4. R.A.E. AIRCRAFT TESTS ON GROOVED, OPEN GRADED AND ASPHALT RUNWAYS IN GREAT BRITAIN

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SUMMARY

Plans for aircraft tests to determine the wet braking force coefficients obtainable on runways with widely differing surface textures are given. Initial tests made with a Scimitar aircraft on the runways at the Royal Aircraft Establishment at Farnborough, and the allied work, are described. The results support the view that a harsh, coarse textured surface will give improved braking at aircraft touchdown speeds.

INTRODUCTION

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For some years it has been appreciated that the braking forces which can be developed in wet conditions by a vehicle tyre are far more dependent on the characteristics of the surface on which the tyre is running than on the tyre or its tread. In particular, it has been established that the wet friction coefficient, especially with a natural rubber unpatterned tread, does not decrease with increasing speed to the same extent on harsh, coarse textured surfaces as on other surface finishes (ref. 1). It was thought that this finding would hold for the much more highly stressed aircraft tyre also; therefore, for such tyres it would also be better to introduce coarse textured runway surface finishes rather than to modify the tyre tread in order to obtain the higher wet braking coefficients now likely to be required. Also, it was thought that, inasmuch as tyre wear now causes considerable concern, footprint drainage should preferably be through interstices built into the runway surface instead of by channels or grooves cut in the tread rubber and, further, that any significant technological advances in tread material should be employed to improve the tyre life rather than to build a complicated siped and patterned high friction tread.

Runway grooving has already been employed widely on military aerodromes and an open graded macadam friction course has been developed and laid at one aerodrome. Tests on the latter surface have been confined to measurements made with a locked wheel trailer or a vehicle and the results have indicated improved wet friction. Pilots' reports were also very favourable. No specific measurements of the rate of tyre wear associated with the surfacing have been made. Road experience has suggested that the frictional properties of grooving would be lower than that of coarse textured surfacing at aircraft landing speeds and would, moreover, be directional. It was decided, therefore, to supplement the tests made for the Air Ministry and the Ministry of Public Building and Works engineers on different runway surfacing with a series of tests to determine the wet braking coefficients which could be obtained with aircraft fitted with antiskid systems on as wide a variety of surfaces as possible. The initial tests made on the runways at the Royal Aircraft Establishment at Farnborough, and the supporting work, are described in this paper.

It is a widely held view that if harsh, coarse-texture surfacing is used on runways, greatly increased tyre wear must result. It was reasoned at the Establishment, however, that wear is related to the kinetic energy destroyed in braking and the texture of surface finishes would have little direct effect on wear; nevertheless, it was thought advisable to plan comparative wear tests on different surfaces. One such test has been completed and is reported.

In addition, a study which was made of the available statistics on tyre life is included inasmuch as this study indicates the magnitude of the problem facing tyre designers if the demand for increased wet friction, together with adequate tyre life, is to be met by tyre modification alone.

TEST SURFACES

The three runways at Farnborough have the following friction courses:

Main runway – Grooved Marshall asphalt to BS 594

Subsidiary runways – Plain Marshall asphalt and open graded macadam of larger aggregate than the standard recommended (The standard open graded macadam was developed for the Air Ministry to provide a friction course through which water could drain.)

Figure 1 shows plaster casts of the three surfaces. Casts were taken as they bring out the texture. Figure 2 shows the concrete finishes recently laid at a Royal Air Force aerodrome, together with a type of road surface finish similar to that recommended for motorways, which is being laid at Cranfield. Tests of these surfaces are planned.

SPIN-UP WEAR ON DIFFERENT FRICTION COURSES

Before it was finally decided to lay a friction course at Cranfield aerodome similar to the recommended road finish, a rig test was made to determine the damage caused to both the tyre and the surface by wheel spin-up (ref. 2). It was done on an undercarriage drop test rig using a 40 × 12, type VII, 16-ply-rating nylon tyre at 140 psi. The wheel was spun up to the equivalent of a touchdown at 105 knots and dropped at $7\frac{1}{2}$ ft/sec on slabs of the recommended road, open graded macadam, and Marshall surfacing. The maximum vertical reaction was 35 000 lb. Some twenty drops were made on each surface with one tyre and the damage to the tyre was up to $\frac{1}{10}$-in-deep striations in the centre three ribs of the tread rubber on the recommended road surface; these striations were widened on the open graded macadam finish with small sections of the rubber being torn out of the tread on this surface and on the Marshall surface which was tested last. No stone was lost from the recommended road surface and the damage to the tyre was limited (fig. 3). On the basis of these results, laying of a section of the recommended road surfacing is proceeding at Cranfield for aircraft tests.

