normal operations. Figure 7 shows the breakdown of the wheel into graphic sections for the heat transfer study.

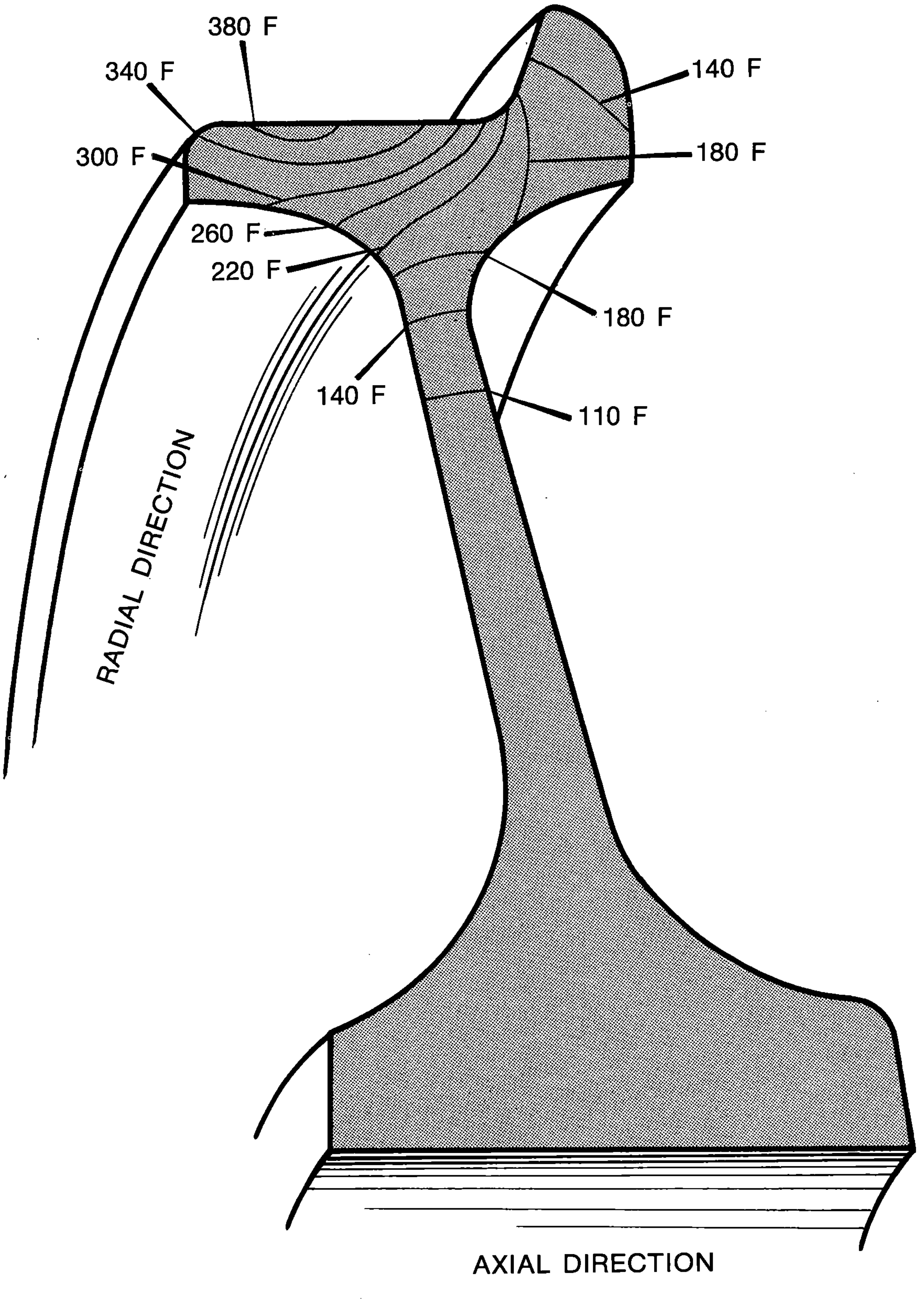


FIG. 7

BREAKDOWN OF WHEEL FOR HEAT TRANSFER STUDY

The elastic-finite-element stress analysis study utilized a three-dimensional model to study mechanical loads on different portions of the wheel. It was observed, as might be expected, that rim loads are most serious and, that in many cases thermal stresses are more severe than mechanical stresses during braking.

It is expected that by utilizing the finite-element model and making several reasonable simplifying assumptions, it will be possible to predict the effect of vertical and lateral loads, mechanical and thermal stresses, and combinations of these factors in the initiation and propagation of flaws.

The contact stress analysis focused on the critical interaction of the wheel and rail head, as shown in Figure 8. Under all but the most unusual conditions, the rim stresses due to wheel/rail contact are the most severe that the wheel must encounter.

The contact stress study included projections of the elastic contact stress distributions for a wheel load of 19,000 pounds for 21 combinations of new and worn wheels and rails. Because wheel and rail wear can produce surface contours that vary at different contact lines, the use of two new computer codes was required for the study of worn components.

It was found that stresses in what was the crown of a

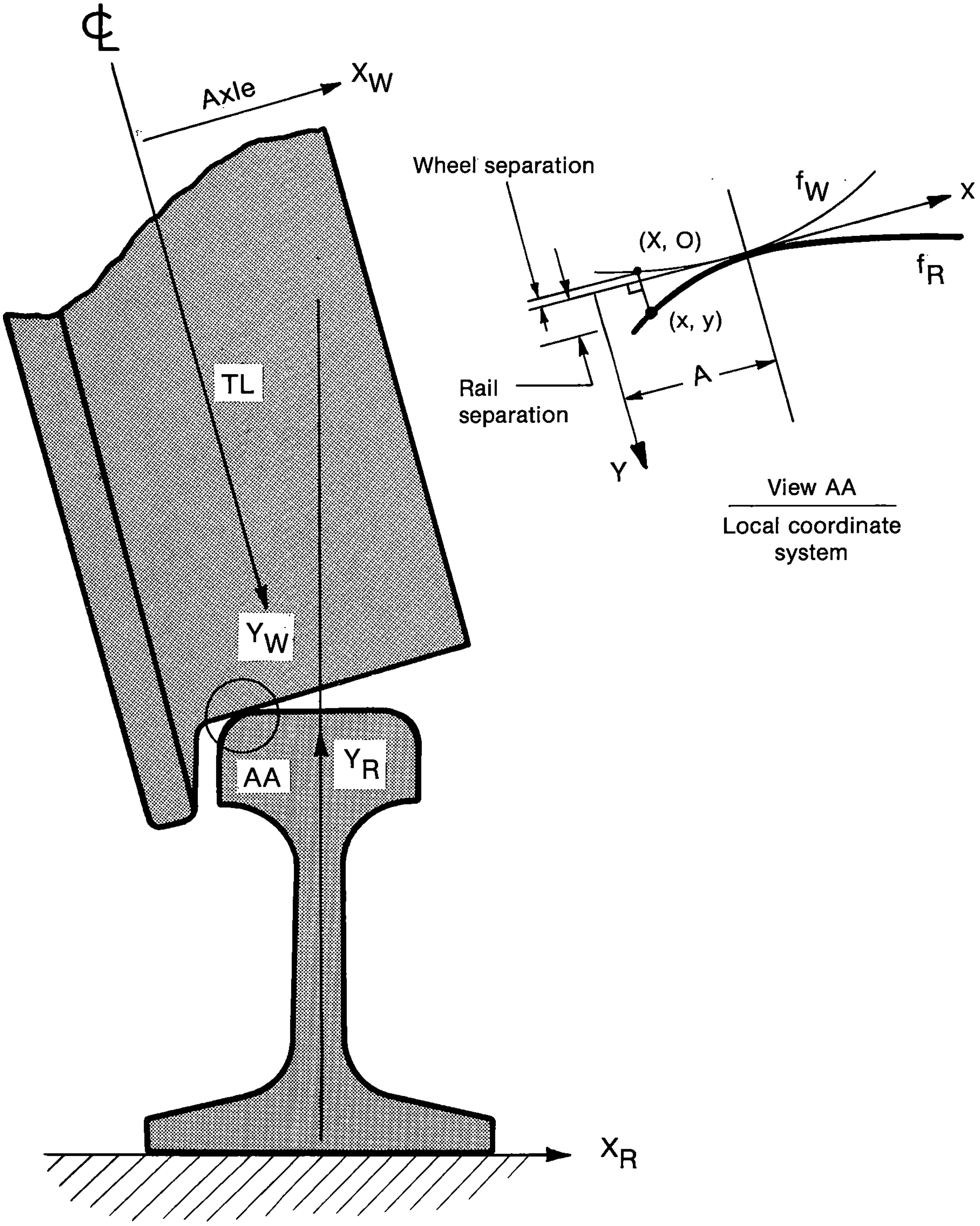


FIG. 8

WHEEL FLANGE/RAILHEAD INTERACTION

now-worn rail are decreased significantly from those in a new rail when new wheels are used, but are either not changed or increased significantly when old worn wheels are used. This is particularly true in instances in which wheel wear has led to a false flange, which leads to severely increased stress.

The results of the Battelle study, as projected by its elastic finite-element model, were in excellent agreement with analytical studies conducted by the Illinois Institute of Technology, University of Illinois and Del Engineering.

Rail Research

If it were possible to accurately predict the point at which worn rail becomes unsafe or begins to cause more damage to wheel, track and car than it would cost for replacement, railroads could take steps to ensure that rail was replaced when needed. Train operation and maintenance costs could then be planned more efficiently.

A contract was given to Failure Analysis Associates of Palo Alto, California, to create a model for rail failure. Specifically, the study of rail head transverse defects was aimed at allowing calculations of remaining rail life under expected loads, given present defects in the rail.

Failure Analysis Associates brought its expertise to bear in the rail failure study by developing a sophisticated model of fracture mechanics for transverse rail head defects.

The fracture mechanics model was specifically designed for the study to aid the task group in determining, through calculation, the remaining life of the rail studied, given the expected loads, extent of current damage, and several other key factors, including the detail fractures which might develop from a shell fracture, as shown in Figure 9. The model was applied to calculate the failure loads of defective or retired rail on the basis of post-fracture measurements obtained in three-point bending tests by the Association of American Railroads. The model then was extended to enable it to predict the fatigue performance of defective rails still in service.

The AAR selected 71 rail sections, which had been rejected during an inspection by a Sperry Railcar, for use in three-point bending tests. The 37-inch rail sections were tagged for age, life tonnage, time since last inspection, tie, ballast and road conditions, fracture plane and failure load.

In addition, dynamic fracture toughness tests were performed on two pre-cracked Charpy specimens from each rail, generating both dynamic and static fracture toughness values. The static values were compared with the AAR's three-point values, which are considered at best to be quasi-static.

The model developed by Failure Analysis Associates

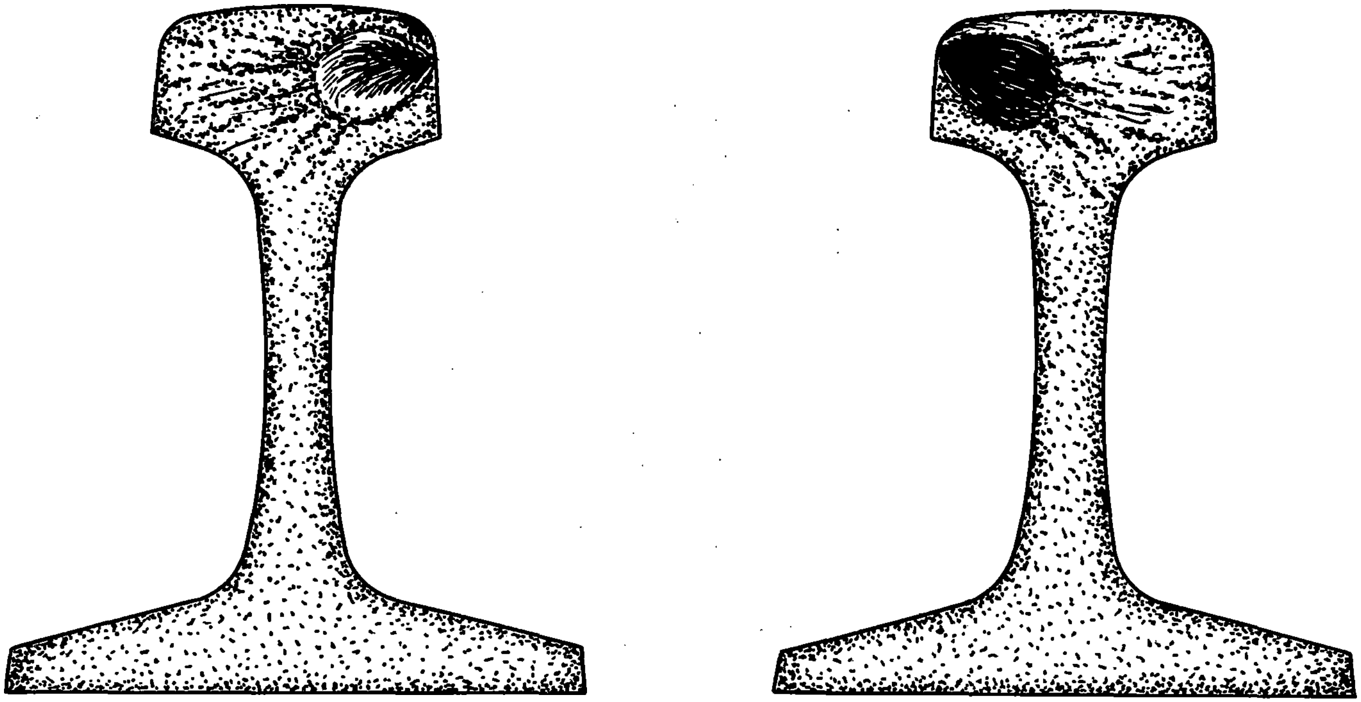


FIG. 9

DETAIL FRACTURES FROM SHELL

shows strong agreement between the calculated and measured failure loads for loads of less than 190-200 kips and crack depths of more than .35 inches. For cracks of less than .35 inches, the model predicts failure loads of lesser severity than those detected in actual tests--giving a larger safety margin. The reason for the underestimate of failure load was traced to possible differences in the shapes and smallness of such cracks.

With its accuracy now known, the model was utilized to predict stress intensity factors for a variety of stress states, including pure bending, tensile stress distribution near the wheel/rail contact and shear stress reversal caused by passage of a single wheel over a crack plane.

Of course, in some instances, the effect of wheel passage or the approach of a wheel may be to compress the crack, rather than to spread its growth, so that load values will not be destructive. However, it is important to know the magnitude of these values in calculating failure loads when a combination of stress factors is considered.

As the wheel approaches, passes, and retreats from a crack point, the stresses change from compressive to tensile. Studies with the fracture model indicate that it is this shear stress cycle that is the driving force in propagation of fatigue cracks. It was discerned from the preliminary model study that bending stress had less effect than the shear stress cycle on transverse defect growth, pointing to the direction to take in engineering for specific stress reductions.

Failure Analysis Associates recommended that research and testing be continued to obtain greater predictability for fatigue failure in in-service rail. Following completion of the first modelling effort, which was published as Rail Analysis Volume I, Failure Analysis Associates received a second project contract.

The new project was designed to develop a model for identifying effective means of reducing the impact of defective rail on railroad operations. The new model would refine the fracture mechanics model to include consideration and prediction of the derailment process, inspection (semi-weekly), fracture models for seven defect types, and a usage-based (rather than time-based) definition of nominal rail life.

As inputs, the new model includes material property distribution, defect and stress distribution, inspection uncertainties and cost factors.

With the refined model, it is possible to develop a strategy for reducing rail defects and failure through selective use of special rail, control of stress in operations, improved inspection systems and improved maintenance programs.

Of course, the modeling effort required extensive test data and the rail research effort extended into several other areas, including the physical properties of track and wheel/rail interactions on both continuous and corrugated rail.

Metallurgical Research

There are several ways to improve rail, chief among them being to change the shape or layout and to change the physical properties of the substances which make up the rail itself.

As part of an American Iron and Steel Institute/Association of American Railroads/American Railway Engineering Association research program, defective rail specimens were gathered for study at the United States Steel Laboratory in Monroeville, Pennsylvania. The defective rails were studied in terms of their metallurgical properties, fracture toughness and fatigue crack growth rates. The group's report contained several detailed suggestions for the properties rail should have.

Another investigation into the physical structure of rail was conducted at the University of California at Los Angeles. The UCLA study, titled, "The Effect of Non-Metallic Inclusions and Grain Boundary Ferrite on Fatigue Crack Propagation in Pearlitic Rail Steels," considered crack propagation at various ambient temperatures. The study also included an evaluation of the effects of varying the maximum stress intensity on pearlitic steel rails containing fatigue cracks.

The effects of alloying metals on the strength and toughness of rail steels were studied at the Carnegie Mellon Institute. In the past, studies of eutectoid rail steel showed strength and toughness to be independent properties, with strength varying according to the pearlite interlamellar spacing and toughness related to austenite grain size. The alloying research included in Phase II considered altered percentages of carbon, manganese, silicon and vanadium in rail steels, correlating those differences with changes created in the microstructure in austenite and ferrite grain sizes, pearlite interlamellar spacing and colony size. The resulting change in strength and toughness indicates that a few basic, non-drastic changes in composition and microstructure can allow producers to manufacture superior and more reliable rail products.

Special Rail Structures

The majority of the wheel/rail study effort was directed at common rail and wheel types, as improvements in these systems offer the greatest economic and safety benefits. But two special programs were undertaken to study less common wheel/rail systems--those involving welded rail and those involving corrugated rail.

Dr. Gregory Martin of the AAR and Dr. K. H. Chu of the Illinois Institute of Technology worked with an Illinois Institute of Technology graduate student in developing a method of experimentally determining the distribution of stresses and the residual stress in continuous rail. (A rail stress model was not developed under the Track/Train Dynamics program. Rather, a Battelle model developed under a contract with the FRA was incorporated into the Track/Train Dynamics computer system.) FRA funding also was obtained for the AAR's welded rail study. A contract under way at U. S. Steel at the date of this report is directed toward determining the typical rail residual stresses.

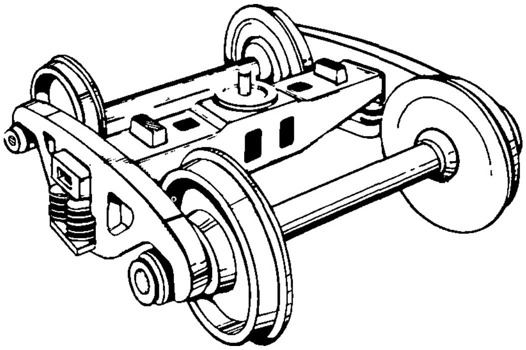
A joint effort by the Track/Train Dynamics program and the National Research Council of Canada involved photographs of wheel/rail interaction on corrugated track. With photographic techniques selected, the test included high-speed photographs of the wheel/rail interface and measurement of axle and accelerations along three axles. The photographic study was conducted in April, 1976, along a section of track in British Columbia.

Abrasion and Wear

The contact between wheel and rail is the interaction that connects the components into a system, and the wear of wheel and rail creates disruptions in that system. In conjunction with Track/Train Dynamics Task IX, under Dr. G. J. Moyar, on loan from Brenco, and Dr. Steven Marich, on loan to the AAR from Broken Hill Proprietary Company, Ltd., Australia, studies were funded at the Illinois Institute of Technology and Clemson University.

At IIT, literature on centerplate/centerbowl wear, the relationship between plastic flow and wear at the wheel/rail contact and the character of worn surfaces was analyzed. At Clemson, laboratory testing apparatus was designed and a study was conducted to enable researchers to predict wear characteristics of the wheel/rail contact under various operating conditions. Much of the input for the studies came from Pueblo, Colorado, where the Facility for Accelerated Service Testing was the site of frequent, controlled occurrences of wear.

The FAST track data also were used for validation of wear models developed at Clemson and IIT which, in turn, provided direction for new measurements and procedures at FAST.



TASK III

TRUCKS AND SUSPENSION

Two dynamic problems provided the objectives for studies in this task: Lateral dynamics interactions with wheel rail contact, more commonly known as hunting; and car rock and bounce associated with track irregularities.

The Trucks and Suspension task group concerned itself with research directed toward performance specifications for both the individual truck and suspension components and the truck-car system as a whole. This led to component test specifications to evaluate fatigue performance of bolsters and system analyses to establish roll and bounce characteristics of typical freight cars.

The Trucks and Suspension task group began its study with several other such studies already under way or completed. One of the group's first jobs, then, was to review material from studies already available and utilize it in the Track/Train Dynamics study.

Among the efforts already available were Phase I studies of truck hunting, curve entry and ride quality, which were under way at Clemson and Arizona State Universities. These efforts, under the direction of Dr. Harry Law of Clemson and Dr. Neil Cooperrider of Arizona State University, were directed toward development of analytical tools for truck performance investigations. AAR support of their program was incorporated into the Phase II Trucks and Suspension effort.

The Southern Pacific's Truck Design Optimization Program, an ongoing effort under contract to the U. S. Department of Transportation, also was utilized as a guidepost and source in this effort.

The studies above were aimed at defining the dynamics for improvement of the truck and suspension system as a whole. Other studies, completed or in progress, also were aimed at improvement of components and were utilized by the Trucks and Suspension group.

Of course, the availability of data and recommendations from so many studies could not eliminate the need for the Trucks and Suspension task, which was concerned with development of new specifications, testing methods, economic evaluations and other matters not covered, or not covered as completely as desired, in the other studies.

The task group was assigned to consider the parameters crucial to problems in harmonic roll and bounce, truck hunting, curve negotiation, and fatigue performance, utilizing data already available and obtaining new data for those questions for which answers had not yet been found.

Among the first jobs for the task group was preparation for the validation of the Truck Hunting Model being developed by Clemson University and Arizona State. Also undertaken were additional parametric studies using the Flexible Car Body Vehicle Model, and validation tests for the AAR's research into auxiliary snubbing device characteristics.

Truck Hunting Model Validation

The original modeling to be validated was that being developed by Drs. Law and Cooperrider. During Phase I, verbal agreement among AAR, FRA, ASU and Clemson had been reached that AAR would supply the test support. This agreement was updated and clarified during Phase II of the program.

During test planning, it was decided that in order to make maximum use of the validation data, the AAR also would develop Truck Lateral Stability models. Thus, the effort furnished validation data to both the Clemson-ASU and AAR models.

To validate the truck hunting model, test runs were conducted near Las Vegas, using the AAR 100 instrumentation car and an 80-ton Louisville and Nashville hopper on both tangent and curved Union Pacific track. The test consist is shown in Figure 10. The test sites were located on the Union Pacific between Las Vegas, Nevada and Barstow, California. The Union Pacific contributed manpower for test vehicle changes and operations. The Test Director for the Union Pacific was Dr. Paul Rhine, Engineer of Tests. N. J. Darien, Task Manager for Test Management of Phase II, was in charge of all Phase II test operations.

The test program involved operating the test vehicle at various speeds up to critical hunting speed on both tangent and curved track in both the light and loaded conditions. Eight different test configurations were used, in various combinations, including: heavy centerplate lubrication, nominal centerplate lubrication, dry centerplate, new AAR profile wheels, CN-'A' profile wheels, rigid truck assembly, and various side bearing preloads.

A unique truck forcer assembly was designed and installed on the test vehicle. This allowed the truck to be rotated and released suddenly to help determine truck rotational damping. Wheel/rail displacements were determined using improved versions of the truck-mounted reference frames utilized during Phase I. The general arrangement and instrumentation of the test vehicle are shown in Figures 11 and 12.

