The Dynamic Performance of Stinger Steer Auto Haulers

Prepared at request of
Interjurisdictional Committee on Vehicle Weights and Dimensions

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1/ Introduction

The Canada-U.S. Auto Pact results in significant trade of automobiles across the common border, in both directions. Most of Canada's production is from plants in Ontario and Quebec. Some of their output moves long distances by rail into the U.S., while the rest moves by road, mostly to large marshalling yards just across the border, where loads are made up for direct delivery to dealers. Both these modes return stock of models not manufactured in Canada for sale in Canada. In other provinces, the shipping distances from the auto plants are so large that auto haul vehicles are mostly used only for distribution from marshalling yards, usually at rail terminals. The stinger steer auto hauler is the vehicle commonly used for the distribution of newly manufactured cars throughout Canada and the U.S.

In the U.S., for operation on interstate and primary federal-aid highway systems, a federal regulation requires that no state impose a semitrailer length limit less than 14.63 m (48 ft), or any overall length limit on a tractor-semitrailer combination. In addition, the tractor is not allowed to carry load. However, the federal regulation then defines an automobile transporter as a specialized vehicle, and allows load on the tractor while restricting the overall length of the combination. No state can set an overall length less than 19.81 m (65 ft) where the fifth wheel is on the tractor frame over its rear axles, or less than 22.86 m (75 ft) for the stinger steer arrangement where the fifth wheel is mounted low behind the tractor rear axles. This rule seems to have caused the stinger steer tractor-semitrailer to become the configuration of choice for automobile transport. In addition to these minima for overall length, no state may impose a load overhang at the front that is less than 0.91 m (3 ft), nor a load overhang at the rear that is greater than 1.22 m (4 ft). This results in a minimum overall length of 82 ft (25 m). While these are minimum values, and there are no upper length limits, it would appear that enough states have adopted these minimum values that they are now the effective upper limits throughout the U.S., since limits on other state roads may restrict semitrailer length to 14.63 m (48 ft).

The stinger steer auto hauler is treated as a tractor-semitrailer by most Canadian provinces, and there may be limits on overall length, semitrailer length, and various internal dimensions, depending on the province. The four western provinces may allow an overall length of 25 m (82 ft), including load. In eastern Canada, the auto hauler must operate within a 23 m (75 ft 6 in) overall length limit that includes all load overhang. This may restrict the flexibility for loading output from a single production line at one plant, where all autos are of the same model and the same size, so may not "fit" all models of auto hauler well. This situation does not arise to the same extent when a mix of models are distributed from a rail terminal or to a dealer, when autos of different sizes can be selected to make full use of the space on the auto hauler. The absence of a load overhang provision within the length laws of the eastern provinces may in some circumstances reduce the average load possible on the typical auto hauler. The difference in overhang provisions is one of many differences between Canadian and U.S. heavy truck weight and dimension regulations.

The Ontario legislature passed Bill 74 in December 1993. This allowed an increase in overall length up to 25 m (82 ft) for certain vehicle configurations, and authorized the promulgation of regulations to define the rules for such vehicles as might exceed the former limit of 23 m. These rules covered only A-, B- and C-train double trailer combinations, in accordance with the exact terms of the national Memorandum of Understanding on Vehicle Weights and Dimensions (the M.o.U.) [1], to promote regulatory uniformity with the other provinces. The Ontario head offices of several Canadian auto haulers then approached Ontario Ministry of Transportation to request

that they be allowed to operate their vehicles with load overhang under the U.S. rule, with a vehicle up to 22.86 m (75 ft) long and load overhang up to an overall length of 25 m (82 ft). The Ontario ministry forwarded this request to be considered on a national basis by the Interjurisdictional Committee on Vehicle Weights and Dimensions, which exists to set national standards for heavy trucks by proposing amendments to the scope and content of the M.o.U. This was considered an appropriate means to deal with a vehicle configuration that operates in all provinces and the U.S. The Committee then asked Strategic Transportation Research Branch of Ontario Ministry of Transportation to undertake a study to define the technical characteristics for a stinger steer auto hauler that would meet the same objective standards of performance related to highway safety that served as the basis for the vehicles defined in the M.o.U.

This report addresses the technical aspects of that request.

2/ Technical Study

2.1/ Preliminary Analysis

The Vehicle Weights and Dimensions Study evaluated the dynamic performance of a number of heavy truck configurations, proposed objective measures for that performance, and suggested appropriate performance standards [2]. This became the basis for regulatory principles [3], that led to the national Memorandum of Understanding on Vehicle Weights and Dimensions [1]. The following briefly describes the eight measures used to characterize vehicle performance, which are generated by three manoeuvres, each defined by a path that a vehicle model follows by means of the driver model in a computer simulation.

