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Wind Effects on Dynamic Stability of Tractor Trailers in Winter Conditions

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ABSTRACT

There is a limited amount of data in literature discussing dynamic instability of tractor trailers due to wind speed and wind gusts on slippery surfaces. This paper outlines an analytical approach to assess tractor trailer performance due to these factors. The paper considers short-period wind gusts as well as uplift effect of the wind, frictional properties of the roadway, vehicle speed, jackknife effects, inertial (both translational and rotational) properties of tractor trailer combinations. Correlation between parameters related to semi dynamic instabilities are offered in a graphical format.

INTRODUCTION

There have been a number of articles written pertaining to the aerodynamic effects associated with tractor trailer combinations and the effects of wind on traveling vehicles. Most of these articles focus on either the aerodynamic drag upon the front of a vehicle, in reference to improving fuel economy, or on the effect of side loading forces inducing tip and causing rollover accidents. In order to cause this, sufficient lateral tire friction must be present to cause a trip, instead of allowing the leading edge tires to slide along the road surface. Sliding along the road surface would occur most likely due to a lack of adequate traction between the road surface and the tire contact area, such as when traversing over hard packed snow, for example.

There are also some references [1,2] which refer to the effects of tractor trailer traveling speed and the reduction of available traction, relating to rollover of the tractor trailer. As the traveling speed increases, the aerodynamic lift increases and causes the tractor trailer to become "lighter" and potentially easier to roll onto its side.

This paper will focus on reduced roadway friction, vehicle traveling speed, and side-wind gusts and their effects on vehicle stability and potential loss of control. Specifically it will focus on the needed conditions to cause a full-sized tractor trailer to slide a certain distance as to be defined as out of control instead of roll over, resulting in unintentional exiting of the roadway, entering oncoming traffic lanes, jackknifing, or a combination thereof. It is the purpose of this paper to construct a model that accurately describes the aerodynamic thresholds present while a semi trailer travels along a roadway of reduced friction and is subjected to a side loaded wind force. Towards the end, an example model will demonstrate the amount of dynamic movement associated with certain wind speeds and will calculate the distance of lateral slide that occurs from a given wind speed under pre-defined initial conditions.

MODEL BACKGROUND

The model will consist of a typical semi tractor, reduced to a box with two drive axles in the rear with a pinned connection to the trailer for simplicity. The equations in

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the model will consider the two rear *tractor axles* to slide sideways with the crosswind loading. The rear tractor axles will travel at constant speed and provide a pivot point for the trailer. The rear tractor axles will also provide an extra point mass, located at the fifth-wheel trailer pin, while trailer weight will be modeled as a point load at the center of mass of the trailer. This extra mass will be accounted for in the equations below and is used to simulate the correct motion of the trailer in reference to the tractor, causing a jackknifing motion, instead of a simple sideways slide or rotation. Contribution of weight on the front axle of the tractor that is greater than the rear axle has been modeled in other papers, notably by reference [3] and resulted in significant movement and related loss of control. This paper will not explore the effects of including the front axle of the tractor in the model. See *assumptions* section for more details on the model.

The trailer will be a typical boxed trailer with a pair of axles located a distance away from the front of the trailer, where the fifth-wheel pivot attachment to the tractor is located. The trailer will have definable height, length (typically 53 feet) and width. The center of mass of the trailer will be used for moment calculations. Locating or calculating the center of mass will not be covered in this paper, but is done off of typical weights and locations. See reference [4] for more details on center of mass calculations. The overall weight of the trailer will be an independent variable, but for this paper, the trailer will be modeled as empty.

The fifth-wheel pivot between the tractor and trailer will provide rotational movement along the vertical axis but will be fixed from relative translational movement of the tractor trailer completely.

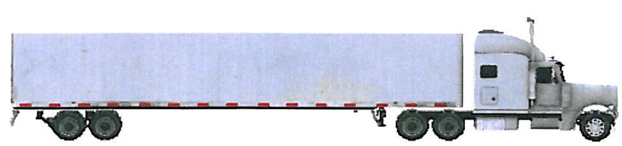

Figure 1: Typical tractor with full 53' length trailer combination as used in this paper. (Image by Knott Laboratory)

LIFT AND DRAG COEFFICIENTS

Ultimately the two most difficult coefficients to estimate in this analysis are the lift (C_l) and drag coefficients (C_d) associated with aerodynamic lift and drag. Literature has been researched to discover acceptable ranges for lift and drag coefficients. Testing the subject to determine lift and drag coefficients requires intensive fluid dynamic testing, which can be both time consuming and cost prohibitive. This paper will rely on pre-existing research into the subject and will not attempt to qualify values given for these coefficients with any further physical testing.