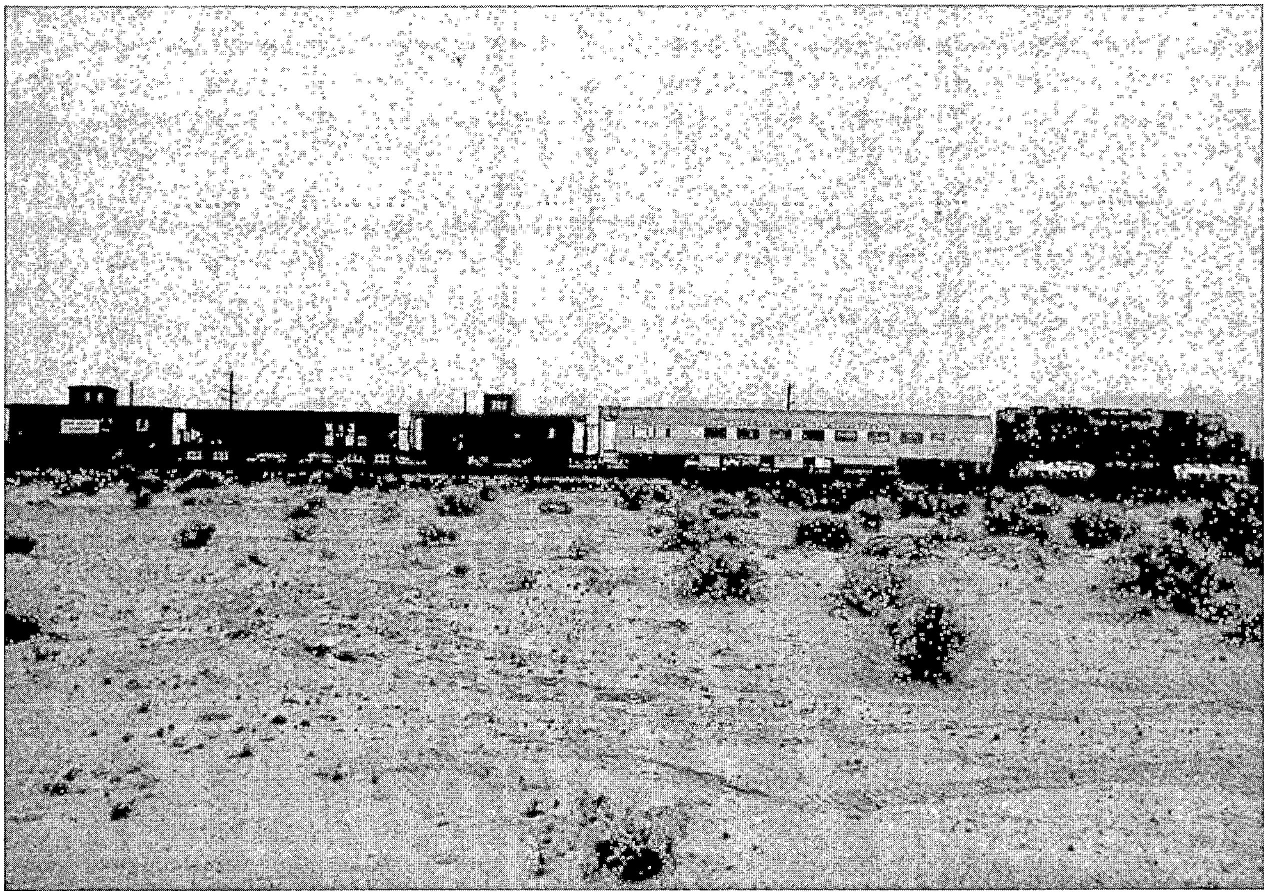
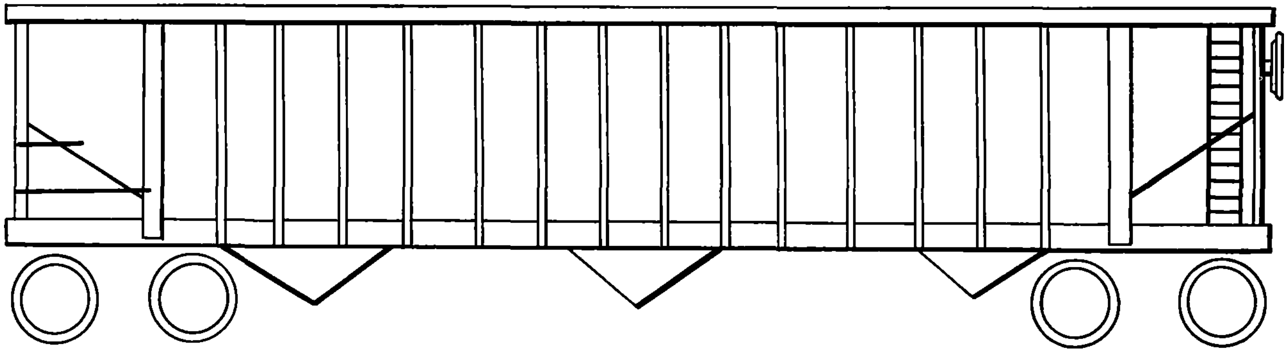


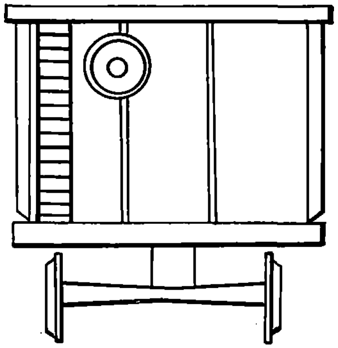
FIG. 10

TRUCK HUNTING VALIDATION TEST CONSIST

FIG. 11

TEST VEHICLE GENERAL ARRANGEMENT





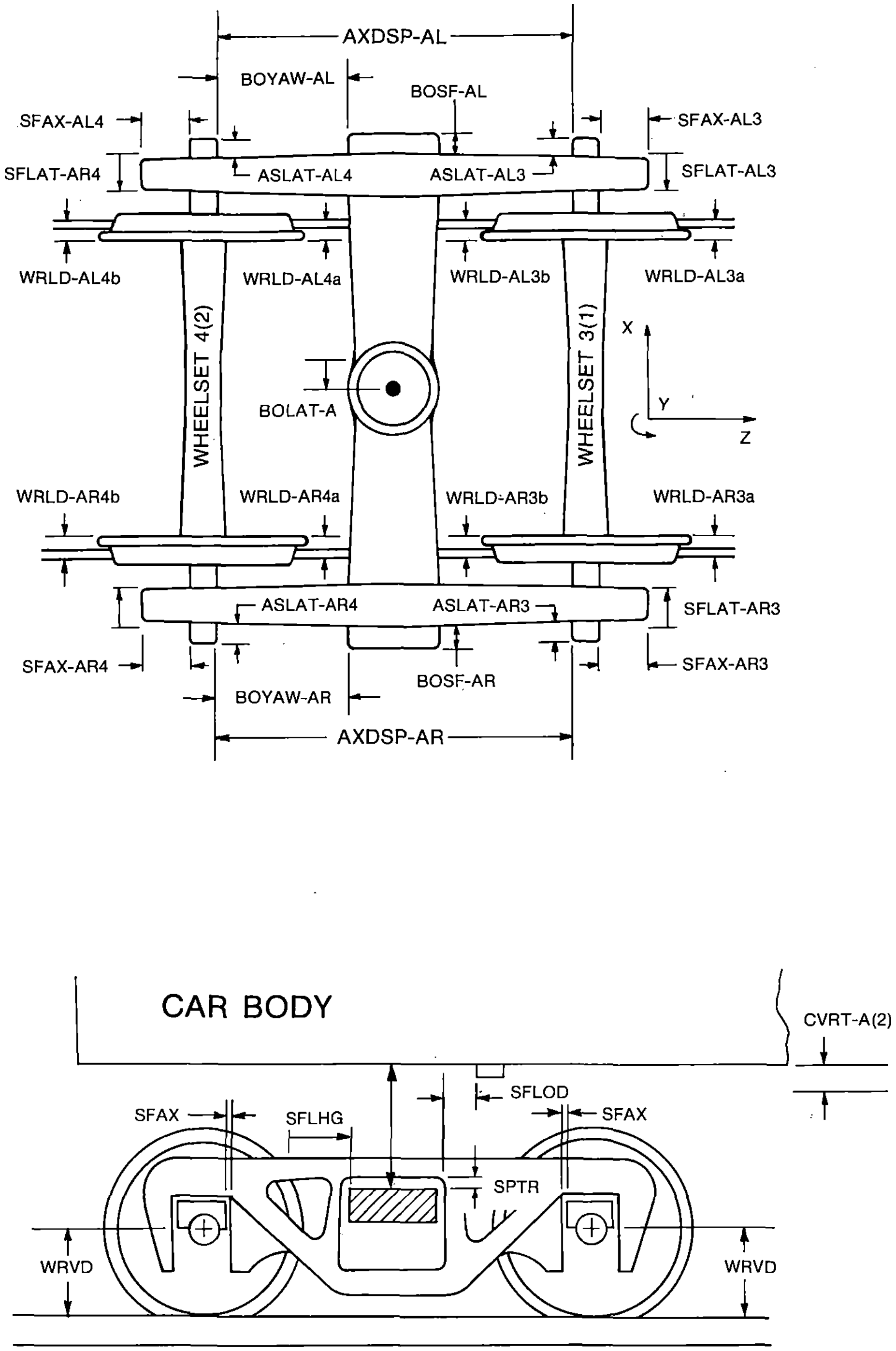


FIG. 12

TEST VEHICLE INSTRUMENTATION

The data obtained in the form of digital magnetic tapes were processed at the AAR, as well as ASU and Clemson.

Vehicle Roll and Bounce

The Flexible Car Body Model is used to predict the response of a car to track conditions that lead to harmonic roll or bounce. The model divides the car body into two parts, front and rear, and considers relative movement of those parts, the front and rear bolsters and the front and rear wheels and side frames, assuming several degrees of freedom for each of the masses. Figure 13 shows the various degrees of freedom considered in the model.

The parametric study which utilizes the Flexible Car Body Vehicle Model was incorporated into volumes one through three of Suspension Dynamics in 1977 and 1978. These volumes, intended for research tools for the truck designer's use, include the results of the group's study, along with recommendations.

In the Harmonic Roll volumes prepared in Phase I, eight case studies were considered for the prediction of forces by the model. Numerous additional case studies were added in the design parameter investigation during Phase II, to determine the effects of track stiffness,

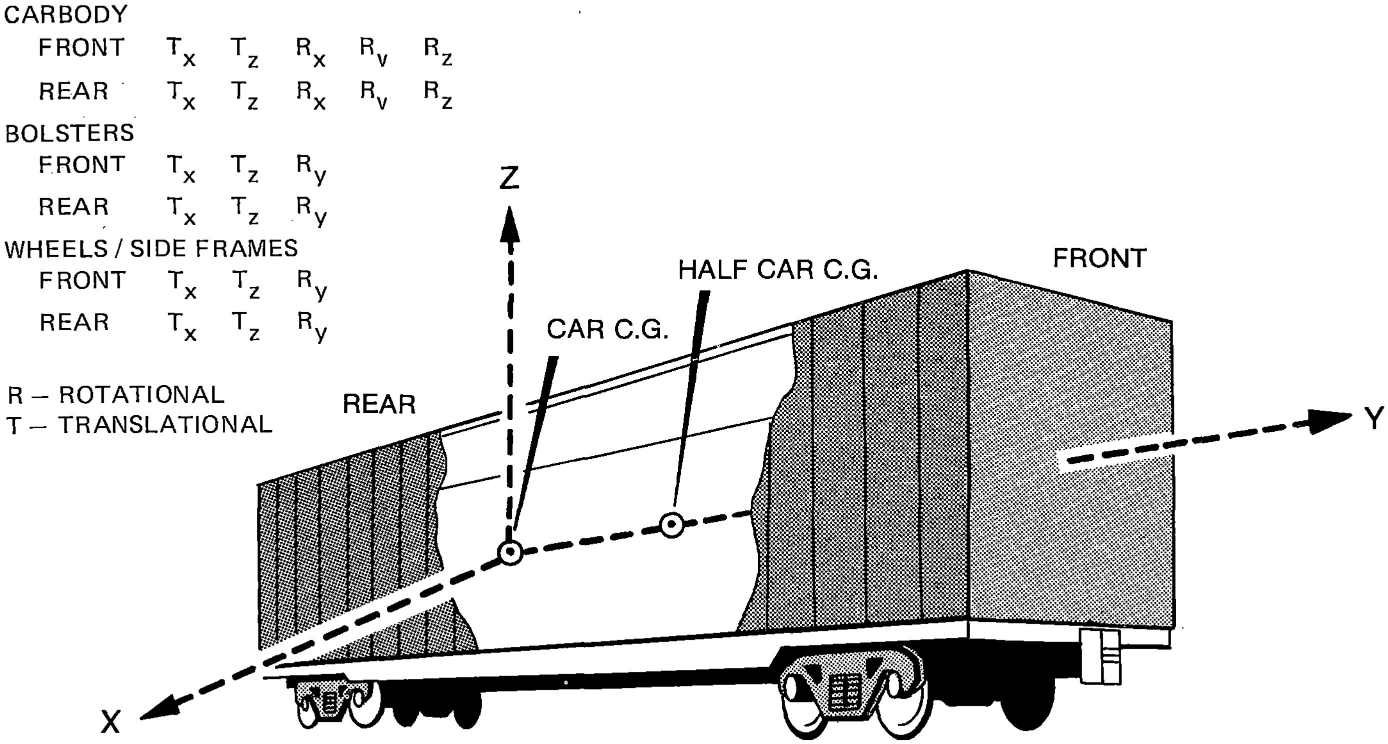
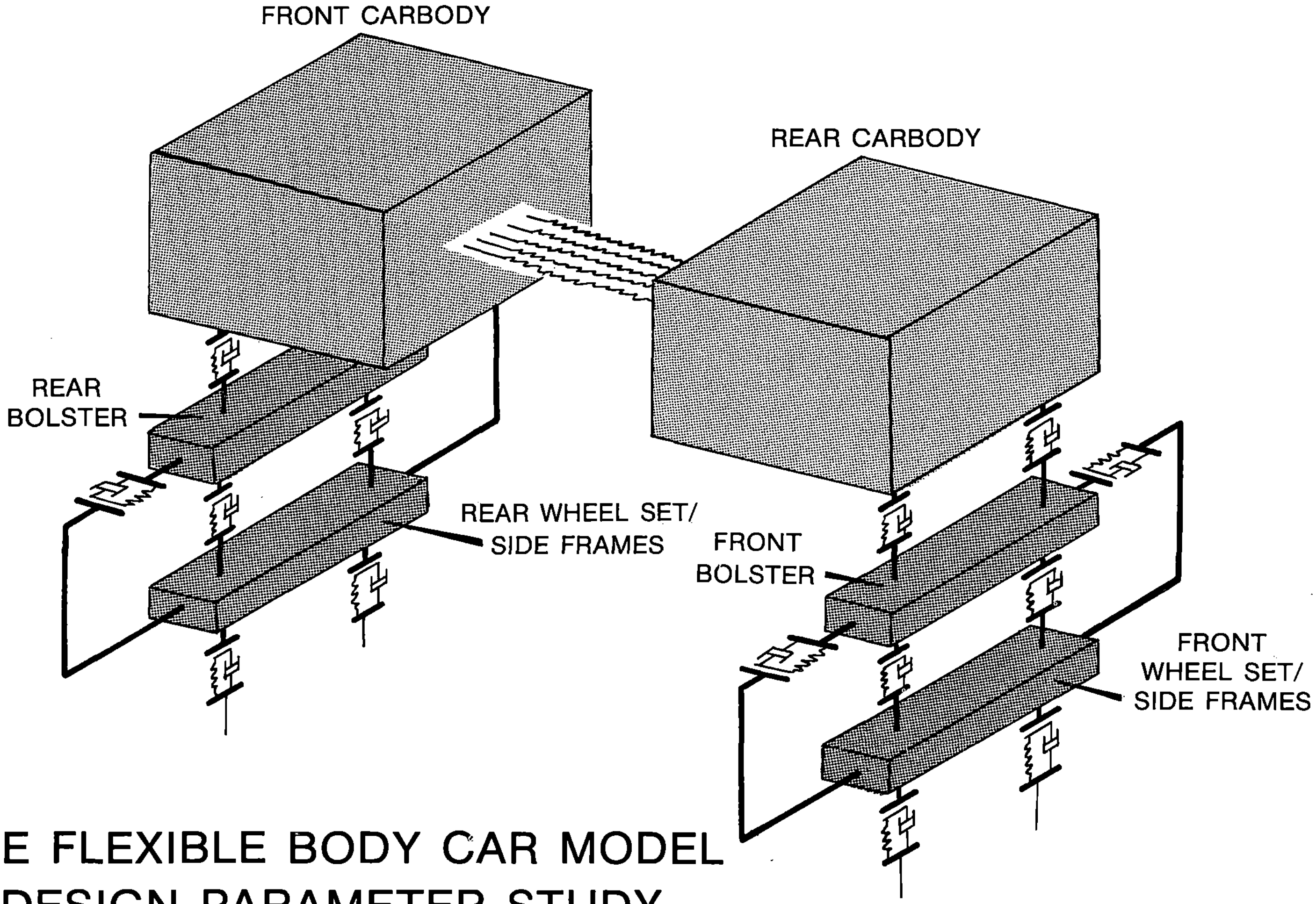


FIG. 13

VEHICLE MODEL DEGREES OF FREEDOM



THE FLEXIBLE BODY CAR MODEL
DESIGN PARAMETER STUDY

coulomb damping, high speeds, variation of moment of inertia, and vertical bounce, etc.

The study indicated that specific track conditions and speeds can lead to extremely high loading conditions, even with the best of the present suspension designs.

Increasing the spring travel distance will appreciably reduce centerplate and wheel forces in bounce, but such an increase also may have a slight tendency to increase the roll angle in harmonic roll. The Trucks and Suspension group recommended a balance between snubbing and spring travel, to improve both roll and bounce behavior.

For one of the cars used in the study, a truck with D-7 springs, 4¼" of travel and a snubbing force of 4,500 pounds, appeared to provide the optimal performance. The task group noted that the D-7 suspension system could reduce spring bottoming in the higher amplitude bounce mode more than with D-5 springs. This mode included three one-inch track depressions at consecutive 39-foot intervals.

The task group also added a caveat: although it is reasonable to believe the changes in spring travel or snubbing force can help mitigate roll and bounce in many cars on various types of track, the specific figures obtained in the Trucks and Suspension report apply only to the specific components and track types studied.

Among the other conclusions reached in the parametric study were: the critical speed for harmonic roll increases and the peak roll angle (at a given speed) decreases as track stiffness increases. The roll angle also is reduced by lowering the center-of-gravity, a conclusion that explains the incidence of harmonic roll in heavy, high center-of-gravity cars. The smaller the maximum roll angle and the higher the speed at which the train may travel before reaching that angle, the greater the improvement in train economics and safety.

Bolster Fatigue Tests

Phase II incorporated the cooperative AAR/RPI Truck Safety Project, directed by R. A. Evans of ASF. This project was primarily concerned with developing a Bolster Fatigue Test specification, although material properties and failure modes also were investigated. Bolster Fatigue testing has been conducted at American Steel Foundries' Test Engineering Lab in Granite City, Illinois, as well as Dresser Industries in Depew, New York.

In the initial tests in Granite City, bolsters were subjected to loads greater than the average encountered in revenue service, and run through 1.4 million cycles of loading. Inspections for cracks were made during the tests.

Later, testing was continued at Dresser's testing facilities in Depew, New York, where the remainder of the bolster tests have been conducted. Data reduction then began in an effort to finalize the specifications for bolster fatigue strength.

Auxiliary Snubbing

As was noted earlier, the AAR was involved in a study of snubbing devices when the Trucks and Suspension study began, and the parametric study utilizing the Flexible Car Body Model includes comparisons of the effects of snubbing. However, additional data were needed on generic types of auxiliary snubbing systems. For this, test runs were conducted at the Transportation Test Center at Pueblo, Colorado. The runs utilized standard truck configuration with no auxiliary devices, an elastromeric type device, a friction type device, and a hydraulic device. The data collected in these runs were reduced at the AAR's Technical Center in Chicago for inclusion within a subroutine in the Flexible Car Body Model of harmonic roll and bounce. The Pueblo test consist is shown in Figure 14.

The results of the validation tests and model modification efforts point to a need for further research into the optimal combination of design, structure and economics for truck and suspension systems.

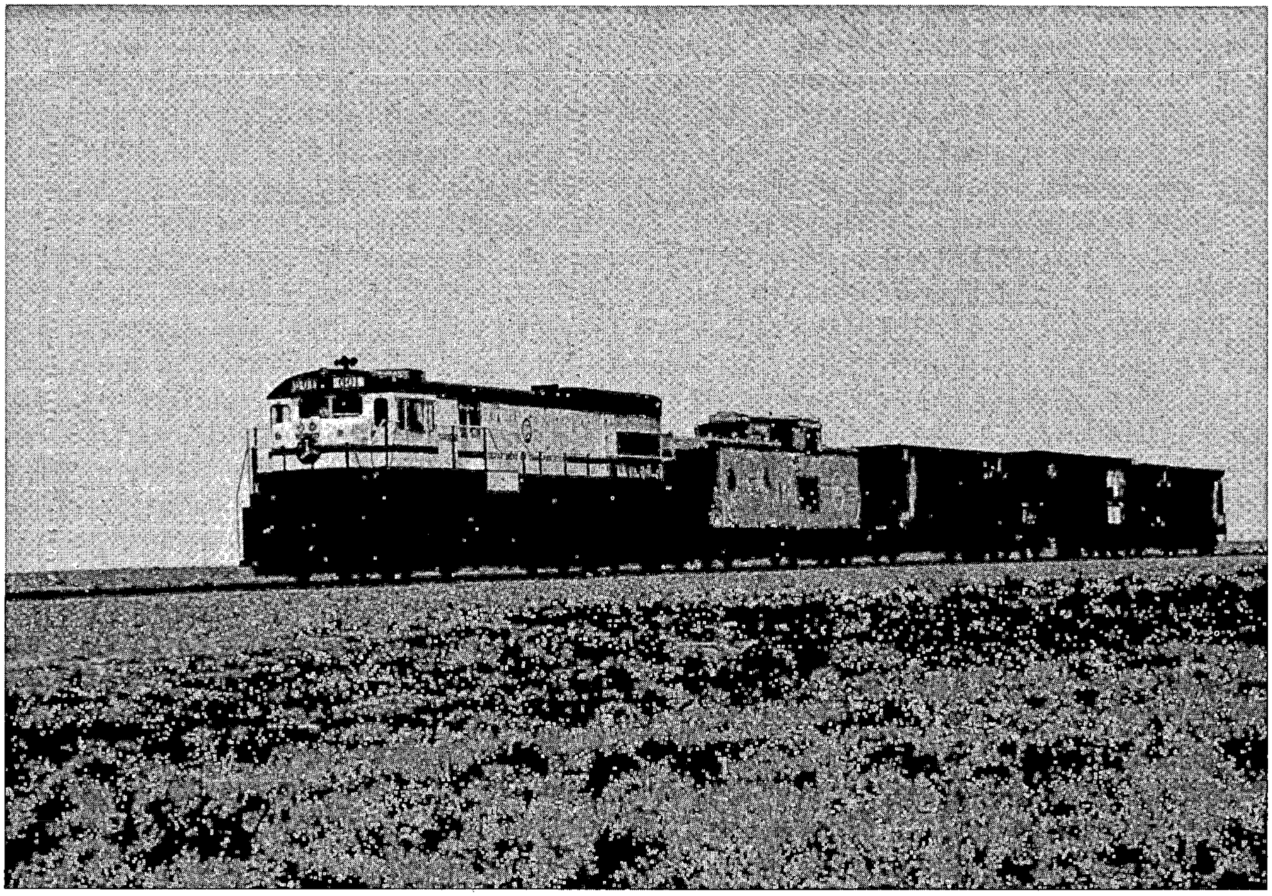
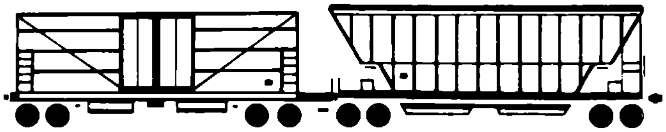


FIG. 14

TEST CONSIST FOR AUXILIARY SNUBBING

TASK IV



CAR BODY STRUCTURES

Unlike the Trucks and Suspension group, the Car Body Structures group was not heir to ongoing research data, but was faced with the job of modernizing specifications for car body structures. At the time the Car Body Structures began, car performance specifications were contained in the AAR's "Specifications for Design, Fabrication and Construction of Freight Cars" and in-house manuals of car builders.

One characteristic of the then-current AAR specifications was that they dealt with static loads, or static loads with some dynamic augmentation, and contained no specific design requirements for fatigue strength.

The Car Body Structures group was assigned to determine the information a car builder or designer would need to improve his product; develop an economically and technologically "best method" for predicting service life under varying conditions; develop tests to measure the service environment of the equipment; and establish and update guidelines for design.

The group originally was asked to consider both car and locomotive structures, but the magnitude of the dual study was too great and the program was narrowed to include only freight cars.

Interim Guidelines

The Car Body Structures group completed and published its Interim Guidelines Manual, Volume One of the Freight Car Fatigue Analysis series, in May, 1977.

The Interim Guidelines are intended to enhance the existing AAR design requirements and provide designers with a method for improving car bodies, with dynamic conditions in mind, as opposed to working solely with static load standards.

Critical areas for fatigue analysis and dynamic specifications were chosen by the task group after a questionnaire was sent to 52 Class I railroads, 6 car leasing companies and 17 car builders, seeking information on the areas in which problems occur with the most frequency. To preserve the confidential nature of the information, an independent contractor, Illinois Institute of Technology Research Institute, was retained to prepare the questionnaire and consolidate the replies into a single report.

