2. RUNWAY AND HIGHWAY TRACTION STUDIES – THE PROBLEM, THE OBJECTIVES, AND THE PROGRAMME IN GREAT BRITAIN

PART I – RUNWAY TRACTION STUDIES

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2-I

SUMMARY

In addition to fundamental studies of friction, the traction research programme in Great Britain is aimed at minimising the risk of accidents due to inadequate friction. Attempts are being made to discover which paving surfaces provide the highest level of wet friction and least susceptibility to aquaplaning. The durability of the surfaces and their influence on tyre wear are also being studied. Criteria and methods for assessing when substandard friction conditions exist and when aircraft are liable to aquaplane are being developed in order to provide engineering and operational control.

It is recognised that the programme may not result in a sufficient reduction in the number of accidents and that it may be necessary to tackle more vigorously the tyre and aircraft aspect of the problem.

THE PROBLEM

Magnitude

The world-wide rate of occurrence of accidents in which modern transport aircraft overrun the end of the runway or leave the side of the runway with resultant serious damage to aircraft and/or fatalities is 2.2 per million flights. Although the rate of occurrence of injuries and fatalities to passengers and crew is relatively low (7.6 percent of accidents), there is, nevertheless, a high potential risk. This fact, the aircraft loss involved, and the disruption of service at airports following such occurrences make a strong case for action to be taken.

Causes

The circumstances in which these accidents occur indicate that a loss or reduction of adhesion with the runway is a feature in 35 percent of them. These may be broken down as follows:

Ice or snow 9.7%
Wet runway:
  Low normal wet friction 10.8%
  Virtual disappearance of friction (aquaplaning) 14.6%

It is apparent from this that there is a case for improving adhesion between runway and tyre in normal wet conditions and in conditions where aquaplaning can occur. There is also a case for improving the situation in ice and snow conditions because, although the total number of ice and snow accidents is relatively small, the rate of occurrence is high, in view of the relatively small proportion of operations which take place in such conditions.

A feeling has been expressed by some experts that aquaplaning is a rarity which is blamed too readily in accident investigations. However, there is considerable evidence of loss of contact between tyre and runway in overrun and loss-of-control accidents. Moreover, the rarity of aquaplaning is belied by the fact that 1 percent of damaged tyres returned to one tyre manufacturer for retreading have evidence of rubber reversion, a phenomenon which can be the end product or the cause of aquaplaning.

FUNDAMENTAL STUDIES OF FRICTION

Three basic activities are involved in our fundamental studies of friction.

Firstly, laboratory tests are made to examine the effect of runway surface asperities on a moving rubber block. Secondly, flow visualisation methods are applied to model tyres to examine the manner in which contact between tyre and runway changes. This work, if successfully concluded, could lead to an explanation of phenomena which are described empirically but which are not understood. In particular, an understanding of the mechanism of the influence of rubber resilience could have a considerable impact on design of both tyres and runways.

Thirdly, a test vehicle has been developed and used to obtain braking friction data at relatively low speed, and now a second vehicle is being developed to enable full-scale tyres to be tested in simulated high-speed conditions in order to obtain friction and side-force data, which are not currently available.

CORRELATION TRIALS

A series of trials are to be carried out on a number of runway surfaces, embracing the range likely to be used on airport runways. Two aircraft with braking characteristics typifying those of modern transport aeroplanes will be run over test strips simultaneously, with various friction-measuring apparatus, in varying conditions of wetness.

The objective of these trials will be to establish (1) whether the apparatus are suitable for indicating the level of friction that can be developed by an aircraft braking on the runway in given conditions of contamination and, hence, whether they provide a suitable indication of the basic friction qualities of runways; (2) whether the apparatus can indicate the likely braking performance of an aircraft as runway conditions change and hence provide up-to-the-minute indications of friction conditions for aircraft crews; and (3) that the apparatus perform these functions in a practical and reliable manner. It is important in these trials to emphasise simultaneous measurement of braking action by aircraft and calibration apparatus in view of the lack of knowledge of the parameters which influence braking friction.

