Design for Safety

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•SAFETY has of late been more in the public eye than usual, but this is no new matter as far as the tire makers are concerned. Although concern for safety has been universal it will be appreciated that different needs and concepts exist in different countries as to how the maximum safety level is best achieved.

We believe, however, that the biggest single contribution that tire makers can make to improved safety is in the area of skidding in the wet. Adhesion in the dry is not now really a major tire problem, and structural failures are hardly a direct cause of accidents to any significant degree (not that there is inactivity in these fields—the reverse is the case). But it is wet hold that we think should be the major field for action. As an international company, we are finding this to be the case worldwide.

At this juncture it should be noted that, although the title of this article is "Design for Safety," it has not been found completely possible to separate this subject from the allied subjects of tread rubber compounds, types of pavement, and aquaplaning. There are too many interactions involved to allow this to be possible.

The main factors involved in wet grip are given in Table 1, with an assessment of their level of variability shown in the column on the right. A higher figure shows a high variability and hence a greater potential for improvement. These data were produced in England some years ago but it is felt that they are still very relevant today. It will be observed that tread design, road surface, water depth, speed, and braking systems are all very important factors, and it will probably be conjectured that their analysis with that of the interactions involved will be complex. This has indeed proved to be the case, and it has taken many years of work, on the proving ground and in the laboratory, and a great deal of thought by many people to arrive at the conclusions which will now be summarized.

Aquaplaning was once a theory and subject of controversy, but it is now a proven fact with very practical implications of a far-reaching nature. Figure 1 shows a side view of the contact area between the tire and ground under flooded pavement conditions. It demonstrates the three-zone theory of tire/road contact that was first put forward by V. E. Gough of our company in 1959. Although aquaplaning was once considered to be a rare case of doubtful relevance to everyday conditions, this is no longer the case and its mechanism and the theory involved are acknowledged to be very pertinent to most cases of wet skidding.

Zone 1 in Figure 1 is the zone of bulk water displacement, and here the tread design effect is predominant. Zone 2 is the thin water film zone. Here pattern is still effective, but pavement and tread compound effects also appear. In the third zone, tire/road contact is substantially dry; tread rubber and pavement effects are the most important, with tread design playing a subordinate part.

Figure 2 shows very simply the main features of tread design that are important. The smooth tire section is shown at the top of the diagram, and section B shows a simple ribbed pattern with circumferential grooves. These grooves are important in zone 1 of Figure 1, i.e., in the bulk removal of water. The small slots, knife cuts or sipes in section C of Figure 2 are the design elements concerned with breaking through the thinner film of water shown in zone 2 of Figure 1. In zone 3 of

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TABLE 1

FACTORS INFLUENCING EFFECTIVE BRAKING FRICTION BETWEEN TIRE AND WET ROAD
(100 mph Maximum)

Factor	Level of Variability Due to Factor Considered
Tire:	
Tread pattern design	Up to 4:1
Tread materials	Up to $1\frac{1}{2}$:1
Patterned tire vs smooth tire	Up to 8:1
Road:	
Road surface characteristics	Up to 5:1
Water depth—film 0.05 in. to 0.30 in.	Up to 3:1
Vehicle:	
Speed—reduction due to an increase in speed from 30 to 80 mph	Up to 10:1
Braking system—perfect non-locking system vs locked wheel braking	Up to 3:1

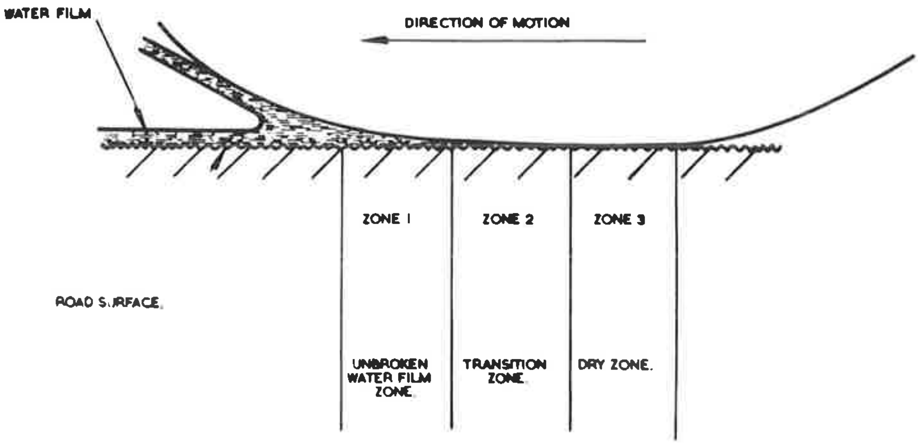

Figure 1. The three zones of the contact area of a tire.

