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# LOCOMOTIVE/CABOOSE CRASHWORTHINESS

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Transportation Systems Center
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Cambridge MA 02142

OCTOBER 1976
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16. Abstract

This report presents the results of the Phase I study of the locomotive/caboose crashworthiness program and the proposed work for the Phase II investigation. The results of the Phase I study include the mechanics of train impact that lead to override, recommended action to control override and means of protection for locomotives and cabooses.

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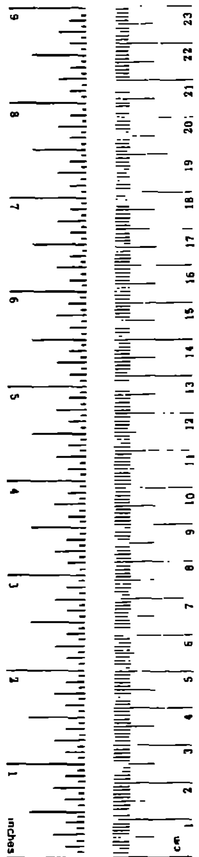
# PREFACE

The locomotive/caboose crashworthiness program is a part of the safety research program under the direction of Don Levine of the Federal Railroad Administration (FRA) devoted to the reduction of collisions and improving the crashworthiness of locomotives, cabooses and other rail vehicles. This report summarizes the results of the Phase I study of the program and the proposed work for the Phase II investigation.

# METRIC CONVERSION FACTORS

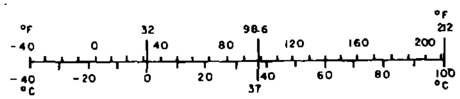
## Approximate Conversions to Metric Measures

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




## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | | **AREA** | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | | **MASS (weight)** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | | **VOLUME** | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



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# 1. INTRODUCTION

The locomotive/caboose crashworthiness program is a part of the rail crashworthiness program sponsored by the Federal Railroad Administration to develop guidelines and performance specifications with low cost impacts for rail vehicle structural integrity, interior and exterior configurations, and operational procedures. The goal is to reduce crew and passenger fatalities and injuries and to minimize property damage due to rail car collisions.

The locomotive/caboose crashworthiness program has been divided into two phases: I. Study of the mechanics of train collision involving a locomotive and a caboose; II. Design analysis and test evaluation of protection system for locomotives.

Phase I is essentially complete. Based on its results, the Phase II program is being developed. The following sections will present a summary of the results of the work in Phase I and an outline of the Phase II work plan.

## 2. PHASE I: MECHANICS OF TRAIN COLLISION

This phase included both analytical and field testing programs for the study of mechanics of train collisions in order to gain insight into the mechanism of car motion and the reasons why the impacted cuts of cars behave as they do (override, jackknife or maintain longitudinal alignment). The study also sought to control the car motion through proper dissipation of the kinetic energy. The results of Phase I have provided a sound technical base and understanding in guiding the development of the Phase II program.

Among train accidents, rear-end collisions resulting in override of one car on another are the most severe type. In these situations, the underframe of the overriding car will intrude into the relatively weak superstructure of the overridden car, crushing the survivable space for the crew or passengers and destroying the overridden vehicle itself. Therefore, the Phase I efforts have concentrated mainly on the problems of override.

### 2.1 ANALYTICAL STUDY

Almost all of the longitudinal strength of a rail vehicle is concentrated on the floor level and all of the longitudinal force generated in impact between cars is transmitted through the couplers which have a vertical dimension of approximately 11 inches. A misalinement of the coupler height, by this amount in the vertical direction will result in override. From the analytical study (Ref. 1), it has been found that such misalignment can be caused by that exists prior to impact together with that induced during impact. The initial misalinement prior to impact can be due to an initial difference in the height of the center sills or a bent coupler of either the impacting or the impacted car (Fig. 1). It can also occur because the impacting car was already derailed (or detrucked) prior to impact. The coupler of a derailed car can be six to nine inches lower than the coupler of a car on the rails. The initial difference in height between cars can also be caused by the variation

