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TESTS WITH A HEAVY LOAD SKIDDING TEST VEHICLE INCORPORATING A MARK I MAXARET ANTI-LOCKING BRAKE SYSTEM TO DETERMINE BRAKING FORCE COEFFICIENTS BETWEEN AN AIRCRAFT TYRE AND VARIOUS WET SURFACES

TRIALS AT THE ROAD RESEARCH TRACK AT CROWTHORNE
AND AT WISLEY AERODROME, WHITE WALTHAM
AERODROME, AND LONDON (HEATHROW) AIRPORT

REPORT OF WORK CARRIED OUT BY THE ROAD
RESEARCH LABORATORY UNDER CONTRACT TO
THE MINISTRY OF AVIATION

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CORRIGENDA TO S & T MEMO 10/64

1. Sheet 1, heading, line 1; delete "S" from "VEHICLES".

2. Sheet 4, FOREWORD, line 7; amend "lists" to read "tests".

3. Paragraph 7.2, line 9; amend "intertia" to read "inertia".

4. Paragraph 8.1.2, line 1; amend "breaking" to read "braking".

5. Paragraph 8.2.1, line 6; amend "usuable" to read "usable".

6. Section I, Table I, right hand heading; amend "breaking" to read "braking".

U.D.C. No. 629.7.022.723 : 629.7.097 : 531.43

S & T Memo 10/64

JANUARY 1965

TESTS WITH A HEAVY LOAD SKIDDING TEST VEHICLES INCORPORATING A MARK I MAXARET ANTI-LOCKING BRAKE SYSTEM, TO DETERMINE BRAKING FORCE CO-EFFICIENTS BETWEEN AN AIRCRAFT TYRE AND VARIOUS WET SURFACES.

Section:

I. Trials at Crowthorne - The effect of an anti-locking brake on the braking performance of an aircraft tyre on four wet road surfaces.

II. Trials at Crowthorne - Preliminary measurements to determine the efficiency of an aircraft anti-locking brake.

III. Trials at Wisley Aerodrome - Measurements of braking force coefficients of an aircraft tyre on a wet asphalt surface with a slurry overlay.

IV. Trials at White Waltham Aerodrome - To determine the skid resisting properties of an aircraft tyre on a wet grass surface.

V. Trials at London (Heathrow) Airport - Measurements of braking force coefficients of an aircraft tyre on a wet brushed concrete surface.

SUMMARY

This report conveys the results of five test programmes with a Heavy Load Test Vehicle to determine braking force coefficients on the following wet surfaces, smooth concrete (Crowthorne), fine cold asphalt (Crowthorne), quartzite macadam (Crowthorne), 3/8" gravel carpet (Crowthorne), wet grass (White Waltham), asphalt with slurry overlay (Wisley) and brushed concrete (Heathrow).

The test wheel was fitted with a Mark I Maxaret anti-locking brake and a ribbed patterned 35 x 10-17 Aircraft tyre inflated to various pressures from 40 to 260 lbs/sq.in., and loaded to 2.8 or 3.5 tons at various speeds up to 60 m/hour (max. on grass 30 m/hour).

It was found that:-

(a) The anti-locking brake system had the effect of improving the braking performance over that obtained for locked wheel configurations under all test conditions. Although the efficiency of the anti-locking system and the locked wheel arrangement were of the same order at 10 m/hour, as the speed of test was raised the anti-locking system showed to increasing advantage.

(b) As in previous tests the braking force coefficient fell with increase in speed. It also fell with increase in inflation pressure, except on the polished gravel carpet. The decrease being most noticeable on smooth or fine textured surfaces.

/(c)

(c) On wet grass, the Maxaret unit failed to cycle correctly at the lower speeds and higher tyre pressures, and, on two slippery paved surfaces there was a tendency to momentary locking accompanied by a slower than normal cycling. Some improvement resulted from a reduction in tyre pressure.

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FOREWORD

In co-operation with the Ministry of Aviation, the Road Research Laboratory of the Department of Scientific and Industrial Research is investigating the effects of varying speeds, wheel loads and tyre pressures on the braking performance of aircraft tyres on typical wet surfaces. This report records the results of five test programmes, with the test wheel fitted with a Mark I Maxaret anti-locking brake. It is the intention to extend this series of lists to include tests with a modified Mark I Maxaret system.

I - THE EFFECT OF AN ANTI-LOCKING BRAKE ON THE BRAKING PERFORMANCE OF AN AIRCRAFT TYRE ON FOUR WET ROAD SURFACES

1. Introduction to Section I

1.1 In cooperation with the Ministry of Aviation the Road Research Laboratory is making investigations into the braking performance of aircraft tyres. This report gives the results of tests made on the special road surfaces on the Laboratory's Research Track at Crowthorne using the Heavy Load Test Vehicle fitted with an anti-locking brake (Maxaret system) and compares these results with some obtained subsequently for a fully locked wheel under similar test conditions.

1.2 The maximum inflation pressure used has been raised in the present tests from 180 lb/sq. in. to 260 lb/sq.in. to provide data appropriate to existing aircraft operational pressures.

2. Test Surfaces

2.1 Of the four test surfaces two were coarse textured, namely, the $\frac{3}{8}$-in. gravel carpet and the quartzite macadam; and two were fine textured, the fine-cold asphalt and the smooth concrete. The gravel and the concrete surfaces were polished; the fine-cold asphalt and the quartzite were harsh. These surfaces are described and illustrated in S & T. MEMO 5/64.

3. Test Conditions

3.1 The test conditions are summarised in Table I. The test tyres were the same type as those described and illustrated in S. & T MEMO 5/64.

3.2 The wheel load of 3.5 tons was comparable with that used in the Swift aircraft tests (S. & T. MEMO 19/61 and 2/62). The effect of load on the locked wheel braking force coefficient was examined in S. & T. MEMO 5/64.

3.3 The test surfaces were kept wet by numbers of water sprays installed in the track. Watering was continuous, the depth of the water film being maintained as far as possible at 0.020 in.

3.4 Water depths measured during the tests showed the following variations on the four test surfaces:-

Fine cold asphalt	0.015 in. - 0.025 in.
Smooth concrete	0.007 in. - 0.025 in.
Quartzite macadam	0.007 in. - 0.032 in.
$\frac{3}{8}$-in. Gravel carpet	0.015 in. - 0.036 in.

The temperature of the surfaces varied during the tests between 15°C and 19°C.

3.5 The anti-locking braking tests were carried out during the months of September and October 1963, and the locked wheel comparisons in January and February 1964.

4. Test Procedure

4.1 Runs were made with the test vehicle at speeds up to a maximum of 60 mile/h. On each run the test wheel was lowered and loaded in advance of the test surface, the tests being randomised for speed and

/Surface

surface. After the vehicle had reached the wetted section the test wheel brake was applied within the confines of the wetted area. At the highest speed the duration of braking was of the order of three to four seconds. Proportionately longer periods of braking were obtained at the lower test speeds. The test sections were found to be long enough to obtain satisfactory records at the maximum speed of the vehicle, using anti-lock braking.

4.2 Rest periods of one hour or more had to be allowed during the anti-lock braking tests in order to keep the temperature of the brake within safe limits, and so to guard against the possibility of a burst tyre.

4.3 The comparable locked wheel braking tests were conducted in the same way as the tests described in S. & T. MEMO 5/64, but omitting the high inflation pressures on the rough surfaces to minimise tyre damage.

5. Examination of the Consistency of the Tests

5.1 Before the main series of tests, preliminary measurements were made with the anti-lock braking system to investigate the consistency of the results obtained in different tests and also when two different but similar tyres and brakes were used. The tyres were loaded to 3.5 tons and inflated to 100 lb/sq.in. This pressure was chosen because at low pressures there was a tendency to damage the tyre walls and at higher pressures there was more tread wear than was desirable at this stage of the tests.

5.2 These preliminary measurements were made on the fine-textured cold asphalt surface at speeds from 10-60 mile/h. A summary of the results obtained expressed as "mean braking force coefficients", is shown in Table II. and Fig.1. Although these tests show that there is no real difference between the "mean braking force coefficient" obtained with the two tyres and brakes, the scatter of the individual measurements is rather larger than in the locked wheel tests. The definition of the "mean braking force coefficient" is given later.

6. Adjustment of the Braking System

6.1 Previous experience in testing the anti-locking brake had shown that if too much braking effort was applied on very low coefficient surfaces the anti-locking unit would function to reduce the pressure supply to the brake but the wheel might lock momentarily or the unit might operate at a much lower frequency than the normal 4-5 c.p.s. Experiments were therefore made to determine the correct braking effort required to maintain the normal response of the brake unit. The disc brake is normally operated by five interconnected hydraulic cylinders to which the fixed brake pads are attached, and is fed with hydraulic pressure from the Maxaret anti-lock device. On the two high coefficient surfaces (the fine cold asphalt and the quartzite macadam), and with a nominal supply pressure of 1750 lb/sq.in., it was found that sufficient braking effort could be obtained from three cylinders, Plate I. To enable the wheel to respond on the two low coefficient surfaces (the ⅜-in. gravel carpet and the smooth concrete), only two operating cylinders were required. It was also observed that the frictional force of these surfaces was insufficient to overcome the residual brake resistance quickly enough, so that the wheel did not spin up again and in some circumstances actually locked completely. To minimise this effect stronger brake release springs were fitted to both brake units.

6.2 Comparison of Plates II and III shows how reducing the braking effort and increasing the brake release spring pressure improve the operation of the anti-locking brake on a low coefficient surface.

/Interpretation

7. Interpretation of the Anti-locked Wheel Results

7.1 The recording system of the test vehicle was initially designed to measure the load and the brake torque by means of hydraulic capsules connected to Bourdon tubes operating a pen recorder. To obtain a reading of brake torque the stationary parts of the test wheel disc brake were mounted on a torque arm which acted on the brake torque hydraulic capsule. Although this system of recording was satisfactory for measuring average locked wheel braking torque of some 1-2 seconds duration it was not sufficiently responsive to enable the more rapid fluctuations of the torque during the anti-lock brake tests to be measured. Therefore, in order to obtain records with the anti-locking system operating, strain gauges were mounted on the existing torque arm and a modified recording system as described in S & T MEMO 5/64 was used. This improved method of recording enables wheel inertia to be allowed for in deriving the braking force from the brake torque.

7.2 When the angular velocity of the wheel is changing rapidly as it does in these tests the brake torque is not exactly equivalent to the braking force acting between tyre and road at the contact area. When the wheel is spinning up, part of the couple due to the ground forces is employed in overcoming the inertia of the wheel and the measured brake torque is less than the ground force couple. When the wheel slows down the opposite is the case. If we assume that the braking force (drag) contributes all the couple due to the ground forces then the equivalent braking force coefficient represented by the intertia effect is given by

$$\frac{F}{W} = \frac{I\dot{w}}{grW}$$

where F = Equivalent inertia force acting at the test surface (lb weight)

I = moment of inertia (lb ft^2)

w = angular velocity of the wheel (radians/sec)

$\dot{w} = \frac{dw}{dt}$ = angular acceleration of wheel (radians/sec^2)

r = rolling radius (feet)

W = wheel load (lb weight)

g = 32.2 (ft/sec^2).

7.3 The moment of inertia I of the rotating parts of the wheel assembly was obtained experimentally as shown on Plate IV, by equating the energy lost by the falling weight to the rotational energy $Iw^2/2$. This was found to be 134 lb. ft^2 so that for a load of 3.5 tons the equivalent braking force coefficient due to the inertia is

$$\frac{134}{32.2} \cdot \frac{\dot{w}}{\frac{35}{2\times12}} \cdot \frac{1}{3.5 \times 2240} = 0.000364\,\dot{w}$$

Estimates made from the test records showed that this did not exceed about 0.05 so that the error due to ignoring it would not be very large. However, if one is concerned not with the instantaneous braking force but with its average value over an interval (this is usually so when one is considering the slowing down of a vehicle) then the effect of inertia may be ignored with very little error. If at the beginning and end of the interval the angular velocity of the wheel has the same value the contribution of the inertia disappears from the average and if the values are approximately equal the error due to neglecting the inertia is small.

/In

7.4 In evaluating the records therefore the inertia term was ignored and the mean brake torque during one oscillation of the system was evaluated. This converted into an equivalent "mean braking force coefficient" is the quantity plotted in Fig.1-8 and estimated in Tables II and III. Since there were several oscillations of the system during a single test run, the evaluation of a single record provided several "mean braking force coefficients" at approximately the same speed.

8. Results

8.1 Braking force coefficients

8.1.1 The results obtained on the four test surfaces with the anti locking brake are shown in Figs.2-5 and summarised in Table III. The comparable locked wheel results are also shown in these figures and in Table IV, but for clarity the individual points have been omitted from the figures. The amount of scatter is indicated however in Table IV.

8.1.2 The effect of inflation pressure on the mean breaking force coefficient for the anti-locked wheel device is also shown in Figs.6-8.

8.2 Damage

8.2.1 Tyre damage was very much reduced when the anti-locking brake was used. The heavy concentrated damage found on the rough-textured surfaces was replaced by a more uniform wear, and although rubber was still deposited on the test surfaces the damage was much less severe. Tests at 260 lb/sq.in. were completed on all four surfaces with the same tyre when the anti-locking brake was used and a usable amount of tread stock was still left intact. Whereas one series of tests at the lower inflation pressure of 180 lb/sq.in. on the quartzite macadam removed the tread stock completely during the locked wheel tests described in S. & T. MEMO 5/64.

9. Conclusions to Section I

The following conclusions can be drawn from the results obtained with the anti-locking braking system:

9.1 Except at speeds below about 20 mile/h on some of the surfaces the anti-locked wheel braking force coefficients are substantially higher than the locked wheel coefficients. The average of the increases on the four surfaces at 60 mile/h and an inflation pressure of 40 lb/sq.in. is about 60 per cent. The improvement on the quartzite macadam, about 25 per cent, is less than on the other three surfaces, but this surface still gives the highest braking force coefficients.

9.2 The anti-locked wheel braking force coefficient decreases with increasing speed. It also falls with increasing inflation pressure except on the $\frac{3}{8}$-in. polished gravel carpet. The speed effect is smaller on the quartzite macadam and $\frac{3}{8}$-in. gravel carpet surfaces at speeds over 20 mile/h.

9.3 When the anti-locking system was used, the tyre wear was much less than the heavy damage experienced during the locked wheel tests. The wear was distributed much more uniformly over the tyre.

9.4 On the two most slippery surfaces the test wheel tended to lock momentarily, and there was a reduction in the response frequency of the anti-lock unit. This situation was improved by reducing the brake capacity on the slippery surfaces and by increasing the pressure of the brake release springs.

/10. Future Work

10. Future Work

10.1 In future investigations it is proposed to fit a later version of the Maxaret unit incorporating a larger valve in the return line, and also a pressure modulator which allows the pressure to be relieved at a higher rate than it is applied. It is hoped that these improvements may overcome some of the difficulties experienced with the anti-lock braking on the slippery surfaces.

