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Federal Railroad Administration

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Low-Profile, Light-Weight Intermodal Railcar

Volume II: Acceptance Test Plan

FRA/ORD-81/04.II
Volume II

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See Volume I: Performance Specification, FRA/ORD-81/04.I and Volume III: Requirements Definition, FRA/ORD-81/04.III

16. Abstract

The Performance Specification and Acceptance Test Plan, respectively contained in Volumes I and II of this report, define the requirements for a low-profile, light-weight intermodal railcar. The Car specified here must be able to operate within restricted clearances when carrying either highway trailers or standard shipping containers and must be designed for low aerodynamic resistance and light weight in order to conserve energy. Also, it must be capable of dynamically stable operation at the high speeds which may be expected in special intermodal unit trains. Both safety and protection of lading against the damage which can be caused by excessive ride vibration must be considered in the design of the Car. It is intended that these requirements will stimulate the development of innovative railcar designs.

The Car specified here is an idealized concept which satisfies the most stringent technological requirements presently envisioned for intermodal service. The performance baseline defined here may not be equally appropriate for all users of the Specification, some of whom may wish to modify some of the requirements better to reflect their particular needs.

The Acceptance Test Plan includes not only the performance tests which must be performed to verify compliance with the Specification, but also the sequence of preliminary and detailed analyses which should be performed to facilitate development of a Car design which will meet the performance requirements.

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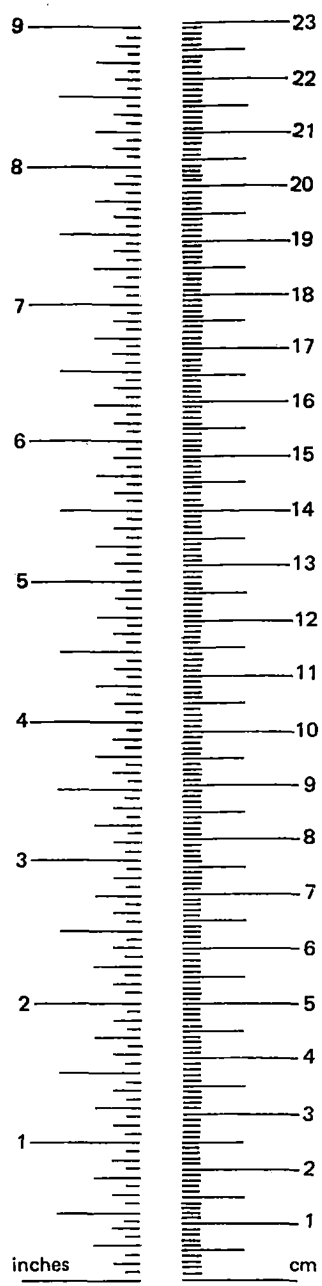
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

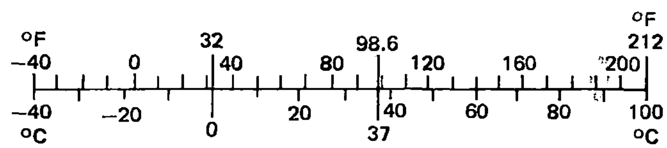
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2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

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



Approximate Conversions from Metric Measures

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



PREFACE

The original reason for the development of the Low-Profile, Lightweight, Intermodal Railcar Performance Specification (Volume I) was for use by the Federal Railroad Administration in a planned procurement of an experimental intermodal car capable of demonstration service throughout the restricted clearances found on the Northeast railroads. Subsequently, it was decided not to proceed with the procurement, but instead, to revise the performance specification to reflect railcar requirements more attainable in the near-term and separately publish the Acceptance Test Plan (Volume II).

In light of the high level of interest in a new generation of intermodal railcars, it is believed that this work will provide a baseline to be utilized by railroads and car builders seeking new high-efficiency, all-purpose, intermodal rolling stock.

Measurement of the clearances in the North and East River Tubes and Penn Station, New York City, was performed in July 1980. Amtrak interpretation of the resulting data has indicated that intermodal railcar operations through these tubes with the most severe (clearance-wise) lading configurations of 13'6"-high trailers is not possible. Nevertheless, many of the requirements of this Specification point out the directions in which new car designs should seek to move for benefits in dynamic stability and energy efficiency. It is for this reason that the Specification and Acceptance Test Plan are being made available for use as appropriate by the railroad industry. As indicated in the Specification, the ultimate users of these documents may wish to exercise trade-off judgements on the actual application of the provisions of either the Specification or the Acceptance Test Plan or both.

Preliminary work in developing the Specification was accomplished by A.T. Kearney, Inc. and the General Motors Transportation Systems Center in the form of a Requirements Definition (Volume III). The Specification and Acceptance Test Plan, which were completed by Systems Control, Inc. (Vt), now incorporate additional information and improvements to the original work. In addition, results of the recent New York tubes measurement project have been incorporated into the material provided.

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I. INTRODUCTION

This test plan is designed to complement the Low-Profile, Light-Weight Intermodal Railcar Performance Specification. The performance requirements for the subject railcar are described in the Specification, while the Test Plan contains descriptions of the analyses and tests which must be performed on the Car to demonstrate compliance with these requirements.

1.1 SEQUENCE OF ANALYSES AND TESTS

The logical development of a new railcar should proceed through a progression of analyses and testing designed to ensure the desired performance. This test plan suggests such a progression. It begins with the preliminary analyses needed to support a conceptual design, and then proceeds through the detailed final design process, supported by more extensive analysis, to testing of vehicle subsystems and then the entire vehicle.

The preliminary analyses, which would be expected to be completed by a Car builder before he offers the Car design to prospective purchasers (i.e. preproposal activities) are listed in Table 1.1. These should be relatively simple and inexpensive to perform, and are the minimum needed to ensure that the design concept is viable. Problems which are not identified by analysis at this level should be remediable at the detailed design and prototype development stage without requiring changes to the basic design concept.

The detailed analyses, which occur during the detailed design process after a commitment has been made to build the Car, are necessary for fine-tuning the design to maximize the chances of meeting or exceeding all of the performance requirements. In addition to the standard static structural analyses used in sizing structural members, finite element analyses are suggested for structural dynamics. The substantial cost of this method of analysis is justified by its greater fidelity in predicting dynamic loading conditions, which in turn permits a more efficient structural design, with reduced safety factors. Similarly, detailed vehicle dynamic analyses are useful in attempting to ensure that the vehicle responds acceptably to the track conditions expected in revenue operation, without an excessive propensity to derail.

Analyses, regardless of how sophisticated they may become, cannot be used to verify that a Car satisfies the performance requirements of the Specification. Verification of compliance with the Specification requires testing of the Car and its subsystems or systems. Any performance requirements which can be tested at the subsystem or system level should be tested at that level to minimize the expense of testing and to facilitate the test schedule. Other requirements, such as those for clearances and dynamic response, must be verified by testing at least one entire Car. The tests which can be performed on portions of the Car and those which must be performed on the entire Car are summarized in Table 4.1. The precise sequencing of these tests is not crucial, but it is advisable to complete the subsystem tests (and any design modifications needed to ensure that these tests are passed) prior to the system tests, and to similarly complete the system-level tests and modifications prior to the full-Car tests. Following each design change, it is necessary to repeat any of the tests which could be expected to show different results from before. Therefore, it is highly desirable to complete all changes following the lowest level tests which indicate the need for changes in order to minimize the number of tests which must be repeated.

1.2 FACILITIES TO USE FOR ANALYSES AND TESTING

The majority of the analyses are quite straightforward and routine, and should be within the capabilities of any organization equipped to build a railcar. Some of the dynamic analyses (stability, ride quality) are more specialized and may in some cases require consulting assistance. The finite element method structural analysis is the most costly and time consuming of the analyses, and those Car builders who do not have staff members familiar with it will need consulting assistance. This assistance should be readily available through computer utilities as well as numerous consultants and independent contractors who specialize in the finite element method of analysis (which is routine practice in various engineering disciplines).