FACTORS INFLUENCING AQUAPLANING

Work is already advanced on a series of tests designed to determine the correlation between the minimum depth of water needed to sustain aquaplaning and the physical shape of the runway surface and tyre tread design. The purpose of establishing such correlation is twofold: firstly, to indicate whether particular tyre treads or runway surface designs have advantages over others in preventing the occurrence of aquaplaning and, secondly, to provide data which can be used as design criteria for developing drainage systems for the runways and also as criteria for the possible development of operational water-depth warning systems.

FACTORS INFLUENCING DRAINAGE

Clearly, if there were no tendency for water to remain on runway surfaces there would not be even a wet braking problem; however, it may be possible to achieve a minimisation of the depth of water which can persist on a runway surface to the point where the risk of aquaplaning is negligible. Consequently, an experiment is being conducted for which an inclined plane, whose slope can be varied and which can be subject to controlled rates of simulated rainfall, has been built in order to assess the drainage characteristics of various types of runway surface.

This apparatus is used in conjunction with a wind tunnel to assess the combined effect of lateral wind and runway slope on the depth of water retained on particular surfaces. The objectives of these trials are (1) to discover whether particular surfaces are superior to others, (2) to provide more data on the influence of runway cross fall or crowning slopes, and (3) to provide possible operational criteria which would enable warning to be given that the combination of rainfall rates and surface wind conditions would be likely to give rise to critical water film depths from the point of view of aquaplaning. The achievement of the last objective is obviously dependent upon the derivation of an adequate knowledge of critical aquaplaning depths from the trials referred to in the previous section.

WARNING SYSTEMS

It is apparent, from both accident experience and the results of aquaplaning trials so far completed, that a knowledge of the depth of water covering a runway could serve to warn a pilot of the hazards he might encounter when attempting to land. It is also apparent that a number of accidents and incidents in icy conditions might have been avoided if the airport authorities and the operating crews of aircraft landing and taking off were aware that runway icing was occurring. Consequently, an attempt is being made to develop apparatus which will indicate remotely whether a runway is wet and, if so, what depth of water covers the runway or, alternatively, whether ice is forming on the runway surface.

The major problem involved in developing such apparatus would appear to be to establish locations for the detector systems which would make their indications representative of the major part of the runway used in the course of operational landings. Another factor, of course, is the availability of authoritative data on critical water depths, as mentioned previously.

DURABILITY OF RUNWAY SURFACES AND EFFECT UPON TYRE WEAR

In the United Kingdom there are a range of runway surface designs in operational use, including grooved runways, whose behaviour is being monitored over a relatively long period. The object of this process is to record any susceptibility of the runway to mechanical or structural damage, the rate of deterioration in wet friction characteristics with time, any tendency for the drainage systems to become choked by various forms of local contamination, and, as far as possible, any influence on tyre wear. At the same time, a number of experimental surfaces have been laid whose performance in braking is being assessed at intervals by specially instrumented aircraft and whose wearing characteristics are being observed. Inevitably such programmes as these are slow in producing positive results and because of the difficulties of exercising proper scientific and statistical controls, the results of such experiments may not be quite so positive as those of other experiments which are conducted on this general subject. Nevertheless, it is important that such work be carried out in order to ensure that the benefits which the introduction of new runway surfaces is intended to provide are likely to be maintained over a reasonable life span and are not offset by undesirable characteristics.

FUTURE OBJECTIVES

The current programme of research in the United Kingdom consists of fundamental studies which, because of their nature, cannot be said to have a particular objective apart from increasing our knowledge of the subject. However, future research consists of an interlocking set of studies with specific objectives. These may be briefly described as follows:

We are seeking to find runway surface designs which, taken in conjunction with current tyre designs, will be practicable and will provide a high level of wet friction and ensure a minimum risk of aquaplaning.

The absolute attainment of these objectives is recognised as unlikely; consequently the need to measure the level of friction developed by a surface over both long and short time periods is recognised. In order to achieve this, friction-measurement apparatus are being developed and their correlation with aircraft performance is being established.

Similarly, the ability to prevent flooding of runways to the point where aquaplaning is very likely to occur cannot completely be avoided. In order to deal with this shortcoming, we are endeavouring to establish critical water film depth for runway surface and tyres which may be used in conjunction with warning criteria based on a range of possible measurement methods, in order to enable operational crews to delay landings until more favourable conditions exist.

