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Improving the Dynamic Performance of Multitrailer Vehicles: A Study of Innovative Dollies

Volume III

Executive Summary

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16. Abstract

This study of the dynamic performance of multitrailer articulated vehicles has led to the development of guidelines for the design of innovative dollies that will improve the roll stability and trailing fidelity of doubles combinations. The major effort of this project involved identification, analysis, and further development of innovative dolly and trailer hitching hardware showing potential for the reduction of rearward amplification and prevention of rollover of the second trailer. Specifically, the project (1) reviewed the current state-of-the-art in innovative coupling mechanisms, (2) performed a parametric sensitivity study, based on computer simulation techniques, on combination vehicles using existing and proposed coupling mechanisms, and incorporating various combinations of 96- and 102-in-width hardware, (3) developed a new type of dolly believed to provide superior safety performance, (4) conducted full-scale tests of combination vehicles using various dollies, including a prototype of the new dolly, and (5) examined the potential safety and economic impacts of the use of innovative dolly hardware.

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IMPACT AND DEVELOPMENT OF THE RESEARCH STUDY

The Surface Transportation Assistance Act of 1982 allows the use of doubles combination vehicles nationwide on the interstate highway system. It also allows for the increase of commercial vehicle widths from 96 inches to 102 inches. This Act is generally expected to result in a major increase in the number of multi-trailer commercial vehicles in use throughout the U.S. At the same time, pressure for allowing the use of triples is increasing. In light of the fact that multi-trailer vehicles are known to suffer from special dynamic characteristics that can limit their stability and emergency maneuverability characteristics, vis-a-vis the tractor-semitrailer, these developments have led to concern over the potential for degradation of the safety quality of the U.S. commercial vehicle fleet. The primary purpose of this research study was to obtain (and disseminate) information on developments in heavy-vehicle technology which might provide improvement in the dynamic performance of multi-trailer vehicles, while this envisioned transition from singles to doubles vehicles was in progress. The purpose of the project was addressed through two specific goals, viz. (1) to develop safer, practical coupling mechanisms for multi-trailer combinations, and (2) to determine the safety effects of various width combinations possible under the 102-in-width limitation.

For purposes of this study, the goal of "improving the dynamic performance" of multi-trailer vehicles implied that the conventional tractor-semitrailer combination vehicle be taken as the reference. It is well established in the literature that maneuvering quality of the tractor-semitrailer portion of an A-train doubles combination vehicle is virtually unaffected by the presence of the full trailer, but that, in emergency maneuvers, the second trailer of the doubles suffers from a "crack-the-whip" phenomenon in which the second trailer substantially exaggerates, or amplifies, the motions of the tractor. The major safety consequence of this "rearward amplification" is the premature rollover of the second trailer. Rearward amplification and the resulting propensity toward rollover of the second trailer is generally recognized as the property of the double which distinguishes (and degrades) its dynamic performance capability from that of the tractor-semitrailer combination vehicle.

The major effort of this project, then, involved identification, analysis, and further development of innovative dolly and trailer hitching hardware showing potential for the reduction of rearward amplification and prevention of rollover of the second trailer. Specifically, the project (1) reviewed the current state-of-the-art in innovative coupling mechanisms, (2) performed a parametric sensitivity study, based on computer simulation techniques, on combination vehicles using existing and proposed coupling mechanisms, and incorporating various combinations of 96-

and 102-in-width hardware, (3) developed a new type of dolly believed to provide superior safety performance, (4) conducted full-scale tests of combination vehicles using various dollies, including a prototype of the new dolly, and (5) examined the potential operational impact of the use of innovative dolly hardware.

The major motivation for the use of multiply articulated trains by commercial trucking interests is to obtain a vehicle with high cargo volume which retains the practical benefit of good, low-speed maneuverability. Within the constraints of vehicle height and width laws, more cargo volume is attained by lengthening the vehicle. Generally, as vehicle length increases, so do maneuvering problems, since the magnitude of low-speed offtracking is directly related to vehicle length. However, the offtracking of a vehicle of a given length is generally reduced by the introduction of additional yaw articulation joints. By virtue of these facts, the so-called A-train doubles combination has become a popular commercial vehicle.

An A-train consists of a tractor-semitrailer pulling one or more conventional full trailers, where a conventional full trailer consists of a semitrailer whose forward end is supported by a dolly which (1) articulates in yaw relative to the semitrailer, (2) is connected to the towing unit by a single pintle hitch, and (3) has one or more axles which are non-steering relative to the dolly frame. While the A-train meets the primary need of providing a large-volume vehicle which can be maneuvered relatively easily at low speed, it is also known to be less stable at highway speeds than is the conventional tractor-semitrailer.