The subsystem and component testing required by this test plan should be routine practice for any Car builder. The truck and Car body tests require more specialized capabilities and facilities (such as million-pound squeeze test fixtures) which some, but not all, current Car builders possess. Because these are specific to railroad engineering practice, organizations which are not currently Car builders are not likely to possess them. The specialized testing of trucks and Car bodies can be accomplished at the U.S. Department of Transportation's Transportation Test Center (TTC) in Pueblo, Colorado, and in part at the AAR Technical Center in Chicago.

The testing of the entire Car in both the laboratory and field environment requires more extensive and specialized facilities than most Car builders possess. The AAR Technical Center can provide some of the test facilities, but the most extensive testing requirements can be satisfied at TTC, particularly in the Rail Dynamics Laboratory (RDL).

The RDL includes two major test machines, the Roll Dynamics Unit (RDU) and the Vibration Test Unit (VTU), as well as data acquisition and processing facilities. Each unit can be used to perform carefully controlled dynamic experiments on a full-scale railcar (or one Car Section, with

Table 1.1 Preliminary Analyses

1. PRELIMINARY OUTLINE AND CONFIGURATION DRAWINGS
2. CLEARANCE OUTLINE
3. CURVE NEGOTIATION
4. LOADING CONFIGURATION
5. AERODYNAMIC AND ROLLING RESISTANCE
6. WEIGHT ESTIMATE
7. CAR BODY STRUCTURE
   - COMPRESSION LOAD
   - VERTICAL LOAD
   - DRAFT LOAD
8. INTERCHANGE SERVICE ASSESSMENT

Table 1.2 Baseline Loading Conditions for Tests

LOADING CONDITION	NUMBER AND LENGTH OF TRAILERS OR CONTAINERS	WEIGHT OF EACH CONTAINER/TRAILER (LB) **	LOCATION OF LOAD *
A. Configuration accommodating <u>one</u> 40' or 45' trailer per Car Section			
1	One 40' trailer (full)	73,000	Centered
2	One 40' container (full)	69,000	Centered
3	One 40' trailer (empty)	13,000	Centered
4	One 40' container (empty)	9,000	Centered
5	Two 20' containers (full)	64,000	Symmetrical
6	One 20' container (full)	64,000	Asymmetrical (at one end)
7	None (empty Car)	--	--
8	One 40' trailer (half full)	43,000	Centered
B. Configuration accommodating <u>two</u> 40' or 45' trailers per Car Section			
9	Two 40' trailers (full)	73,000	Symmetrical
10	Two 40' containers (full)	69,000	Symmetrical
11	Two 40' trailers (empty)	13,000	Symmetrical
12	Two 40' containers (empty)	9,000	Symmetrical
13	Four 20' containers (full)	64,000	Symmetrical
14	None (empty Car)	--	--
15	Two 40' trailers (half full)	43,000	Symmetrical
16	One 40' trailer (full)	73,000	One end
17	Two 20' containers (full)	64,000	One end
18	Two 20' containers (full)	64,000	Centered

* 40' trailer loadings shall be applied according to Paragraph 4.3.4.1 of Reference Document 1 , which specifies:

King pin to nose distance	36"
Rear of trailer to real axle of bogie	27"
Trailer bogie axle center spacing	48"

** Lading shall be of the appropriate density to completely fill the volume of the trailer or container for those conditions labeled "full" (i.e., about 20 lb/ft^3 for 40' containers and trailers and 40 lb/ft^3 for 20' containers).

trucks, of an articulated Car), recording up to 128 channels of response data.

The RDU is a full-scale roller rig which can be used to simulate wheel-rail interaction and suspension dynamics for operation on smooth tangent track at speeds up to and exceeding 100 mph. Therefore, it can be used to assess dynamic stability (critical speed for onset of hunting) and longitudinal dynamics effects such as braking performance and rolling resistance. The effects of worn wheel profiles on dynamic response can be assessed (by installing worn wheels on the test Car). The present configuration of the RDU does not permit the direct evaluation of loss of damping as the critical speed is approached, but the equipment for applying lateral or yaw force inputs to the trucks, now on order, will enable the identification of damping.

The VTU is designed to vibrate a railcar by applying combinations of vertical and lateral forces to each wheel in the appropriate phase relationships to represent a wide variety of track perturbation inputs, over a substantial range of operating speeds. These vibrations, over a frequency range from 0.2 to 30 Hz, can simulate track roughness, alignment and cross-level inputs, stimulating vertical, lateral, pitch, roll and yaw responses of the rail vehicle. By adjusting the time delays among the inputs at the different axles, operations at different speeds can be simulated. The inputs can be sinusoidal, random, or reproductions of sections of track measured in the field. These capabilities make the VTU suitable for evaluating vehicle ride quality, suspension characteristics, rock-and-roll response, some aspects of curving (applying a steady roll offset), and structural dynamics (modal response).

In addition to the RDL capabilities already described, TTC offers component and subsystem testing (identifying Car characteristic values), mathematical modeling and software support, and extensive test track facilities. The test tracks available at TTC include:

- Railroad Test Track - A 14.7-mile electrified closed-loop track designed for very high speed operations (up to 160 mph). This track is suitable for evaluating wheel/rail dynamic effects such as hunting at high speeds on top quality track (better than Class 6), and the associated "balloon track" can be used to study performance in tight curves (7 30' curves with 5" superelevation).

- Transit Test track - A 9.1-mile electrified track designed for testing urban transit vehicles at speeds up to 100 mph under several typical transit track conditions. Although this track was not developed for use with freight cars, it could be used after normal operating hours if applicable for testing of the intermodal Car.

- Facility for Accelerated Service Testing (FAST) - A 4.8-mile loop track consisting of 22 test sections, each with different track characteristics. The FAST track is used 16 hours per day, five days a week, by a very heavy train consist in order to accelerate wear processes. If the proper approvals were granted, a new intermodal Car could be added to the FAST consist to accumulate many miles of operation in the fastest, cheapest way. The track could be used on weekends for independent testing of the new Car on heavily worn track.

- Impact Track - A 0.8-mile tangent spur track for vehicle impact (and derailment) testing.

- Train Dynamics Track - A 2.2-mile track designed for studying wheel/rail and vehicle dynamics operating over intentionally perturbed track. Tests can be conducted at speeds up to 65 mph, and wayside instrumentation permits measurement of lateral and vertical wheel/rail forces.

Arrangements for use of the TTC facilities and tracks are varied and flexible. Proprietary tests, maintaining confidentiality of procedures and results, can be accommodated. Private Car builders and railroads may choose to use their own instrumentation and data analysis capabilities, or they may rely on the TTC support staff for these functions. TTC provides as a minimum (for track testing) the test controller, locomotive, crew and security. Detailed policies and procedures for use of TTC facilities are found in Policy Order No. 1320.8C, December 10, 1979, available from the TTC Director's Office in Pueblo, Colorado.

1.3 BASELINE LOADING CONDITIONS

A light-weight intermodal Car is likely to be subjected to more widely varying loading conditions than most other railroad equipment. The fully loaded containers or trailers carried by such a Car may weigh as much as three times the light weight of the Car so that the weight supported by the Car's suspension may vary by a factor of four. The dynamics of a vehicle can change significantly over such a broad range of loading conditions, some characteristics being more important for the unloaded vehicle, some more important for the fully loaded vehicle, and some requiring evaluation over the full range of loads. The choice of loads is complicated by the added dynamics introduced by the suspensions of the container chassis and trailers which can be mounted on an intermodal Car. The costs of testing can become prohibitive if too many different loading conditions are specified, so it is important that a limited set of baseline loadings be chosen carefully for the complete set of Car tests. These are summarized in Table 1.2, for two assumed Car Section configurations.

The unloaded conditions (Numbers 7 and 14) are the most demanding for hunting stability, while the fully loaded trailer conditions with the highest centers of gravity are most critical for rock-and-roll response. Curve negotiation should be tested both empty (for the worst case L/V force ratio) and full (for flange climbing), while ride quality should be evaluated at both the extreme and intermediate loading conditions because the relative severity of the vibration response under the different loadings will depend on the effective stiffness of the railcar and trailer suspensions.