COMPARATIVE WEAR TESTS

One test comparing the wear on the open graded macadam subsidiary runway with that on the grooved asphalt main runway has been completed (ref. 3). Thirty-five landings were made on each runway in dry weather with a Meteor Mk.7 aircraft equipped with low pressure tyres (60 psi). Five pilots participated in the test and each made, insofar as it was practicable, the same number of landings on each surface. They aimed for a touchdown speed of 105 knots and a brakes-on speed of 95 knots. The aircraft brakes did not develop sufficient torque to lock the wheel on a dry runway so that maximum braking could be used and almost the same decelerations (0.2g) could be achieved on every landing. It was found that the wear was significantly less on the open graded macadam friction course, being 8.2 percent less as determined by groove depth measurement and 10.6 percent less by loss of weight.

This result was supported by accelerated wear tests carried out by the Natural Rubber Producers Research Association on motor vehicle tyres (ref. 4). In these tests, tyres were mounted on a towed trailer with the wheels alternately toed in and out to give slip angles of $\pm 7\frac{1}{2}^{\circ}$.

It is believed that by making tests with an aircraft, in which similar decelerations are recorded by all test pilots, the true wear rating of the runway is obtained; moreover, these decelerations were comparable with those normally used in Civil airline operation. Further wear tests with higher pressure tyres are planned.

FOOTPRINT DRAINAGE THROUGH THE FRICTION COURSE

An investigation of the drainage available under the tyre footprint from the different surface finishes has been started. The object is to provide a rig which gives a measure of the flow of water through the footprint—runway-surface interface under a given pressure. The rig is illustrated in figure 4. Water is supplied from a fire engine through a measuring venturi to the centre of a 11-in-diameter circular rubber pad held down on the test surface by a loaded beam pivoted on a bridge piece, which in turn is held down by two heavy vehicles. The preliminary results obtained with this rig are given in figure 5 and indicate the advantage of either a coarse textured or open graded surface, inasmuch as at the same pressure a much greater quantity of water is discharged with these surfaces than with the smoother textured finishes. It is intended to compare the interface discharge with grooved rubber pads representing new and worn ribbed tyres.

BRAKING COEFFICIENT TESTS ON THE FARNBOROUGH RUNWAYS

Preliminary trials were made first with a Meteor aircraft and later with a Lightning aircraft. It is realised that the tests would be conducted much more expeditiously if they were not flight tests and the aircraft could be accelerated and braked within the length of the runway under test. It was also apparent that if the undercarriage flexed appreciably, the measurements would be affected. It was decided that a Scimitar aircraft would be used for the trials proper. It has a high thrust-weight ratio and an antiskid braking system while, being a Naval aircraft, the undercarriage and airframe structure are sturdy. The aircraft was tested at an all up weight of 28 000 lb.

Instrumentation

The Scimitar aircraft was equipped with an accelerometer, stabilised against aircraft pitching by mounting the instrument in a modified master reference gyro. Brake pressure and brake supply pressure were recorded for both port and starboard brakes by pressure transmitters and enabled the antiskid operation to be followed. An airspeed indicator with a low speed range was installed to enable the pilot to gauge his ground speed. As a check on the accelerometer, the aircraft speed was measured at entry to and exit from the test section by the aircraft nose wheel interrupting two light beams across the runway 10 ft apart, which were focused on photoelectric cells starting and stopping an electric timer. (See fig. 6.) A high-speed cinefilm, portraying the aircraft against marker posts along the runway and with a time base, was made and served as an additional check.