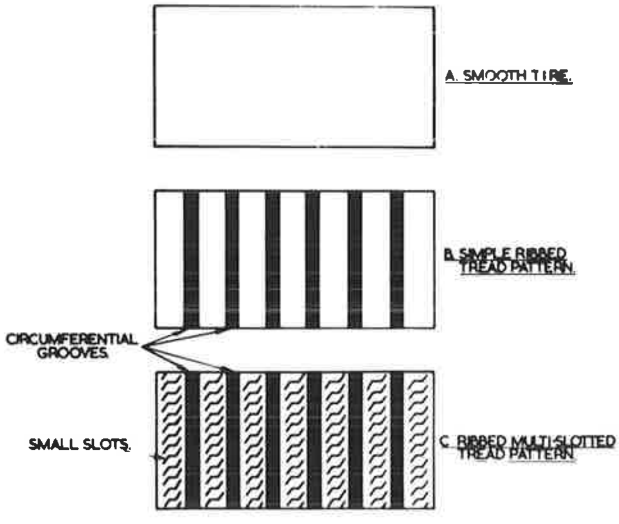

Figure 2. Main features of the experimental tread patterns.

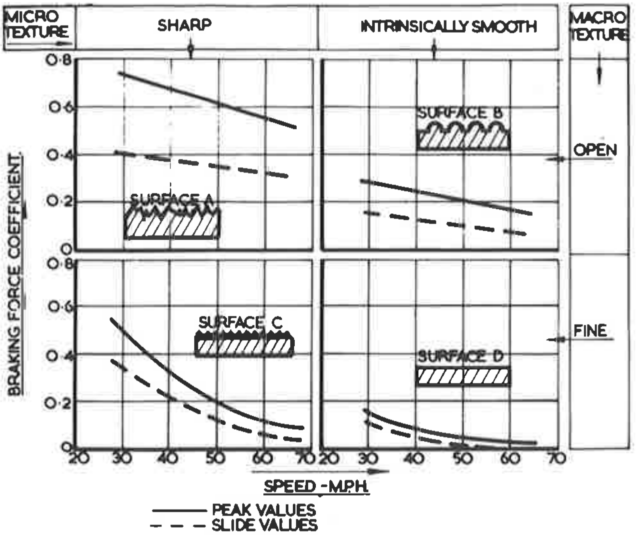

Figure 3. Effect of road surface—smooth tire.

Figure 1 it has been noted that the contact is substantially dry and that the tread rubber comes into its own. But even here it is the tread design that dictates how much tread rubber is in contact with the ground and hence still affects the adhesion.

It at once becomes clear that requirements for the three zones may oppose each other. For instance, zone 1 requires numerous wide grooves, but zone 3 calls for a closed pattern to give the greatest possible amount of rubber in contact with the ground. Hence, a compromise is required. This may also be necessary to preserve other essential tire properties such as tread life, good vehicle handling, and transient stability, all of which are dependent on tread design as well as on other factors.

Our laboratories have, over the past few years, carried out a very full evaluation of adhesions in the wet. This work has been performed on test tracks with actual vehicles, supported where necessary by work on laboratory test machines. The variables studied have included tread patterns, tread compounds, types of pavements, speed variations up to 80 mph, and braking conditions. The last variant entailed measuring peak adhesion values with the tire just rolling and adhesion values with the tires fully sliding.

It will probably be easier first to describe the findings on a smooth, polished surface. We have known for a very long time (since 1925-1930) that such a surface is the most sensitive to tread pattern design and compound variations. For this reason, such a surface has been selected for the bulk of tire development testing.

Using, therefore, a smooth, polished, flooded surface, the following conclusions were reached:

1. At high speeds, tread pattern characteristics dominate tire performance.
2. At all but the slowest speeds, the simplest type of pattern is vastly better than a smooth tire.
3. A modern pattern (one with numerous well-designed grooves and a multiplicity of knife cuts on the ribs) shows less loss of adhesion with increasing speed than any other type.
4. Under the conditions described, the type of tread rubber has relatively less effect than the tread design. An improved compound gives a straightforward improvement in braking adhesion, this improvement being nearly independent of speed.

