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TESTS OF THE AMTRAK SDP-40F TRAIN CONSIST CONDUCTED ON CHESSIE SYSTEM TRACK

EXECUTIVE BRIEF

DEPARTMENT OF TRANSPORTATION ★ UNITED STATES OF AMERICA ★

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FINAL REPORT

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16. Abstract

This report describes results of tests of an SDP-40F train consist conducted on Chessie System track during June, 1977. The test consisted of the operation of two test trains intended to be typical of AMTRAK passenger consists, one powered by two SDP-40F's and the other by two E-8's, over a variety of track conditions. The objectives of the tests were to compare dynamic performance of the SDP-40F locomotive with a baseline case, the E-8, and to determine the sensitivity of the SDP-40F response to track geometry variations, operational parameters and several maintenance and configuration states of the truck/suspension system.

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PREFACE

This report comprises the Executive Brief (Chapter 1) of a more comprehensive report (FRA/ORD-79/19) and describes a test which was carried out under the auspices of the FRA Office of Rail Safety Research and conducted and analyzed by a joint government/industry group. As in most tests, "insights" were gained beyond the pure factual information gathered. Although the prime emphasis of this report is on providing technical data on the relative performance of the SDP-40 consist under the specific conditions of test made on trackage of the Chessie System, the format has been structured to convey the insights and the facts toward reaching the decision-makers involved in the "real world" problem of operating trains with this type of locomotive power.

Accordingly, the Executive Brief is aimed at railroad managers who can best assess and translate the importance of facts, trends, insights and judgments into meaningful actions. While this executive brief attempts to provide the reader with sufficient data and exhibits to convey the conclusions and recommendations in a clear fashion, the actual data upon which this executive brief is based, is contained in the full report which the reader is encouraged to obtain. The full report is available from the National Technical Information Service (NTIS), Springfield, Virginia 22161.

Acknowledgement is made to the many groups which contributed to the test and report. A very special acknowledgement is due to the Review Group, composed of representatives of the Association of American Railroads, National Railroad Passenger Corporation (AMTRAK), Electro-Motive Division of General Motors Corporation, the FRA Office of Safety, and the Chessie System, whose active participation and comments proved invaluable in providing guidance during the conduct of the analysis and on the organization and interpretation of the final results. Finally, special thanks are due to AMTRAK for providing the equipment used in these tests, and to the Chessie System for permitting use of their track and for their active and complete cooperation during all phases of the test and analysis activity.

EXECUTIVE BRIEF

1. BACKGROUND

The SDP-40F locomotive was introduced in Amtrak passenger service in June, 1973, and by August, 1974, a total of 150 SDP-40F locomotives were in service. This locomotive, a 3,000-hp, 6-axle, 6-motor unit like the SD40-2 locomotives which are widely used in freight service is equipped with HTC trucks. These passenger models have steam generators and water tanks and weigh nominally 396,000 lbs. with full supplies.

The SDP-40F locomotives generally replaced E-8 and E-9 locomotives originally delivered to the railroads between 1950 and 1962. These "E" type locomotives utilizing swing hanger type trucks were designed for passenger service and were 2250- to 2400-hp, 6-axle, 4-motor models weighing nominally 335,000 lbs. with full supplies. They were generally considered as dependable with no widely recognized safety problems.

By January, 1978, Amtrak passenger trains powered by SDP-40F locomotives had been involved in 21 derailments at speeds of 30 mph or greater. Concurrently, between 1974 and 1977, several special tests were conducted to factually determine the derailment tendencies of these consists as operated by Amtrak. Table 1 summarizes the essentials of prior derailments and the major test activities (page 18).

2. CHESSIE TESTS OVERVIEW

To provide data that would complement and extend the findings of the referenced tests, the FRA Office of Rail Safety Research, in cooperation with the AAR, Amtrak and EMD, conducted a series of controlled tests using typical Amtrak SDP-40F and E-8 locomotive consists over Chessie System track in June, 1977. The data analyses of these tests concentrated primarily on 2° to 3° curves on Class 3 jointed track with train speed ranging from 30 to 60 mph.

