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Development of an analytical multi-variable steady-state vehicle stability model for heavy road vehicles

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ABSTRACT

Road vehicles tend to be more vulnerable to accidents especially at motorway speeds. Commercial vehicles in particular are more prone to overturning accidents due to adverse conditions like cross winds and abrupt acceleration/braking conditions. Thus, it is essential to investigate vehicle stability under various conditions of manoeuvring, cross winds and on inclined ground planes. This work presents a methodology of determining rollover stability of road vehicles. A wide range of destabilising factors have been investigated. These include the longitudinal and lateral inclination of the ground plane, road surface curvature; acceleration and braking effects; centrifugal cornering effects as well as the aerodynamic effects of cross winds at various wind speeds and angles of attack. These destabilising factors have been described in detail, with a description of associated variables that influence vehicle stability. A four-equation model has been proposed to evaluate the vertical ground reaction forces at each wheel, based on the force-moment system created by the above-mentioned destabilising factors. A parametric study is carried out to investigate the influence of various parameters on the overall stability of the vehicle. It is noted that higher magnitude of wind velocities cause a reduction in the maximum safe vehicle speeds. Moreover, for high magnitude of wind speeds, it is also seen that for some vehicles wind angles as low as 5° can cause overturning accidents, even at low vehicles speeds of 15 m/s (33.5 mile/h, 54 km/h). Additionally, the influence of acceleration, braking, turning and road surface curvature has been investigated. An increase in vehicle mass is seen to be beneficial as it increases the maximum safe vehicle speeds for a given set of wind conditions, thus making the vehicle more stable. The proposed vehicle stability model can predict stability characteristics of a wide range of vehicle types.

1. Introduction

Heavy commercial vehicles (HCV) like trucks and buses have always been designed with utilitarian needs, like load-carrying capacity etc., in view. The rapid development of transport infrastructure has caused a significant increase in average road speeds for such commercial vehicles as well. However their simplistic construction and basic shape make them more prone to overturning accidents. Although the modern steering system has its origins in the stub-axle steering that was conceived in the early nineteenth century, it was not until the early twentieth century that concepts of lateral forces and

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Nomenclature

English alphabet and symbols

a	longitudinal acceleration of the vehicle, negative if braking (m/s^2)
A	area (m^2)
C	non-dimensional coefficient, see subscript (–)
F	external force, see subscript (N)
g	acceleration due to gravity (m/s^2)
h	height (m)
h_{CG}	height (perpendicular distance) of the CG from the ground plane (m)
I	moment of inertia (kg/m^2)
k	turbulent kinetic energy (m^2/s^2)
K	spring constant, see subscript (N/m)
l	length (m)
L_T	length of vehicle track (distance between left and right wheel centres) (m)
$L_{T,B}$	length of vehicle track at the back axle, where applicable (m)
$L_{T,F}$	length of vehicle track at the front axle, where applicable (m)
$L_{T,L}$	distance between CG and left wheel (m)
$L_{T,R}$	distance between CG and right wheel (m)
L_W	length of wheel base (distance between front and back axles) (m)
$L_{W,B}$	distance between CG and back axle (m)
$L_{W,F}$	distance between CG and front axle (m)
m	mass (kg)
M	external moment (N m)
R	rolling resistance force (N)
S	lateral side-slip reaction forces at the ground contact point (N)
T	tractive force (N)
$u_{VEH,LAT}$	lateral displacement due to side-slip instability.(m)
V	vertical reaction force (N)
v_{REL}	magnitude of wind velocity relative to vehicle velocity (m/s)
v_{VEH}	magnitude of vehicle velocity (m/s)
$v_{VEH,CRIT}$	magnitude of critical vehicle velocity at which rollover is imminent (m/s)
$v_{VEH,LAT}$	lateral vehicle speed of course deviation due to side-slip instability (m/s)
v_{WIND}	magnitude of absolute wind velocity (m/s)
$v_{WIND,ACC}$	magnitude of wind speed at which accident is imminent (m/s)
W	weight (N)
x	longitudinal position (along X-axis) (m)
X	Spring reaction force of the suspensions (N)
y	vertical position/displacement (along Y-axis) (m)
z	lateral position (along Z-axis) (m)

Greek alphabet and symbols

β_{WIND}	absolute direction of the wind relative to vehicle (rad, °)
ε	vertical displacement of the wheel centre (m) turbulence dissipation rate (m^2/s^3)
ζ_R	steering angle of the front right wheel (rad, °)
θ_{LAT}	lateral angle of inclination of the ground plane (rad, °)
θ_{LONG}	longitudinal angle of inclination of the ground plane (rad, °)
ψ	angle of the wind relative to vehicle (rad, °)

Subscripts

A	longitudinal acceleration
B,L	back, left
B,R	back, right
C,z	centrifugal/cornering, vertical component
C,y	centrifugal/cornering, lateral component
C	centrifugal/cornering
CG	centre of gravity
D	of drag
F,L	front, left
F,R	front, right