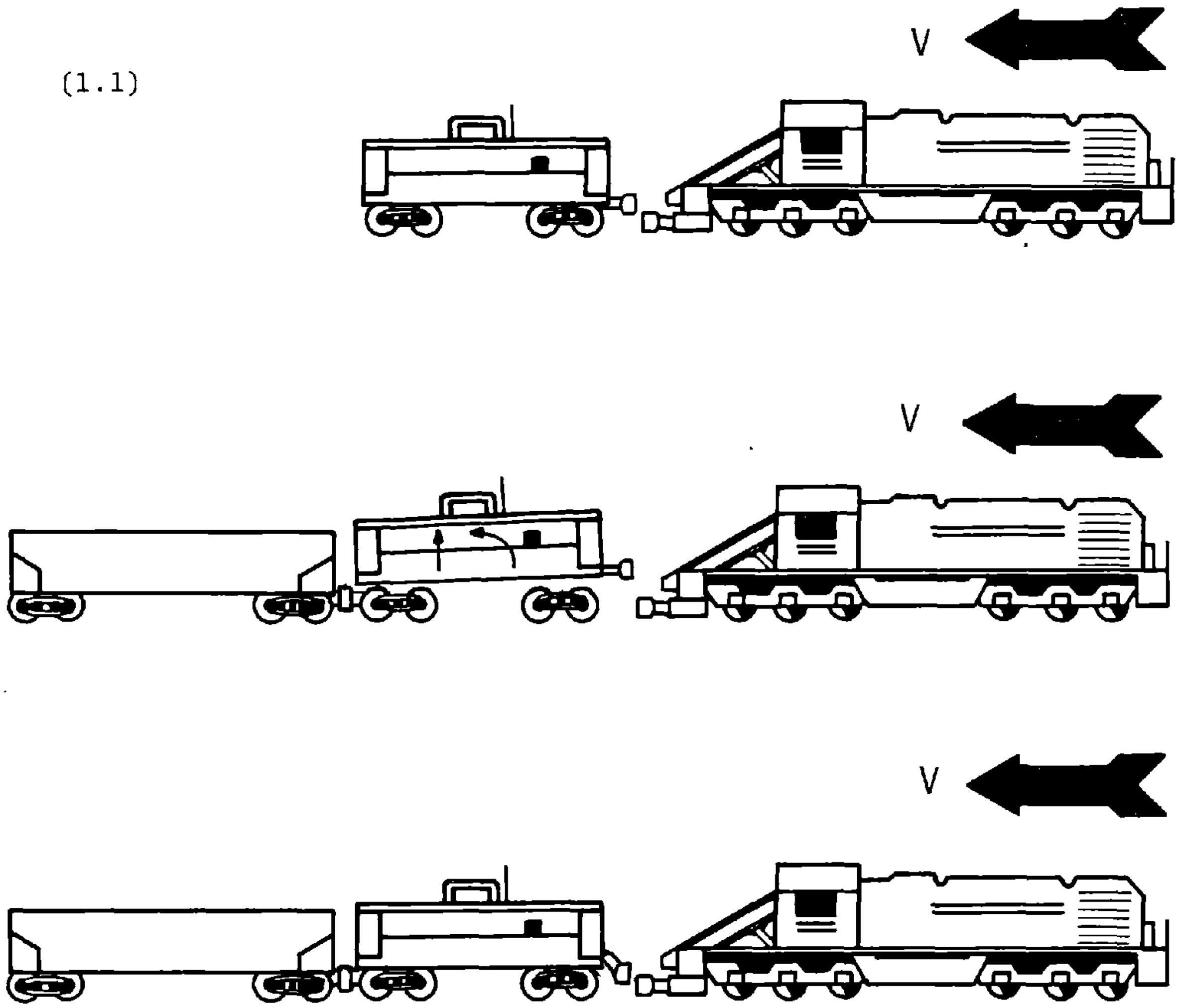


FIGURE 1. BASIC MECHANISM OF OVERRIDE

in lading load and/or improper maintenance. The derailed (or detrucked) impacting car can be caused by an emergency brake application when a collision is imminent. The induced misalignment is either due to the vertical and the pitching motions of the cars (Fig. 1.2) or is a result of buckling (elastic or plastic) (Fig. 1.3) or breaking of the coupler (most likely at the shank) or the center sill (most likely near the body bolster) during impact. The vertical and the pitching motions are caused by the fact that the longitudinal force generated in impact is, in general, not horizontal and is usually applied below the center of gravity of the impacted car. The stiffness of the rail vehicle is concentrated primarily at one height, so that when the impact force exceeds the elastic limit, large bending and buckling deformation can easily occur and cause override.

Four basic override modes have been identified. They are the first, the second, and the third impact override and override caused by buckling or breaking of couplers or sills (Fig. 2). These modes are categorized based on the timing of the occurrence of the override and the nature of the structural deformation. The details are given in Ref. 1. A summary of the causes of the different modes, their likely initial configurations and the override configurations is given in Table 1. Among these modes, the third impact override is unlikely to happen except in a switchyard accident because it requires a loose car separated from the rest of the train. In an actual collision, one or a combination of these modes can occur.

The important parameters which affect the dynamics of car motion and the force generated in collision are the impacting speed, the weight, the mass moment of inertia of cars and ladings, the car length, the location of the center of gravity, the longitudinal, vertical and lateral stiffnesses and strengths, the alignment and the slacks between cars, the draft gear capacity, etc. Since all rail cars are usually heavy, the forces generated in collision are large. The maximum longitudinal forces are estimated to be