Three measures are obtained from a high-speed turn made at 100 km/h, where the truck makes a spiral entry into a curve of 0.2 g lateral acceleration, drives along the curve for 10 s, then tightens the turn at a steering wheel steer rate of 2 deg/s until loss of control occurs :

Static roll threshold is the lateral acceleration of the power unit at which a roll-coupled unit of the truck just rolls over. It should exceed 0.4 g.
High-speed offtracking is the lateral offset from the path of the steer axle of the power unit to the path of the rearmost axle of the truck at 0.2 g lateral acceleration. It should not exceed 0.46 m outwards.
Understeer coefficient is a measure of how aggressively a truck responds to steering at 0.25 g lateral acceleration.

Two measures are obtained from a high-speed evasive manoeuvre of one cycle of sinusoidal lateral acceleration of 0.15 g at the power unit, made at 100 km/h, which gives a sidestep of 2.11 m :

Load transfer ratio is the fractional change in load between left- and right-hand side tires of the rearmost roll-coupled unit of the truck. It indicates how close that unit came to lifting off all of its tires on one side, and should not exceed 0.6.
Transient high-speed offtracking is the peak overshoot in lateral position of the last axle of the truck from the path of the front axle of the power unit, an indication of potential intrusion into an adjacent lane of traffic. It should not exceed 0.8 m.

The final three measures are obtained from a low-speed (8.8 km/h) 90 degree right-hand turn of 14 m radius at the power unit's left front wheel :

Low-speed offtracking is the inboard offtracking of the rearmost axle of the vehicle from the path of its front axle. It should not exceed 5.78 m, based on the turning performance of large tractor-semitrailers.
Outswing is intrusion into an adjacent lane by the truck's left rear corner, and should not exceed 0.2 m.
Friction demand represents the resistance of multiple axles to turning, and describes the minimum friction needed at the power unit drive axles for the vehicle to make a turn without jackknife. It should not exceed 0.1.

It is known that the auto hauler, as a class of vehicle, is generally loaded quite well within its allowable gross weight. While the load often reaches the maximum overall height, design of the trailer ensures that the payload centre of gravity does not rise as high as it can when a van or flatdeck is loaded to the same height with a homogeneous commodity. The auto hauler, therefore, is generally not expected to have serious deficiencies in rollover or high-speed offtracking, compared to the tractor-semitrailer. However, the rearward placement of the fifth wheel of a stinger steer configuration is known to diminish lateral-directional stability compared to the conventional fifth wheel placement of a tractor-semitrailer [4]. It was therefore considered desirable to compare this, and low-speed turning performance, with a standard tractor-semitrailer. A generic stinger steer auto hauler was configured using dimensions provided by industry, typical tare weights, and typical component properties. It was compared with the same tractor-semitrailer used in the Weights and Dimensions Study, using the same computer simulation methodology [2], with a 14.63 m (48 ft) van semitrailer, loaded to the same gross weight as the auto hauler. The results are presented in Table 1.

Table 1/ Comparison of Performance Measures

Measure	Standard	Semi	Auto hauler
Load transfer ratio	< 0.60	0.485	0.468
Transient offtracking	< 0.80 m	0.36 m	0.43 m
Low-speed offtracking	< 5.78 m	5.78 m	4.21 m
Outswing	< 0.20 m	0.01 m	0.22 m

It is observed that both vehicles are well within the performance standards for most of these measures. The slightly poorer transient offtracking of the auto hauler should be attributable to the stinger steer fifth wheel arrangement that provides the significant improvement in low-speed offtracking.

The one area of concern is that the auto hauler has an outswing in a low-speed turn, perhaps because the trailer effective rear overhang significantly exceeds the 35% limit set for semitrailers in the M.o.U. to control the initial outswing of the left rear corner of the semitrailer during the right-hand turn. The result in Table 1 might be regarded as marginal, at best. The tendency to outswing is certainly ameliorated by the stinger steer arrangement, but it was considered necessary to review this aspect of vehicle configuration in more detail, to treat this vehicle on the same basis as the tractor-semitrailer. It could be argued that the narrower swept path of the stinger steer auto hauler compared with the tractor-semitrailer would reduce the likelihood of the left rear corner of the trailer encroaching into the adjacent lane during a turn. However,

observation suggests many drivers tend to stay as far to the left as possible when making a right-hand turn, making full use of the entry lane width to make the turn as easy as possible. It is suggested that if one vehicle takes less space to turn than another, then its driver uses that capability to make a rolling turn at a slightly higher speed than the driver of the other vehicle. Such turning practices suggest that dimensional limits to control outswing should be applied uniformly to all vehicle configurations, regardless of their turning capability.

To address this concern, the Ontario head offices of three major Canadian auto hauling companies were requested to provide detailed dimensions of the vehicles in their national fleet that could exceed a length of 23 m when combined with a total load overhang up to 2.13 m (7 ft). Figure 1 shows generic vehicle dimensions, and Table 2 lists the data obtained. It is evident that there is considerable similarity in the dimensions within current members of this class of vehicle. Aside from one tractor, all others have a wheelbase within about 0.3 m (12 in) of each other, and none exceed the 6.2 m limit of the M.o.U. No trailer exceeds 14.63 m (48 ft) in length, presumably so that these vehicles can go anywhere in the U.S. All except one trailer have axle spreads within the 1.2 to 1.85 m range specified in the M.o.U.

