HAZARDOUS MATERIAL TANK CARS - TANK HEAD PROTECTIVE "SHIELD" OR "BUMPER" DESIGN

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FINAL REPORT
(March 8, 1971)

Hazardous Material Tank Cars - Tank Head
Protective "Shield" or "Bumper" Design
(Contract No. DOT - FR - 00035; RPI - AAR Project Phase 13)

ABSTRACT

The objective of this study program is to design a railroad tank car head protective device which will reduce the frequency of head punctures in accidents. Accident data were reviewed in detail for the years 1965 through 1970 to correlate head damage frequency and severity with various types of tank cars, to determine distribution patterns of damage over tank car head surfaces, and to assess the costs to the railroad shipping industry of head punctures. Full scale head impact tests, previously run were also reviewed. From these two reviews, design criteria were established and used to reduce an initial compilation of 74 concepts to a group of 15, which when applied to various classes of cars, comprised a semi-final total of 42 combinations, or schemes, as referred to in this report.

Designs for these 42 schemes were then detailed and cost estimated. Next, a comprehensive cost/benefit analysis was applied. In doing this, several important conservative assumptions were made. First, the six year accident record was assumed to be typical and totally representative of the future, notwithstanding the considerable distortion caused by several major accidents in two of the six years. Also, no potential reduction in head punctures was assumed attributable to other "overlapping" solutions, such as effective interlocking couplers or changes in train operation.

Finally, the design criteria were again applied to these 42 schemes and this, in combination with the cost/benefit analysis, led to the conclusions that three schemes appear attractive for the non-insulated pressure cars of the DOT 112A or 114A type and that no schemes are justified for any other class car. Recommendations are made that a test program be conducted to establish complete details of the final design and final performance specifications. The recommended test program is outlined, and a preliminary estimate of its cost is given.

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FINAL REPORT
(March 3, 1971)

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I. INTRODUCTION

This is the final report on the subject DOT contract and covers all work done from 9/30/70 to 2/28/71, the technical period of the contract.

This contract has been handled administratively by the Association of American Railroads; however, technical performance has been carried out by the RPI-AAR cooperative team which is working on a more general tank car safety project under AAR administration. This RPI-AAR Project has been progressing under 12 technical phases, and the subject contract study has been carried out under newly added Phase 13.

The background, objectives, and work plan of this head shield study are described below. The work was divided into six tasks, and details of activity under the first three tasks have been reported on in the four monthly progress reports previously submitted. For completeness, all of this information, including updating where applicable, is repeated in this final report along with the details of the work since completed under the remaining three tasks.

To simplify the presentation, the complete discussions and results for each of the six tasks are given in the attached six appendices. A brief summary of each of these and final conclusions and recommendations are presented in this main body of the report.

II. BACKGROUND

Railroad tank car damage in derailments has been a railroad and tank car industry problem for many years. With the trend toward shipping increased quantities of certain hazardous products, particularly liquefied compressed gases, the problem has become more serious. In many of these accidents, a tank car head is punctured, a flammable hazardous product, either a liquefied compressed gas or a low vapor pressure liquid, is released, and substantial damage occurs as a result of the ensuing fire or violent tank rupture. The reduction of tank head punctures can lead to a reduction in both magnitude and frequency of such catastrophies.

The study program sought under this subject DOT contract covers a direct method of accomplishing this reduction.

The 12 technical phases of the RPI-AAR Project, which is progressing concurrently, are:

Phase 1 - Accident Review

Phase 2 - Derailment Environment Study

Phase 3 - Materials Study - Steels

Phase 4 - Review of Literature and Related Experience

Phase 5 - Head Study

Phase 6 - Safety Valve in Liquid Study

Phase 7 - Safety Relief Devices - General

Phase 8 - Reduced Scale Model Studies

Phase 9 - Design Study - Tanks and Attachments

Phase 10 - Design Study - Car

Phase 11 - Thermal Effects Study

Phase 12 - Vessel Failure Research

The Phase 1 effort was fairly well along at the time of initiating this subject head shield study and provided considerable input in the form of head damage statistics. Also, a preliminary series of full-scale impact tests had been completed under the Phase 5 study, and this information was also valuable as input.