$$F_{max} = V \sqrt{k_1 \; m_1 m_2/(m_1+m_2)} \qquad (2.1)$$

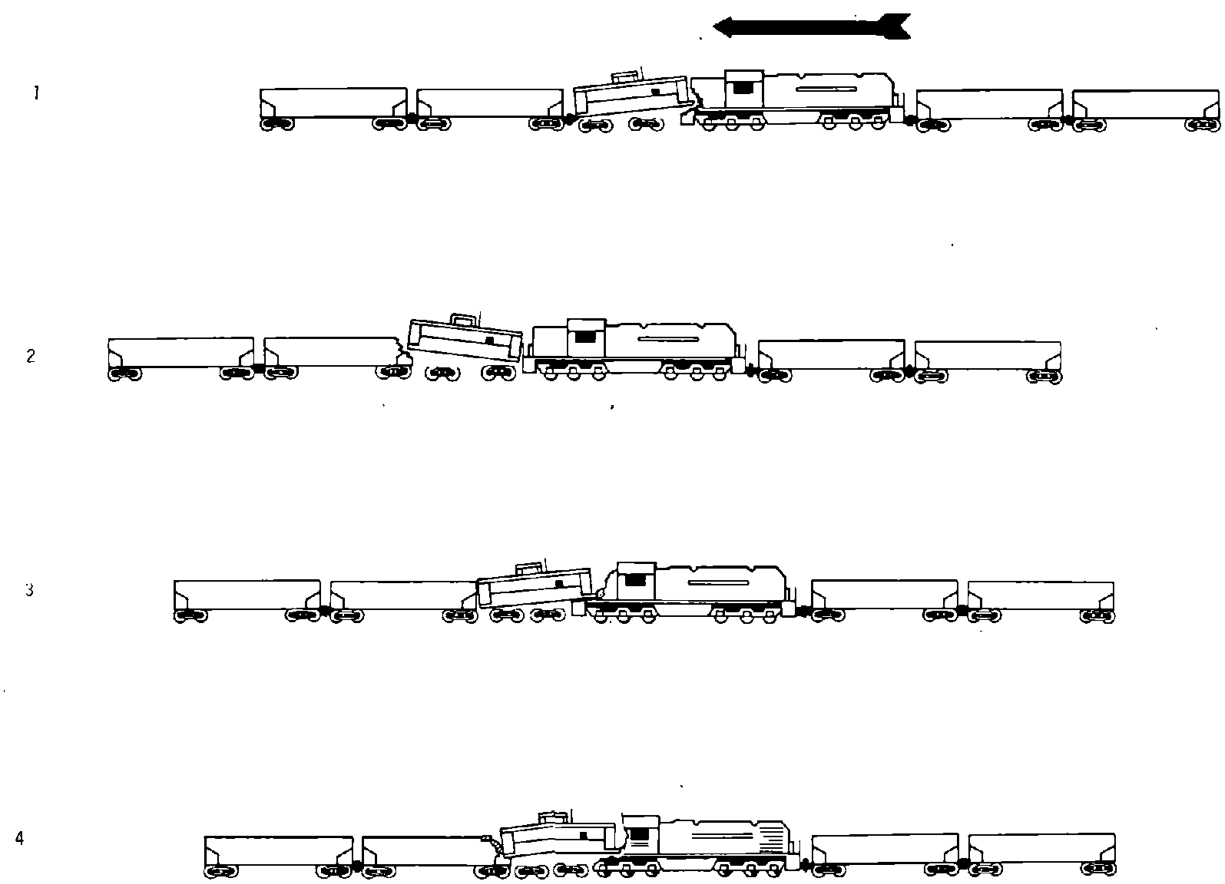


FIGURE 2. OVERRIDE MODE IN TRAIN COLLISIONS

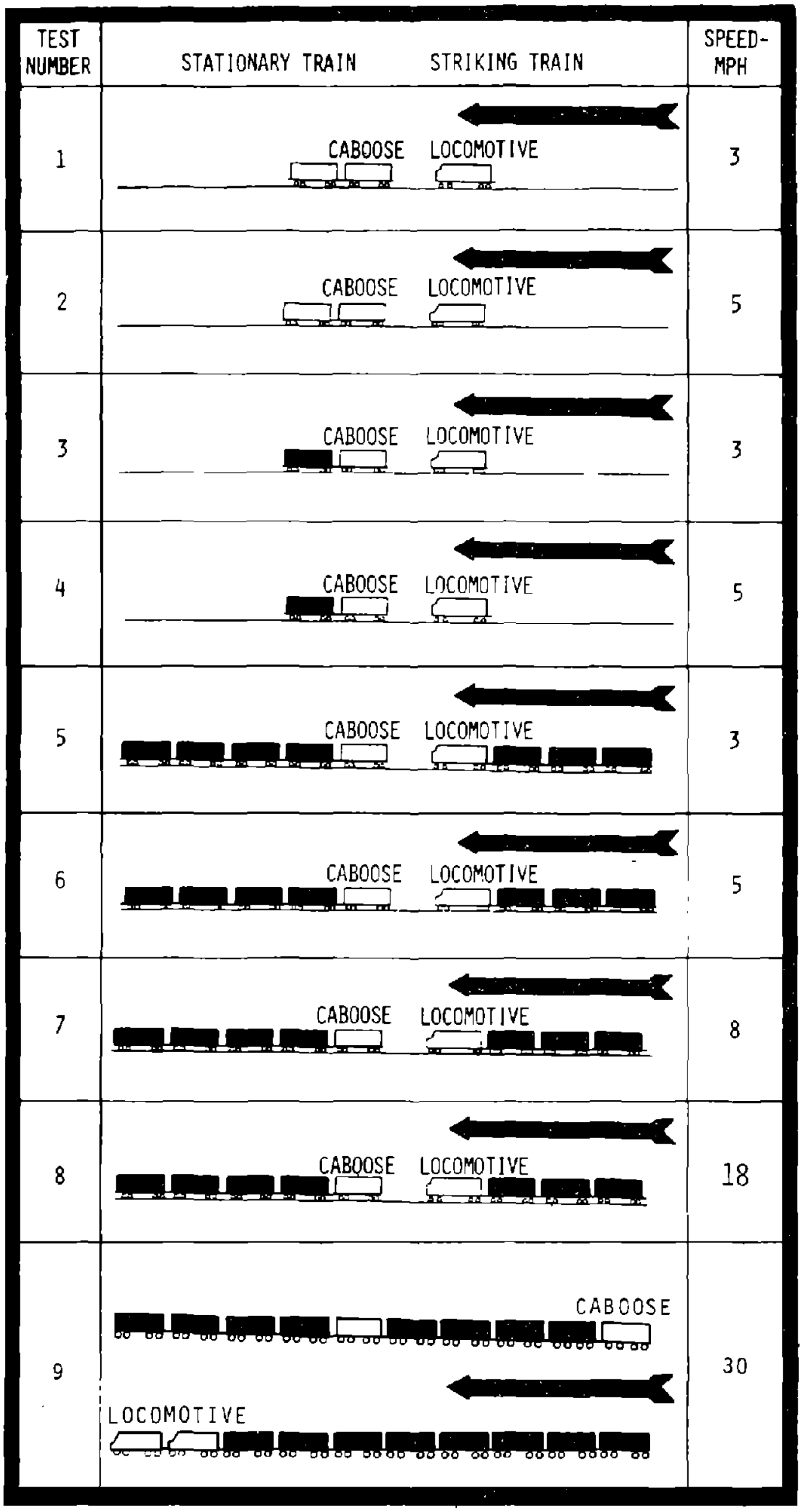


FIGURE 3. TRAIN-TRAIN IMPACT TEST CONFIGURATIONS OF PHASE I

TABLE 1. SUMMARY OF OVERRIDE MODES AND CONFIGURATIONS

| OVERRIDE MODE | CAUSES | LIKELY INITIAL CONFIGURATIONS | OVERRIDE CONFIGURATION |
|---|---|---|---|
| First impact (Fig. 2.1) | Initial misalignment between two impacting cars.<br>Yielding of the coupler and the center sill between two impacting cars during the first impact. | Light or heavy impacted car.<br>Impacted car with low center of gravity | Impacted car overrode impacting car. It occurs before or barely after the impacted car impacts on the back-up car. |
| Second impact (Fig. 2.2) | Misalignment due to the vertical and pitching motions of the impacted car induced by the first impact.<br>Yielding of the coupler on the center sill between the impacted and the back-up car during the second impact | Light impacted car.<br>Moderate spacing between the impacted and the back-up car. | Impacted car overrode the back-up car. It occurs when the impacted car hits the back-up car. |
| Third impact (Fig. 2.3) | Misalignment due to the vertical and pitching motions of the impacted car induced by the second impact.<br>Yielding of the coupler on the center sill between the impacted and the impacting car during the third impact. | Light impacted car.<br>Large spacing between the impacted and the back-up car. | Impacted car overrode the impacting car. Override occurs when impacting car hits the impacted car for the second time |
| Buckling (Fig. 2.4) | Buckling or plastic deformation of the center sill or the entire car body of the impacted car at high speed impact. | Light or heavy impacted car.<br>Little or no gap between the impacted and the back-up car. | Impacted car overrode either the impacting car or the back-up car. Override occurs when buckling or breaking of the center sills or the couplers of one of these cars. |