10.2 It is also intended in the next series of tests to make a more detailed examination of tyre wear.

TABLE I

Details of test conditions

	Anti-locked wheel braking tests			Locked wheel breaking tests		
Load (tons)	3.5	3.5	3.5	3.5	3.5	3.5
Tyre inflation pressure (lb/sq.in.)	40	160	260	40	160	260
Tyre size	35 x 10 - 17 in.					
Tread pattern	5 circumferential ribs $1\frac{1}{8}$ in. wide with 3/16 in. wide grooves between ribs, depth 0.264 in.					
Tread rubber hardness	64° (Dunlop scale)			63° (Dunlop scale)		
Resilience* (%)	45 @ 20°C			46 @ 20°C		
Surface water temperature (°C)	15°C - 19°C			3°C - 8°C		
Water depth	approx. 0.020 in.					

*As measured with a modified B.S. Lupke resiliometer on an unsupported tyre.

TABLE II

Tests to Estimate the Consistency of the Results

Wetted test surface	Test wheel	Load (tons)	Inflation pressure (lb/sq.in.)	Braking force coefficients at the following speeds (mile/h), (from smooth curves drawn through the plotted points)						Maximum observed deviations (positive and negative) from smooth curve
				10	20	30	40	50	60	
Fine cold asphalt	A	3.5	100	0.54	0.51	0.49	0.47	0.45	0.42	+0.06 - 0.09
"	B	3.5	100	0.54	0.51	0.48	0.46	0.43	0.41	+0.06 - 0.05
"	B	3.5	100	0.55	0.53	0.50	0.48	0.45	0.43	+0.10 - 0.08
"	A	3.5	100	0.56	0.53	0.50	0.48	0.45	0.43	+0.05 - 0.07

TABLE III

Anti-locked Wheel Braking Tests

Wetted test surface		Load (tons)	Inflation pressure (lb/sq.in.)	Braking force coefficients at the following speeds (mile/h), (from smooth curves drawn through the plotted points)						Maximum observed deviations (positive and negative) from smooth curve
				10	20	30	40	50	60	
Fine textured surfaces	Fine cold asphalt	3.5	40	0.60	0.56	0.53	0.50	0.48	0.46	+0.05 - 0.04
		3.5	160	0.56	0.53	0.50	0.47	0.44	0.41	+0.04 - 0.05
		3.5	260	0.48	0.46	0.43	0.41	0.38	0.36	+0.07 - 0.04
	Smooth concrete	3.5	40	0.55	0.48	0.44	0.40	0.36	0.33	+0.08 - 0.05
		3.5	160	0.40	0.34	0.28	0.24	0.22	0.21	+0.06 - 0.03
		3.5	260	0.29	0.24	0.21	0.20	0.18	0.17	+0.05 - 0.03
Coarse textured surfaces	Quartzite macadam	3.5	40	0.68	0.62	0.58	0.56	0.53	0.52	+0.04 - 0.05
		3.5	160	0.60	0.57	0.55	0.53	0.52	0.52	+0.05 - 0.06
		3.5	260	0.51	0.51	0.50	0.50	0.50	0.50	+0.03 - 0.02
	⅜-in. polished gravel macadam	3.5 3.5 3.5	40 160 260	0.34	0.30	0.28	0.27	0.26	0.25	+0.06 - 0.05

/TABLE IV

TABLE IV

Locked Wheel Braking Tests

Wetted test surface		Load (tons)	Inflation pressure (lb/sq.in.)	Braking force coefficients at the following speeds (mile/h), (from smooth curves drawn through the plotted points)						Maximum observed deviations (positive and negative) from smooth curve
				10	20	30	40	50	56	
Fine textured surfaces	Fine cold asphalt	3.5	40	0.59	0.53	0.47	0.41	0.35	0.31	+0.02 - 0.06
		3.5	160	0.50	0.43	0.36	0.31	0.27	0.25	+0.07 - 0.06
		3.5	260	0.40	0.33	0.29	0.26	0.23	0.21	+0.04 - 0.06
	Smooth concrete	3.5	40	0.51	0.44	0.36	0.29	0.23	0.20	+0.03 - 0.02
		3.5	160	0.37	0.29	0.24	0.19	0.15	0.13	+0.03 - 0.04
		3.5	260	0.29	0.22	0.18	0.14	0.11	0.09	+0.02 - 0.02
Coarse textured surfaces	Quartzite macadam	3.5	40	0.70	0.63	0.56	0.50	0.45	0.43	+0.03 - 0.03
	$\frac{3}{8}$-in. polished gravel macadam	3.5	40	0.31	0.25	0.21	0.18	0.17	0.16	+0.03 - 0.02

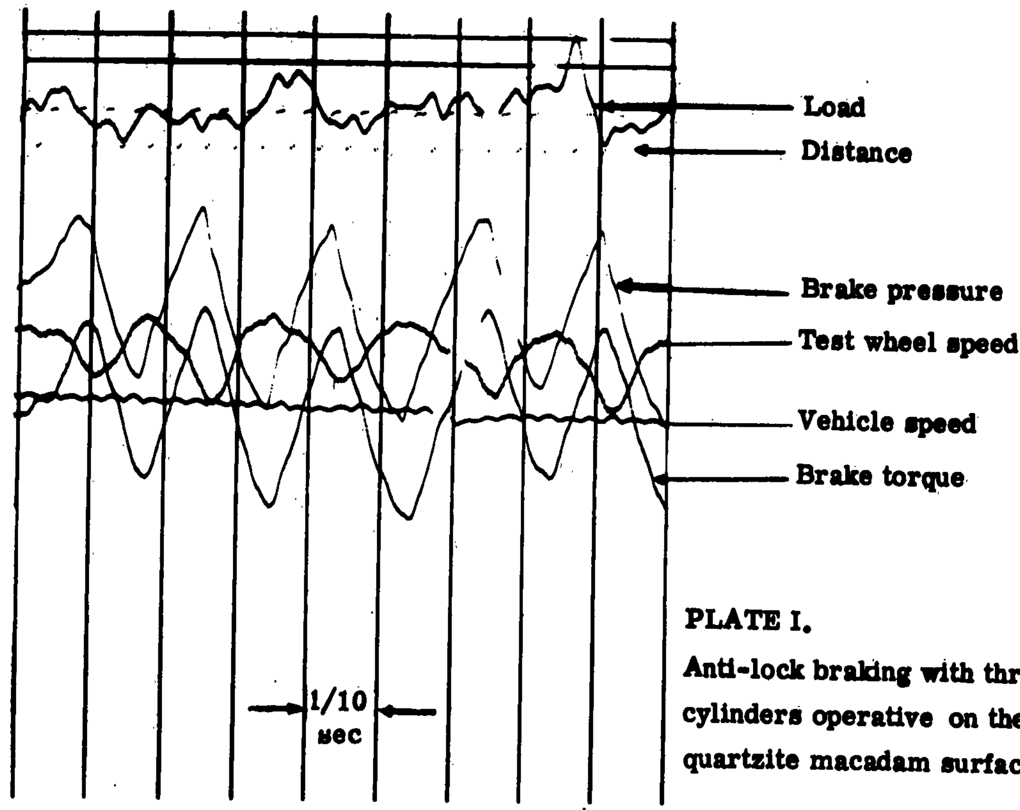


PLATE I.
Anti-lock braking with three brake cylinders operative on the wet quartzite macadam surface.

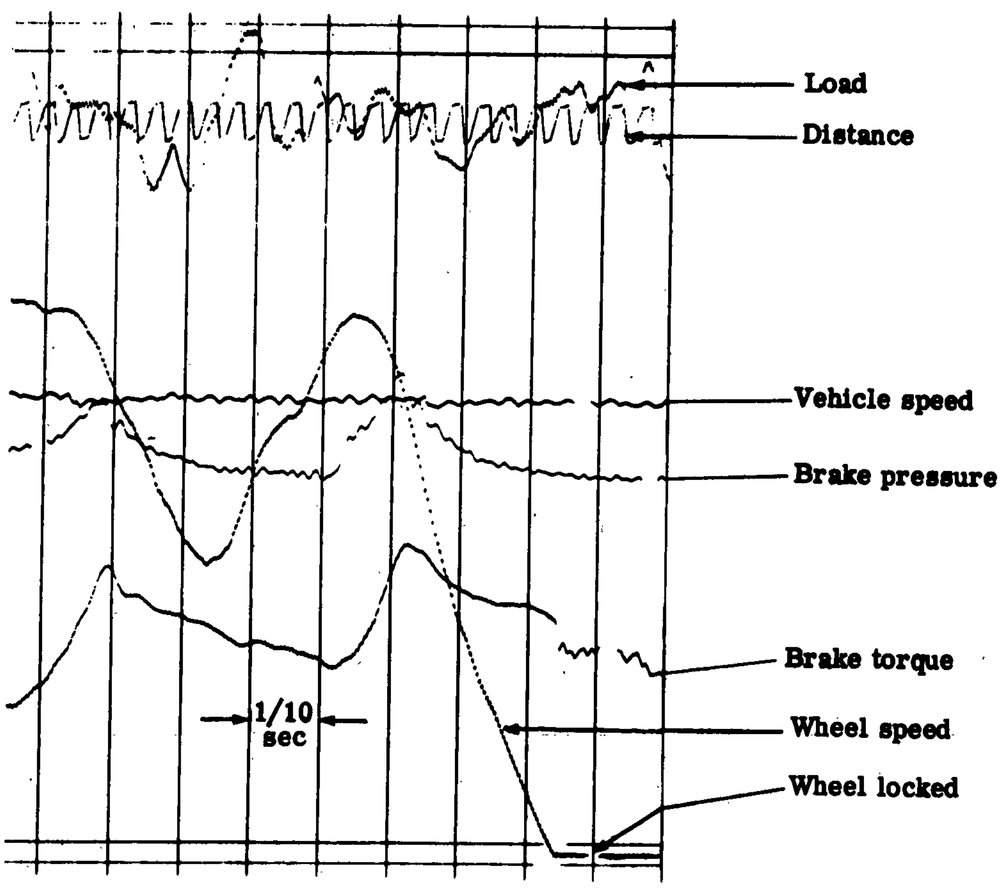


PLATE II. Anti-lock braking with three brake cylinders operative on the wet smooth concrete surface. Brake response is shown to be poor.

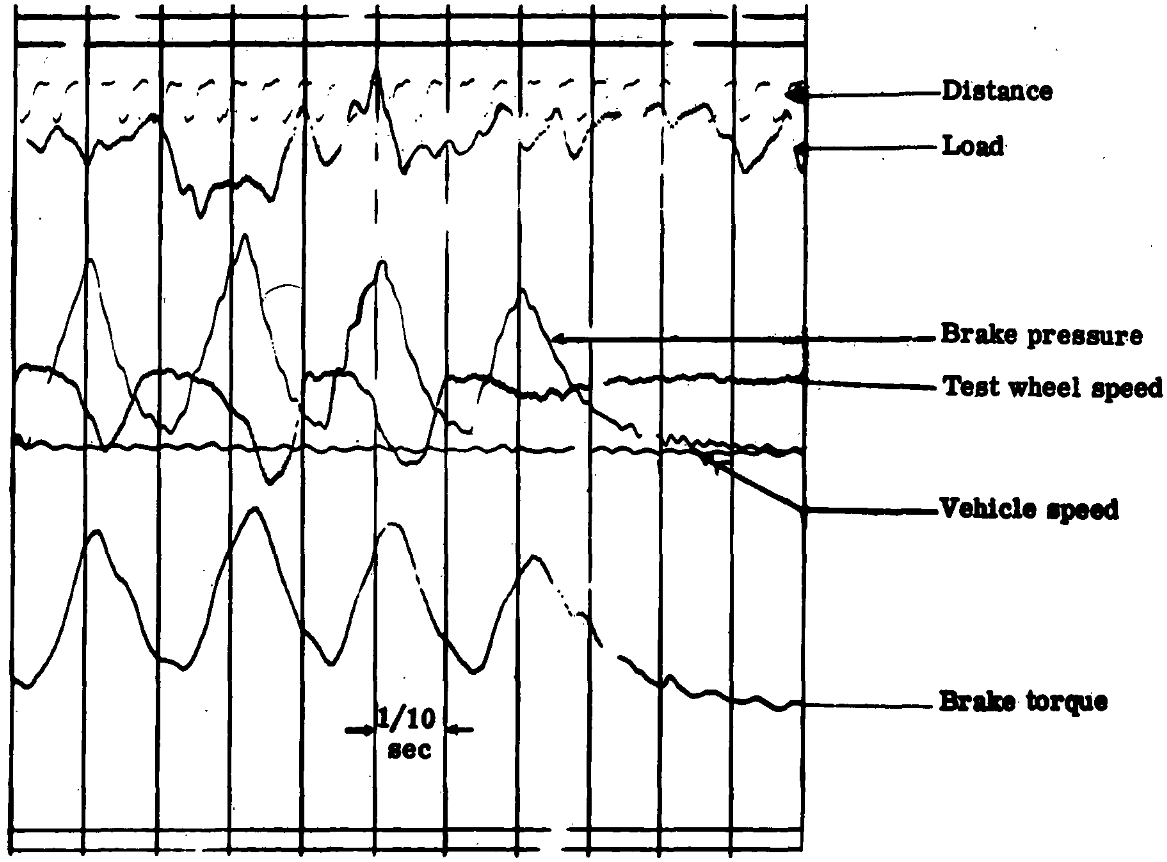


PLATE III. Anti-lock braking with two brake cylinders operative on the wet smooth concrete surface. Brake response is improved.

PLATE IV. Arrangement for determining the moment of inertia of the aircraft test wheel.