Table 2/ Stinger Steer Auto Hauler Dimensions (m)

No	A	B	C	D	E	F	G	H
1	0.79	5.36	1.32	3.00	1.88	9.78	1.32	3.28
2	0.76	5.36	1.32	3.17	1.83	10.19	1.32	3.86
3	0.94	5.68	1.40	2.55	1.94	10.39	1.27	3.56
4	0.89	5.64	1.52	3.73	1.85	10.57	1.52	3.81
5	0.76	5.56	1.37	3.99	2.16	9.96	1.52	4.27
6	0.79	5.31	1.32	3.81	1.83	10.29	1.42	3.96
7	0.76	5.61	1.52	4.06	2.24	9.96	1.52	4.27
8	0.66	5.99	1.32	3.14	1.77	8.88	1.62	4.01
9	0.73	5.46	1.32	3.55	2.23	8.97	2.59	5.25

2.2/ Load Front Overhang

Turning performance was investigated using a computer simulation of low-speed offtracking, for a 90 degree right-hand turn of 14 m (46 ft) radius at the outer face of the tractor left front wheel. 14 m is the radius used to configure the geometric design standard for the curb at a roadway intersection by Ontario Ministry of Transportation. It is greater than the minimum turning radius of most trucks, because most trucks must be able to make the turn without encroaching on the space of other vehicles, or running over the curb.

The tractors in Table 2 have front axle setbacks between 0.66 and 0.94 m (26 and 37 in), typical for this class of equipment. This results in an outswing in the steady part of the turn between 0.16 and 0.28 m, as shown in Figure 2 for the example of Vehicle 7 from Table 2. Overhang of 0.91 m (3 ft) for the load at the front results in an additional outswing of 0.21 m for each vehicle, to between 0.38 and 0.50 m (15 to 20 in), also shown in Figure 2. This corresponds to a range of front axle setback of about 1.14 to