A comparative test procedure involving the predecessor E-8 power was dictated since absolute criteria for specific safe limits of wheel/rail force or force ratios were not available. The design of the test and the subsequent data analysis was established based on a recognition that SDP-40F derailments are rare events. While a given difference in wheel/rail force levels between the SDP-40F and baseline E-8 consists may not be significant in itself, the potential force levels reachable may be far above test results due to cumulative effects, i.e., additive increments in force due to the effects of sanding, maintenance states and operating practices. Thus, detection of marked differences in performance trends rather than absolute levels were considered especially important since unfavorable locomotive consist combination of conditions could conceivably occur in actual operations at the same time that "marginal" track conditions are encountered. Accordingly, the subsequent analysis was aimed at uncovering trends in those factors that could contribute to adverse performance even if a particular factor or level of force in itself may not justify attention as a sole cause of derailments. Since the focus of inquiry was on determining the mechanism for SDP-40F powered train derailments, concentration of efforts centered primarily on analysis of those portions of the test data where the performance of the SDP-40F consist exhibited unfavorable trends in comparison to the E-8 baseline case. (This is not meant to infer that the SDP-40F never compared favorably to the E-8 during the tests.) Also, a number of measurements were made in relationship to the SDP-40F consist which were not correspondingly done on the E-8.

The stated objectives of the tests and subsequent data analysis were:

1. Comparative characterization of SDP-40F consist performance,

2. Evaluation of the contribution of track and operational variations,

3. Evaluation of the contribution of various wear and equipment maintenance conditions, and

4. Development of guidelines for evaluating and ensuring the safety of new locomotive designs over their life-cycles.

Key elements in accomplishing these objectives were:

1. Continuous onboard wheel/rail force measurements on each of the two separate locomotive consists,

2. Selection of a specific test site based upon comparison of performance of the two locomotive consists operating over hundreds of miles of representative track,

3. Complementary wayside measurement of wheel/rail forces for each vehicle of <u>entire</u> consists at the selected test site,

4. Simultaneous measurement of track geometry for all trackage traversed by the consists, and

5. Application and validation of fresh analytical approaches toward establishment of <u>trends</u>.

3. FINDINGS AND RECOMMENDATIONS

At the risk of oversimplifying the results of a many faceted study, the findings and recommendations of this Executive Brief are intended to minimize the communication obstacles often posed by technical complexities. Since emphasis is on highlighting those comparative <u>trends</u> which best address the regime of actual SDP-40F consist derailment experience, the body of the report must be referred to for a more in-depth understanding as to performance differences over the broader spectrum. Obviously, incorporation of this approach:

1. is aimed at reaching the largest possible audience with maximum clarity,

2. relies upon judicious selection of <u>important</u> factors,

3. assumes that extrapolation of comparative trends is justified,

4. supports individual conclusions with varying degrees of certainty, and

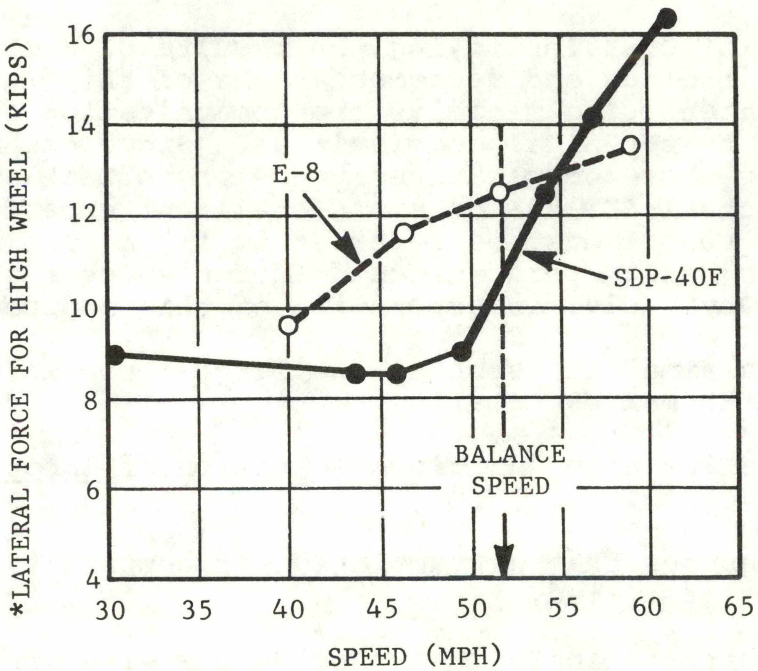
5. does not include <u>all</u> the details of caveats and/or qualifications which are contained in the body of the report.

This section presents the major results of the testing program. Findings are based on the test data and analysis which are provided in greater detail in the body of the report. The graphs included illustrate pertinent results but are not the sole basis for arriving at conclusions and/or recommendations.

3.1 Comparative Characterization of SDP-40F Consist Performance

Locomotive Single Axle Forces

1. The SDP-40F maximum single axle lateral load tended to exhibit greater increase in levels with increasing speed beginning near the "balance" speed. Figure 1 shows a severe case selected from actual data to illustrate this characteristic.



*95th Percentile - 5% of the time the forces exceeded this level.