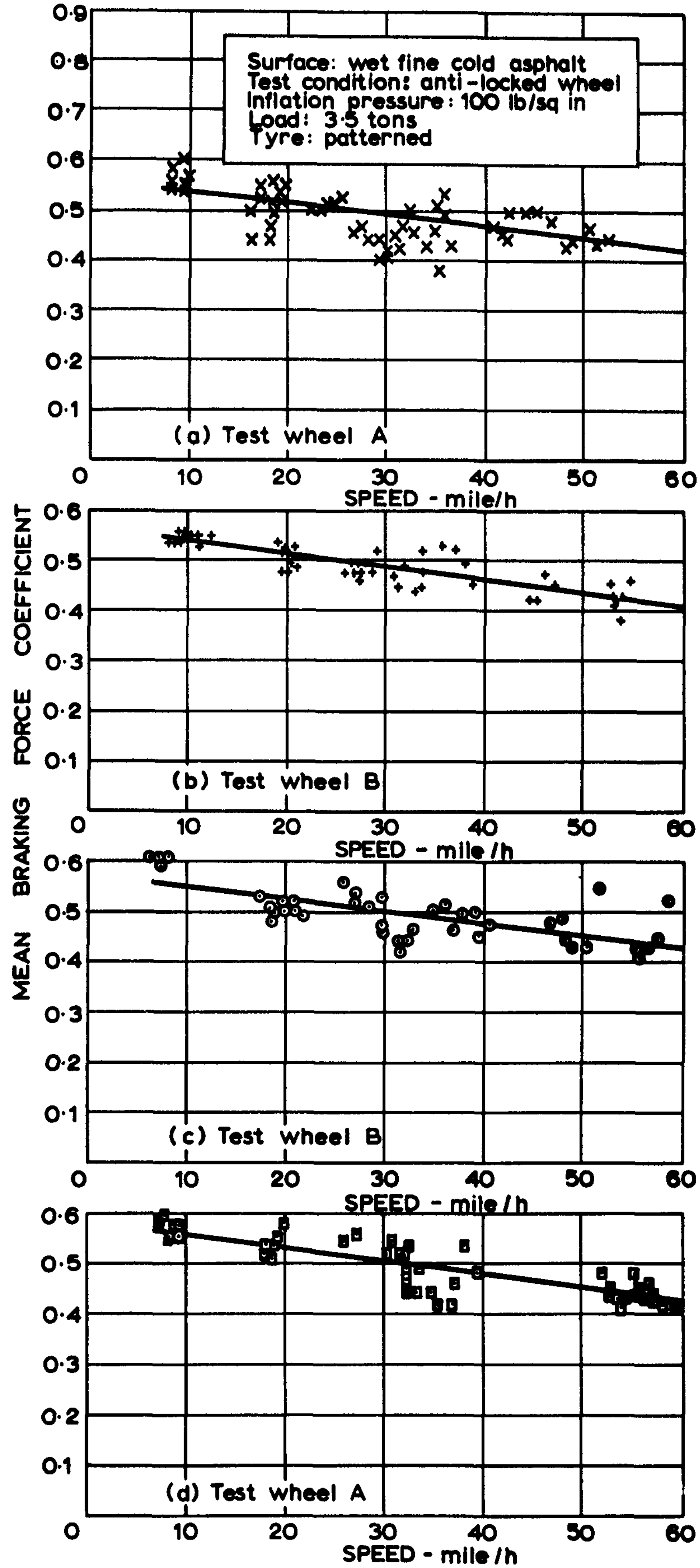


Fig. 1. RELATION BETWEEN MEAN BRAKING FORCE COEFFICIENT AND SPEED FOR TWO WHEEL AND BRAKE ASSEMBLIES USING THE SAME TEST CONDITIONS.

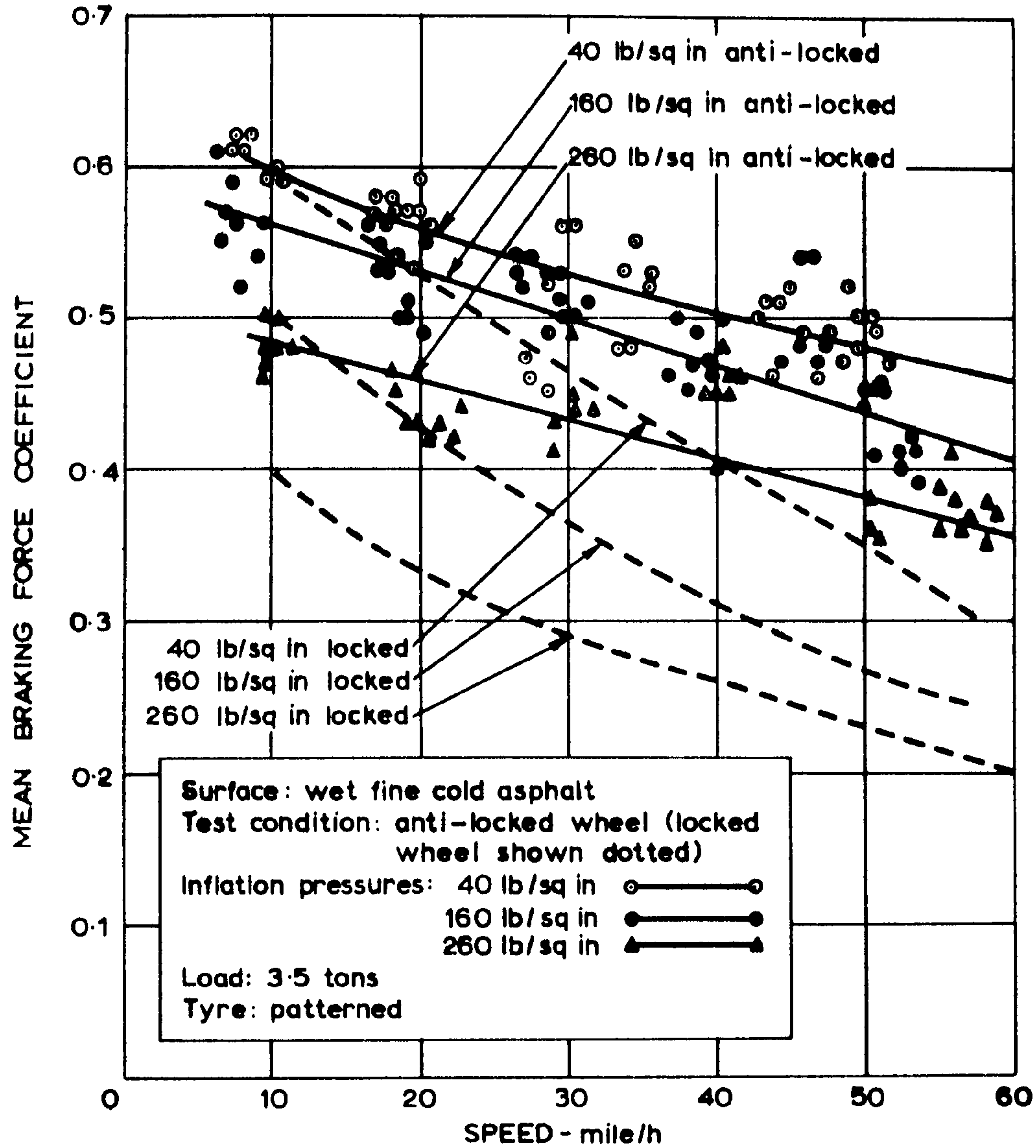


Fig. 2. RELATION BETWEEN ANTI-LOCKED AND LOCKED WHEEL BRAKING FORCE COEFFICIENT AND SPEED ON A FINE TEXTURED HARSH SURFACE (POINTS OMITTED FROM LOCKED WHEEL CURVES FOR CLARITY)

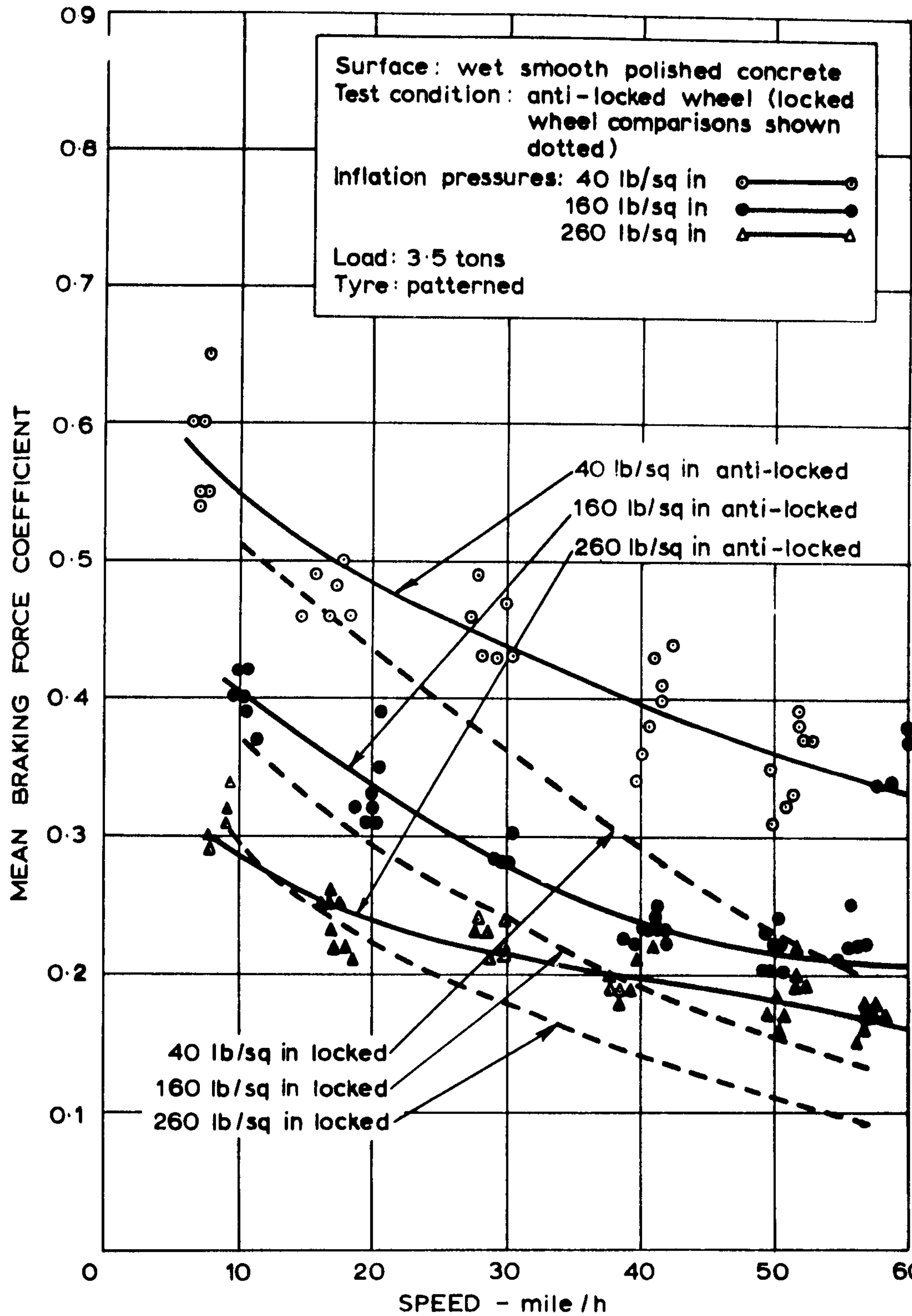


Fig. 3. RELATION BETWEEN ANTI-LOCKED AND LOCKED WHEEL BRAKING FORCE COEFFICIENT AND SPEED ON A FINE TEXTURED POLISHED SURFACE (POINTS OMITTED FROM LOCKED WHEEL CURVES FOR CLARITY)

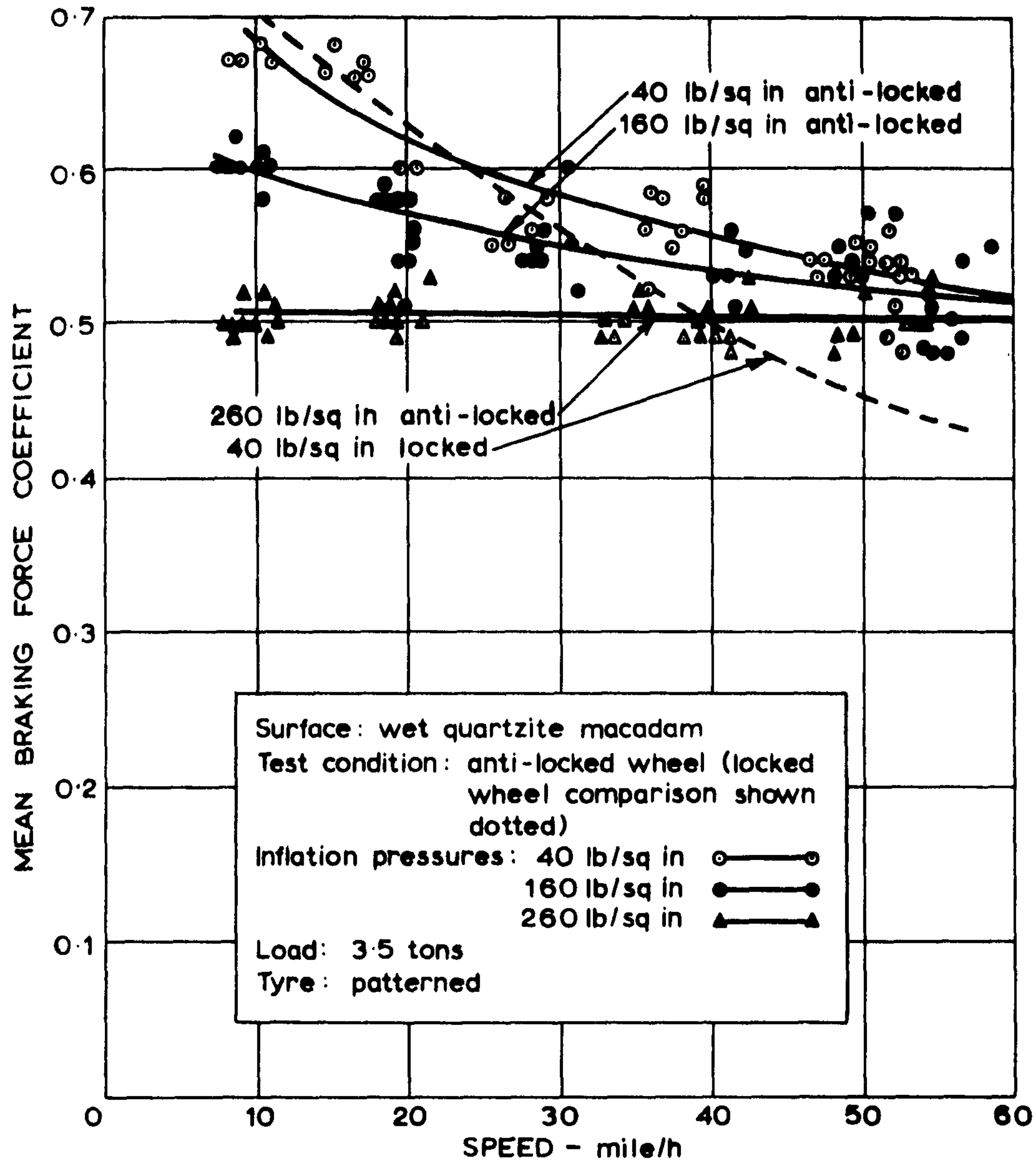


Fig. 4. RELATION BETWEEN ANTI-LOCKED AND LOCKED WHEEL BRAKING FORCE COEFFICIENT AND SPEED ON A COARSE TEXTURED HARSH SURFACE (POINTS OMITTED FROM LOCKED WHEEL CURVE FOR CLARITY)