Tests

After the first test run with the Scimitar on a dry runway showed that the braking was limited by both the brake pressure and the antiskid system, the brake pressure was increased and the threshold of the antiskid unit was raised. Tests were then made on the grooved asphalt main runway when the weather was fine and showed that with the modification there was no brake torque limitation. Inasmuch as the brakes were operated at increased pressure, it was decided to strip and inspect them after every test run; however, no undue wear was observed.

For each test the aircraft was accelerated to reach the intended speed, allowing for either head or tail wind, at a point some 350 ft short of the test section. The port engine was then flamed out and the starboard engine throttled back to a fast idle. After a free run of about 200 ft, while engine thrust died down, maximum braking was applied; the aircraft then was about 150 ft short of the test section. Maximum braking was maintained until the aircraft came to a halt.

For the tests on a wet surface, water was distributed over the runway surface to a depth of 0.2 inch by water bowsers in a total time of between 5 and 10 minutes, and the test run was made within 5 minutes on this being done. Figure 7 illustrates the aircraft leaving the wetted test section on the open graded surface.

Some trouble was experienced with the interrupted light beam timer, which is experimental, but sufficient readings were obtained to check the operation of the accelerometer on three tests. The differences in the speeds at entry to and exit from the test section agreed, within 2 mph, with those obtained by integration of the acceleration recorded from these two points and until the aircraft came to rest.

Unbraked free running trials were made on the grooved asphalt surface to determine the effect of residual engine thrust, aerodynamic drag, and rolling resistance at four speeds and the aircraft was tracked by a kinetheodolite. These results were used to obtain the net braking. The instantaneous values of the braking force coefficient, as a function of ground speed, are shown in figure 8 for the open graded macadam friction course.

Results

The results of the tests made so far are given in figure 9, together with some measurements made by the Road Research Laboratory (ref. 5) with the Ministry of Technology heavy load vehicle using a similar tyre. The significant features of the aircraft results are as follows:

(1) The marked drop in wet friction on the grooved asphalt surface at high speed was from 0.3 at 90 knots to 0.18 at 110 knots.

(2) The wet friction on the grooved asphalt and on the Marshall surfaces is the same at 90 knots – that is, 0.3.

(3) The open graded coarse aggregate macadam gave a slightly higher wet friction at both 70 and 90 knots than either the Marshall or the grooved asphalt. The tests on this coarse aggregate macadam surface at 110 knots could not be made because the end of the runway was being reconstructed at the time.

(4) The dry friction measured on the grooved asphalt surface at 90 knots is only a little higher than the wet friction on the same surface and is the same as the wet friction on the open graded macadam.

The low dry friction obtained with the Scimitar without brake or brake torque limitations led to a look at some American results for dry friction coefficients where a value of 0.51 at 90 knots was recorded with a tyre at 140 psi and a load of 25 000 lb. The gross footprint area of this tyre is approximately 180 square inches compared with that of 117 square inches of the Scimitar main wheel tyre. This fact together with the lower value found for the Lightning tyre which has a gross footprint area of only 65 square inches and the fact that dry friction values for vehicle tyres are in many cases over 1.0 suggested that since the forces necessary for braking must be developed in the footprint, a study of the kinetic energy dissipated in braking in relation to tyre size might be valuable from both the wear and friction aspects.

TYRE LIFE AND DUTY

It seemed reasonable to expect that the reduction in tyre life in recent years, which is causing some concern, might be related to the increased kinetic energy of the aircraft at landing and some factor affected by tyre size. Landing kinetic energies have risen rapidly. For example, the kinetic energy is nearly 50 times greater for the Concorde than for the DC-3 while tyre sizes have in general decreased, the higher loads being catered for by increasing the number of wheels and the tyre inflation pressure. The idea of a tyre duty, which is defined as the designed braking energy capacity per unit of wearable tread volume, was therefore put forward. Figure 10 shows the relationship between tyre life and tyre duty for a wide range of aircraft tyres. Despite the inadequacies of much of the data on the actual energies which have been absorbed by braking, on tread volumes, and on tyre lives, the correlation is reasonable. It is seen, for example, that the life of the tyres of the Twin Pioneer with a duty of 6×10^3 ft-lb/in^3 was about 900 landings per tread, whereas the Boeing 707 tyres with a duty of 35×10^3 ft-lb/in^3 have a life of 72 landings per tread. In particular, it is worth noting that the short tyre lives of the higher performance military aircraft are a continuation of current civil tyre life and indicate the likely future civil position with the present trends.