The guidelines specify that fatigue analyses must be made of bolsters, center plates, center sills and stub center sills, front draft lugs and supports, rear draft lugs and supports, box car doorway areas, side sills on hopper cars without center sills, covered hopper car roofs, covered hopper car interior partitions, automobile carrier side sills, tank car head shields, and flat car trailer hitch supports. These parts are depicted in Figures 15A, 15B and 15C. Those are the recommended essentials under the guidelines although, of course, other components may also be subjected to fatigue study.

The task group noted that the analysis methods employed in the Interim Guidelines Manual are not the only reliable methods available, but suggested only those generally accepted and proven over a wide range of test cases should be considered in place of the proposed methods.

A three-day seminar was held in Chicago in the fall of 1978 to acquaint car builders and railroads with the new analysis recommendations.

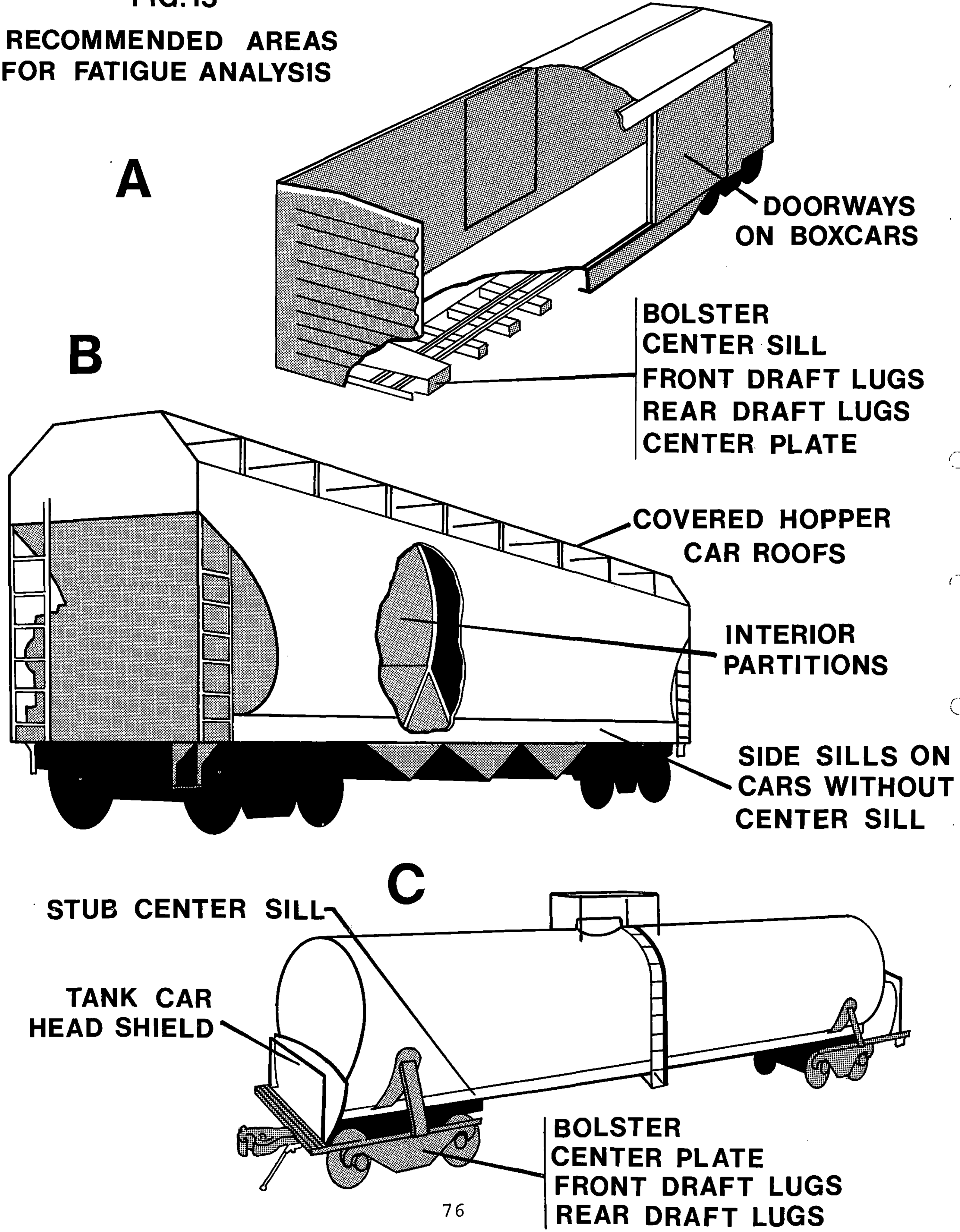
Material Properties and Load Spectra

Critical to the development of new designs and analysis guidelines is a data base concerning fatigue strength of the materials being used and the loads to which the components will be subjected.

The Car Body Structures group solicited materials

FIG.15

RECOMMENDED AREAS FOR FATIGUE ANALYSIS



property data from several sources, including ACF Industries, the Society of Automotive Engineers, National Cooperative Highway Research Program, American Welding Society and the American Institute of Steel Construction. ACF contributed a substantial amount of fatigue properties data as well as a considerable number of load spectra.

In addition, AAR consultants utilized fracture mechanics to suggest a method of predicting usage life and improving service inspection guidelines for car body components.

To test the environments in which components would be operating and the loads created by those environments, the Car Body Structures group developed the Freight Equipment Environmental Sampling Test program (FEEST). Test runs for the program included study of the following: 100-ton open top hopper; 100-ton covered hopper; 50-foot, 70-ton rigid underframe box car; 70-ton flat car; and 100-ton stub sill tank car. A typical consist arrangement is shown in Figure 16.

Data from these tests were to be obtained through the AAR 100 Research Car and were to be incorporated into the final guidelines for Freight Car Fatigue Analysis.

Fatigue Analysis Computer Program

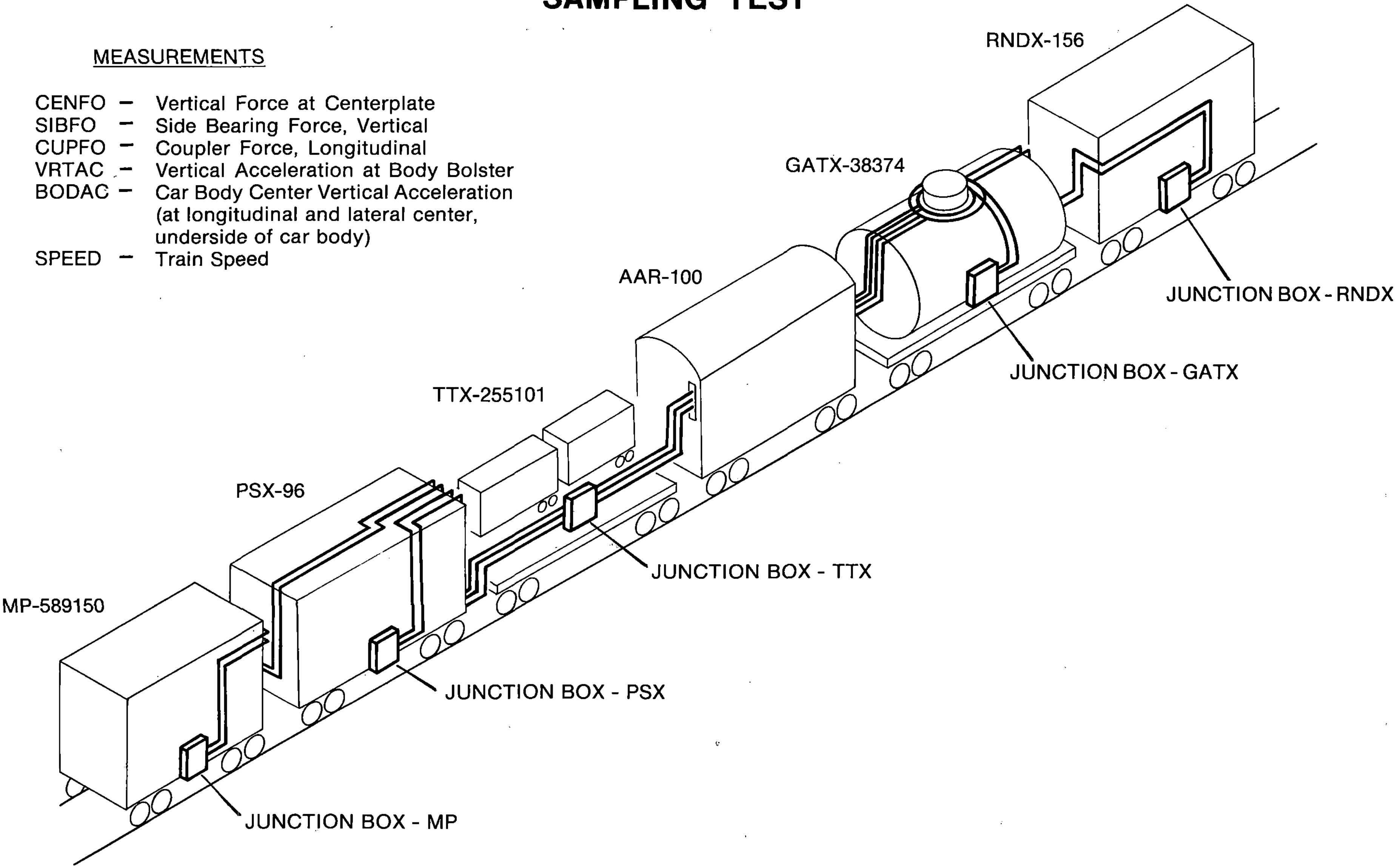
Also a part of the Fatigue Guidelines was a computer

FIG. 16

TEST CONSIST - FREIGHT EQUIPMENT ENVIRONMENTAL SAMPLING TEST

MEASUREMENTS

CENFO – Vertical Force at Centerplate
SIBFO – Side Bearing Force, Vertical
CUPFO – Coupler Force, Longitudinal
VRTAC – Vertical Acceleration at Body Bolster
BODAC – Car Body Center Vertical Acceleration (at longitudinal and lateral center, underside of car body)
SPEED – Train Speed



program for freight car fatigue analysis. The program, developed by Dr. Allen Zarembski of the AAR Technical Center under a contract with the Federal Railroad Administration, was completed early in 1977. A User's Guide to the fatigue analysis model was prepared for inclusion in the manual on Freight Car Design Fatigue Specifications and Analysis and is scheduled to be adopted as of June 1, 1980.

Freight Equipment Environmental Sampling Test (FEEST)

The goal of FEEST is to improve the quality of freight equipment by studying the severity of "in-service" loads experienced by typical freight cars under a variety of actual conditions, and then using this "real load" knowledge to better understand the relationship between the operating environment and the strength needed for a freight car to survive that environment for a specific period of time. Documentation of the results will then be incorporated into an updated version of the existing Track/Train Dynamics Interim Guidelines on Freight Car Fatigue Analysis.

The cars in the test consist are as shown in Figure 16. Each car was to be equipped with measuring devices which send signals through wires along the consist to the computer and tape recorders aboard the AAR 100 Research Car. The magnetic tapes are then analyzed using the computers at the AAR Technical Center in Chicago. Measurements for each car are made at the bolsters, side bearings, center plate, and car body.

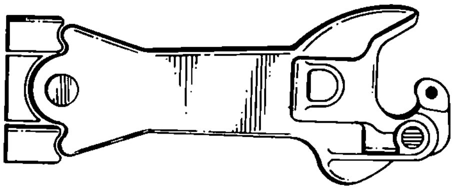
The over-the-road tests were scheduled intermittently and in two stages over a period of 12 to 18 months.

Stage I tests were planned over roads operating in the states adjacent to Chicago, to provide an understanding of "how far" the test cars must travel to be exposed to a typical, rather than a limited, collection of "in-service" loads.

Stage II tests, using Stage I tests as a guide, sample typical operating environments at a number of locations within the continental United States. The test cars are subjected to environments having various combinations of weather, terrain, track conditions, and train types.

TASK V

COUPLERS, YOKES, DRAFT GEARS AND CUSHION UNITS



Heavy cars and long trains generally result in larger forces being transmitted through the train consist. This places a burden on the coupler systems and the cushioning units.

The Couplers, Yokes, Draft Gears, and Cushion Units task group was assigned to study existing systems' ability to control the longitudinal environment. Performance specifications were to be developed for such equipment.

Already under way when the Phase II effort began was the AAR/RPI Coupler Safety Project. This project was under the direction of N. A. Morella of National Castings. The Coupler Safety Project group had been assigned: the study of operating conditions of couplers and yokes; investigation of in-service coupler failures; evaluation of coupler and yoke designs; preparation of performance and specification guidelines for couplers and yokes; and the re-evaluation of current standard coupler system designs in light of the guidelines developed.

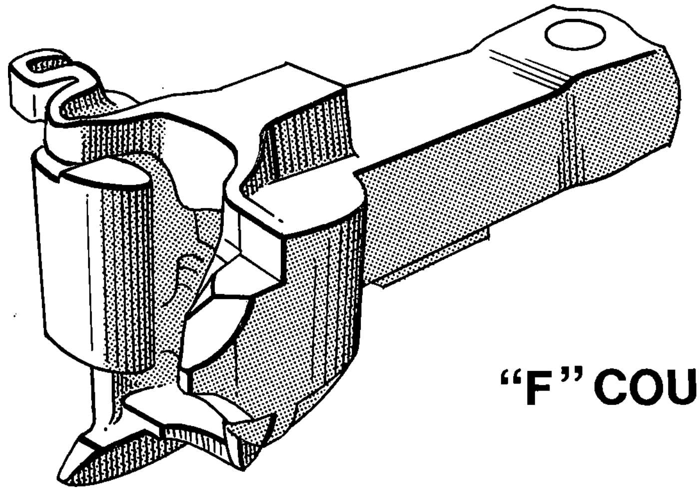
Many of the goals of the Coupler Safety Project were shared by Task V of Phase II. To avoid duplication of effort, the Coupler Safety Project was integrated into Task V as a sub-task.

The other group concerned itself with development of performance specifications for draft gears and cushioning units. This effort was directed toward investigating the possible optimization of cushion units and draft gear in unit train service. The optimization study involves an analytical effort built around use of the Detailed Train Action Model (DTAM). Draft gear and cushion unit performance data are obtained by conducting an impact test. This portion of Task V was funded by the FRA.

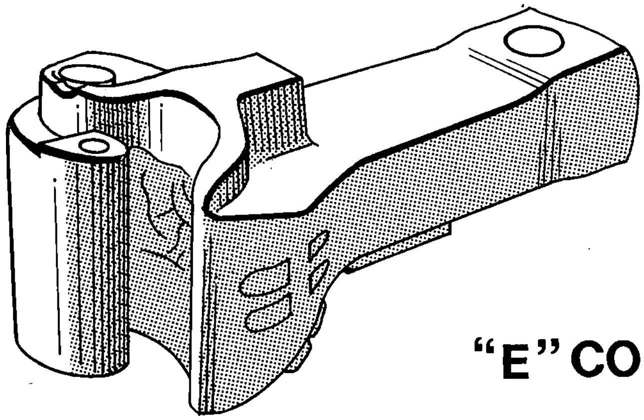
F-Butt Coupler Study

This study, begun under the Coupler Safety Project, included hundreds of measurements of E-head, F-butt couplers and F-head, F-butt couplers manufactured before 1970. Figure 17 shows the appearance of the two couplers.

The objective of the study was to develop recommendations for the mileage at which standard couplers with F-butts cast prior to 1970 should be removed from service. The key figure here would be the minimum strength reached over that number of miles, as measured by the size of the



"F" COUPLER



"E" COUPLER

FIG. 17

E-HEAD, F-BUTT and F-HEAD
F-BUTT COUPLERS

fatigue cracks and amount of wear.

As shown in Figure 18, the 185 couplers removed from service showed an average wear of 0.0073 inches per 10,000 miles. As other couplers of this type were located, they too were removed from service and studied. Both grade C and grade E steels were studied, with the grade E steel showing a smaller wear rate. In a comparison of E-head, F-butt couplers and F-couplers of the same grade steels, the wear rates were approximately equal.

The project suffered some delay as efforts to locate appropriate couplers took great periods of time, but the final data collection ended in 1977 and data reduction was conducted.

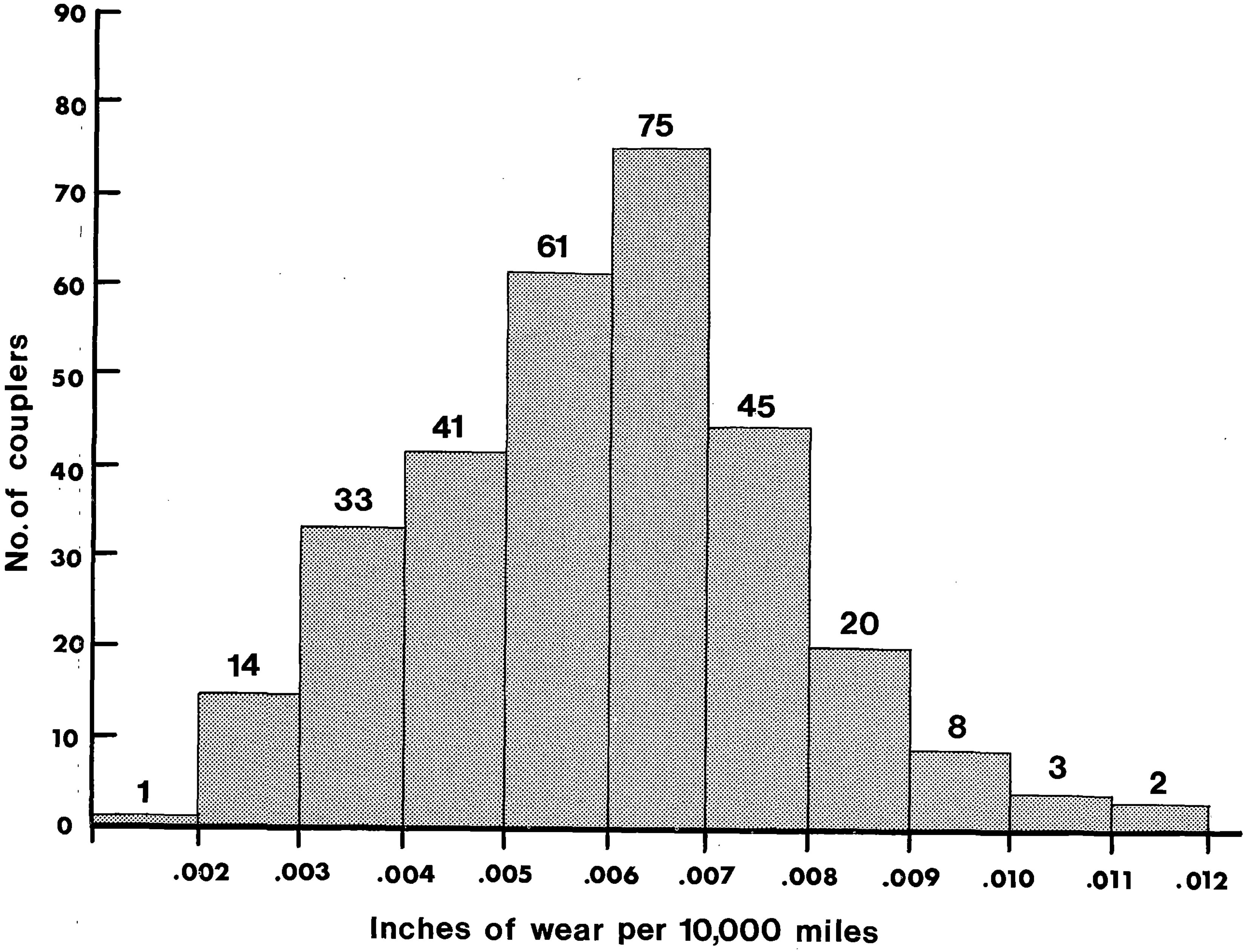
Service Test Runs

Under the Coupler Safety Project, service tests were begun on the Union Pacific, Denver and Rio Grande, Burlington Northern, Southern, Southern Pacific, Santa Fe, and Missouri Pacific railroads, with data collection on coupler forces in various states of train action.

By the time the test runs were completed, more than 30,000 miles of test runs had been recorded, through the areas shown on Figure 19. The data obtained were reduced at the MTS Corporation and studied with the use of AAR computer programs.

FIG. 18

COUPLER WEAR vs. MILEAGE, F-BUTT STUDY



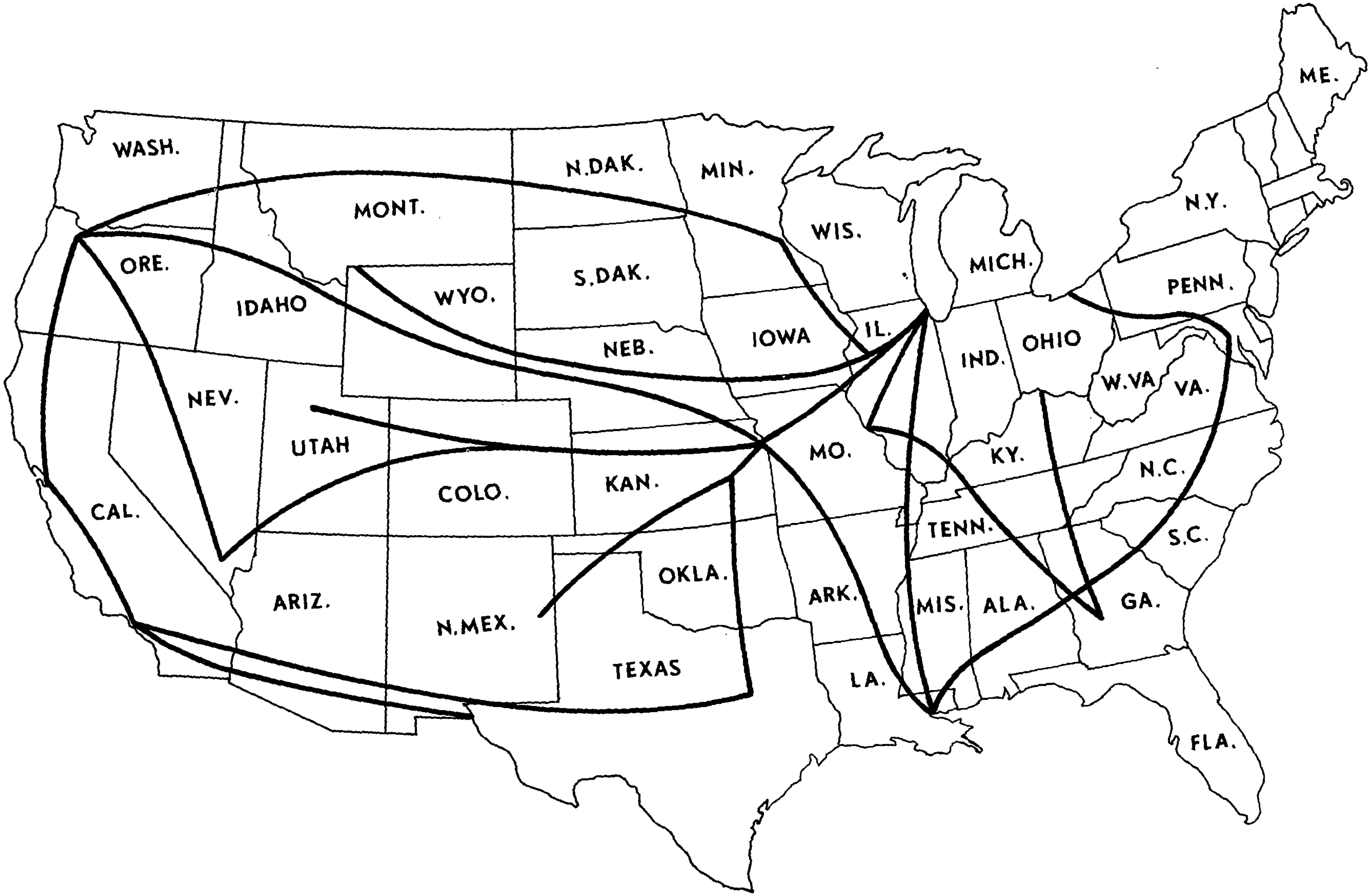


FIG. 19

SERVICE TEST ROUTING

The results of the study were various fatigue damage per mile figures, as a function of load severity in service life.

Other coupler studies:

--A study was conducted to determine the fatigue, NDT and dynamic tear properties of grades M, C, C(Q & T), and E steels in couplers at Case Western Reserve University in Cleveland.

--A machine was developed to test the fatigue strength of couplers at the AAR Technical Center in Chicago. Couplers and yokes were supplied by the industry. Beginning with ten E60 CHT couplers and ten F70 CHT couplers, and yokes, the test machine developed data to correlate static and dynamic test results.

