INVESTIGATING THE HYDROPLANE PHENOMENOM

(TO AQUAPLANE OR NOT TO AQUAPLANE)

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I originally wrote this piece under the title "Investigating the Hydroplane Phenomenon" for LAW and ORDER magazine. They published my article in their June 1990 issue. I later submitted the article to IMPACT, The Journal of the Institute of Traffic Accident Investigators (ITAI), then headquartered in London, England. I never heard from them since so I don't know if IMPACT ever published the article. However, since the Internet has many European and Australian users, what follows is the manuscript as submitted to the British publication. I had changed all my "tires" to "tyres," and "trucks" to "lorries" but since I'm not up on British vernacular, I'll leave it to the reader to make any changes he or she feels necessary. (In the United States, we call it Hydroplaning instead of Aquaplaning so allow me to use our term.

It's raining! There is so much rain, in fact, that roadway ruts, the kind etched in roadways by substantial amounts of vehicular traffic, are full of water. You realise [yes, I know, in America it's "realize"] a considerable measure of water must be "standing" because if you allow one of your tyres to get into that area you can feel a "tug" on the steering wheel.

Usually, the "tug" lasts only a fraction of a second because your car moves through the deeper areas and onto a portion of the surface not covered by as much water.

During wet weather, other than "normal" phenomena occurs under your tyres. The reason you feel a tug at your wheel is that the tyre that got into the deeper water slowed down quickly. Fortunately, by the time that circumstance could slow down sufficiently to pull your vehicle to one side, you pass through, or over, the high water.

Side forces are acting on your wheels and tyres all the while you are moving. Forces from the front are also present. Unless you are driving perfectly straight on a perfectly level road in a perfectly balanced vehicle, the side forces tend to be greater in one direction than the other.

Therefore, when the front force changes - owing to the water - the side forces also change. If the side force change is great enough over a sufficiently long period of time, the tyre at which the force is changing starts moving laterally.

A lot of this motion depends on the speed of your car. Part of the action results from the tread condition of the tyre. The grooves in tyres are there primarily to channel away water. More water is channeled if the tyre tread has good depth; likewise, worn tyres cannot channel as much water.

On a dry pavement, bald tyres are not too bad (other than they are more apt to "blow"), which is why they put "slicks" on racing cars. The race drivers want as much rubber as possible in contact with the road. That would work fine for passenger cars, except what happens when it starts to rain? If it rains in Indianapolis on Memorial Day, they postpone or stop the Indy 500. If you wanted to drive with smooth tyres, you would have to stop every time it rains and change tyres.

What happens if the tyre tread is not adequate and water cannot be channeled out from under the tyre? It hydroplanes. When a tyre hydroplanes, it actually rides up onto the surface of water as a skier would behind a boat.

When a vehicle is on dry pavement, there is quite a bit of tyre-to-road friction. Tyre-to-water friction is remarkably less. Now, rather than plowing through the water, the tyre is riding ON the water and it can still produce a pulling sensation because that tyre "spins down." That is, it rotates slower than the others.

Investigators sometimes attribute the cause of hydroplaning to accidents where that is not the case. Wet road accidents are generally prevalent within the first thirty minutes after rain begins. Over time, a normally dry asphalt pavement accumulates dust and within the surface material is a combination of "road oil" and the petroleum products used to manufacture the aggregate. Rain brings that "oil" to the surface and brings road dust to the top of the combination of oil and water. This mixture provides a lubricant between vehicle tyres and the pavement.

Rather than a "true" or dynamic hydroplane, the car's tyres actually lose traction and slide. (This is sometimes called viscous hydroplaning.) This can occur with brand new tyres. When an automobile goes into a curve at a given speed and slides off the road, the driver may believe the vehicle hydroplaned. The motorist passes along this belief to the investigator who puts that in the report.

If there is some "standing water," the word "hydroplane" often comes into play when, in fact, the vehicle may have simply lost traction because of a significantly decreased drag factor.

The officer needs to take into account the nature of the vehicle's tyres, the wetness of the roadway AND the air pressure in the tyres.

Anyone that has ever gone water skiing knows it is easier to "get up" on wide skis than narrow ones. That is why they make wider skis for beginners. That is also why air pressure in a tyre contributes to the hydroplane problem. As the pressure in the tyre decreases, the wider the "ski" becomes and the easier it is to hydroplane.

Work on the hydroplane situation came about when aircraft was forced to land on wet runways. Investigators found that aircraft tyre hydroplaning varied with tyre inflation pressure. As a consequence, an empirical equation was eventually developed through testing. Accident reconstructions have in their arsenal of formulas one that says the Speed to Hydroplane is equal to the square root of the tyre pressure times the mathematical constant of 10.35.

However, the constant is not always 10.35. That figure assumes a tyre of "normal" wear. Some researchers lower the constant to eight (8) when considering badly worn or bald tyres. The reader also should be reminded that the equation was originally developed for aircraft tyres.

