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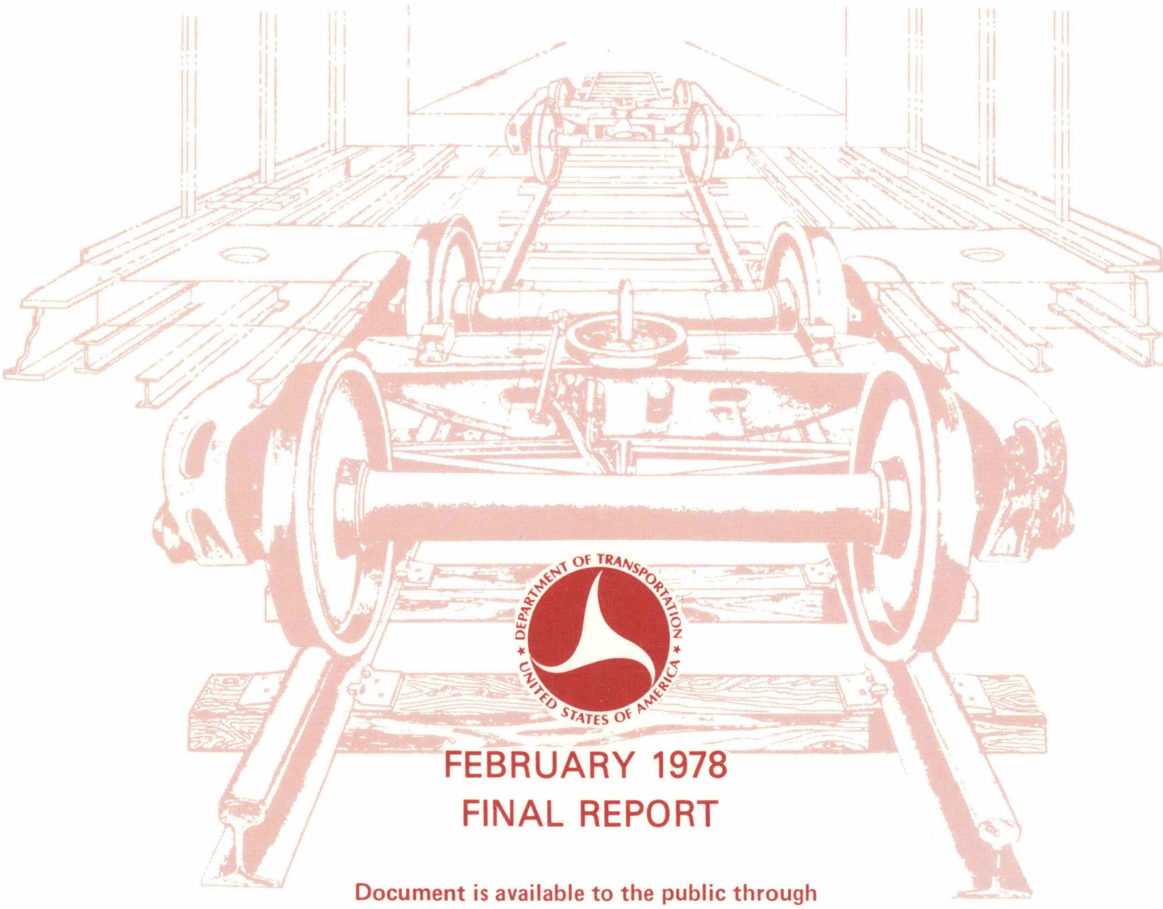
FREIGHT CAR TRUCK DESIGN OPTIMIZATION

VOLUME I — EXECUTIVE SUMMARY



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FINAL REPORT

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See Volume II prepared by the Contractor for complete documentation of Phase I

16. Abstract This report has been prepared by the FRA as an overview of work accomplished by the Southern Pacific Transportation Company for FRA. It reviews and gives conclusions of Phase I of the Truck Design Optimization Project (TDOP). It represents the first of a six volume published set. See also:

Vol. II - Phase I Final Report, FRA/ORD-78/12.II
Vol. III - Phase I Frequency Domain Model, FRA/ORD-78/12.III
Vol. IV - Critique of Frequency Domain Model - Solution Techniques, FRA/ORD-78/12.IV
Vol. V - Critique of Frequency Domain Model - Equations of Motion, FRA/ORD-78/12.V
Vol. VI - Critique of Phase I - Test Series Results Reports, FRA/ORD-78/12.VI

Also available in microfiche or photocopy form from NTIS:
Vol. VII - Results Report for Test Series 1, FRA/ORD-78/12.VII
Vol. VIII - Results Report for Test Series 2 and 5, FRA/ORD-78/12.VIII
Vol. IX - Results Report for Test Series 4, FRA/ORD-78/12.IX
Vol. X - Results Report for Test Series 3 and 5, FRA/ORD-78/12.X
Vol. XI - Performance Guidelines for Type I Trucks FRA/ORD-78/12.XI
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PREFACE

The Federal Railroad Administration's Truck Design Optimization Project (TDOP), Phase I, conducted by the Southern Pacific Transportation Company, was concluded on July 31, 1976. Due to the sheer volume of the material developed during this research, it has taken to the present time to establish the best manner in which to make the information collected available. A scheme involving the publication of six volumes that highlight the major findings and results has been adopted. This basic series of reports is augmented by six additional reports which provide supporting information. The second series will not be published documents, however, their content will be made available to interested parties through the National Technical Information Service's photocopy and microfiche process.

This report is intended to serve as an overview of the extensive Phase I activity to study the performance of the standard three-piece truck. It is also intended to serve as an introduction to TDOP Phase II participants and other interested parties where an understanding of the challenges and conclusions of the preceding research phase should prove beneficial. More detailed information and associated critiques and assessments are contained in Volumes II through VI of the published series.

Phase I TDOP provided a major contribution to the research data banks on truck performance; therefore, the documentation of its findings, successes, and shortcomings is considered essential to further meaningful truck research and development activities.

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1. INTRODUCTION

1.1 Project Background

A goal of the Federal Railroad Administration's (FRA) Office of Freight Systems is to increase railroad profitability by investigating ways to improve the efficiency and economics of the movement of intercity freight. Increased profitability includes the goal of recovering the shipment of manufactured goods now diverted to other modes by raising the performance levels of components critical to reduction of lading damage, maintenance, and wear.

The Equipment Performance Analysis Subprogram seeks this profitability potential through the improvement of rail equipment systems/subsystems and the characterization, technically and economically, of new configurations derived through applied research and exploratory development. Railroad profitability can be increased through the objective of reduction of lading damage. A combination of longitudinal forces (humping and train action), lateral oscillations (hunting), and vertical dynamics (rock n' roll) is one cause of lading damage which can be eliminated by the railroad industry's adoption of performance guidelines which define performance values to control truck and carbody motion. Another profitability objective is to reduce the costs of wear and maintenance on rail vehicle components. Wheel flange and tread wear represent one of the major costs to operating railroads and car leasers, and can be attributed to poor truck performance and adverse wheel/rail interface dynamics. The thirty percent of car repair costs associated with wheels can be substantially reduced through improved truck performance. Both of these objectives must be backed by the development of a sound economic methodology useful in the equipment acquisition process and the attendent alternative investment decisions.