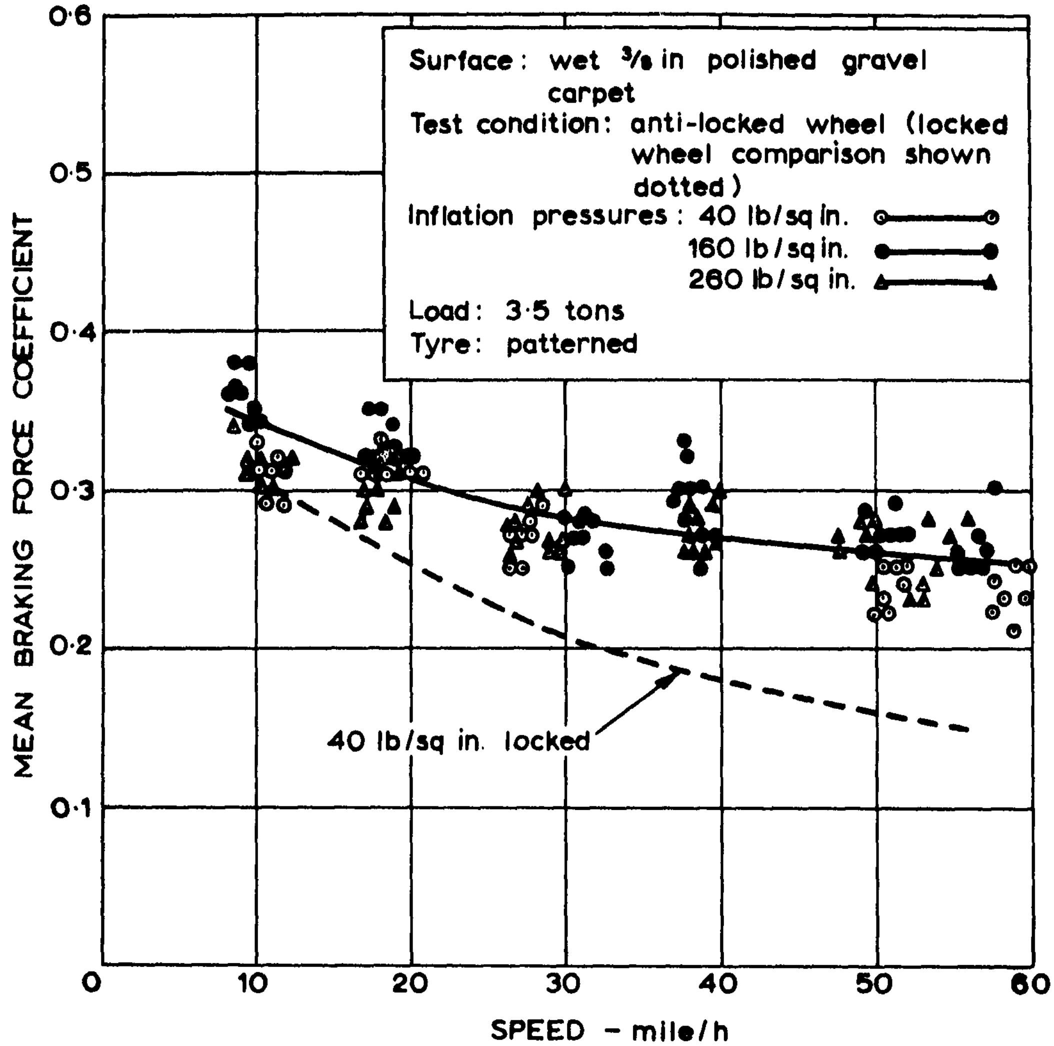


Fig. 5. RELATION BETWEEN ANTI-LOCKED AND LOCKED WHEEL BRAKING FORCE COEFFICIENT AND SPEED ON A COARSE TEXTURED POLISHED SURFACE (POINTS OMITTED FROM LOCKED WHEEL CURVE FOR CLARITY)

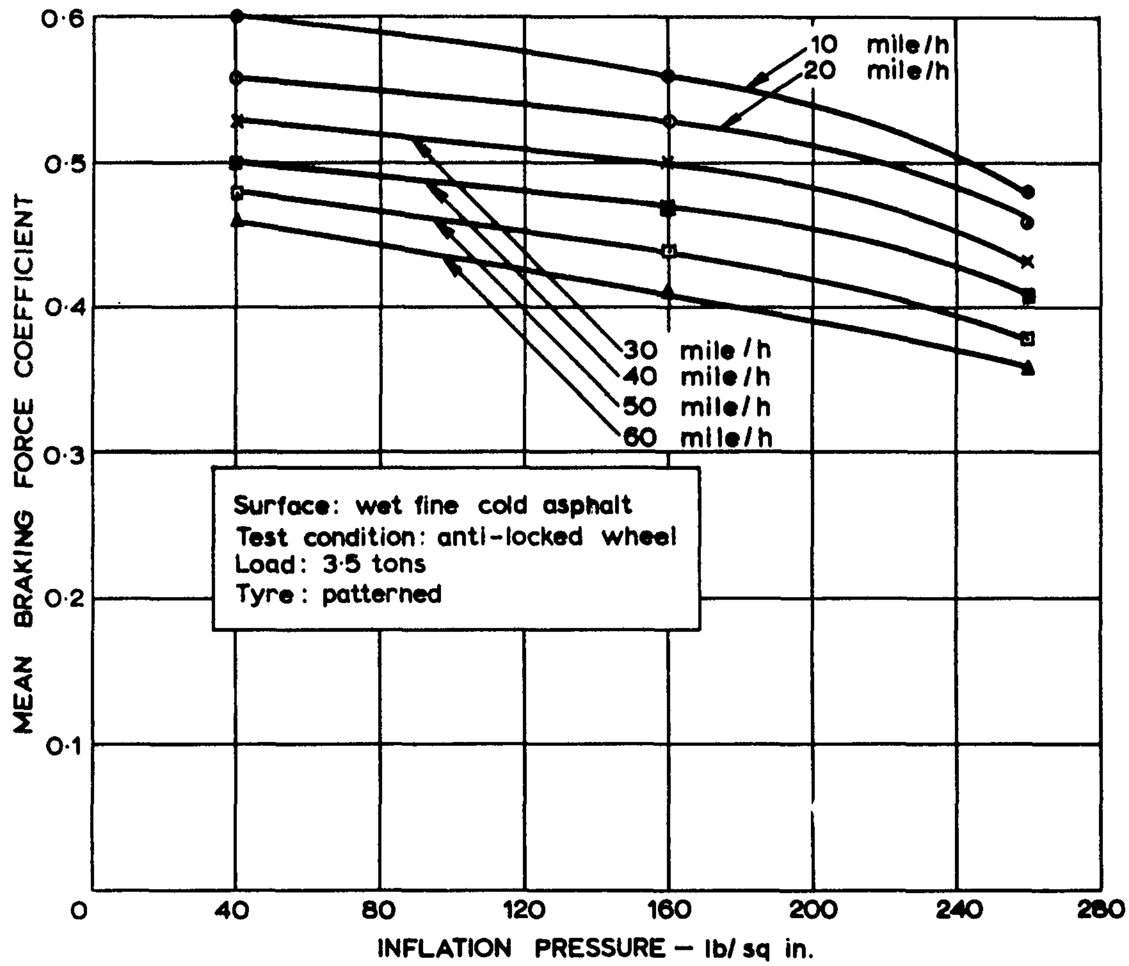


Fig. 6. RELATION BETWEEN MEAN BRAKING FORCE COEFFICIENT AND INFLATION PRESSURE AT DIFFERENT SPEEDS ON A FINE TEXTURED HARSH SURFACE

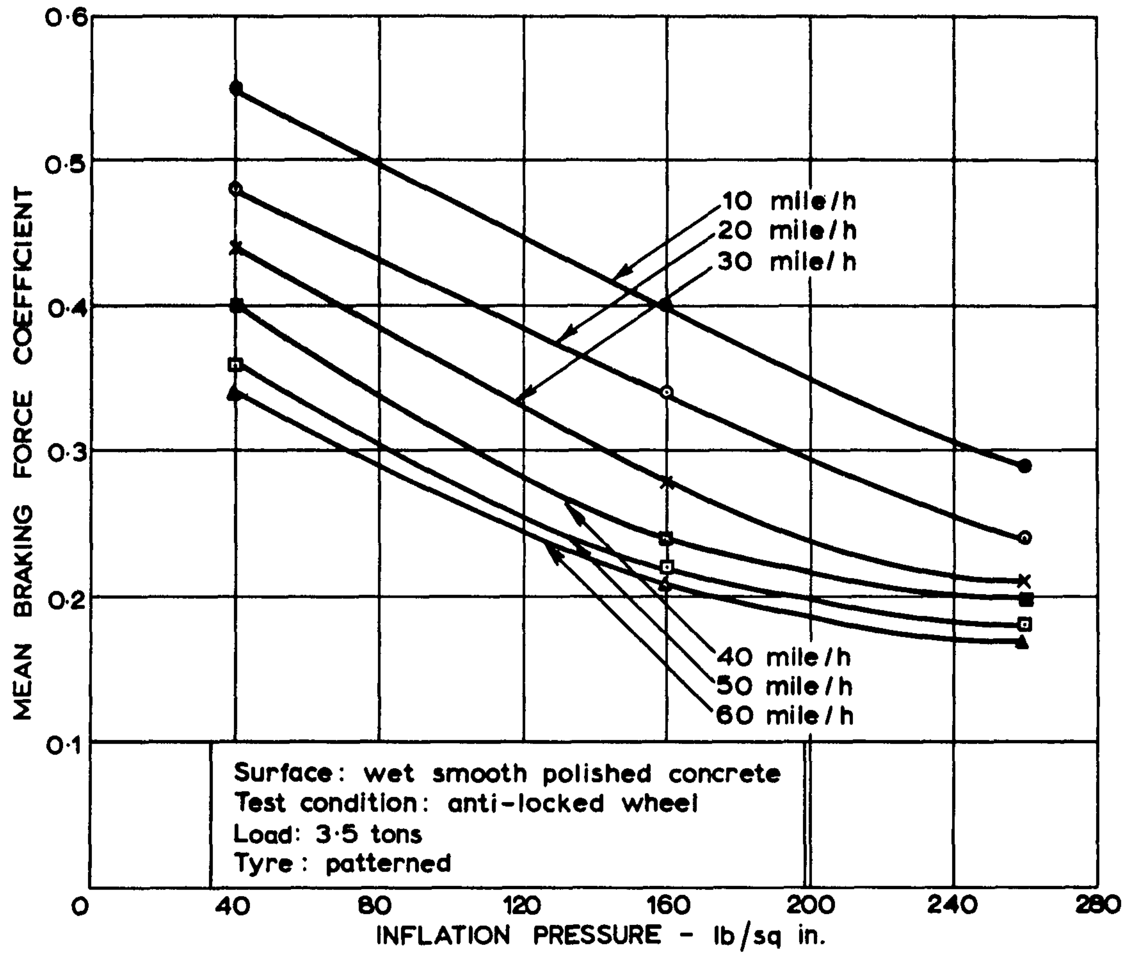


Fig. 7. RELATION BETWEEN MEAN BRAKING FORCE COEFFICIENT AND INFLATION PRESSURE AT DIFFERENT SPEEDS ON A FINE TEXTURED POLISHED SURFACE

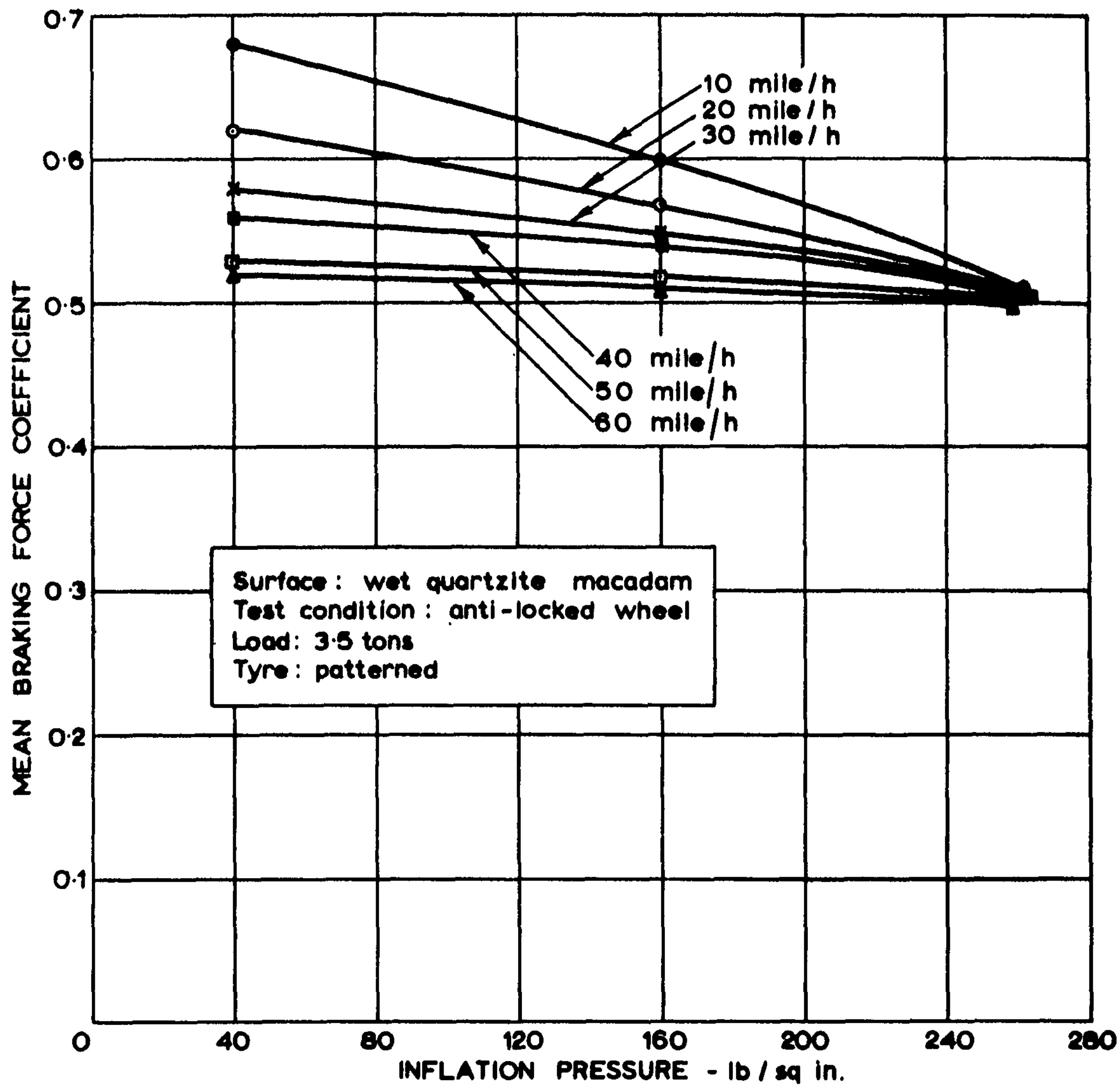


Fig. 8. RELATION BETWEEN MEAN BRAKING FORCE COEFFICIENT AND INFLATION PRESSURE AT DIFFERENT SPEEDS ON A COARSE TEXTURED HARSH SURFACE

II - PRELIMINARY MEASUREMENTS FOR THE MINISTRY OF AVIATION ON THE EFFICIENCY OF AN AIRCRAFT ANTI-LOCKING BRAKE

11. Introduction to Section II

11.1 This report gives the results of braking tests using a Mark I Maxaret anti-locking brake on an aircraft tyre and wheel fitted to the Heavy Load Braking Test Vehicle. The tests were made on the Road Research Laboratory's Research Track at Crowthorne using the fine-textured asphalt surface.

