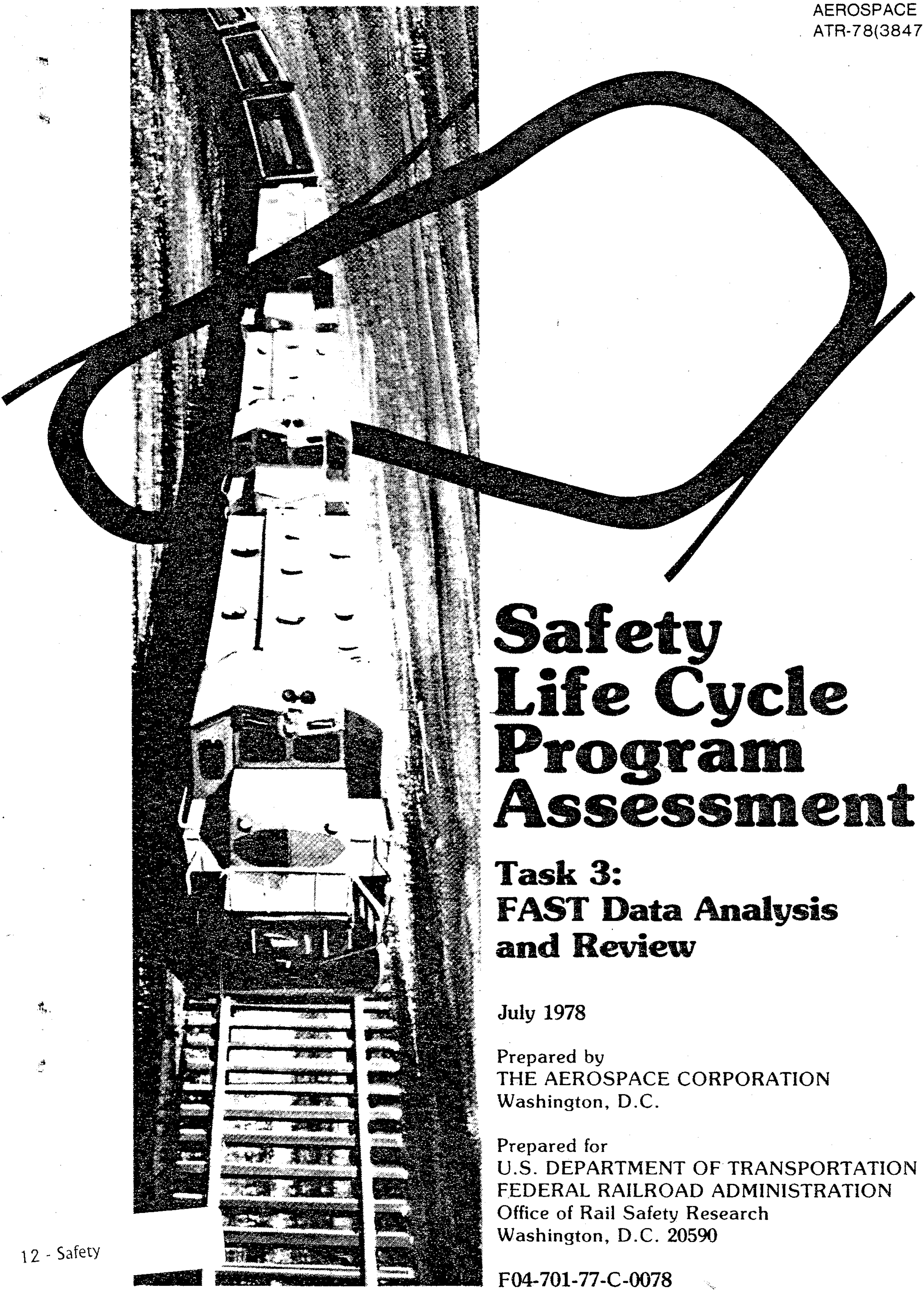
AEROSPACE REPORT NO.
ATR-78(3847-01)-3



Safety Life Cycle Program Assessment

Task 3: FAST Data Analysis and Review

July 1978

Prepared by
THE AEROSPACE CORPORATION
Washington, D.C.

Prepared for
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
Office of Rail Safety Research
Washington, D.C. 20590

12 - Safety

F04-701-77-C-0078

Aerospace Report No.
ATR-78 (3847-01)-3

SAFETY LIFE-CYCLE PROGRAM ASSESSMENT

TASK 3: FAST DATA ANALYSIS AND REVIEW

July 1978

Prepared by

THE AEROSPACE CORPORATION
Washington, D. C.

Prepared for:

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
Office of Rail Safety Research
Washington, D. C.

F04-701-77-C-0078

Report No.
ATR-78(3847-01)-3

SAFETY LIFE-CYCLE PROGRAM ASSESSMENT

TASK 3: FAST DATA ANALYSIS AND REVIEW

Prepared by:

Jeff A. Daneman

Jeffrey A. Daneman

Approved by:

WD Pittman

W. D. Pittman
Principal Director
Development Programs

Joseph Meltzer

Joseph Meltzer
General Manager
Eastern Technical Division

FOREWORD

This report was prepared for the U.S. Department of Transportation, Federal Railroad Administration, Office of Rail Safety Research, Washington, D.C. Work was performed under Contract Number F04-701-76-C-0077 by The Aerospace Corporation in response to the requirement in the Statement of Work, Paragraph 3.1.3 of the Safety Life-Cycle Program Assessment Program.

The purpose of the overall program is to perform an assessment for the applicability of current safe-life technology to railroad vehicle systems and components. The effort is divided into six primary tasks. Task 1 involves the assessment of railroad industry use of safe-life concepts. Task 2 is concerned with the development of a safe-life program applicable to rail vehicle systems and components. Task 3 assesses the applicability of the Facility for Accelerated Service Testing (FAST) to the safe-life program. Task 4 analyzes the applicability of a rail vehicle component validation/qualification program to improve railroad safety. Task 5 provides for project management and engineering direction of technical projects in support of overall program goals. Task 6 involves performing an analysis to develop structural integrity criteria for the safety life-cycle of rail vehicle components that are critical to safe operation.

This report presents the findings of Task 3, which included a review and analysis of the FAST program and its test specifications for their applicability to the safe-life program. This review includes an assessment of the FAST Phase I tests, test measurements, and data as inputs in determining the safe life of rail vehicle. Recommendations are made that include additional test programs for increasing the usefulness of FAST in determining the safety life cycle of rail vehicle systems which might be incorporated into Phase II of FAST test planning. Additional recommendations include improvements to FAST that can more realistically simulate railroad service environment.

CONTENTS

LIST OF ILLUSTRATIONS

I. INTRODUCTION

The number of accidents occuring on the United States' railroads that is caused by failure of rail vehicle equipment warrants improvement of the current safety life-cycle assessment process. From a total number of 10,248 train accidents which occurred in 1976, equipment failures were held responsible for 2,174.[1] The number of these accidents has continued to increase as has the related damages. Of particular importance is the fact that the equipment-related damage costs per million train miles steadily rose from $39,876 in 1967 to $88,508 in 1976.