III. OBJECTIVES AND WORK PLAN

The purpose of this head shield study as stated in the RFP is to develop a "shield", "bumper", or other possible protective structure which can be applied to the lower part of the heads of existing and new tank cars in order to significantly reduce the number of head punctures and end head contacts.

The objectives of the study are to include:

(1) A review of the characteristics of tank car head failures and determination of the approximate magnitude of probable tank head failure forces.

(2) The development of the criteria governing the design of the tank car head protective structure.

(3) The determination of the cost criteria for the addition of the protective structure including revenue loss due to increase of light weight of car, cost of structure, application and maintenance.

(4) The development of performance specifications, conceptual designs and application requirements for the protective tank head structure.

(5) The formulation of a performance test specification for the recommended design(s).

To accomplish these objectives, the work was divided into six tasks which are discussed briefly below. Complete discussions and results for each task are given in the appendices to this report.

TASK 1 - IDENTIFICATION OF TANK HEAD FAILURE CHARACTERISTICS

1.1 Accident Data Survey and Review
1.2 Identification of Primary Failure Parameters
1.3 Specification of Important Protection Features

Under Task 1, the major parameters associated with tank head punctures were evaluated using data obtained from a review of the RPI - AAR Project accident files. These files contain records of over 4500 cars which were damaged in accidents during the period 1965 through 1970. Of these, over 1200 cars suffered head damage, and 200 of these had punctured heads.

Based on the data for these 1200 + cars, the likelihood of head puncture was statistically analysed to assess the influence of several major parameters: type and size of car, location on the head, effect of load (vs empty), and insulation.

Next, that portion of the accident cost attributable to the head puncture of each car (loaded cars only) was estimated and tabulated by class of car. Also, statistics were tabulated on the number of cars of each class in service during the period 1965 through 1970. Both of these tabulations were used later in the cost/benefit analysis under Task 4.

TASK 2 - DESIGN CRITERIA

2.1 Tank Car Design Review
2.2 Head Failure Analysis and Correlation with Failure Data
2.3 Establishment of Protective Structure Design Criteria

This task was devoted to establishing design criteria for head protection devices based primarily on the full-scale head impact tests conducted previously under the RPI - AAR Project.

Semi-empirical equations were developed to "match" the test results and to permit analysis of the influence of various parameters on puncture phenomena.

Based on this analysis, the Task 1 accident review, and engineering judgement, a complete list of design criteria was then developed.

TASK 3 - DESIGN SPECIFICATIONS

3.1 Concept Formulation
3.2 Concept Analysis
3.3 Concept Review and Final Evaluation
3.4 Performance Specifications
3.5 Design Finalization and Drawings

This task comprised the generation of design concepts, their evaluation based on the above established design criteria, and development of performance specifications. The evaluation served as a screening process to reduce an originally lengthy list of concepts to a semi-final total of 15. Application of these to various classes of cars led to 42 combination schemes for design and cost estimating. Sketches of all 42 schemes are given in Appendix C.

TASK 4 - COST ANALYSIS

4.1 Cost Item Identification and Clarification
4.2 Structure Costs
4.3 Application Costs
4.4 Maintenance Costs
4.5 Cost-Affected Items
4.6 Cost/Benefit Analysis

The estimated installed cost for each of the 42 schemes was developed under this task. Analyses of less tangible cost affected items were also made.

At this point, each of the 42 schemes was evaluated on the basis of the economic benefit which would be realized from its application to a tank car. This was done using the estimates of installed cost and the Task 1 data on accident costs and number of cars in service.