12. Dates of Tests

12.1 The tests were carried out on 29th, 30th April and 1st May, 1963.

13. Test Conditions

13.1 The test surface was wetted to a nominal water depth of 0.020". The surface water temperature varied between 21-24°C. Other details are given below.

Tyre size	35 x 10 - 17
Tread pattern	Ribbed
Tyre hardness	64° (Dunlop scale)
Resilience	52 at 20°C
Load	2.8 tons
Inflation Pressure	90 lb/in²

14. Details of Tests

14.1 Measurements were taken over the 10-60 mile/h speed range. Peak, and locked wheel coefficient values were obtained by restricting the hydraulic supply to the brake with a fine control valve, so as to give a slow build-up in brake pressure (Plate 1b). Measurements with anti-lock braking were made with the Maxaret unit in operation (Plate 1a).

15. Results

15.1 The results obtained for the three conditions of test are summarised in Fig.1 and also in Table 1 below:-

TABLE I	Results taken from smooth curves drawn through the plotted points at the following speeds (mile/h)					
	10	20	30	40	50	60
"Peak" braking force coefficient	0.81	0.77	0.72	0.68	0.63	0.59
Braking force coefficient obtained using the "Maxaret" unit	0.60	0.57	0.54	0.52	0.49	0.46
Locked wheel braking force coefficient	0.57	0.52	0.46	0.40	0.35	0.30

/Braking "Efficiency"

16. Braking "Efficiency"

16.1 In these tests the "efficiency" of the two types of braking i.e. "Maxaret" and locked wheel braking, has been estimated by comparing the average braking force coefficient obtained under these two conditions with the "peak" braking force coefficient. The estimated efficiencies of the anti-lock brake obtained in this way compared with those obtained with the locked wheel braking condition are shown in Fig.2 and in Table II below:-

TABLE II

		Speed (mile/h)					
		10	20	30	40	50	60
"Maxaret" Braking "Efficiency"	(Average braking force coefficient x 100 / "Peak" coefficient)	74	74	75	76	78	78
Locked wheel Braking "Efficiency"	(Locked wheel braking force coefficient x 100 / "Peak" coefficient) %	70	68	64	59	56	51

17. Conclusions to Section II

17.1 The "efficiency" of the anti-locking system and the locked wheel configuration were of the same order at 10 mile/h but as other tests have shown the anti-lock system showed to increasing advantage as the speed of test was raised.

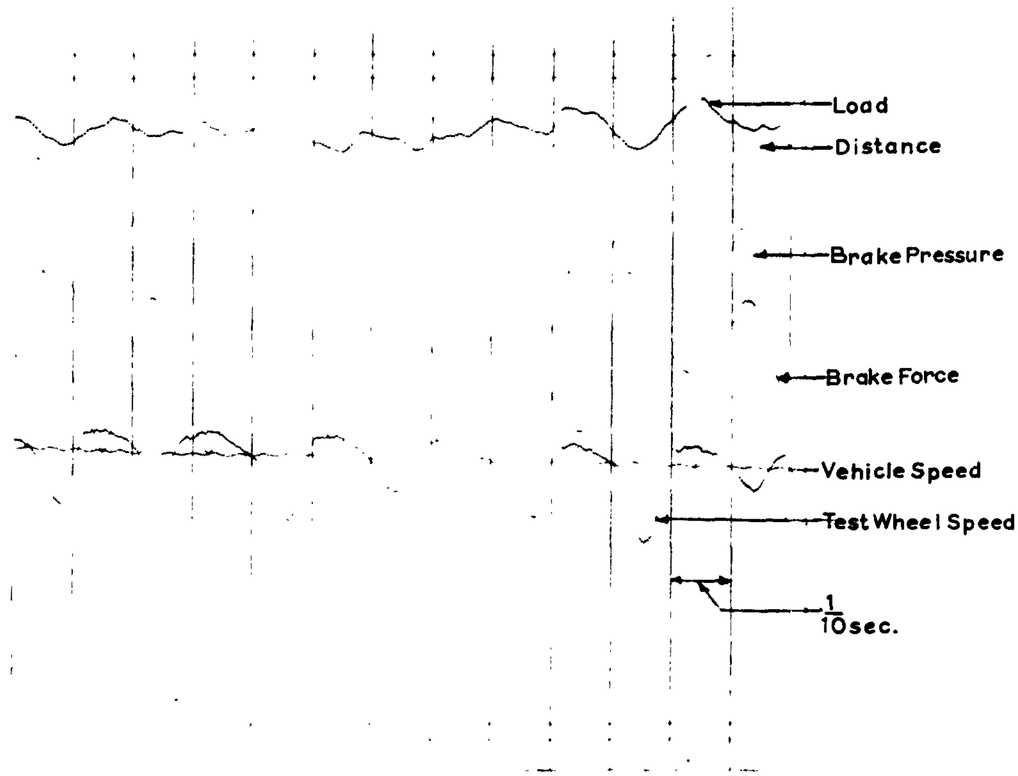


Plate 1(a) RECORD OBTAINED WITH "MAXARET" IN OPERATION

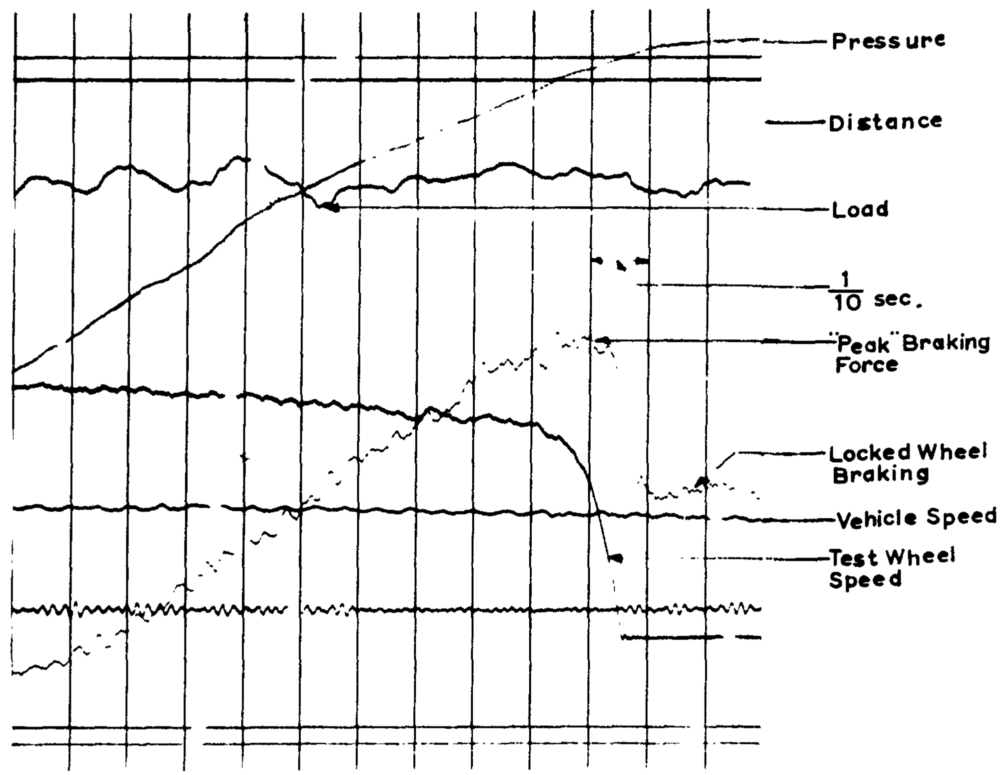


Plate 1(b) RECORD SHOWING PEAK AND LOCKED WHEEL BRAKING FORCES

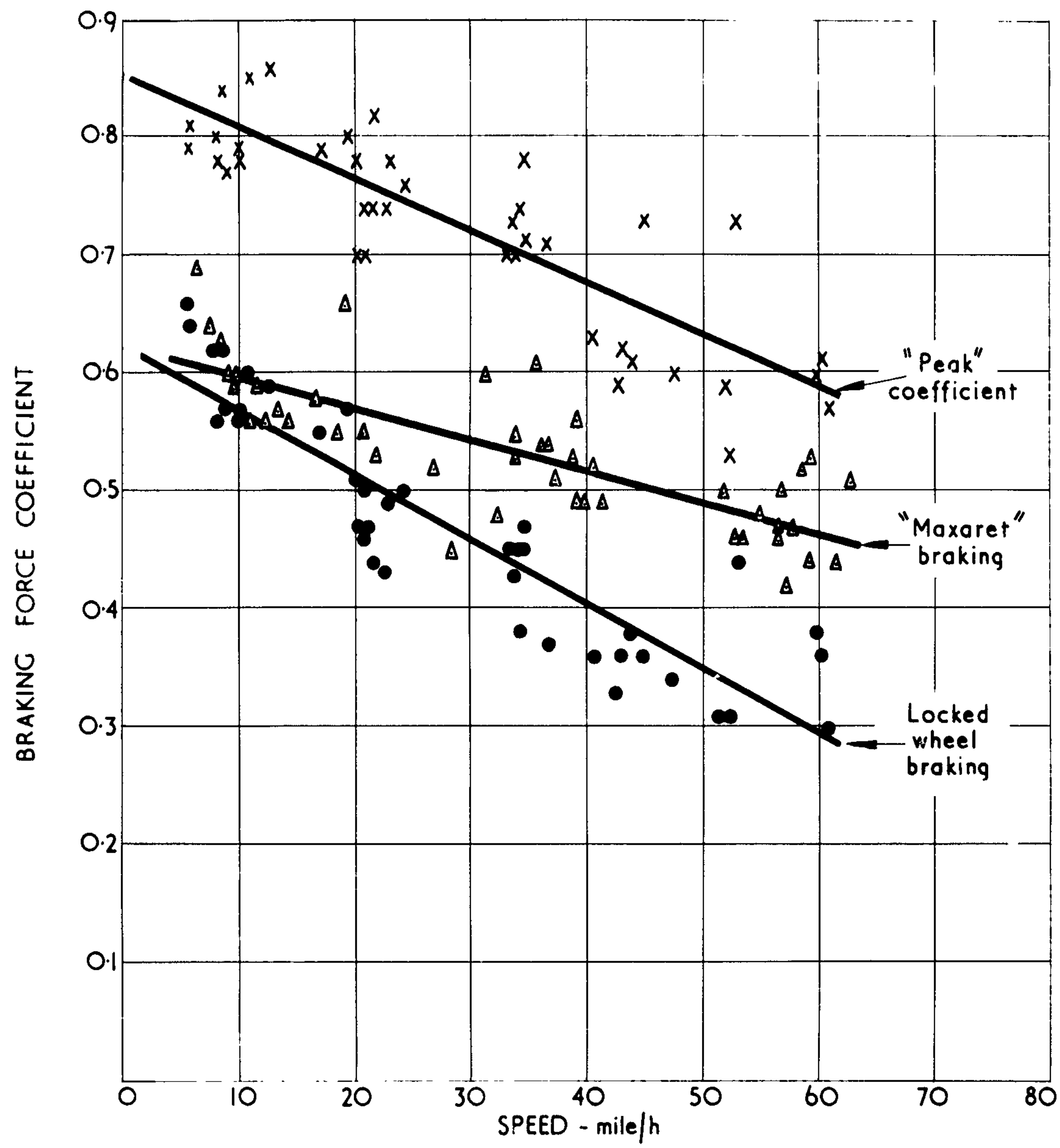


Fig. 1. RELATIONSHIP BETWEEN BRAKING FORCE COEFFICIENT AND SPEED UNDER VARYING CONDITIONS OF BRAKING

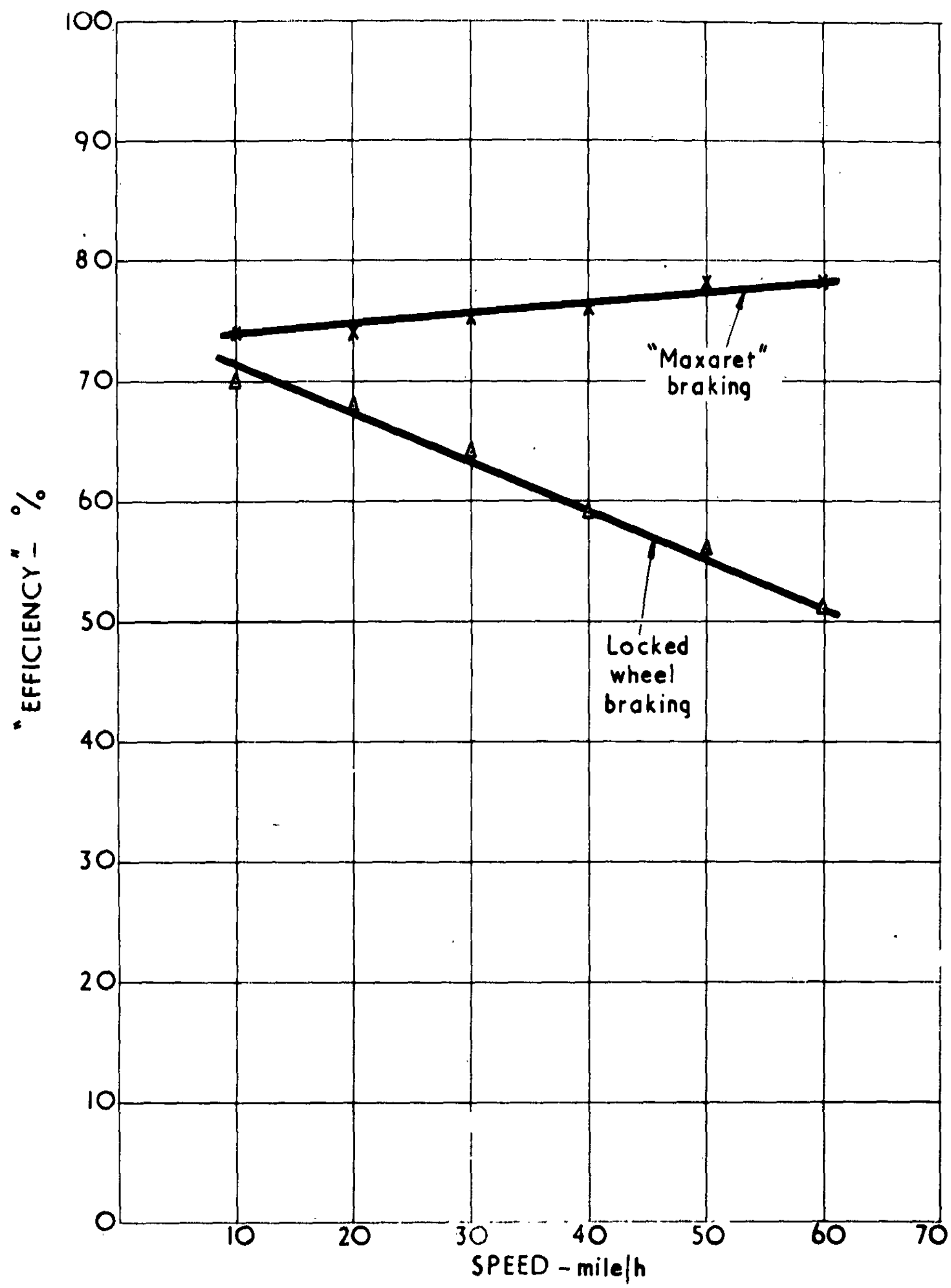


Fig. 2. COMPARISON OF "MAXARET" AND LOCKED WHEEL BRAKING EFFICIENCIES

III - MEASUREMENTS OF BRAKING FORCE COEFFICIENT FOR THE MINISTRY OF AVIATION ON A WET ASPHALT SURFACE WITH "SLURRY" OVERLAY, AT WISLEY AERODROME

18. Introduction to Section III

18.1 Tests were made with the heavy wheel load test vehicle, at the request of the Ministry of Aviation, to determine the braking force coefficients, using an aircraft tyre and loading conditions on a wet asphalt surface with slurry overlay, at Wisley aerodrome.