It must be recognised that although such a programme of testing and development appears logical and should be capable of a successful outcome, there is insufficient knowledge at the present time concerning some of the fundamental processes involved in friction between tyres and runways, and alternative approaches may have to be made.

Work on automobile tyres indicates that low-resilience rubbers are capable of producing high levels of friction on wet runways having suitable surface roughness characteristics. The use of such rubbers in aircraft tyres has not been found feasible at the present time. However, if other research is insufficiently productive it may be necessary to pursue this line of activity more vigorously.

Another aspect of the general problem is the lag between establishing improved methods of runway construction and their general introduction into airport constructional practice. This is particularly acute for aircraft of a small country like Great Britain, because some 80 percent of all take-offs and landings occur abroad where we have no direct control or influence over the airport design. It may therefore be necessary to pursue the development of systems for improving wet braking and minimising the risk of aquaplaning which are self-contained within aircraft. Here the work done by NASA and McDonnell Douglas on air jets comes to mind.

CONCLUSIONS

The programme of runway friction research and development in Great Britain is aimed at defining runway surface designs which will enable the consistent achievement of higher levels of traction under wet conditions than have been achieved hitherto. The programme seeks to answer the following questions:

(1) What runway surfaces must be provided at airports to avoid risk of overrunning the end of the runway or loss of control leading to the aircraft leaving the side of the runway?

(2) What control methods can be used to ensure that the minimum design friction characteristics are still in existence after the runway has been worn and/or contaminated?

(3) How can the risk of aquaplaning be reduced to negligible proportion, either by suitable runway design or by the introduction of measuring systems and associated criteria which can be used to advise aircraft operating crews when hazardous conditions are likely to exist?

(4) What are the fundamental parameters that influence friction characteristics of tyres and runways?

Finally, the programme recognises that there is scope for research and development of tyres and braking systems on aircraft and that this aspect will have to be pursued more vigorously if the first three questions cannot be answered satisfactorily.

2. RUNWAY AND HIGHWAY TRACTION STUDIES – THE PROBLEM, THE OBJECTIVES, AND THE PROGRAMME IN GREAT BRITAIN

PART II – HIGHWAY TRACTION STUDIES

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2-II

SUMMARY

In Great Britain, skidding has always featured prominently in road accidents; it is reported in one of every three accidents occurring on wet roads. Much research has been carried out to identify and study the numerous factors that influence skidding. It has been shown that to maintain high resistance to skidding – or good traction – on wet roads at the lower speeds, the road surface should have a harsh feel; to cater for high-speed travel, the surface should incorporate in its construction materials having large and angular projections. Whilst these requirements can be met with a freshly laid surface, it is difficult to maintain them because of the polishing and compressing action of traffic. The increasing volume and speed of traffic has aggravated the problem, and methods of resisting polishing are being studied at the Road Research Laboratory. Research is also in progress to relate the skidding resistance of road surfaces to the incidence of accidents and to set up standards for different classes of road and for specific types of road layout – such as intersections – where skidding is a greater potential hazard than on a straight road. To locate road surfaces that are slippery and to ensure that standards of skidding resistance are maintained, equipment for monitoring the skidding resistance of the country's roads has been developed.

INTRODUCTION

Research on road accidents, carried out for many years, has shown that skidding continues to be a problem in Great Britain. It is on wet roads that the problem is most difficult. This paper discusses the wet-road problem, and describes the research and the future programme at the Road Research Laboratory aimed at reducing the number of skidding accidents on wet roads.

THE PROBLEM

Although much is known about skidding and the measures necessary to prevent it, the improving performance of motor vehicles makes greater demands on the skidding resistance of road surfaces. The main problem therefore becomes one of producing and maintaining a skidding resistance sufficient to prevent accidents.