1.4 ORGANIZATION OF TEST PLAN

The main body of this Test Plan is arranged so as to correspond approximately to the sequence in which the analyses and tests would be performed during the development of a new intermodal railcar.

Section II describes the preliminary analyses which are expected to be performed in support of a Car builder's proposal to develop the Car. These should be sufficient to convince the purchaser's representative that the proposed design configuration is likely to meet the fundamental requirements of the Specification (clearances, weight, structural integrity, resistance, interchangeability), but should not require costly computerized detail calculations. This level of analysis would be performed at the Car builder's expense as part of his preliminary design, prior to the award of a contract to build the Car.

The detailed analyses to be performed as part of the final design after contract award, concurrently with prototype (Test Train Set) fabrication, are described in Section III. These require the use of some sophisticated computer techniques to try to gain assurance that the Car design will meet all the requirements of the Specification prior to tooling up for production. The major efforts here will be finite element structural analyses of the Car body and trucks (if a new design) and simulations of the dynamic performance of the Car (ride quality, stability). The detailed design and analyses of Section III should be completed satisfactorily before the Car builder receives authorization from the purchaser's representative to proceed with tooling and production. The use of the detailed analyses to demonstrate that the requirements of the Specification probably have been met successfully serves as a key milestone in the railcar development process.

Section IV describes the acceptance tests to be performed in order to demonstrate that the specified performance requirements have been met. In the interest of conserving both time and money, this testing should be conducted at the lowest feasible level of assembly. That is, portions of the Car which can be tested realistically, in isolation from the rest, at the component level, should be tested at that level as soon as they are available in prototype (Section 4.1). Similarly, those tests of the trucks and carbody which can be conducted separately should be conducted prior to assembly of the Car (Sections 4.2 and 4.3). Finally, those which cannot be conducted at lower levels must be conducted on the entire Car, after all its components have been fabricated and assembled. These are described in Section 4.4.

1.5 DEFINITIONS OF TERMS AND ABBREVIATIONS

The following definitions of terms and abbreviations shall apply throughout this Test Plan unless otherwise noted.

- AAR - Association of American Railroads
- Car - the smallest combination of complete low-profile, light-weight intermodal Car Section(s), including trucks, which will be routinely coupled and uncoupled during railroad operations.
- Car Section - the Car body structure, capable of withstanding in-train and load forces referenced in the Specification. Each Car Section shall be capable of carrying at least one 45-foot trailer or one 40 - foot container, but may be able to carry more than that.
- CFR - Code of Federal Regulations (Reference Document [2]).
- Gross Rail Load - the maximum gross weight on the rails per Car. This load is determined from the maximum load allowed per wheel.
- Light Weight - the total weight of the empty Car, including trucks and all appurtenances considered part of the Car. This term is also applied to trailers and containers in this Test Plan.
- Maximum Design Load - the sum of the maximum gross weights of the heaviest combination of containers and/or trailers which the Car can carry at any one time.
- Reference Train Set - the combination of intermodal Car Sections and configurations that can carry six 45-foot highway trailers.
- RDL - Rail Dynamics Laboratory, the laboratory testing facility at the Transportation Test Center.
- TTC - Transportation Test Center, the U.S. Department of Transportation facility for laboratory and field testing at Pueblo, Colorado.
- Test Train Set - the number of Cars to be delivered to the purchaser for acceptance

testing. This number will be a function of the Car configuration, but will correspond to at least one Reference Train Set.

1.6 REFERENCE DOCUMENTS

The following documents are referred to by the numbers shown below throughout this Test Plan. For the reader's convenience, and in order to maintain consistency with the Specification, the reference numbers used here are the same as the numbers which were used in the Specification.

[1] "Specifications for Design, Fabrication, and Construction of Freight Cars," M1001, Volume 1 Standard; Association of American Railroads, Operations and Maintenance Department, Mechanical Division, 1920 L Street, N.W., Washington, D.C. 20036 (Section C, Part II of Reference Document [4]).

[2] "Code of Federal Regulations," Section 49 - Transportation, Parts 215, 231, 213, 232, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

[3] "Field (a) and Office (b) Manuals of the Interchange Rules." Mechanical Division, 1920 L Street, N.W., Washington, D.C. 20036, January 1, 1980.

[4] "Manual of Standards and Recommended Practices." Association of American Railroads, Operations and Maintenance Department, Mechanical Division, 1920 L Street, N.W., Washington, D.C. 20036.

[5] "Installation, Freight Car Brake Equipment, Specification No. 2518." As adopted by the Association of American Railroads, Westinghouse Air Brake Division, Westinghouse Air Brake Company, Wilmerding, PA 15148.

[6] "Freight Car Hunting Model." Report No. R-251, Association of American Railroads, Research and Test Division, 3140 South Federal Street, Chicago, Illinois.

[7] Fred E. Ostrem and Basil Libovics, "A Survey of Environmental Conditions Incident to the Transportation of Materials," General American Research Division, General American Transportation Corp. Report 1512-12, Oct. 1971, PB 204 442.

[8] Andrew G. Hammitt, "Aerodynamic Forces on Freight Trains, Volume I - Wind Tunnel Tests of Containers and Trailers on Flatcars," Report No. FRA/ORD-76/295.I, December 1976, PB 264 304.

[9] Andrew G. Hammitt, "Aerodynamic Forces on Various Configurations of Railroad Cars for Carrying Trailers and Containers," Report No. FRA/ORD-79/39, January 1979, PB 80 - 174881.

[10] Andrew G. Hammitt, "Wind Tunnel Tests of Trailer and Container Models to Determine the Influence of Height and Gap Spacings on Aerodynamic Forces," Report No. FRA/ORD - 80/51, December 1980.

[11] Klauder and Associates, Louis T., "Washington Metropolitan Area Transit Authority - Specification for 184 New Cars," April 12, 1978, Preliminary Specification for Industry Comments, Philadelphia, PA.

[12] G. Kachadourian, N.E. Sussman, J.R. Anderes, "FRATE" Volume I: User's Manual," Report No. FRA/ORD-78/59, September 1978, PB 291 206.

II. PRELIMINARY ANALYSES

Analyses needed to support the preliminary design of the railcar are outlined here. These analyses are to be submitted to the purchaser's representative for approval before finalizing the design. They will be reviewed to provide assurance that the design is proceeding towards a final configuration that will meet the essential requirements of the Specification.

Table 2.1 lists the preliminary analyses needed to demonstrate that the design of the Car is fundamentally capable of meeting the most limiting performance requirements of the Specification. These analyses are described in the remainder of this section.

2.1 PRELIMINARY LAYOUT AND CONFIGURATION DRAWINGS

Preliminary layout drawings showing the proposed structure and configuration of the Car shall be submitted. These drawings shall include dimensions which define the overall size and cross-section of the Car, demonstrating compliance with the configuration requirements of Section 2.3 of the Specification.

2.2 CLEARANCE OUTLINE

A comparison of the Car's cross-section with the specified clearance outline (see Section 2.2, Figure 2.1, or Section 2.2.1, Figure 2.3, of the Specification) shall be performed early in the design of the Car to demonstrate that an allowance has been made for dynamic motions and that these motions will remain within the outline. The assumed loading of the Car for this comparison shall be that yielding the least clearance.

2.3 CURVE NEGOTIATION

The proposed length and width of the Car shall be compared with the curve negotiation requirement (Section 2.2 of the Specification) to show that this requirement will be met. If Section 2.2.1 of the Specification applies as well, compliance shall also be shown with the requirement for swingout on Figure 2.3 of the Specification.

2.4 LOADING CONFIGURATION

An analysis shall be performed to show how the Car will be configured such that the loading requirements of Section 2.3 of the Specification will be met.

2.5 AERODYNAMIC AND ROLLING RESISTANCE

A preliminary analysis of the aerodynamic and rolling reistance of the Car shall be made to show that the requirements of Section 2.8 of the Specification will be met.

2.6 WEIGHT ESTIMATE

A preliminary estimate of the total weight of the vehicle shall be made to ensure that the weight requirement of Section 2.9 of the Specification will be met.