The Truck Design Optimization Project (TDOP) was conceived to address these objectives. Phase I was initiated on June 28, 1974 with the Technical Research and Development Group, Southern Pacific Transportation Company (SPTCo.) as the Contractor. This work was concluded on July 31, 1976. The purpose of Phase I was to evaluate the performance characteristics of the existing, unmodified, three-piece friction snubbed freight car truck (designated Type I); to determine through cost benefit analyses the economics of modifications or improved designs; and to provide preliminary performance and testing guidelines for this type of truck.

1.2 Project Objectives

Achievement of the project's goal is anticipated to result in reduction of railroad operating expenses under conditions of rising traffic and more critical service demands. The objectives of this project include, but are not limited to:

a) Improved quality in freight car ride and curve negotiability.

b) Reduced freight car truck hunting.

c) Technological and economic bases for assessing truck performance and new designs.

d) Reduced time for inspection and maintenance.

e) Lowered maintenance costs for freight cars, trucks and track.

f) Reduced claims for lading damage.

g) Increased performance and reliability in freight car planning and utilization.

h) Increased equipment life and reduction in required spare parts inventory.

i) Improved safety.

j) Decreased truck inspection and surveillance requirements.

k) Integrated carbody support systems.

l) Expanded car design options through relief from existing constraints.

m) Uniform evaluation standards for assessing truck and carbody support system designs.

n) Supporting information for use in the Track/Train Dynamics Program.

1.3 Project Scope

It was originally intended that the SPTCo. carry out all three planned phases of the TDOP: Phase I involving the existing three-piece freight car truck (Type I); Phase II examining new or premium truck designs (Type II); and Phase III investigating advanced carbody support systems. Due to unforeseen circumstances it became necessary to undertake Phase II as a competitive procurement, and, at this time the possibility of a Phase III is in question.

The scope of Phase I involved the performance of six tasks specified by the Statement of Work. In summary, they were as follows:

Task 1.0 - Literature Search, Equipment and Site Selection. The Contractor was required to conduct a thorough search of railroad and related technical literature for material relating to freight car truck design and development, and prepare a comprehensive bibliography for publication. Test tracks were to be selected based on track geometry measurements, representative operating conditions, and excitation levels required to characterize all modes of truck performance. Under this task the Contractor was also responsible for the instrumentation of both 70-ton (63.5-mt) and 100-ton (90.7-mt) configurations of the American Steel Foundries (ASF) Ride Control and Barber S-2 trucks for the measurement of the dynamic responses necessary to quantitatively define performance. In conjunction with this, the Contractor was also responsible for the design, fabrication and installation of components and devices required to assess the potential for improved truck performance as derived from predictive analytical work performed under a separate task.

Task 2.0 - Analytical Models. In this task, the Contractor was required to develop a mathematical model or models capable of predicting all aspects of performance of the three-piece friction snubbed truck and suitable for use in evaluating proposed engineering design changes or modifications. The model(s) were to have been validated with field test data to provide a high level of correlation between simulation and actual performance prior to physical truck modification. The Contractor was also responsible for testing those modifications or new designs that analysis indicated offered improved performance.

Task 3.0 - Field Tests and Criteria. The Contractor was responsible for the performance of the work necessary to provide for the collection and processing of data permitting the characterization of the dynamic performance of existing and modified trucks. This task specified the orderly progression of test events to be conducted in accordance with a detailed test plan with well integrated points of analysis and data processing prior to proceeding to the next level of complexity.

Task 4.0 - Economic Analysis Under this task the Contractor was to develop an economic methodology for freight car trucks which would include, but not be limited to, initial investment cost, maintenance cost, failure rate, economic life, effect on car utilization, damage to lading attributable to truck performance characteristics, damage to track, cost of capital, and other investment alternatives. The results of this effort were to be compiled into an Economic Analysis Plan delineating the data collection and analytical procedures to be followed in determining the cost effectiveness of alternative truck designs. The Contractor was also to initiate the compilation of the economic data base.

Task 5.0 - Type I Truck Performance and Testing Specifications. This task involved the preparation of preliminary performance and testing specifications based upon verifiable test data and in such a format that a Type I truck could be designed, procured, or retrofitted using common industry practices. A Type I truck is defined as one which is interchangeable with existing trucks so as to preserve the present truck coupler height, supports the car body on center plates, utilizes air brakes which are compatible with existing systems, accepts standard wheel sets and journal bearings, and whose components meet applicable Association of American Railroads (AAR) requirements.

Task 6.0 - Survey and Appraisal of Type II Trucks. The Contractor was to make a preliminary determination on the desirability of testing other freight car truck designs by assessing the technical risk, timing of availability, and cost factors involved. A Type II truck is defined as a special purpose truck which utilizes current wheel set and journal bearing assemblies, is compatible with existing air brake systems, and preserves car coupler height. The Type II truck, however, may employ mechanisms other than center plate and side bearings for support and stabilization of the car body.

In order to achieve the objectives specified within the scope of the contract and with due cognizance and participation from all sectors of the rail community, the Contractor was authorized to engage industry consultants to provide specialized technical assistance.

2. METHODOLOGY

2.1 Test Series Structure

In fulfilling the articles of the Statement of Work and bearing in mind that life-cycle testing was not within the scope of the Contract, the SPTCo. chose to divide the testing activities into five distinct test series, each geared to evaluate the effect of certain parameters upon truck performance.

Test Series 1 examined the effect of variations in gib and side bearing clearance on a 70-ton (63.5 mt) ASF Ride Control Truck under a mechanical refrigerator car. Six gib and side bearing configurations were tested including the nominal clearances. Baseline performance information on the behavior of the present-day unmodified three-piece friction snubbed truck were to have been generated from the results of this series of tests.

Test Series 2 utilized the same truck/carbody configuration and was designed to evaluate the performance of trucks with various components in a simulated worn condition. Wheel and snubber wear were reproduced for this series. The effects of spring changes were also studied.

Test Series 3 was performed primarily to extend the data base (from Series 1 and 2) to other types and capacities of freight car trucks and freight cars. These tests included a 70-ton (63.5-mt) covered hopper and a 100-ton (90.7-mt) box car in addition to the 70-ton (63.5-mt) refrigerator car used in Series 1 and 2. Other trucks utilized were the Barber S-2-C 70-ton (63.5-mt), the 70-ton (63.5-mt) ASF low-level trucks, 100-ton (90.7-mt) ASF trucks, and the 100-ton (90.7-mt) Barber trucks.

Test Series 4 involved modifications recommended as a result of studies performed by the Japanese National Railway for the SPTCo. These tests examined the effects of a side frame intertie, hydraulic lateral dampers between the bolster and side frames, constant-contact side bearings, a longitudinal control device between the roller bearing and the pedestal legs of the side frame, elastomeric adapter pads, and various amounts of centerplate friction. The final test in this series examined the effect of combining high centerplate friction, constant-contact side bearings and longitudinal pedestal controls. The equipment combination used in this testing was the mechanical refrigerator car with the ASF Ride Control 70-ton (63.5-mt) trucks.

Test Series 5 was designed for the study of harmonic roll behavior to complete the data base required for the development of a performance specification. Both ASF 70-ton (63.5-mt) and Barber 100-ton (90.7-mt) trucks were utilized under the refrigerator car and boxcar, respectively. This test series also examined the effects of cylindrical wheels on high speed dynamics.