The dynamic stability of the A-train suffers from the phenomenon known as rearward amplification, wherein, in steering maneuvers of relatively high frequency content, trailing units in the train will tend to experience higher lateral accelerations than their towing unit. Thus lateral acceleration "amplifies" as one moves rearward along the train, and the rearmost trailer may experience accelerations much larger than those experienced by the driver in the tractor. The most serious safety consequence of the phenomenon is the resulting rollover of the rear trailer. Further, the addition of yaw articulation joints tends to reduce the yaw damping of the vehicle, and the reduction of low-speed offtracking tends to aggravate high-speed offtracking.

In recent years, the safety-degrading influence of additional articulation joints has become broadly recognized. Nonetheless, the economic motivations for the use of multi-trailer trains is so compelling that the use of such vehicles does and will continue to grow. In an attempt to improve the safety quality of these vehicles, however, a number of innovative dollies and hitching mechanisms have been developed. This project was intended to examine these developments and further the process of improving the dynamic performance capability of multi-trailer commercial vehicles.

HIGHLIGHTS OF THE RESEARCH RESULTS

The computer simulations and vehicle tests showed that innovative dolly arrangements can provide significant improvements in the dynamic performance of multi-trailer combination vehicles. At least four different types of dollies with double drawbars (B-dollies) or special steering arrangements for the dolly wheels exhibited better performance than the conventional double with wagon-tongue steering and a single pintle connection to the first semitrailer. The prototype dolly, that was designed and developed in this project, demonstrated less rearward amplification of the motion of the tractor, more roll stability of the rear trailer, and no more offtracking than a conventioanl double.

With regard to increases in wheel and spring spacings due to the allowance of 102-in widths, the results show that an increase in width at any axle will be beneficial to roll stability. The greatest improvement in roll stability is attained by increasing the track widths of as many wheel and spring sets as possible.

The accident studies showed that singles and doubles have comparable fatal-accident rates. Doubles have a greater tendency to roll over than singles. By reducing the rollover tendency of doubles to that of singles, a safety benefit with an economic value of 0.84 cents per mile was estimated.

The economic analysis indicated that the dollar value of reduced accident costs was not large enough to provide a profit motive for the use of heavier and more complex dollies. Additional incentives such as weight allowances or less restricted access to pick up and delivery sites would be required to provide a profit motive for using B-dollies.

APPLICATIONS OF THE FINDINGS

The findings of this research investigation suggest that it is both reasonable and practical to develop commercial vehicle dollies which can significantly improve the dynamic performance of the multi-trailer combination vehicle. Accordingly, a set of reasonable performance and design "guidelines" have been enumerated to provide goals in the development of innovative commercial vehicle dollies. The guidelines set forth in the final technical report apply specifically to the vehicle configuration commonly known as the Western Double in the fully loaded 80,000-lb GVW condition with both trailers having sprung mass c.g. heights of 80 in (typical of "medium density" freight). Performance expectations would be different for other configurations. In that regard, current understanding suggests that caution should be exercised in applying B-dollies in long-drawbar configurations.

The guidelines provide goals with respect to (a) vehicle dynamics performance properties, (b) dolly mechanical propeties, and (c) the ability to withstand worst-case levels of structural loads.

With regard to future development of innovative dollies, the findings of this study indicate that B-dollies are dynamically superior to A-dollies and other types of innovative dollies because of (a) the roll coupling between the leading semitrailer and the dolly, and (b) the possibility of steering the dolly wheels to achieve good trailing fidelity of the last trailer. However, as long as productivity is the ruling force, there is not much economic incentive to use heavier B-dollies in place of lighter, simpler A-dollies.

The permit system that exists in the western Provinces of Canada encourages the use of B-dollies there. Weight allowances and the right to operate on secondary roads are strong economic incentives that promote the use of B-dollies in Canada. The ability to back up and make local deliveries means that the operation of doubles with B-dollies can be very attractive and profitable in certain types of service. In order for B-dollies to become popular in the United States, economic incentives may need to be developed. These incentives might come from (a) reduction, through design or special permission, of the weight penalty associated with B-dollies, (b) extraordinarily unfavorable changes in insurance rates and/or increases in settlements from lawsuits, thereby increasing the economic importance of safety, or (c) allowance to travel off of the interstate and primary highway system to make deliveries and pick ups.

The findings of this study are positive enough with respect to B-dollies to support a recommendation that combinations with new types of dollies be tested and evaluated in practical service in the United States. This evaluation effort would be in addition to a field trial of the prototype dolly that is currently underway in Canada.