As evidenced from examination of Table 103-C in Accident/Incident Bulletin No. 145[1], most equipment failures were caused by degradation of various vehicle components such as couplers, axles, journal bearings, wheels, side bearings and bolsters. In addition, there were many system failures attributed to excessive lateral truck forces, rock and roll, and hunting which may be caused by equipment degradation but which are not as clearly determinable. For example, the National Transportation Safety Board determined that the probable cause of the Amtrak train derailed near Pulaski, Tennessee, on 1 October 1975 was:

> The overturning of the outside rail in a 3°8' curve by high lateral forces induced by the six-wheel truck of the SDP-40F locomotive[2] . . .

In order to reduce this failure potential, a prime objective of the Safety Life-Cycle Program is to identify and develop improved techniques to control the risk of such accidents caused by the excessive service degradation of rail vehicle systems and their related components.

Accomplishment of this task necessitates performing accelerated service testing to 1) study the effects of service degradation and 2) verify SLC guidelines and prediction techniques that will be developed as a result of planned program activities. At present, there exists a Facility for Accelerated Service Testing (FAST) which was implemented to provide a test bed for this type of research. The purpose of the study described in this report is to evaluate the applicability of the FAST Phase I tests, test measurements, and data to provide effective inputs for determining the safety life cycle of rail vehicle systems and their related components. The Aerospace Corporation evaluation was limited to a review of the FAST tests specifications and other available pertinent documents listed in the bibliography. Testing and statistical analyses were not within the scope of this task.

Recommendations offered as a result of this evaluation are made in the interest of increasing the usefulness of the FAST Phase II tests to determine the safe service life of rail vehicle systems. Some of the recommendations are directly applicable to the FAST Phase II tests. Recommendations which may require major capital outlays are included in the interest of completeness in the analysis.

II. BACKGROUND

Several research and test programs such as the Kansas Test Track (KTT) were conducted to study the life-cycle performance of railroad vehicles and track. Much information was collected at these test sites but two major drawbacks were revealed. First, life-cycle testing is a long process requiring service tests of 150 million gross tons (MGT) or more for evaluation.[3] This would require approximately 3 years to accomplish assuming an annual revenue tonnage of 50 MGT; therefore, a faster method of full-scale testing was needed. Second, with various revenue trains running in service over the test zone, it was not possible to perform a controlled life-cycle study of the rail and captive vehicle components and their related interaction. Subsequent test programs such as the Light Weight Flat Car (LWFC) Program evaluated truck component wear; however, the train involved in these tests traveled over thousands of miles of track that could not be correlated with the vehicle components because of unknown track parameters. It was determined by the Federal Railroad Administration that a test facility was needed that would provide a systematic approach to:

- Conduct safe, full-scale, completely controlled tests at an accelerated rate between a captive portion of track and train;
- Simulate real world railroad environmental conditions;
- Perform required safe-life testing functions, measurements, etc., with the necessary tools and utilities;
- Allow experimentation of new and unproven concepts, both in track and vehicle components;
- Perform a separate function that would not interfere with railroad field operations;
- Develop improved inspection, maintenance, and repair techniques; and
- Determine the safe life of rail vehicle components.

The Facility for Accelerated Service Testing (FAST) was developed to fulfill these requirements. It consists of a closed-loop test track 4.77-miles (7.67-km) long that was constructed with track common to the Railroad Test Track (RTT) and the Impact Track at the Transportation Test Center (see Figure 1) of the U.S. Department of Transportation near Pueblo, Colorado. A major purpose of the FAST Program is to determine how track and track-related components perform under life-cycle loading. Numerous experiments are underway to test new track structure theories and materials and to compare the results to the performance of current track systems built by standard methods and techniques of track construction. The FAST track circuit is divided into 22 separate test sections (as shown in Figure 2) for these comparative evaluations. These sections are described in Table 1. A train weighing an average of 9500 tons and consisting of four diesel locomotives and an average of 75 fully loaded freight cars of mixed types selected from a pool of 90 cars (see Table 2) runs continuously around the track at the rate of 16 hours per day for five days a week. The cars are shopped and the consist rearranged periodically as discussed in the section on Mechanical Measurements--Static. The train attempts to average 42 mph which means it accrues track loading at the rate of approximately 1.33 MGT per day or 345.80 MGT per year.

The FAST program is divided into two primary phases. Phase I involves testing with a train consisting of primarily 100-ton-capacity cars fully loaded. The end of Phase I testing will occur when 400 to 500 MGT have been loaded onto the FAST track. Then, the entire consist will be changed to 70-ton capacity equipment and run to accumulate another 400 to 500 MGT. This will be considered Phase II. The main purpose of the two phases is to compare track performance between the two types of loading.