Figure 1 Comparison of Lateral Force Trends Versus Speed for Lead Axles

2. A statistical regression analysis of 25 other curves supports an increasing force trend for the SDP-40F. At some point above the balance speed the SDP-40F lateral forces exceed those of the E-8 by increasing amounts.

Locomotive Middle Axle Forces

3. The middle axle lateral force tended to be higher for the SDP-40F than the E-8 virtually over the entire tested speed ranges; which contributed to higher lateral truck forces (Figure 2).

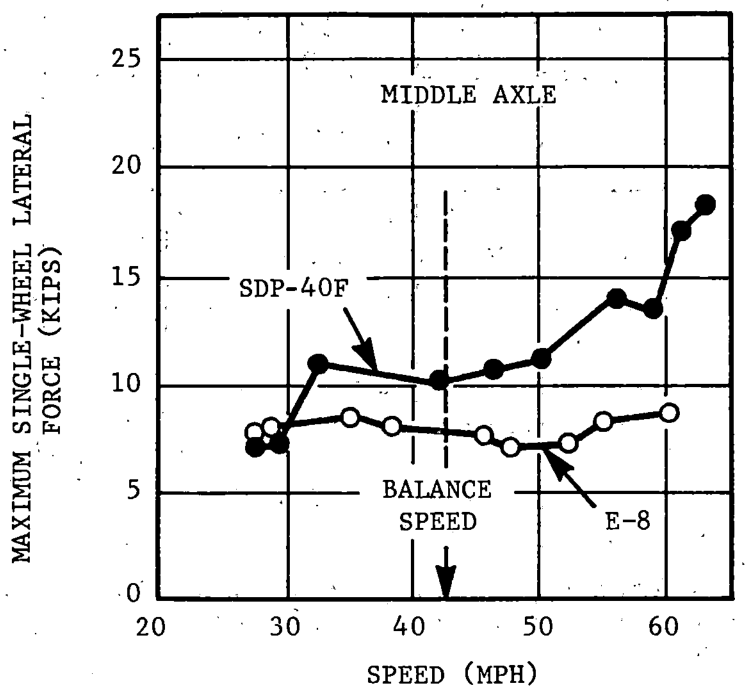


Figure 2 Comparison of Maximum Single-Axle Lateral Force for Middle Axles

Locomotive Third Axle Forces

4. The third or trailing axle lateral forces of the SDP-40F and E-8 were roughly comparable and at relatively lower levels.

Locomotive Truck Forces

5. Total <u>truck</u> lateral loads, which may be most significant for the reported causes of SDP-40F powered train derailments, were derived from measured axle data and tended to be higher on the SDP-40F than on the E-8 with the differences increasing with speed (Figure 3).

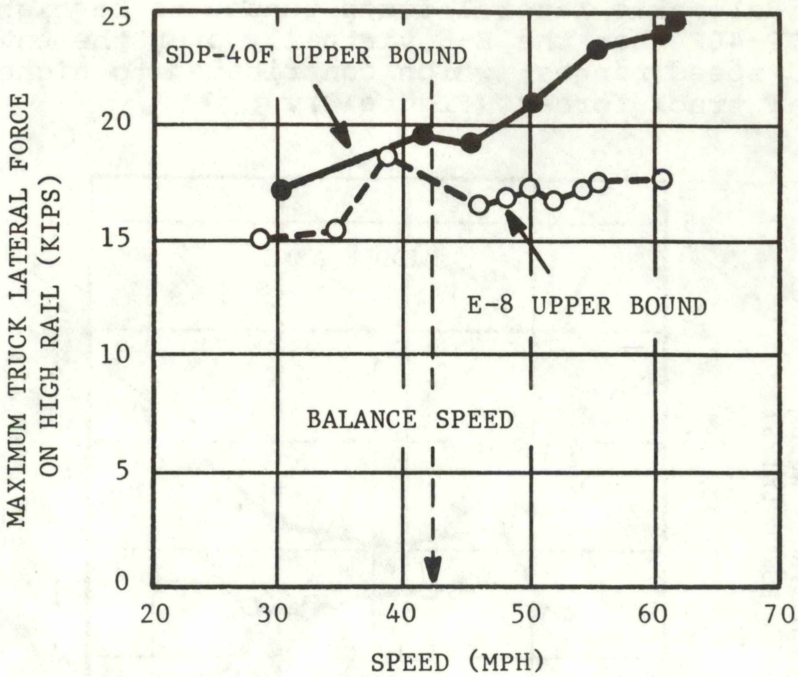


Figure 3 Comparison of SDP-40F and E-8 Upper Bounds of Lateral Force on High Rail for Trailing Truck

Locomotive L/V Ratios

6. The regression analysis of 25 curves indicated that the L/V ratios were higher on the E-8 than the SDP-40F. Specific individual runs showed that for the SDP-40F (consistent with lateral force findings), the L/V ratio had a definite trend towards higher rates of increase beyond the balance speed. The L/V ratios measured are below the derailment criteria commonly applied in the industry.