2.7 CAR BODY STRUCTURE

Preliminary analyses of the Car body structure shall be performed to show that the Car body will be able to withstand the compression, vertical and draft loads called out in Sections 3.3.3, 3.3.4, and 3.3.6 of the Specification. These analyses shall consider the forces and moments to be imposed on the structure and the cross-section area and moment of inertia and materials properties of the principal structural members.

2.8 INTERCHANGE SERVICE ASSESSMENT

The requirements for interchange service established by the Association of American Railroads shall be reviewed.

Descriptions of the Car design, drawings, stress analyses, and other information required to obtain a preliminary assessment of acceptability for interchange service shall be submitted to the purchaser's representative (see Sections 2.4 and 5.4.2 of the Specification).

III. DETAILED ANALYSES

This section of the Test Plan presents analytical requirements necessary to demonstrate that the physical and performance requirements stated in the Specification have been met. Table 3.1 lists the detailed analyses that are required. The sections that follow describe the requirements of each analysis, organized the same way the requirements are organized in the Specification.

3.1 VEHICLE PERFORMANCE ANALYSES

3.1.1 Production Cost Estimate

A production cost estimate that includes labor, materials, and overhead shall be made. The cost estimate shall be based on 1980 dollars and on assumed annual production rates of 200, 500, and 1,000 Car Sections (including trucks). See Section 2.6 of the Specification.

Table 3.1 Preliminary Analyses

I. VEHICLE PERFORMANCE ANALYSES
   1. Production Cost Estimate
   2. Maintenance Program Plan and Cost Estimate
   3. Life-Cycle Cost Estimate
   4. Clearance and Curve Negotiation
   5. AAR Interchange Approval
   6. Dynamic Performance
      - Stability
      - Ride Quality
      - Impact
   7. Aerodynamic and Rolling Resistance
   8. Weight Estimate
   9. Safety Analysis

II. CAR BODY STRUCTURAL ANALYSES
   1. Fatigue
   2. Compression End Load
   3. Vertical Load
   4. Torsional Strength
   5. Impact Load

III. TRUCK ANALYSES

IV. ANALYSES OF OTHER EQUIPMENT
   1. Articulation Joints
   2. Brake System

V. DRAWINGS AND DIAGRAMS

3.1.2 Maintenance Program Plan and Cost Estimates

A plan for programmed maintenance shall be provided, including a projected maintenance cost estmate for the life of the Car. The maintenance plan shall identify service intervals (by Car mile) for all programmed maintenance actions. The maintenance cost estimate shall include labor and materials costs associated with the programmed maintenance plan in each year of the expected life of the Car (based on the assumed utilization of 100,000 miles per year per Car). The maintenance cost per Car-mile in each year, and for the life of the Car, shall be shown, each in 1980 dollars (see Sections 2.1 and 5.4.3 of the Specification).

3.1.3 Life Cycle Cost Estimate

An estimate of the complete life-cycle cost, in 1980 dollars per Car Section, shall be provided to the purchaser's representative. This estimate shall incorporate the proposed purchase price, plus the maintenance costs described in Section 3.1.2 above and an additional estimate of the cost of the energy needed to overcome the resistance of the Car Section in typical operations. The purchaser's representative shall specify the conditions of locomotive type, unit energy costs, operating speeds, grades and loading used in the energy cost estimate.

3.1.4 Clearance and Curve Negotiation

A dynamic outline envelope of the proposed Car shall be provided and shall include all projecting appurtenances and shall be based on all expected Car and load motions including bounce and roll. Both normal values of spring conditions and rate, and "worst case" conditions of broken and solid springs, and worn wheels, shall be considered. The resulting dynamic outline shall be overlaid on the Clearance Out-line, Figure 2.1 or 2.3 of the Specification.

Tangent track and worst-case curved track shall both be considered. The clearance outlines of Figure 2.1 and 2.3 of the Specification applies to both. The curve negotiation capabilities of the Car shall be evaluated using the requirements of Table 2.2 of the Specification and the calculation formulae presented in Reference Document [1], Paragraphs 2.1.4.4.3 through 2.1.4.4.4.10. See also Section 2.2 of the Specification.

3.1.5 AAR Interchange Approval

Descriptions of the Car design, drawings, stress analyses, and other information required to obtain approval for interchange service shall be submitted to the purchaser's representative. A formal approval of the design by the Car Construction Committee of the AAR will be requested as described in Sections 2.4 and 5.4.2 of the Specification.

3.1.6 Dynamic Performance

Analyses which predict the dynamic stability and ride quality of the Car as described in the following paragraphs shall be performed and the results submitted to the purchaser's representative. The conditions to be analyzed shall be chosen to aid in isolating the worst-case operating conditions, and the results of the analyses shall be used in selecting precise conditions for vehicle testing in Section IV (worst speeds, loading conditions, etc.)

3.1.6.1 Stability

The results of analyses of the dynamic stability of the Car shall be provided. The analyses shall consider hunting, rock and roll, flange climbing, and rail overturning as specified in Section 2.7.1 of the Specification. Computer models (such as "Freight Car Hunting Model," Reference Document [6] for hunting and FRATE, Reference Document [12], for rock and roll) shall be used in the prediction of the vehicle dynamics and in optimizing the design of the suspension and structure for stability.

Loading conditions effectively spanning the full range expected in use, chosen from those listed in Table 1.2, shall be considered in the analyses. These should include an empty Car (Condition 7 or 14 in Table 1.2), a Car with empty trailer(s) (Condition 3 or 11), a maximum loaded Car (Condition 5 or 13), and an asymmetrically loaded Car (Condition 6, 16 or 17), and the configuration having the highest center of gravity (Condition 1 or 9).

3.1.6.2 Ride Quality

The results of an analysis of the ride quality and trailer vibration environment of the Car shall be provided. The analysis shall be conducted by use of a computer program such as "Freight Car Response Analysis and Test Evaluation" (FRATE), Reference Document [12]. Ride quality simulations shall be performed using track geometry input data representative of the range of track that the Car will be used on (appropriate track classes and speed ranges). The track data used should be reviewed with the purchaser's representative to obtain his approval. The following three loading conditions shall be modeled: (1) empty Car, no load, (2) Car loaded with empty standard 40-foot trailer (loading case 3 or 11 of Table 1.2), and (3) loaded standard 40-foot trailers (loading case 1 or 9 of Table 1.2). Selected speeds covering the full operating speed range of the Car shall be simulated. The results of the simulations shall be compared to the requirements of Section 2.7.2 of the Specification, and any indications that those requirements will not be met must be explained to the satisfaction of the purchaser's representative.

Power spectral density (PSD) plots of the predicted ride vibration of the Car deck and trailer (or container) floors shall also be provided for track classes 3,4,5 and 6 at the maximum speeds given in Table 4.1 of the Specification.

3.1.6.3 Impact

The results of a dynamic analysis of the 10 mph Car-to-Car impact tests called out in the AAR documents referenced in Section 2.7.3 of the Specification shall be provided. This analysis shall be performed to demonstrate that the maximum forces permitted by AAR Specifications M-928--75 and M-952-72 (in Section I of Reference Document [4]) for trailer hitches and container securements are not exceeded during the 10 mph impact tests described in the referenced AAR Specifications. In addition, the analysis should predict the accelerations on the floor of empty trailers (above kingpin and above trailer bogie center) and containers mounted on the Car. These accelerations are not to exceed 10g vertical and 5g longitudinal during the impact test.

3.1.7 Aerodynamic and Rolling Resistance

An estimate of the Car resistance in the absence of wind, as specified in Section 2.8 of the Specification, shall be provided by applying the following formulas to each Car Section:

$$R = 0.6 + \frac{20}{W} + 0.01V$$

$$+ \frac{V^2}{WN} \frac{(20.06 + 0.97S)}{391.1} \frac{H}{16.5}, \quad 0 \le S \le 16$$

where

R = Car Section (including trucks) resistance ratio, per trailer/container, in pounds per ton

W = weight in tons per axle of Car Section, including trailers or containers with or without chassis

N = number of axles per Car Section

V = velocity in miles per hour

S = average gap distance (in feet) between trailers or containers with or without chassis, including end-of-Car spaces

H = height from above the top of the rails to the top of trailers or containers, in feet.