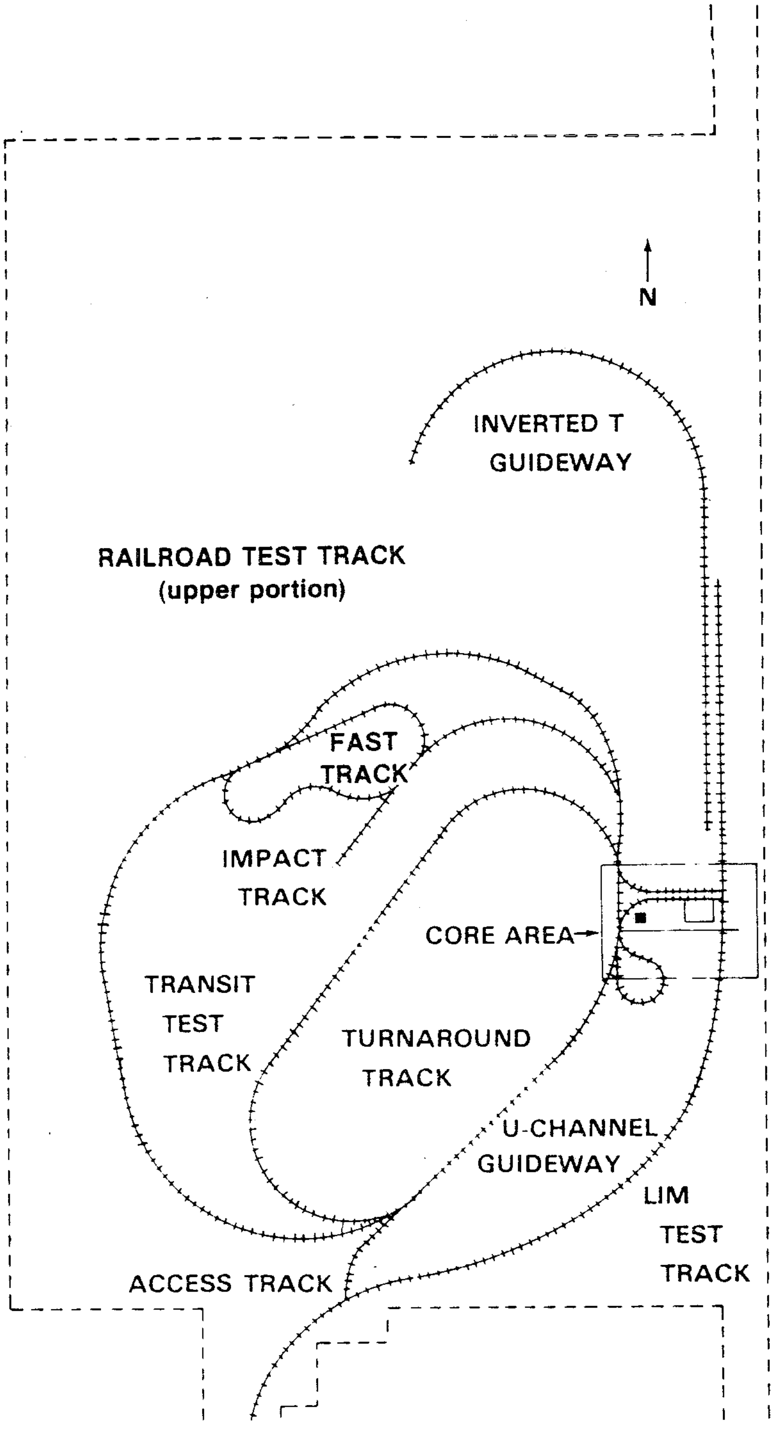


Figure 1. Transportation Test Center (TTC)--Pueblo, Colorado

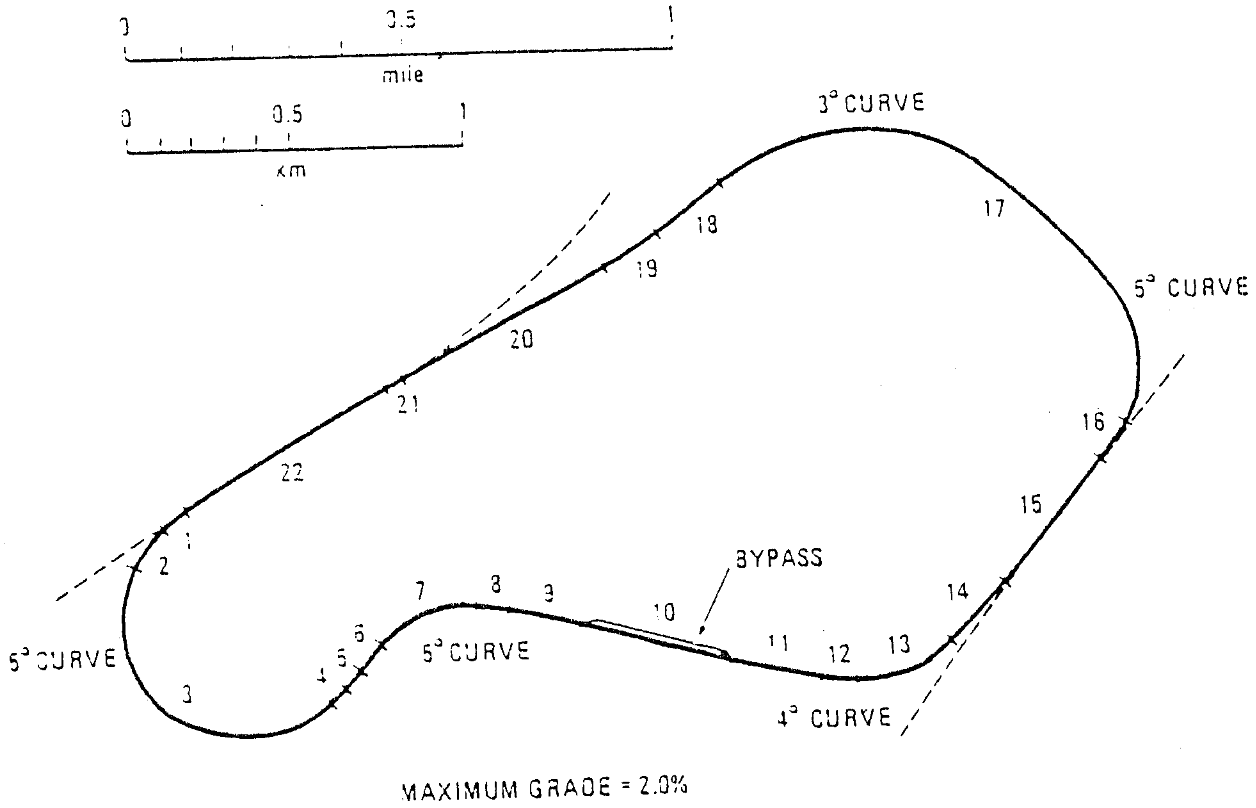


Figure 2. Location of FAST Track Sections

Table 1. FAST Experimental Track Components

Test Section	Length/ Feet (meters)		Special Test Track Experiments	Rail Type
1	170	(52)	Standard No. 20 Turnout	Jointed
2	329	(100)	Tie Plate Rubber Pads	Welded
3	3740	(1140)	Railmetallurgy, Spiking Patterns Tie Plate Cant, Ballast Shoulder Width	Welded
4	211	(64)	Continuous Welded Rail	Welded
5	222	(67)	Field Assembled Bonded Joints	Jointed
6	300	(91)	Steel Ties (Replaced with Standard Wood Ties)[4]	Welded
7	1000	(305)	Rail Tie Fasteners	Welded
8	300	(91)	Wood Tie Plugs	Welded
9	628	(191)	Reconstituted and Lamintated Wood Ties	Jointed
10	1550	(472)	Elastic Spikes, Safety Equipment Turnouts, Spring Frogs, Guard Rail	Jointed/ Welded
11	895	(273)	Joints, Frogs, Guard Rail	Jointed
12	339	(103)	Jointed Welded Rail	Jointed
13	1248	(380)	Rail Metallurgy and Spike Hole Fillers	Welded
14	818	(249)	Standard No. 20 Turnout	Jointed
15	1300	(396)	Ballast Shoulder Width	Jointed
16	170	(52)	Glued No. 20 Turnout	Welded
17	6143	(1872)	Concrete Ties and Tie Pads	Welded
18	822	(250)	Ballast Depth	Jointed
19	600	(183)	Hardwood and Softwood Ties	Jointed
20	2278	(694)	Ballast Types and Depths, Rail Anchors	Jointed
21	172	(52)	No. 20 Welded Turnout	Welded
22	1950	(594)	Spiking Patterns and Rail Anchors	Welded
Total Length	25,185 (4.77 mi.)	(7671) (7.67 km)		

Table 2. FAST's Freight Car Test Pool

Freight Car Type	Quantity	Capacity (tons)
Open-Top Hoppers	66	100
Tankers	18	100
Piggybacks	3	70
Bathtub Coal Gondolas	3	105

III. FAST PROGRAM ADVANTAGES FOR SAFE-LIFE CYCLE DETERMINATION

The FAST program has currently (1 February 1978) accumulated 192.6 MGT accelerated testing. In April 1977, the first progress report[4] was written. That report pointed out the ability of FAST to rapidly predict some service failures that could be directly compared to those in revenue service. For example, it was noted that steel ties started to fail in the fastener areas at 22 MGT. Similar ties that had been in revenue service for some time were examined and found to be failing the same way. Analogous comparisons are expected to be found on vehicle systems when more testing miles have been accumulated. It is predicted that the program has the ability to accommodate safe gross ton mileage at up to 10 times normal service rates.

There are several other factors that make the FAST program uniquely advantageous for performing safety life-cycle studies on railroad vehicles. One of the key items is the successful integration of a joint Government/industry effort. The organizations participating at present are the Federal Railroad Administration (FRA), Association of American Railroads (AAR), the Transportation Development Agency (TDA) of Canada, the Railway Progress Institute (RPI), the railroad companies, and the railroad supply industry. This combined expertise should increase the program effectiveness and establish a unified standard base for research and development.