With the exception of the study of harmonic roll which utilized track shimmed at opposite rail joints, the tests described were conducted over three different types of track representing normal railroad operating conditions: high-speed tangent track, medium and low speed tangent track, and curved track of different degrees of curvature.

2.2 Instrumentation, Data Collection, and Test Procedures

The various carbodies and trucks tested were instrumented to quantify ride quality, measure track input, trace energy transmission through the truck, and measure movement between truck components. Displacement transducers, accelerometers and force transducers were used on the trucks; accelerometers were optimally located to record carbody movement. Truck mounted instrumentation was predominantly located on the B-end truck, which was the leading truck in the direction of motion during all tests.

The data collection system was capable of recording 48 channels of information from the test car and was mounted in the SP-250, a converted Southern Pacific 83-ft (25.3 m) Baggage Dormitory car. Each testing day checks were made to assure positioning and securement of all transducers, and correctness of amplifier zero readings and previously determined resistance calibration values. Instrument calibration procedures were conducted both before and after each test run. During each test run twenty-two (22) of the forty-eight (48) channels were monitored on oscillograph and brush chart recordings for unusual behavior and improper zeroes. At the end of each test run, two channels at a time were converted from digital-to-analog with the first and last four seconds of data and associated calibration voltages plotted on a brush chart. Any specific corrections or comments were included with the raw data at that time.

The reader is referred to Volume II, Phase I Final Report, of this series for more detailed information on this topic.

2.3 Data Reduction

A great deal of data was collected, processed, and prepared for analysis under the five test series previously described. The Contractor chose to select only portions of the data collected for reduction and presentation in the results reports. The majority of this reduced data was presented in the form of Power Spectral Density (PSD), Root Mean Square (RMS) versus velocity and time history plots. A computer program which permits the user to select the format of presentation was developed to process the raw data. Histograms and maximum amplitude versus velocity plots are also available. More details on how the data has been submitted and the challenge of its use can be found in Volume VI, Critique of Phase I - Test Series Results Reports, of this series of reports.

2.4 Other Required Tasks

The economic analysis required by Task 4.0 of the Statement of Work was conducted as a separate item and the Contractor chose to report the results in three independent reports. The methodology provided the user with an approach to the problem of determining the economic consequences of technical modifications being considered in truck design. The economic analysis provided the details and examples of such calculations. Observations regarding the economics of the Type I truck were also to be provided as a result of this task.

The survey and appraisal of Type II trucks and the literature search were independent efforts. However, the Contractor also elected to handle the development of the mathematical model as peripheral activity. The mathematical modeling effort was to provide a program to calculate the steady state vibratory responses of a freight car moving over rough tangent track, and include the effects of truck instability (hunting), truck friction damping, and a first-order approximation of freight car structural flexibility. For the Type II truck survey and the literature search, the Contractor reviewed existing material pertinent to truck dynamics and future truck research studies.

The Performance Guidelines for Type I trucks were developed with the intent that the performance criteria would be derived from the measured data taken during the five test series.

2.5 Methodology Assessment

Phase I TDOP was a pioneering undertaking which provided the industry with much information. An omission in the Phase I methodology was a consolidated, logical engineering plan which integrated the economic, modeling, and testing facets for achievement of the overall program objectives. A test plan requires guiding concepts if the results of a test are to be anything but a collection of data. Similarly, the interpretation of data requires a conceptual framework if anything but the more obvious relationships between variables are to be identified and explained.

One of the objectives of Phase I was the characterization of a standard truck. In accomplishing this, it was necessary to identify and quantify not only the variables usually dealt with in practice, but also those taken for granted which sometimes have a more profound effect on dynamic behavior. The latter implies the employment of a theoretical approach which in this case would have been the mathematical modeling effort. In the absence of this theoretical base, much of the test planning was based on operational data and procedures customarily used in railroad practice. Since some factors were not included, the results may prove difficult to interpret or even be inconclusive. An example is the inclusion of gib clearances as a variable, with omission of brake rigging torque that slews the truck and may drastically alter gib clearances.

The absence of an integrated test plan also precluded the collection of data upon which certain economic considerations could have been based. In separating the economic analysis, which was intended to be an integral part of the major activities, the opportunity of marrying cost data and measurable technical quantitites to derive benefits was not achieved.

The field testing and data acquisition in Phase I was carried out with a high degree of efficiency, and much credit is due to the SPTCo. personnel who were instrumental in this success. The data reduction, however, was not as successful due to the lack of a coherent theoretical structure which affected the results. Qualitative judgements concerning what information was desired should have been made prior to undertaking the massive job of data processing.

Finally, the dissemination of information to the industry at-large was minimal. This was particularly true in the development of the Performance Guidelines for the Type I trucks. Neither the format nor the selected performance indices were discussed with the industry at-large until it was presented in its final form. The numbers selected as maximum or minimum measured values (e.g., g's, degrees, degrees/sec., pounds, etc.) permitted under specified test situations were presented as values at which hunting was imminent. Current knowledge indicates that no existing Type I truck can satisfy the guidelines as written.

3. RESULTS

3.1 Documents Generated

Products corresponding with each of the tasks were delivered at contract conclusion along with a Final Report and voluminous supporting documentation. It is the additional material or supporting documentation that actually constitutes the bulk of the output from Phase I TDOP and that is discussed in Volume VI, "Critique of Phase I - Test Series Results Reports". A summary list of the Phase I TDOP end products is provided in Appendices A and B.

3.2 Test Observations and Conclusions

The five test series described in paragraph 2.1 were specifically designed and constructed to relate truck performance to certain dynamic regimes. The regimes examined included lateral dynamics at high speed operation, vertical dynamics corresponding to the freight car vertical harmonics, roll dynamics, and curve negotiation factors. The SPTCo. submitted the following observations and conclusions corresponding to the indicated regime of operation. These conclusions may also be found beginning on page A-16 of Appendix A, Vol. II-Phase I Final Report.

3.2.1 High Speed Tangent Track Operation

- The lateral dynamics action (hunting) developed at high speeds on tangent track is the most significant problem demonstrated by the conventional three-piece, friction-snubbed, freight car truck.

- The empty car begins to hunt at a substantially lower threshold speed than the loaded car for any particular freight car-truck combination.

- For the same speed, lateral dynamics on jointed rail track are different than when operation is on continuous welded rail track.

- At 79mph (127 km/hr), the response frequency of a car hunting on continous welded rail varies in accordance with the natural frequency of the car spring-mass system. On jointed rail, the response frequency corresponds to the frequency of inputs from the rail joints or 2.97 Hz.

- At speeds up to 79mph (127 km/hr), not all empty cars exhibit hunting. Furthermore, not all loaded cars exhibit lateral stability over the same speed range.

- Wheel tread profile is the most profound freight car system parameter influencing lateral stability. Wheels with AAR 1:20 taper profile exhibit hunting behavior. Service worn wheels used in this investigation results in hunting with carbody response amplitudes greater than for 1:20 taper profile wheels. (Other studies show that worn wheels, under certain conditions, result in lateral stability.) Cylindrical tread wheels and wheels with 1:40 tapered profile furnish lateral stability through 79mph (127 km/hr).

- Freight car trucks can be modified to improve the lateral dynamics of the system. In general, these modifications involve more coupling among components of the truck and/or the truck and carbody. Such modifications, however, may degrade performance in other operating regimes such as curve negotiation. The following modifications were found to be technically effective for raising the threshold speed where hunting develops:

  - Coupling side frames in tram through use of an intertie.