The above formula, which is derived from Reference Document [8], shall be applied to the Reference Train Set. The Train Set shall be loaded with the maximum number of 40-foot trailers that it can carry. Analyses shall be performed both for the case of all the trailers empty and for the case of all the trailers loaded to their maximum gross vehicle weights, as specified in Table 2.1 of the Specification. The total resistance shall be calculated for the Car at velocities of 5, 20, 40, 60, and 80 mph, using the following formula:

$$R_{tot} = RWN$$

where R, W and N are as defined above, and

R_{tot} = resistance per trailer or container, in pounds.

The calculated value of R_{tot} shall be compared with the maximum allowable values shown in Table 2.4 of the Specification.

For the purpose of predicting train aerodynamic forces, a suitably scaled model of one Reference Train Set with trailers and containers shall be provided for wind tunnel testing. In Reference Documents [8], [10] and [11], the method and results for the wind tunnel testing of various models of railroad cars carrying trailers and containers were presented and may be used for reference.

3.1.8 Weight Estimate

A detailed estimate of the weight of the Car shall be provided to demonstrate conformance with the requirements of Section 2.9 of the Specification. The estimate shall list the weights of the following groups of components separately:

- couplers, articulation joints, draft gear, yokes, and cushioning devices
- trucks
- Car body structure
- total weight of Reference Train Set.

Measured weights may replace the estimates when available. In addition, an estimate of the maximum static loading on any axle of the Car at the Maximum Design Load shall be given.

3.1.9 Safety Analysis

A report summarizing the critical safety factors considered during the design of the Car and the reasons for the selection of each safety-related design alternative shall be presented. The major assumptions that were made concerning human capabilities and limitations shall be described in detail. Sections 2.10 and 3.2.2 of the Specification describe the safety requirements of the Car.

3.2 CAR BODY STRUCTURAL ANALYSES

The stress analyses described in this section shall be performed by the Car builder for the Car body. Simplified preliminary analyses may be performed first. These shall be followed by comprehensive finite element analyses of the structure, where applicable. The fatigue analysis may consist of combined finite element analysis and hand calculations. The finite element analysis shall be used to compute the stresses produced by the specified loadings and the hand calculations shall be used to determine the life of the structure.

The following documentation and data are required for each finite element analysis. First, the input data shall be documented by providing

- illustrations of the structural design
- size, materials and thicknesses of structural members
- material and physical properties of materials including yield strength, tensile and shear moduli
- load forces and locations of forces on the Car structure

Next, the following outputs of the finite element analysis shall be given:

- type of software utilized
- number and description of simulations conducted
- a geometry model that defines all elements and nodes
- plots of the distorted geometry defining maximum deflection areas
- computer output data containing stresses and deflections
- computer graphic stress contour plots, when applicable.

A discussion of the results shall complete the analysis. The discussion shall include:

- summary of significant stress values and maximum deflection values for each loading condition
- comparison of the structural requirements referenced in the remainder of this section with the results of the analysis.

3.2.1 Fatigue

An analysis of the fatigue strength of the Car body shall be performed. The analysis shall follow the guidelines published by the AAR in Chapter VII of Reference Document [1] as specified in Section 3.3.1 of the Specification.

Consideration shall be made, in the analyses, of the frequency of occurrence of the disturbances. Loads such as on-road loads exert many cycles on the structure and require that the structure be designed to withstand an infinite number of these loadings. Switching loads are less frequent and only require design for finite life.

3.2.2 Compression End Load

An analysis of the Car body structure shall be performed to show that the structure can sustain the compressive columnar end load specified in Section 3.3.3 of the Specification.

3.2.3 Vertical Load

Analyses shall be performed showing that the Car body structure has been designed to sustain the vertical loads imposed by trailers and containers under the worst case conditions listed in Table 1.2 (Loading Conditions 1,2, and 5, or 9, 10, and 13), as well as vertical coupler and jacking loads. These analyses shall be used to evaluate whether the requirements of Section 3.3.4 of the Specification have been met.

3.2.4 Torsional Strength

A stress analysis of the Car body structure shall be performed to show that the torsional strength requirement of Section 3.3.5 of the Specification will be met.

3.2.5 Impact Load Analysis

An analysis of the response of the Car body structure to the reaction and inertial forces specified in Section 3.3.7 of the Specification shall be performed. This analysis is to show if the Car body structure is designed to sustain these loads.

3.3 TRUCK ANALYSES

Finite element stress analyses shall be performed for any trucks which have not already been approved by AAR. These analyses, if required, shall consider fatigue, static and dynamic loads as specified in Section 4.3 of the Specification. Both stress levels and deflections shall be calculated and compared with the specified requirements. Maximum stresses, their locations and their direction shall be identified. The procedure for the finite element analyses shall follow that required for the Car body in Section 3.2 of this Test Plan.

3.4 ANALYSES OF OTHER EQUIPMENT

3.4.1 Articulation Joints

If a non-AAR-approved articulation joint is used, then the Car builder shall have performed a structural analysis on it to affirm its integrity under the loadings and stresses which will be imposed on it during testing and operation, as specified in Section 5.1 of the Specification. The analyses shall include finite element analysis of the structure (as in Section 3.2 of this Test Plan) to determine stress distributions and deflections.

3.4.2 Brake System

An analysis of the brake system shall be made to show that the system will meet the requirements specified in Section 5.2 of the Specification. If any part of the system is of a new or untried design, then the analysis shall include (1) a review of the AAR and FRA standards (Reference Documents [4] and [2]) with a discussion and/or analysis showing how each of the requirements is met and (2) a discussion showing how the design is inherently fail safe and complies with AAR Specification No. 2518, "Freight Car Braking Equipment Installation Specifications," Reference Document [5].

3.5 DRAWINGS AND DIAGRAMS

Detailed engineering drawings as specified in Section 5.4.1 of the Specification shall be provided. Additionally, configuration drawings that show the floor plan, the equipment arrangement, the exterior side elevations of both sides of the Car, the elevation views of both ends of the Car, and a sufficient number of transverse half sections or full sections through the Car to show all variations in cross-section are required.

The configuration drawings of the Car shall be dimensioned. All key points shall be located by dimensions from the longitudinal center line, the pulling face of the couplers, and the top of the rails.

IV. ACCEPTANCE TESTS

The Car builder shall have performed the acceptance tests specified in the following sections of this Test Plan. A summary of the tests to be performed is presented in Table 4.1.

Vehicle, Car body, truck, and component test requirements are presented separately in the following sections. The Car builder shall notify the purchaser's representative at least one week prior to the start of any test.

The purchaser's representative shall have the right to witness all tests and inspections and shall have access to fabrication and test facilities at all times during the peformance period of the Order.

A summary of test results in a form that can be directly compared with the requirements of this Test Plan without further calculations shall be provided for each test.

Table 4.1 Acceptance Tests

I. COMPONENT TESTING

II. TRUCK TESTS
- A. STATIC LOAD TEST
- B. FATIGUE TEST
- C. LOAD DEFLECTION AND ACCELERATED AGING TESTS
- D. TRUCK EQUALIZATION TEST

III. CAR BODY PERFORMANCE TESTS
- A. VERTICAL STRUCTURAL TEST
- B. TORSIONAL STRENGTH TEST
- C. COMPRESSIVE STRENGTH TEST
- D. FATIGUE STRENGTH TEST

IV. VEHICLE TESTS
- A. CLEARANCE TESTS
- B. CURVE NEGOTIATION
- C. CONFIGURATION TESTS
- D. COUPLER OPERATION
- E. DYNAMIC PERFORMANCE TESTS
  - 1. STABILITY
    - HUNTING
    - ROCK AND ROLL
    - FLANGE CLIMBING
    - RAIL OVERTURNING
  - 2. RIDE VIBRATION
  - 3. IMPACT TESTS
- F. RESISTANCE
- G. WEIGHT
- H. BRAKES

All tests may be reviewed by the purchaser's representative to verify that the requirements of the Specification have been met. If the test results do not satisfy the requirements of the Specification, correction and/or redesign of non-conforming parts, components or assemblies shall be made and re-tests shall be performed at the expense of the Car builder.