Locomotive Force Levels

7. Although the levels of forces measured for nominal consist configurations at the test site would not in themselves be considered excessive, the totality of results indicated that the important wheel/rail force trends uncovered can be augmented by other more unfavorable combinations of equipment configurations, maintenance/operations and track geometry conditions

(i.e., gage, cross level and alignment). These additives could produce more critical train derailment tendencies.

Locomotive Recommendations

- *Based on the Chessie System Tests, and under the criterion of equivalence to E-8, SDP-40 powered trains can be operated to maximum speeds corresponding to about 1-1/2" unbalance on typical Class 3 track. With greater track strength and smaller rates of changes in track geometry deviations, consideration could be given to various degrees of relaxation of this limit.*

- *In view of the increase in lateral force with speed which the SDP-40F exhibits in operation above balance speed, precautions should be taken with SDP-40F locomotive consist operations to ensure that trains are not operated in excess of recommended speed limits (over speed).*

Locomotive Vertical Dynamics

8. Application of vertical 1800/1800-lb. shock absorbers to the SDP-40F resulted in reductions in vertical carbody accelerations of up to 25% at the resonant conditions.

Locomotive Recommendations

- *Apply vertical 1800/1800-lb. shock absorbers to the SDP-40F locomotives. This has the potential of lowering L/V ratios and improving the coupling interface dynamics with adjacent vehicles.*

Locomotive Curving Characteristics

9. The tests indicate differences in curving characteristics of the SDP-40F and the E-8 locomotives. While the SDP-40F frequently produced second axle high-rail dynamic lateral force levels which approached or exceeded lead axle lateral forces, this was not the case for the E-8. On the E-8, the leading wheel on the high rail (commonly thought of as the "guiding" wheel in curve negotiations) consistently exhibited

wheel/rail lateral force levels greater than the wheels on the trailing axles (Figure 4).

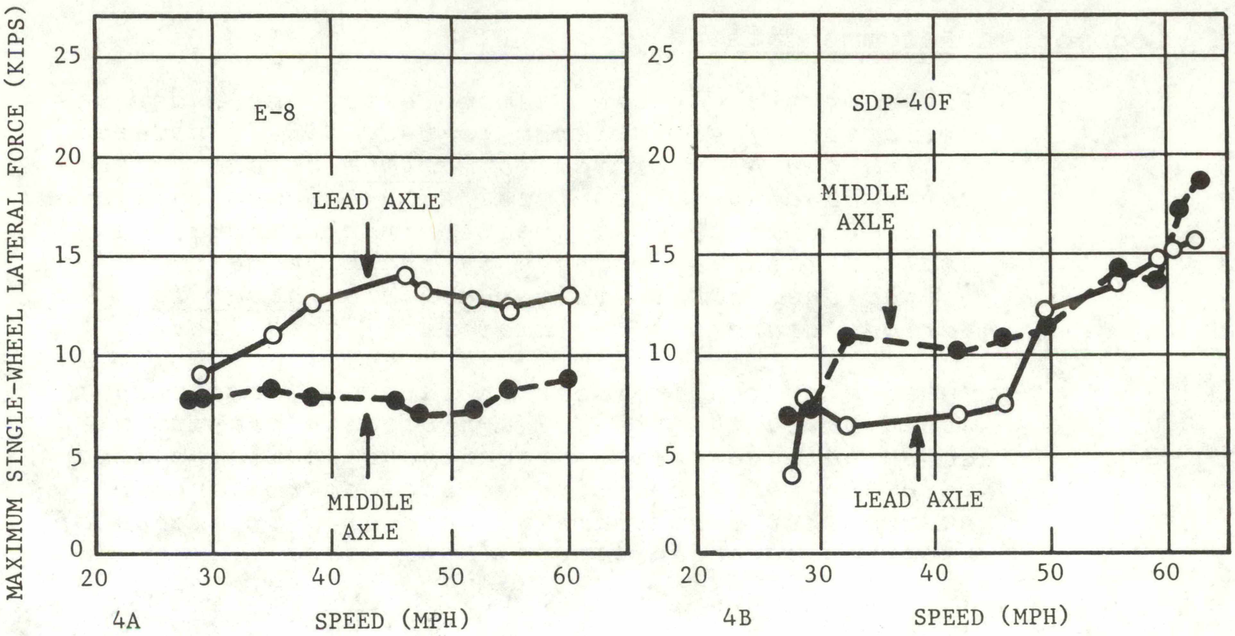


Figure 4 Comparison of First and Middle Axle Lateral Forces

Locomotive Baggage Car Coupling

10. The tests produced evidence of interactions between the locomotive and adjacent baggage car which will be referred to as coupling. Both vertical coupling and lateral coupling were observed. A strong indication of lateral coupling between the locomotive and baggage car was seen in the tests. The baggage car behind the SDP-40F (which has alignment control) generated maximum axle lateral loads twice as high as the baggage car behind the E-8 (which does not have alignment control) (Figure 5). Although there were some indications of alignment control involvement, it was not possible to accurately quantify the influence on performance.