DISCUSSION

Tyre Friction

The results obtained with the Scimitar aircraft and the Ministry of Technology heavy load vehicle show the expected decrease in braking coefficient with increasing ground speed. The decrease is, however, less for the coarser textured open graded macadam than for the grooved asphalt friction course.

At the same time that the heavy load vehicle tests were made, some measurements of the locked wheel braking force coefficient were made with the Road Research Laboratory small braking force trailer at speeds up to 87 knots on both grooved asphalt and the open graded runways. Above 70 knots the braking force coefficient increased rather than decreased as the speed was raised on both surfaces. This result confirms the view that aircraft braking performance cannot be estimated from locked wheel measurements (ref. 6), particularly if these measurements are made with lightly loaded vehicle tyres. Because of the time required to make aircraft tests, and the associated difficulties, a test vehicle using a driven, instead of a braked, test tyre has been proposed inasmuch as this type of vehicle enables the important actions taking place in the tyre footprint during braking to be reproduced at much lower speed (ref. 7). Although to make realistic tests the fully laden weight of such a vehicle would need to be about twice the load to be carried by the test wheel, involving a vehicle weight of, say, 20 to 30 tons, the test vehicle could readily be moved from aerodrome to aerodrome as it could be driven on the public roads. The primary object of this proposal was to avoid the difficulties associated with operating a heavy test vehicle at aircraft rejected take-off and touchdown speeds, but the stable operation of a driven test tyre at any slip ratio has many advantages. The friction values are obtained by steady, as against instantaneous, measurements so that at constant slip ratio and steady speed it will be possible to assess the average friction characteristics of any runway or any type of surface-tyre combination.

The wet braking force coefficients obtained with the Scimitar aircraft, even on the open graded macadam surface, are appreciably below those obtained with vehicle tyres of either natural rubber or high wet friction synthetic rubber. (See fig. 9.) The difference in the braking force coefficients of the aircraft tyre and the natural rubber vehicle tyre is perhaps accounted for by the reduced efficiency due to the antiskid operation on the aircraft and the very much lower tyre duty of the vehicle. However, the considerably higher braking force coefficients obtained with the high wet friction synthetic rubber vehicle tyre suggests that appreciable benefits might be gained if the low temperature requirements for aircraft tyres were relaxed so that tread compounds based on synthetic rubbers might be used.

Experience with the Open Graded Macadam Friction Course

The open graded macadam friction course was laid at Farnborough over 2 years ago. The winters had been mild but on one occasion a fall of a few inches of snow cleared remarkably rapidly from the open graded surface due, it is believed, to the dark colour and good drainage; this runway was in use several hours before the grooved asphalt main runway. No damage has resulted from the few night frosts experienced and intensive tests, in a cold chamber, on a sample of this surface did not cause breakup of the surface.

It was observed that the flocks of lapwings, which from time to time settle on the runways not in use at Farnborough, never collected on the open graded surface although there might be a hundred or so on the asphalt surfaced ends.

CONCLUSIONS

The limited aircraft tyre tests made so far support the view that greatly improved wet friction at aircraft brakes-on speed may be obtained with harsh, coarse textured friction courses and that such finishes will not increase the tyre wear problem. Additionally, such finishes will provide the drainage under the footprint necessary to prevent aquaplaning and will not necessitate the use of a grooved tread, with the attendant disadvantage of inadequate drainage when the ribs are worn away. A plain tread in turn would increase tyre life and make fabrication easier.

Although a major improvement tyre-runway friction will undoubtedly be gained by alterations to the texture of runway surfacing, some gain could be expected from the use of the high friction synthetic rubber tread compounds which might prove practical if the low temperature requirements for aircraft tyres were relaxed.