All test data shall be submitted to the purchaser's representative and shall include copies of all original records for each test. The test data shall also be included in the Car Data Book for each Car of the Test Train Set, as specified in Section 5.4.4 of the Specification.

4.1 COMPONENT TESTING

If not already AAR-approved, couplers, draft gear, cushioning devices, articulation joints, trailer hitches, container securements and brakes shall be tested according to the AAR approved procedures referenced in the Specification in order to obtain approval for interchange service.

4.2 TRUCK TESTS

Trucks are considered to be of either a standard or an untried type. A determination of which type a truck is shall be made by the purchaser's representative. If the trucks are of a standard type, the trucks shall conform to the requirements of Reference Document [4], Sections A and D. The tests to be specified here, augmenting the tests in the references cited above, are not required for standard trucks. If the trucks are of an untried type, the following tests shall be performed on the number of trucks specified by the purchaser's representative.

4.2.1 Static Load Test

The static load test is required to verify the accuracy of the stress estimates prepared by the manufacturer (Section 3.3). The test shall be repeated three times with complete release of the load between applications. The trucks shall be tested either as individual load bearing components or as assemblies, as the manufacturer elects. If the load bearing components of the trucks, rather than the complete assemblies, are tested, provisions must be made to apply all input loads described herein in a manner that is identical to the reactions which would occur when these components are included as part of the assemblies. Forces shall enter the components of truck assemblies at the normal application points, and shall be so combined in each case as to produce the maximum stresses at the critical points for which the stress estimates were furnished. The stress readings from three applications shall be averaged for comparison with the estimated stresses.

The test loads to be used are as follows. The vertical load applied to each truck tested shall be equal to the load carried by the truck when the Car is loaded to the Maximum Design Load. The lateral load shall be 10% of the vertical load. The longitudinal load shall be the maximum load the brakes will hold before the wheels start to skid. This load can be estimated by multiplying the coefficient of friction of steel wheels on rails by the load carried by the wheels. The vertical load shall be increased by an amount equal to the weight of the brake assembly if the brake assembly is not attached to the truck at the time of the test.

The vertical, lateral and longitudinal loads are to be applied simultaneously. Locations expected to experience maximum stress are to be instrumented with strain gauges. The locations and directons of the maximum stresses are to be established using brittle lacquer in static tests prior to the static load test. The purchaser's representative shall have the option of modifying the strain gauge locations if he disagrees with the locations chosen by the manufacturer.

The stress values computed by averaging the results of the three static loadings of this test shall be compared to the values predicted in the analysis of Section 3.3. Significant discrepancies must be explained to the satisfaction of the purchaser's representative. Also, there shall be no deformation exceeding the elastic limit of the material. If this requirement is violated, the purchaser's representative shall have the right to require that the design be corrected to bring the test stresses within the allowable limits. The truck shall be retested at the expense of the manufacturer, and all trucks shall be installed in the Cars of the Test Train Set in accordance with the corrected design.

4.2.2 Fatigue Test

To demonstrate that the trucks have adequate fatigue strength under dynamic loading, they shall be subjected to two million cycles of combined loading within the limits specified below.

The vertical load component applied to each truck tested shall vary between the static load carried by the truck when the Car is empty and the static load carried by the truck when the Car is loaded to its Maximum Design Load. The lateral components shall vary with the vertical component and be 14 percent of it. Braking loads shall vary between full release and the maximum steady state conditions with brake cylinders under full pressure.

The frequency of the load cycling shall be approximately equal to the vertical natural frequency of the truck assembly.

At the conclusion of the test, a magnetic particle or dye penetrant inspection shall be made to identify cracks. This test shall be performed in the presence of the purchaser's representative. If any crack is found, the design shall be corrected, the truck retested at the expense of the manufacturer, and all trucks installed in the Cars of the Test Train Set shall be in accordance with the corrected design.

4.2.3 Load Deflection and Accelerated Aging Tests

A load deflection and accelerated aging test procedure agreed to by the purchaser's representative shall be performed to demonstrate that the spring rate of the primary suspension system and the creep rate for the materials used are within the design limits. These tests shall prove that the primary suspension system behaves as predicted; that is, it will not result in excessive deflection causing reduced clearance above the top of the rail in violation of the minimum Clearance Outline of the Specification.

4.2.4 Truck Equalization Test

To verify the equalization provided by the truck design (see Section 4.4.2 of the Specification), a truck installed under an empty Car or a truck subjected to a loading equivalent to that produced under an empty Car shall have one wheel jacked up two and one half inches. Contact between the other wheel treads on the same truck and the rails shall be verified. Alternately, one wheel may be run up a wedge to obtain two and one half inches of elevation while the other wheels remain on level track. Also, one wheel shall be jacked up two inches with no change of more than 25% in the weight on any wheel. If the test indicates that suitable equalization is not attained, the truck design shall be corrected, the truck retested at the expense of the manufacturer, and all trucks installed in the Cars of the Test Train Set shall be in accordance with the corrected design. For articulated Cars, this test shall be performed separately for one truck at the end of the Car and one truck at an interior location.

4.3 CAR BODY PERFORMANCE TESTS

The Car body structure shall be tested to prove its adherence to the requirements of the Specification. The tests detailed in this section are designed to demonstrate that the structure of the Car body can withstand the stress and strain of revenue operation.

In the following tests, locations of maximum stress points and stress directions shall be determined by performing preliminary static tests using brittle lacquer. Strain gauges shall be applied to the Car body structure at maximum stress points as determined in these tests and agreed to by the Car builder and the purchaser's representative, the latter having the power of decision in case of disagreement.

To determine compliance with the Specification, a part shall be considered to have yielded or developed permanent deformation if the measured strain multiplied by the Manufacturer's published modulus of elasticity is greater than the Manufacturer's published yield stress, yield point or yield strength, whichever applies. Multiple loadings of the structure before these acceptance tests are allowed to settle the structure.

If a strain gauge indicates attainment of the yield point or yield strength, the Car builder may request a retest prior to redesign. The purchaser's representative may grant this request with the provision that up to four additional strain gauges will be required in the same general area to determine the effects on surrounding material of the plastic deformation that has presumably occurred, and to determine whether stress values as great as the published yield point or yield strength are reached in the retest. If the high reading has been accompanied by visible evidence of distress in the member, a design correction will be required regardless of strain gauge values indicated in any retest.

4.3.1 Vertical Structural Test

The Car body without trucks shall be subjected to a vertical load test to demonstrate compliance with the requirements of Section 3.3.4 of the Specification. During this test strain gauge readings are to be zeroed with the empty Car body at no load. A test load equal to the Maximum Design Load of the Car shall be applied to the empty Car body, the test load being applied in five equal increments. The test load may be applied by means of weights or jacks, and shall be distributed in proportion to the distribution of weight on the finished Car under the most severe loading conditions (number 5 or 13 in Table 3.2).

The Car body shall have met this specification with respect to vertical load if:

(1) Maximum recorded stresses and strains do not exceed the corresponding allowable stress and strain values defined in the introduction to Section 4.3 above.

(2) Maximum recorded stresses and strains are judged by the purchaser's representative to be in reasonable agreement with the predictions of the analyses of Section 3.3.3 of the Specification.

(3) Recorded residual vertical deflection between bolsters, following removal of the maximum vertical loading, does not exceed 0.03 inch; and

(4) Recorded residual strain anywhere in the structure does not exceed that corresponding to the yield point.

The Car builder may cycle the Car body through several loadings to settle the structure before making these measurements.

4.3.2 Torsional Strength Test

With the same strain gauges as in the Introduction to Section 4.3 in place, the Car body, loaded to the Maximum Design Load, shall be lifted at diagonally opposite jacking pads. The jacks shall then be lowered, the load removed from the Car body, and measurements of any permanent deformation of the Car body shall be recorded to verify that the requirements of Section 3.3.5 of the Specification have been met. The procedure is to be repeated for the opposite set of jacking pads.