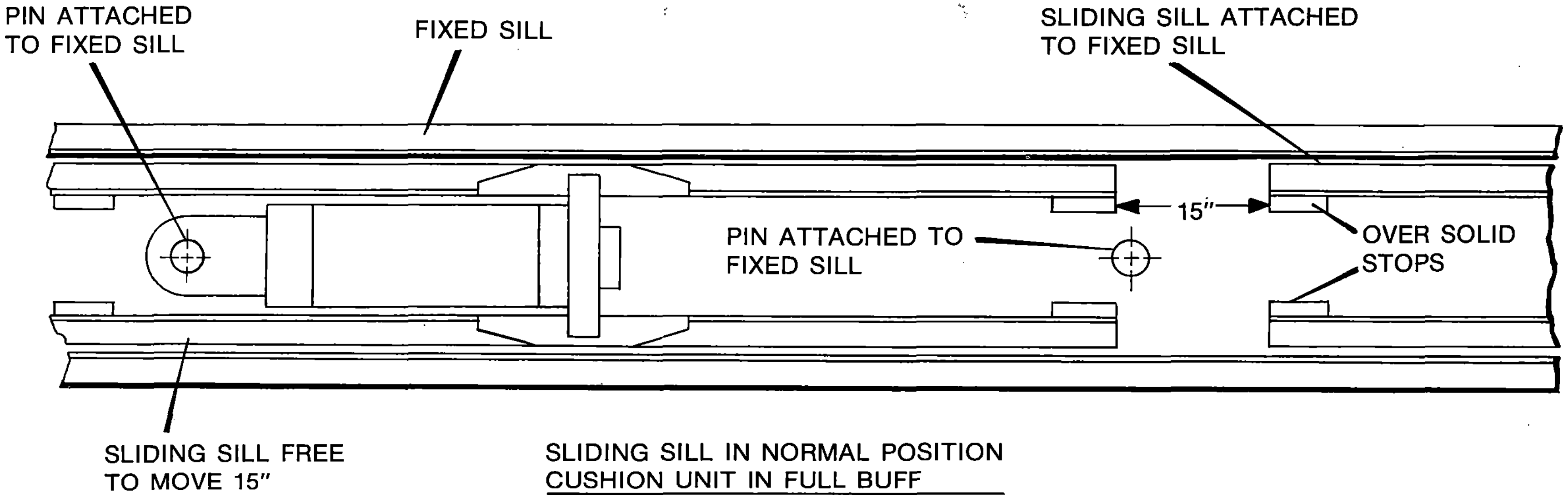
--The Federal Railroad Administration supplied computer printouts of information on coupler-related accidents in 1975, which were analyzed by the sub-group. The study group also investigated a few of those accidents more closely, obtaining more detail than available in the FRA data.

Draft Gear and Cushion Unit Optimization

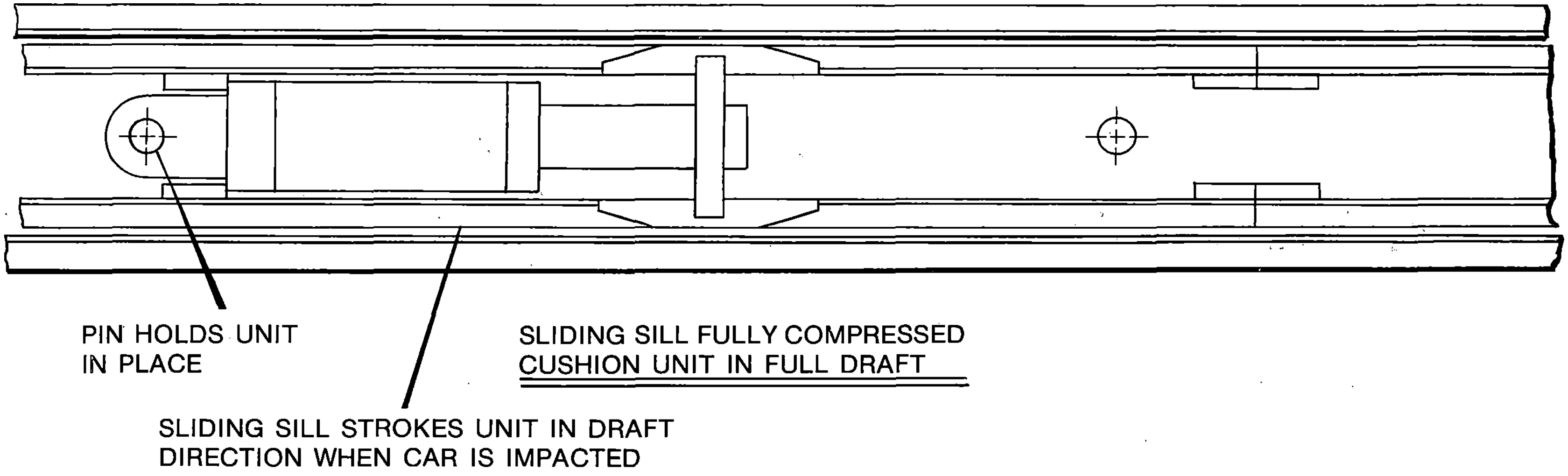
Utilizing the Detailed Train Action Model developed during Phase I, the Cushion Draft Gear and Cushion Unit Optimization sub-task studied the effect on train forces when the characteristics of draft gears and cushion units were varied. The computer simulation allowed changes in the force-travel-velocity characteristics of the draft gears and cushion units.

Model runs began with a 50-car train, with coupler forces studied for the last locomotive and every tenth car during such operations during emergency brake applications.

With additional draft gear data generated by the Southern Railway, and data already available, the sub-group also developed a sub-routine describing in detail the draft gear and end-of-car cushioning unit characteristics. Subroutines were validated by the Miner Corporation, with use of an extensively modified Southern Pacific sliding sill car. The modifications allowed cushion units to be loaded in tension or compression via car impact testing. Figure 20 shows how this was accomplished.



SLIDING SILL IN NORMAL POSITION
CUSHION UNIT IN FULL BUFF



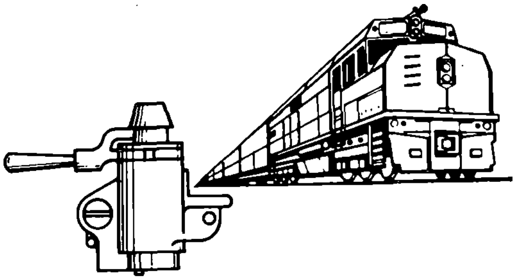
SLIDING SILL FULLY COMPRESSED
CUSHION UNIT IN FULL DRAFT

FIG. 20

CUSHION UNIT TEST VEHICLE/UNDERFRAME ARRANGEMENT

TASK VI

BRAKE SYSTEMS



Like the coupling systems, braking systems act to control slack action. Besides fulfilling the obviously essential function of stopping the train, brake systems must act in conjunction with the coupler system to stabilize the train longitudinally.

In starting, the couplers must transmit the force of the locomotive throughout the train. If the brake system could provide the same deceleration rate for each car in the train, no coupler buff (or draft) forces would be created in stopping. If brake systems perform unevenly, buff and draft forces can be extensive and dangerous.

The Brake Systems task group was originally assigned to study the effects of various brake system actions on train performance and then to develop component specifications to provide for improved train performance within the constraints of an economic model. The function of the brake system is to decelerate the train and minimize adverse slow action between cars.

One of the first assignments facing the Brake Systems group concerned the evaluation of existing brake systems.

As a result of such assessment, the group was to determine the effects of different brake shoe compositions on brake system performance. Additionally, dynamic brake rigging efficiency was to be studied through field tests.

The Braking Systems test group, under the direction of G. R. Misner of the Association of American Railroads, planned to conduct a two-phase braking test, measuring shoe composition effects on single car drag and stopping distance tests.

Drag Tests

To conduct the studies, a 100-ton open hopper, built in 1969, was supplied by Illinois Central Gulf. The initial test program was conducted at the Transportation Test Center at Pueblo, Colorado. The test car had all the instrumentation installed on it (e.g. no data collection car).

Special equipment on the test vehicle ensured that the total brake effort remained constant, by measuring individual brake shoe retarding forces and adjusting cylinder pressures to increase or decrease the total force.

The instrumented car measured brake shoe forces, retarding forces per shoe, average retarding force, brake cylinder pressure, reservoir pressure, temperature of wheel tread, speed, wheel slide, elapsed time and distance, draft force and special events such as unusual changes in test parameters.

The tests were intended to enable the task group to study the characteristics of various brake shoe types. The effects of temperature changes, car velocity, brake shoe force on brake shoe friction coefficients and the energy absorption capacity of the brake shoe/wheel system were to be developed.

Following recommendations from the Brake Systems Technical Review Committee, the group also made preparations to conduct quality control tests on the brake shoes selected and measure shoe wear as a result of the tests and grind the brake shoe test samples to match the wheel contour before conducting the tests. This pre-grinding reduces break-in time.

Test runs were subject to several delays caused by instrumentation, specifically the development of an instrumented brake beam. The dynamometer brake beam was, of course, a crucial component in stopping distance and drag tests. The first beam, designed and built at the AAR, was not successful. The task group eventually obtained a dynamometer brake beam developed at the University of Illinois, Figure 21, and after the remaining instrumentation problems were corrected, the tests were rescheduled

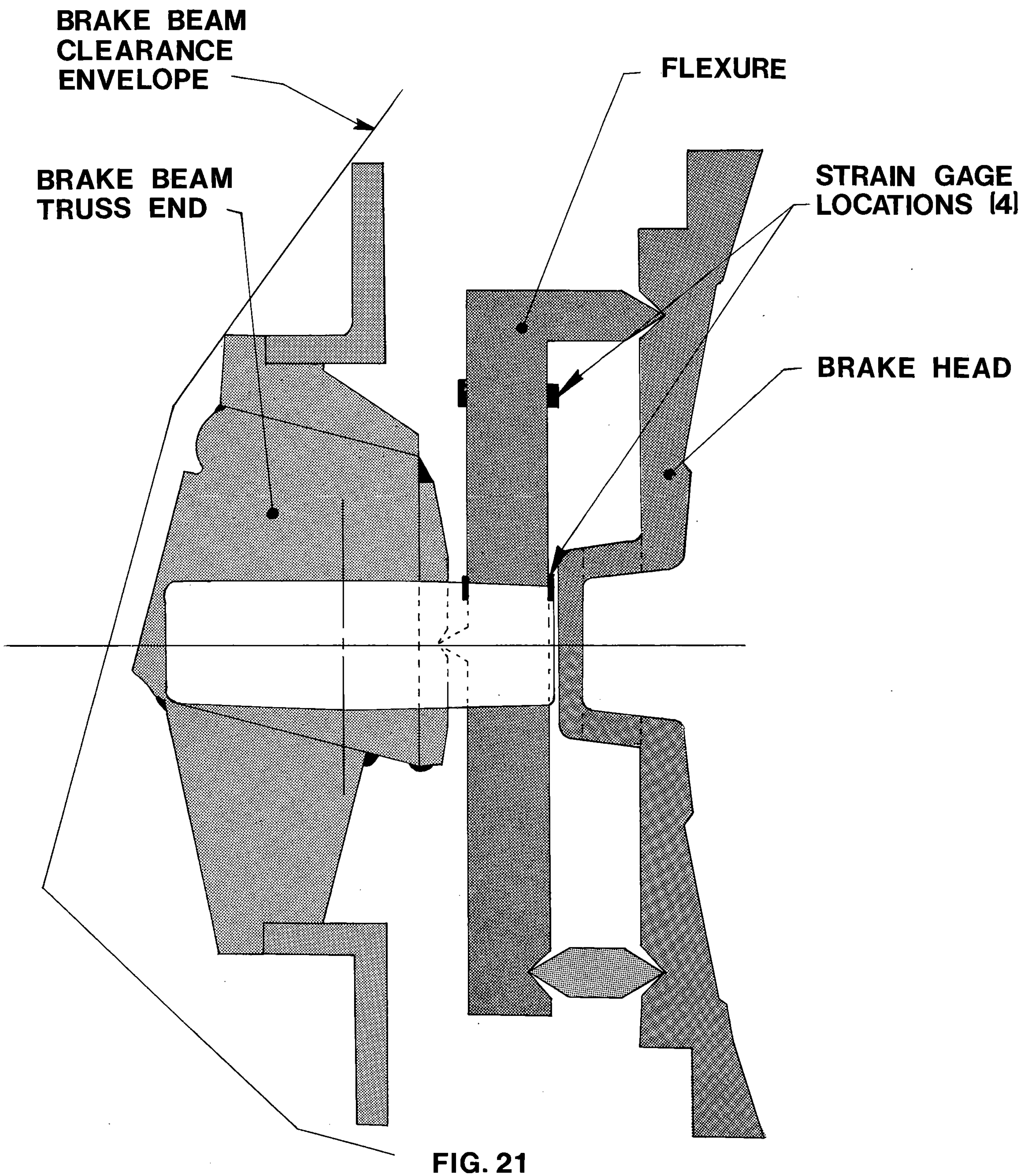


FIG. 21

DYNAMOMETER BRAKE BEAM

to be conducted in 1978.

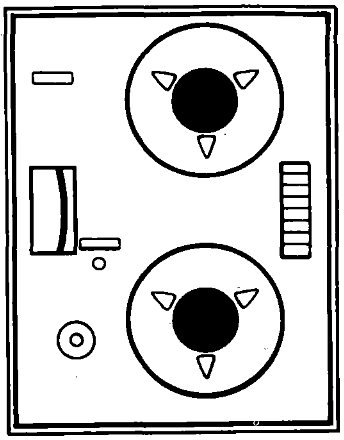
Stop Distance Tests

Stop distance tests were to be conducted by pulling a test vehicle at a pre-selected speed, separating the test vehicle from the locomotive and setting its brakes at some pre-selected force level.

The initial speed, brake cylinder pressure, test vehicle weight and shoe type were to be varied during the experiments. The parameters to be measured included brake cylinder pressure, brake shoe force, retarding force per wheel, temperature of brake shoe, speed, deceleration rate, wheel slide, and elapsed time and distance the test vehicle travels before a complete stop is achieved.

TASK VII

TEST MANAGEMENT



The need for test management in any program of the size of Phase II hardly has to be stated. The needs of two task groups might overlap or conflict, test schedules of sites might coincide and individual task groups might need assistance in dealing with outside agencies. This was the function of the Test Management group. The accomplishments of support groups such as Test Management are largely unheralded when test data, results and conclusions are published, but their accomplishments often are key to the individual task successes.

The Test Management group, headed by N. J. Darien of the AAR Technical Center, was assigned to develop test procedures and test equipment requirements for any task group requesting such plans, as well as assembling the test equipment and overseeing the testing. When testing functions were to be fulfilled by outside groups, the Test Management team was responsible for reviewing their test plans and performance.

Another responsibility, shared with the Program Analysis task group, was to define the best means of capturing the required dynamic data. This long-term effort includes standardization of study techniques that have been incorporated into the AAR standard procedures. The Test Management group was involved specifically in four major projects -- truck hunting model validation, brake tests, locomotive tests and dynamic environment study.

Truck Hunting Model Validation

As may be recalled from the section on the Trucks and Suspension system, Clemson and Arizona State Universities worked on a system for validating their truck hunting model, which was initiated during Phase I. The Test Management group worked closely with the Trucks and Suspension group, Dr. Harry Lawl of Clemson University, and Dr. Neil Cooperrider of Arizona State University, in providing the instrumentation and field testing required for that validation.

The test vehicle was an 80-ton Louisville and Nashville open hopper on 70-ton, A-3 Ride Control trucks. This same car was utilized during Phase I for a dynamic structural test performed by Martin-Marietta in Denver, Colorado (AAR R-324). The model validation study called for 81 measurements of car/truck/track dynamic interactions and other data. Thus, it became necessary to develop and equip the test car with instrumentation to provide these measurements. All instrumentation applications were designed and installed by the AAR Technical Center Test Division.

The test data acquisition system, which was installed on the AAR 100 research car, required a mini computer capable of handling up to 100 channels of information. The performance criteria for this system were developed by the AAR staff. The data collection system itself was designed by Reaction Instruments of Reston, Virginia. Reaction Instruments also constructed major sub-systems. The finished system utilizes a Data General Eclipse S-200 mini computer and two 1600 bi tape drives. Figures 22A and 22B show block diagrams of the system.

In both this study and others, the AAR 100 test car was utilized extensively and required substantial upgrading of its diesel-electric generating system, air conditioning and other equipment. Following this upgrading, the test car and the 100 were dispatched to the Union Pacific line between Las Vegas and Barstow, California, for test runs.

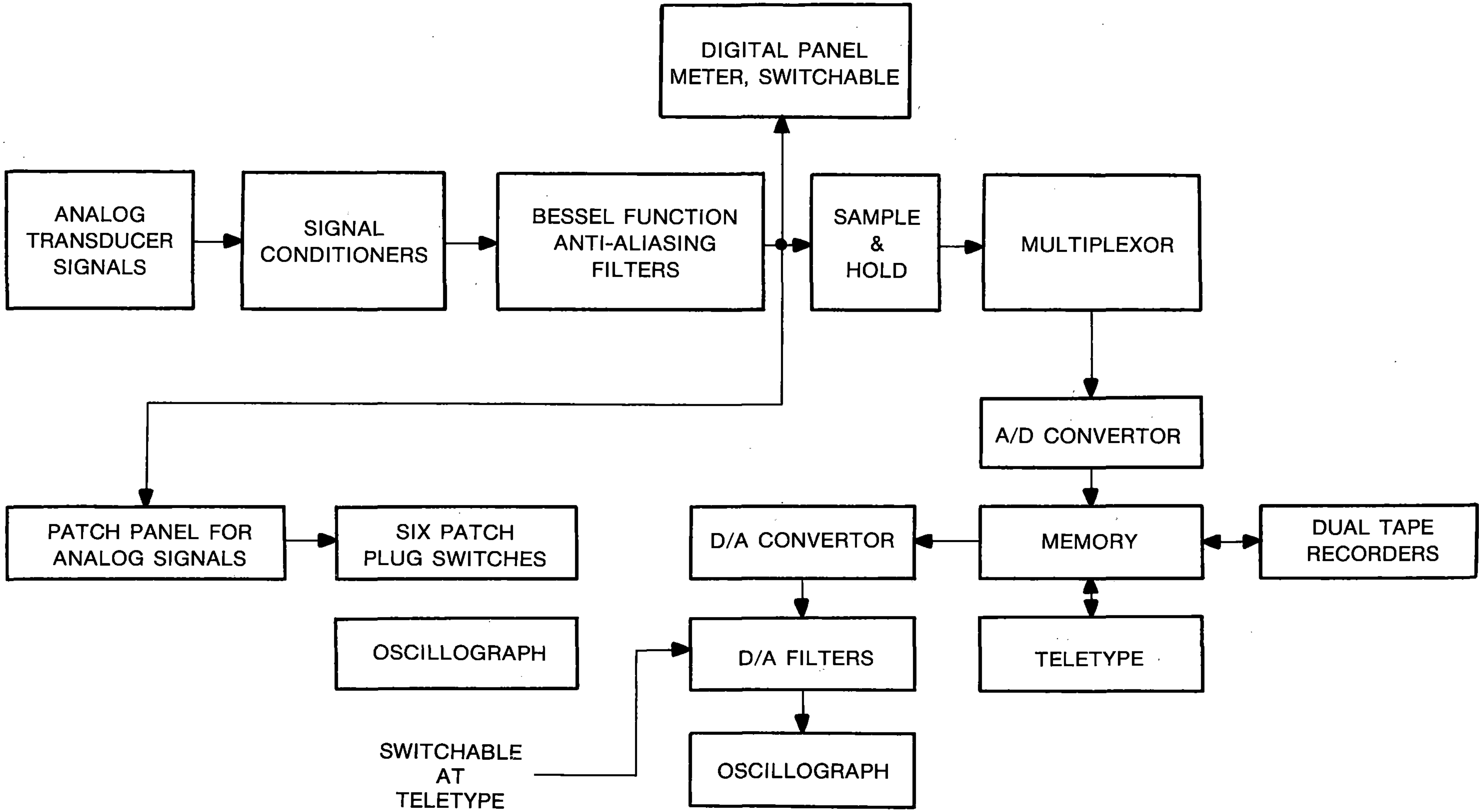
Following completion of the test runs, the Test Management group coordinated analysis and distribution of test results.

Brake Tests

As noted in the Brake System section, the initial

FIG. 22A

AAR 100 DATA COLLECTION SYSTEM



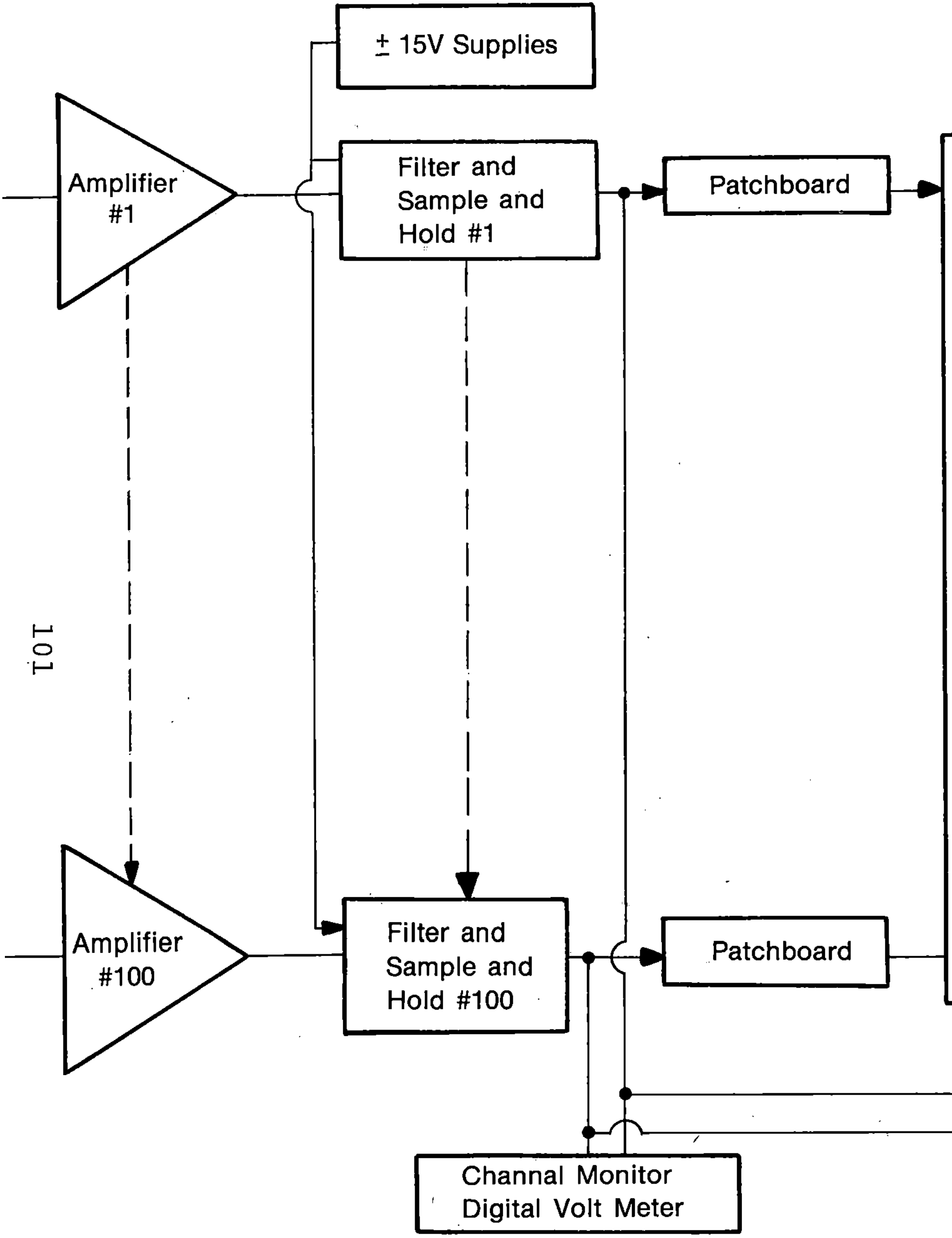
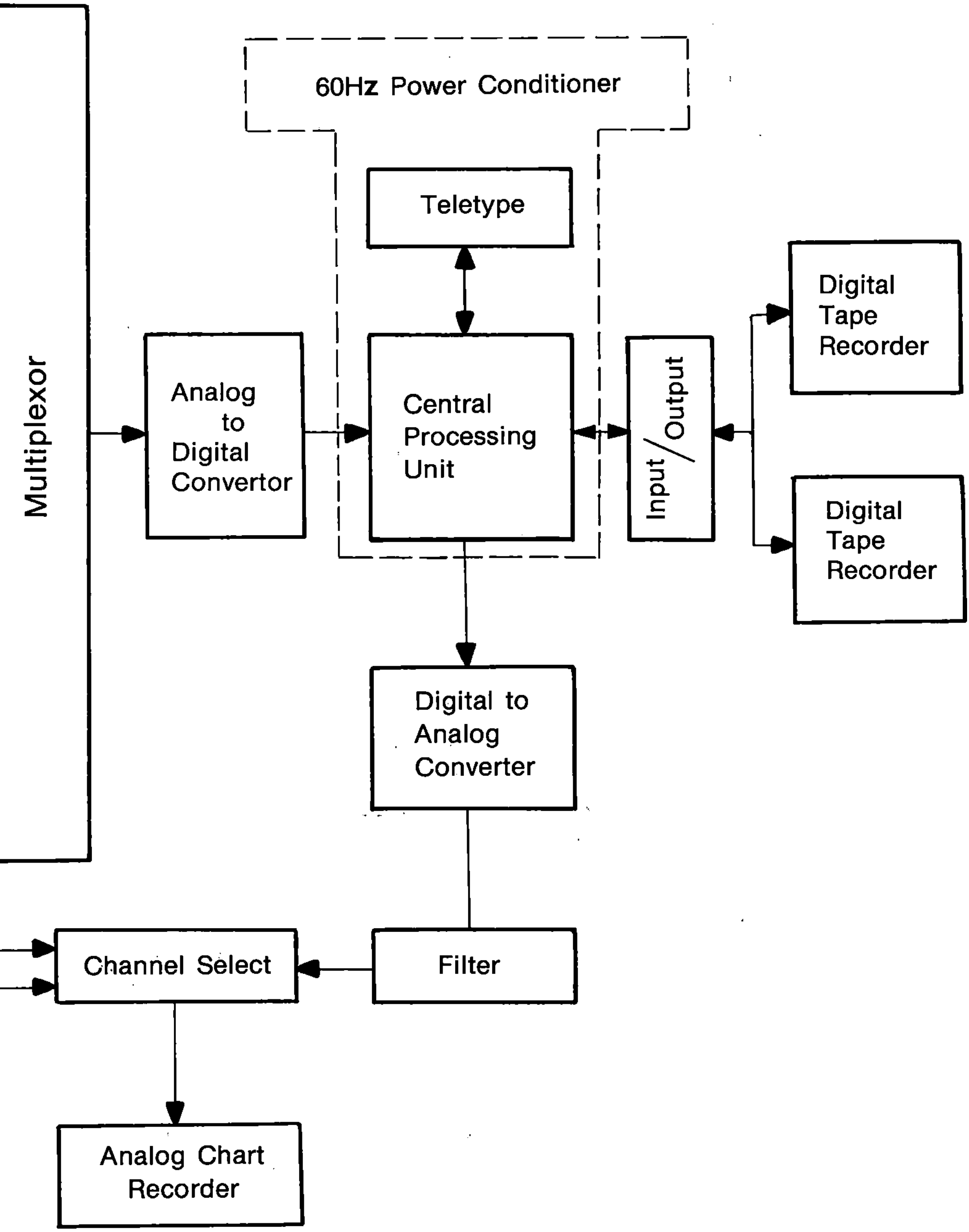