The Transportation Test Center (TTC) was selected as the site for construction of FAST. The test center is modern, fully integrated, and well equipped to support the FAST test program. It has performed in this capacity for several years as the site for the Railroad Test Track (RTT), the Transit Test Track, the Impact Track, the Linear Induction Motor Research Vehicle (LIM) Test Track, and the Tracked Air Cushion Vehicle (TACV) Guideway. This layout provides the flexibility required for special testing and includes facilities such as the Center Services Building (CSB) for inspection, maintenance, and repair. In addition, it is a Federally owned complex and, as such, is a separate entity that will not interfere with revenue railroad service or operations.

In the past, all tests were conducted on revenue track, and real-world, full-scale testing was attempted. However, as previously discussed, life-cycle tests could not be controlled and correlation between track and vehicle systems in this area was virtually impossible. The closed-loop concept provides the most realistic situation for meaningful life-cycle testing to date. Here, full-scale tests can be conducted safely under controlled conditions between known, unique segments of track and rail vehicles. This greatly reduces the errors from unknown track/vehicle interactions. Furthermore, this closed system makes baseline measurements possible and extremely valuable.

As results of the tests continue to accumulate, the AAR plans to establish a computerized data base.[5] An important element of the FAST program is the processing, handling, and analyzing of the large amounts of data gathered during the tests. Even with modern, sophisticated equipment, a great deal of information has yet to be gathered. After the data are collected, coded, and recorded on magnetic tape at the test facility, they are processed at the AAR Technical Center in Chicago. The scheme is to make this information readily available to anyone in the railroad industry (e. g., equipment suppliers and railroad companies). The qualified recipient would merely have to telephone the Technical Center using the proper code number to obtain reduced data on a CalComp plotter or similar device.

A final major advantage of the FAST program is that safe and controlled experimentation of new and unproven systems and concepts can be tested without endangering railroad operations. Because the facility includes both a test track and an inspection center and is programmed for special test operations, a closer scrutiny can be given to potential failures than would be possible in field operations. Therefore, it is possible that more exotic and advanced designs can be tested at the FAST facility than in the railroad service environment.

IV. FAST PROGRAM DISADVANTAGES FOR SAFETY LIFE-CYCLE DETERMINATION

From a review of the advantages discussed in the preceding section, it is apparent that the FAST program is a significant improvement over prior programs for railroad vehicle system life-cycle studies. To further increase the effectiveness of FAST to simulate the actual railroad operational environment, there are several areas in the program that could be modified. Only those directly involved with rail vehicle system safety life-cycle performance are discussed in this section. The main problem is that the conversion factors are still unknown for relating FAST results to real world conditions. The concern can be divided into two categories:

- Failure Mode Dynamics and
- Failure Time History.

A. FAILURE MODE DYNAMICS

The September 1976 report containing a recommended FAST layout included a description of a large test area adjacent to the RTT that was to incorporate all the requirements considered necessary for a total life-cycle program; but the economic resources available did not permit this for Phase I. Therefore, the smaller loop (Figure 2) was built. It has the following deviations from real-world simulation.

- Curved Track to Tangent Ration. The ratio of curved track to tangent is high (54 percent). This condition has resulted in abnormal wheel and track wear. The wheels have been replaced at a rapid rate due to extreme flange wear. This quick turnover of wheels results in a train's running with minimal wheel tread wear. This condition, coupled with almost all the wheels starting with identical flange heights, has caused excessive rail head wear on the gage side. Finally, the high curve ratio causes unusual loading to the axles and other related vehicle track components.
- Speed Limitations. The maximum train speed range is limited to 45 mph. This is due to the relatively short length of the loop (4.77 miles of track), curve negotiation, and minimal train acceleration/deceleration capabilities. This limitation, coupled with the

intent to maximize loading mileage by running the train as fast as possible, does not allow for low- and high-speed performance testing. Absence of low-speed motion disallows rock and roll phenomena on vehicle components which is usually maximum between 15 and 20 mph. In most cases, truck hunting dynamics are not present because it usually initiates at speeds in excess of 45 mph.

- Track Standards. Originally, the FAST track structure was to be maintained to main-line industry standards and allowed to degrade to Class 4. However, because of the complexities of maintaining the different sections to their individual requirements for Class 4 track, the current plan is to:

> try to maintain the track in such a manner as to guarantee there will be no derailments, regardless of the designation under the FRA Track Safety Standards. We (FRA) are now striving for better maintenance than originally planned.[5]

Regardless of the track maintenance selected, in the general railroad environment, track is divided into six classes with speed limiting geometry and other requirements in accordance with Part 213-Track Safety Standards of the Code of Federal Regulations[6] (see Table 3). By maintaining all track at the same level, the loading spectrum of different track structures is not experienced. Therfore, the rail reactions to the vehicle components due to variations in track stiffness such as soft spots, deteriorated cross-ties, and joints are not provided. Because of this situation and the high ratio of curved track and speed restrictions previously discussed, it is difficult to conduct low- and high-speed tests representative of the real-world environment.

o Track Inputs. One important factor required for safety life-cycle evaluations is an understanding of the relation of track inputs to the vehicle systems. The arrangement of the FAST loop's 22 different sections presents a major complication. Some rail sections are too short. From a review of track geometry data,[3] a track test section needs to be on the order of 1000 feet plus 100-foot transition sections on either side. This will ensure that the information is representative of the sections and not influenced by perturbations from adjacent ones. Sufficient time is then allowed for any

Table 3. Speed Limiting Track Geometry Requirements by Class

	Maximum Allowable Operating Train Speed (MPH)		Track Gage (in.)				Track Alignment (Maximum Deviation by inches in 62 feet)		Track Surface			Crosslevel Deviation		
Track Class	Freight	Passenger	Tangent		Curved		Tangent	Curved	Maximum 31 Ft. Rail Runoff (in.)	Maximum Profile Deviation (in.)	Maximum Spiral Elevation Deviation (in.)	Maximum Variation Spiral Crosslevel	Maximum Crosslevel Deviation Tangent or (in.) Curves	Maximum Warp (in.)
			Min	Max	Min	Max								
1	10	15	56	57¾	56	57¾	5	5	3½	3	1¾	2	3	3
2	25	30	56	57½	56	57¾	3	3	3	2¾	1½	1¾	2	2
3	40	50	56	57½	56	57¾	1¾	1¾	2	2¼	1¼	1¼	1¾	1¾
4	60	80	56	57¼	56	57½	1½	1½	1½	2	1	1	1¼	1¼
5	80	90	56	57	56	57½	¾	5/8	1	1¼	¾	¾	1	1
6	110	110	56	56¾	56	57	½	3/8	½	½	½	½	½	5/8

Source: Reference 6

resonances to dissipate from disturbances such as a rail joint in a previous section. As shown in Table 1, only seven sections (3, 10, 13, 15, 17, 20, and 22) are long enough. Therefore, interpretation of rail input data for vehicle life-cycle system assessments would be complicated. Mechanical vehicle system evaluations could be improved by having a separate loop of uniform track structure.

- Miscellaneous Operations. The FAST program consists of conducting tests under conditions simulating a freight car rolling at a constant speed over main-line track. However, recent findings by Task Force 3 of the AAR Freight Car Utilization Research-Demonstration Program, have shown that an average freight car spends only 12 percent of its time actually moving in a road train, loaded or empty.[7] The remaining time is consumed in yard operations, loading and unloading, storage during lull periods, or awaiting handling. Yard operations such as humping, switching, and coupling are sources of considerable safety life cycling that are not included in the current FAST Phase I testing. The same is true for loading and unloading cycles. Without these necessary additional inputs, testing is incomplete and not representative of true railroad operations. The only yard operations currently done under the FAST program are the minimal amount necessary to locate the cars where required for life-cycle track tests and vehicle inspection and maintenance.