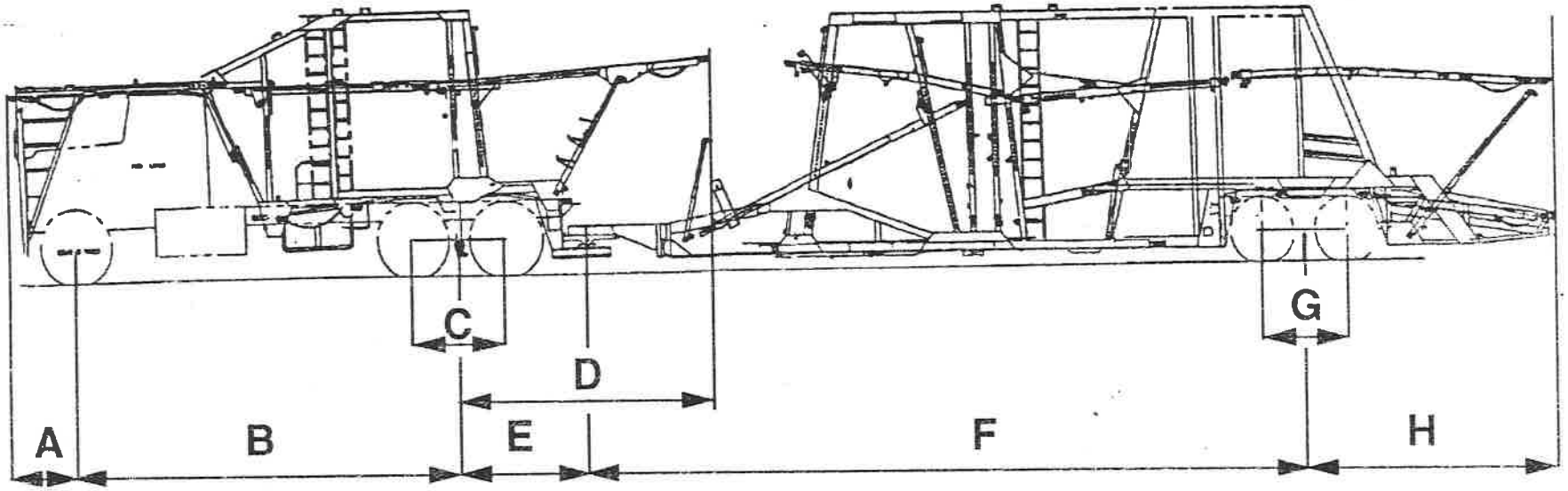

Figure 1/ Stinger Steer Auto Hauler Dimensions

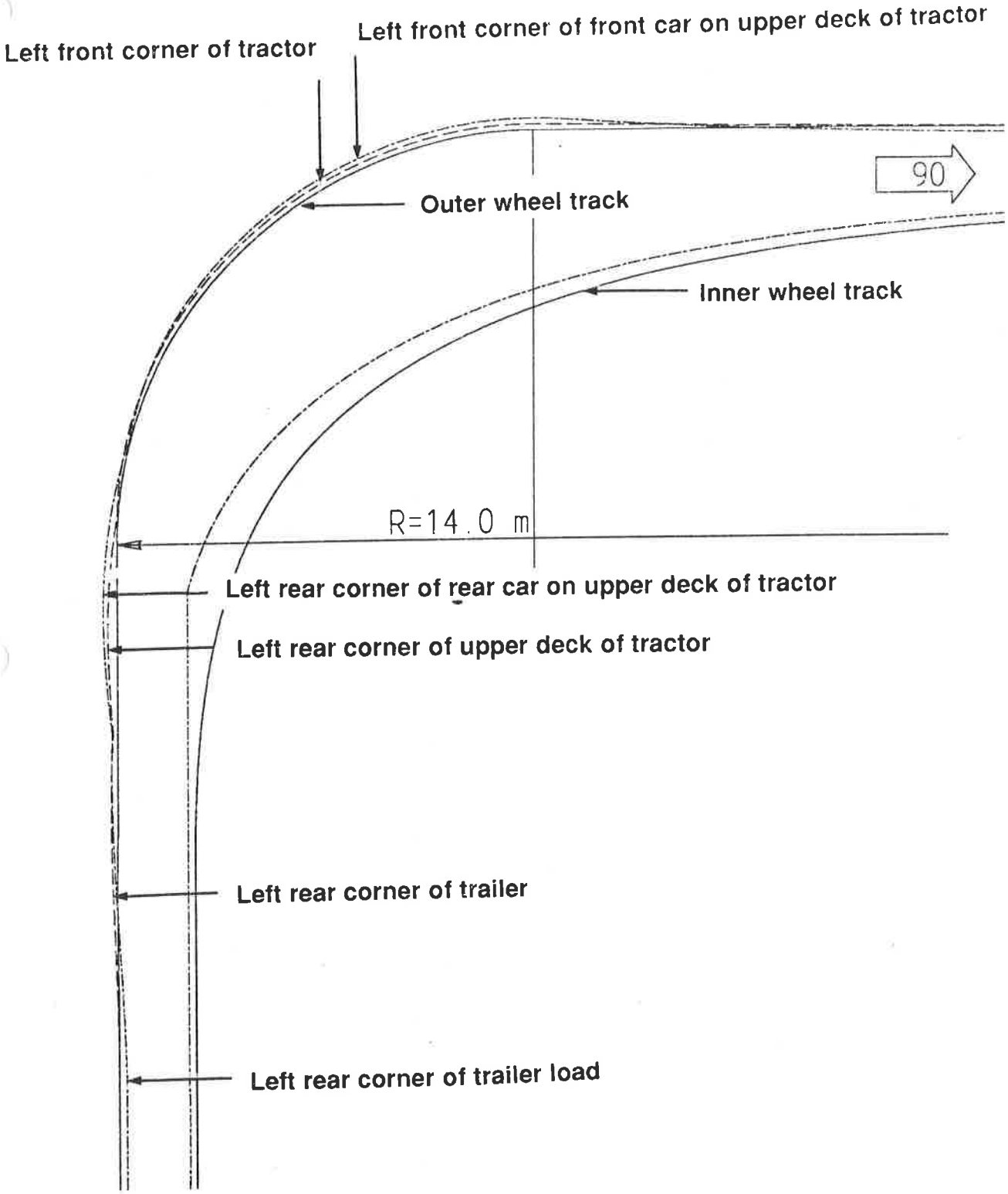

Figure 2/ Swept Paths of Vehicle 7, Scale 1:200

1.39 m (45 to 55 in), which is within the range of front axle setback for current models of tractor. The load outswing is about 2.2 m (7 ft) above the road, where it will not be likely to interfere with car traffic. Further, the driver of the auto hauler making a turn can see and is aware of the front of both the tractor and any overhanging load, as well as the speed and position of approaching traffic. The driver of another vehicle can also see the turning truck, and between them, the two drivers can invariably make adjustments to either the trajectories of their vehicles, or their speeds, so that conflict is avoided.

Load overhang up to 0.91 m (3 ft) on the front of an auto hauler is not regarded as a significant concern for other traffic. However, the critical dimension is the distance of the front of the load from the front axle, so it would also be appropriate to control the tractor front axle setback from the foremost point of the vehicle and its load carrying structure, in addition to the load front overhang. A limit of 1.0 m would not seem restrictive.

2.3/ Load Rear Overhang

Table 3 presents the trailer effective rear overhang with the trailer empty, and with a load overhang of 1.22 m (4 ft). The large overhang arises because the trailer has minimal kingpin setback, and an axle placement that takes proportionately more of the trailer payload than a conventional semitrailer, because payload on the tractor consumes a significant part of the drive axle capacity that would normally be available for the trailer kingpin load. The table also presents the outswing at the left rear corner of the trailer and the left rear corner of the overhanging load during a 90 degree right-hand turn with a 14 m (46 ft) outside radius at the tractor left front wheel. This outswing occurs at the beginning of the turn, as shown in Figure 2, and can potentially intrude into the travelled lane to the left.