  - High centerplate friction.

  - Constant side bearing pressure. Threshold speed is a direct function of static side bearing pressure.

  - Reducing clearance between the roller bearing adapter and the side frame outer pedestal leg.

- A combination of modifications consisting of high centerplate friction, constant side bearing pressure at high levels, and reduction of roller bearing-pedestal clerance furnished lateral stability throughout the speed range to 79mph (127 km/hr). The use of cylindrical or 1:40 tapered wheel tread profiles installed in the basic contemporary truck furnished a higher level of performance, when considered in all operating regimes, than the above combination of modifications.

- Truck and carbody vertical dynamics consisted of responses to inputs from track and wheels. On jointed rail, the inputs included joint forcing functions at frequencies corresponding to the rail length, half rail length, truck wheel base, and freight car truck centers. Wheel rotation frequency also developed.

- No substantial bounce or pitch resonance peaks developed on the high speed tracks. There are indications of vertical resonances between 50 and 60 mph (81 and 97 km/hr) in several test results covering a variety of cars and conditions.

- Springing and snubbing changes affect vertical response behavior as follows:

  - Reduced spring capacity and reduced snubbing capacity had the same effect of slightly lowering bounce acceleration amplitudes between 50 and 60 mph (81 and 97 km/hr).

- D-5 and D-7 springs showed equivalent behavior in both 70-ton (63.6-mt) and 100-ton (90.9-mt) trucks under both empty and loaded conditions. D-7 springs have a greater reserve capacity.

- D-3 springs consistently show higher vertical mode accelerations as compared to D-5 and D-7 springs for both 70-ton (63.6-mt) and 100-ton (90.9-mt) cars tested both empty and loaded.

- Compared with the nominal 100-ton (90.9-mt) friction configuration for either the loaded or empty 100-ton (90.9-mt) car, supplemental friction snubbing substituted for certain springs in the spring nest results in generally higher bounce accelerations with the additional power concentrated above 5 Hz.

- Supplemental hydraulic snubbing installed in the spring nests of 100-ton (90.9-mt) trucks results in slightly higher bounce amplitudes at frequencies below 5 Hz for the loaded car as compared to the nominal case. Essentially no differences were noted in bounce behavior for the empty 100-ton (90.9-mt) car operating at the higher speed.

3.2.2 Medium and Low Speed Tangent Track Operation

° Between 10 and 45 mph (16 and 72 km/hr), the principal truck and car motions are frequency induced from track joints acting to provide steady state inputs that match spring mass resonances of the freight car-truck system.

° Car response motions are primarily lower center carbody roll, bounce and pitch.

° Variations in gib dimensions and side bearing clearance had minimal effect on the roll dynamics characteristics. AAR gib and side bearing dimensional requirements were found to be satisfactory.

° Truck tramming motions respond quickly to rail joint inputs for the loaded car.

° For loaded cars, critical speed for harmonic roll is a direct function of spring rate. The spread between critical speeds measured with D-3, D-5, and D-7 springs approximates four miles per hour (6 km/hr), with D-7 springs having the lowest critical speed and the D-3 springs showing the highest.

° For empty cars, the critical speed range is not as sensitive to variations in spring rate as for loaded cars.

- For loaded cars, operating below the critical speed for harmonic roll, carbody roll angle and roll accelerations for D-3 springs are lower than for either D-5 or D-7. Above critical speed, the D-5 and D-7 springs, acting equivalently, show lower values of carbody roll angle and acceleration compared to the D-3 springs.

- Supplemental friction snubbing slightly increases the loaded car critical speed, reduces the roll angle below the critical speed, and furnished essentially equivalent carbody roll accelerations as compared with the conventional snubber arrangement. Truck tram stiffness increases significantly with this modification. For the empty car, supplemental friction results in an equivalent speed and lower roll angles for 6 to 8 mph (10 to 13 km/hr) above the critical speed. Truck tram is slightly reduced. Carbody roll acceleration is slightly increased above the critical speed.

- For the loaded car operating above the critical speed up to 45 mph (73 hm/hr), supplemental friction snubbing results in increased tram stiffness and higher carbody roll accelerations. For the empty car, carbody roll acceleration remains higher than for the conventional arrangement, but truck tram stiffness is equivalent over the same speed range.

- Supplemental hydraulic snubbing slightly increases the loaded car critical speed, reduces the roll angle below the critical speed, and furnishes essentially equivalent carbody roll accelerations as compared with the conventional snubber arrangement. Truck tram stiffness moderately increases with this modification. For the empty car, supplemental hydraulic units did not affect critical speed, as indicated by carbody roll angles. Just above critical speed, truck tram stiffness was increased with respect to the tram angles developed with the conventional arrangement. Carbody roll accelerations were equivalent for the conventional and modified arrangements.

- For operation above the critical speed up to 45 mph (73 km/hr), the significant difference in performance behavior between the conventional arrangement and the use of supplemental hydraulic snubbing is the significantly increased tram stiffness measured for the modified configuration.

3.2.3 Curve Negotiation

- Centerplate rotation (truck swivel), bolster-to-side frame rotation (truck tram), track history (direction and magnitude of preceding curve) and speed (in relationship to equilibrium speed) are the primary parameters affecting the curve negotiation of a given car.

- The degree of curvature generally reflects the sum of the amplitudes of the swivel and tram parameters. Thus, truck swivel and truck tram parameters are usually inversely related, when one is higher than expected, the other is lower.

- Truck swivel is affected by:
  - increased centerplate load which inhibits the truck from swiveling as it enters the curve; empty cars swivel more, loaded cars swivel less;
  - over equilibrium speed which tends to pin wheel flanges on axles 1 and 2 to the outside rail increasing truck swivel;
  - the previous curve (track history), especially for loaded cars.
- Truck tram is affected by:
  - the momentum of a loaded car which allows the bolster to move more freely relative to the side frames; empty cars often do not break free of their friction snubbers and therefore exhibit less tram motion than loaded cars;
  - the relative rotation of truck swivel, which is the first constraint of the loaded car system.
- Loaded cars at over equilibrium speed create the highest curving forces, specifically the highest lateral forces on axles 1 and 2, due to basic centrifugal force considerations. Further conclusions will pertain to this condition only. Axle 1 lateral forces are always higher than axle 2.
- Lateral force on axle 2 is directly related to the degree of truck swivel on a given curve. Allowing the truck to swivel more increases the lateral force on axle 2, equalizing the force distribution. The lateral force on axle 1 is related to the combination of both the swivel and tram rotations.
- Wheel profile affects the truck swivel and truck tram rotations, and the lateral forces as well. Service worn wheel profiles resulted in higher degrees of truck tram rotation and a higher lateral force level on axle 1.
- Based on cylindrical wheel curving tests, D-3, D-5, or D-7 spring sets had little effect on curve negotiability.
- Based on tests with new 1:20 tapered wheels, gib and side bearing clearance changes had no significant effect on curve negotiability.
- The combination of devices consisting of steel-on-steel centerplate conditions, constant-contact side bearings (7500 lb [3402 kg] pre-load), and pedestal longitudinal clearance controls, allowed less truck swivel, higher truck tram, and generally higher lateral forces on axle 1 than the nominal truck conditions. The overall effect of this combination is reduced curve negotiability.