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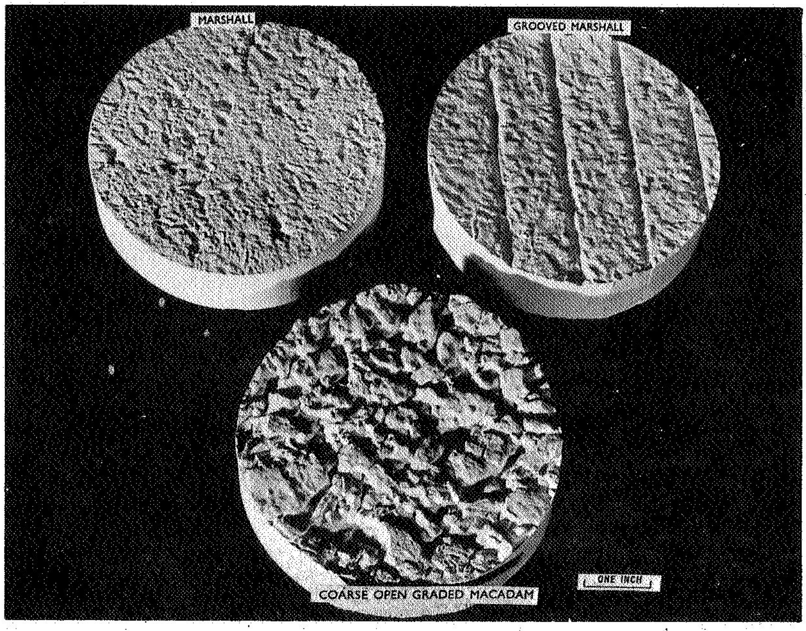

Figure 1.- Plaster casts of R.A.E. runway surfaces.

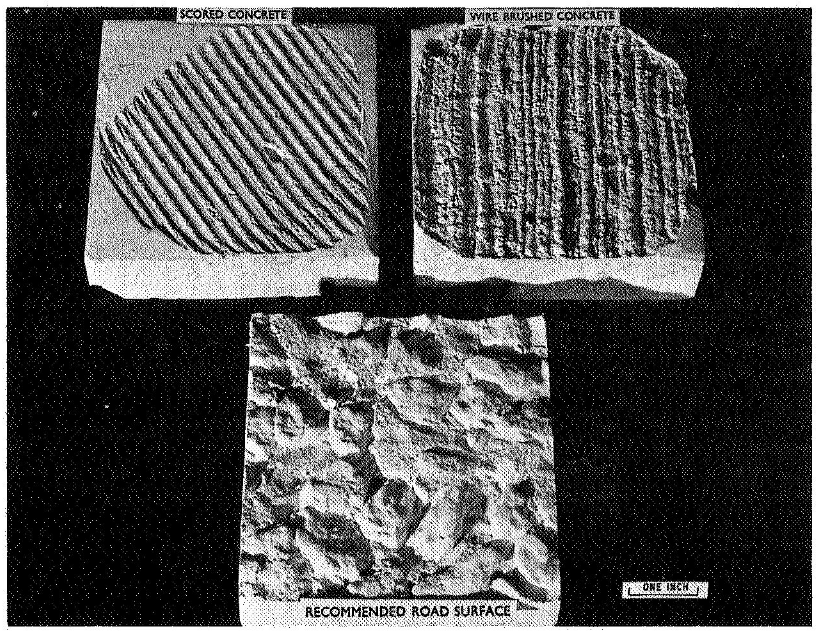

Figure 2.- Plaster casts of two concrete runway surfaces and a recommended road surface.

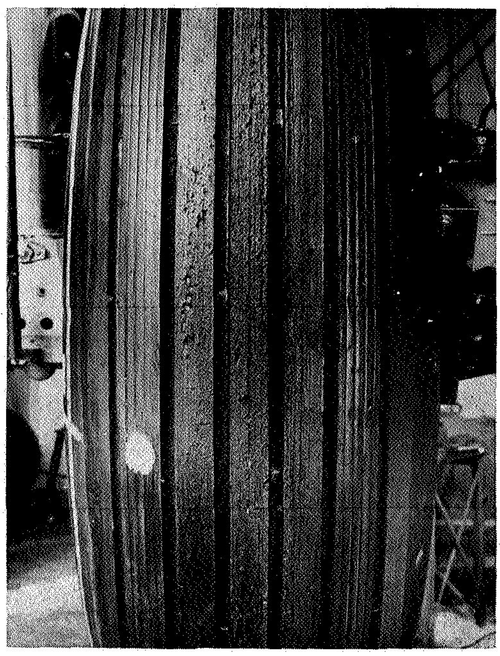

Figure 3.- Worst area of tread damage after 56 spin-up wear tests on three surfaces.