- Braking Operations. As reported in the FAST Progress Report No. 1[5], the braking operations being conducted at FAST are minimal and unprogrammed. The only braking operations are those required for routine stops and safe operation. No high-speed or dynamic braking tests are being conducted at present. These tests are especially important for wheel fracture studies of thermal crack initiation and nucleation. The "Report of AAR Wheel Failures for Year 1976"[8] (Table 4) indicates that 24.7 percent of all wheel failures were determined to be the direct result of thermal cracks. In addition, it is unknown how many failures attributed to cracked or broken rims or flanges were influenced by thermal loadings.

- Climate Conditions. The climate conditions at the Transportation Test Center do not represent the extremes experienced in the United States. The normal temperatures at Pueblo, Colorado,

Table 4. Wheel Failures Caused by Thermal Cracks

CAUSE - INTERCHANGE RULE 41 - SEC. F6										
REPORT OF AAR WHEEL FAILURES FOR YEAR 1976	Total Failures	Cracked or Broken Flange	Cracked or Broken Rim	Shattered Rim	Spread Rim	Thermal Cracks	Tread Shelled	Burst Hub	Cracked or Broken Plate	Sub Surface Defect
		66	68	71	72	74	75	82	83	88
28"										
1W - CS	21		18			1	2			
1W - WS	36		1	16		6			13	
2W & MW - CS										
2W & MW - WS	1		1							
TOTAL										
33"										
1W - CS	273	3	30	17		176	25	1	20	1
1W - WS	255	5	63	75	1	25	22	1	63	
2W & MW - CS	16	1	3			9	2		1	
2W & MW - WS	87	2	12	30		26	7	1	9	
TOTAL										
36"										
1W - CS	69	8		2		17	37	1	4	
1W - WS	367	4	47	211		18	71		16	
2W & MW - CS	25		1	4		12	7		1	
2W & MW - WS	94	2	12	27	1	15	22		15	
TOTAL										
38"										
1W - CS										
1W - WS	7			2		2	2		1	
2W & MW - CS										
2W & MW - WS	3		1			2				
TOTAL										
GRAND TOTAL	1254	25	189	384	2	309	197	4	143	1

Source: Reference 8, Exhibit 5.

range from a high of 92.1°F in July, to a low of 14.7°F in January. Rainfall varies from 0.3 inches in December to 1.85 inches in August. Application of the data obtained at FAST can be difficult. For example, because the average rainfall at TTC is only about 12 inches per year and because the average rainfall on Conrail lines is 43 to 45 inches[5], the FAST evaluation of limestone ballast is difficult for Conrail to apply to its rail system since rain is a principal contibuting factor to this type of aggregate deterioration. In addition, freeze-thaw conditions are prevalent at Pueblo only in the winter months. Therefore, any components being assessed for moisture-stress, life-cycling performance would have to be tested during the season when these environmental conditions prevail.

B. FAILURE TIME HISTORY

A problem always associated with accelerated life-cycle testing is dealing with those parameters that need time to affect performance. One such item that influences system life is weathering. In Progress Report No. 1,[4] it was pointed out that abnormally high wear (compared to service) on the track bolster gibs may be attributable to the contacting surfaces having insufficient time to "rust over."

C. SUMMARY

In summary, all these factors must be carefully considered if a meaningful determination of FAST's ability to accurately predict the safety life-cycle of rail vehicles and their related components is to be accomplished. At the present time, no programmed measurements are being taken of rail-wheel dynamics. These would be necessary to correlate the rail input to the safety life-cycle with the reservations related to track inputs under Failure Mode Dynamics on varying track sections. Only then can FAST results be compared to field conditions.

V. REVIEW OF "FAST TEST SPECIFICATION," VOL. III-MECHANICAL

Volume III of the "FAST Test Specification" describes the mechanical measurements and the safety maintenance performed on the rail vehicles used in the FAST program test train. In Phase I of the FAST program, freight cars are removed at the average rate of four per day during testing and delivered to the repair facility for inspection and required safety maintenance. Four previously inspected cars replace them to keep the consist at 75 cars. Eight cars are relocated from one end of the consist to the other every second test day. Each day the direction of train travel around the loop is reversed. The purpose of these procedures is to provide maximum random conditions and minimum biases in component wear data. Finally, mechanical measurements are taken on test components (including mating parts) during shopping for the purpose of determining wear rates. During the life of each measured component, obtaining data points at two locations during at least five separate inspection intervals is attempted. The measurements are divided into the following three areas.

- Mechanical Measurements--Static. This category is composed of 12 experiments that are underway. Results at present have been minimal because of the low gross ton mileage accumulated thus far. Table 5 is a list of these special test groups and summarizes the static measurements being taken and recorded. Experiments 1 through 3 involve wheels, axles, and roller bearing adapter components. Experiments 4 and 5 deal with truck components. Center plates and side bearings are represented in Experiments 6 and 7, respectively. Experiment 8 is concerned with brakes. Draft rigging is tested in Experiments 9 and 10. Finally, components related specifically to trailers on flat cars (TOFC) and bathtub coal cars are investigated in Experiments 11 and 12. A list of measuring instruments used in these experiments is presented in Table 6. The measurements taken are for material wear and hardness, and do not include fatigue or damage tolerance.

Table 5. Summary of FAST Static Mechanical Measurements Recorded

Experiment No. and Title	Item/Static Mechanical Measurements	Test Cars
1. Truck Wheels	Flange/Wear Rim/Wear Tread/Hardness Front Face/Hardness	76 Cars: 1-72, 74, 75, 84, 85
2. Axle Journal Roller Bearings	Grease/Loss Inner ring bore/Growth Cap screw/Retention Bearing movement/Lateral Grease/Properties Pedestal Sides at Journal Outer Ring/Wear	30 Cars: 1-19, 21-26, 28-32
3. Roller Bearing Adapters	Crown/Wear & Hardness Pedestal roof/Wear & Hardness Thrust Shoulder/Wear Bearing Outer Ring/ Wear & Hardness Pedestal Adapter Lug/Wear Adapter Side at Pedestal/ Wear	31 Cars: 2, 4, 12, 22, 24, 30, 33-44, 64-69, 71-77
4. Trucks	Friction Casting/Wear Bolster/Wear Sideframe/Wear Stabilizer Assembly/Wear Transom/Wear & Hardness Rocker Seat/Wear & Hardness	24 Cars: 2, 4, 12, 22, 24, 30, 33-44, 64-69
5. Truck Springs	None/Maintenance Only	34 Cars: 2, 4, 12, 22, 24, 30, 33-41, 48-66

Table 5. Summary of FAST Static Mechanical Measurements Recorded (continued)