Research into lift coefficients has been carried out in order to determine the amount of aerodynamic lift applied to a vehicle. Research provided by [1] on scale model "lorries" determined that an acceptable aerodynamic lift coefficient would be approximately 1. However, the tests used in these experiments involved a scale model measured in a wind tunnel, at rest. Additionally, reference [2] indicates that an acceptable lift coefficient is between 1 and 1.1. This paper will focus on a documented lift coefficient for this analysis of approximately 1.0.

Research into drag coefficients has been carried out largely by the construction engineering industry, in designing for wind loading applied to structures. It has been stated in previous testing by reference [1] and [2] that the force applied to the side of a tractor trailer can be approximated to that of a low-rise building structure. Since many commercial buildings are relatively rectangular in shape, drag coefficients pertaining to these structures may provide a rough estimate to acceptable drag coefficients of wind forces in the lateral direction of a semi tractor trailer. Reference [5] gives a coefficient of drag upon the leeward face of a low-rise building of approximately 2. This paper will explore the effects of aerodynamic drag using this drag coefficient, but further research and testing may alter this value in the future.

WIND GUSTS

There are several different definitions used today to define wind speeds across the surface. Due to variations in elevation of the earth's surface from mountains and gorges, low/high pressure zones, and surface features such as trees, wind speeds are very dynamic while moving along the surface of the earth. Because of this, averaging techniques have been developed to approximate the speed of the wind over a certain distance or time. Wind speed fastest mile is one measurement technique, which measures the speed of the wind as it covers one mile of distance. Basic wind speeds, as defined by *ISO 4354*, designate a measurement of wind speed averaged over a time period of approximately 10 minutes. Because of the fluctuations associated with wind speeds, wind speed fastest mile measurements will typically be higher than those of 10-minute basic wind speeds. Additionally, over this 10-minute period of time, a specific wind gust speed can be approximated by a "gust factor" applied to the average wind speed, as outlined in [6]. A gust factor is defined as:

$$G = \frac{v_{wind}}{v_{w,s}}$$

According to [6], wind data suggests that typical gust factors fall in the range of 1.35 to 1.7. This paper will focus on 10-minute basic wind speed measurements, using a gust factor of approximately 1.5. Due to the sensitive nature of wind speed and gust factors in the calculations, the reader is encouraged to research into [7] and *www.noaa.com* to determine the time step in which wind speed data is presented for specific cases.

A crosswind traveling over a traveled roadway can impart a significant force on a moving vehicle. [3] states that the most critical wind direction is perpendicular to the direction of travel. This is especially so with tractor trailers, since they present an enormous lateral area, even compared to their large frontal area. This model will apply gusts perpendicular to the direction of travel. In [8], the author indicates that a simple step increase of wind speed as opposed to a linear increase of wind speed is acceptable. For this paper's model, the gust will be applied instantaneously and kept uniform for a changeable period of time.

In adverse driving conditions, the traction between the tires and the roadway can be significantly reduced. Because of this, many regions of the country have imparted special precautions for commercial vehicles to avoid a potential loss of control if slippery conditions exist. For example, The *New York State Commercial Driver's Manual* States that, when driving over slippery surfaces and on packed snow, "reduce speed by half, or more." In periods of high winds and reduced traction, lowering the speed by at least half can eliminate the occurrence of trailer lateral slide completely, as shown, in detail, in the example below.

DRIVER INPUT AND LOSS OF CONTROL

In publication [8], a definition of what constitutes an accident is formulated, in which, for our purposes, defines that the lateral movement – slide – of a tire or axle can exceed a certain amount. The angular rotation of a vehicle or trailer must also exceed some certain amount. Although this distance can be subjective, an acceptable distance to cause a loss of control is the distance that cannot be recovered from by the natural movement of the vehicle, or a distance that causes the vehicle to travel in a different dangerous path away from the original path of travel.