± 15V Supplies
Amplifier #1
Filter and Sample and Hold #1
Patchboard
Amplifier #100
Filter and Sample and Hold #100
Patchboard
Channal Monitor Digital Volt Meter

FIG. 22B

AAR 100 DATA COLLECTION SYSTEM



breakaway and drag tests conducted at the Transportation Test Center involved extensive planning. New testing procedures and test equipment were to be designed and the timing of the tests was to be planned so as not to interfere with other studies at Pueblo.

The Test Management group worked closely with the Brake System group to find ways to consolidate an insurmountably large number of desired tests and test runs into a manageable number without seriously affecting the results which could be obtained in the study.

Locomotive Study

The major testing effort of the Locomotive Special Project was the instrumentation of Amtrak SDP-40F and F40PH locomotives and associated equipment. This extensive study effort was coordinated by the Test Management group.

With outstanding support and assistance from the Electromotive Division of General Motors and the Burlington Northern Railroad, instrumentation was added to Amtrak SDP-40F locomotives, including an instrumental baggage car, to make up a test consist similar to a typical Amtrak passenger train. The test consist was operated between Minneapolis and Seattle and over 150 digital data tapes of track/train interactions were recorded. From the thousands of miles of operations, several sites were selected for further study. Additional test runs, using both SDP-40F and F40PH locomotives, were conducted. These tests are more fully described in the section on Task 10.

Following test runs on the Burlington Northern, the same consist, with BN cars replaced by similar Amtrak equipment, was routed to the Chessie System in Huntington, West Virginia. The consist then was operated together with a similar test train powered by two E-8 locomotives. The E-8 consist was prepared by and under the control of the FRA. The purpose of the TTD/FRA coordinated effort was to compare the track/vehicle interaction characteristics of the E-8 and SDP-40F units.

Freight Equipment Environmental Sampling Test

The Freight Equipment Environmental Sampling Test (FEEST) was the major long-term effort of the Test Management group. The planners of Phase II noted that standardized methods of reporting, identifying and studying dynamic behavior of equipment in train revenue would help lead to improved design techniques.

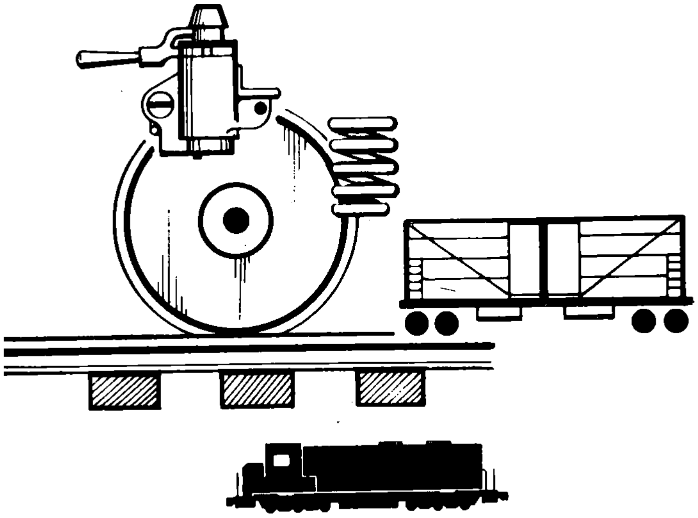
The Test Management group was assigned to consult with other task managers on the data needed to establish load environments for different sub-systems, develop the most suitable means for measuring and presenting such data, develop standard instrumentation arrangements and data reporting formats, upgrade the data recording equipment on the AAR 100 and participate in field testing.

(The data acquisition system and upgrading of the AAR 100 for the Truck Hunting Model Validation were a part of this long-term effort as well.)

In the FEEST study, dynamic interaction data are to be collected through test runs of several types of vehicles. The Test Management group shared its responsibility for the Dynamic Environment Load Study with the Program Analysis task group, with the Test Management group taking responsibility for performance of test and the Program Analysis group being responsible for the statistical design of the study.

TASK VIII

PROGRAM ANALYSIS



With limited funds and time, and variations in the defined benefits from different studies, it was necessary to assign priorities to investigations. Such was the task of the Program Analysis study group.

The group was assigned to direct various task groups toward the most economically beneficial forms of study on the most critical components.

Early in its work, the Program Analysis group sought to develop a means of determining the effects of potential research efforts on life-cycle costs of equipment. The group considered the use of the life-cycle cost methodology developed by Battelle Columbus Laboratories for the AAR in an earlier study. That methodology utilized three basic types of input--variables for which reasonably good estimates can be obtained; variables that may be treated as constants; and variables for which field data collection efforts must be conducted. Excessive data requirements necessitated the investigation of alternative cost methodologies.

The Program Analysis group awarded a contract to Shaker Research for review of potential cost models for selected components. Potential models reviewed fall into two general categories--simulation modeling and life-cycle costing.

Life-cycle costing follows a component through its service life, from purchase to scrap, adding all costs attributable to the component. This method is useful in determining total costs of a component to the industry or firm using it, but falls short in determining yearly operating costs of the component. Data requirements render the use of the life-cycle costing methodology burdensome.

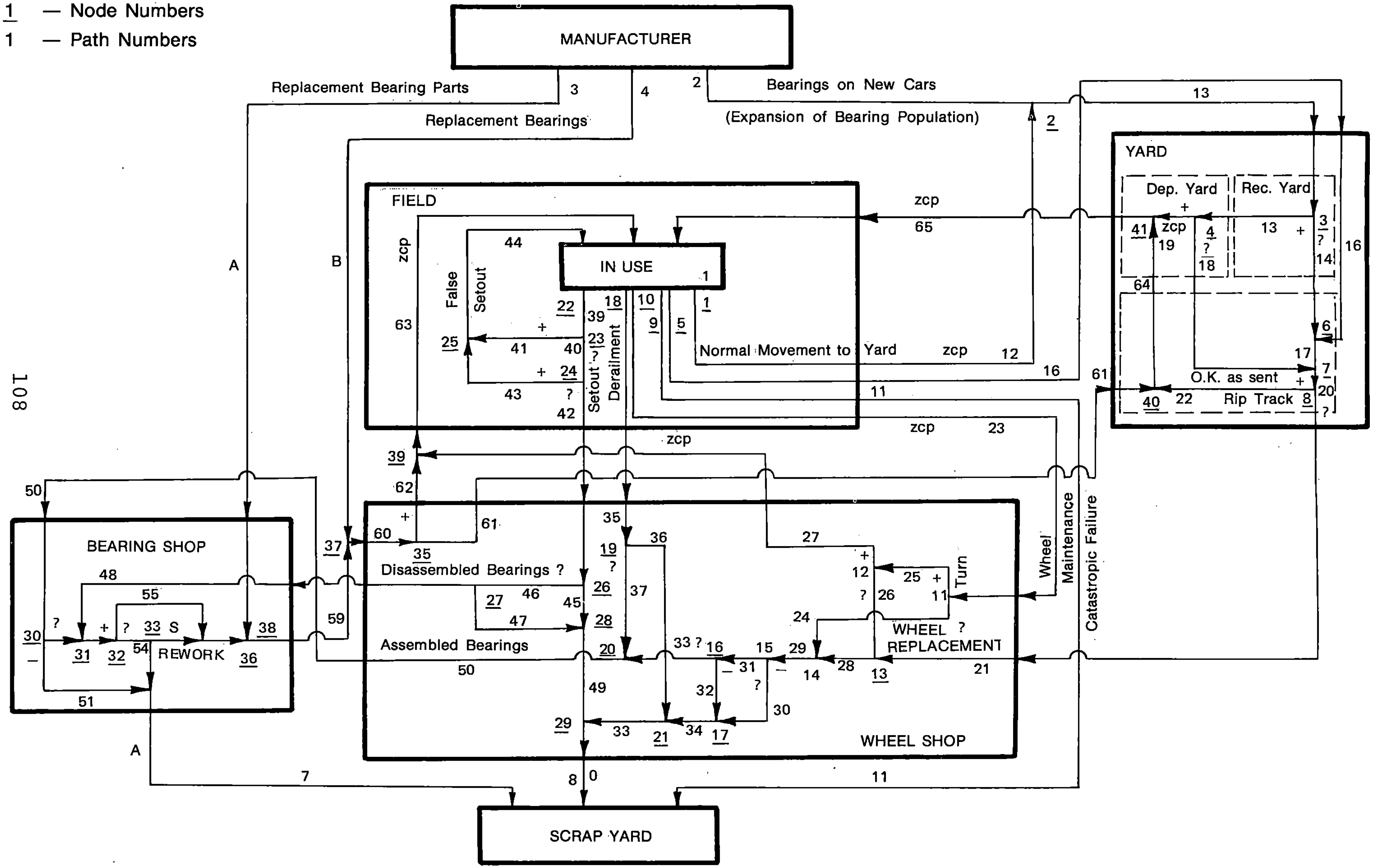
The simulation approach, on the other hand, follows the usage of the component throughout the railroad system, computing costs per year on the basis of various costs, usage decisions and other factors. Through an inherent ability to isolate sample data sites, the simulation methodology eases data requirements. The simulation methodology was therefore selected for further development.

Simulation cost models were developed for four components: wheels, roller bearings, bolsters, and sideframes. The models determined both yearly costs and the sensitivity of those costs to various decisions made during the life of the components. For instance, changes in maintenance schedules, usage rates or other factors can greatly alter yearly costs. The amounts of such alterations were considered by the models as well as the "base costs" of component usage. Typical flow charts for simulation costing of a bearing shop are shown in Figures 23A, 23B and 23C. The simulation costing methodology will continue to be used during Phase III.

FIG. 23A

SIMULATION COST MODEL FLOW CHART

zcp — Zero Cost Path
1 — Node Numbers
1 — Path Numbers



zcp — Zero Cost Path
1 — Node Numbers
1 — Path Numbers

FIG. 23B

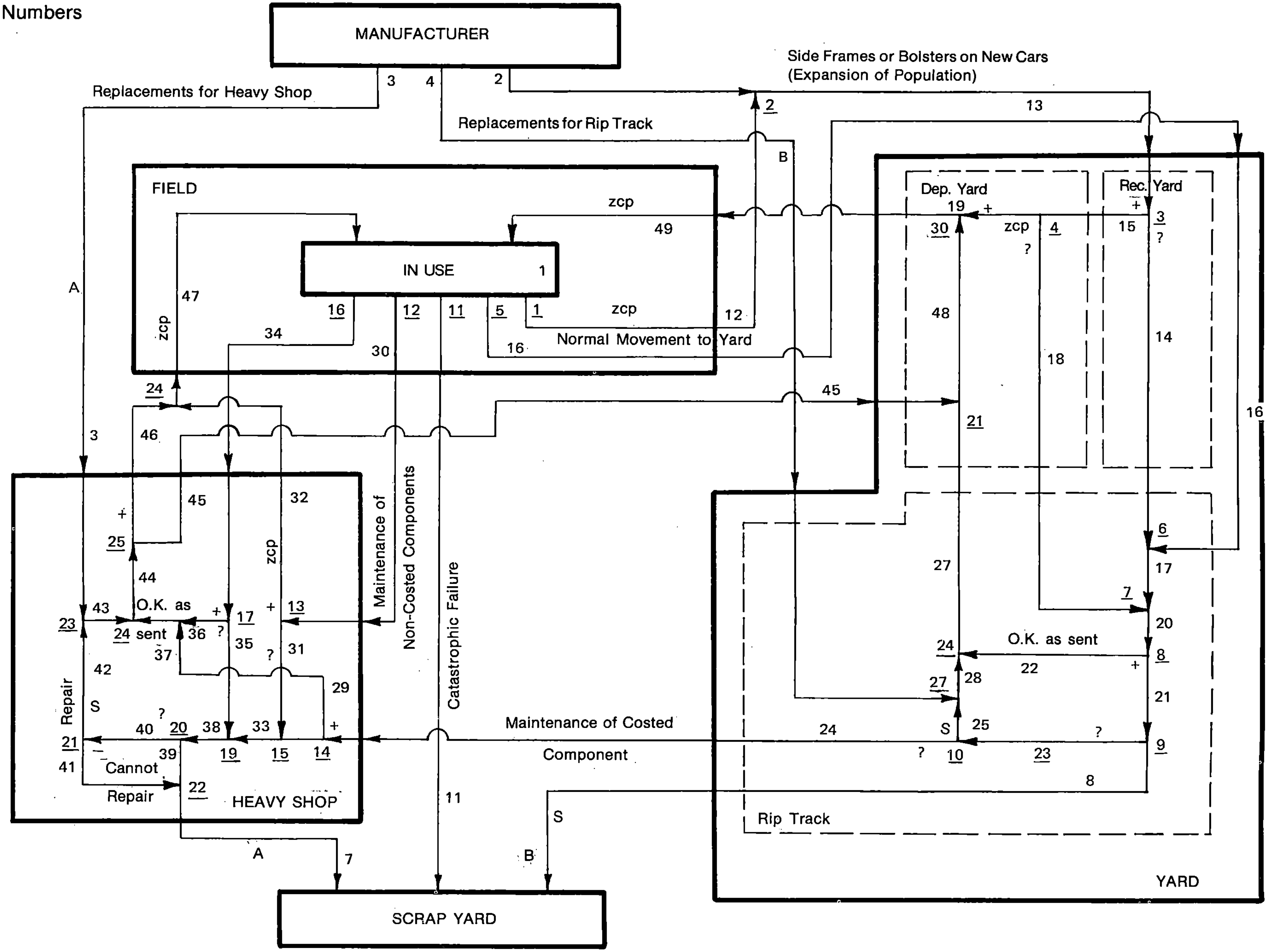
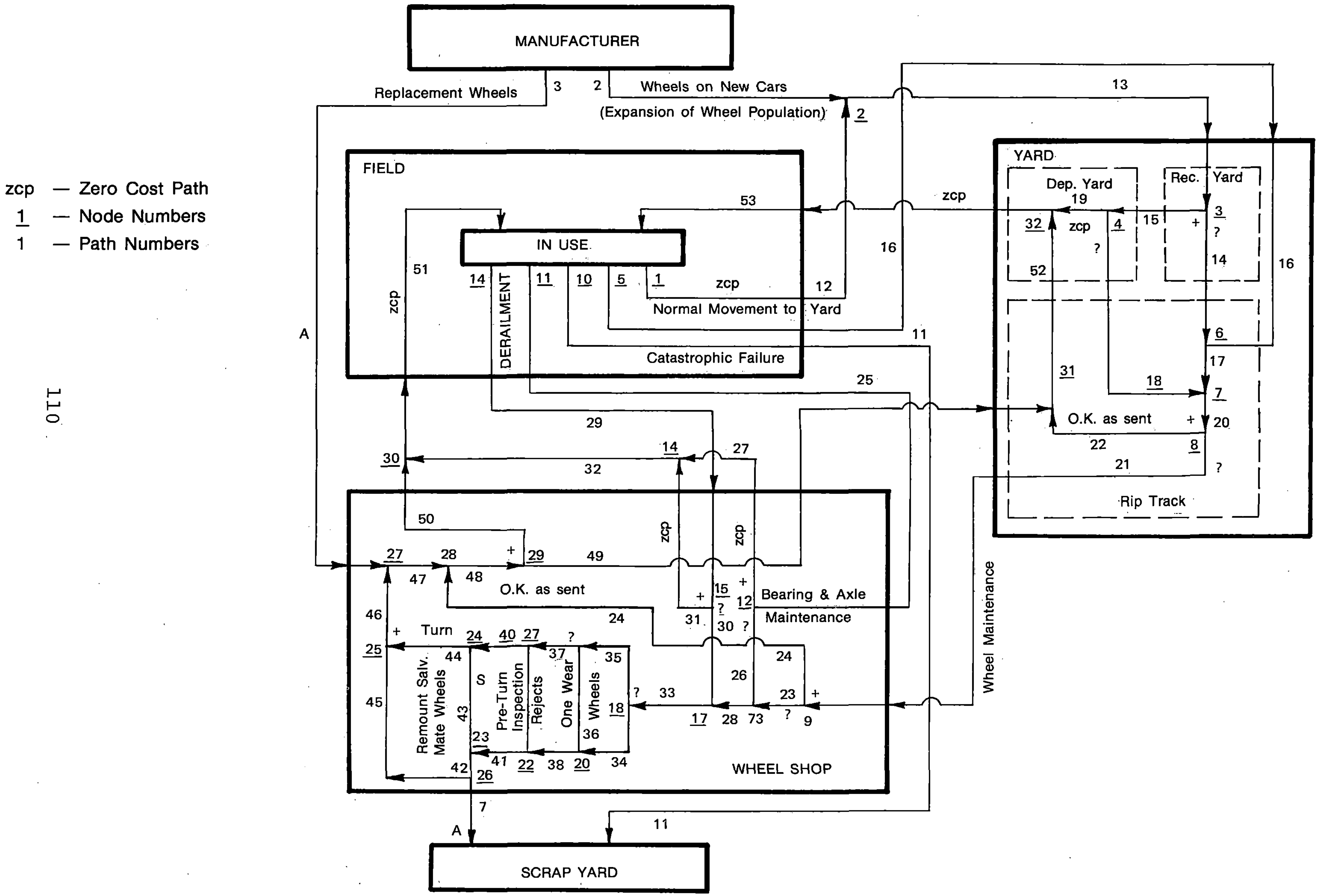
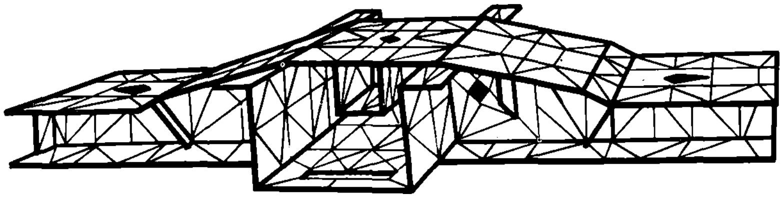


FIG. 23C


zcp — Zero Cost Path
1 — Node Numbers
1 — Path Numbers
MANUFACTURER
Replacement Wheels
3
2
Wheels on New Cars
(Expansion of Wheel Population)
2
13
YARD
Dep. Yard
19
Rec. Yard
3
+
?
zcp
32
4
15
?
14
52
16
6
17
31
18
7
O.K. as sent
+
20
22
8
21
?
Rip Track
FIELD
53
zcp
IN USE
51
zcp
14
DERAILMENT
11
10
5
1
zcp
12
Normal Movement to Yard
16
11
Catastrophic Failure
25
29
14
27
30
32
A
WHEEL SHOP
50
zcp
zcp
27
28
+
29
49
47
48
O.K. as sent
+
15
?
+
12
Bearing & Axle Maintenance
31
30
?
24
46
+
Turn
24
40
27
?
25
44
37
35
24
S
Remount Salv. Mate Wheels
Pre-Turn Inspection Rejects
One Wear Wheels
26
45
43
18
?
33
23
+
17
28
73
?
9
23
36
41
22
38
20
34
42
26
Wheel Maintenance
7
A
11
SCRAP YARD

TASK IX



ADVANCED ANALYTICAL TECHNIQUES

Task IX of Phase II was concerned with the furtherance of various methods of techniques of a more general nature than could be accommodated in the other tasks. Since it was felt that several of the Task IX efforts would essentially involve "state-of-the-art," it was given the name Advanced Analytical Techniques. The Manager for the Task was Dr. Gerald Moyar, of Brenco, Inc.

One of the two major work areas for the task was structural mechanics. In this area, the goal was to seek out, adapt and demonstrate for rail industry use, the best existing computerized design evaluation techniques. In the second area, materials science, collecting information and sponsoring research of fundamental significance to material design and component performance specification was carried out.

Dynamic Test and Analysis of a Flat Car Structure

This test was completed in 1976 at the DOT Transportation Test Center and subjected to an analytical correlation effort by a team of AAR, railroad and supply industry specialists. Volume I of this project illustrates the principles of dynamic structural analysis and provides a correlation of the analytical predictions and the experimental observations for the case of free vibrations. Volume II treats forced vibrations and illustrates the application to dynamic fatigue analysis. The possibility of additional tests in the TTC Rail Dynamics Laboratory, using the new Vibration Test Unit and Roll Dynamics Unit, was planned.

Interactive Graphics Structural Mechanics Program for Rail Industry Access

Since much engineering time is spent on data preparation and computer results interpretation, available non-proprietary computer systems that might be specially adapted to rail industry use was a primary interest. The GIFTS system developed by Professor Kamel at the University of Arizona may be such a system. This system has been implemented on AAR's new DEC 20 computer at the Chicago Technical Center. It was made available through remote terminal access by participating railroads and supply industries in 1978.

Structural Mechanics Computer Technology

Professor Walter Pilkey, a well-known authority in computerized structural mechanics, submitted to Task IX a consultant report which provides a good overview of existing technology and options for its transfer to the rail industry. His paper, based on this survey report, was included in the proceedings of a conference on Advanced Analytical Techniques and Design held September 27 and 28, 1977, in Chicago. (This book is available from AAR.) This conference, attended by some 160 individuals from the railroads, supply industries, universities and government agencies, featured many brief technical presentations on a range of advanced structural mechanics, dynamics and materials techniques, as well as a number of on-line interactive graphics computer demonstrations.