19. Dates of tests

19.1 19th, 20th and 21st August, 1963.

20. Location of test section

20.1 The test section was located on the main 28 runway, south west of the service road adjacent to the control tower.

21. Runway surface

21.2 The original runway surface was asphalt and when tested, it had received an $\frac{1}{8}$ inch Slurry overlay, consisting of a mixture of powdered limestone, silica sand and bitumen emulsion, (see Plate I).

22. Test conditions

Test tyre	35 x 10 - 17.
Tread Pattern	Ribbed
Wheel load	3.5 tons.
Tyre pressures	40, 100 and 260 lb/in^2.
Test surface	Asphalt with slurry overlay.
Water depth	0.01 in. - 0.06 in.
Surface temperature	16-19°C.

23. Details of test

23.1 Measurements were made using the three different inflation pressures given above at various speeds up to 60 mile/h using the Maxaret anti-locking system fitted to the test wheel of the heavy load vehicle, and also with the test wheel locked.

24. Results

24.1 Table I summarises the results of the tests taken from the smooth curves drawn through the plotted points. The Maxaret values given in this table were obtained by taking the mean of the highest and lowest braking force values recorded for each Maxaret cycle. It is considered that this procedure is justified because of the almost sinusoidal form of the braking force time curves obtained with the Maxaret system.

/TABLE I

TABLE I

Summary of results obtained in tests on a wet asphalt surface with slurry overlay, at Wisley Aerodrome

Load (tons)	Inflation pressure (lb/in^2)	Braking condition	Value of braking force coefficient from smooth curves drawn through plotted points at the following speeds (mile/h):-					
			10	20	30	40	50	54
3.5	40	"Maxaret"	0.64	0.53	0.46	0.43	0.41	0.40
"	100	"	0.55	0.50	0.46	0.42	0.37	0.35
"	260	"	0.45	0.42	0.39	0.35	0.32	0.30
"	40	Locked wheel	0.63	0.45	0.35	0.28	0.23	0.20
"	100	"	0.44	0.38	0.32	0.26	0.20	0.17
"	260	"	0.29	0.25	0.21	0.17	0.13	0.11

The results obtained in the various measurements are shown plotted in the graphs given in Figs. 1, 2 and 3.

24.2 As the measurements were being made it was found that the braking tests removed portions of the thin slurry overlay on the test surface. The extent to which this affected the surface texture can be seen by comparing Plates I, II and III. Plates II and III show the condition of different parts of the test section after the completion of the test runs.

25. Conclusions to Section III

25.1 Over the whole range of test conditions the mean coefficients obtained with the anti-lock braking system show an improvement over the corresponding locked wheel values over the whole range of test conditions and speeds. Compared with similar tests carried out in July, 1962 (S. & T MEMO 8/63) the locked wheel test results are about 0.1 lower than the previous values. This may have been due to the removal of the "slurry" overlay by the test tyre. An unusual feature of the measurements is that the tyre showed practically no wear during the tests.

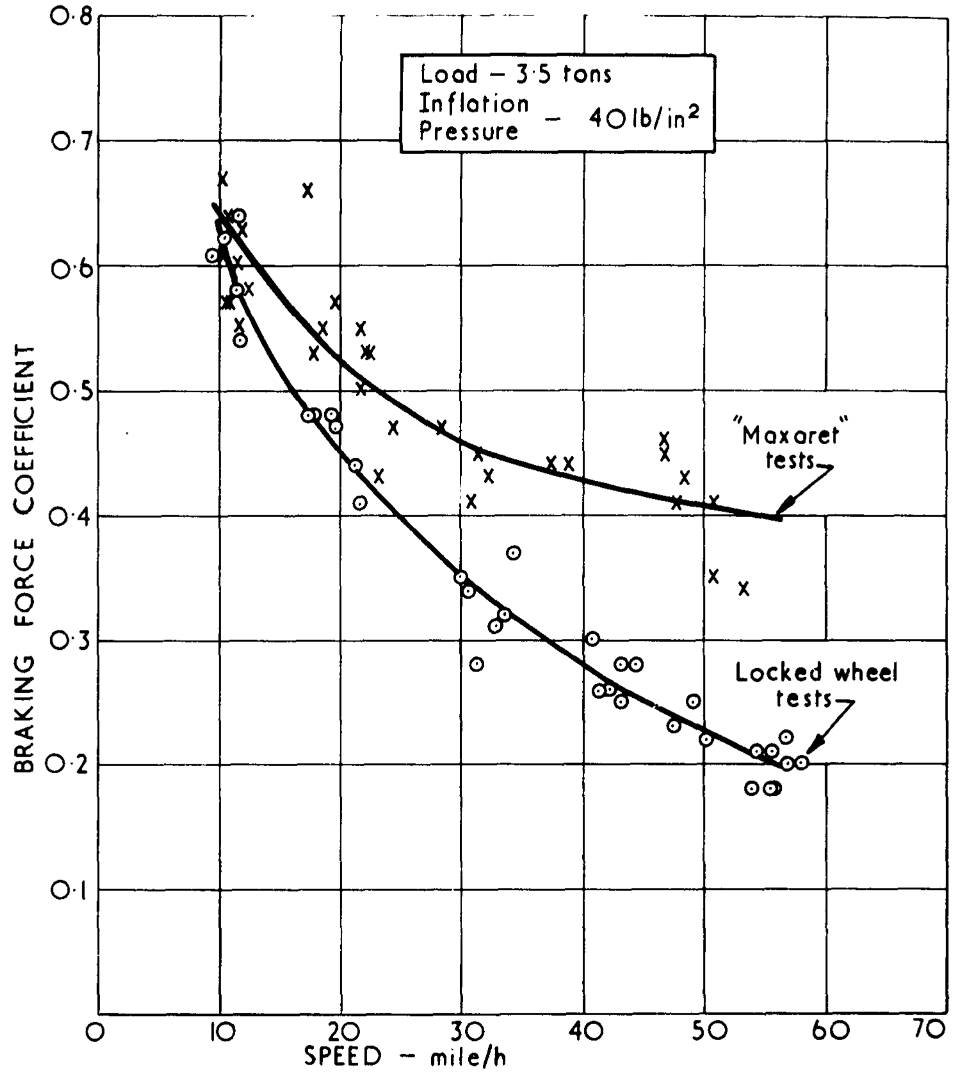


Fig. 1 BRAKING FORCE COEFFICIENTS MEASURED ON A WET ASPHALT SURFACE AT WISLEY AERODROME TREATED WITH A SLURRY OVERLAY. TESTS MADE USING 3·5 TONS VERTICAL LOAD AND A TYRE INFLATION PRESSURE OF 40 lb/in², WITH A LOCKED WHEEL AND THE ANTI-LOCKING SYSTEM OPERATING

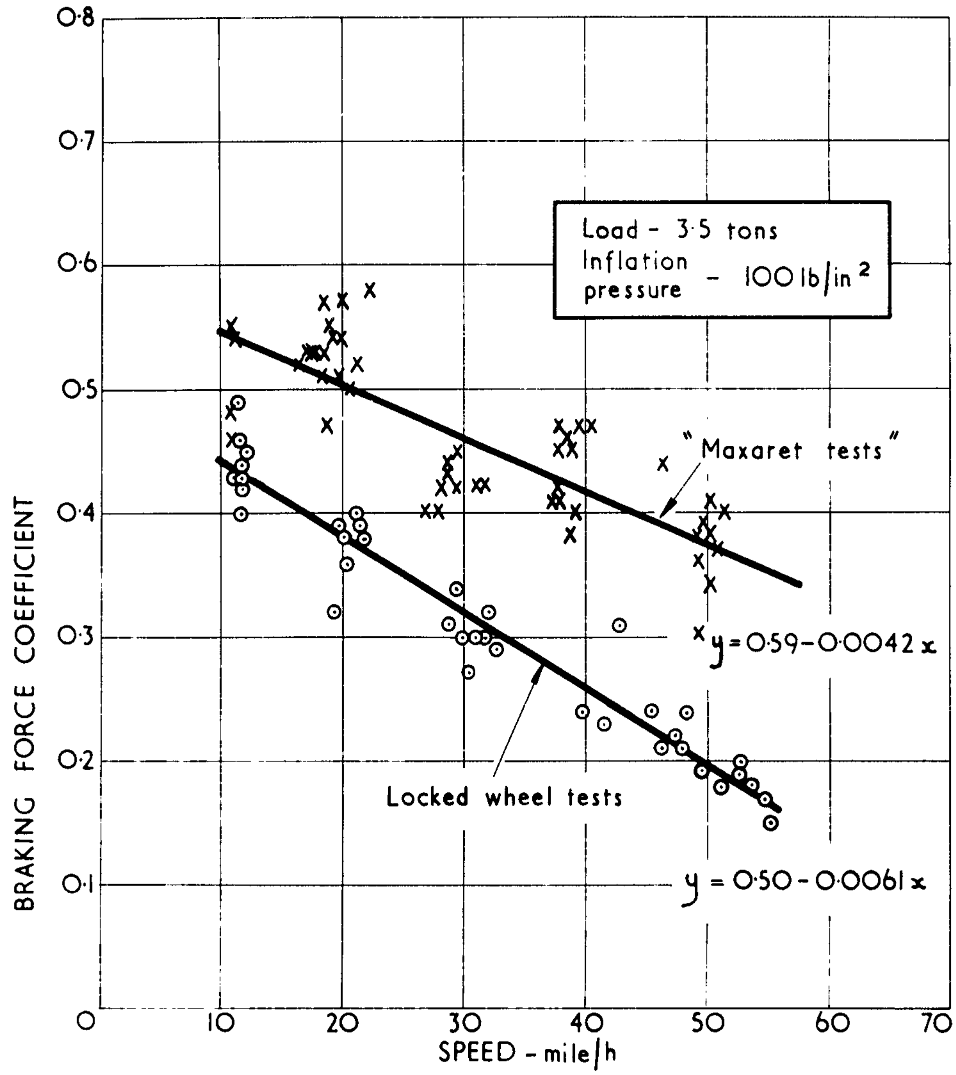


Fig 2 BRAKING FORCE COEFFICIENTS MEASURED ON A WET ASPHALT SURFACE AT WISLEY AERODROME TREATED WITH A SLURRY OVERLAY. TESTS MADE USING 3·5 TONS VERTICAL LOAD AND A TYRE INFLATION PRESSURE OF 100 lb/in² WITH A LOCKED WHEEL AND THE ANTI-LOCKING SYSTEM OPERATING

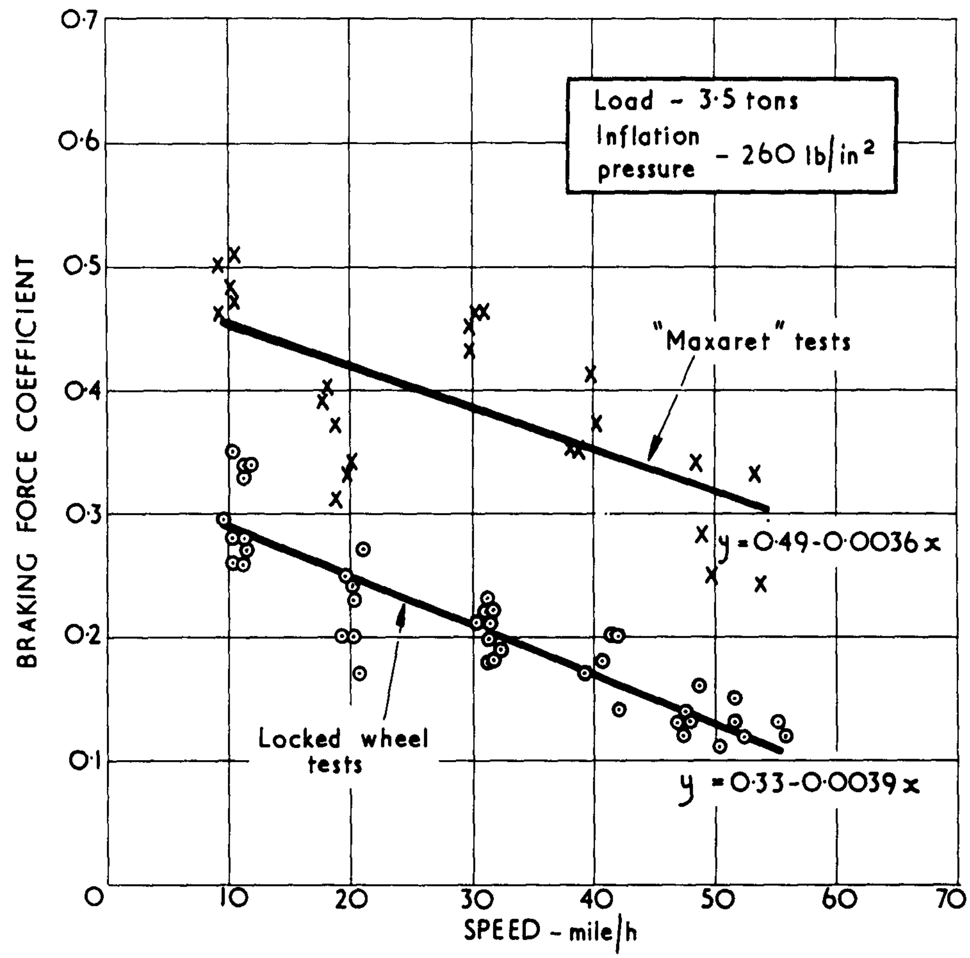


Fig 3 BRAKING FORCE COEFFICIENTS MEASURED ON A WET ASPHALT SURFACE AT WISLEY AERODROME TREATED WITH A SLURRY OVERLAY. TESTS MADE USING 3·5 TONS VERTICAL LOAD AND A TYRE INFLATION PRESSURE OF 260 lb/in² WITH A LOCKED WHEEL AND THE ANTI-LOCK SYSTEM OPERATING