3.3 Recommendations Offered

Having provided the industry with numerous conclusions and observations on the behavior of the three-piece friction snubbed freight car truck, the SPTCo. indicated several areas for consideration in utilizing Phase I information and in initiating future investigative programs. In summary, their suggestions were as follows:

a) It was recommended that the Performance Guidelines for Type I Trucks be submitted to and adopted by the Association of American Railroads (AAR).

b) It was proposed that the Type II Truck Survey be used as a starting point for future research in this area.

c) It was recommended that future truck research should include the provision for extended wear testing which would add another dimension to the technical data made available through Phase I.

d) It was concluded that a brake system effects study should be implemented to evaluate the influence of current designs on the dynamic performance of trucks.

e) It was suggested that the economics studies be carried on to encourage individual railroads to establish economic data collection and analyses systems and, completion of the data collection necessary for validation of economic models.

f) It was recommended that the FRA construct test tracks suitable for the evaluation, appraisal, and study of freight car trucks.

g) Finally, SPTCo. recommended the initiation of a comprehensive study on the optimum characteristics required of a wheel tread profile with respect to rail head contour, wear, braking arrangements, ride behavior, returning time, cost, and other applicable areas of investigation. It was stated that this study was urgently needed to evaluate the possibility that wheel profiles can be used more efficiently to control overall truck performance without incurring excess maintenance on the wheels or increasing costs.

In addition, the Contractor stated that all possible combinations of data were not attempted in Phase I and that other combinations may well develop further insight into freight car truck performance. Suggestions for improved instrumentation were also offered. It was felt that equipment for measuring vertical and lateral forces between the axle and side frame were a necessity. It was also suggested that a method for obtaining a physical zero position for the truck and for achieving a precise coordination of train speed should be explored. Not withstanding the above, the SPTCo. concluded that the performance requirements established in the guidelines they developed provided for stability through the operating speed range and that the technology is currently available to apply to existing trucks to achieve these performance levels.

3.4 ASSESSMENT OF RESULTS

As stated earlier, the TDOP Phase I provided a major contribution to the research data banks on truck performance. Technical documentation to support the conclusions drawn may be found in TDOP Phase I data or from other industry sources. However, with the exception of cylindrical wheel configurations and the combination of modifications which the Contractor has termed "optimized" in their Final Report, there are no comparisons or trade-offs made between performance and the different regimes of operation. Operating conditions differ greatly from one railroad to another, particularly with respect to track roughness, curvature, and speed. Therefore, each truck configuration should have been related to the requirements of all, or at least the majority of the railroads, and the project could have produced results useable over a wide spectrum of operational conditions.

3.4.1 Wheel Profiles

In discussing the "optimized" combination of modifications (high centerplate friction, constant side bearing pressure at high levels, and reduction of roller bearing-pedestal clearance), the Contractor acknowledges that the system provides improved lateral stability with the risk of decreased curve negotiability. On the other hand it was stated without qualification that cylindrical wheels improved performance in both operating regimes. While it can be observed that a new cylindrical wheel confers lateral stability because the wavelength of kinematic hunting of the truck is theoretically infinite, some stipulation should have been placed on this conclusion to indicate that it applied only to new profiles and that experience had not yet been gained with the worn cylindrical tread.

It is now a matter of common experience that cylindrical wheels tend to wear in the throat because there is no taper to provide centering action. Further, what were believed to be hairline cracks in the throat have been identified as being due to plastic flow of a metal surface layer. This is another mode of deterioration to be considered. The slightly worn cylindrical profile wheelset also tends to behave somewhat unpredictably with respect to its lateral position on the track. It has more than one neutral equilibrium position, each of which corresponds to the slightly hollowed tread, near each flange. While one hollowed tread is in contact with the rail the opposite wheel runs on the relatively unworn cylindrical position. Thus, the equilibrium position of the wheelset depends on the initial conditions, and it may shift back and forth.

In the worn cylindrical wheel condition, one of the hollows becomes deeper than the other such that the effective conicity is increased, but not to the extent characteristic of the highly unsymetrical, stable wheelset. As a result, the worn cylindrical wheelset has poor lateral stability, which can only be avoided by reprofiling at more frequent intervals.

Finally, a comparison of new cylindrical and 1:40 tapered wheels with worn 1:20 tapered wheels is not meaningful. It is quite likely that the 1:40 wheel will wear into a more stable contour with certain types of brake shoes and arrangements of brake rigging. This remains to be demonstrated in TDOP Phase II.

3.4.2 Test Series

Test results with wheels machined to match service worn profiles should be reviewed to determine their validity with respect to values of critical speed obtained. With regard to changes in centerplate friction, other road tests have indicated that there is no noticeable beneficial effect. Other tests have shown that a truck with increased truck swivel resistance may be more stable up to a higher speed, but that at some point it will hunt more violently than one with less resistance.

The addition of hydraulic snubbers between the side frame and bolster in Test Series 4 is a questionable modification. It is difficult, if not impossible, to optimize the suspension of the standard friction-snubbed truck with respect to both vertical and lateral dynamics. To improve the dynamic behavior of the empty car, a lower friction coefficient would be desired for optimum lateral damping than is achievable with friction snubbing. The addition of hydraulic snubbers, therefore, would appear to increase the lateral damping beyond that supplied by the friction snubbers, which does not appear to be a step in the right direction. The reader should bear this in mind when reviewing the test data.

3.4.3 Performance Guidelines

The Contractor should be commended for his statement in the Preface of the Performance Guidelines that the arbitrary addition of "hunting control" hardware may furnish the intended results but could result in suboptimal performance in other requirement categories. This point was previously made in connection with increasing truck swivel resistance for lateral stability but leading to greater wheel flange wear in curves.

3.4.3.1 Braking

The guideline's however, do not consider the effects of braking. The importance of braking relates not so much to the deceleration of the vehicle, but to the long-term effects on such performance indices as stability and wear. Studies have indicated that the contour of a worn wheel is greatly affected by the material and width of the brake shoe, and the kinematics of the brake rigging. Identical cars, on identical trucks, with identical lading, have exhibited wide differences in lateral stability, traceable only to wheel contours differently worn by braking.

3.4.3.2 Wear Life Factors

The wear life factors suggested in the Performance Guidelines are the vertical and lateral forces on the lead axle bearing adapters, and the algebraic difference of the leading end side bearings. None of these are believed to be adequate measures of the various modes and mechanisms of deterioration.

3.4.3.3 Curve Negotiation Factors

Finally, the forces specified for curve negotiation factors seem very low when compared to those obtained in other road tests. The discrepancy is probably due to the instrumentation used to measure lateral forces. The strain-gauged roller bearing adapters utilized in Phase I can only measure the net lateral force between the axle and the side frame. The lateral force measured between the wheelset and the side frames may differ from the sum of the lateral forces exerted between the wheels and the rails, since some of these forces may be reacted internally between the two wheels through the axle. This is true, for example, when the slopes of the contact planes differ for the two wheels of a wheelset as will happen in steady-state curve negotiation at balance speed, without flange contact. When there is flange contact at the outer leading wheel, the contributional lateral friction forces by the two wheels of the forward wheelset cannot be separated. Even if inertia forces and centrifugal forces due to curving at non-balance speed are eliminated from consideration, only the net lateral creep forces acting on the axles, which counter-act the longitudinal creep couples can be measured at the bearings. Thus, lateral wheel forces must either be measured directly at the wheels, or at the axles. In both cases, components due to normal forces must be subtracted.