Experiment No. and Title	Item/Static Mechanical Measurements	Test Cars
6. Center Plates	Truck/Wear & Hardness Body/Wear	30 Cars: 2, 4, 12, 14, 16, 19, 22, 24, 30, 33-46, 49, 64-69
7. Side Bearings	Cage/Wear & Hardness Roller/Wear Constant Contact/Permanenet Set & Precompression	34 Cars: 2, 4, 12, 22, 24, 30, 36-41, 48-69
8. Brake Shoes	Brake Shoe/Force & Wear	41 Cars: 1-41, 48-69
9. Coupler and Carrier wear Plates	Coupler Shank Plate/Wear & Hardness Coupler Carrier Plate/Wear & Hardness	15 Cars: 5, 6, 7, 8, 13, 15, 22, 24, 30, 32, 49, 53, 57, 61, 71
10. Couplers	Head/Wear & Hardness Knuckle/Wear & Hardness Pulling Lug/Wear Shank Length/Permanent Set Butt/Permanent Set & Hardness Key Slot/Wear & Hardness Draft Key/Wear & Hardness	8 Cars: 5, 6, 7, 13, 15, 67, 68, 69
11. Trailers on Flat Cars	Trailer King Pin/Wear & Hardness Trailer Hitch/Wear & Hardness Coupler Connector Rim/Wear & Hardness Center Sill/Permanent Set	3 Cars: 67, 68, 69 (These cars were also used in experiments 1, 3, 6-8, 10)

Table 5. Summary of FAST Static Mechanical Measurements Recorded (continued)

Experiment No. and Title	Item/Static Mechanical Measurements	Test Cars
12. Bathtub Coal Gondolas	Side Plates/Permanent Set Side Sills/Permanent Set	3 Cars: 42, 43, 44 (These cars were also used in experiments 1, 3, 4, 6)

Table 6. Static Mechanical Measurement Instruments Used at FAST

Instrument/Material	Experiment Number* 1	2	3	4	5	6	7	8	9	10	11	12
AAR Standard Wheel Gage (AAR 1952)	W										W	W
Steel Ruler (Starrett, No. 604RE)	W	W	W	W					W		W	W
Portable Brinell Hardness Tester	H	H	H	H		H	H		H	H	H	H
Profilometer (ABEX DWG. No. 19770)	W										W	W
Point Location Gage (ABEX DWG No 19764)	W										W	W
Carbon Paper	W										W	W
Dynamic Hardness Tester	H			H					H		H	H
Weighing Scale		G									G	
Dial Bore Gage		W									W	
Torque Wrench		S									S	
Magnetic Base and Dial Indicator		L									L	
Straight Edge		W		W			W		W	W	W	W
Feeler Gage		W		W							W	W
Depth Dial Gage (Starrett No 64e)		W		W							W	W
Magnetic Base (Central Tool No. 600T)		W									W	
Adapter Wear Gage			W	W							W	W
Thickness Gage (Starrett No. 72)			W								W	
Dial Gage Caliper (Starrett No. 120)			W	W		W	W		W	W	W	W
Vernier Gage Caliper (Starrett No. 123)			W	W		W	W				W	W

*W=wear, H=hardness, G=grease loss, S=screw retention, L=lateral movement, K=spring constant, F=brake shoe force.

Table 6. Static Mechanical Measurement Instruments Used at FAST (continued)

Instrument/Material	Experiment Number* 1	2	3	4	5	6	7	8	9	10	11	12
Roller Bearing Adapter J16 Fixture			W								W	
Vernier Gage (AAR Spec. M-024)			W								W	
Friction Casting Gage (76-3018)				W								W
Spreader Gage (Starrett No. 579)				W			W			W	W	W
Parallel Gage (76-2802)				W								W
Spreader Gage (Starrett No. 39)				W								W
Telescoping Gage (Starrett No. 579)				W								
Vernier Gage (24")				W			W		W	W	W	
Block Clamp Caliper Gage				W								
Horizontal Surface Measurement Gage						W					W	W
Test Machine (AAR Page D-68)							K				K	
Golden Shoe								F			F	
Hydra-Cell								F			F	
Weighing Scale (Pitney 3770)								W			W	
Square (AAR Spec. M-211)									W		P	
Trailer Hitch Jaw Template											W	
Piano Wire											P	
Anchors											P	
Outside Caliper (AAR Page C-38B)											P	

*W=wear, H=hardness, G=grease loss, S=screw retention, L=lateral movement, K=spring constant, F=brake shoe force, P=permanent set.

Table 6. Static Mechanical Measurement Instruments Used at FAST (continued)

	Experiment Number*											
Instrument/Material	1	2	3	4	5	6	7	8	9	10	11	12
Surveyor's Level & Rod											P	P
Steel Tape (Stanley No. PL320)												P
Electronic Surveyor (HP3810P)												P
Coupler Head & Knuckle Gage (AAR)										W	W	
Steel Rule (AAR Spec. M-211)										W	W	
Outside Caliper Gage (AAR Page C-36)										W	W	

*W=wear, H=hardness, G=grease loss, S=screw retention, L=lateral movement, K=spring constant, F=brake shoe force, P=permanent set.

Also, as stated in the specification under Section 2.1:

> The objective of the static measurement program is to compare the performance of various car component designs and to determine which is the most cost effective.

A typical measurement entitled "2.6.9 Measurement 1d-Thin Rim Wear" is shown in Figure 3. A standard wear gage is used to measure "Thin Rim-Wear" in accordance with the applicable AAR manual. It is concluded that safety life-cycle criteria other than wear are not prime factors for consideration.

- Mechanical Measurements--Dynamic. The only dynamic mechanical measurements being taken at present that form a direct part of the FAST program are those acquired in the Train Operation Recorder System (TORS). This system is mounted in the cab of an operating locomotive and records a history of its brake applications, throttle positions, travel distances, train speeds, and total time and train stop times.

  Other dynamic tests such as the "Third Dynamic Hopper Car Test,"[10] which instrumented selected cars in the FAST consist were conducted. The purpose of this test was to measure the dynamic response characteristics of certain freight car components in relation to component wear. This special program and others under separate contracts are not considered an integral part of the FAST program, and therefore, will not be discussed in further detail during this report.

- FAST Mechanical Maintenance. All maintenance performed on the rail vehicles is done in accordance with the appropriate AAR or FRA manuals, which focus primarily on wear and material hardness. These references are listed below.

  AAR, "Field Manual of the A.A.R. Interchange Rules," Association of American Railroads, Washington, D.C., January 1976.

  AAR, "Manual of Standards and Recommended Practices," Association of American Railroads, Chicago, Illinois, 1975.

2.6.9 MEASUREMENT 1d - THIN RIM-WEAR.

2.6.9.1 Equipment. Use AAR standard wheel gage to determine thinning at required section.

2.6.9.2 Locations. Take measurements at two sections, diagonally opposite (180° apart) and marked 1 and 2, so subsequent measurements are made at same locations. (Number 1 to be on same radial line as one roller bearing cap screw).