Table 3/ Stinger Steer Auto Hauler Trailer Outswing

Vehicle No	Empty Vehicle Effective Overhang	Empty Vehicle Trailer Outswing (m)	Loaded Vehicle Effective Overhang	Loaded Vehicle Load Outswing (m)
1	33.5 %	0.104	46.0 %	None
2	37.9 %	0.157	49.9 %	0.101
3	34.2 %	0.123	45.9 %	0.038
4	36.0 %	0.145	47.6 %	0.079
5	42.8 %	0.224	55.0 %	0.205
6	38.5 %	0.168	50.3 %	0.121
7	42.8 %	0.227	55.0 %	0.209
8	45.2 %	0.178	58.9 %	0.139
9	58.5 %	0.426	72.1 %	0.513

Table 3 shows that despite the large trailer effective overhang, the stinger steer arrangement ensures that the trailer itself is within the 0.2 m performance standard for all vehicles except Vehicles 5, 7 and 9. The trailers of Vehicles 5 and 7 have the same dimensions, though their tractors are slightly different. Vehicle 9 has a particularly short trailer wheelbase, and could almost be described as a pony trailer, whereas the others can be considered to be semitrailers. The data points in Figure 3 plot the outswing against effective rear overhang for all vehicles, and the line shows a best linear fit for

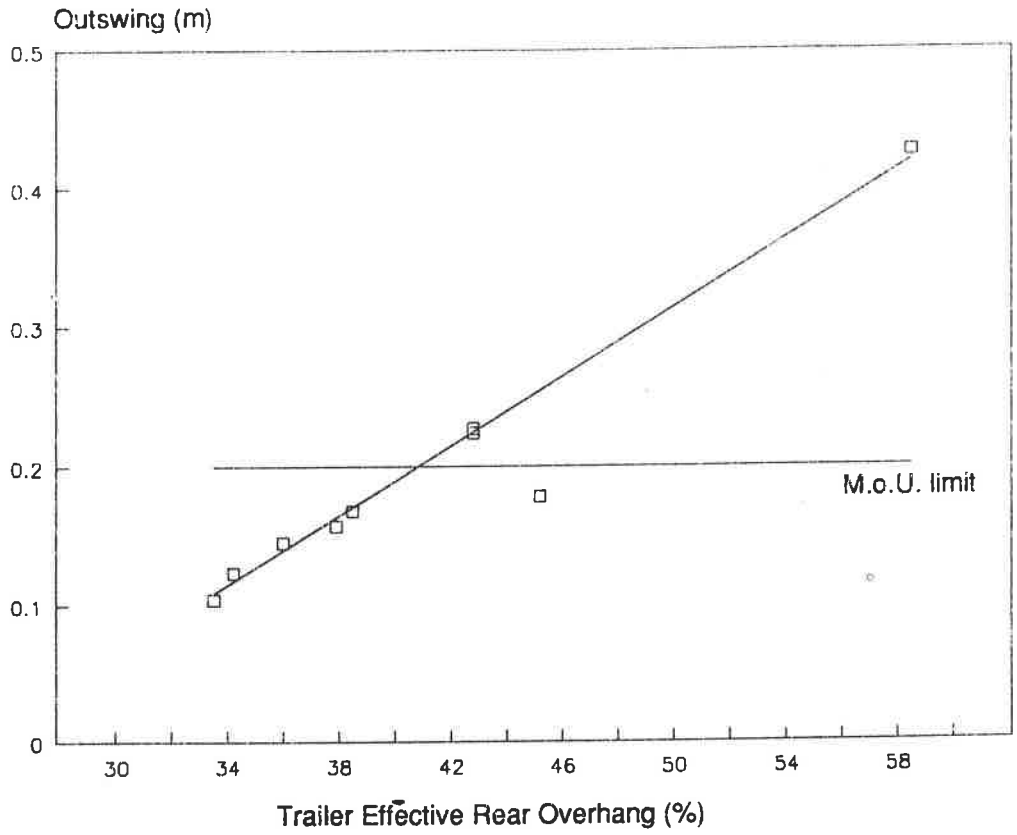

Figure 3/ Outswing from Trailer Rear Overhang

Vehicles 1 through 7. It would appear that an effective rear overhang of 40% of the semitrailer wheelbase would ensure that this class of vehicle meets the outswing performance standard for the trailer itself.

For the loaded vehicle with a rear load overhang of 1.22 m (4 ft), outswing of the overhanging load is in fact less than that of the trailer itself, except for Vehicle 9, because the load is narrower than the trailer. An auto overhanging the rear of the trailer up to 1.22 m (4 ft) that stays within the swept path of the trailer should not be a concern for outswing.