According to [9], a loss of controllability will more likely result in a vehicle crash than a loss of stability which would result in loss of road grip, or loss of tracking. Because loss of control is linked with the effects of driver reaction, driver inputs can result in significant changes of vehicle direction during an emergency event. Driver input can be difficult to mathematically model and can include items such as counter steering, braking, swerving, accelerating, and other split-second maneuvers, all after a certain perception reaction time. Because of the uncertainties included in measuring these actions, any sort of driver reaction will not be included in this paper's model.

LIST OF VARIABLES

A	Distance, Trailer Pin to C.G. of Trailer
B	Distance, Trailer Axle(s) to C.G. of Trailer
C	Distance, Center of Geometry to C.G. of Trailer
C_D	Aerodynamic Drag Coefficient
C_L	Aerodynamic Lift Coefficient
d_1	Trailer Rotational Dist. (SA): $0 \leq t \leq t_w$
d_2	Trailer Rotational Dist. (SA): $t_w \leq t \leq t_{nd}$
d_3	Trailer Lateral Slide Dist: $0 \leq t \leq t_w$
d_4	Trailer Lateral Slip Distance: $t_w \leq t \leq t_{nd}$
F_1	Net lateral force applied to trailer
F_2	Frictional force applied to decelerate trailer during t_{nd}
F_D	Aerodynamic Side Force
$F_{D,TH}$	Threshold Aerodynamic Side Force
F_L	Aerodynamic Lift Force
G	Wind Gust Factor applied to average wind speed ($v_{w,s}$)
H	Trailer Height
I	Trailer Moment of Inertia
L	Trailer Length
M_1, M_2	Moment(s) Applied at Pin and Axle(s)
m	Trailer Mass
N_1	Normal Force Applied to Trailer Pin
N_2	Normal Force Applied to Trailer Axle(s)
T_1, T_2	Applied Torque(s) from Wind Force, F_d
t_{nd}	No Wind Gust Time to Stop
t_{nw}	Time Period of No Wind
t_w	Wind Gust Time Duration
v_{0cg}	Trailer Lateral Slip Speed at t = 0s
v_{1cg}	Trailer Lateral Slip Speed at $t = t_w$
v_{max}	Max. Combined Translational Velocity
v_{truck}	Truck Traveling Speed
v_{wind}	Lateral Wind Speed, During Gust
$v_{w,s}$	Constant Wind Speed (10 min, fastest mile, etc.)
W_d	Trailer Width
W_t	Trailer Weight
W_{tk}	Rear Tractor Axle(s) Weight
θ_1	Trailer Angle of Rotation at $t = t_w$
θ_2	Trailer Angle of Rotation at $t = t_{nd}$
μ	Roadway Surface Friction Coefficient
ρ	Local Air Density
ω	Maximum velocity of lateral side slip
ω_0	Rotational Speed at t = 0s
ω_1	Rotational Speed at $t = t_w$
ω_2	Rotational Speed at $t = t_{nd}$