for the impact of two cars of masses $m_1$ and $m_2$ with V being the impact speed and $k_1$ being the stiffness between the two cars, and

$$F_{max} = V\left[\sqrt{\frac{k_1k_2}{k_1+k_2}\ \frac{m_1m_3}{m_1+m_3}} + \frac{1}{2}\sqrt{\frac{k_1{}^2m_2}{k_1+k_2}}\right] \qquad (2.2)$$

for impact of a heavy car, $m_1$, onto a light car, $m_2$, backed up with a heavy car, $m_3$, (or cars) with $k_1$ and $k_2$ being the stiffnesses between $m_1$ and $m_2$ and between $m_2$ and $m_3$, respectively. The above results can be used to estimate the force magnitude for an impact involving many vehicles when the impacting cut of cars is led by a heavy car, $m_1$. However, these force magnitudes are limited by the longitudinal strength of the vehicles involved. For example, the force magnitude can exceed a million pounds* for an impact above 10 mph, which can cause yielding of the coupler shank and the center sill.**

## 2.2 FIELD TESTING

A series of nine train-train impact tests were conducted under the Phase I program. The train consists and the impact speeds are given in Figure 3. The tests were designed to collect the maximum amount of information on the dynamics of train impact. The data collected include accelerations, forces and displacements of the cars. There were also extensive high-speed movies recording the car motion. One of the many uses of this information is to verify the analytical model and to assist its further development for the understanding of the mechanics of train collision. The information

*The stiffness between two rail vehicles is of order of several hundred thousand pounds per inch.

**These components have cross section areas of approximately 23 sq. inches, and the yielding stress of structural steel is roughly 40,000 psi.

is also used to help in the design of the Phase II program. The details of the test procedures, the data collection system and the collected data are given in Ref. 2.