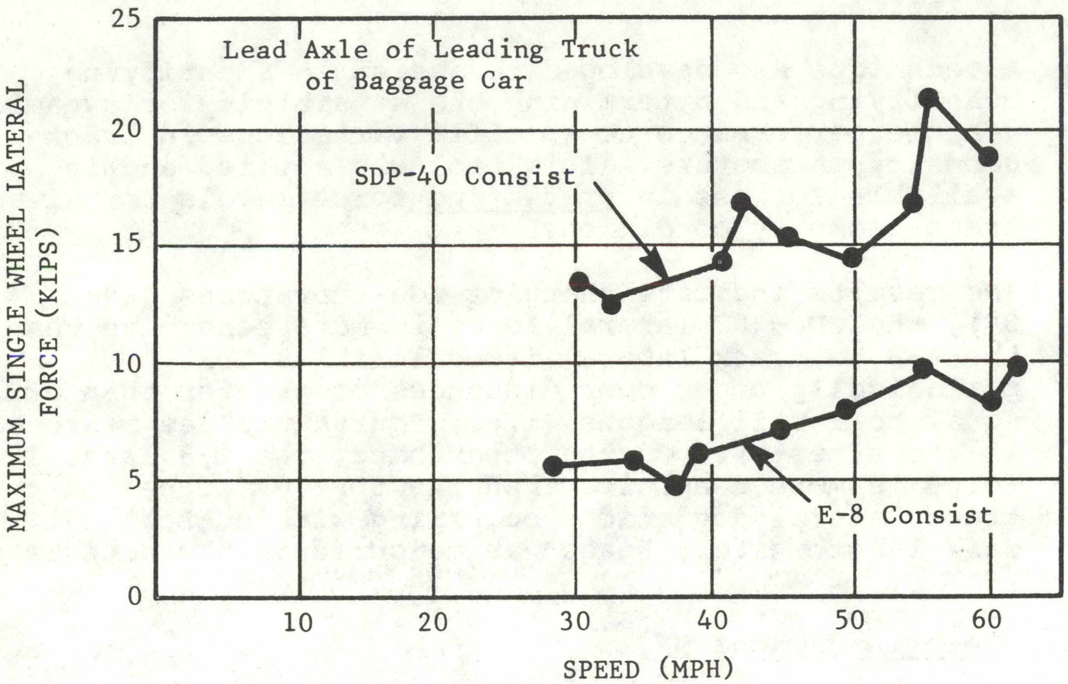


Figure 5 Upper Bound of Maximum Single-Axle Lateral Force on E-8 and SDP-40F Baggage Cars

Locomotive Recommendations

- *Remove the alignment control from SDP-40F locomotives to eliminate any locomotive-baggage car lateral coupling which may result from its use (only if it can be verified that alignment control is not necessary for the relatively short passenger train consists used by Amtrak).*

3.2 Evaluation of the Contribution of Track and Operational Variations

Track Influence

1. It was found that SDP-40F and E-8 lateral wheel-rail loads were generally higher in the vicinity of rail joints in the high rail than in other places on the track. These loads were associated with rapid changes of gage and/or alignment. The maximum dynamic lateral loads occurring in the immediate vicinity of joints

were commonly 2-4 times the steady state loads associated with curved track with minimal geometry deviations.

2. A technique was developed to assist in identifying, quantifying and determining the sensitivity of dynamic vehicle performance to specific variations in track geometry parameters. This tool was applied and is available for use in <u>predicting</u> force levels for given track geometry conditions.

3. The results indicate that for low curvatures (2°-3°), the SDP-40F lateral force is more sensitive than the E-8 to track lateral irregularities that periodically occur over distances of greater than or equal to 2 rail lengths (i.e., "curvature" as measured in these tests). On the other hand, the E-8 lateral force is more sensitive than the SDP-40F to periodic track lateral deviations occurring within about one rail length (i.e., "gage" as measured in these tests).