2.4/ Tractor Rear Overhang

The most striking factor from Figure 2 is that outswing for most vehicles is dominated by the tractor upper deck rear overhang, and the additional 1.52 m (5 ft) rear overhang assumed for the load on that deck. This load overhang dimension seems to be reached easily with current models of medium size auto, van and pickup truck. It appears from Table 2 that there may have been a trend to cut back the upper deck of the front of the trailer to allow extension of the tractor upper deck rearward, perhaps to balance the axle loads on the tractor as a consequence of a front load overhang. Table 4 lists the upper deck and load rear overhangs, and corresponding outswings, in the same 14 m radius turn. Five vehicles exceed the outswing limit of 0.2 m at the upper deck, and two more exceed that limit with a load overhang of 1.52 m (5 ft), even though the load is only 2.1 m wide.

There was no need in the M.o.U. to place a rear overhang restriction on the tractor of a

Table 4/ Stinger Steer Auto Hauler Tractor Outswing

Vehicle No	Empty Tractor Rear Overhang (m)	Empty Tractor Upper Deck Outswing (m)	Loaded Tractor Load Rear Overhang (m)	Loaded Tractor Load Outswing (m)
1	3.00	0.150	4.52	0.187
2	3.17	0.173	4.69	0.235
3	2.55	0.093	4.07	0.078
4	3.73	0.258	5.25	0.375
5	3.99	0.310	5.51	0.457
6	3.81	0.281	5.33	0.413
7	4.06	0.325	5.58	0.480
8	3.14	0.159	4.68	0.202
9	3.55	0.231	5.07	0.331

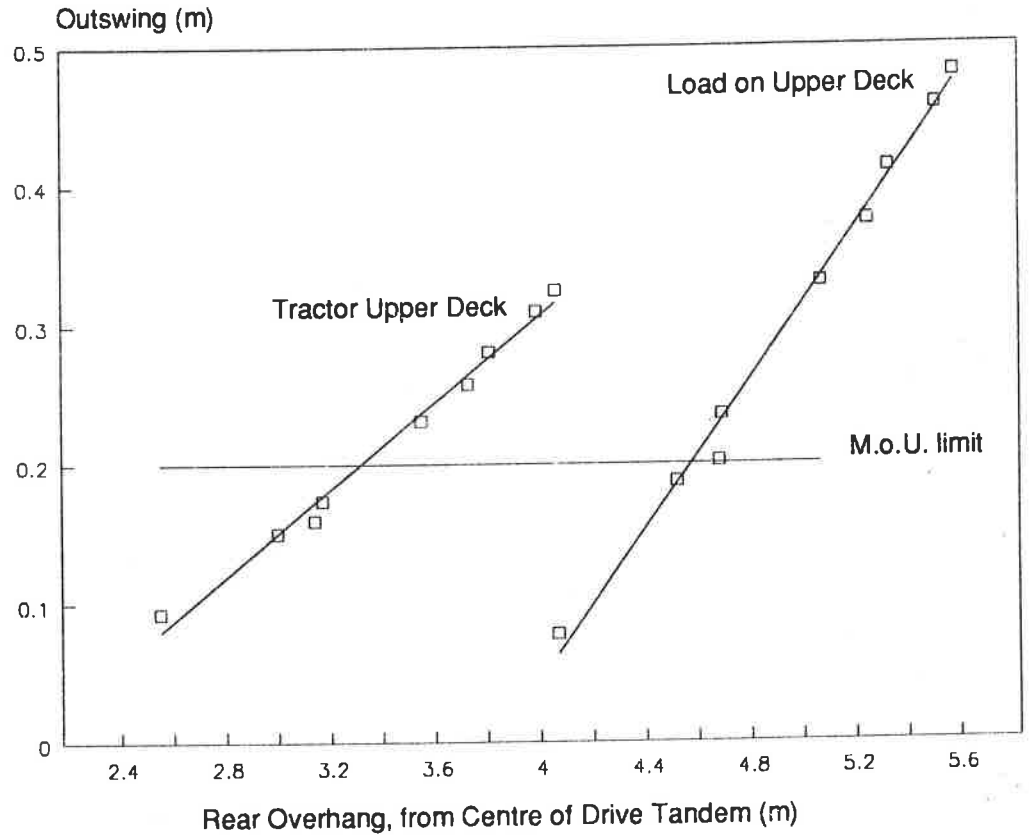

Figure 4/ Outswing from Tractor Upper Deck and Load

conventional tractor-semitrailer, as its design precludes overhang. A straight truck with a wheelbase in the range 4.0 to 6.2 m (157 to 244 in) can have a body rear overhang up to 3.1 to 3.4 m and still stay within the 0.2 m outswing standard. Such a body overhang is greater than would be built in practice, so there was no real need for the M.o.U. to control overhang on the vehicle. However, there was a general concern about safety for a vehicle carrying a load with a large overhang, and it was felt that there should be some limit on load overhang. The M.o.U. therefore includes a 4.0 m (13 ft) limit on truck rear overhang, including load [1]. Table 4 shows that five of the tractors exceed 3.4 m rear overhang. All exceed 4.0 m rear overhang with a 1.52 m (5 ft) load overhang. Table 4 also presents the outswing of the tractor upper deck, and of a vehicle on the deck. Those vehicles that exceed the overhang limit also exceed the outswing limit.