It should be noted most carefully that this statement concerning the relative importance of compound and design must not be taken out of context. For designing a tire to give the maximum in wet grip under all conditions of road, speed, etc., they would rank about equal. Certainly both are key safety features.

The above findings will be found to agree closely with the three zone concepts mentioned previously.

To illustrate road effects, Figure 3 should be studied. This shows results obtained under flooded pavement conditions with smooth tires. Smooth rather than patterned tires are chosen at this stage to eliminate the main design interactions.

Figure 3 shows braking coefficients plotted against speed for four typical types of surface. The solid lines show peak braking coefficients, and the dotted lines show

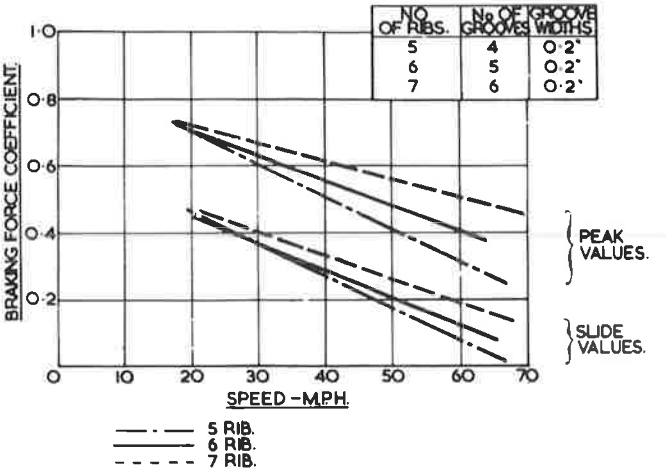

Figure 4. Comparison of tread patterns with four, five, and six drainage grooves.

coefficients obtained with the tires sliding. The two road surfaces in the upper half of the diagram are both open-textured, with a sharp micro texture on the left and a polished macro texture on the right. The lower graphs are for close-textured surfaces, again with a sharp micro texture on the left and polished macro texture on the right.

Thus, surface A (upper left) combines the good drainage of open texture with the good frictional properties of a sharp micro texture. Conversely, surface D (lower right) has poor drainage from close texture, and poor frictional properties from polished macro texture. The other surfaces are obviously intermediate in properties.

As would be expected, surface A is by far the best with the highest brake coefficients and surface D is by far the worst. Again, the other surfaces are, as expected, intermediate.

The results from the full series of tests, where both the tread design and the tread compound were varied for each type of pavement, lead to the following conclusions:

1. Friction on the worst types of surfaces at high speeds is more associated with the removal of water than with compound types. At the risk of being repetitious, it should be noted again that this statement does not denigrate at all the place of the compound in tire development where we want the best performance for all conditions.

2. Tread pattern design has most effect on the closed type of surface such as C or D, but it does not compensate for the deterioration of road surface by polishing.

3. Tire pattern has least effect on open-textured, polished surfaces. This may be partially because the grooves in an open road surface, unlike the grooves in tread patterns, may retain water and feed it into the contact patch.

4. Open-textured surfaces give adhesion coefficients that are less dependent on speed than do closed-textured surfaces.

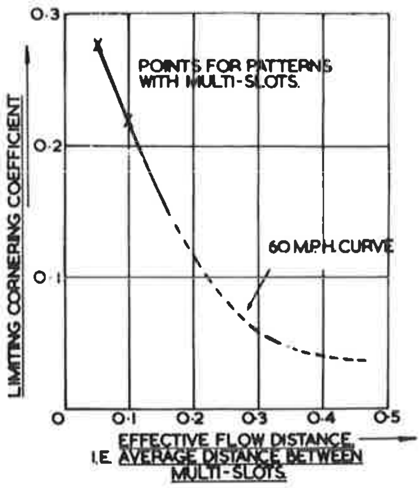

Figure 5. Limiting cornering coefficient vs average distance between tread slots.

The above dependence of tread pattern effect on the type of pavement is of very great practical importance. Measurement of pavement friction by trailer and standard tires is under consideration by official bodies, as is the extension of this principle of tire testing.

The most scrupulously careful consideration should be given here before final decisions are reached. Without meticulous care in specifying the surface, tire testing could become of little meaning. For other reasons we selected driven-vehicle testing in place of trailer testing for our development work a long time ago, as we found the former method to be more realistic.