## 2.3 ANTICLIMBING CONTROL

Because of the structural configuration (stiffness concentrated on the floor level) of present vehicles, override and jackknifing are the prevailing post-impact motions. However, overriding on the locomotive and crushing its cab are the worst means of dissipating kinetic energy in a train collision. The question is then whether override can be controlled. The override modes of first impact, third impact, and buckling or breaking of the coupler or the center sill are of paramount concern. From the discussion in Section 2.1, it is clear that the key to control these override modes is to control the misalinement and the vertical motion and to provide sufficient strength for all vehicles to avoid buckling and breaking of the major structural components. We shall discuss separately the usefulness of various anticlimbing controls.

### 2.3.1 Minimize Initial Misalinement

The initial misalinement of the coupler heights can be minimized by proper maintenance and inspection in service operation. However, the difference in coupler height caused by the derailment of an impacting locomotive is hard to control. The derailment can be caused by emergency brake application. It can also be caused by impact, i.e., in collision, the lateral force may push the end car or cars of the impacted train aside and cause the locomotive itself to derail. However, because of the enormous amount of kinetic energy in the moving cut of cars, the locomotive may continuously move forward. When it reaches a car that is still on the rails, there may be sufficient misalinement to cause override in impact.

### 2.3.2 Control of Vertical and Pitching Motion

The induced misalinement due to the vertical and pitching motions can be reduced by adding proper constraints. There are various ways to achieve this:

a) Truck retention - For a lightweight vehicle, retaining the trucks on the car body can almost double its moment of inertia. For a given moment applied to the car body, this can reduce the pitch motion by a factor of two. However, if the impact force causes buckling or plastic deformation of the couplers or the center sill between two impacting cars, these components can have large rotations which can still make the couplers of two cars slip off from each other.

b) F- or Shelf E-coupler - Use of these devices will limit the relative vertical motion between two couplers. However, if the cars are not coupled, or if the cars are coupled but the coupler shank or the center sill breaks during impact, these devices are ineffective. For shelf E-couplers, the relative vertical displacement between two couplers can be as much as seven inches. In this case, the longitudinal force is applied eccentrically on the couplers, and can easily bend or even break them.

c) Anticlimber - A locomotive equipped with an anticlimber can prevent the coupler of another car reaching the cab. The anticlimber is located above the coupler as shown in Figure 4. It should have enough vertical strength to restrain the vertical motion of the coupler of another car. However, its longitudinal strength should be less than that of the sill of the locomotive, so that in the case of head-on collision. the anticlimber will not lock uo the two locomotives causing crush of the sills and the cabs. In general, an anticlimber is very effective particularly at low speed impact, because the retained coupler or the center sill does not break or undergo large bending and rotary deformation in this situation.