4.3.3 Compressive Strength Test

A Static End Compression Test of the Car body structure shall be made, as specified in Reference Document [1], Paragraph 1.2.6.3. The Dynamic Squeeze Test, Paragraph 1.2.6.3.3.2 of Reference Document [1], shall be performed only if requested by the AAR Car Construction Committee. Instrumentation and test conditions shall be in accordance with Paragraphs 1.2.6.1 and 1.2.6.2 of Reference Document [1].

4.3.4 Fatigue Strength Test

A Car body fatigue test shall be performed by the Car builder. The Car builder shall develop load cycling input data for the fatigue test from analyses of data representative of track conditions in the U.S., and from analysis of expected Car operations (e.g., humping, coupling, braking and loading). Alternatively, such data may be provided by the purchaser's representative. The expected total number of cycles of exposure to each type of load and the expected mean and maximum value of each load shall be estimated. Modeling of the Car dynamics will be required in estimating some of the loads.

The estimate of the number of cycles will be used to determine the duration of the tests. Loadings for which more than 2×10^6 cycles are expected need be tested for only 2×10^6 cycles in the fatigue tests. Loadings for which fewer than 2×10^6 cycles are expected during the Car's lifetime (see Section 2.1 of the Specification) shall be applied for only the number of cycles expected.

The Car body shall be tested as an integral unit without trucks, couplers and brake equipment. Hydraulic test equipment that provides simulated vertical, lateral and horizontal vibration load inputs shall be installed at each of the truck mounting locations, and at the coupler locations. The load cycling input data developed above shall be applied to the hydraulic test equipment.

At the conclusion of fatigue testing, a magnetic particle or dye penetrant inspection shall be made to identify any cracks. Inspections shall be performed in the presence of the purchaser's representative. If any crack is found, the design shall be corrected, the Car body structure shall be retested at the expense of the Car builder, and all Car body structures in the Test Train Set shall be in accordance with the corrected design.

4.4 VEHICLE PERFORMANCE TESTS

The following tests shall be performed on the fully assembled Car (or in some cases on one Car Section, with its trucks, of an articulated Car). These tests are designed to determine the acceptability of those aspects of the Car's performance which cannot be evaluated on components or subsystems of the Car (including major assemblies such as trucks or Car body). The specific facilities to be used for these tests are generally left to the choice of the Car builder (subject to the approval of the purchaser's representative). However, some of the tests require use of the unique capabilities of the TTC in Pueblo, Colorado, especially those of the RDL. These are specified in the text.

4.4.1 Clearance Tests

The static clearance estimates used in the analysis of Section 3.1.4 of this Acceptance Test Plan shall be verified and compliance with Section 2.2 or 2.2.1 of the Specification demonstrated by moving a loaded Car through a clearance template constructed over tangent track.

The Clearance Outline presented in Figure 2.1 or 2.3 of the Specification, as appropriate, shall be followed in constructing the clearance template. The clearances between this template and the Car and cargo shall be measured and recorded. Two loading cases shall be considered. These are:

(1) The Car fully loaded with empty 45' highway trailers having a width of 8' and an empty height of 13'6";

(2) The same case with the trailers loaded to their maximum gross vehicle weight, per Table 2.1 of the Specification.

The measured clearance shall be compared with the values used in the analysis of Section 3.1.4. If the measured clearance is different from that predicted in the analysis, the analysis shall be modified. If the new analysis shows that the requirements of Section 2.2 of the Specification are violated, the Car design must be modified to eliminate this violation.

4.4.2 Curve Negotiation

Truck-to-Car-body clearances, side bearing clearances, Car-center swingout, Car-end overhang, air hose connections, and coupler and draw bar clearance shall be checked by moving a Test Train Set of Cars on a single curve and then a reverse ("S") curve which duplicates or exceeds the most restrictive track specified in Table 2.2 of the Specification.

Curve negotiation shall be tested by pushing and pulling against the Test Train Set with a locomotive on one end of the Test Train Set and another (unpowered) locomotive or a set of heavily loaded Cars on the other end of the Test Train Set, both forward and reverse through the crossovers and track curvatures specified in Table 2.2 of the Specification. This test shall be conducted first using an unloaded Test Train Set and then again using 45-foot trailers, fully loaded, corresponding to Load Condition C in Table 2.1 of the Specification. In each case, the drawbar pull shall be at least 200,000 pounds. The lateral and vertical forces between the wheels and rails shall be recorded.

These tests are needed to demonstrate compliance with the requirement of Sections 2.2 and 5.1.1.3 of the Specification.

4.4.3 Configuration Tests

Conformance of the Car with the configuration requirements of Sections 2.3 and 5.1.5 of the Specification shall be shown by the following test.

The trailer hitch mechanisms shall be tested functionally by loading and unloading a 40-foot and a 45-foot trailer onto each Car Section by use of standard overhead and side loading equipment (including bottom lift equipment). Container support and latching mechanisms shall be tested by loading and unloading 20-foot, 35-foot, and 40-foot containers onto each Car Section. A test designed to demonstrate total system compatibility among the Cars, other freight cars, and terminal handling equipment shall also be performed by the Car builder.

The trailer wheel platform heights and widths shall be measured for each Car and entered into the Car Data Book.

4.4.4 Coupler Operation

The operation of the mechanical couplers shall be functionally tested in the presence of the purchaser's representative to demonstrate conformance with Section 5.1 of the Specification.

4.4.5 Dynamic Performance Tests

The dynamic performance tests described below shall be performed to verify compliance with the dynamic performance requirements specified in Sections 2.7 and 2.8 of the Specification. The specific and final choice of test speeds and loading conditions shall be made on the basis of the results of the detailed analyses described in Section 3.1.6 of this Test Plan (to focus on the most demanding conditions).

One Car of the Test Train Set shall be instrumented and tested to verify compliance with the dynamic stability and ride vibration requirements specified in Sections 2.7.1 and 2.7.2 of the Specification. All tests shall be performed using wheels with modified Heumann profiles.

Instrumentation capable of measuring and recording the vertical, lateral, and longitudinal accelerations at frequencies up to 50 Hz shall be installed at the following locations:

- above the kingpin and above the trailer bogie center on the trailer cargo floors,
- above each bearing adapter on one truck (on one of each type of truck if there is more than one type), and
- on principal structural members of the Car body at sufficient locations to deduce (1) Car body roll, pitch, yaw, lateral, and vertical responses, and (2) the first bending and torsional modes.

Instrumented wheelsets shall be installed on one of the trucks to measure vertical and lateral wheel/rail forces. The truck with the instrumented wheelsets shall be one of those having accelerometers mounted above the bearing adapters.

Provisions shall be made for recording the accelerations and forces concurrently with speed and location along the test track.

The dynamic performance tests specified here require the use of the facilities of the Rail Dynamics Laboratory (RDL) at TTC and unspecified test tracks. The track testing can be performed at facilities mutually acceptable to the Car builder and the purchaser's representative, and may include use of some of the TTC test tracks described in Section 1.2 of this Test Plan.

When both RDL and track testing of the same phenomenon are required, the RDL tests shall, if possible, be performed first in order to aid in refining the choice of conditions (especially speeds) for the track tests. Because of the significant time required to set up each test, all tests using the same facility (either the VTU or RDU) should be scheduled together.

4.4.5.1 Stability

Hunting

The following tests shall be performed to investigate Truck and Car body hunting stability. The results shall be used to verify the analyses of these phenomena in Section 3.1.6.1 of this Test Plan and to show compliance with the requirements of Section 2.7.1 of the Specification. These tests shall be conducted for loading conditions 1, 5, 6 and 7 or 9, 13, 14 and 16 of Table 1.2, depending on the Car Section configuration.

One Car Section, with trucks, shall be mounted on the Roll Dynamics Unit (RDU) at TTC. The speed of the RDU shall be increased from zero to the vicinity of the lowest speed for which hunting was predicted in the detailed analyses of Secton 3.1.6.1, and then more gradually increased from that speed to the maximum speed of 100 mph. The amplitudes of wheelset lateral and yaw displacements and truck and Car body accelerations shall be recorded to identify the incidences of hunting. The test shall be continued for speeds gradually decreasing from 100 mph to zero to identify possible different hunting behavior.