The upper deck and load outswing both occur at an elevation of about 2.2 m (7 ft) or so above ground, which is above the elevation at which interference with a car would occur. However, interference would still be possible with a cube van or truck.

The stinger steer tractor is clearly a different vehicle than the typical tractor considered by the M.o.U. It would be consistent for it to be treated on the same technical basis as other vehicles covered by the M.o.U. While current designs use overhang on the upper deck, there is presently no control of it, and nothing to prevent similar extension of the lower deck. It would seem that there should be some limitation on rear overhang. The data presented in Table 4 are also plotted as symbols in Figure 4, and the lines are the best linear fit to the points. From these data, it appears that the tractor upper (or any) deck rear overhang should be restricted to 3.3 m from the centre of the drive tandem, and the rear overhang of the load should be restricted to 4.6 m from the same point.

2.5/ Other Issues

A stinger steer auto hauler with load overhang would reach an overall length of 25 m. While it would have a 25 m long "shadow" on the ground, the vehicle itself would still be within an overall length of 23 m. Since it is not clear that 25 m long vehicles have an impact on traffic that is significantly different than 23 m long vehicles [5], the proposed overhang should not be a factor on traffic movements.

This class of vehicle seems to have relatively good control on payload weight and centre of gravity, and the use of a fifth wheel coupling, which results in acceptable load transfer ratio performance. It is noted from Table 2 that the fifth wheel offset from the rear drive axle varies from 1.77 to 2.23 m. While there appears little need for it to increase, it would be desirable that there should be a control on the hitch offset dimension, as it does have a significant effect on lateral/directional vehicle dynamics, and 2.3 m seems to be a limit that would not be restrictive.

3/ Conclusions

There appears to be considerable uniformity in current generations of stinger steer auto hauler. Since it can only be used for the purpose for which it was designed, it could be treated as a class of specialized vehicle in Canada, as it is in the United States.

While these vehicles appear to be configured to dimensions set by the U.S. federal government, they also have significant dimensional compatibility with the tractor-semitrailer in the national Memorandum of Understanding on Vehicle Weights and Dimensions.

Load overhang up to 0.91 m (3 ft) beyond the front of the tractor is not expected to pose significant additional risk to other traffic during turning movements by this class of vehicle. Load overhang up to 1.22 m (4 ft) behind the rear of the trailer remains within the swept path of the trailer.

Dimensions are proposed for a standard configuration for the stinger steer auto hauler that could allow it to be considered for addition to the national Memorandum of Understanding on Vehicle Weights and Dimensions, with front and rear load overhang allowances, provided the tractor is configured with adequate controls on front axle setback, rear overhang, and load rear overhang.

4/ Recommendations

The regulatory options which would ensure a stinger steer auto hauler will meet the performance standards of the M.o.U. are presented in Figure 5 and Table 5. The vehicle overall dimensions are compatible with the tractor-semitrailer in the M.o.U., and with U.S. practice.

The tractor dimensions are also compatible with the tractor-semitrailer in the M.o.U. The wheelbase, hitch offset and drive axle spread limits do not seem to be restrictive, and will help ensure future auto haulers are similar to current generations of equipment. The front axle setback, rear overhang, and front and rear load overhangs on the tractor are all designed to control outswing in a low-speed turn within the standard that is the basis for the M.o.U. The load front overhang is compatible with U.S. practice.

The trailer dimensions are also compatible with the tractor-semitrailer in the M.o.U. The trailer length, wheelbase, axle spread and effective body rear overhang limits do not appear to be restrictive. The load rear overhang is compatible with U.S. practice.

References

[1] "Memorandum of Understanding on Interprovincial Heavy Vehicle Weights and Dimensions", Roads and Transportation Association of Canada, Ottawa, February 1988.

[2] Ervin R.D. and Guy Y., "The Influence of Weights and Dimensions on the Stability and Control of Heavy Trucks in Canada - Part 1", CCMTA/RTAC Vehicle Weights and Dimensions Study Technical Report Volume 1, Roads and Transportation Association of Canada, Ottawa, July 1986.

[3] "Recommended Regulatory Principles for Interprovincial Heavy Vehicle Weights and Dimensions", CCMTA/RTAC Vehicle Weights and Dimensions Study Implementation Committee Report, September 1987.

[4] Winkler C.B., Fancher P.S. and MacAdam C.C., "Parametric Analysis of Heavy Duty Truck Dynamic Stability", University of Michigan Transportation Research Institute Report UMTRI-83-13, March 1983.

[5] "The Effect of Vehicle Length on Traffic on Canadian Two-lane, Two-way Roads : Committee Report", Transportation Association of Canada, Ottawa, March 1991.