4. CONCLUSION

A large step has been taken in the characterization of the standard and modified three-piece, friction-snubbed freight car truck. The industry has been provided with a wealth of data from which many valuable facts can be gleened. TDOP Phase I has caused the industry to re-structure its thinking on truck performance improvement and the Contractor is to be commended. TDOP Phase II will continue in this vein and bring to the forefront integrated economic and technical performance criteria for both the Type I and Type II trucks.

APPENDIX A

PHASE I - TECHNICAL REPORTS

All titles are preceded by the major title "Freight Car Truck Design Optimization".

A. NTIS Accession Number Available:

Introduction and Detailed Test Plan Series 1, 2, and 3 Tests - Phase I, FRS-OR&D 75-59, PB 248632

Detailed Test Plan Series 4 Tests - Phase I, FRA-OR&D 75-60, PB 246389

Detailed Test Plan Series 5 Tests - Phase I, FRA-OR&D 75-82, PB 248631

Truck Economic Data Collection and Analysis, FRA-OR&D 75-58A, PB 251400

Methodology for a Comprehensive Study of Truck Economics, FRA-OR&D 75-58, PB 248832

Survey and Appraisal of Type II Trucks, FRA-OR&D 76-133, PB 248633

Literature Search - Volume I, II and III; FRA-OR&D 75-81A, 75-81B, 75-81C; PB 248350, 248351, 248352

Economic Analysis Report - Phase I, FRA/ORD-76/287.1, PB 259366

All data tapes - Listing and Accession Numbers provided in Appendix B.

B. NTIS Accession Numbers not yet available:*

Volume I - Executive Summary, FRA/ORD-78/12.I

Volume II - Phase I Final Report, FRA/ORD-78/12.II

Volume III - Phase I Frequency Domain Model, FRA/ORD-78/12.III

Volume IV - Critique of Frequency Domain Model - Solution Techniques, FRA/ORD-78/12.IV

Volume V - Critique of Frequency Domain Model - Equations of Motion, FRA/ORD-78/12.V

Volume VI - Critique of Phase I - Test Series Results Reports, FRA/ORD-78/12.VI

*NTIS will accept orders citing FRA Report Number

C. Available on Microfiche, Accession Number not yet available:

Volume VII - Results Report for Test Series 1, FRA/ORD-78/12.VII

Volume VIII - Results Report for Test Series 2 and 5, FRA/ORD-78/12.VIII

Volume IX - Results Report for Test Series 4, FRA/ORD-78/12.IX

Volume X - Performance Guidelines for Type I Trucks, FRA/ORD-78/12.XI

Volume XII - TDOP Postprocessing Program Manual, FRA/ORD-78/12.XII

APPENDIX B

PHASE I - MAGNETIC DATA TAPES

Available to the public through the
National Technical Information Service
Springfield, VA 22161

Test No.	Tape No.	Accession No.	Variables: Gibs Nominal	Gibs Closed	Side Bearings Tight	Side Bearings Nominal	Side Bearings Open
1-1-3	0010 0011	PB 250 163/AS PB 250 164/AS	X				X
1-1-1	0012 0013 0014	PB 250 165/AS PB 250 166/AS PB 250 167/AS	X			X	
1-1-2	0015 0016 0017	PB 250 168/AS PB 250 169/AS PB 250 170/AS	X		X		
1-1-5	0017 0018	PB 250 170/AS PB 250 171/AS		X	X		
1-1-6	0019 0020	PB 250 172/AS PB 250 173/AS		X		X	
1-1-4	0001 0002	PB 250 160/AS PB 250 161/AS		X			X
1-1-4-C	0003	PB 250 162/AS		X			X
1-1-6-C	0021	PB 250 174/AS		X		X	
1-1-5-C	0021 0022	PB 250 174/AS PB 250 175/AS		X	X		
1-1-2-C	0022	PB 250 175/AS	X		X		
1-1-1-C	0023	PB 250 176/AS	X			X	
1-1-3-C	0023	PB 250 176/AS	X				X
1-3-2	0024 0025	PB 250 177/AS PB 250 178/AS	X				X
1-3-1	0026 0027	PB 250 179/AS PB 250 180/AS		X	X		
1-2-2-C	0028	PB 250 181/AS		X	X		
1-2-1-C	0028 0029	PB 250 181/AS PB 250 182/AS		X		X	
1-2-3-C	0029	PB 250 182/AS		X			X
1-2-4-C	0030	PB 250 183/AS	X				X
1-2-6-C	0030 0031	PB 250 183/AS PB 250 184/AS	X			X	
1-2-5-C	0031	PB 250 184/AS	X		X		
1-2-2	0032 0033	PB 250 185/AS PB 250 186/AS	X		X		

Car Load			Track Type		
MT	1/2	GRL	H.S. Tang.	M.S. Tang.	Curved
		X	X	X	
		X	X	X	
		X	X	X	
		X	X	X	
		X	X	X	
		X	X	X	
		X			X
		X			X
		X			X
		X			X
		X			X
		X			X
	X		X	X	
	X		X	X	
X					X
X					X
X					X
X					X
X					X
X					X
X			X	X	

Test No.	Tape No.	Accession No.	Variables					Car Load			Track Type		
			Gibs		Side Bearings						H.S.	M.S.	
			Nominal	Closed	Tight	Nominal	Open	MT	1/2	GRL	Tang.	Tang.	Curved
1-2-4	0033 0034	PB 250 186/AS PB 250 187/AS		X			X	X			X	X	
1-2-3	0035 0036	PB 250 188/AS PB 250 189/AS	X				X	X			X	X	
1-2-1	0036 0037	PB 250 189/AS PB 250 190/AS	X			X		X			X	X	
1-2-6	0038 0039	PB 250 191/AS PB 250 192/AS		X		X		X			X	X	
1-2-5	0038 0039 0040	PB 250 191/AS PB 250 192/AS PB 250 193/AS		X	X			X			X	X	

*The equipment combination for these tests consisted of a mechanical refrigerator car (SPFE 459997) with ASF Ride Control 70-ton (63.6-mt) trucks. For further information concerning Series 1 Tests, see Freight Car Truck Design Optimization Introduction And Detailed Test Plans Series 1, 2, and 3 Tests - Phase I, Report No. FRA-OR&D 75-59

Test No.	Tape No.	Accession No.	Gibs		Side Bearings			
			Nominal	Closed	Tight	Nominal	Open	D-3
2-1-2	0041	PB 250 194/AS		X	X			
	0042	PB 250 195/AS						
2-1-1	0042	PB 250 195/AS	X				X	
	0043	PB 250 196/AS						
	0044	PB 250 197/AS						
2-2-5	0045	PB 250 198/AS	X				X	
	0046	PB 250 199/AS						
2-2-6	0047	PB 250 200/AS	X				X	X
	0048	PB 250 201/AS						
2-2-3	0048	PB 250 201/AS	X				X	
	0049	PB 250 202/AS						
	0051	PB 250 204/AS						
2-2-4	0049	PB 250 202/AS		X	X			
	0050	PB 250 203/AS						
2-2-3-C	0051	PB 250 204/AS	X				X	
	0052	PB 250 205/AS						
2-3-3-C	0052	PB 250 205/AS	X				X	
	0053	PB 250 206/AS						
2-3-3	0053	PB 250 206/AS	X				X	
	0054	PB 250 207/AS						
2-3-6	0055	PB 250 208/AS		X	X			
	0056	PB 250 209/AS						
2-3-4	0057	PB 250 210/AS	X				X	
	0058	PB 250 211/AS						
2-3-5	0059	PB 250 212/AS	X				X	X
	0060	PB 250 213/AS						
2-4-1	0061	PB 250 214/AS	X				X	
	0062	PB 250 215/AS						
2-4-2	0063	PB 250 216/AS		X	X			
	0064	PB 250 217/AS						
2-4-3	0065	PB 250 218/AS		X	X			
	0066	PB 250 219/AS						
2-4-4	0067	PB 250 220/AS	X				X	
	0068	PB 250 221/AS						