The equation: $S = 10.35\sqrt{psi}$

Where S = Speed in miles an hour and psi is pounds per square inch of tyre pressure. In the metric system, the equation is:

$V = 3.43\sqrt{p}$

for speed in meters/second or SI units. (SI = Systeme Internationale de Unites.) For the sake of my British friends, let me add that throughout this article I'll be using U.S.A. equations and it might be easier for you to simply solve for miles per hour and then use your conversion to kilometers per hour. More on revisions of this equation later. Remember that one mile is 1.6093 kilometers and one kilometer is 0.6214 miles. A good rule of thumb is that 50 of ours is about 80 of yours.

Another matter to consider is the amount of water on the road. The predicament intensifies when the pavement's water depth is greater than the tyre's tread depth.

The person probably most responsible for data surrounding the hydroplane phenomenon is Walter B. Horne. He did much of the background work and did a paper considering 56-inch diameter, 24-ply-rating aircraft tyres in August, 1954 (NASA TN 3235). Other papers include SAE 970C ("Pneumatic Tyre Hydroplaning and Some Effects on Vehicle Performance") presented in 1965, and one presented to the American Society of Testing and Materials (ASTM) E-17 meeting in Montreal, June 24-25, 1975.

As researchers did more experimenting, they realised the involvement of a factor other than the tyre pressure. This factor, as we know from the fact it is easier to ski on wider skies, is the amount of tyre surface that is in contact with the pavement. We refer to the contact patch as the tyre's "footprint."

Later tests suggested the original equation was fine for aircraft tyres, but it required an adjustment when considering car, lorry and bus tyres. The old equation:

$S = 10.35\sqrt{psi}$

evolved into one that incorporated the footprint. That is, now you consider the aspect ratio of the contact patch's length and width, and a lower "constant."

The "New and Improved" formula is: $V = 7.95\sqrt{P\left(\frac{L}{W}\right)^{-1}}$

Where P = tyre inflation pressure, pounds per square inch V = minimum dynamic hydroplaning speed, miles per hour W = tyre footprint width, inches L = tyre footprint length, inches The expression (W/L) is the aspect ratio.

Mathematicians always try to make things difficult for us.

The -1 exponent is awkward without the right kind of calculator. You will obtain the same answer if you use:

$V = 7.95\sqrt{P\left(\frac{W}{L}\right)}$ and forget the -1 superscript.

The Texas Transportation Institute (TTI) conducted testing of tractor trailer tyres with a quarter-inch depth of water. The results indicated that lorry tyres would hydroplane at 58-62 MPH with a 940 pound vertical load, but not with a 1300 pound vertical load.

The question arises: How much water was on the road? There was an amusing video tape prepared by an attorney shortly after a nice rain. The location where the client had an accident, the road "ruts" had filled with water. As car after car went through the area, water splashed away indicating there was indeed a lot on water on the road. Therefore, with all that water, the client's car must have hydroplaned. However, car-after-car went through the same area and DID NOT hydroplane.

It could have been because of the car's tyre inflation and tread (or lack of it) AND the speed of the car in the first place.

How do you go about obtaining the tyre's footprint? It is not easy.

Assuming the tyre(s) are not disabled, the contact patch can be determined by first having a wrecker lift each corner of the vehicle off the ground. Second, if the tyre is dirty enough, with a solid surface underneath (blacktop or concrete - the ground itself may be too rough) lower the tyre onto a piece of plain paper. Typing paper may be sufficient as long as the tyre's footprint will fit.

If the tyre is not dirty enough to leave a print, you might try tracing around the tyre with a pencil or lay a piece of carbon paper - face down - on the paper before you lower the tyre. The latter is a viable technique if you happen to live in a Dark Ages region where they still know what carbon paper is.

Remember to find out the tyre pressure. If the water area is quite large and you suspect all the tyres were hydroplaning, determine the tyre pressure in each tyre and use the average.

Measure also tyre tread depths at various points across the tread and, if possible, ascertain the load weight on each tyre.

Usually, the calculated speeds to hydroplane, especially for large lorries, are quite high. So high, in fact, that you can almost rule out hydroplaning. For instance, in his paper to ASTM Committee E-17 meeting at Texas Transportation Institute, College Station, Texas, June 4-6, 1984, Walter Horne presented a table showing tractor trailer (18 wheels) tyre footprint characteristics. The table indicated the inflation pressure equal to 100 lbs./square inch.

For the lorry's rear drive axle, the loaded weight was 3825 pounds. The footprint width was 7.33 inches, the length 7.03 inches for an aspect ratio of 1.04. The equation is then:

$$V = 7.95\sqrt{(100)\left(\frac{7.33}{7.03}\right)^{-1}}$$, mph OR

$$V = 7.95\sqrt{(100)\left(\frac{7.03}{7.33}\right)}$$, mph.

The result: V = 78 mph. That is for that one tyre. The load weights and aspect ratios for the other tyres are different and if the speeds are higher. For instance, the speed for the front steering axle was 91 mph. The hydroplane speeds for the same tyres on an EMPTY tractor trailer were somewhat less.

I mention all this to point out that in most cases, especially those involving loaded tractor trailer combinations, dynamic hydroplaning is probably not the issue. Misuse of trailer brakes can precipitate trailer swing; braking on the drive axles only often causes jackknifing.