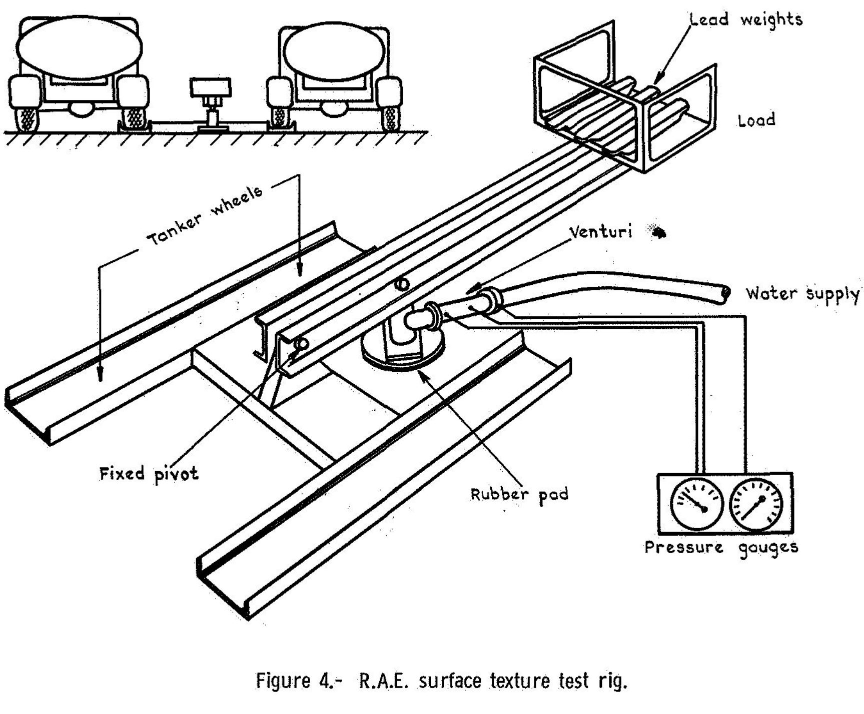

Figure 4.- R.A.E. surface texture test rig.

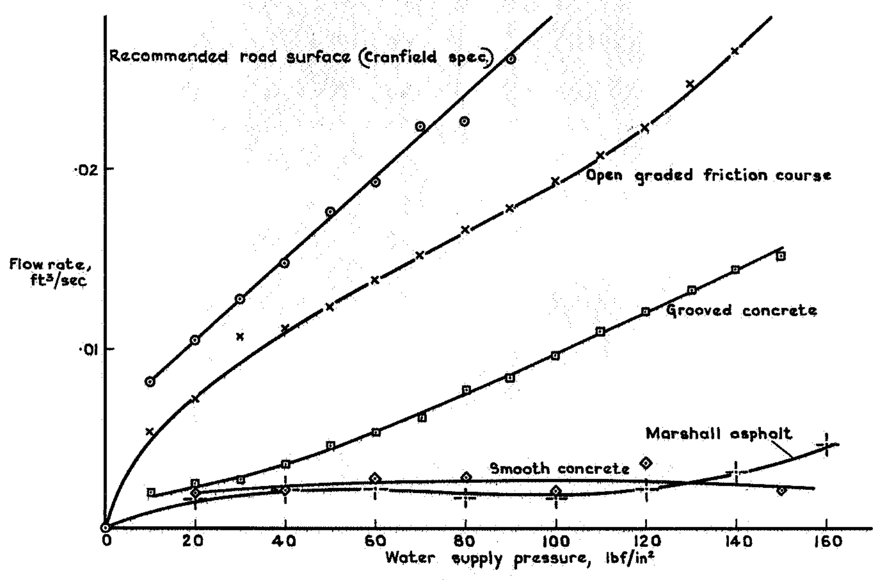

Figure 5.- Water flow rate against water supply pressure with 100 lbf/in^2 pad pressure.