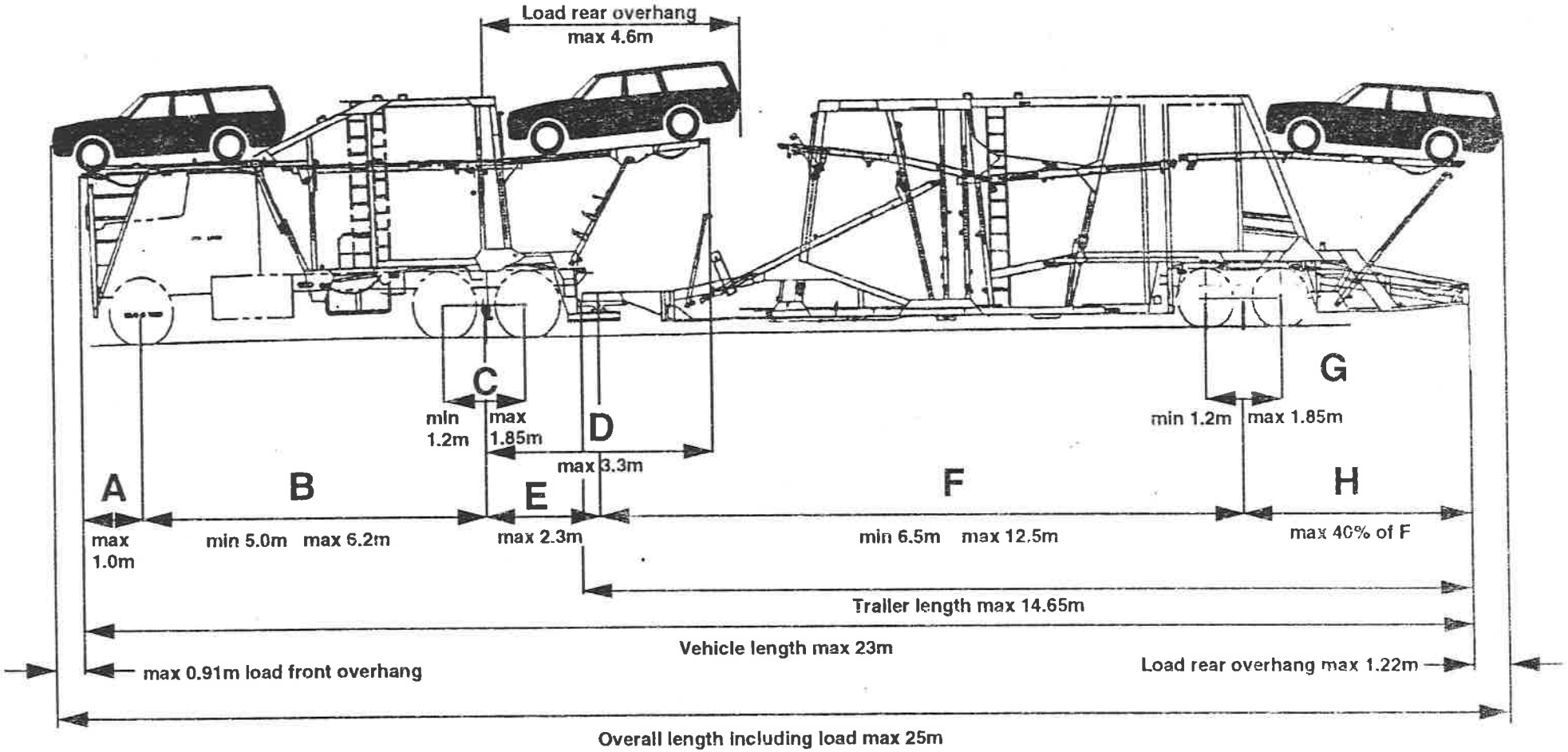

Figure 5/ Regulatory Options for Stinger Steer Auto Hauler Dimensions

Table 5/ Regulatory Options

Overall dimensions	
Overall length	Maximum 23 m for the vehicle Maximum 25 m including load
Overall width	Maximum 2.6 m
Overall height	Maximum 4.15 m
Box length	Not controlled
Tractor	
Wheelbase	Minimum 5.0 m Maximum 6.2 m
Front axle setback	Maximum 1.0 m from foremost point of tractor, or load-carrying structure
Tandem axle spread	Minimum 1.2 m Maximum 1.85 m
Hitch offset	Maximum 2.3 m
Rear overhang	Maximum 3.3 m from centre of drive tandem
Load front overhang	Maximum 0.91 m
Load rear overhang	Maximum 4.6 m from centre of drive tandem
Trailer	
Overall length	Maximum 14.65 m
Wheelbase	Minimum 6.5 m Maximum 12.5 m
Tandem axle spread	Minimum 1.2 m Maximum 1.85 m
Track width	Minimum 2.5 m Maximum 2.6 m
Effective body rear overhang	Maximum 40% of trailer wheelbase
Load rear overhang	Maximum 1.22 m from rear of trailer
Interaxle spacings	
Single to tandem	Minimum 3.0 m
Tandem to tandem	Minimum 5.0 m
Weights	
Steering axle	Maximum 5500 kg
Tandem axle	Maximum 17000 kg
Gross weight	Maximum 39500 kg