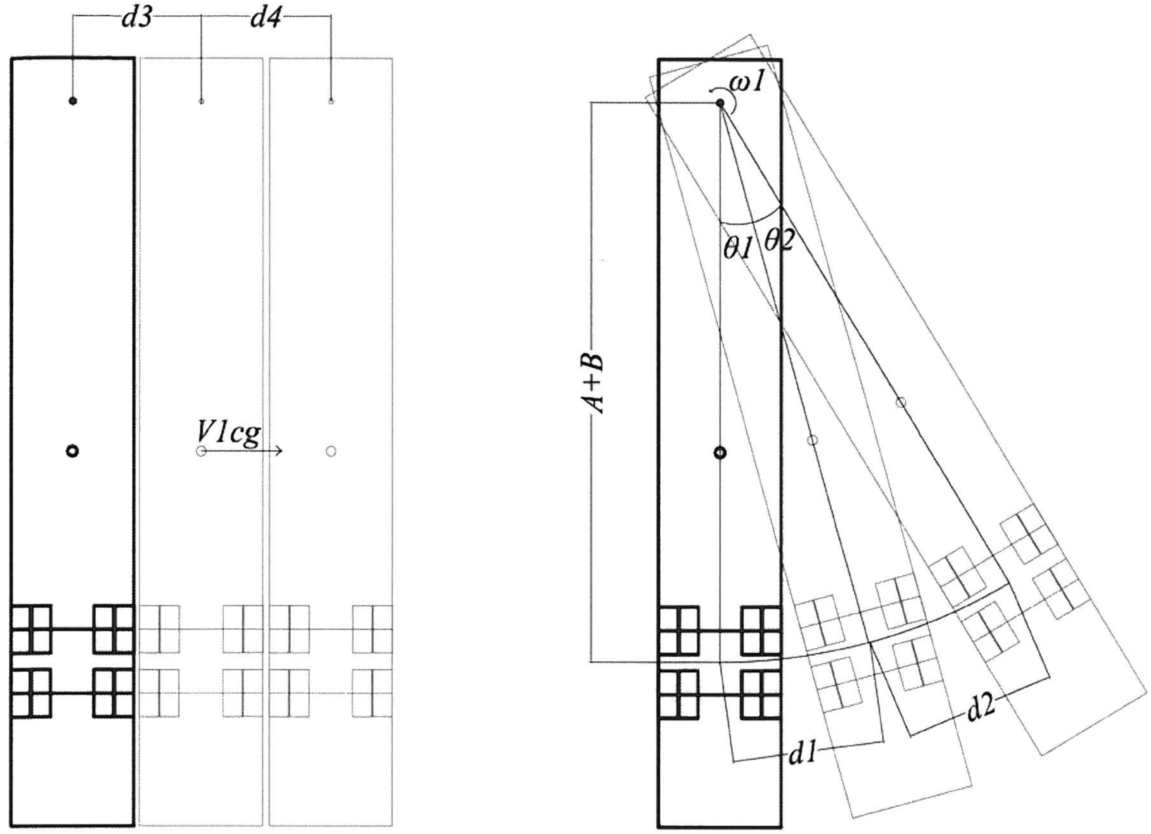

Figure 2: Schematic of variable locations as they appear in the model.

ASSUMPTIONS

In order to create an accurate but solvable model of trailer movement, certain assumptions must be taken into account. These assumptions are listed below:

1. The semi tractor trailer is subject to a cross wind gust perpendicular to the direction of travel.
2. The semi tractor itself will have no influence of lateral force from the wind gust or lift from traveling speed, aside from acting as a barrier to the front of the trailer from frontal traveling speed drag.
3. The wind gust, t_w instantaneously occurs at t = 0s and remains at a constant velocity for the duration of the wind gust.
4. After the end of the wind gust, crosswind speed will instantaneously reduce to zero.
5. The gust profile is laminar and uniform across the entire surface area of the tractor trailer.
6. The tractor trailer travels along at a constant speed in a direction perpendicular to the cross wind gust.
7. The roadway surface is completely flat and level.
8. The friction coefficient between the roadway and the trailer tires is constant as defined in the equations.
9. The tires will be modeled as incompressible and will not displace under the lateral sliding of the trailer.
10. The trailer and chassis will be rigid bodies with no suspension.
11. The trailer mass will be considered a single point located at the center of gravity.
12. The forces and resulting movement of the trailer will utilize small angle (SA) assumptions to simplify the calculations.
13. Aerodynamic turbulence will not be modeled or considered in this model.

EQUATIONS

The following list of equations are used in the model to define the forces, motion, and distance related to a cross wind affecting a tractor trailer, causing side sliding.

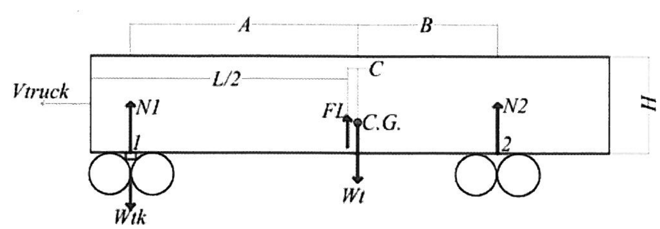

Figure 3: Elevation View: Free Body Diagram of forces, showing direction of travel and variable names.

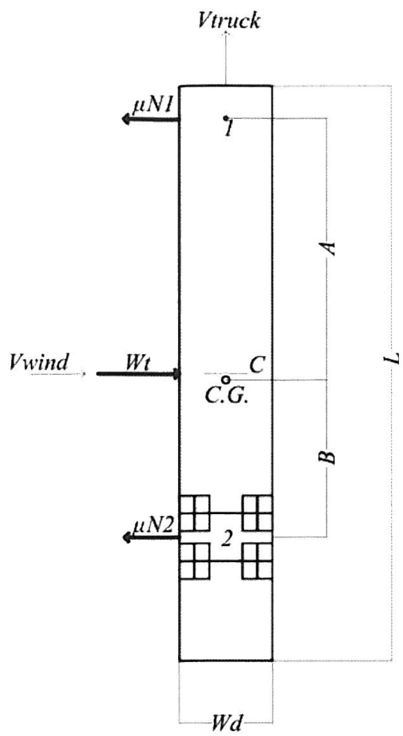

Figure 4: Plan View: Free Body Diagram showing direction of travel.