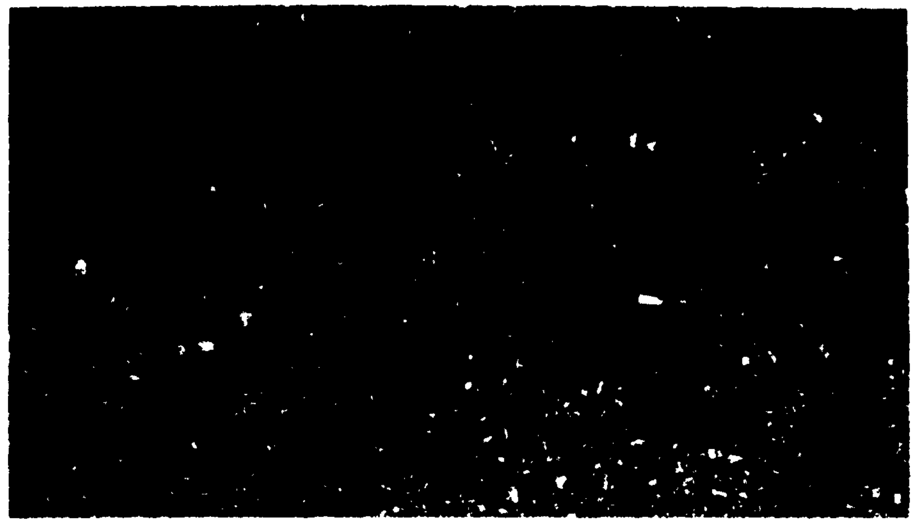


PLATE I. Wisley - Surface texture before braking tests. (full size)

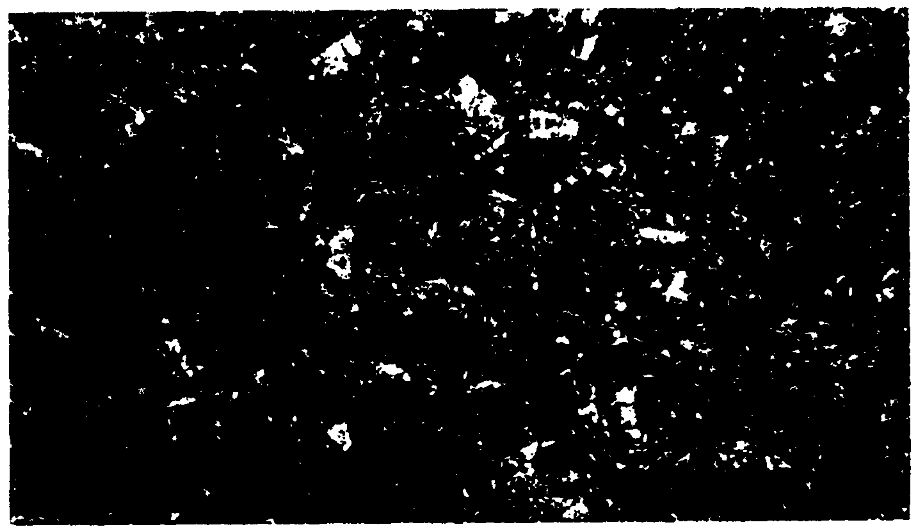


PLATE II. Wisley - Surface texture with some "slurry" overlay removed by repeated braking tests. (full size)

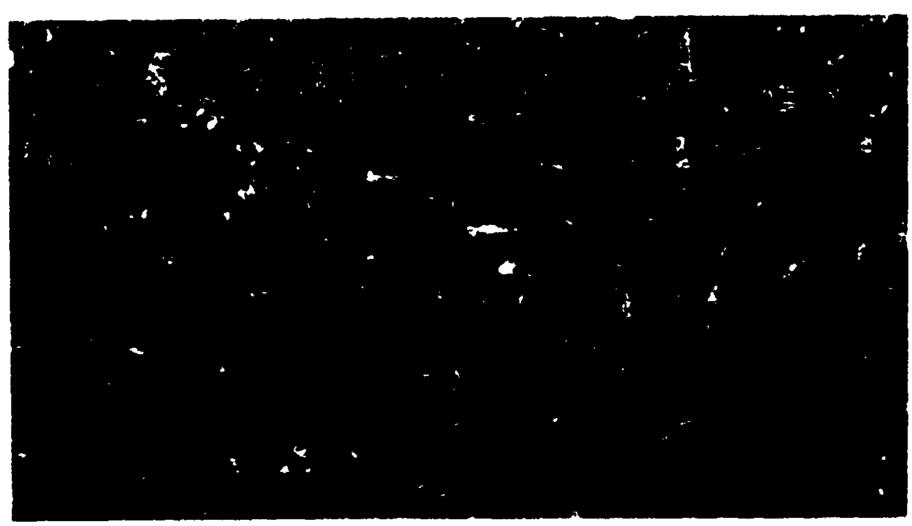


PLATE III. Wisley - Surface texture showing the majority of the "slurry" overlay removed by repeated braking tests. (full size)

Department of Scientific and Industrial Research,
Road Research Laboratory. Laboratory Note No. LN/432/TW.

IV - MEASUREMENTS OF BRAKING FORCE COEFFICIENT FOR THE MINISTRY OF AVIATION ON A GRASS SURFACE AT WHITE WALTHAM AERODROME

26. Introduction to Section I

26.1 The tests described below were made with the Heavy Load Vehicle at the request of the Ministry of Aviation to obtain information on the skid-resisting properties of a typical aircraft tyre on a wet grass surface.

27. Date of test

20th June, 1963.

28. Location of test section

28.1 The test section was located on the south side of White Waltham Aerodrome, adjacent to the R.A.F. hangars.

29. Test conditions

29.1	Test tyre	35 x 10 - 17
	Tread pattern	Ribbed
	Load	2.8 tons
	Tyre pressures	40 p.s.i.; 90 p.s.i.
	Test surface	Grass, wetted by rain, mowed to between ¼ in. and ½ in. length.
	Surface temperature	16-18°C.

29.2 The grass was growing on a loamy organic type of soil and samples taken at the time of the tests showed that it had an average moisture content of 14 per cent.

30. Details of test

30.1 When the tests were carried out it was found that the maximum speed of test was limited to 30 mile/h, because of the uneven nature of the surface. The actual test runs were made over a 100 yard strip, using tyre pressures of 40 and 90 p.s.i.

31. Results

31.1 Table I below summarises the results obtained for both conditions of inflation pressure.

/TABLE I

TABLE I

Summary of results obtained in tests on a wet grass surface at White Waltham Aerodrome

			Values of braking force coefficient from smooth curves drawn through plotted points (mile/hour)				
Load tons	Inflation pressure lb/in^2	Test condition	10	15	20	25	30
2.8	90	"Peak" coefficient	0.41	0.40	0.39	-	-
"	90	Locked wheel	0.20	0.19	0.18	0.17	-
"	40	"Peak" coefficient	0.43	0.41	0.39	0.37	-
"	40	Locked wheel	0.22	0.22	0.22	0.22	-
"	40	"Maxaret"	-	-	0.27	0.27	0.27

The results obtained in the various measurements are shown plotted in the graphs in Fig.1.

32. **Remarks on Section IV**

32.1 It was found that under the condition of the tests the Maxaret unit failed to cycle correctly at the lower speeds and higher tyre pressure. There was some improvement in operation with the lower inflation pressure of 40 p.s.i.

32.2 Over the range of conditions covered the braking force coefficients were rather low. It was clear from the tests that for investigations on grass over a wider range of speed a specially prepared surface would probably be required.

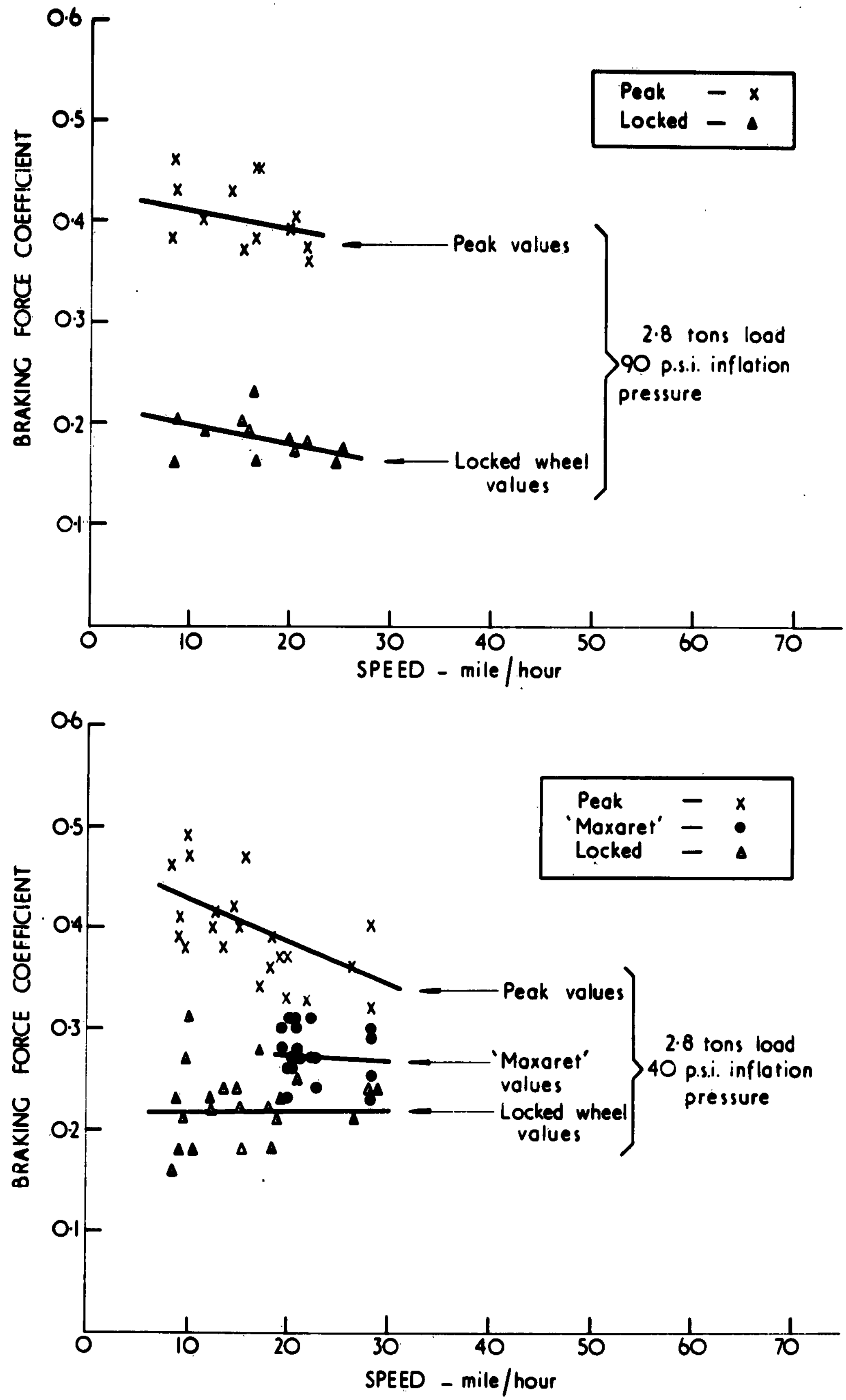


Fig 1 BRAKING FORCE COEFFICIENT OBTAINED ON A WET GRASS SURFACE AT WHITE WALTHAM AERODROME

V - MEASUREMENTS OF BRAKING FORCE COEFFICIENT FOR THE MINISTRY OF AVIATION ON A WET CONCRETE SURFACE AT LONDON AIRPORT

33. Introduction to Section V

33.1 Tests were made with the Heavy Wheel Load Test Vehicle at the request of the Ministry of Aviation, to determine the braking force coefficients using an aircraft tyre and loading conditions on a wet brushed concrete surface at London Airport.

34. Dates of Tests

8th, 9th, 10th, 11th, and 24th July, 1963.

35. Location of Test Sections

35.1 Because of the difficulty of closing a runway for any prolonged period, the present tests were made on a length of taxi-strip considered to be similar in texture to the main runways and situated on the North West side of the airport.

36. Test Conditions

Measurements were made under the following conditions of test:-

Test tyre:	35 x 10 - 17
Tread pattern:	Ribbed
Wheel load:	3.5 tons
Tyre pressures:	40, 100 and 260 p.s.i.
Test surface:	Brushed concrete
Water depth:	0.01" - 0.06"
Surface temperature:	18-22°C.

37. Details of Test

37.1 Measurements were made at various speeds up to 60 mile/h using the Maxaret anti-lock system fitted to the test wheel of the heavy load vehicle, and also using locked wheels, at the three inflation pressures given below.

38. Results

38.1 Table I summarises the results of the tests taken from the smooth curves drawn through the plotted points. The Maxaret values given in this table were obtained by taking the mean of the highest and lowest braking force values recorded for each Maxaret cycle. It is considered that this procedure is justified because of the almost sinusoidal form of the braking force curves obtained with the "Maxaret" system.

/TABLE I

TABLE I

Summary of results obtained in tests on a wet concrete surface at London Airport

Vertical Load (tons)	Inflation pressure (lb/in^2)	Braking condition	Value of braking force coefficient from smooth curves drawn through all plotted points (mile/h)					
			10	20	30	40	50	57
3.5	40	"Maxaret"	0.57	0.53	0.48	0.44	0.40	0.37
"	100	"	0.55	0.51	0.46	0.42	0.38	0.35
"	260	"	0.45	0.38	0.33	0.30	0.29	0.29
"	40	Locked wheel	0.53	0.45	0.38	0.33	0.29	0.28
"	100	"	0.52	0.42	0.35	0.29	0.24	0.22
"	260	"	0.38	0.30	0.24	0.19	0.16	0.15

38.2 The results obtained in the various measurements are shown plotted in the graphs given in Figs.1 and 2.

38.3 Figure 3 shows the effect of inflation pressure on the braking force coefficient at constants speeds.

39. Conclusions to Section V

39.1 In these tests, mean coefficients obtained with the anti-lock system show an improvement over the corresponding locked wheel values, over the whole range of test conditions and speeds.