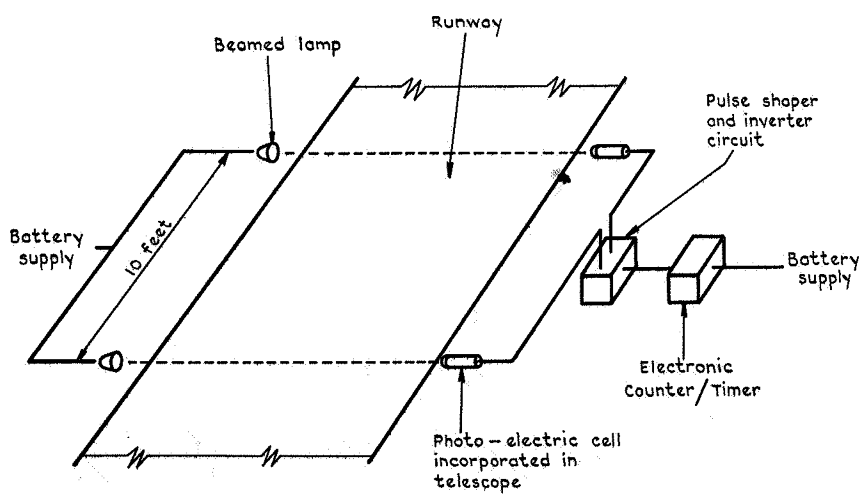

Figure 6.- Interrupted light beam equipment.

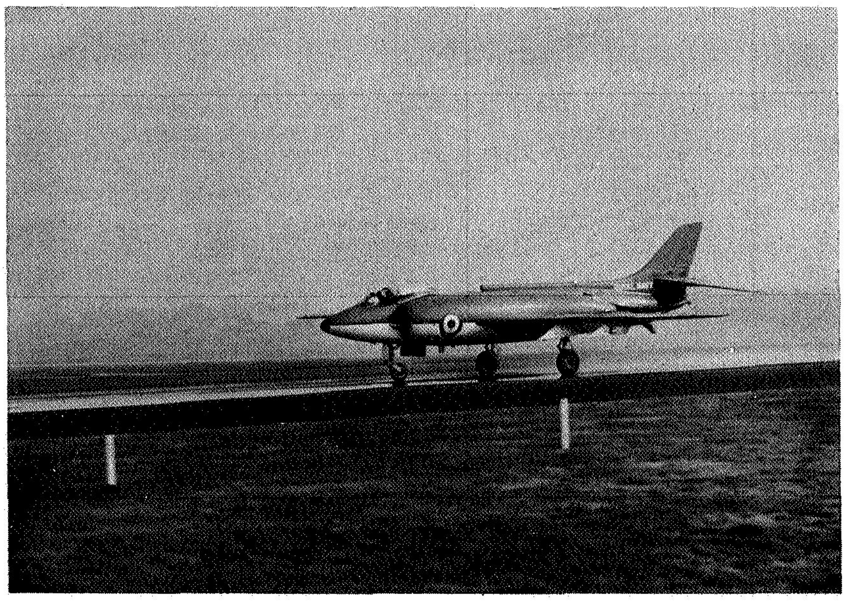

Figure 7.- Scimitar on wetted test section of open graded surface.