Variables												
Springs			Snubbing		Wheel Profile			Car Load		Track Type		
D-5	D-5 Reduced	D-7	2/3	Nominal	New	1/2 Worn	Worn	MT	GRL	H.S. Tang.	M.S. Tang.	Curved
X				X		X		X		X	X	
X				X		X		X		X	X	
		X		X			X	X		X	X	
				X			X	X		X	X	
X				X			X	X		X	X	
X				X			X	X		X	X	
X				X			X	X				X
X				X			X		X			X
X				X			X		X	X	X	
X				X			X		X	X	X	
		X		X			X		X	X	X	
				X			X		X	X	X	
X			X		X				X	X	X	
X			X		X				X	X	X	
X			X		X			X		X	X	
X			X		X			X		X	X	

Test No.	Tape No.	Accession No.	Variables																		
			Gibs		Side Bearings			Springs				Snubbing		Wheel Profile			Car Load		Track Type		
			Nominal	Closed	Tight	Nominal	Open	D-3	D-5	D-5 Reduced	D-7	2/3	Nominal	New	1/2 Worn	Worn	MT	GRL	H.S. Tang.	M.S. Tang.	Curv[illegible]
2-4-5	0069 0070	PB 250 222/AS PB 250 223/AS	X				X			X			X	X			X		X	X	
2-4-6	0071 0072	PB 250 224/AS PB 250 225/AS		X	X					X			X	X			X		X	X	
2-4-7	0073 0074	PB 250 226/AS PB 250 227/AS		X	X					X			X	X				X	X	X	
2-4-8	0075 0076	PB 250 228/AS PB 250 229/AS	X				X			X			X	X				X	X	X	

*The equipment combination for these tests consisted of a mechanical refrigerator car (SPFE 459997) with ASF Ride Control 70-ton (63.6-mt) trucks. For further information concerning Series 2 Tests, see Freight Car Truck Design Optimization Introduction And Detailed Test Plans Series 1, 2, and 3 Tests - Phase I, Report No. FRA-OR&D 75-59

Test No.	Tape No.	Accession No.	Equipment Arr.*	New Wheels
3-1-2	0077	PB 250 230/AS	A	X
	0078	PB 250 231/AS		
	0079	PB 250 232/AS		
3-2-2	0080	PB 250 233/AS	B	X
	0081	PB 250 234/AS		
	0082	PB 250 235/AS		
3-2-2-C	0083	PB 250 236/AS	B	X
3-1-2-C	0084	PB 250 237/AS	A	X
3-1-1-C	0085	PB 250 238/AS	A	X
3-2-1-C	0086	PB 250 239/AS	B	X
3-2-1	0087	PB 250 240/AS	B	X
	0088	PB 250 241/AS		
	0089	PB 250 242/AS		
3-1-1	0090	PB 250 243/AS	A	X
	0091	PB 250 244/AS		
3-3-1	0102	PB 250 252/AS	C	X
	0103	PB 250 253/AS		
3-4-1	0111	PB 250 261/AS	D	X
	0112	PB 250 262/AS		
	0113	PB 250 263/AS		
3-4-1-C	0110	PB 250 260/AS	D	X
3-3-1-C	0098	PB 250 251/AS	C	X
	0104	PB 250 254/AS		

* A=SP FE Mech. Refer.--Barber S-2-C 70-ton (63.6-mt) trucks

B=SP 60-foot (18.3-m) Box Car--Barber S-2-C 100-ton (90.9-mt) trucks

C=SCL Box Car X5B--Barber S-2-C 70-ton

D=LN Covered Hopper Car--ASF Ride Control 100-ton trucks

E=SP 89-foot, 4-inch (27.2-m) Flat Car--ASF Ride Control 70-ton trucks

Variables			Track Type		
Worn	Car Load		H.S.	M.S.	
Wheels	MT	GRL	Tang.	Tang.	Curved
		X	X	X	
	X		X	X	
	X				X
		X			X
	X				X
		X			X
		X	X	X	
	X		X	X	
		X	X	X	
		X	X	X	
		X			X
		X			X

Test No.	Tape No.	Accession No.	Equipment Arr.*	New Wheels
3-3-2-C	0097	PB 250 250/AS	C	X
3-4-2-C	0114	PB 250 264/AS	D	X
3-4-2	0115 0116	PB 250 265/AS PB 250 266/AS	D	X
3-3-2	0092 0093	PB 250 245/AS PB 250 246/AS	C	X
3-5-1	0094 0095	PB 250 247/AS PB 250 248/AS	E	X
3-5-1-C	0096	PB 250 249/AS	E	X
3-5-2-C	0105	PB 250 255/AS	E	X
3-5-2	0106 0107	PB 250 256/AS PB 250 257/AS	E	X
3-5-3	0108 0109	PB 250 258/AS PB 250 259/AS	E	

Variables					
Worn	Car Load		Track Type		
			H S.	M.S.	
Wheels	MT	GRL	Tang.	Tang.	Curved
	X				X
	X				X
	X		X	X	
	X		X	X	
	X		X	X	
	X				X
		X			X
		X	X	X	
X	X		X		

Test No.	Tape No.	Accession No.	Modifications						
				Ctr. Plt. Friction				Elast.	
			Lt.	Med.	Hvy.	Ped. Shims	Intertie	Adapt. Pads	Hydr. Dmpr.
4-1-1	0124	PB 250 267/AS	X						
4-1-2	0125	PB 250 268/AS	X			X			
4-1-3	0126	PB 250 269/AS		X		X			
4-1-4	0127	PB 250 270/AS		X					
4-1-5	0129	PB 250 272/AS			X				
4-1-6	0128	PB 250 271/AS			X	X			
4-2-1	0132 0133	PB 250 273/AS PB 250 274/AS	X			X	X		
4-2-2	0134 0135	PB 250 275/AS PB 250 276/AS	X				X		
4-2-3	0138 0139	PB 250 279/AS PB 250 280/AS	X				X	X	
4-2-4	0136 0137	PB 250 277/AS PB 250 278/AS	X			X	X	X	
4-3-1	0142 0143	PB 250 283/AS PB 250 284/AS	X			X	X		X
4-3-2	0140 0141	PB 250 281/AS PB 250 282/AS	X				X		X
4-3-3	0146 0147	PB 250 287/AS PB 250 288/AS	X						X
4-3-4	0144 0145	PB 250 285/AS PB 250 286/AS	X			X			X
4-4-1	0150 0152 0153	PB 250 291/AS PB 250 293/AS PB 250 294/AS	X			X			

* The equipment combination for these tests consisted of a mechanical refrigerator car (SPFE 459997) with ASF Ride Control 70-ton (63.6-mt) trucks.