Combining this economic benefit analysis with the Task 2 design criteria, a final scheme selection was made for each class of car. These are summarized in Table I which is discussed under Conclusions below.

TASK 5 - PERFORMANCE TEST SPECIFICATIONS

5.1 Test Parameter Identification
5.2 Relation of Performance Specifications to Test Parameters
5.3 Test Specification Formulation

The specifications for a prototype test program for the selected design were developed under this task.

TASK 6 - PROTOTYPE RESEARCH PROGRAM

6.1 Technical Design Requirements
6.2 Prototype Construction
6.3 Prototype Qualification
6.4 Cost Estimate

Based on the above test specifications, a complete prototype evaluation test program was outlined and cost estimated under this task.

IV. SCHEDULE

The project schedule was planned in detail during October, 1970, and technical activity followed in November through February, 1971.

With minor exceptions, the six tasks and sub-tasks listed above were conducted in sequence, but overlapping necessarily in some areas.

V. CONCLUSIONS

The following conclusions have been reached under this program:

The head protection schemes given in Table I have been identified as the economically and technically optimum of all schemes considered for each class of car listed.

This table does not include all classes of tank cars which are authorized to carry hazardous materials, although the first four classes listed cover approximately 97% of all new car types, and the latter four classes cover approximately 55% of existing car types. Class 103W, 104W, aluminum, and riveted cars constitute the balance and are fairly similar in design to the class 111 types listed.

This table also gives the estimated additional cost and benefit values for each scheme. The costs are, by our definition, those which would be incurred by a shipper-owner, excluding maintenance and less tangible related costs. The benefits are the maximum amounts which justifiably could be spent for each scheme and have been derived from estimated costs attributable to head punctures in past accidents, discounted to present value on a 10% annual rate of return on investment. Supporting details for these cost and

TABLE I

SUMMARY OF OPTIMUM HEAD PROTECTION CONCEPT BY CLASS OF CAR

Class Car	Optimum Head Protection Concept		Eff. of Scheme, % **	Est. Added Cost/ Car	Estimated Benefit/ Car	Estimated Economic Value (Benefit less Cost)
	Scheme*	Description				
New 112 & 114	O-1	1/2" butterfly plate	85	$430	$425	$ - 5
	P-1	1/2" vert. curv. plate	77	280	385	+105
	N-1	1/2" vert. straight pl.	55	200	275	+ 75
New 111 non-ins	N-2	1/2" vert. straight pl.	41	140	14	-126
New 111 ins.	J-3	3/8" jacket	75	270	13	-257
New 105 ins.	J-3	3/8" jacket	75	295	5	-290
Exist. 112 & 114	O-4	1/2" butterfly plate	85	500	425	- 75
	P-4	1/2" vert. curv. plate	77	335	385	+ 50
Exist. 111 non-ins.	N-5	1/2" vert. straight pl.	41	175	14	-161
Exist. 111 ins.	N-6	1/2" vert. straight pl.	79	200	10	-190
Exist. 105 ins.	N-6	1/2" vert. straight pl.	82	240	4	-236

* See Table C-2 for scheme identification code.

** Relative to a 1/2" steel plate covering entire head, see Table D-3, column labelled "B".

benefit values are given in Appendices A and D. The benefits were first derived in Appendix D on the assumption that head protection, had it been on cars which experienced head punctures, would have been 100% effective in preventing lading loss. The values shown in the benefit column of Table I are lower since the efficiency of the specific listed scheme is taken into account. These efficiencies are discussed in Appendix D, but noteworthy here is the fact that they are based on the assumption that a 1/2" steel plate, spaced away from, but covering the entire head, is 100% efficient. Variations in material, thickness, and head area covered (taking into account puncture distributions from accident data) lead to the estimated efficiencies.