Dry road surfaces have a high resistance to skidding, practically independent of speed, whereas wet surfaces generally have a lower resistance to skidding and the resistance decreases as the speed is raised, the rate of decrease being a characteristic of surface texture. On icy surfaces, the resistance to skidding is obviously very low at all speeds. The relative proportions of accidents in which skidding is reported on dry, wet, and icy roads in Great Britain can be obtained from police reports. In the United Kingdom it is a statutory requirement that all accidents on roads involving fatalities or injuries must be reported to the police. Details of these accidents are recorded in a uniform and systematic manner and are then reported to the Ministry of Transport. (See ref. 1.) From these forms data such as those shown in table I can be obtained.

TABLE I.- SKIDDING IN PERSONAL-INJURY ACCIDENTS IN 1967

State of road surface	Number of accidents in which skidding was reported	Total number of accidents	Skidding rate
	(A)	(B)	$\left(\frac{A}{B} \times 100\right)$
Dry	31 350	180 320	17
Wet	29 470	88 400	33
Icy	4 740	6 060	78
All conditions	65 560	274 780	24

To put these figures into perspective, it is necessary to take into account the varying times that roads are dry, wet, or icy and the amount of traffic, in terms of vehicle mileage, using the roads under these conditions. Unfortunately these data are not readily available; therefore the total number of accidents under the different weather conditions are used as a basis for comparison. The number of skidding accidents, expressed as a percentage of the total number of accidents in each weather condition, is known as the skidding rate. The last column of table I gives the relative risk of skidding in accidents in terms of the skidding rates for the different surface conditions. The fact that the skidding rate for wet roads is about twice that for dry roads indicates quite clearly the room for improvements in the skidding resistance of wet roads. The national accident data can be further analysed to show the skidding rate on roads having different speed limits, and table II shows data for 1966.

TABLE II.- SKIDDING IN PERSONAL-INJURY ACCIDENTS ON WET ROADS IN 1966

Speed limit on road, miles/hour	Number of accidents in which skidding was reported	Total number of accidents	Skidding rate
	(A)	(B)	$\left(\frac{A}{B} \times 100\right)$
30	18 920	69 030	27
40 or 50	2 130	5 250	41
70	11 020	24 420	45
Total	32 070	98 700	32

Although this table highlights the effect of speed on the skidding rate for the country as a whole, surveys of accidents and measurements of skidding resistance on long lengths of unrestricted* roads showed that the skidding rate varied between 25 and 70 percent, the higher values occurring on surfaces which were classified as "smooth" textured.

Again, by studying the locations of individual skidding accidents on wet roads it was shown that the frequency of skidding increased on busy roads at sites such as bends, steep hills, and roundabouts where combined braking and manoeuvering tended to make more demands on the frictional characteristics of the surface.

THE OBJECTIVES

Main Objective

The objectives of a rational programme to prevent skidding accidents are obviously to be based on analysis of the accident data; it is therefore of the utmost importance that these data be reliable. The original forms for reporting personal-injury accidents in the United Kingdom have been amended so that the reporting officer is not required to make a subjective assessment of the cause of the accident but merely to state whether or not skidding occurred.

The ultimate aim of all highway engineers and those concerned with skidding accidents should be to progressively reduce the skidding rate until it becomes equivalent to that on dry roads; with further developments in tyre/road adhesion it may even be possible to reduce the large number of skidding accidents occurring on dry roads. In order to keep the skidding rate at a low level, road surfaces should have high frictional coefficients at all speeds throughout the year.

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*Since December 1965 these roads have been subject to an overall speed limit of 70 miles/hour.

Requirements for good skidding resistance.- The requirements for good skidding resistance on wet roads have been investigated at the Road Research Laboratory and are clearly defined. (See refs. 2 and 3.) The first requirement is to facilitate breaking through the water film to establish local areas of dry contact between the road and the tyre. This can be achieved only if there are sufficient fine-scale sharp edges; these give the surface a harsh feel. This fine-scale texture is the dominant factor in determining the skidding resistance at speeds of about 30 miles/hour. As speed increases, drainage channels provided by the large-scale texture of the road as well as the pattern on a tyre become important in permitting the removal of the bulk of the water, but the residual portion of the water layer is more difficult to remove in the short time available (1/200 sec at 60 miles/hour), however harsh the surface texture. Hence, at high speeds additional requirements for good skidding resistance are necessary. These are met to a large extent by making use of the energy losses in the rubber of the tyre as it is deformed by projection in the road surface. It is, therefore, essential on high-speed roads to have sufficiently large and angular projections in the road surface to deform the tread, even though a film of water may still be present, and so take advantage of the higher hysteresis tread materials now in use in Great Britain for passenger car tyres. It has been recommended that these projections should provide a minimum texture depth of 0.025 inch (ref. 3 and p. 80 of ref. 4) on roads where speeds are likely to be high.