<u>Track Recommendations</u>

- *Priority maintenance should be directed at lateral track strengthening to provide greater rail fastening capacity in curves - including those of moderate degree of curvature which are sometimes considered almost "tangent" and do not always receive the speed reduction warranted. In jointed track, special attention should be given to tamping and improved fastening, e.g., additional spiking, in the immediate vicinity of joints.*

- *Railroads should give emphasis to maintaining track in curves to avoid large rates of change of track geometry and combinations of track geometry variations even though individual minimum standards allow such conditions.*

- *Railroads should give serious consideration to periodically utilizing an instrumented locomotive for the purpose of detecting those track locations which produce maximum dynamic responses. Critical track maintenance needs could thus be determined -- especially for routes where new passenger equipment which might have different degrees of sensitivity to track/operating variations will be used.*

Rail Surface Condition

4. In the tests at speeds up to 35 mph, sanding nearly doubled the maximum dynamic lateral wheel/rail force in curves. Conversely, the lateral loads were significantly reduced with rain on the rails.

Operating Recommendations

- *Both unnecessary manual and improperly triggered automatic use of sand in curves should be avoided. The benefits/problems associated with the use of onboard lubricator systems (similar to Swiss applications) which might reduce lateral forces in curves should be investigated and tested.*

Train Handling Practices

5. For the relatively short Amtrak passenger train consists, normal train handling practices involving changes in power or braking modes had little effect on lateral wheel-rail loads.

3.3 Evaluation of the Contribution of Various Wear and Equipment Maintenance Conditions

Locomotive Wheel Size Variations

1. The tests showed that increases in wheel L/V ratios of 40% can be produced with a simulated 1-1/4 inch radial wheel mismatch between axles (Figure 6).

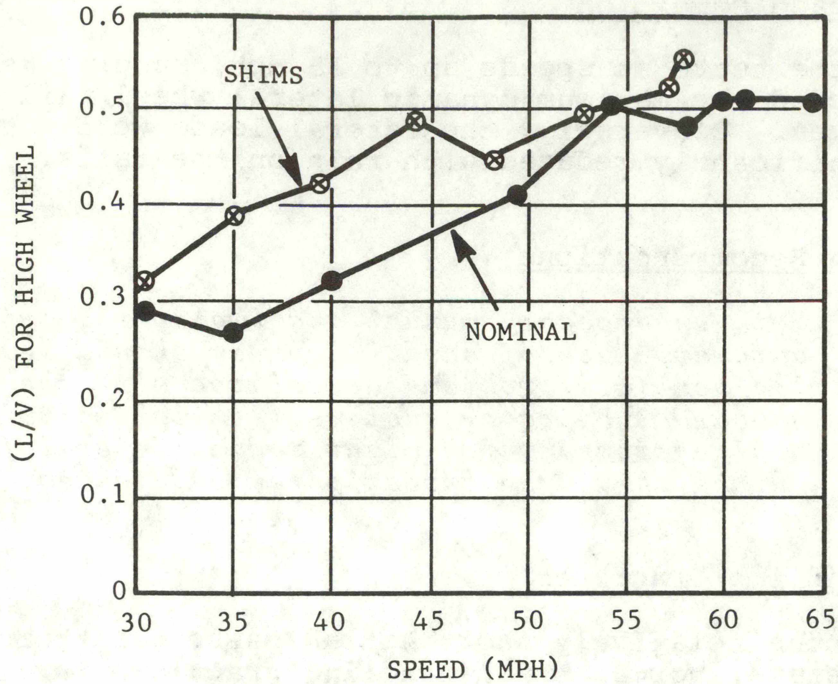


Figure 6 Effects of Simulated Wheel Mismatch

<u>Locomotive Wear and Maintenance Recommendations</u>

- *EMD releases of June 1, 1971, and July 12, 1971, provide recommendations on wheel size variations and journal spring shimming. If wheel size mismatch within a 3-axle truck exceeds 1/4 inch on the radius (but less than the maximum allowable variation of 5/8 inch on the radius), shimming should be used to equalize vertical wheel loads. Excessive mismatch (even if properly shimmed) can induce false wheel slip indications and subsequent sanding. Maintenance procedures and practices should be aimed at ensuring that mismatches beyond limits specified do not occur.*

<u>Locomotive Lateral Axle Clearances</u>

2. **For the relatively short Amtrak passenger train consists, increasing lateral axle clearance on the SDP-40F had a negligible effect on lateral wheel-rail loads.**

Control of Vertical Accelerations

3. The maximum vertical baggage car accelerations were about 45% higher than the maximum vertical accelerations of the SDP-40F locomotive with nominal vertical shock absorbers.

4. Resonant speeds for baggage car body bounce and pitch (48-58 mph in Chessie Tests) can overlap the resonant speeds for SDP-40F body bounce and pitch (40-50 mph range in Chessie Tests), depending on the baggage car load and the locomotive supplies. The overlap of resonant speeds can accentuate the vertical interaction between locomotive and baggage car if the couplers are vertically misaligned.