WIND & NORMAL FORCES

The Bernoulli equation is used to find a pressure applied from a fluid in free stream velocity. It is defined as:

$$pressure = \frac{1}{2}\rho \cdot v_{wind}^{2}$$

From this, simple lift and drag equations are formed and the corresponding forces acquired from a semi tractor trailer are as follows. Recall that the aerodynamic lift identifies the contribution of a force supplied by a side wind to the vertical load of the trailer, therefore so applied, will act to lighten the effective "load" of the trailer. The force of lift developed from a non-turbulent flow across the area of the underside of the trailer is defined as:

1. $$F_L = \tfrac{1}{2} \cdot \rho \cdot C_L (V_{wind}^2 + V_{truck}^2) \cdot L \cdot W_d$$

The forward traveling velocity of the truck is squared and combined in series with the square of the gust wind speed.

The force developed across the side length of the trailer as it is subjected to a perpendicular wind gust is given by:

2. $$F_D = \tfrac{1}{2} \cdot \rho \cdot C_D \cdot V_{wind}^2 \cdot L \cdot H$$

The normal force in the vertical direction applied to the trailer pin is denoted N_1 in the list of variables. See figure 3. This normal force includes the additional weight from the front tractor axles, which is denoted W_{tk} in the list of variables for simplification purposes as described in the *model background*. To find the threshold in which the forces in the vertical direction become equal, the moment equation must be set equal to zero, and the balancing equation must be solved. The Moment about the axles of the trailer yields the balancing equation for N_1:

$$\sum M_2 = W_t \cdot B - F_L(B+C) - N_1(A+B) = 0$$

3. $$N_1 = \frac{W_t \cdot B - F_L(B+C)}{(A+B)} + W_{tk}$$

Similarly to the trailer pin normal force, the trailer axle normal force, N_2 , is provided by balancing the moment about the trailer pin:

$$\sum M_1 = W_t \cdot A - F_L(A-C) - N_2(A+B) = 0$$

4. $$N_2 = \frac{W_t \cdot A - F_L(A-C)}{(A+B)}$$

SLIDE CONDITION

In order to create a condition where the trailer axles will slide sideways, a threshold wind force is required. This threshold wind force is defined as the force required to break the lateral traction of the tires, beginning a slide. The horizontal moment taken about the trailer pin will yield this force balance:

$$\sum M_1 = F_{D,TH}(A-C) - \mu \cdot N_2(A+B)$$

5. $$F_{D,TH} = \frac{\mu \cdot N_2(A+B)}{(A-C)}$$

A wind speed and corresponding force greater than this threshold value will cause a slide:

$$F_{D,TH} < F_D$$

A wind speed and corresponding force less than this threshold value will not cause side slip:

$$F_{D,TH} > F_D$$

SPEEDS, TIME, AND DISPLACEMENTS

Moment of inertia can be calculated as a point mass located a distance away from center of rotation, the trailer pin:

$$I = m \cdot A^2$$

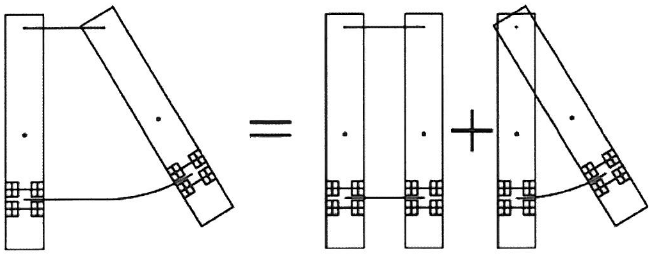

Figure 5: Plan View: General Planar Motion can be approximated by adding the components from simple translation and rotation.