Effect of traffic.- Although surfaces can be produced with textures that give high skidding resistance, it is difficult to maintain this high coefficient under the compacting and polishing action of heavy traffic. Road surfaces therefore have to be laid with materials that resist this polishing and "pushing in" action. Because of this stringent requirement, the polished stone test was introduced in British Standard 812 (ref. 5). It is important that this aspect of the problem be considered if the grooving of road surfaces is to be used as a practical remedial treatment for slippery roads. British experience with the transverse grooving of heavily trafficked motorways (p. 150 of ref. 4 and pp. 98 and 165 of ref. 6) has shown that although the treatment can be effective when new, its effectiveness at low speed can be reduced in a comparatively short time. In a particular example, when a slippery concrete surface was grooved, the braking force coefficient at 30 miles/hour was increased from 0.44 to 0.60, while at 80 miles/hour it was increased from 0.13 to 0.49. After a year of heavy traffic, however, the coefficient at 30 miles/hour had fallen to 0.40 and the coefficient at 80 miles/hour to 0.31. These remarks do not necessarily apply to runway surfaces, since in comparison to roads, traffic is very light even at the busiest of airports.

Subsidiary Objectives

The subsidiary objectives of the programme were: (1) to examine the reliability of methods to determine the suitability of road surfacing materials to resist polishing by traffic and (2) to relate the skidding resistance of road surfaces to the incidence of skidding accidents so that standards can be established in terms of measured values of frictional coefficient for different classes of road, road layout, and density of traffic.

In Great Britain the first of these subsidiary objectives has been met by British Standard 812 and the second by standards based on measurements with the laboratory's test vehicles (p. 80 of ref. 4). Over the long period covered by the measurement of skidding resistance and its correlation with skidding accidents, it has been found that if the test vehicles are to be used as a standard they must reliably and consistently indicate skidding-accident risk. To do this the measurements should be made under closely controlled standardised conditions; this is already done in the case of the laboratory's testing vehicles and procedures.

As an example of the importance of careful control over the measuring techniques, it has been found that subtle changes in tyre profile and in the resilience of the tread compound can give variations in coefficients on the same road surface. Special tests have therefore been devised to ensure that all the laboratory's test vehicles are fitted with tyres with standardised physical properties. (See ref. 7.)

THE PROGRAMME

The programme for the future in Great Britain is, in the main, to apply throughout the country the knowledge recently obtained in the hope of bringing about a substantial reduction in the numbers of skidding accidents on wet roads. It is estimated that an average increase nationally of 0.05 in the friction coefficient at 30 miles/hour corresponds to a reduction in skidding rate of $3\frac{1}{2}$ percent. Nationwide, this would represent a reduction of about 2000 personal-injury accidents per year.

Artificial Roadstones

In Great Britain there is a shortage of supplies of natural roadstone with a sufficiently high polished-stone value (PSV) to meet the required standard of skidding resistance for those sites requiring special treatment. Investigations have already revealed several artificial materials with very high PSV, and further research will be carried out to develop artificial road aggregates which can eventually be produced on a commercial scale. (See pp. 31 and 134 of ref. 4.)

Pervious Layers

Allied to the need for high PSV roadstones is the need to remove rainwater quickly from roads. This becomes more important as vehicle speeds and the width of carriageways increase. Consequently, studies are being made of various forms of pervious layers as wearing courses which can withstand heavy traffic without losing their permeable nature. (See p. 114 of ref. 4.)