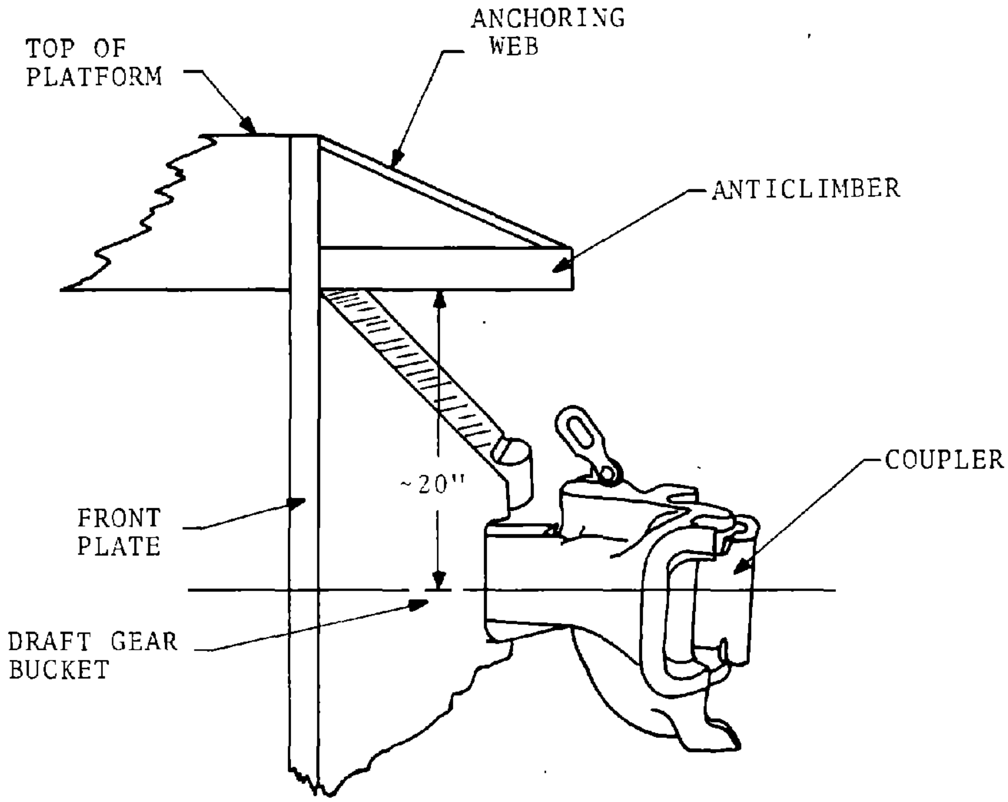


FIGURE 4. SIDE VIEW OF ANTICLIMBER AT A SHORTHOOD OF THE LOCOMOTIVE

### 2.3.3 Increase Strength of Couplers and Center Sills

It is clear that the yielding of the major structural components such as the coupler or the center sill resulting in a large rotation or even breaking of either of these components may render the various anticlimbing schemes ineffective. Plastic deformation of these components can occur at an impact speed as low as 10 mph. One may logically conclude that to increase the effectiveness of the various anticlimbing devices, one must increase the strength of the couplers and the center sills of all vehicles.* In practice, this can be very difficult. To increase strength means using better material or more material for these components. This can be very costly and for the latter add substantial weight to a vehicle. Adding to the strength of a vehicle often increases its stiffness.** This means, that for the same impact speed, a higher impact force will be generated. In other words, increasing vehicle strength may not be the most effective or economical way to avoid the failure of these major structural components.

There is still another way to avoid override resulting from the failure of the major structural components, and that is to redesign these components with higher stiffness and strength in the vertical direction than in the lateral direction. In the event of buckling and the formation of a plastic hinge, the rotation of the coupler and/or the center sill will be more lateral than vertical. This will cause a car to jackknife rather than to override. The only drawback of such a scheme is that if there is an excessive lateral motion, the jackknifed car may be thrown sideways to another track inducing other damages or may be possibly thrown

*Even though most collisions are either head-on or rear-end with a locomotive impacting on a caboose. In the latter case the caboose can be pushed aside and the locomotive impact then on the cars ahead of it. Therefore, all cars must be strengthened in order to achieve total effectiveness.

**In the case of using more material, recall that the longitudinal strength is proportional to the cross-sectional area and the impact force is proportional to its square root.

down a hill if the collision occurs in a mountain track. However, such a drawback may not be a major one, because, in practice, lateral movement is unavoidable in the post-impact motion, regardless of whatever scheme is used.

## 2.4 DIRECT PROTECTION OF LOCOMOTIVE CAB

From the previous discussion, one may conclude that no anticlimbing control is totally effective or economically feasible to eliminate override. Most of the anticlimbing schemes may not be effective if the resulting force from a collision exceeds either the coupler or the center sill strength of the impacted cars. Therefore, for the crashworthiness of the locomotive, the cab must still be directly protected even if some kind of anticlimbing control is instituted.

Protection of the shorthood end from intrusion is the most critical task. A locomotive is often operated with the shorthood forward; therefore, in the event of a collision, the chance of the shorthood end being impacted is great. In addition to which, there is only a short crush distance available. The following are some of protection concepts for the shorthood end.

(1) Collision Post - This is a popular protection device used in many rail vehicles. However, it is not effective if the intruding object is a caboose or a freight car, because these vehicles have a protruding coupler and center sill which can intrude into the cab unless the protrudence impacts directly on a collision post.

(2) Energy Absorption - This idea is to provide enough material around the cab to absorb the energy of the car overriding on the locomotive. Since the intruding object is usually a car with a protruding coupler or center sill which has a frontal area much less than one square foot, only the material near the point of impact will actively absorb the impacting energy, and consequently will require a large crush distance in order to absorb all the kinetic energy of the overriding car. This is especially true in the case of a head-on collision; it is not an efficient

way for utilizing the energy absorption material. Because the impact point varies, almost equal protection must be provided for the entire cab front, even though most of the area does not participate in absorbing energy in the collision.

(3) Deflecting Concept - This is intended to deflect objects from intruding into the cab. The deflector is a stiff surface inclined at an angle (Fig. 5). Instead of absorbing the kinetic energy, the deflector will alter the motion of the overriding car toward the vertical direction. The stiffness and the inclination angle of the deflector are designed to have the overriding car sliding over the top of the cab without crushing the survivable volume for the crew. Because of the irregular shape of the overriding car, its precise trajectory after being deflected and its final location are hard to predict. It may sit on the top of the locomotive or fall to one side.

Protection of the longhood end from intrusion is relatively straightforward. Firstly, there is a long crush distance available. Secondly, there are massive structures such as the engine, etc., already in this end. One can utilize these structures to absorb the impacting energy. It is necessary only to have these structures properly anchored to the sills, so that they will not be sheared off by an intruding object. Actually for crashworthiness, it is safer to operate a locomotive with its longhood forward provided its structures are properly anchored to the sills. However, operating with the longhood forward hinders the crew's visibility. A solution to this is to provide some kind of visual aid system for the crew.

There is little chance of a cab being impacted from the top. At most, a rail car may end up sitting on the top of a cab in override. Therefore, it is only required that the vertical strength of a cab should be able to support a heavy rail vehicle.

There is also very little chance that the sides of a cab will be directly impacted. However, it is possible in the case of jackknifing that the side of the cab be hit by another car. Therefore, a part of the cab sides should be strengthened for added protection, e.g., only the part of the cab which is designated for crew survival volume.