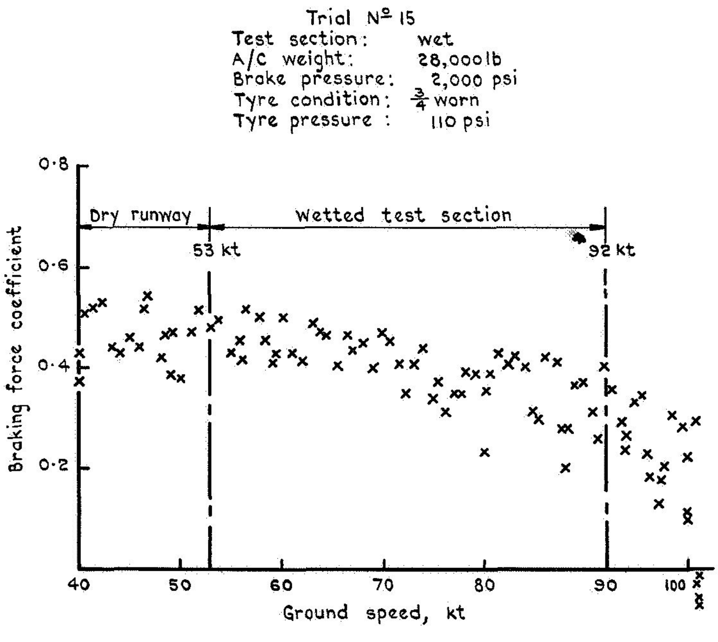

Figure 8.- Instantaneous values of braking force coefficient on the open graded friction course.

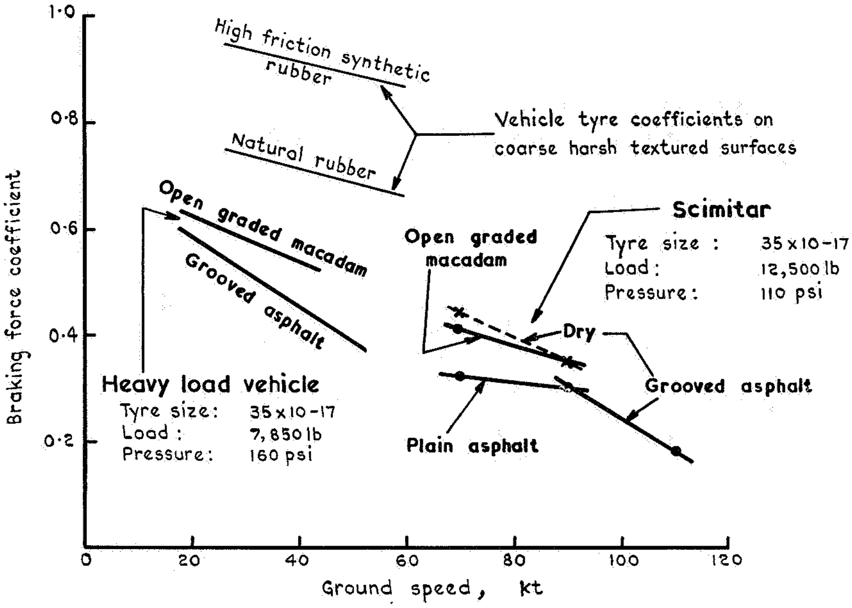

Figure 9.- Scimitar braking force coefficients measured in wet conditions on R.A.E. runways.

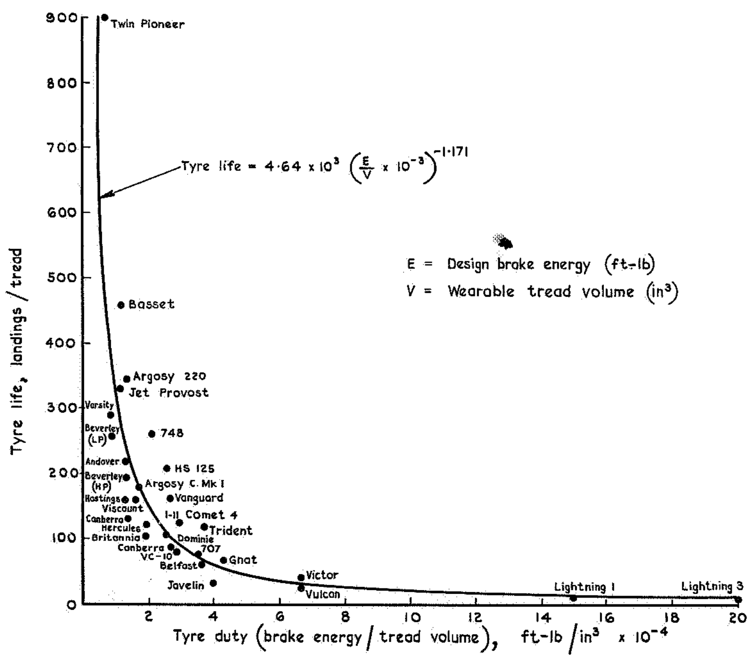

Figure 10.- Relationship between tyre life and tyre duty.