Monitoring Systems

As the engine performance, suspension, and braking system of cars have improved, the skidding rate on dry roads has increased substantially. This indicates that drivers are demanding more and more in terms of tyre/road adhesion from the road surface. It is only the overall improvement in skidding resistance that has prevented a similar upward trend in the wet-weather skidding rate. Recently, the ratio of skidding rates on wet and dry roads, which indicates the overall standard of skidding resistance under wet conditions, has, in fact, shown a downward trend. However, with the continued increase in volume and speed of traffic the problems of maintaining the proposed standards of skidding resistance will increase in the future. For this reason plans have been made to set up a unified system of monitoring the skidding resistance of the whole of the country's 30 000 miles of main roads.

To enable this to be done a new skid test vehicle has been developed (fig. 1) which is especially designed to measure the slipperiness of some 1500 miles of road in the summer testing period. The vehicle employs the sideway force coefficient principle of measuring skidding resistance, and average values of sideway force coefficient for every 10 or 20 metres of the road will be recorded digitally.

The vehicle will carry its own water supply, sufficient for some 20 miles of continuous testing, and will be capable of a maximum test speed of 60 miles/hour. Unlike any of the machines used before, it will be able to operate in traffic. The organisation of the proposed monitoring system will involve the setting up of a central calibration centre and the deployment of 30 test vehicles throughout the country.

It is hoped that this overall system for measuring the skidding resistance of the country's roads under controlled conditions, together with the establishment of standards, will lead to the general upgrading of skidding resistance and, in consequence, to a reduction in the number of skidding accidents on wet roads. It is also reasonable to hope that this monitoring service will enable the £125 million spent on the maintenance of the country's roads to be allocated in such a way that all roads that need to be resurfaced because of their low coefficients will receive attention.

Tyres

In addition to the improvement of road surfaces, development of tyres for improved wet-road adhesion should continue. Efforts should be directed towards making full use of the greater texture depth of future roads by increasing the energy losses within the tyre tread compound but without undue tyre wear. Figure 2 shows the advantage of tyres with low-resilience tread compounds. Although past work has shown that tread pattern design does not play a great part in improving skidding resistance on surfaces with large texture depths at low speeds, the basic tread-pattern mechanism needs investigation, particularly for high speeds.

CONCLUDING REMARKS

Great Britain is now embarked on a countrywide road-improvement programme including a comprehensive motorway network. Although this will do much to promote the overall flow of traffic, it will be difficult to cope with the steady growth of traffic, which is increasing at the rate of about 6 percent per year. Also there are continual advances in the performance of vehicles, and it is logical to conclude that, as time goes on, the problem of keeping the skidding accidents on wet roads to a minimum will become more difficult.

The basic concepts for providing road surfaces with high skidding resistance are known, and now it is required to use the monitoring system and apply the findings as soon as possible to those surfaces requiring attention.

ACKNOWLEDGEMENTS

Contributed by permission of the Director of Road Research.

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Figure 1.- Skid test vehicle to be used in monitoring the skidding resistance of roads in Great Britain.

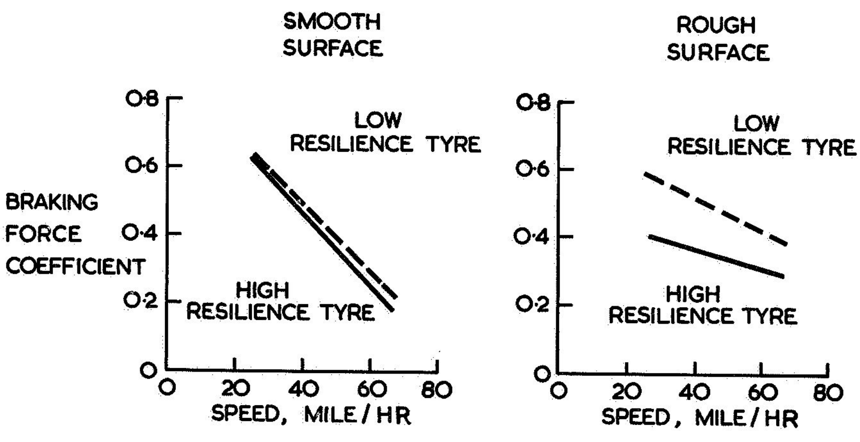

Figure 2.- Skidding resistance of tyres of different resilience on surfaces of different textures.