Baggage Car/Locomotive Vertical Coupler Alignment

5. Vertical coupling (forced interactions) between locomotive and baggage car increased when test variations in locomotive wheel diameters produced conditions wherein the couplers were misaligned vertically. Figure 7 indicates the extent of the resulting higher accelerations measured in the baggage car.

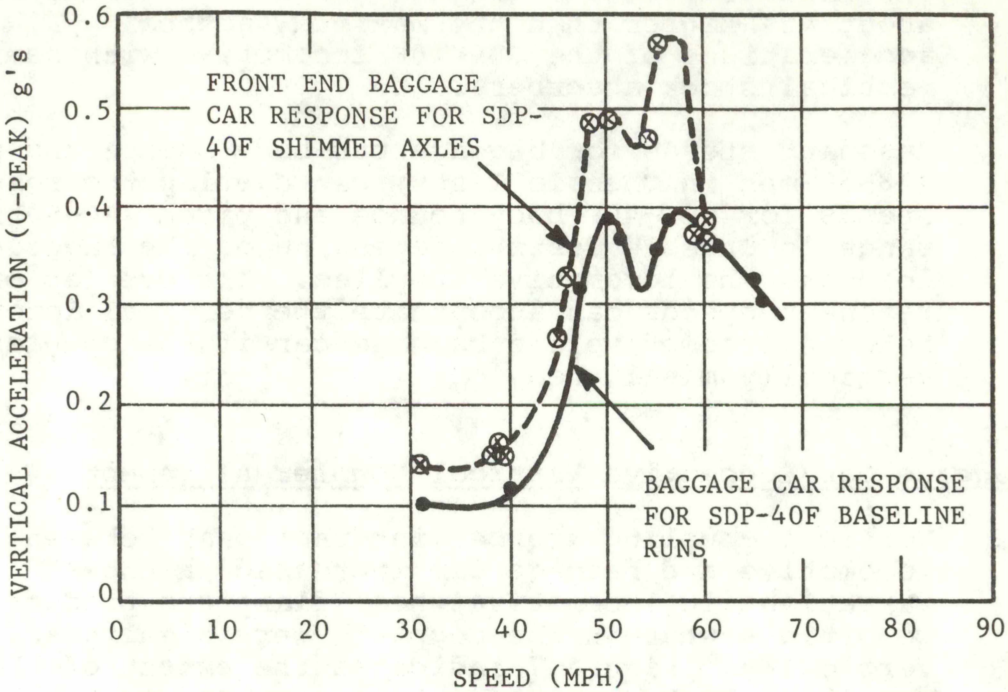


Figure 7 Baggage Car Vertical Effects

__Baggage Car/Locomotive Wear and Maintenance Recommendations__

- *Maintain proper coupler heights on locomotive and baggage cars. Allow for variations in locomotive/baggage car coupler heights as fuel, water supplies and baggage car lading changes.*

- *Maintain the spring-load coupler carrier on locomotives and baggage cars.*

- *Install and maintain vertical shock absorbers on all baggage cars.*

3.4 __Development of Guidelines for Evaluating and Ensuring The Safety of New Locomotive Designs Over Their Life-Cycles__

__Facilitation of Future Testing__

1. The Chessie Tests and the previous individual tests (referenced in the Background) incurred large

expenditures of manpower, equipment and other resources in reoccurring type tasks basically associated with setting up test procedures, instrumentation, establishment of logistics, means to support data collection, searching for a representative site, tear down, etc. In spite of prior intentions and careful planning, "field" tests inevitably cannot be "efficient" since the conduct of tests must fit in with critical railroad operations and time changing physical states. Additionally, such individual tests invariably take place under varying conditions which require extended time and effort to arrive at any meaningful comparison between different individual tests. More control, standardization and reduction in costs per test is needed.

Testing Guideline Recommendations

- *The feasibility of structuring a dedicated section of trackage which incorporates a known and representative range of track conditions and appropriate support facilities to minimize test costs and maximize the reliability of performance comparisons should be rigorously explored. Such a site could serve as the nucleus for arriving at more objective quantification of track/rolling stock/operations derailment criteria and results could be supplemented by limited field tests where warranted.*

Measurement and Analysis Tools

2. Tests predating the Chessie Tests did not clearly show the trends revealed in this report, apparently because instrumentation techniques and analytical tools that were especially developed for this series of tests were not practically employable. Without these aids, the statements contained in the report could not be made with reasonable confidence. Because of the potential importance to both the railroad and supply industries, definitive descriptions of improved instrumentation and analytical methods developed for/during this program are being included in this report. These advancements should prove valuable in future evaluation efforts.