Application of Advanced Finite Element Stress Analysis Methods

Over the past few years, the AAR, government, ACF and Pullman Standard have sponsored some stress analysis development work of fundamental significance at Washington

University in St. Louis, under the direction of Professor Barna Szabo. An application of the theory, developed for such a "second generation" stress analysis (finite element) method, to produce an efficient computer code for welded plate structures, was undertaken with sponsorship by Task IX. The success of a fundamentally more satisfactory mathematical approach is illustrated in the much simpler (coarser) finite element model needed for structures like car body bolsters and the improved accuracy obtainable for reduced cost and time over conventional programs. Professor Szabo has summarized this research in the above-mentioned proceedings. The great strength of the method is in dealing with structural discontinuities and regions of stress concentration. Thus it is especially appropriate for advanced treatment of fracture and fatigue analysis.

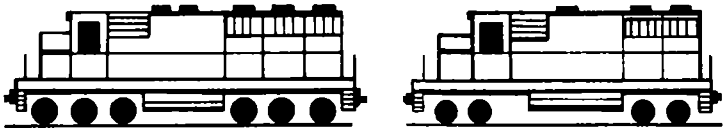
Basic Wear Research

Contract work was undertaken at both the Illinois Institute of Technology by Professor Sudhir Kumar and at Clemson University by Professor Warren Jamison (now at the Colorado School of Mines) to explore the basic wear mechanism and suitable material property tests needed to improve material specifications for wheels, rails, center-bowls, etc. It was believed they would improve our ability to extrapolate from laboratory tests with analytical models to predict service wear. The FAST track experiment provided a good benchmark test for this effort.

Cyclic Plasticity Effects in Wheel Stress Analysis

In support of stress analysis work being contracted by Task II at Battelle Labs, a critical examination of the limitations of current plasticity and computational approaches in application to the complex cycle and changing state of stress created by the combination of rolling mechanical load and drag braking thermal loading was undertaken. In this area, the frontier of mechanics of materials knowledge was probed. Since the dominant effect seems to be thermal loads due to braking, this isolated situation is first being studied analytically and experimentally.

TASK X



LOCOMOTIVE SPECIAL STUDY

The Locomotive Special Study was not originally a part of the Phase II effort. The Track/Train Dynamics Steering Committee had decided to limit research to freight cars, equipment and track. However, it was added by the Steering Committee after a request from the Penn Central Railroad.

The question had arisen as to whether six-axle locomotives are more apt to derail than four-axle locomotives. Several railroad officials felt they were, while others had reported no indication that such was the case.

The Locomotive Special Study group contacted 13 U.S. and Canadian railroads and studied thousands of derailments, of which less than 200 involved locomotive derailments of the type under consideration.

The results of the study were viewed as non-conclusive by the study group. For instance, many railroads restrict six-axle locomotives to main lines, while placing four-axle locomotives on the less used, less maintained, sections of track. So when the data indicated that most four-axle derailments occurred at speeds under 21 mph and most six-axle derailments at higher speeds, it was not clear if this was due to an increased derailment tendency or was merely a reflection of the fact that the six-axle locomotives were restricted in their operations. Thus, the results of the accident investigation study were not given general distribution by the Steering Committee because of a lack of adequate accident data.

The Track/Train Dynamics Steering Committee directed the Locomotive Special Study group to take on a new direction in the creation of a locomotive/car mathematical model. The model would be used in parametric studies to evaluate derailment tendencies. The model developed includes a mathematical description of the first car trailing the locomotive.

The locomotive model itself, shown in Figure 24, consists of a locomotive body mounted on two trucks. The body is assumed to be rigid and has three translational degrees of freedom (lateral, vertical, and longitudinal) and two rotations (yaw and roll). Each truck frame has vertical, lateral, yaw and roll motions, making it eight degrees of freedom for two trucks. Each wheel-axle set also has vertical, lateral, yaw and roll motions, thus giving a total of twenty-four degrees of freedom. The complete locomotive model thus has thirty-seven degrees of freedom. The car, which is coupled to the locomotive, has

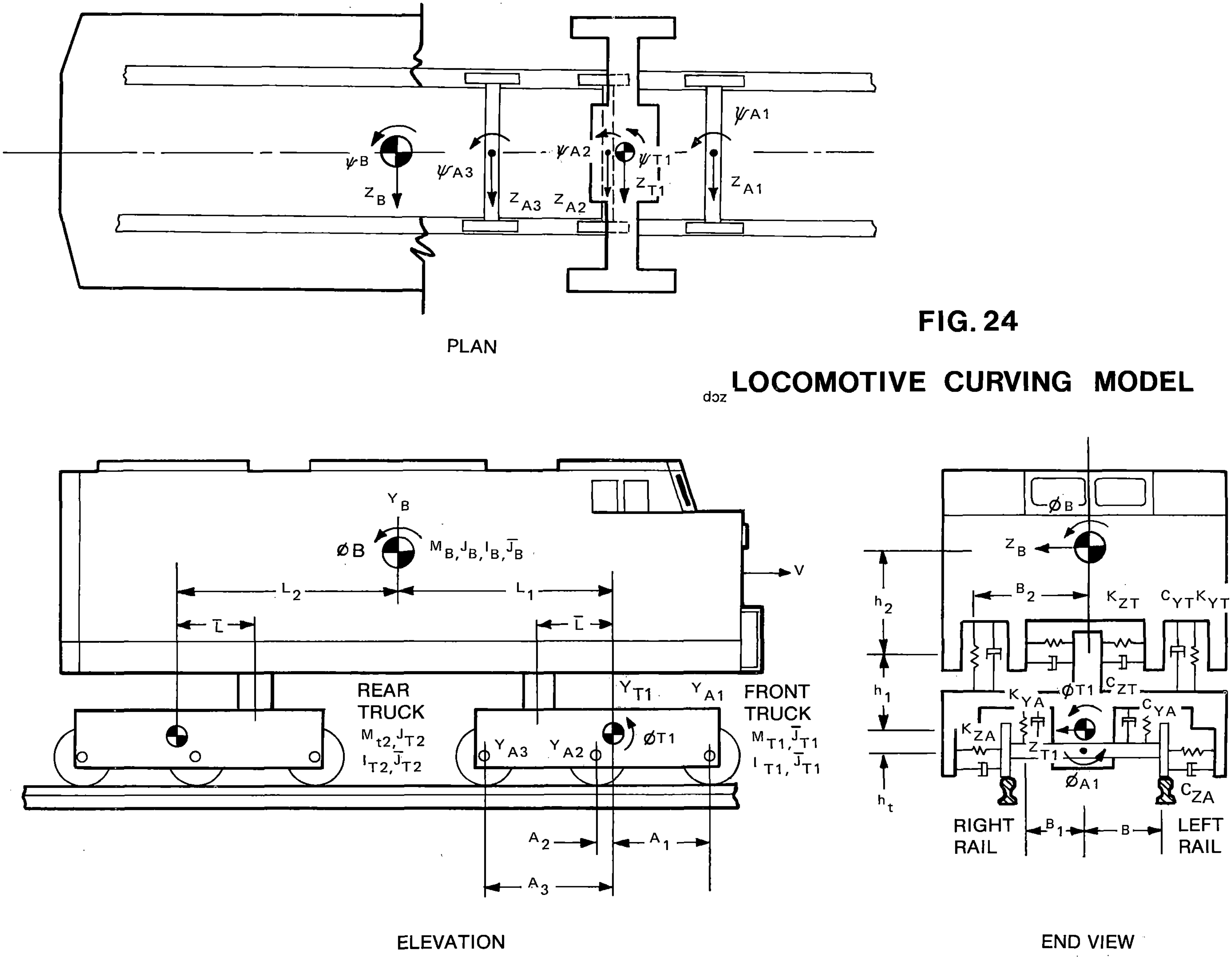


FIG. 24

LOCOMOTIVE CURVING MODEL

the car body and trucks assumed as one rigid mass. The car body has three translational degrees of freedom (lateral, vertical and longitudinal) and two rotations (yaw and roll). Each wheel-axle set has been provided four degrees of freedom in vertical, lateral, yaw and roll directions. The car model has twenty-one degrees of freedom. The mathematical model can simulate the locomotive alone or locomotive coupled to a car.

Amtrak Study

The Locomotive Study was originally freight-oriented, due to the direction of the entire Track/Train Dynamics program. However, following an Amtrak derailment at Ralston, Nebraska, on Burlington Northern track in late 1976, speed restrictions were placed by several railroads on the Amtrak trains using SDP-40F locomotives. These restrictions had such a drastic effect on Amtrak schedules that the AAR assigned its Research and Test Department to investigate SDP-40F behavior. The investigation was intended to determine, if possible, whether the Amtrak SDP-40F was, in fact, causing excessive forces on curves which could lead to derailment.

The Locomotive Special Study group conducted test runs on the Burlington Northern and Chessie System to evaluate the performance of the six-axle, SDP-40F locomotive as affected by track geometry.

As these tests were aimed at helping Amtrak understand the derailment problems, the test runs were prepared in such a way as to duplicate the consist of the train that derailed on the Burlington Northern line at Ralston, Nebraska. That duplication went so far as to include the same locomotives that were involved in the Burlington Northern derailment (No. 586 leading and No. 620 trailing).

The test consist is shown in Figure 25. Note that on this figure certain cars have two numbers or names shown. Those numbers or names in parentheses apply to the Chessie consist, whereas the others apply to the Burlington Northern consist. Instrumentation of the SDP-40F is shown in Figures 26 and 27. Instrumentation for Amtrak baggage car A-1025, trailing the locomotive, is shown in Figures 28 and 29. The Burlington Northern test consist had the BN Track Geometry Car B-9 for most of the test run on the BN. Data from the B-9 sensors were recorded on the AAR-100 simultaneously with locomotive data. Location of the BN B-9 is shown in Figure 25. With this arrangement, and with the use of a capacitive type automatic location device (ALD) supplied by ENSCO and mounted on the AAR-100, it was relatively easy to determine the cause/effect relationship between locomotive and track. For example, whenever a

FIG. 25

LOCOMOTIVE TEST CONSIST

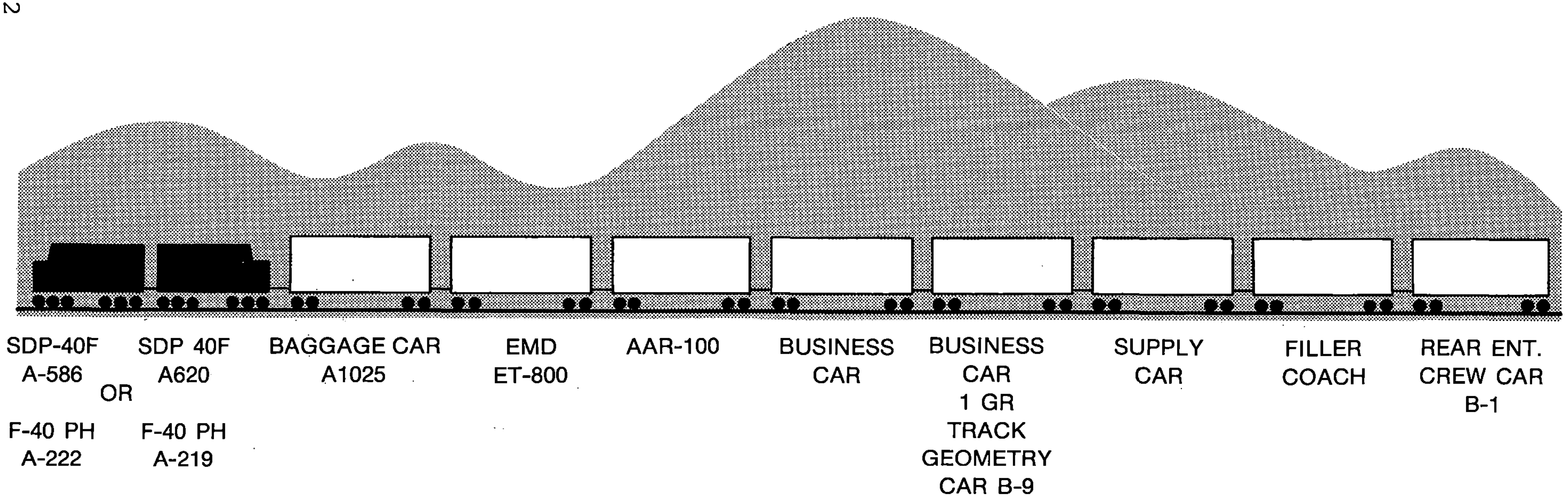
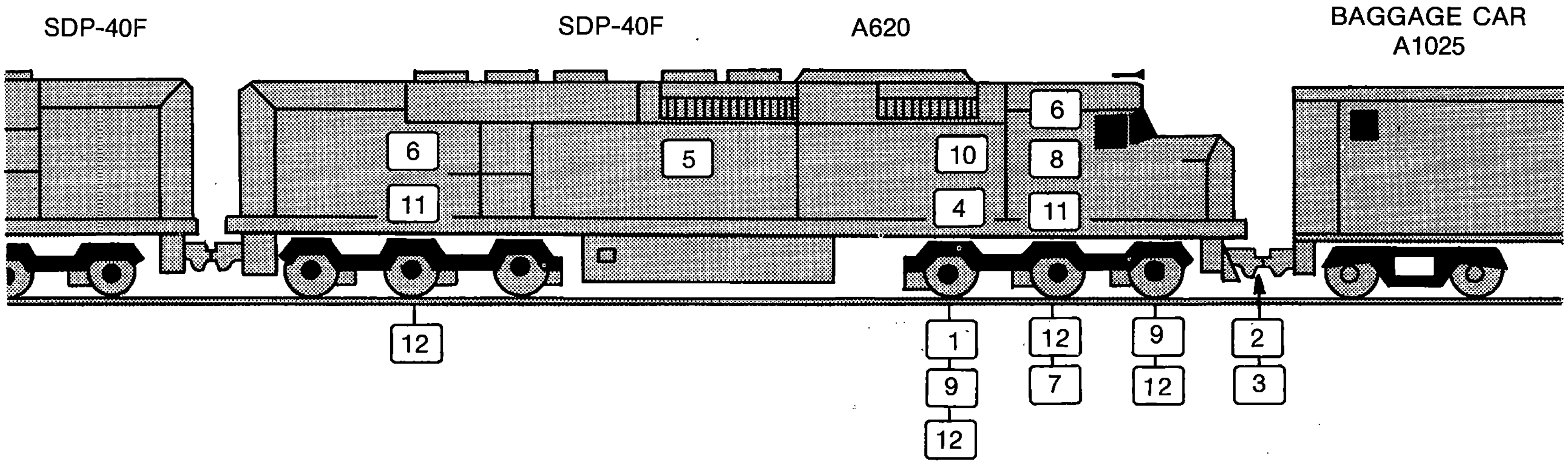


FIG. 26

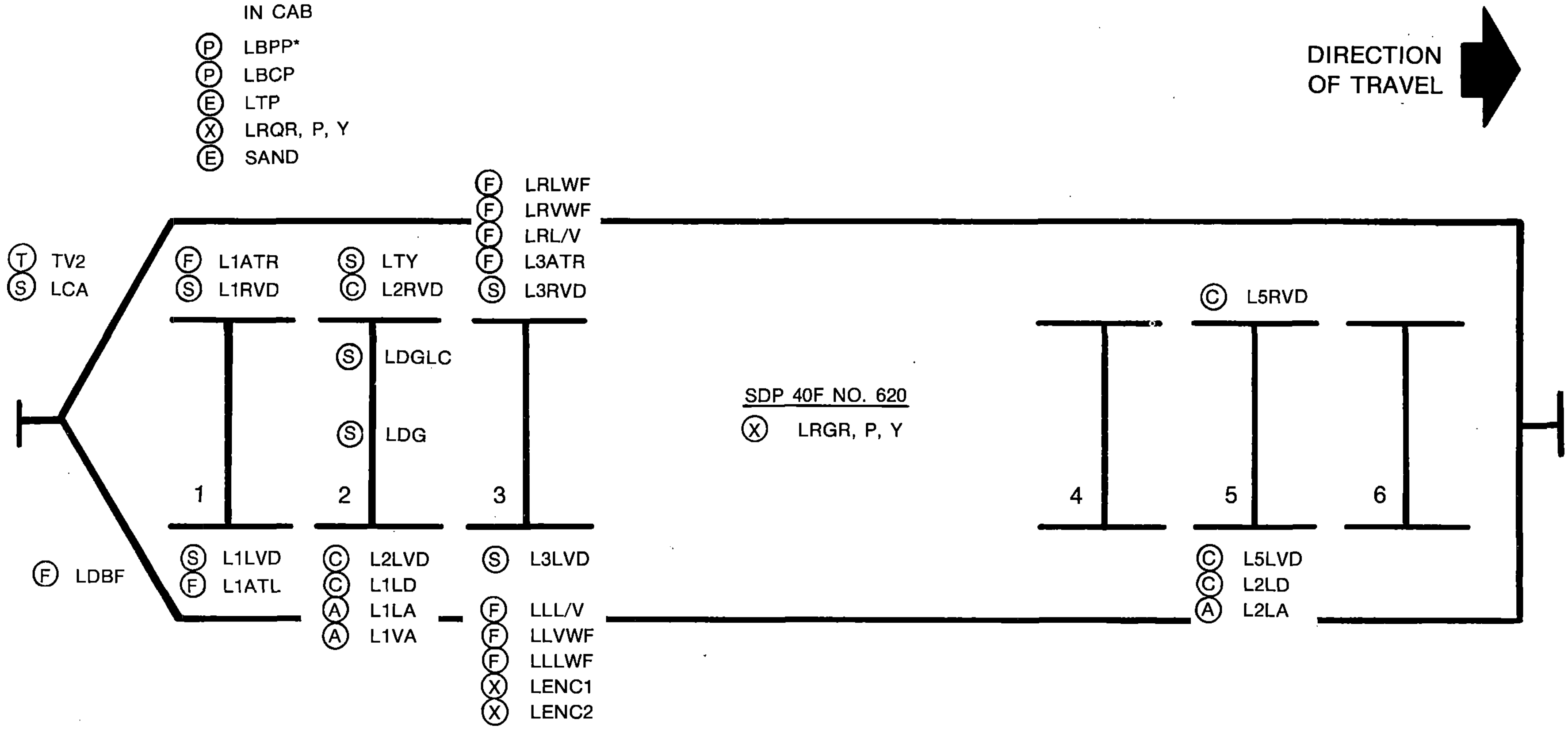
LOCOMOTIVE INSTRUMENTATION SIDE VIEW



1. Instrumented Wheel/Axel Set (Lateral & Vertical Force)
2. Instrumented Coupler (Vertical, Longitudinal Force)
3. Coupler Angle
4. Train Line & Brake Cylinder Pressure & Throttle Position
5. Pitch, Roll and Yaw of Carbody
6. Lateral Acceleration of Carbody
7. Dynamic Gage Measurement
8. Truck Yaw
9. Axle Thrust Load
10. Ride Quality
11. Lateral Displacement
12. Lateral/Vertical Displacement

FIG. 27

LOCOMOTIVE INSTRUMENTATION TOP VIEW

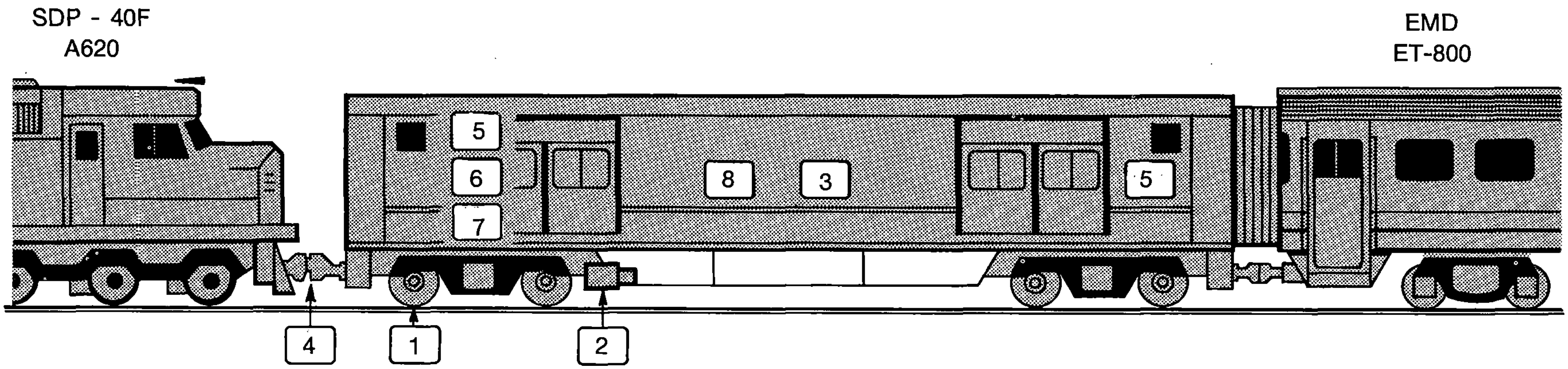


LEGEND

Ⓐ PIEZO RESISTIVE ACCELEROMETER
Ⓒ CANTILEVER DISPLACEMENT TRANSDUCER
Ⓔ ELECTRICAL TRANSDUCER
Ⓕ FORCE TRANSDUCER
Ⓟ PRESSURE TRANSDUCER
Ⓣ TELEVISION
Ⓧ SPECIAL TRANSDUCER
* MONITORED BY EMD ONLY

FIG. 28

AMTRAK BAGGAGE CAR INSTRUMENTATION SIDE VIEW



1. Instrumented Wheel/Axle Set (Lateral & Vertical Force)
2. Brake Cylinder Pressure
3. Pitch, Roll & Yaw of Carbody
4. Coupler Angle
5. Lateral Acceleration of Carbody
6. Truck Yaw
7. Lateral Displacement
8. Ride Quality

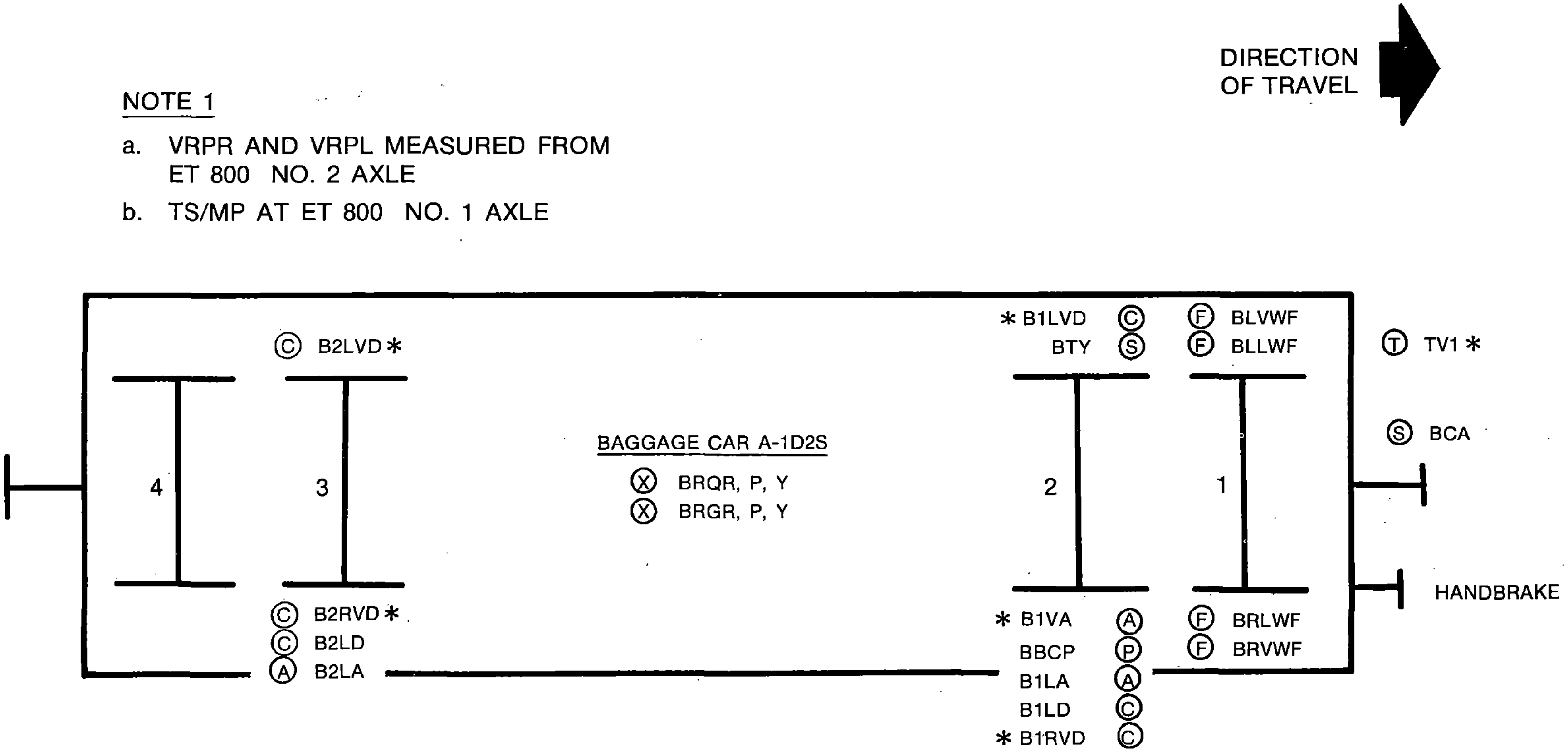
FIG. 29

AMTRAK BAGGAGE CAR INSTRUMENTATION TOP VIEW

NOTE 1

a. VRPR AND VRPL MEASURED FROM ET 800 NO. 2 AXLE

b. TS/MP AT ET 800 NO. 1 AXLE



LEGEND

Ⓐ PIEZO RESISTIVE ACCELEROMETER
Ⓒ CANTILEVER DISPLACEMENT TRANSDUCER
Ⓕ FORCE TRANSDUCER
Ⓟ PRESSURE TRANSDUCER
Ⓢ STRINGPOT DISPLACEMENT TRANSDUCER
Ⓣ TELEVISION
Ⓧ SPECIAL TRANSDUCER
MONITORED BY EMD ONLY

significant response was noted on the equipment, and by taking into account the physical separation between B-9 and equipment sensors, a particular track condition could be studied in conjunction with equipment response, simply by reviewing data records. With the track geometry record available, and by noting milepost or ALD signal, one could then return to the specific location where the response was noted.