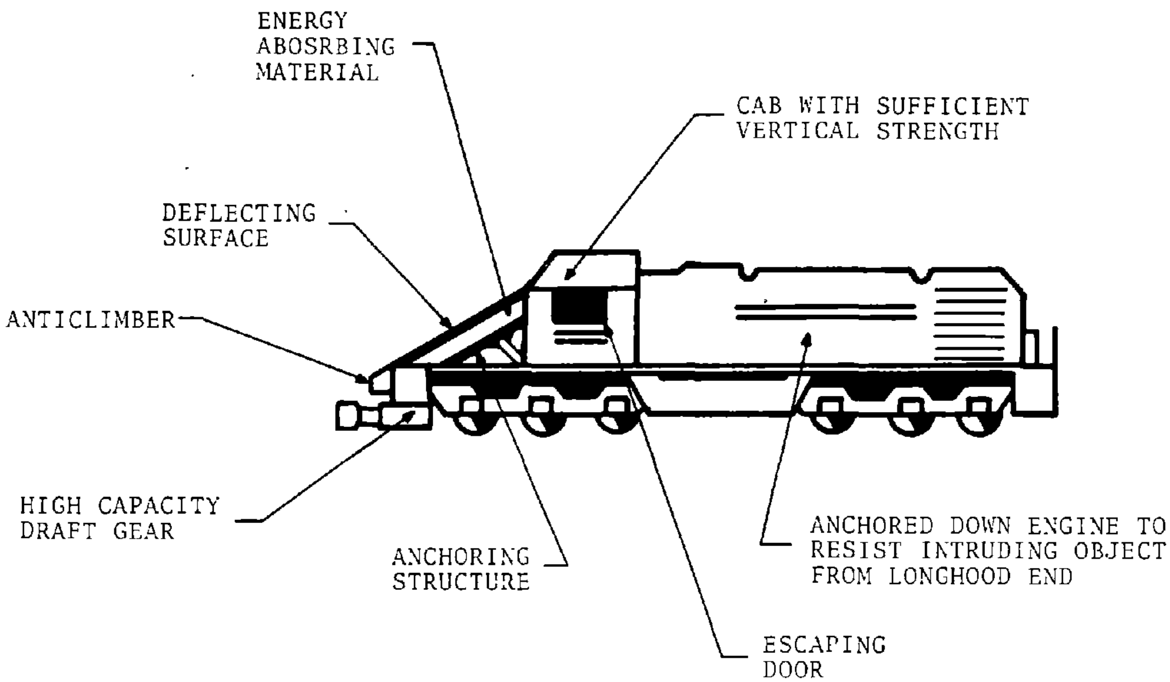


FIGURE 5. CRASHWORTHY LOCOMOTIVE

## 2.5 OTHER PROTECTION REQUIREMENTS FOR LOCOMOTIVE CAB

Most rail vehicles are heavy and, therefore, fatalities and injuries due to high deceleration in a collision are not a severe problem. However, personnel may suffer injuries and even fatalities from impacts with the interior surfaces or laceration from the shatter glass of the windshield. Thus, the interior must be designed to avoid having people thrown against the walls or a sharp object, and to have enough padding to reduce the blows when a person is thrown against a fixture. Tempered glass should be used for windshield.

One must also give special consideration to the location and the configurations of doors and windows of the cab to provide escape routes for the crews in the pre- or post-collision environment.

## 2.6 CRASHWORTHINESS FOR CABOOSES

The caboose is relatively light in comparison to many other rail vehicles. Instead of being crushed, a caboose usually bounces up to override another car or is pushed aside and derails in a collision. Therefore, a crew in a caboose is less vulnerable than those in a locomotive cab. However, some improvements are desirable on interior padding and escape routes for crews in the pre- and post-collision environment.

## 2.7 RECOMMENDATIONS

Overclimbing is a devastating mode of post-impact motion in railcar collisions. Misalinement, induced vertical and pitch motions (particularly critical when a loose light car is impacted), and failure of the major longitudinal structural components such as center sills and couplers are the primary causes of override. To improve the crashworthiness of the locomotive and the caboose, these causes must be eliminated or controlled by a cost-effective approach. The following are specific recommendations:

(1) Institute inspection procedures to assure that the alinement of the rail vehicles are within the AAR limit.

(2) Use tempered glass for windshield to reduce laceration from shatter glass in accidents.

(3) Equip locomotives with top shelf couplers or equip the shorthood ends of locomotives with anticlimbers (Fig. 5). In the latter case, the height should be selected to capture the overriding coupler after it slips off from that of the locomotive. Recess should be provided to avoid impact between anticlimber when two locomotives are coupled at the shorthood ends. The anticlimber should have adequate vertical strength. (The vertical force is estimated to be 200,000 lbs. when the coupler is restrained from upward motion in override. The load should be applied at the end of the anticlimber.) The longitudinal strength should be below that of body sills in compression. This is to avoid locking up of two locomotives in the case of head-on collision and crushing both of them. The anticlimber is expected to be effective in preventing override for impact below 12 mph.

(4) Require all the longhood structures to be anchored to the sills with adequate shear strength. (A strength of 1.2 million lbs. is desirable because this is roughly the strength of present rail vehicles.) This is to prevent intrusion from the longhood end. There are the long crush distance and structures to absorb impacting energy as long as these structures are anchored down properly to the sills.

