Modeling Vehicle Rollover

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Inspired by the recent paper[1] in *The Physics Teacher* on the dynamics of vehicle rollovers, we modeled "rollover" in a laboratory experiment. The combination of fundamental physical principles, application to a "real world" problem, and ease of doing the experiment with readily available material and equipment makes the experiment an attractive one for use in a high school or introductory college physics course. A suggested method, sample results, and suggestions for further experimentation follow.

First, some information about the significance of rollover crashes:[2] Rollover crashes are more likely to result in fatalities than other types of crashes, primarily due to ejection of the occupant from the vehicle. In the United States in 2001, more than half of all single vehicle crash deaths were the result of rollovers. Rollovers are the leading cause of fatalities in SUVs (sport utility vehicles), as opposed to frontal collisions in passenger cars. Almost 80% of fatalities for SUV occupants involve rollovers, as compared to 34% of fatalities for pick-up truck occupants and 19% in passenger cars. This leads to the question of how the design of SUVs increases the risk of rollover.

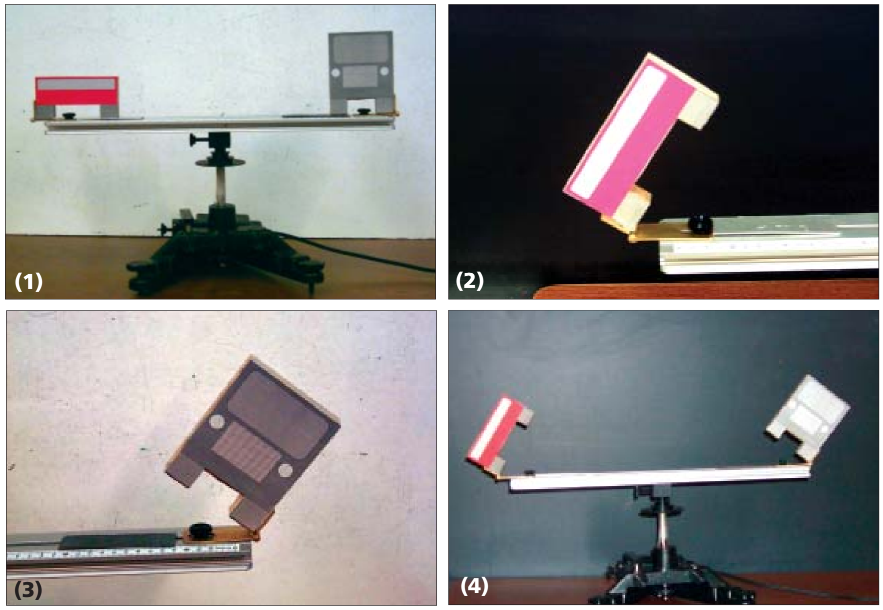
For a moving vehicle making a sudden turn on a flat, smooth road, impending rollover is predicted by the Static Stability Factor (SSF) and is derived in "Rollover of Sport Utility Vehicles"[3] by Desmond Penny. For a vehicle with a track width of t and a center of gravity at a height of h above the road, the Static Stability Factor is $(t/2h)$. When the SSF is equal to (v^2/rg), where v = speed of the vehicle, r = radius of the curve, and g = the acceleration due to gravity, the vehicle is on the verge of rolling over. It is also shown[4] that for a vehicle parked sideways on a slope, the SSF is also equal to the tangent of the angle ϕ of the slope at which the vehicle is about to tip over.

The three methods of determining the Static Stability factor are:

(1) Calculating the SSF from the height of the center of gravity and the track width. With a simple model, the location of the center of gravity is easy to calculate. If the model's shape is more complex, the center of gravity can be found experimentally by suspending the model vehicle along with a plumb bob from two or more points and marking the point where the plumb lines intersect. The track width t is measured and the SSF is calculated from $(t/2h)$.

(2) Following a suggestion by Penny in his paper, we made a physical model of a vehicle by cutting blocks of wood to model the outline of an "SUV" and of a "sports car" as seen from the front (see Figs. 1–4). The "SUV" was 9 cm wide and 12 cm high. The "sports car" was 12 cm wide and 6 cm high. We then attached the bottom outside corner of each model (the "tire") to a hinge. The other side of the hinge was mounted to a rotating platform. In our case, we used a PASCO rotating platform (ME-8951), though any similar device would suffice. We then spun the platform with slowly increasing speed until the vehicle overturned or "rolled over." While there are other ways to measure the speed, we used a rotary motion sensor (PASCO CI-6538) with a Science Workshop

750 Interface (CI-6450) and the Data Studio computer program. The speed $v = r\omega$, where ω = angular velocity in radians/second and radius r is the distance from the center of gravity of the model to the axis of rotation. Having the computer graph the angular velocity versus time, it is easy to determine the speed at which the model rolled over, because when it does there is a sudden drop in the speed at the moment the model vehicle "flips over," and the moment of inertia of the platform increases. The SSF is then calculated from (v^2/rg). One factor to pay attention to is to have the "tires" of the model vehicle at the same level at the start; having one tire higher than the other "banks" the curve and changes the speed at rollover.



Figs. 1–4. **AU: Please provide caption for these?**

(3) We also placed the models on an inclined plane and measured the angle ϕ at which the model vehicles tipped over. SSF = tan ϕ.

The results of calculating the SSF by the three independent methods are tabulated below:

Model Vehicle Type =	SUV	Sports car
(1) SSF = ($t/2h$)	0.70 ± 0.02	1.70 ± 0.02
(2) SSF = (v^2/rg)	0.70 ± 0.02	1.80 ± 0.13
(3) SSF = tan ϕ	0.68 ± 0.02	1.66 ± 0.07

There are several considerations that make this experiment attractive. While the ease of the experiment makes it appropriate for an introductory physics course, at the same time it illustrates important physics principles of a significant "real world" application. It also demonstrates the power of using a model to predict the behavior of a vehicle without having to actually roll over the vehicle itself. One could then also test the effects of varying track width and of loading the vehicle. While we made "generic" model vehicles to see how well the experiment worked, a model could be designed based on the characteristics of a specific vehicle. The results could then be compared to actual rollover data for that vehicle and the importance of other factors not considered in the static model (the suspension and the condition of tires).

Students could design and build their own model vehicles and predict and test their stability. The only material and equipment required is a block of wood and a saw. There is also the "fun factor": the model vehicles could be painted and accessorized to look like a favorite vehicle. Once the test platform is set up, the only additional work would be to attach the models to the hinge. This could be used for a physics contest, having students design and build a model vehicle following a set of constraints, such as having a minimum rollover speed for a given size vehicle.

References

1. Desmond N. Penny, "Rollover of sport utility vehicles," *Phys. Teach.* **42**, 86–91 (Feb. 2004).
2. Fact sheet, http://www.saferoads.org/issues/fs-rollover.htm.
3. See Ref. 1, p. 87.

4. See Ref. 1, p. 88.

PACS codes: 01.50P, 46.02B, 46.07

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