Consider now the tread design in more detail. We prefer circumferential groove designs to block designs for the following reasons:

1. They are less liable to uneven wear than are block designs, and we have found that what is known as heel and toe wear can, on blocks, assist in initiating the water wedge and hence can facilitate slipping.

2. Water can flow more easily through straight or nearly straight grooves than through channels between irregularly spaced blocks.

3. The continuous ribs associated with continuous grooves are stiffer than blocks and hence distort less in the contact patch. Remember that a design can function as a water remover only in proportion as its grooves or channels remain open in the contact patch where the water is.

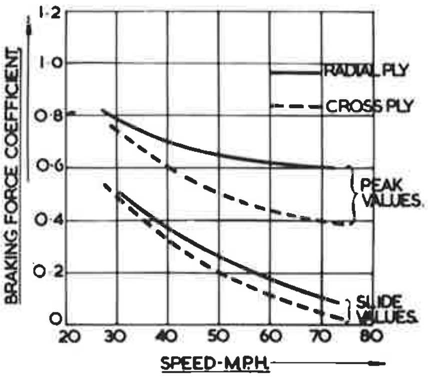

Figure 6. Comparison of production radial ply and cross ply tires; braking carried out on smooth, wet asphalt.

So, having established a preference for grooves, we should consider how many we need. This is illustrated in Figure 4, which shows a plot of braking coefficients against speed. This shows that as the number of grooves is increased from 4 to 6, keeping the groove width constant meantime, the adhesion improves both for peak and slide values. Here results for the 4-groove tire are chain dotted; for the 5-groove tire, solid line; and for the 6-groove tire, plain dotted. The corresponding numbers of ribs in the designs are 5, 6, and 7 respectively.

The importance of groove design having been shown, let us next consider knife-cuts or multi-slots. Figure 5 is a plot of limiting cornering coefficient against average distance between slots in the tread pattern. As will be easily seen, there is a strong correlation, adhesion reducing rapidly as the distance between slots increases and hence the number of slots decreases.

As well as tread design, tire construction can have a significant effect. As previously mentioned, to function in the wet a pattern must not be unduly distorted in the contact patch. Now the radial ply tire has the least distortion of all types due to the high modulus of the tire laterally caused by the rigid breaker. And, as Figure 6 shows, it does in fact have an advantage in grip over the cross ply tire. In this graph of braking coefficient against speed, the dotted lines are cross ply tire results and the solid lines show results from the equivalent radial ply tire. There is a clear advantage for the latter both for peak and for slide values.

Now, it may be asked, what have been the practical results? All the data obtained have been used continuously in our new pattern and compound development work. The result has been that tires are now being supplied with up to 50 percent better stopping power and 50 percent better cornering power in the wet than tires that were being made a decade ago. Under fully flooded conditions, on smooth surfaces, we can now achieve braking coefficients in excess of 0. 50. This figure has often been quoted as marking the line between safety and the reverse. It can therefore be claimed, with some justification, that the latest tires are approaching a position where they are as safe in the wet as in the dry.

More recently we have turned our attention to the problem of truck tires. Here there has long been a discrepancy between truck and automobile behavior. Work in this field has been basically similar to that on passenger tires and we have found that, by pattern improvement, we can almost halve the stopping distance. If we add the effect of compound improvement, we can produce tires which, on flooded roads, can stop a truck in distances equivalent to those in which cars can stop.

Finally the future—what has to be achieved? Work is currently in progress on safety improvements in all three of the aquaplaning zones. We want to be able to deal with more water more quickly, to wipe the ground more completely dry in the second zone by better knife-cuts and more of them; we want further compound improvement to grip the ground better in the dry zone.

We want tires that are safer and that are felt to be safer by the driver. Safety in the wet is not only a question of stopping and cornering; tires must also handle safely when passing another vehicle at 60-70 mph. To help make the safe tire universally desired, it must be improved in other respects—better handling, better transient stability, longer safe tread life—and it must still retain a good boulevard ride.

We would hope that improvement in pavement surfaces would go together with improvements in tires. The first objective should be to eliminate the bad surfaces. A 10 percent loss of adhesion on a good surface does not have the impact on safety that the same percentage loss on a poor surface has. A gain of 0.05 braking coefficient on a poor surface can have a better effect than double that gain on a good surface. So no radically new development is needed for this initial step.

These I am sure are the areas for attack, and these will be our targets for the future. If we can make the same kind of impact in the next few years that has been made in the past, we may all have done well indeed.