39.2 As shown in previous tests, (S & T MEMO 8/63) it was also found that the braking force coefficients obtained at any given speed on this wet concrete surface diminish in value as the tyre inflation pressure increases under the same wheel load.

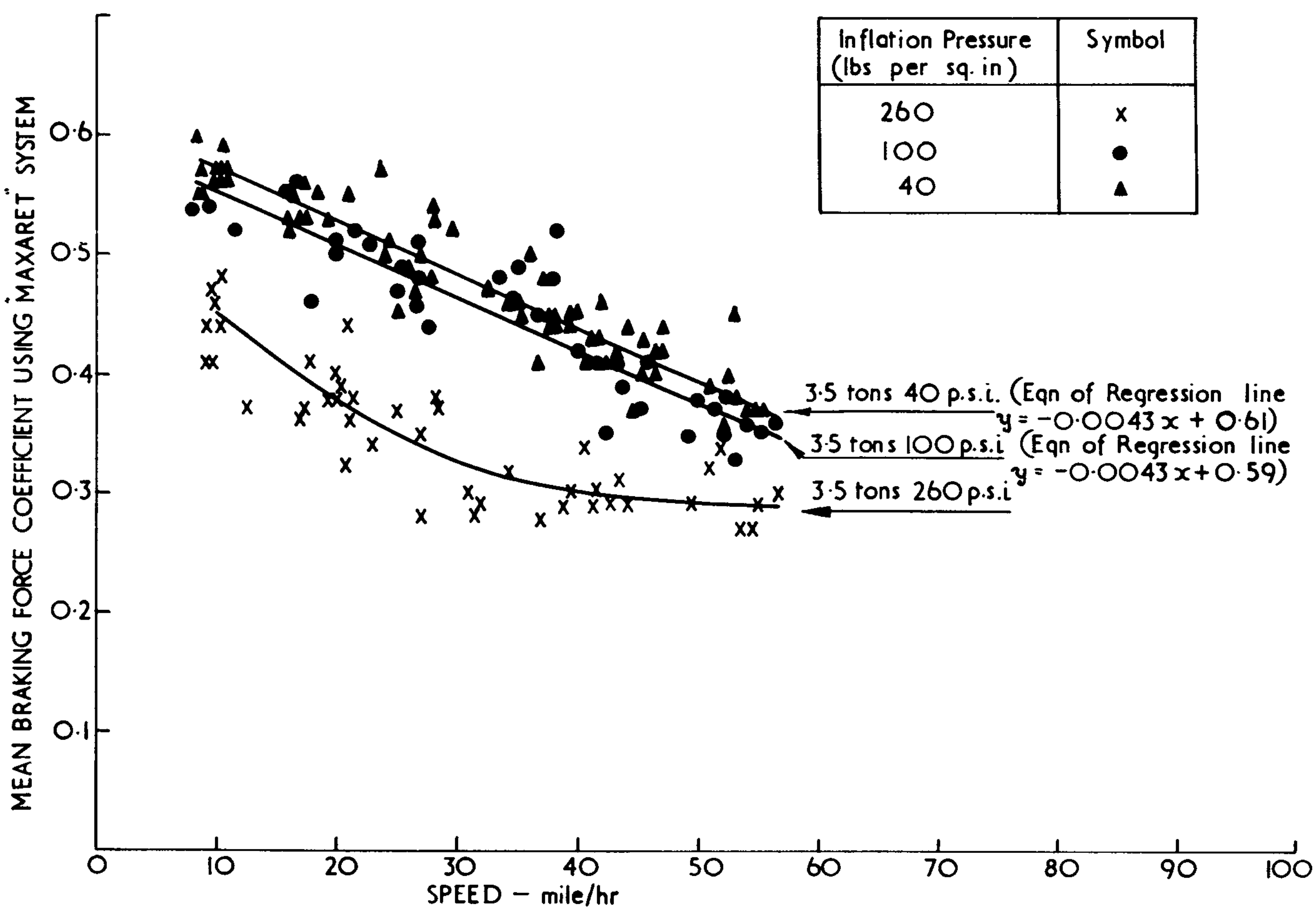


Fig. 1 BRAKING FORCE COEFFICIENTS MEASURED ON A WET CONCRETE SURFACE AT LONDON AIRPORT USING 3·5 TONS VERTICAL LOAD AND TYRE INFLATION PRESSURES OF 40, 100 AND 260 p.s.i WITH THE ANTI-LOCK SYSTEM OPERATING

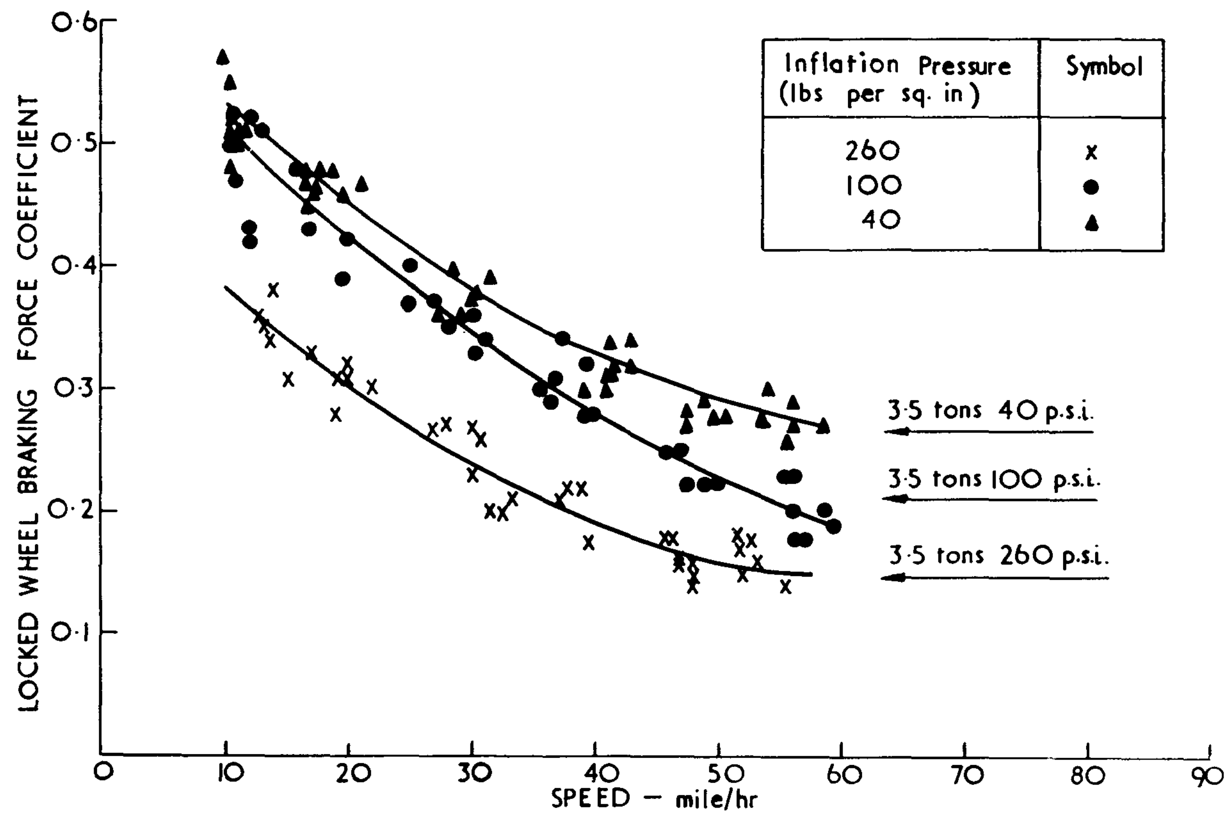
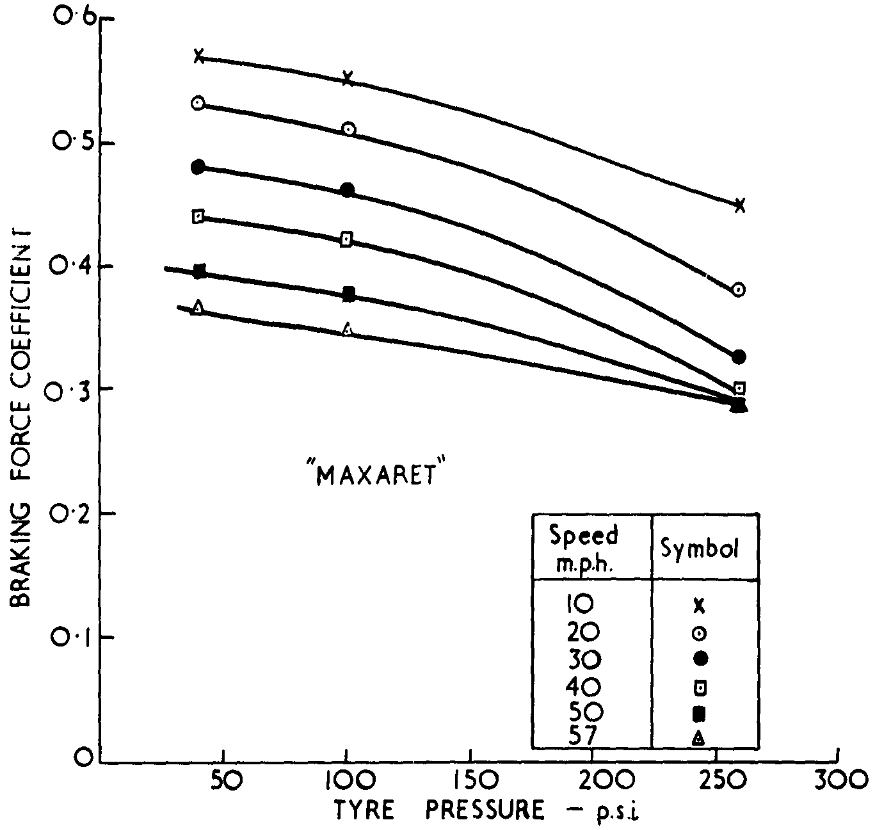


Fig. 2 BRAKING FORCE COEFFICIENTS MEASURED ON THE CONCRETE AT LONDON AIRPORT USING 3·5 TONS VERTICAL LOAD AND TYRE INFLATION PRESSURES OF 40, 100 AND 260 p.s.i. WITH LOCKED WHEEL BRAKING



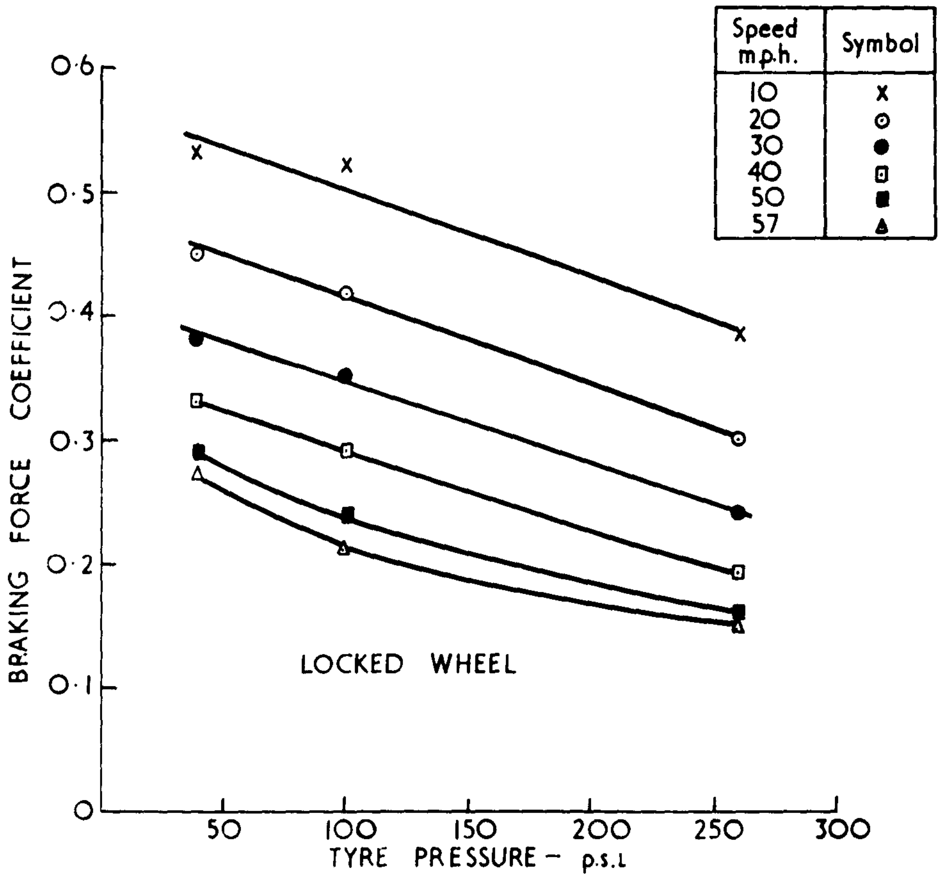


Fig 3 VARIATION IN BRAKING FORCE COEFFICIENT WITH TYRE INFLATION PRESSURE FOR 3·5 TONS VERTICAL LOAD ON A WET CONCRETE SURFACE AT LONDON AIRPORT

REFERENCES

No.	Author	Title
1	K.W. Tate	Flight tests to determine the coefficient of friction between an aircraft tyre and various wet runway surfaces - S & T. MEMO 19/61, March, 1962.
2	K.W. Tate and N. Lalor	Ibid. S & T. MEMO 2/62, April, 1962.
3	-	Test with a Heavy Load Skidding Machine to determine the friction coefficient between an aircraft tyre and various wet surfaces - S. & T. MEMO 8/63, June, 1963.
4.	-	Ibid. S & T. MEMO 5/64, June, 1964.

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TESTS WITH A HEAVY LOAD SKIDDING TEST VEHICLE INCORPORATING A MARK I MAXARET ANTI-LOCKING BRAKE SYSTEM TO DETERMINE BRAKING FORCE COEFFICIENTS BETWEEN AN AIRCRAFT TYRE AND VARIOUS WET SURFACES (Report of Work by the Road Research Laboratory under Ministry of Aviation contract)
Jan., 1965 pp., 4ref.

Gives the results of five test programmes with a Heavy Load Test Vehicle to determine braking force coefficients on the following wet surfaces:- smooth concrete (Crowthorne), fine cold asphalt (Crowthorne), quartzite macadam (Crowthorne), ¾ in. gravel carpet (Crowthorne), wet grass (White Waltham), asphalt with slurry overlay (Wisley) and brushed concrete (Heathrow). The test wheel was fitted with a Mark I Maxaret anti-locking brake system. This system had the effect of improving the braking performance, over that obtained for locked wheel configurations, under all test conditions. The anti-locking system showed to increasing advantage as the speed of test was raised.

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