3.5 Future Study Needs/Potentials

The findings of the tests on the Chessie System, together with the data provided in previous tests and from the derailment statistics, suggest several areas to be considered in future research.

Coupler Design

While proper coupler height on locomotive and baggage cars is important to minimize vertical coupling between the vehicles, consideration might also be given to using an "E" type coupler in place of the "F" type interlocking coupler on the locomotive to further minimize transmission of vertical loads through the couplers between locomotives or between a locomotive and a baggage car. Since it is desirable to keep the vehicles coupled together in the event of a passenger train derailment, an "E" type double shelf coupler might be a good candidate for evaluation.

Track Geometry

While initial steps have been taken to study the relationships between track geometry and vehicle response, additional work needs to be done to clarify these relationships and to make the information a useful input to track maintenance decisions. This includes development of guidelines on maximum rates of change of gage and alignment and the effects of combinations of cross level, gage and alignment deviations.

Seasonal Effect on Derailments

The higher incidence of Amtrak train derailments in the winter months indicates that vehicle and track characteristics and operating practices at low temperatures should be addressed. The FRA has sponsored laboratory testing of low temperature properties of the rubber bolster springs used on many locomotives including the SDP-40F. Additionally, available data for low temperature characteristics of track indicate that frozen roadbed can produce very large increases in track stiffness. Consideration should be given to investigating wheel-rail loads under the combination of frozen roadbed effects, low-temperature vehicle effects, and combinations of track geometry deviations. Truck lateral forces applied under rigid roadbed conditions might well roll over the rail in cases which would have resulted in no damage with a less rigid roadbed.

Derailment Criteria

Although still somewhat controversial, derailment criteria for wheel climb associated with wheel L/V ratios over stipulated time durations have been proposed by several sources. However, there is definitely a lack of adequate grounds for derailment criteria for lateral wheel loads, lateral truck loads and truck L/V ratios. There is a need to develop and validate criteria which will directly address the reported predominant causes of SDP-40F consist derailments.

TABLE 1 SUMMARY OF DERAILMENTS AND TEST CONDUCTED (1 of 2)

Derailments

- Twenty of the 21 derailments involved occurred at reported speeds of 40 to 70 mph with an overwhelming majority occurring in curves of less than approximately 3°.
- In 12 of the cases, locomotives derailed. In 11 of these 12 derailments, the car adjacent to the locomotive was a baggage car and was also derailed. In 10 of these 11 derailments, the derailed locomotive was the trailing unit of a multi-locomotive consist.
- In 10 of 14 cases where the mechanism of derailment was identified, the reported causes were excessive lateral force, rail spreading, wide gage, and rail rollover. Wheel climb was never designated as the mechanism of the derailment.
- In 9 cases, locomotives did not derail. In 4 of these, the first derailed car was a baggage car immediately following an SDP-40F locomotive.
- The derailment analysis indicated a seasonal trend, with the majority occurring in the winter months.
- Exposure and derailment rates (miles per derailment) varied widely from railroad to railroad.

Major Testing

- In 1974, EMD conducted tests of the SDP-40F locomotive up to 120 mph to study the influence of new and worn wheels and to investigate complaints that the locomotive exhibited an uncomfortable ride under some conditions. As a result of these tests, SDP-40F locomotives were equipped with wheels having a 1:40 taper profile and lateral shock absorbers.
- In 1975, EMD conducted a series of tests on similar freight locomotives to confirm and extend the work done with wheel profiles and lateral damping.
- In 1975, tests sponsored by the FRA were conducted on the Northeast Corridor to measure lateral loads of various vehicles, including the SDP-40F locomotive.

TABLE 1 SUMMARY OF DERAILMENTS AND TEST CONDUCTED (2 of 2)

- In early 1976, Amtrak sponsored a test program on the ICG Railroad to compare the dynamic wheel-rail loads and ride performance of SDP-40F and E-8 locomotives. The FRA participated in the planning and observation of these tests. As a result of this work, EMD recommended in 1976 that the SDP-40F locomotives be retrofitted with softer rubber springs and increased lateral clearance in the secondary suspension.

- In the spring of 1977, Amtrak, EMD and the AAR began an SDP-40F baggage car test series on the Burlington Northern Railroad. The program included survey runs with an SDP-40F over several thousand miles of track and tests comparing SDP-40F and F40PH locomotives at selected sites. The analysis of this test data is currently being performed by the AAR.

Tests of the Amtrak SDP-40F Train Consist Conducted on Cheesie System Track (Final Report), 1979
P. Tong, R Brant Map, R Greig, J Mirabella, US DOT FRA