There are two other important conservative assumptions underlying these benefit values. First, the accidents reviewed were for the six year period 1965 - 1970, and although the data was considerably distorted by several major accidents in two of the six years, 1968 and 1969, the assumption was made that the entire data set is typical and totally representative of the future. Second, no potential benefit has been assumed for other solutions which may overlap this head shield solution and which, therefore, would reduce the net benefit value of head shields.

Based on this approach and its associated assumptions, the estimated economic values given in Table I are finally established. From these, it is concluded that the head protection concepts, N, O, P or some combination design incorporating the best design and economic features of each, appear attractive for new and existing Class 112 and 114 cars. Conversely, no designs are justified for the balance of the cars.

VI. RECOMMENDATIONS

A. Prototype Test Program

The head shield concepts N, O, P or some optimum combination thereof, appear sufficiently attractive for class 112 and 114 cars to warrant a follow-up prototype test program. All of these concepts involve a 1/2" steel plate with slightly different shape and supporting structure. The test program is considered essential since the available data used to establish design criteria, though substantial, has not been sufficient to establish final performance specifications and the actual degree of protection offered by the concepts. This test program, outlined in Appendix F, has the direct objectives of:

- establishing quantitatively the degree of protection offered by the 1/2" steel plate design. This relates particularly to the values in the estimated benefit column in Table I which are based on the assumption that a 1/2" plate covering the entire head is 100% effective. For example, a 3/8" or 5/8" plate may be closer to being 100% effective; and, of course

overriding all of this is the still undetermined "typical" impact speed and consist of impacting cars against which the shield is to protect. The test program is expected to provide a basis for establishing these unknowns.

- establishing a practical set of test performance specifications for the head shield and a set which can be used also for future submitted designs.

- establishing final design details and specifications for the recommended head shield and hence, final estimated additional cost.

Another benefit of the test program as proposed involves the evaluation of certain other energy absorbing materials which were considered under the present study, but which were discarded because of the uncertainty of their energy absorbing properties.

B. Overlapping Solutions to Overall Tank Car Safety Problem

Means other than a head shield, per se, can be instrumental in reducing the frequency of head punctures or ruptures. For example, an efficient interlocking coupler will reduce the frequency of head impact from couplers on adjacent cars. Operational changes such as speed reductions and/or car spacings will also tend to produce the desired result. While effective thermal shield coatings will not reduce the frequency of head punctures, they can affect the total benefit by reducing the magnitude of chain reactions initiated by head punctures. The estimated benefit values given in Table I do not take these overlapping solutions into account; instead, they are based on the assumption that only head shields will be available to produce the stated benefits.

With other potential solutions to the overall problem of improving tank car safety being studied under the RPI - AAR Project, it would be premature at this time to incorporate the head shield solution on actual cars. Fortunately, by the time the prototype head shield test program is completed, more will be known concerning these other solutions, and all can be considered simultaneously. Since the overall goal of the entire tank car safety program is to achieve improved safety as soon as practical, attractive potential solutions, whether overlapping or not, must be studied simultaneously; thus, speedy persuance of the outlined test program, is recommended.

VII. ACKNOWLEDGMENTS

Credit is due the following Project team members for their efforts in supervising the activities under their respective tasks:

R. A. Westin, UTC, Task 1
J. C. Shang, GARD, Task 2
J. E. Everett, GAT, Task 3

A. M. Skogsberg, NAC, Task 4
J. E. Everett, GAT, Task 5
C. E. Reedy, ACF, Task 6

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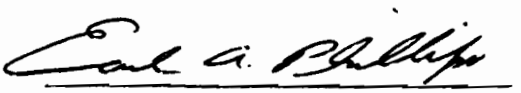
A. M. Skogsberg (North American Car Corp.)
F. Brown (Union Tank Car Company)

Respectfully submitted,



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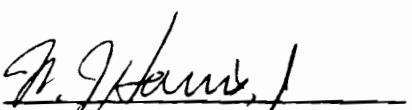

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Attachments:
Appendices A, B, C, D, E, F.