(5) Provide a deflecting shield to protect intrusion from the shorthood end (Fig. 5). The deflector is inclined at an angle to guide objects away from penetrating into the cab. The inclination angle must be determined from a trade-off between visibility from the cab and the strength requirements of the deflecting surface. The deflector should be backed up with energy absorbing material (honeycomb, foam, etc.) which is anchored to the sills properly. The deflecting plate can then redistribute the impact load on this material. The deflector should have enough strength so that it will not be punctured by an overriding car at the designed maximum impact speed. (The desired maximum speed for the crashworthiness of the locomotive has not yet been set. It is expected that the required deflecting plate thickness will be linearly proportional

to the magnitude of desired impact speed, while the thickness of the energy absorption layer will be proportional to the square of the speed.) The design analysis and the test evaluation of the effectiveness of the deflector are the tasks of the Phase II program and which will be discussed in Section 3.

(6) Increase the vertical strength of the cab to be able to support the weight of a heavy rail vehicle.

(7) Provide "soft" interior of the cab and the caboose and eliminate sharp objects.

(8) Provide adequate emergency escape routes in the cab and the caboose for pre- and post-impact environments.

(9) Improve the coupling mechanism to assure that cars are coupled when they are humped. This is to reduce the chance of having a loose car in a cut of cars in a switchyard.

(10) Use high capacity draft gear for locomotives. This is to help in dissipating some of the impacting energy.

In the above recommendations, all of the items can be implemented or retrofitted to the present vehicles separately. It is recommended that the first four items be implemented as soon as possible and the rest of the items be implemented after further studies are completed and assessed.

Each of the control and the protection devices in the above recommendations will serve its function, only if a locomotive equipped with such devices is used as the leading locomotive of the train in collision. Therefore, the implementation of the recommendation should be required on all locomotives, or only the ones with protection device (or devices) are allowed to be the leading locomotive. (The latter option can be expensive, because the locomotives' switching operation is costly.)

# 3. PHASE II: DESIGN ANALYSIS AND TEST EVALUATION OF THE LOCOMOTIVE DEFLECTOR

It was concluded in the Phase I program that the control of override can only be effective for low-speed impact, say less than 12 mph. In the case of an impact at higher speed, the retained coupler or center sill can be broken or yielded causing large bending and rotary deformation; the impacted car body can then slip by the anticlimber and impact on the locomotive cab. Thus, direct protection of the cab is still necessary, especially against intrusion of the shorthood end. One may provide enough material around the cab to absorb the energy of the car overriding on the locomotive. As discussed in Section 2.4.2, it will require a lot of material and thus is not an efficient scheme. It seems that the best strategy for protecting the shorthood end of the cab is to use a deflector which is backed up with an energy absorbing layer. The design analysis and test evaluation of this concept is the objective of the Phase II program which basically consists of the following three major tasks.

## 3.1 ANALYSIS AND DESIGN

This includes a cost/benefit analysis to recommend the maximum impact speed for the design of such a protection system, structural analysis of the crash environment, and determination of optimum low-cost designs. Analyses include impacts of different vehicles at different speeds, impact angles (impact in the horizontal direction is perhaps the most critical condition) and at different temperatures (the puncture of the deflecting surface depends on the transition temperature of the metal). Design parameters include but are not limited to the materials and thicknesses of the deflecting shell and the energy absorption layer, inclination angle and height of the deflector, strength of the back-up support and methods of attachments, etc. (It is expected that the deflecting shell will not be rigidly anchored to the sills, but the back-up support will be.) Detail design includes the design of the protecting system for both new locomotives and the retrofit of the existing ones.

## 3.2 TEST EVALUATION

This task will include both scale model and full scale tests. Scale model tests are to be used to screen the basic design concepts and the verify design analysis. Scale model tests can be performed swiftly with many parameters allowed to vary. From the results of design analysis and the scale model tests, one or two designs will be selected for full-scale prototype test evaluation.

In the full-scale tests, only the deflecting system properly mounted on a locomotive rig is necessary. However, it will also be desirable to have a mock-up of a locomotive cab with dummy included in the tests. This is to study the human dynamics response in impact under the new protection system.

The system will be impacted at the maximum design speed by an elevated object simulating an overriding car of certain weight. The impact will be horizontal only, since it is more severe than an impact with a component of upward motion. However, the impact evaluation should be a test parameter.

Proper test procedures and required instrumentation are to be worked out.

## 3.3 DESIGN GUIDELINES AND INFORMATION DISSEMINATION

Detail design guidelines will be established from the design analysis and test evaluations. All the test results will be available to the trade, the union, the industry and other interested parties who are concerned about the locomotive/caboose crashworthiness. A training program should also be instituted for cab and caboose crews on how to utilize the protection system for maximum safety.

## REFERENCES

1. Tong, P., "Mechanics of Train Collision," Report No. FRA-OR&D-76-246, April 1976.

2. Cramer, P. L. and Anderson, R. L., "Train-to-Train Impact Tests," Vol. I and II, Dynamics Science Report No. 8261-75-155, DOT-TSC-840.