The test train consist began its run at Minneapolis, traveled through North Dakota, Montana, Idaho, and into Seattle, Washington.

The runs were initially made at maximum speeds of 60 mph on tangent track and 40 mph on curves of 2 degrees or more. At halfway points in the trips, speed restriction on curves were raised 5 mph. Speeds were raised in increments of 5 mph to a maximum of 60 mph on curves of 2 degrees or greater. This was done to allow detection on the dynamic performance of the equipment as affected by speed and track irregularities. (The critical speeds of interest to Amtrak were in the 45-60 mph range.)

With data collected over 5,000 miles of test runs, along the route shown on Figure 30, three sites were selected where relatively high levels of equipment response had been noted. Repeated runs were made at the test sites using various operating procedures, after which a four-axle

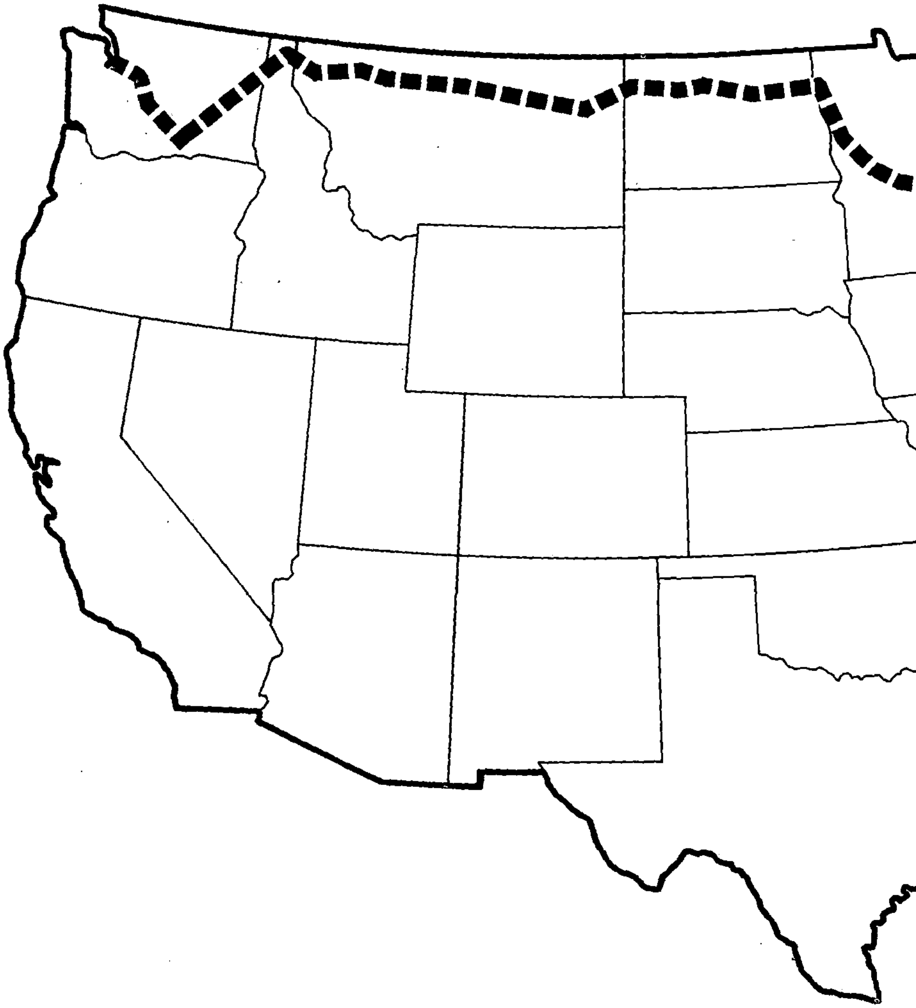


FIG. 30

LOCOMOTIVE TEST ROUTING ON B-N

locomotive (F40PH) was substituted for the six-axle SDP-40F. This substitution was made for comparative purposes at the request of the FRA. The test runs were then repeated and data sent to the AAR for study.

The test consist then returned to the Chicago area and plans were begun for further test runs on sections of Chessie track on which two of the derailments had occurred.

New factors were added for the Chessie tests, including trackside instrumentation, mismatched wheel diameters and shimming of a test truck to simulate a mismatched wheel diameter.

The tests were run at a site near Clifton Forge, Virginia, after trial runs were completed on a larger track section stretching from Huntington, West Virginia, to Charlottesville, Virginia.

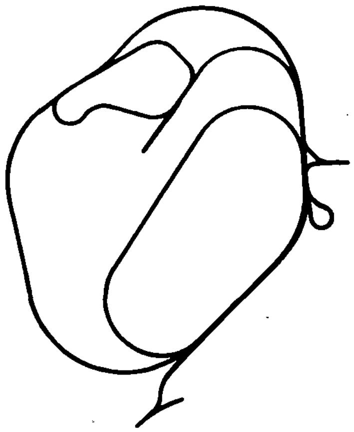
Data from this study also were sent to the AAR for analysis.

Locomotive Model Validation

The locomotive equipment model described above was to be validated under the Phase II effort during late 1978 and early 1979, using instrumentation similar in many respects to that used for the Amtrak equipment tests.

TASK XI

FACILITY FOR ACCELERATED SERVICE TESTING



The type of studies being conducted under the Track/Train Dynamics program present several trade-offs to researchers. First, because the operation of a train includes so many dynamic interactions, it must be possible to measure all the major forces developed if any experiment is to be complete and informative. Experience has shown static tests to be insufficient for accurately projecting dynamic force limitations of equipment, so tests must be taken out of the laboratory and conducted in the field. But field tests present other difficulties. New equipment is the exception and not the rule in service revenue operations, so equipping test trains and track with new components will not recreate service conditions. Using older equipment presents a problem in that the previous load and service levels of that equipment cannot be documented, as could be done with new equipment.

The best approach for combining realistic dynamic interactions with laboratory test controls is to have a special track and train on which the deterioration of new equipment could be measured over time. With equipment designed, as present-day railroad equipment is, for hundreds of thousands or millions of miles of service life, even these tests would take excessively long periods, unless conducted almost continuously.

This is the function of the Facility for Accelerated Service Testing (FAST), a 4.8-mile track loop constructed at the Department of Transportation Test Center in Pueblo, Colorado.

Like the Locomotive Special Study, the FAST track was not originally included in the Phase II program. The AAR had been studying the use of such tracks in Czechoslavakia and the USSR since 1972 and cooperated with the Federal Railroad Administration in finalizing plans to build such a facility in late 1975. At that time, it was decided that planning and coordination would become part of the Track/ Train Dynamics program.

FAST was constructed at the Transportation Test Center during 1976 and operations began at the facility during that year. The rapid progress from concept to implementation is a fine example of the accomplishments that can be made with government, industry and supplier cooperation. Most of the track and equipment were provided by individual railroads and by suppliers through the Railway Progress

Institute. Analysis and coordination were provided by the AAR, site and funding through the FRA, and staffing came from all aspects of the railroad industry and government.

The placement of the track in the Transportation Test Facility, shown on Figure 31, allowed the rapid creation of FAST with the least disruption to the other operations at Pueblo. The loop, containing 1.8 miles of new track and using 3 miles of existing track, is maintained near FRA Class 4 standards, while operating about 16 hours per day--10 times the traffic density on many main lines and 15 times the average traffic density of U.S. lines.

As shown in Figure 32, the track loop is divided into 22 sections, each of which contains different types or combinations of ties, ballast, rail, joints or spikes, and on various degrees of curvature. The track profile is shown in Figure 33.

In brief, the track sections were designed to test: No. 20 turnouts; rubber pads under tie plates on wood ties; rail metallurgy; tie plate cant; spiking patterns; ballast shoulder width; bonded joints; steel ties; rail/tie fasteners; reconstituted and laminated ties; spring frogs and guard rail; joints; standard frogs and guard rails; spike hole filler; a glued-joint turnout; concrete ties; tie pads; ballast depth effects; hardwood versus softwood ties; ballast types and depths; rail anchors; welded turnout;

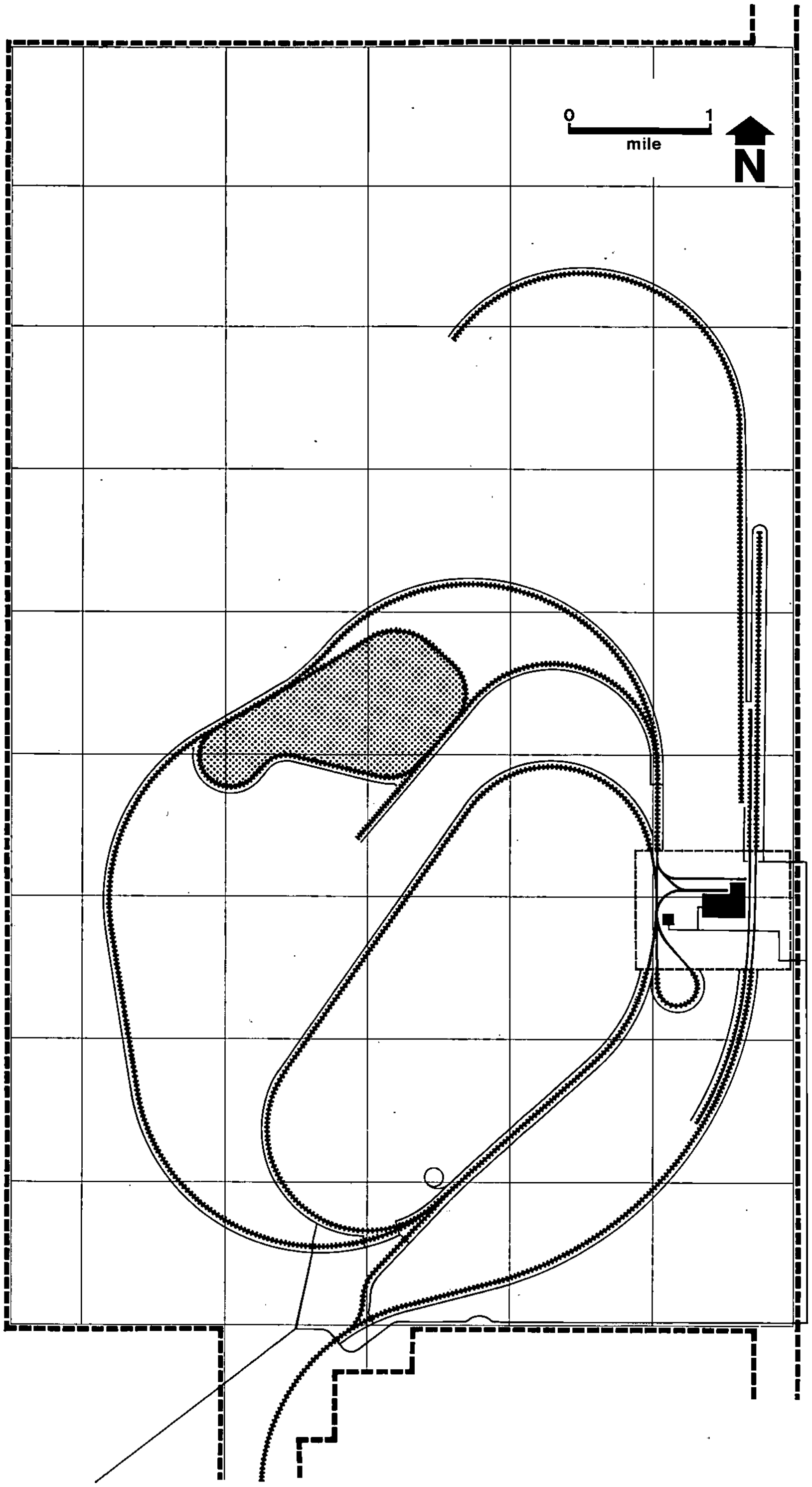
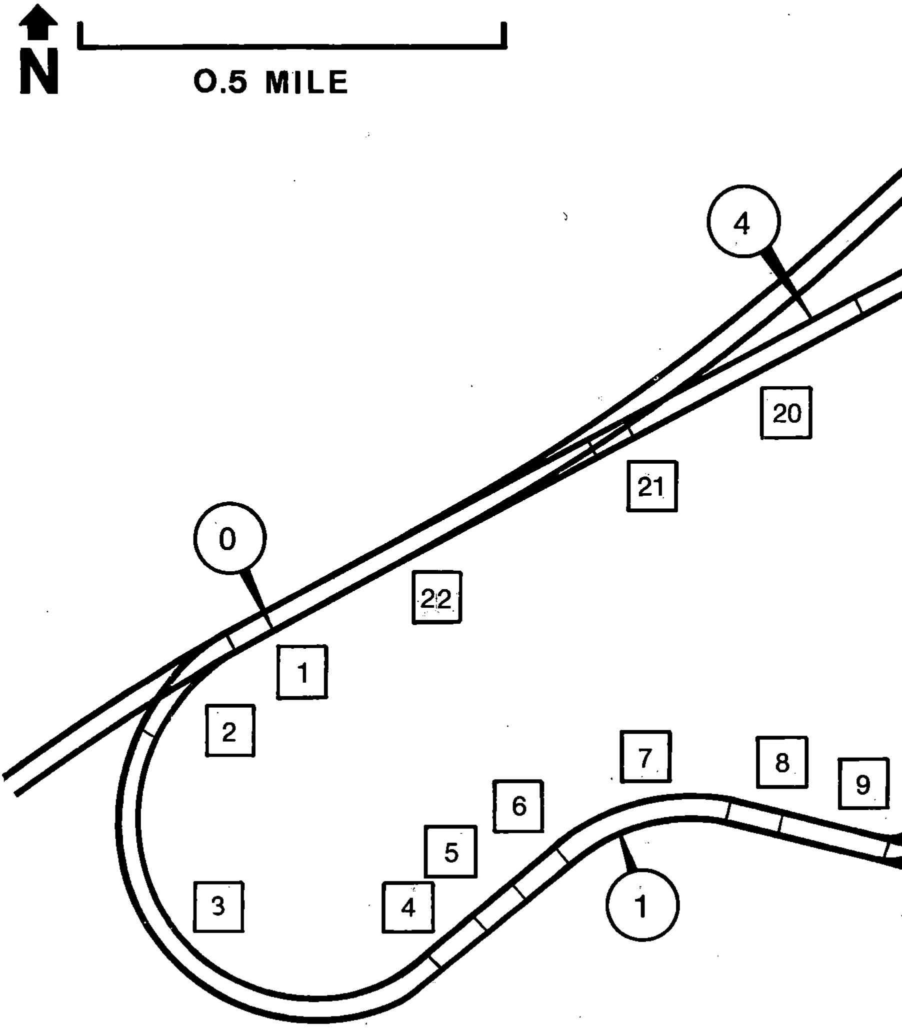


FIG. 31

"FAST" LOOP PLAN

FIG. 32

“FAST” TEST SECTION



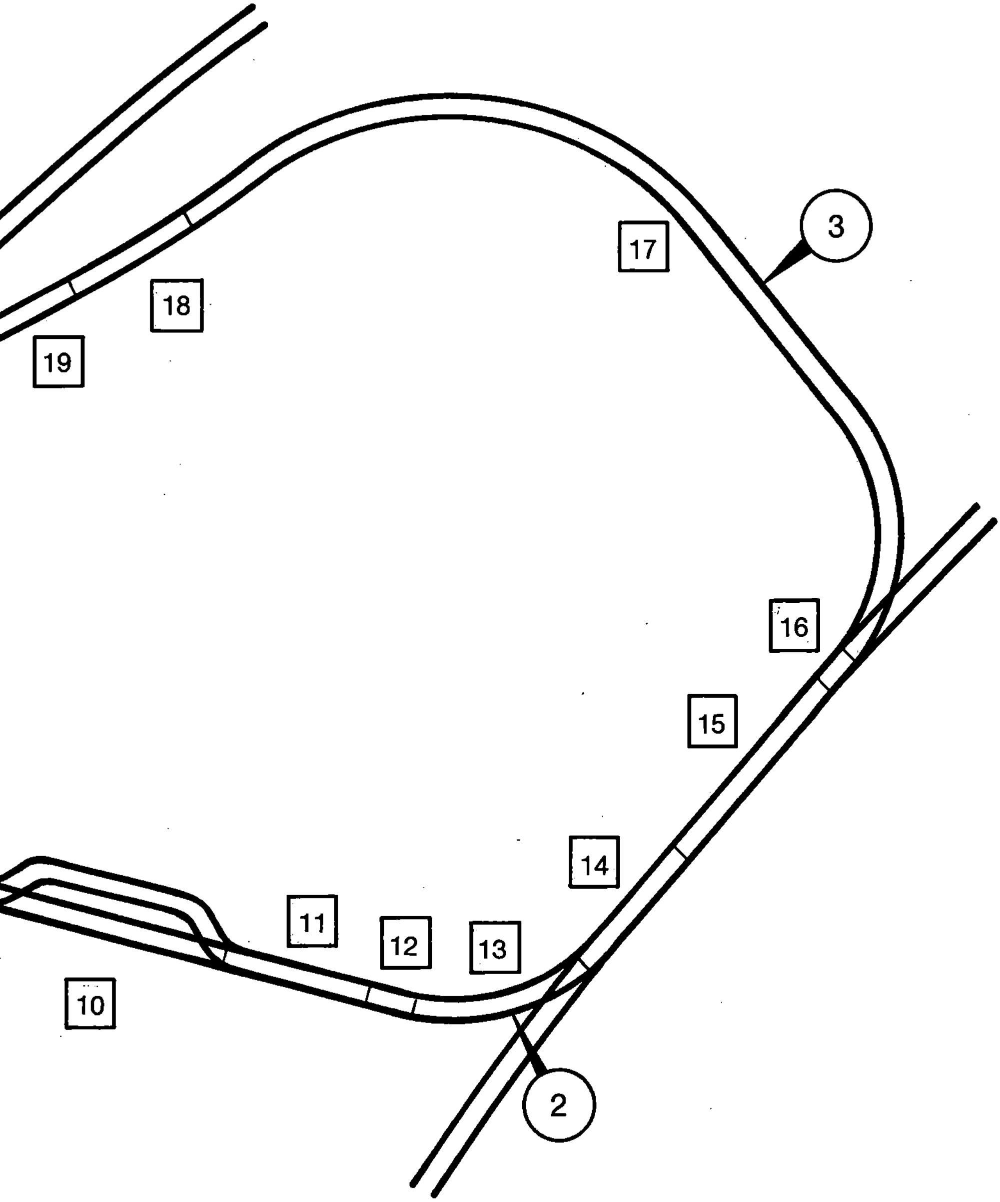
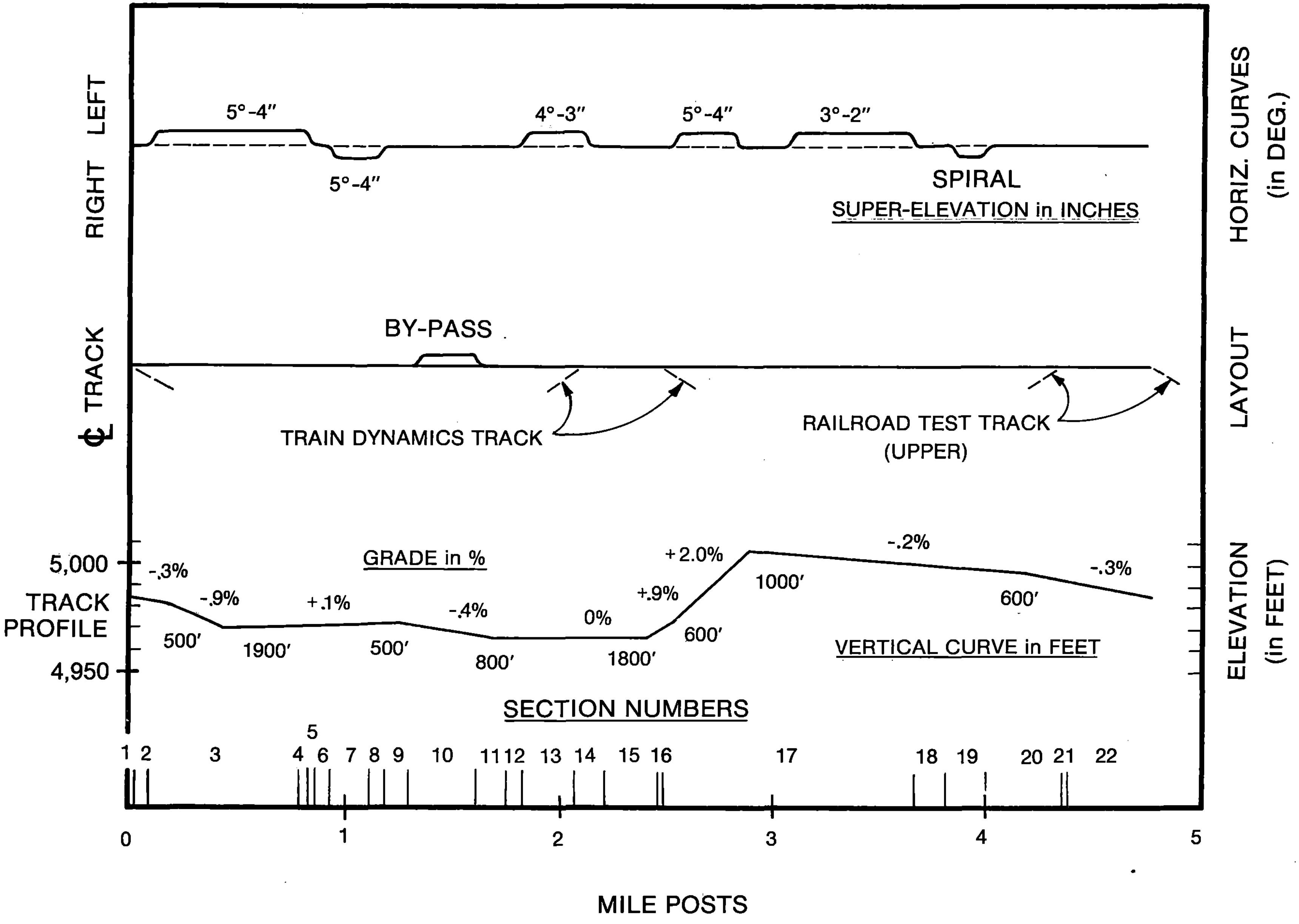

3
17
18
19
16
15
14
11
12
13
10
2

FIG. 33

“FAST” TRACK PROFILE



and spiking patterns.

The following pages provide more detailed descriptions of the components of the test track sections.

FAST was dedicated on August 20, 1976, and the first test runs were performed on September 22 of that year--less than 10 months after construction had begun.

After shakedown runs, operation began with a 75-car consist of 100-ton cars, mostly fully loaded and pulled by a set of four, four-axle locomotives, running about 16 hours per day five days per week. The train is reversed to move in both directions around the track, completing a four-step cycle of turnarounds and reverses once in every four days. By changing the directions and placement of the cars regularly, wear was distributed more evenly among the cars and the track.

Even, but excessive, flange and rail curve wear developed quickly on the FAST track and train. The facility permits continuous operations under controlled conditions but, because it is a short test loop, it contains a substantially greater percentage of curved track (54%) than almost any revenue train is likely to encounter. This permits extensive study of curve problems, but also leads to the rapid development of excessive wheel/rail wear. To correct this problem, added lubrication was applied at several locations to slow the rate of wear.