2.6.9.3 Typical measurement and accuracy. .98" for one wear wheels and 1.86" for two wear wheels.

2.6.9.4 Frequency. Take measurements every 11,000 miles and when vehicles are removed, remachined or replaced.

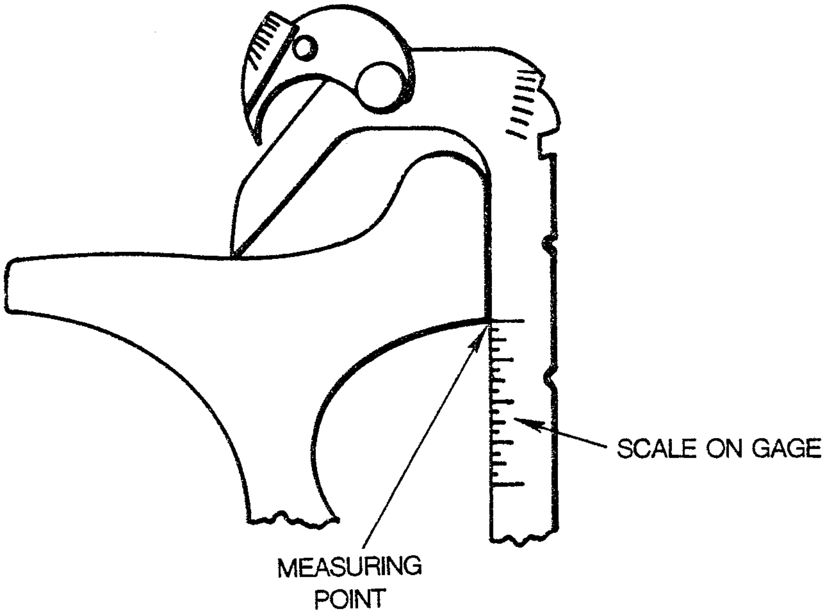
2.6.9.4.1 Notes.

a. Profilometer provides complete record of flange and rim wear. This data to be retained for future analysis.

b. Wheel tape size to be determined before and after test and when wheels are removed, remachined or replaced.

2.6.9.5 Illustrations.

2.6.9.5.1 Figure. Thin Rim Measurement. Scale is read directly from gage in increments of 16th of an inch.



THIN RIM MEASUREMENT, AAR STEEL WHEEL GAGE

Scale is read directly from gage in increments of 16ths of an inch.

Figure 3. Typical Static Mechanical Measurement

AAR, "Wheel and Axle Manual," Association of American Railroads, Chicago, Illinois, October 1975.

AAR, "Roller Bearing Manual," Association of American Railroads, Chicago, Illinois, September 1975.

AAR, "Supplement to Manual of Standards and Recommended Practices," Association of American Railroads, Washington, D. C., January 1975.

AAR, "Code for Designating Design Features for Side Frames and Truck Bolsters Having Built-In Snubbing Devices," Association of American Railroads, Chicago, Illinois, 1969.

"Car and Locomotive Cyclopedia," Centennial Edition, Simmons Boardman Publishing Corporation, New York, New York, 1974.

FRA, "Part 215 - Railroad Freight Car Safety Standards," Federal Railroad Administration, Code of Federal Regulations, Title 49, Washington, D. C., 1976.

There are a few isolated cases of crack inspections such as those for a cracked or broken wheel flange (Rule 41, A. 1. d., Field Manual of the AAR Interchange Rules, 1977). These inspections are conducted in accordance with standard industry practice and are not precise enough to permit any recommendations with regard to the current inspection practices. For example, Paragraph 4. 6. 12 states:

> Measurement 1i - Built Up Tread. Any length of tread is condemnable, Rule 41, A.1.k.

It would be reasonable to assume that some amount of tread buildup is tolerable. This practice may lead to premature wheel replacement. Paragraph 4. 8. 11 states:

> Measurement 2h - Backing Ring-Loose. Bearing is condemnable if ring can be rotated by tapping lightly with 1# hammer. RULE 3.2, AAR Roller Bearing Manual.

The question arises as to the preciseness of a measurement made by "tapping lightly with 1# hammer."

> Present inspection methods require entire wheel assemblies to to be removed and/or disassembled for proper inspection of components such as center plates and yokes. Because this practice must be performed relatively frequently (compared to the normally desired service life of 20 years), the probability of subjecting a component to further damage from mishandling during disassembly and assembly increases. In addition, teardown inspections are costly and time consuming.

Some required inspection equipment and techniques that are currently available are not required by the FAST Mechanical Specification. Specifically, in the area of wheels and axles, only visual inspections for flaws and cracks are called out. Recently, these specifications were complemented with the Wheel-Fax cracked wheel flange detector because of unusually high wheel wear rates occurring during testing.

In conclusion, the "FAST Test Specification," Volume III--Mechanical provides a comprehensive format for inspections and maintenance. The procedures are systematic and thorough for measuring component wear and material hardness, but they should be augmented to include investigation of the other areas of interest to the Safety-Life-Cycle Program including damage tolerance, fatigue life, inspection/maintenance assessment, and system dynamic response alterations. These are recommended for developing an improved inspection and maintenance program to control the risk of in-service failures. Additional tests and inspection should be performed to accomplish this effort. These recommendations are discussed in Section VI.

VI. RECOMMENDATIONS

As a result of the review and analysis of Phase I of the FAST program, the recommendations described below are proposed for incorporation into the plans for Phase II. The primary purpose of these recommendations is to maximize the usefulness of the FAST program in accomplishing the near-term objectives of the Safety Life-Cycle Program. The recommendations are divided into two categories. Category A describes additional functions that could be performed (subject to the limitations discussed in Sections IV and V of this report) at FAST without major program equipment/facility modifications or expenditures. Category B identifies potential capabilities possible if major equipment/facility modifications including the proposed FAST Loop II, Pilot Perturbed Track (PPT), and SAFE were implemented at TTC.

A. CATEGORY A. SAFETY LIFE-CYCLE TESTING USING THE EXISTING FAST

The existing facility can be used more comprehensively for Safety Life Cycle research and testing. The following recommendations describe the uses of FAST in the proposed activities.

1. Safety Life-Cycle Guideline Verifications

A plan is being prepared to formulate preliminary guidelines for rail vehicle systems (initially locomotives). These will be used to assess the safety life cycle of new or modified rail vehicles in accordance with the methodology* outlined in Task 2 of the Safey Life Cycle Program. Following preparation of the guidelines, it will be necessary to perform verification tests to demonstrate their potential. Part of this evaluation will involve accelerated service aging tests which will simulate a rail vehicle rolling at a constant moderate speed (40-45 mph) over mainline track. It is recommended that

---

*Aerospace Report No. ATR-78(3847-01)-2. See Reference 11.

this segment of testing be conducted at FAST. The remaining verification evaluations should be conducted at other facilities. (As discussed in Section IV of this report, the portion of a rail vehicle service spectra that can be tested at FAST under the current program is limited.)

2. Safety Life-Cycle Prediction Research and Verification

For a meaningful program, the ability to predict the safety life cycle of a rail vehicle system must be established in order to control the risk of service failures. To accomplish this, SLC prediction techniques must be developed and incorporated into the guidelines. They include:

- Identifying allowable levels of degradation;
- Determining lengths of time for reaching dangerous levels;
- Determining dynamic response alterations caused by system structural degradation; and
- Developing prediction analysis models that will approximate the safety life cycle of the system as a function of service spectra, inspection, and maintenance criteria.

The development of these prediction techniques will require input data which include crack growth, corrosion, and wear rates as a function of service spectra loading. Where unavailable, these rates will have to be determined experimentally, especially for those cases in which the dynamics of the system are too complex to be determined analytically. It is recommended that FAST be used for this purpose, provided normal program experiments are not unreasonably affected. As discussed in Section V of this report, only wear and hardness measurements are currently taken. An integral part of safety life-cycle prediction is the identification of the influence of inspection and maintenance on system degradation. By understanding this influence, combined with the capability to predict degradation rates and their related system dynamic response alterations, an improved inspection and maintenance program can be established. This program would identify the inspection and maintenance criteria required to control a system's premature failure over its entire safety life cycle. Therefore, because of the existing integrated inspection and maintenance processes available, a potential area to consider for FAST utilization would be performance of required research in the area of inspection and maintenance criteria for identifying:

1) The effectiveness of current practices to detect and prevent premature failures and excessive maintenance and repairs;
2) Initial crack sizes and distribution to establish assumed degradation starting points for prediction analyses; and
3) The optimum inspection/maintenance criteria including degrees of inspectability, inspection techniques and periods, and required maintenance for monitoring and controlling degradation levels which can endanger the systems dynamic response.