The rotational and translational speeds are calculated separately and combined in simple planar motion as shown in figure 5. Consider the impulse equation and sum of torques about the trailer pin. The initial rotation of the trailer pin, ω_0 , is zero and can be removed from the equation. The torque, T_1 , applied to the z-axis (vertical, pointing through the fifth wheel) of the trailer pin is defined below. The resulting rotation, ω_1 , from the wind gust of time, t_w , is calculated as:

$$I \cdot \omega_0 + \int \sum T_1 dt_w = I \cdot \omega_1$$

$$\sum T_1 = F_D(A - C) - \mu \cdot N_2(A + B)$$

Solve for ω_1

6. $$\omega_1 = \frac{t_w}{I}\left(F_D(A - C) - \mu \cdot N_2(A + B)\right)$$

As described in figure 5, the side slip speed is combined with the rotational speed to create a composite movement. The lateral slip speed is found in a similar fashion by identifying the initial sideways velocity, v_{0cg} , as zero and calculating the net force, F_1 applied to the trailer. The lateral slip speed, v_{1cg} , is calculated by:

$$m \cdot v_{0cg} + \int \sum F_1 dt_w = m \cdot v_{1cg}$$

$$\sum F_1 = F_D - (\mu \cdot N_1) - (\mu \cdot N_2)$$

Solve for v_{1cg}

7. $$v_{1cg} = \frac{t_w}{m}\left(F_D - \mu(N_1 + N_2)\right)$$

The rotational speed of the trailer at the trailer pin from maximum to stop, ω_2 , is defined again as ω_1. The time period associated with this angular deceleration, with no applied wind gust, is defined as t_{nw} and is calculated as shown below:

$$I \cdot \omega_1 + \int \sum T_2 dt_{nw} = I \cdot \omega_2$$

$$\sum T_2 = -\mu \cdot N_2(A + B)$$

8. $$t_{nw} = \frac{I \cdot \omega_1}{\mu \cdot N_2(A + B)}$$

Now, consider the time period associated with the lateral displacement of the trailer, as described in figure 2. After the gust, the trailer will slide a certain displacement to the side while decelerating to a stop. The time period, t_{nd} , associated with this deceleration is given as:

$$m \cdot v_{1cg} = \int \sum F_2 dt_{nd}$$

$$\sum F_2 = -\mu(N_1 + N_2)$$

9. $$t_{nd} = \frac{m \cdot v_{1cg}}{\mu(N_1 + N_2)}$$

The angle of rotation caused by the wind gust can be calculated as:

10. $$\theta_1 = \frac{\omega_1}{2} t_w$$

The angle of rotation after the wind gust, decelerating to a stop is given as:

11. $$\theta_2 = \frac{\omega_1}{2} t_{nw}$$

Small angles are defined as angular values that are similar whether evaluated trigonometrically or taken at face value. This paper will utilize the small angles taken at face value for simplicity. As shown in figure 2, when small angle (SA) assumptions are used, the distance of the rear axles of the trailer compared to the angular rotation of the trailer can be approximated with the following equation:

12. $$d_1 = 2 \cdot \sin\left(\frac{\theta_1}{2}\right)(A+B)$$

And, again for the angular distance after the wind gust, to stop:

13. $$d_2 = 2 \cdot \sin\left(\frac{\theta_2}{2}\right)(A+B)$$

The lateral slip distance of the trailer and rear tractor axles can be calculated with the following equation:

14. $$d_3 = \frac{v_{1cg}}{2} t_w$$

And

15. $$d_4 = \frac{v_{1cg}}{2} t_{nd}$$

ADDITIONAL EQUATIONS

The maximum translational velocity combines the maximum velocity of the lateral side slip with the maximum velocity of the rotational velocity, as a sum of squares:

$$V_{MAX} = \sqrt{(\omega(A+B))^2 + v_{1cg}^2}$$

EXAMPLE

Consider a typical 18-wheeled semi tractor trailer combination traveling northbound along a two-lane paved road covered in packed snow (μ = 0.3) with a crosswind from the east and significant wind gusts occurring every 10 minutes. The posted speed limit is 45mph and the truck is traveling along at this speed. A wind gust suddenly hits the side of the truck and the trailer drifts over the fog line, redirecting the tractor into oncoming traffic. The trailer tires hit the embankment at the edge of the paved road, approximately 6 feet from the trailer's original path.

a. Weather reports show that the average gust speed for any 3-second gust that day was approximately 31 knots (36mph). Would this trailer drift have occurred if the tractor trailer were traveling at half the speed, 22.5mph?

b. Find the wind gust speeds required in order to slide the trailer axles off of the path of travel by 6 feet, if the tractor trailer is traveling at 45mph and 22.5mph.