Since one issue is "how wet is wet," it is extremely helpful to have photographs taken as soon as possible after the accident. If possible, where there is standing water, the investigator should attempt to measure water depth of the area in question.

The National Transportation Safety Board (NTSB), in its treatise TE-IA-85-1 entitled "Highway Lorry Tyre Loading Investigative Alert," offers a technique for calculating water depth on the roadway at the time of the accident.

That equation, tendered here, merely lets you know the formula exists. With "ponding" on the road, you should not use this equation.

$$WD = 0.0038(TXD^{0.11} L^{0.43} I^{0.59} S^{-0.42}) - TXD$$

Where WD = Water Depth (in inches above the top of the aggregate surfaces) L = Drainage path length, in feet TXD = Average texture depth, in inches I = Rainfall intensity, in inches/hour S = Slope of surface, in feet/feet.

The method procedure for determining the average texture depth is beyond the scope of this article; however, suffice it to say it requires a special sand-spreading tool, a balance sensitive to 0.1 grams and a particular type of natural silica sand. This sand must be graded to pass a No. 50 (297-micron) sieve and retained on a No. 100 (149 micron) sieve. Plus you will need a twelve inch ruler in 0.1 inch increments, a metal cylinder with a volume of approximately 1.5 cubic inches, a wire brush and a soft hand brush. [From the ACPA Technical Bulletin No. 6, "Interim Recommendations for the Construction of Skid-Resistant Concrete Pavement."]

Unless you are investigating a MAJOR spectacular accident with untold ramifications, it probably would be impractical to attempt this on your own.

Another less cumbersome method of "assuming" water depth at the time of the accident is to place a STRAIGHT 1 x 4 board, on its edge, across the lane of travel. There should be some incline to the board owing to the "crown" of the road. Normally, there will be a slant from the crown to the berm.

There is almost always some rutting (except in recently surfaced roadways) because of traffic. If heavy lorries use the road frequently, this rutting is likely to be more evident. If you see considerable space between the board and the roadway, measure it at various points.

A good technique is to make marks on the board resembling a long ruler. Make them large enough so they will show clearly in a photograph. You should then take incremental depth measurements, perhaps every twelve inches if the rut is quite wide, or every six inches if only two or three feet wide. With equally spaced intervals, you could ascertain the average depth but your prime concern is the deepest part.

Don L. Ivey, as Associate Director, TTI, presented a paper for the Mini-Tech Seminar on Tyres, November, 1984, ("Truck Tire Hydroplaning - Empirical Confirmation of Horne's Thesis") wherein he described testing a trailer and towing unit in a trough with a water depth of about .25 inch.

Tyre pressures varied between 20 and 100 psi. Aspect ratios were around 1.40 and hydroplane speeds ranged from 43 to "over 62." You probably can toss out the 43 (at 20 psi) as not even automobile tyres would have this inflation, normally. However, this does demonstrate under-inflated tyres are more apt to hydroplane.

If, during your investigation, you find the inflation pressure is "normal"; that is, 32-35 for a car tyre, the car could hydroplane at highway speeds. But, if the roadway is covered with water and the rain is pouring down, such a speed might not be reasonable nor prudent.

Many states employ the use of an ASTM trailer. This is an intricate device pulled behind a pickup truck in which a special computer is installed. The operator drives at a steady speed and when on the surface to be tested a switch is thrown. At that moment, the device applies a precise amount of water to the roadway immediately in front of one of the trailer tyres. [The amount of water (thickness of water film) does not approximate dynamic hydroplane conditions.]

Then, that trailer tyre is "locked." The computer verifies the speed of the unit and the amount of drag on the tyre and calculates a Skid Number (SN). The SN is the "drag factor" x 100. Keep in mind that this is a measurement on a wet surface.

Officials routinely perform such tests on state highways to determine the resistance to skidding when the surface becomes wet. When that resistance gets close to the highway department's minimum specifications, the road is resurfaced.

Keep in mind during the investigation, wet roads - in and of themselves - do not CAUSE accidents. The amount of standing water or wetness of the surface may well CONTRIBUTE to the accident, but "driver error" is generally the chief factor.

In the U.S., most states have a law under TRAFFIC that reads to the effect drivers must obey the speed limit and in a manner that is reasonable and prudent given the weather and road conditions. If the speed limit is 55 mph, that does NOT mean motorists MUST drive 55 miles an hour. That is the fastest maximum LIMIT! And it applies only under optimum road and weather conditions.

It is not always reasonable and prudent to maintain the LIMIT when it is raining. When the roadway looks "glassy" or the tyres of the vehicle in front of you are leaving imprints, the tread is "channeling away" some water. These are hints to reduce your speed, especially if you have worn tyres. If there appears to be some water in the grooves where traffic generally runs, move over a bit so as not to "track" the same path.

When called to an accident, make these observations en route so you will have a good idea what the road situation will be (and was when the accident happened) at the scene.

Immediately after attending to emergencies at the site, make note of current road state and when you question witnesses, ask about the conditions as they were when the accident happened.

Verify early on whether hydroplaning could have been a factor, observe tyre tread at various points and measure the inflation pressure and tread depths of each tyre.

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