The hunting tests shall be continued on railroad track at speeds near those which produced hunting in the RDU tests. These shall initially be performed on the smoothest available track, Class 6 or better, such as the RTT at Pueblo. They shall then be repeated on Class 5 and 3 track, for speeds which do not exceed the maximum allowed on these classes of track.

Rock and Roll

The "rock and roll" stability of the Car shall be tested at the speeds found most likely to induce rock and roll response in the analyses of Section 3.1.6. The loading shall be that with the highest center of gravity, Condition 1 or 9 of Table 1.2.

The standard test procedures for rock and roll stability are found in Reference Document [4], Section D - Trucks and Truck Details, pages D-65 to D-66, as specified in Section 2.7.1.2 of the Specification. This procedure provides useful guidance for the rock and roll testing needed here, particularly in the choice of track crosslevel input. The VTU can be very effective for testing for rock and roll, and shall be used to investigate response to track crosslevel inputs at several different amplitudes (corresponding to the different track classes) for the speeds suggested by the analyses. The VTU results shall then be confirmed by track testing based on (or adapted from) that described in Reference Document [4].

Flange Climbing

The L/V force ratio of each wheel of the instrumented wheelsets shall be recorded and reported to demonstrate compliance with Section 2.7.1.3 of the Specification. Operating conditions shall include:

- empty Car and loading to Maximum Design Load;
- tangent and curved track of Classes 2, 3 and 5;
- speeds up to the maximum allowed for each track class on tangent tracks, while speeds in curves shall not exceed that corresponding to 3 inch unbalanced superelevation.

Rail Overturning

The combined L/V force ratio of the wheels on one side of a truck shall be measured for both sides of the truck to demonstrate compliance with Section 2.7.1.4 of the Specification. The operating conditions shall be the same as those specified above for flange climbing.

4.4.5.2 Ride Vibration

Ride vibration tests shall be performed on the Vibration Test Unit (VTU) and on TTC or mainline track. These tests serve two distinct functions:

- The dynamics of the Car with trailers or containers attached shall be characterized. The characterization is to include mode shapes, resonant frequencies and damping.
- Ride quality response data shall be obtained for a representative range of track conditions and vehicle speeds.

The maximum allowable operating speeds to be used for each class of track are given in Table 4.1 of the Specification. Loading conditions 1, 3, 5, 6 and 8 or 9, 11, 13, 15 and 16 of Table 1.2 shall be tested. Accelerometers shall be mounted on the floors of the trailers mounted on the Car, centered above the kingpins and trailer bogies. The trailer acceleration measurements shall be compared with the requirements of Section 2.7.2 of the Specification.

The VTU tests of a single Car Section, with trucks, shall be performed first in order to focus on the most important response characteristics in the track tests. Sine sweep tests shall be used to isolate the significant response modes as a function of speed and loading condition. These shall be followed by tests using simulated track inputs corresponding to track classes 2, 4 and 6 at several representative speeds (chosen on the basis of the analysis results of Section 3.1.6) up to the maximum allowed for each class of track.

The VTU tests shall be followed by field tests on track of classes 2, 4 and 6 at those combinations of speeds and loading conditions which produced the most severe responses in the VTU tests.

The measurements collected in all ride vibration tests shall be processed in forms suitable for comparison with the requirements of Section 2.7.2 of the Specification. Power Spectral Density (PSD) plots shall also be provided for comparison with the analytic results of Section 3.1.6.2 and for use by shippers planning to ship goods on these Cars.

4.4.5.3 Impact Tests

The impact tests are to be performed for two purposes: (1) to demonstrate that the Car is capable of providing shock protection for the cargo, as specified in Section 2.7.3 of the Specification, and (2) to demonstrate that the Car body structure can sustain the forces resulting from impact, as specified in Section 3.3.7 of the Specification.

The contractor shall instrument one Car Section for a single Car impact test as defined in Paragraph 1.2.6.3.3.1 of Reference Document [1]. In addition to the standard instrumentation specified for this test, vertical, lateral, and longitudinal accelerations shall be recorded using the same locations specified above in Section 4.4.5. At impact, the displacement of the draft gear and cushioning units shall also be recorded. Test conditions shall be as defined in Paragraphs 1.2.6.1, 1.2.6.2, and 1.2.6.3.3.1 of Reference Document [1]. The Car shall be impacted against either standing Cars or a test device.

The results of these tests shall be used to validate the analyses of Sections 3.1.6.3 and 3.2.5 of this Test Plan.

The Car shall be tested under load conditions 1 and 3 or 9 and 11 of Table 1.2.

4.4.6 Resistance Tests

The combination of aerodynamic and rolling resistance of the Car shall be measured over a representative portion of its operating speed range (at least at the speeds of 5, 20, 40, 60 and 80 miles per hour). The baseline loading condition for these tests shall be either number 1 or 9 from Table 1.2. Adherence of the Car's design to the resistance requirement of Section 4.8 of the Specification can be verified by either of two test procedures, at the option of the purchaser's representative:

(1) Scale-model wind tunnel testing for aerodynamic resistance and RDU tests for rolling resistance of one full-scale Car Section with trucks, or

(2) Full-scale testing of one or more complete Cars on tangent track.

Because the resistance forces which must be measured are small relative to most of the forces present in the railroad environment, extreme care must be taken in executing these tests and multiple repeats are strongly urged to enhance the statistical confidence of the results.

The scale model wind tunnel tests shall follow the procedures described in Reference Documents [8], [10] and [11], for the zero-yaw case (no cross-wind component). The RDU tests shall be conducted at the speeds and loading conditions already described, with the rolling resistance estimates being derived from longitudinal force measurements obtained from the load cells in the RDU longitudinal restraints.

The track tests must be carefully controlled to separate out the effects of ambient wind on aerodynamic drag and the effects of track compliance, roughness and grade on the apparent rolling resistance. These tests shall be performed on the smoothest, straightest, flattest and most rigid track available (such as the Railroad Test Track at TTC), and shall be run in both directions so that any direction-dependent influences can be averaged out. The drawbar forces at the forward end of the Car shall be recorded during constant-speed operation at each of the required test speeds, and the calibration of the force-measuring device shall be re-checked before and after each test run. The forward speed and air speed of the locomotive pulling the Car shall be recorded. Mean values and standard deviations of the measurements are the minimum data to be provided, but the purchaser's representative may also request time history plots of all measurements. Should more than one Car be available at the time of this test, the Car builder is encouraged to provide the longest consist he can in order to enhance the reliability of the results (the larger forces on the first drawbar being likely to enhance the significance of the test).

The net (mean) measured resistance force per trailer at each of the specified speeds shall be computed from the test data and compared to the requirements in Section 4.8 of the Specification. Resistance values exceeding those cited standards must be explained to the satisfaction of the purchaser's representative, or the design of the Car must be modified and re-tested until it is in compliance.

4.4.7 Weight

In order to show compliance with Section 2.9 of the Specification one representative Car shall be weighed as follows: each Car Section shall be weighed at both ends, with and without the trucks, using a weighing device that provides a permanent record of the weight. Copies of the weight tickets shall be included in the Car Data Book. The weighing device shall have a tolerance of one-half of one percent. Certification of the device shall be provided to the purchaser's representative.

4.4.8 Brakes

The following brake system tests shall be performed to show compliance with the requirements of Section 5.2 of the Specification.

4.4.8.1 Brake Efficiency Test

Brake shoe forces shall be measured on each wheel of the Car to verify compliance of the Net Braking Ratio with requirements referenced in Section 5.2.3 of the Specification.

4.4.8.2 Air Brake Test

The Car builder shall perform a complete In Date Test and Stencil (IDT&S) functional test of the air brake system.

4.4.8.3 Hand Brake Test

Brake shoe forces shall be measured on each wheel of the Car when the hand brake is applied, in accordance with the procedures outlined in Reference Document [4], Section E, using first new, and then fully worn, brake shoes or pads.

The automatic hand brake release and hand brake indicator shall be tested functionally in the presence of the purchaser's representative.

Low-Profile, Light-Weight Intermodal Railcar, **Volume II: Acceptance Test Plan**, 1981
US DOT, FRA, Russell L Hull, Steven E Shladover