The following is known about the incident:

A = 24.12 ft
B = 14.51 ft
C = 0.62 ft
C_D = *2.00*
C_L = *1.00*
H = 9.80 ft
L = 53.00 ft
t_w = *3.00 s*
W_d = *8.50 ft*
W_t = *14000.00 lb*
W_{tk} = *5000.00 lb*
ρ = 0.002376 slug/ft^3

a. From equations 1-4, the lift and side forces can be calculated, along with the normal forces at the trailer axles and trailer pin. Because the trailer started sliding first, the tractor will not be considered in these calculations:

45MPH TRAVELING SPEED:

Lift Force:	*3825 lb*
Side Force:	*3442 lb*
Normal force on trailer pin:	*8760 lb*
Normal force on trailer axles:	*6414 lb*

22.5MPH TRAVELING SPEED:

Lift Force:	*2076 lb*
Side Force:	*3442 lb*
Normal force on trailer pin:	*9445 lb*
Normal force on trailer axles:	*7478 lb*

Use equation 5 to find out the slip / no slip condition. If the side force value is under the threshold force, then no slip will occur at this wind speed:

45MPH TRAVELING SPEED:

Threshold force: *3163 lb < 3442 lb ← SLIDE*

22.5MPH TRAVELING SPEED:

Threshold force: *4214 lb > 3442 lb ← NO SLIDE*

b. Because of the length of the calculations, only the 45mph travel speed will be calculated in detail:

To find the wind gust speeds for 6 feet of slide, a range of wind gust speeds will be used to calculate corresponding force values which, in turn, will be used to impart impulses on the trailer to create movement. A 3 second gust time period will be used. Equations 6 and 7 were used to find the rotational and slide speeds. Note that if the friction force is greater than the net force at a specific wind speed, the trailer will not move at all. In this example, no movement occurs until approximately 35mph wind speeds:

Distance of Slide					
Wind Speed	d1	d2	d3	d4	Total Distance
	t ≤ 3 sec	$t \le t_{n\omega}$	t ≤ 3 sec	$t \le t_{n\omega}$	
[mph]	[ft]	[ft]	[ft]	[ft]	[ft]
25	0.00	0.00	0.00	0.00	0.00
26	0.00	0.00	0.00	0.00	0.00
27	0.00	0.00	0.00	0.00	0.00
28	0.00	0.00	0.00	0.00	0.00
29	0.00	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00
31	0.00	0.00	0.00	0.00	0.00
32	0.00	0.00	0.00	0.00	0.00
33	0.00	0.00	0.00	0.00	0.00
34	0.00	0.00	0.00	0.00	0.00
35	1.07	0.02	0.00	0.00	1.09
36	4.51	0.40	0.00	0.00	**4.91**
37	8.04	1.28	0.00	0.00	**9.32**
38	11.64	2.72	0.00	0.00	14.36
39	15.32	4.77	0.00	0.00	20.09
40	19.05	7.49	0.00	0.00	26.54
41	22.83	10.94	0.34	0.00	34.12
42	26.64	15.16	2.24	0.15	44.20
43	30.47	20.20	4.19	0.53	55.39
44	34.30	26.06	6.18	1.16	67.70
45	38.11	32.72	8.22	2.06	81.10

Wind Speed	Side Force	Normal Force, Trailer Pin	Normal Force, Trailer Axles	Trailer Pin Rotational Speed	Lateral Slide Speed
[mph]	[lbf]	[lbf]	[lbf]	[deg/s]	[f/s]
25	1660	9063	6884	0.0	0.0
26	1795	9040	6849	0.0	0.0
27	1936	9017	6811	0.0	0.0
28	2082	8992	6773	0.0	0.0
29	2234	8966	6733	0.0	0.0
30	2390	8939	6692	0.0	0.0
31	2552	8912	6649	0.0	0.0
32	2720	8884	6605	0.0	0.0
33	2892	8854	6559	0.0	0.0
34	3070	8824	6512	0.0	0.0
35	3253	8793	6464	1.1	0.0
36	3442	8761	6414	4.5	0.0
37	3636	8728	6363	8.0	0.0
38	3835	8694	6310	11.6	0.0
39	4040	8659	6256	15.2	0.0
40	4249	8624	6201	19.0	0.0
41	4465	8587	6144	22.9	0.2
42	4685	8550	6086	26.9	1.5
43	4911	8511	6027	31.0	2.8
44	5142	8472	5966	35.1	4.1
45	5378	8432	5903	39.4	5.5

Once the rotational speed and slide speed are found for given wind speeds, equations 10, 12, and 14 can be used to find the corresponding distances. For the distances from the end of the wind gust to the stop of sliding, equations 11, 13 and 15 can be used. The distances for each component, as well as the total distance of the trailer slide off of the original direction of travel are given below:

The total distance traveled shows that a wind gust speed of approximately 36mph will result in a trailer axle lateral slide distance of 6ft, shown above in large bold numerals. This is similar to the gust speed found by the weather reports in part “a”.