C.C. Side Bear. (psi)			Optimized Comb.	Car Load		Track Type		
32	64	96		MT	GRL	H.S. Tang.	M.S. Tang.	Curved
				X		X		
				X		X		
				X		X		
				X		X		
				X		X		
				X		X		
				X		X	X	
				X		X	X	
				X		X	X	
				X		X	X	
				X		X	X	
				X		X	X	
				X		X	X	
				X		X	X	
X				X		X	X	

Test No.	Tape No.	Accession No.	Lt.	Ctr. Plt. Friction Med.	Hvy.	Ped. Shims	Inertie	Modifications Elast. Adapt. Pads	Hydr. Dmpr.
4-4-2	0150	PB 250 291/AS	X						
	0151	PB 250 292/AS							
	0152	PB 250 293/AS							
	0153	PB 250 294/AS							
4-4-3	0151	PB 250 292/AS	X						
	0152	PB 250 293/AS							
	0154	PB 250 295/AS							
4-4-1-C	0148	PB 250 289/AS	X						
4-4-2-C	0148	PB 250 289/AS	X						
	0149	PB 250 290/AS							
4-4-3-C	0149	PB 250 290/AS	X						
4-4-4-C	0155	PB 250 296/AS	X						
	0156	PB 250 297/AS							
4-4-5-C	0156	PB 250 297/AS	X						
4-4-6-C	0157	PB 250 298/AS	X						
4-4-6	0159	PB 250 300/AS	X						
	0163	PB 250 304/AS							
4-4-5	0158	PB 250 299/AS	X						
	0160	PB 250 301/AS							
	0162	PB 250 303/AS							
4-4-4	0158	PB 250 299/AS	X						
	0160	PB 250 301/AS							
	0161	PB 250 302/AS							
4-5-1	0164	PB 250 305/AS							
	0165	PB 250 306/AS							
4-5-1-C	0166	PB 250 307/AS							
4-5-2-C	0167	PB 250 308/AS							
4-5-2	0168	PB 250 309/AS							
	0169	PB 250 310/AS							

C.C. Side Bear. (psi)			Opti-mized	Car Load		Track Type		
32	64	96	Comb.	MT	GRL	H.S. Tang.	M.S. Tang.	Curved
	X			X		X	X	
		X		X		X	X	
X				X				X
	X			X				X
		X		X				X
X					X			X
	X				X			X
		X			X			X
		X			X	X	X	
	X				X	X	X	
X					X	X	X	
			X		X	X	X	
			X		X			X
			X	X				X
			X	X		X	X	

Test No.	Tape No.	Accession No.	Equip. Arr.*	Cyl. Whls.	1/40 Tpr. Whls.
	0174	PB 250 315/AS			
5-1-1	0175	PB 250 316/AS	A	X	
	0178	PB 250 319/AS			
5-1-1-C	0177	PB 250 318/AS	A	X	
5-1-2-C	0182	PB 250 323/AS	A		X
	0179	PB 250 320/AS			
5-1-2	0180	PB 250 321/AS	A		X
	0181	PB 250 322/AS			
5-2-1	0183	PB 250 324/AS	A		X
	0184	PB 250 325/AS			
5-2-1-C	0185	PB 250 326/AS	A		X
5-2-3	0099	PB 250 352/AS	A	X	
	0100	PB 250 353/AS			
5-2-2-C	0101	PB 250 354/AS	A	X	
5-2-4	0117	PB 250 355/AS	A		
	0118	PB 250 356/AS			
5-2-4-C	0119	PB 250 357/AS	A		
5-2-5-C	0120	PB 250 358/AS	A		
5-2-5	0121	PB 250 359/AS	A		
	0122	PB 250 360/AS			
5-1-3-C	0131	PB 254 326/AS	A		
5-1-3	0123	PB 254 324/AS	A		
	0130	PB 254 325/AS			
5-1-4	0171	PB 250 312/AS	A		
	0172	PB 250 313/AS			
5-1-4-C	0170	PB 250 311/AS	A		
5-4-3	0173	PB 250 314/AS	B		
	0176	PB 250 317/AS			
5-4-3-C	0186	PB 250 327/AS	B		
5-4-4-C	0187	PB 250 328/AS	B		
5-4-4	0188	PB 250 329/AS	B		
	0189	PB 250 330/AS			

Variables Selec.** Whls.	Spring Nest Snubbers Fric.	Hydr.	Spring Comp. D-3	D-5	D-7	Car Load MT	GRL	Track Type H.S. Tang.	M.S. Tang.	Curved	Mod. w/ Low Joints
				X		X		X	X		X
				X		X				X	
				X		X				X	
				X		X		X	X		X
				X			X	X	X		X
				X			X			X	
				X			X	X	X		X
				X			X			X	
X			X				X	X	X		X
X			X				X			X	
X					X		X			X	
X					X		X	X	X		X
X					X	X				X	
X					X	X		X	X		X
X			X			X		X	X		X
X			X			X				X	
X					X		X	X	X		X
X					X		X			X	
X			X				X			X	
X			X				X	X	X		X

Test No.	Tape No.	Accession No.	Equip. Arr.*	Variables													
				Cyl. Whls.	1/40 Tpr. Whls.	Selec.** Whls.	Spring Nest Snubbers Fric.	Spring Nest Snubbers Hydr.	Spring Comp. D-3	Spring Comp. D-5	Spring Comp. D-7	Car Load MT	Car Load GRL	Track Type H.S. Tang.	Track Type M.S. Tang.	Track Type Curved	Mod. w/ Low Joints
5-4-5	0191 0192	PB 250 332/AS PB 250 333/AS	B			X				X			X	X	X		X
5-4-5-C	0190	PB 250 331/AS	B			X				X			X			X	
5-4-2	0193 0194	PB 250 334/AS PB 250 335/AS	B			X	X			X			X	X	X		X
5-4-1	0195 0196	PB 250 336/AS PB 250 337/AS	B			X		X		X			X	X	X		X
5-3-5	0197 0198	PB 250 338/AS PB 250 339/AS	B			X		X		X		X		X	X		X
5-3-4	0199 0200	PB 250 340/AS PB 250 341/AS	B			X	X			X		X		X	X		X
5-3-1	0201 0202	PB 250 342/AS PB 250 343/AS	B			X				X		X		X	X		X
5-3-1-C	0203	PB 250 344/AS	B			X				X		X				X	
5-3-3-C	0209 0210	PB 250 349/AS PB 250 350/AS	B			X			X			X				X	
5-3-3	0208 0211	PB 250 348/AS PB 250 351/AS	B			X			X			X		X	X		X
5-3-2	0205 0206	PB 250 346/AS PB 250 347/AS	B			X					X	X		X	X		X
5-3-2-C	0204	PB 250 345/AS	B			X					X	X				X	

*A = SPFE 70-ton (63.6-mt) mechanical refrigerator car 459997 with ASF Ride Control 70-ton capacity trucks

B = SP 60-foot (18.3-m), 100-ton (90.9-mt) box car with Barber S-2-C

** Selected wheels will be chosen from either the 1/40 taper or cylindrical wheels following test 5-2-2-C