The main advantage of using FAST is that it is basically programmed (including major equipment expenditures already acquired) for this activity. This allows direct interpretation of and correlation among the effects of accelerated service aging and inspection/maintenance procedures on a system's safety life cycle behavior.

3. Systems Tagging Verification

As tagging and tracing procedures are developed, they will be assessed for their ability to provide needed data for identifying safety life cycle prediction and failure causes. Since recording the required information (i. e., service history including detected failures, performed inspections, maintenance, repairs, and replacements) is a normal operation at FAST; it is recommended that this facility be used as a test bed for this activity (augmenting current practices as warranted). By carefully evaluating these data, the initial criteria can be determined for 1) signalling potential service hazards from recognition of unusual failure or maintenance patterns and 2) tracing service history to aid in eliminating unacceptable safety conditions.

4. Safety Alarms Research and Testing

The final area to be considered is increased development efforts for practical alarm concepts that would signal potential failures on rail vehicle systems. In certain cases, it may be impractical to depend on current inspection and maintenance procedures to adequately control system failures in actual service operations. Under these circumstances, it may be advantageous to develop an additional level of safety monitoring techniques. This is especially important in areas where 1) the levels of confidence for the safety life cycle prediction of critical systems are not yet considered acceptable; or 2) the inspection/maintenance criteria identified to minimize the risk of failures to an acceptable level are impractical in actual railroad operations. For example, in 1976, 110 accidents were attributed to center plate/pin failures.[1] Because it is difficult to inspect the center plate area with the vehicle assembled, the potential for undetected degradation is assumed to be high. The impracticality of tear-down inspections during normal service and the potential for system failure qualifies the center plate/bowl interface as a good candidate for a place to establish a safety alarm.

Subsequent to the development of safety alarm concepts, it would be necessary to conduct accelerated service testing on resulting alarm designs to verify effectiveness, determine reliability, determine safety life cycle, and assess service feasiblity. It is recommended that FAST be used as a test bed for these purposes--subject to the limitations of the current program as discussed in Sections IV and V. Any additional equipment necessary for this activity would not be a major expenditure if integrated with the current FAST.

B. CATEGORY B. INCREASED SAFETY LIFE-CYCLE CAPABILITIES FOR FAST PHASE II

The following items are recommended for consideration in Phase II of the FAST Program to improve the simulation of the railroad service environment. These modifications could involve considerable equipment/ facility modifications and expenditures that would be defined by the identified service spectra. As previously discussed, Phase I of the FAST program allows accelerated service testing for a rail vehicle rolling at a constant moderate speed (40-45 mph) over mainline track that has been subdivided into 22 sections. To improve the capabilities of the facility, the following modifications are submitted for consideration.

- Ensure a representative combination of curved-to-tangent track ratios (including required degrees and variations of curvature and spirals);
- Construct representative grade levels and variations;
- Define track sections of determined length and structure for load inputs to rail vehicles (instead of experimental track containing multiple test segments of insufficient transition and test lengths (FAST-Loop I));
- Modify existing track structure and length to allow for testing at Class 1 through 6 speeds;
- Construct or modify a section of track so that rail vehicles are subjected to representative stiffness and geometry including perturbation necessary to induce special loading conditions such as rock and roll, hunting, and shock loadings resulting from track discontinuities;
- Equip track section with ramp capable of accelerating a rail vehicle to humping velocities for impact testing; and

- Construct a captive track section for special accelerated service testing which would eliminate the interruption of general test schedules of other vehicles undergoing SLC evaluation. For example, one such test would be to assess the degradation of wood chip cars which is caused by the use of unloading vibrators.

At present, three new facilities are being considered for rail vehicle testing at TTC. These are the FAST Loop II, the Pilot Perturbed Track (PPT), and the Safety Acceptance Facility for Equipment (SAFE). Loop II proposes a mechanical test loop for conducting accelerated service testing of rail vehicle systems. This concept would differ from Loop I by using a more uniform track system as input to the test vehicles instead of using the consist as input for the track experiments. It is anticipated that Loop II will incorporate the first four enhancements, which could greately increase the applicability of the FAST to the Safety Life-Cycle Program. The inclusion of the suggested modifications/enhancements will better approximate the service spectrum of a rail vehicle system throughout its entire life cycle, while performing the safety life cycle research and testing discussed in Category A.

However, regardless of the expanded capabilities of the mechanical Loop II to provide more realistic magnitudes and proportions of track conditions (e.g., curve to tangent ratio, grades, geometry, stiffness), the main function of such a loop should be to accumulate as many gross ton miles as possible in a relatively short period. Therefore, the other necessary forms of service spectra loading such as programmed braking, humping, loading and unloading would have to be performed at another facility incorporating the last three enhancements described. PPT/SAFE are currently being proposed to include these features in a test site for the primary purpose of assessing the dynamic performance of rail vehicles.

In summary, by integrating the FAST program (including the test loops and inspection/maintenance facilities) with the proposed PPT and SAFE facilities, a rail vehicle's safety life-cycle could be assessed. This would improve the effectiveness of the evaluation of a system's degradation and resulting dynamic response alterations which is required to develop and verify the guidelines and prediction techniques. As discussed in Section 5.0 of the Task 2 methodology report, a very important part of safety life-cycle assessment is to determine the period of service in which a system will continue to meet the performance requirements that were necessary to ensure the vehicle's acceptability for railroad operation prior to introduction. This could be accomplished by applying the results of the SLC program research to perform the following steps on a rail vehicle system.

1) Measure dynamic response of new vehicles during inital static/dynamic acceptance test to establish a baseline for predicting parameters;
2) Determine if system SLC requirements criteria have been met;
3) Conduct accelerated service tests at FAST;
4) Measure degradation rates;
5) Assess current inspection/maintenance effectiveness;
6) Repeat step 2;
7) Perform next iteration of static/dynamic acceptance tests to determine change in dynamic response as compared to reference test results; and
8) Continue Steps 1 through 7 until the overall safety life-cycle of the system can be verified to be at an acceptable level of confidence in accordance with safety life-cycle guidelines.

Finally, the Rail Dynamics Laboratory should be considered as a research tool in the Safety Life-Cycle Program and a possible extension of FAST capabilities. This facility will contain the Roll Dynamics Unit and Vibration Test Unit. Both units can induce accelerated service testing in a rail vehicle[12] and could become valuable alternatives to track testing under certain conditions. There may be circumstances in which it would be more feasible and cost effective to use the RDL, especially in the case when only one vehicle requires special controlled SLC testing and does not warrant use of FAST and/or delays of other test programs.

BIBLIOGRAPHY (continued)

Romanzi, R., "FAST Strain Gaged Ties Calibration Test and Structural Finite Element Model," Technical Report No. MTD-7487, Metrek Division, Mitre Corporation, March 1977.

"Third Dynamic Hopper Car Test Results Report", ENSCO, Inc., draft report for Federal Railroad Administration, Washington, D. C., (unpublished) June 30, 1974.