The equations for calculating the distance of slide for 22.5mph are identical, but not included in this paper. Instead, Figures 6 and 7 show the comparison between a travel speed of 45mph and 22.5 mph. Information in [10] indicates that a speed of 45mph and a friction coefficient of 0.3, the friction coefficient will increase by approximately 14% if the speed is dropped to 22.5mph. This phenomenon will not be discussed here, but the reader is encouraged to research the effects on friction coefficients at different speeds in the references.

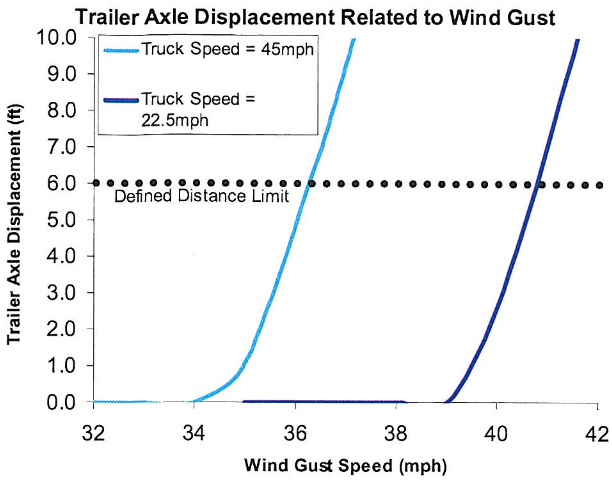

Figure 6: Graph of trailer axle displacement at given wind gust speeds. Note the limit of six feet of lateral movement.

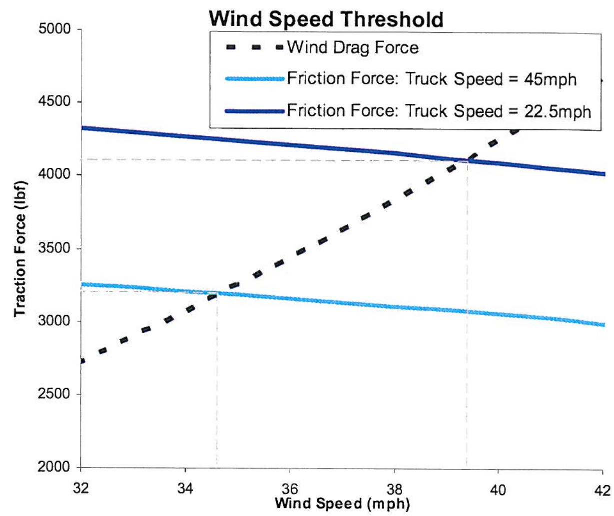

Figure 7: Threshold wind speed for 45mph and 22.5mph truck velocities.

CONCLUSION

From the equations included in this paper, it is possible to create a semi tractor trailer model of trailer sliding that is a reasonable approximation to actual events. Because this is a dynamic model, assumptions must be made to simplify the calculations. It is evident that vehicle traveling speed has an effect on whether or not a loss of control will occur at a given wind gust speed. From the influence of vehicle speed, it is acceptable to conclude that traveling at half the indicated speed limit will reduce the risk of trailer fishtailing and could reduce the risk of loss of control of the vehicle.

Driver input during an event of trailer sliding may have a significant influence on loss of control. Any sort of counter steering or braking during an event could potentially reduce or exacerbate the sliding motion of the trailer. It is important to consider this input in conclusions made as to what caused a loss of control.

Local weather reports can be used in conjunction with the data provided from these equations to indicate acceptable speeds of travel during high wind conditions. However, these equations should be used as a starting point for more rigorous investigation. Additional research using local and relative wind speeds should be undertaken to improve forecasts and driving advisories. This paper provides a starting point in which truck drivers and law enforcement can determine safe driving speeds for commercial vehicles in adverse weather conditions.

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