The FAST loop cannot duplicate revenue conditions in other ways. The climatic conditions, such as temperature and humidity at the test site, are not quite as extreme as those encountered in other regions of the U.S. and Canada. Materials become more brittle in sub-zero temperatures increasing their susceptibility to fracture; and humid salt air causes corrosion, which increases stress levels on structural components. These factors cannot be provided at Pueblo.

The consist operates on the FAST loop at an average speed of 45 mph, whereas in some revenue service, a mix of varied train speeds would more than likely be encountered. The truck hunting condition normally occurs at speeds in excess of 45 mph. Therefore, the effects of this phenomenon cannot be evaluated on the present loop.

However, it has been possible to develop meaningful analysis of test data by taking the limitations of the track into account when significant.

Besides rapid wheel/rail wear, other results also developed quickly. Inspection of section 6, containing steel ties, indicated cracking at fastening points. All steel ties were removed from the track early in the test for inspection. They were replaced by standard wood ties.

Similarly, rail breaks and near rail breaks were also common. After 14,924 miles were accumulated by the train, fifteen rail breaks or near breaks had developed. To improve the quality of repairs conducted by Transportation Test Center personnel, Southern Railway provided an instructor to train FAST workers in the art of rail field welding.

In section 3, standard rail was replaced with premium rail, as rapid wear rates occurred. Thin flanges also developed quickly and often. Wheel rim cracking was traced to fatigue, due to the way in which rims contacted worn rail.

Excessive wear and breakage also developed on switch points in two sections, leading to the installation of manganese tips to those switches.

The FAST loop experienced a derailment on February 24, 1977. An empty tank car derailed to the outside of section 3 and continued through a half-mile of track into section 2 before rerailing itself at the frog of the turnout in section 1. The derailment broke a spacer block and damaged a guard rail, but no injuries were reported. Needless to say, the accident was given quick and complete study.

In the first six months of operation, the FAST loop accumulated 61 million gross tons of load and the train covered 31,539 miles of travel. The heavy usage and quick wear of equipment proved extremely valuable in even that short time. The discovery of steel tie failures in FAST operation led to a subsequent review of revenue service installations of such ties and a determination that a design weakness was responsible. The development of that flaw by the FAST study came in one-tenth the time it would have taken for the problem to develop in revenue service--and it was discovered much more quickly than such a problem could be discovered in internationally dispersed operations.

Similarly, a manufacturer of roller bearings was able to eliminate one design and develop a screening test to prevent similar problems after leaks were found in seals. The preferability of alloy springs over carbon springs was affirmed through FAST testing.

The first series of FAST tests, using 100-ton cars and four-axle locomotives, was extended until 400-500 MGT were accumulated on the loop. Following that series, four other tests were planned for the 4.8-mile loop.

Test 2 -- 70-ton cars with four-axle locomotives
Test 2a -- 70-ton cars with six-axle locomotives
Test 3 -- 50-ton or empty cars
Test 4 -- mixed trains

The FAST group also has begun developing plans for design of a FAST Loop II, a 15-20 mile section including more tangent track than the original loop allowing tests of truck hunting and other phenomena not completely studied under the FAST program so far.

PHASE II

PUBLICATIONS

TRACK STRUCTURES - MINIMUM TANGENT LENGTH BETWEEN REVERSE CURVES FOR SLOW SPEED OPERATION (R-228)

A Quasi-Static Lateral Train Stability Model program was used to determine maximum lateral/vertical force ratio on reverse curves from 6 degrees through 16 degrees with no spiral or superelevation. Previous AAR recommendations were substantiated.

EFFECTS OF SPIRAL LENGTH ON REVERSE CURVES WITH MINIMUM TANGENT LENGTH FOR SLOW SPEED OPERATION (R-309)

Reverse curves from 6 degrees to 14 degrees with minimum tangent length and no superelevation are studied. Test train consists operated at speeds equivalent to 3 inches of unbalanced superelevation. Quasi-Static Lateral Train Stability program used to determine maximum L/V ratio and maximum coupler lateral angles; information therefrom analyzed as to effect of spiral length.

STUDY OF THE EFFECTS OF SPIRAL LENGTH ON SIMPLE CURVE NEGOTIATION (R-355)

In this study various spiral lengths with variations in amounts of superelevation are studied. Various spiral lengths are correlated with given superelevations in order to reduce maximum L/V ratios and coupler angles.

EFFECTS OF TRACK GEOMETRY ON DYNAMIC RESPONSE OF A RAILWAY VEHICLE ON TANGENT TRACK (R-377)

The effect of various irregularities in track geometry on the rock and roll behavior of freight cars has been studied for 3 different types of cars. Irregularities include rail profile, gage, warp and alignment errors. These errors were studied individually and in combination. Certain conclusions are made about the magnitude of the errors to avoid extreme loading on vehicle components resulting from adverse rock and roll behavior.

RAIL ANALYSIS, VOLUME I - FRACTURE MECHANICS (R-225)

Describes fracture mechanics model for rail head transverse defects-detail fractures from rail shelving. Model applied to predict with reasonable agreement the failure strength of 71 rail segments rejected by inspection, removed and tested in 3-point loading by AAR.

RAIL ANALYSIS, VOLUME II - ENGINEERING COST-RISK ANALYSIS OF DEFECTIVE RAIL (R-265)

This report develops a program that is aimed at reducing costs associated with rail failures and defects.

RAIL ANALYSIS, VOLUME III - STATISTICAL ANALYSIS OF RAIL DEFECT DATA (R-302)

Rail Defect Data from six locations on American railroads are summarized using Weibull probability distributions. Equations for defect occurrence as a function of traffic and stress are given.

RAIL ANALYSIS, VOLUME IV - METALLURGICAL EXAMINATION OF RAILS WITH SERVICE-DEVELOPED DEFECTS (R-300)

This report covers the failure analysis of 33 carbon steel rails with service induced detail fractures. All of the cracks investigated initiated at sharp internal notches such as non-metallic inclusions.

RAIL ANALYSIS, VOLUME V - FATIGUE AND FRACTURE BEHAVIOR OF CARBON STEEL RAILS (R-301)

This report gives the fatigue crack growth and fracture toughness properties of carbon steel rails. It concludes that cracks initiate at tensile strength level stresses.

RAIL OVERTURNING/GAGE WIDENING FIELD TESTS (R-323)

Report of testing where rail deflections in a track section were measured under combinations of vertical, lateral, and longitudinal loads. Certain longitudinal loads can be a major factor in causing "sudden" wide gage which can lead to rail overturning.

WHEEL RESEARCH, VOLUME I - ELASTIC STRESS ANALYSIS (R-268)

This document presents a three dimensional finite element computer program which can be used for an elastic stress analysis of a rail car wheel under mechanical and thermal loads.

SUSPENSION DYNAMICS, VOLUME I - TRUCK SUSPENSION (R-224)

First part of extensive parametric computer simulation studies of rail car roll and bounce as influenced by track stiffness, suspension snubbing, spring travel, high speed, and car center-of-gravity. Continues parametric studies started in Phase I.

SUSPENSION DYNAMICS, VOLUME II (R-350)

A parametric study of carbody and suspension system performance for freight car rock and bounce modes. Includes 70-ton box car, 100-ton open and covered hopper cars and a COFC car. Includes constant and variable column damped trucks.

SUSPENSION DYNAMICS, VOLUME III

A continuation of parametric study of Volume II with auxiliary damping characteristics added to the truck suspension.

VALIDATION TESTS FOR FLEXIBLE CARBODY MODEL

A description of validation tests with results compared to simulations using the Flexible Carbody Model.

WEAR RESEARCH, VOLUME I - CENTERBOWL/CENTERPLATE SURVEY

Survey made by Illinois Institute of Technology on the factors affecting wear and fracture of centerbowl and centerplates of freight cars. Various parameters identified with respect to materials used in components. Recommendations made concerning materials, design improvements, and lubrication of the system.

WEAR RESEARCH, VOLUME II - TANGENT TRACK

A preliminary analytical, parametric, and experimental investigation of the combined friction-creep and wear behavior of a simulated steel wheel on simulated tangent track under dry, tractive conditions. A dimensional analysis is made of the various parameters influencing friction and wear behavior. Interrelationship of creep, wear, normal load, hardness, toughness, roughness, and time have been derived to yield non-dimensional expressions. Reasonable agreement with experimental data.

WHEEL RESEARCH, VOLUME III - CURVED TRACK

Combined experimental and analytical program conducted to study mechanical wear of railroad wheel flanges and rail gage face during curve negotiation. A computer analysis predicts complex behavior on the mechanical environment with respect to different car loadings, car speeds, and wheel and rail profiles.

FREIGHT CAR HUNTING MODEL - USER'S MANUAL (R-251)

This document presents input-output information for a freight car system to study the hunting stability of the system. An example has been presented to aid the user in preparing input data.

USER'S GUIDE TO FATIGUE LIFE ANALYSIS PROGRAM (FLAP) (R-273)

This model describes the fatigue analysis technique outlined in the Interim AAR Guidelines for Fatigue Analysis of a Freight Car.

VALIDATION OF FREIGHT CAR HUNTING MODEL

A description of the validation tests with results compared to simulations using the Linear and Non-Linear Hunting Models.

TRUCK HUNTING MODEL VALIDATION FIELD TESTS (R-378)

This test was conducted to provide freight car dynamic response data for validating mathematical models for truck hunting. Document describes test operations, measurement methodology, and data collection equipment. The test vehicle was a 70-ton open top hopper car.

FREIGHT CAR DYNAMICS - DEMONSTRATION TEST AND ANALYSIS, VOLUME I - FREE VIBRATION STUDY (R-280)

Several structural idealizations (finite element models) of a flat car structure are analyzed for flexural and torsional mode shapes and natural frequencies. Results compare successfully with experimental data obtained at the DOT Transportation Test Center.

FREIGHT CAR DYNAMICS, VOLUME II (R-322)

Using finite element models reported in Volume I, a force vibration study was made with known acceleration time history input to generate dynamic stress history of a component which was used to predict fatigue life of components. These results are compared with the Ad Hoc approach used in the industry, for calculating fatigue life.

INTERIM AAR GUIDELINES FOR FATIGUE ANALYSIS OF FREIGHT CARS (R-245)

A fatigue design method for freight car critical locations is presented and illustrated, based on interim data on load history and fatigue properties in the form of modified Goodman diagrams for a range of typical structural details.

PROCEEDINGS OF CONFERENCE ON ADVANCED TECHNIQUES IN TTD AND DESIGN (R-289)

Contains 23 technical papers and related discussions (including cost/benefits) on general structural and dynamic analysis and testing of freight cars, components, locomotives, and track structure, as well as mechanics of materials investigations of wheel/rail fracture and wear. September 27-28, 1977, Chicago conference.

DIRECTORY - STRUCTURAL MECHANICS PROGRAMS (R-366)

A complete survey of structural mechanics computer technology available for the railroad industry compiled from questionnaire distributed in 1976. Lists information sources, reviews of available programs, and available reviews of computer graphics, pre- and post-processors, and minicomputers. Design and Software Dissemination Sources are listed.

SIX-AXLE LOCOMOTIVE RESPONSE MODEL - USER'S MANUAL (R-294)

This document gives the input and output information for the 6-axle Locomotive Response Model to study the dynamic interactions of the locomotive to a deterministic track input. A sample problem is presented to prepare necessary input data.

SIX-AXLE LOCOMOTIVE RESPONSE MODEL - TECHNICAL MANUAL (R-295)

A 39 degree-of-freedom model for a 6-axle locomotive is described to study the response of the locomotive on tangent track to a deterministic track input. A limited parameter study has been presented.

SUMMARY OF PHASE II ACTIVITIES

This document is a general overview of work done in both the experimental and analytical areas designed to achieve the Phase II objectives.

Details pertaining to individual activities can be obtained in specific books or manuals dealing with that subject.

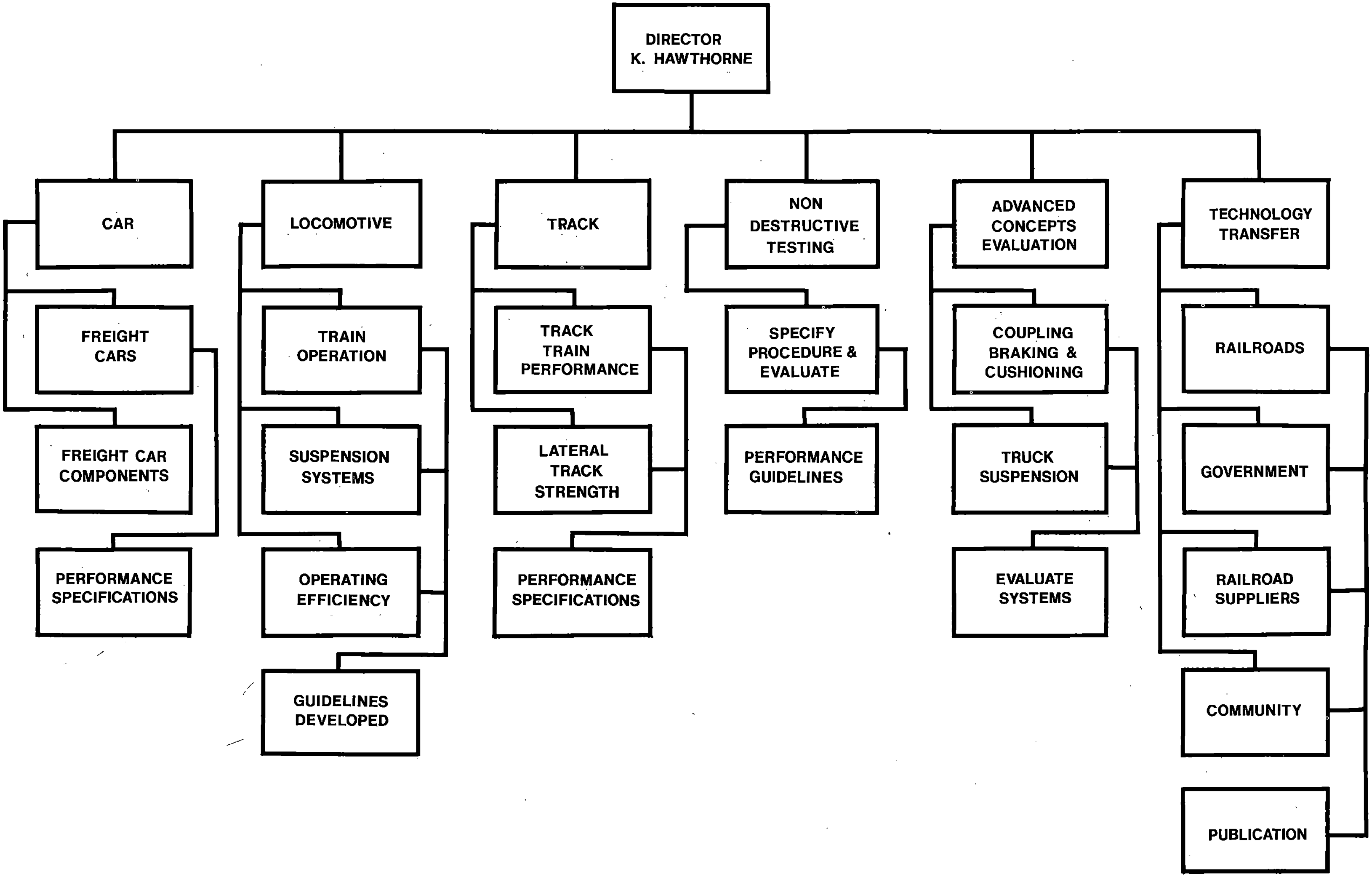
PHASE III - PLANNING AND INITIAL PROGRESS

FALL, 1978

This phase contains new tasks not dependent on completion of Phase II work, as well as some of the longer range subtasks of Phase II. The Phase III program, projected to cover a period of five years, has as its goal the development of requirements for advanced design vehicles, track structures and operating systems to meet the future needs of America's railroads, as well as the introduction of advanced technology to improve the safety and reliability of present systems. The first stage of Phase III includes several tasks to fulfill four major functions: TTD technology sharing and implementation; advanced design methodology development; train operation aids; and future system studies. Figure 34 is a breakdown into key research elements of the various tasks of Phase III.

PHASE III

TRACK TRAIN DYNAMICS PROGRAM



PHASE III

TASK I: Freight Car Systems and Dynamics

Objective

The primary objective of the Freight Car Systems and Dynamics task is to foster the development of improved freight cars and freight car components, both dynamically and structurally. Track/Train Dynamics staff will generate performance guidelines for a series of prototype vehicles and equipment components for improving dynamic performance, operating characteristics and safety features, as well as an increased net to tare ratio. Prototype vehicles will be evaluated and tested so that performance guidelines may be validated and performance specifications established.

Scope

Track/Train Dynamics participants will develop performance guidelines for two or more prototype vehicles along the following lines:

1. Dynamically improved car of nominally 100 tons capacity which exhibits the effect of a 70-ton car in its dynamic input to the track. Development of performance guidelines for this car will utilize dynamic

and structural analytical techniques which have resulted from previous TTD research, or are readily available from other sources.

2. Dynamically and structurally advanced cars with an increased net to tare ratio and, where feasible, incorporating alternative brake systems, coupling systems, safety appliances, etc. Development of the performance guidelines for these cars will utilize advanced dynamics and structural analysis techniques and the incorporation of advanced concept equipment will be provided for.

It is anticipated that prototype vehicles and components will be obtained through purchase orders based on selection following a design competition. Although a major part of the effort toward design of a more dynamically stable freight car will likely involve suspension design, it is anticipated that the prime designers (possibly car builders) will design, have designed, or select such subsystems to incorporate into the total system (freight car) package. Track/Train Dynamics will evaluate proposed vehicles using both in-house analytical capabilities and contracted services, and will evaluate the resulting vehicles using such facilities as the Rail Dynamics Laboratory, SAFE and FAST. Dynamic and structural analysis programs will be made available to qualified bidders and, in some cases, be required for design evaluation. Every effort will be made to ensure full benefit is realized from such research efforts as the Phase II Suspension Dynamics research and FRA's Truck Design Optimization Project.

Selection of prototype vehicles and components will include consideration of all elements which may improve safety and operating efficiency. Where practicable, structures and components will be designed to interface with modern non-destructive inspection techniques. Human factors studies are envisioned for such features as safety appliances and hand brakes. Concepts such as hydraulic foundation brake rigging, compatible and non-compatible automatic coupling, incorporation of lightweight materials, and others will be pursued in the Advanced Concepts Evaluation task and applied where beneficial.

This task effort will incorporate many current activities within the Track/Train Dynamics program, including advanced design methods and future systems studies. Other activities such as the AAR Safety Research and Applied Technology Division's hand brake study will be incorporated as appropriate.

TASK II: Locomotive Performance and Train Operation Systems

Objective

The objective of this task is to cause to be developed improved train operation systems, to encourage the development of more dynamically stable locomotives, and to determine if means are available by which the availability, trip reliability and maintainability of locomotives can be enhanced.

Scope

Track/Train Dynamics will develop locomotive and train monitoring systems such as a rear-end train line pressure telemetry system and on-board high-speed data processing as may be required for condition monitoring and enhancing operating efficiency. This effort will essentially perform the activities required of the train operations aids function of Phase III. An important additional consideration is continuous monitoring of fuel consumption and establishment of a liason with the AAR/SWRI Alternate Fuels Laboratory.

Guidelines for locomotive dynamic performance will be developed which will ultimately lead to the development of performance specifications. Development of the guidelines will utilize parametric studies conducted with dynamic models available within Track/Train Dynamics, and both track structures and vehicle response test data resulting from appropriate laboratory and field experiments. New truck designs developed to meet these guidelines should be considered for testing using the latest facilities such as Rail Dynamic Lab, SAFE and FAST to assure the validity of the guidelines and demonstrate adequate performance.

An evaluation of the availability, maintainability and trip reliability of locomotives will be conducted. Studies that are currently in progress will be utilized to determine desirable mean times between failures of selected components to establish performance goals. It is anticipated that a series of performance specifications will be established to encourage locomotive systems designers and maintenance personnel to pursue desirable trip reliability, maintainability and availability goals. Upon successful completion of these activities, it is anticipated that the Track/Train Dynamics program would procure an entire locomotive or locomotives having both the improved suspension systems mentioned above and improved trip reliability.

TASK III: Track Structure Systems

Objective

The objective of the Track Structure Systems task will be the incorporation of existing knowledge of track dynamic performance with current developments in lateral track strength into the development of performance specifications for alternative track structures and components.

Scope

Track structures research currently being conducted under the Phase III program will continue toward an improved understanding of lateral track strength. Following this activity, the development of a performance specification for alternative track structures will be pursued. It is proposed that such track structures be constructed and evaluated within existing facilities such as the AAR Track Laboratory and the FAST loop. It is further anticipated that certain maintenance cycles best based on non-destructive evaluation and track structure usage can be defined for rail, ties, ballast, and so forth.

TASK IV: Non-Destructive Evaluation

Objective

The objective of the Non-Destructive Evaluation task will be to specify, procure and evaluate systems for evaluation of track and equipment condition. Included for consideration will be moderate speed flaw detection equipment, residual strength equipment for wheels and rail, track geometry measuring equipment, etc.

Scope

Initial steps in this project will be determination of opportunities for the application of non-destructive evaluation techniques. As opportunities are identified, TTD will develop performance guidelines for appropriate equipment and procure such equipment for evaluation. It is anticipated that such equipment can be evaluated in conjunction with ongoing FRA programs at the Transportation Test Center or in-place in railroad facilities. Of primary interest will be the enhancement of rail flaw detection equipment with onboard processing for the determination of flaw criticality. This will include utilization of the results of rail metallurgy and residual stress studies under the Phase II Track/Train Dynamics program and the continuation of the rail risk studies previously being conducted within the Phase II Track/Train Dynamics program.

TASK V: Advanced Concepts Evaluation

Objective

The primary objective of the Advanced Concepts Evaluation task is to evaluate systems for demonstration of their potential economic value in improving train makeup and train handling. Concepts to be considered will be in the area of coupling, braking, and cushioning, with separate implementation considerations for general service cars and unit train type service. Truck suspension concepts for low tare unit train type cars will also be evaluated for use on the lightweight car design contemplated in Task I.

Scope

Since the genesis of the Track/Train Dynamics program, a considerable emphasis has been on improving the operating environment by control of in-train forces through better train handling techniques while retaining, for the short term, all the current equipment characteristics. It was envisaged that Phase III would address hardware improvements in such subsystem areas as coupling, braking, and cushioning. The widespread use of TOS for operations planning and accident analysis has continued to demonstrate that the present coupling, braking and cushioning characteristics should not be taken as ideal; rather, consideration should be given to meaningful cost effective improvements which could make substantial difference in train handling and train makeup.

The AAR Research and Test Department, in 1975, initiated a separate project in cooperation with the RPI on Advanced Coupling Concepts. The primary output of this project was the development of an economic model and an evaluation of the economic benefits from selected changes to the coupling system (including functional braking items). Using available economic and operations data, it was concluded that further consideration was warranted within the scope of the Track/ Train Dynamics program in concert with consideration of braking systems and cushioning characteristics. In so doing, train handling and train makeup would be addressed from a total systems point of view. Another observation and conclusion reached pointed to the need to demonstrate in physical terms what advantages could be gained in terms of train makeup and handling. Economic benefits can only derive from operation changes which improve safety and productivity and not merely by adding additional hardware. So the need to demonstrate these potential improvements is paramount. These demonstrations will facilitate any additional economic analysis and further data collection.

The question of implementing advanced systems has been further addressed within the TTD program. The task definition is structured with eventual implementation in mind for general service cars and unit train cars. The degree and level of compatibility necessary between the existing and advanced hardware is a question which must be answered.

To accomplish the general objective, it is necessary to catalog concepts for consideration, evaluate them for technical feasibility and engineering value. A set of performance guidelines would be written for all concepts selected for demonstration. This would be followed by a procurement of hardware for demonstration purposes of selected concepts. The actual demonstration would have to consist of operation in yards and/or in designated trains. This would permit a large and diverse group of railroad personnel to evaluate and estimate the impact of operations--present and future. A set of functional performance specifications would eventually be written for the systems adopted for full implementation.

TASK VI: Technology Transfer

Objective

The objective of the Technology Transfer task is to assure a continuing communication between the TTD program and the railroads, railroad suppliers, government, and academic community.

Scope

The Technology Transfer task will continue the writing, publication and distribution of the TTD newsletter on a quarterly basis. This newsletter will relate current information on research and implementation status.

The continuing link between the TTD program and operating railroads will be maintained through the Implementation Officers organization. In addition to sharing current implementation information, it is expected that the Implementation Officers will participate in updating and revising the Guidelines for Train Handling and Train Makeup on approximately a three-year cycle.

Near term in the Technology Transfer task are preparations for the planned November 27-29 technical conference.