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A Method of Improving Aircraft Ground Performance in Slush and Wet Conditions

By

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A Method of Improving Aircraft Ground Performance in Slush and Wet Conditions

- By -

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SUMMARY

A small wheel placed ahead of an aircraft main landing wheel can effectively clear a path for it through slush or standing water. In this investigation, model pneumatic wheels of 9 in and 3 in diameter were used to determine the effect of the forewheel on the drag and spray from the main wheel and on its aquaplaning characteristics. The model was run at speeds up to 115 ft/sec in a water depth of 0.25 in on a moving runway apparatus.

Total wheel drag was reduced by the auxiliary wheel except at very low speeds, the maximum reduction of nearly 50% occurring just below the normal aquaplaning speed of the main wheel.

Aquaplaning of the main wheel only occurred after the auxiliary wheel had aquaplaned. This could be prevented by using a very high auxiliary wheel tyre pressure.

The height of the intense region of the main spray plume was considerably reduced.

1. Introduction

Many of the delays in aircraft operation due to slush and wet runway conditions could be avoided if take-off and landing performance under these adverse conditions could be substantially improved. The word performance is used here to embrace not only the speeds, distances and times involved in take-off or landing, but also other aspects of these operations which directly affect the safety and integrity of the aircraft. Some of these aspects depend on the aquaplaning characteristics of the aircraft, for example the degree of directional control attained at high speed in cross winds, or the ability to stop safely in emergency conditions, such as after an aborted take-off run. Others are the result of impingement on the aircraft of spray from the wheels; these include structural and component damage, engine failure and slush deposition, the last occurring in wheel bays and other openings where it may cause trouble later in flight.

To be effective, any measures taken on an aircraft to improve ground performance in slush and wet conditions should achieve the following:

(i) Suppression of aquaplaning, and improvement of braking at sub-aquaplaning speeds,

(ii) reduction of wheel drag in slush,

(iii) control of the spray to reduce impingement drag and eliminate risks to the integrity of the aircraft.

Additionally,/

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* Replaces A.R.C.33 108

Additionally, the improved ground performance must be entirely predictable and runway conditions must be measurable, before the operating rules at present in force can be relaxed.

During the design and evolution of a new aircraft, substantial improvements in runway performance under adverse conditions could be gained by careful choice of the aircraft configuration and the position of the undercarriage units. Engines could be sited so as to remain clear of the spray, and the wheel arrangements on the undercarriage units could be chosen for minimum runway drag and spray. Such opportunities seldom occur in practice because there are usually other overriding requirements which decide the aircraft configuration in general, and the positions of undercarriage and engines in particular. Similarly, the size, number and position of the wheels on each undercarriage unit is likely to be dictated by the space available for retraction and the runway load bearing capacity, so that arrangements which could minimise drag and spray may be impossible to accommodate, or be otherwise impractical.

Because there are these limitations in applying design philosophies aimed at reducing the problems of slush and wet runways, and because there is a need to improve the runway performance of existing aircraft, other means of controlling aquaplaning, spray and wheel drag must be sought. Several methods have already been evaluated, and are finding limited use on civil and military aircraft. Aquaplaning has received the greatest attention, with much of the effort going toward improving the design of the tyres. The use of deep radial grooves and special rubbers in the tread, together with high inflation pressures, has improved braking at sub-aquaplaning speeds and has raised aquaplaning speeds substantially under most conditions. It has not been possible to eliminate aquaplaning entirely, as the inflation pressures required are impractically high and because special tread designs are only effective when the water or slush depth is less than the tread depth. Considerable effort has also gone into improving the drainage afforded by the runway in the tyre contact patch, by such means as lateral grooving and the use of porous surfaces.

Alternative methods of reducing the risk of aquaplaning were first examined by Harrin[1]. His experiments with model wheels in tandem showed that the forward wheel of the pair partially cleared a path in the runway slush or water layer for the rear wheel. This delayed the onset of aquaplaning of the rear wheel, and also reduced the overall drag force on the wheels. Harrin also examined the use of air jets to clear the water or slush from the path of the wheel. This work is also described in Reference 1. The apparatus, which employed wheels of 12" diameter, was rather restricted in its range of speeds and water depths, but was sufficient to demonstrate that wheel drag and aquaplaning could both be improved if sufficient air could be made available. More recently, tests by Roberts[2], on the Bristol University Wheel Test Apparatus, with a developed air jet system, have shown the method to give large reductions of drag and spray and complete elimination of aquaplaning to considerable speeds and depths of water. The quantity of compressed air required was generally such that, at full scale, the system could in theory be powered by bleeding the main engines, although to be effective at the higher ground speeds auxiliary compressors would be needed to provide the high blowing pressures. The weight penalty due to the complex duct system and the loss of engine performance due to the high bleed flow would, in most cases, make this method impractical and other schemes have been suggested, such as rechargeable high pressure air vessels, or solid fuel gas generators.

A full scale investigation of the air jet method has been undertaken in the USA by the NASA at the Langley Field Research Centre. This work, described in References 3 and 4, showed alleviation of aquaplaning with large improvements in braking friction over the entire range of ground speed.

Air jets are also effective in controlling the spray thrown up by the wheels. Other methods of spray control have involved special chines and fences fitted to the tyre, and shields around the wheel. These methods have achieved some success and Figures 1 and 2 show examples of a "chine" tyre and shield respectively, both of which have been adopted for use on civil aircraft. The former figure shows a chine tyre made by the American company of B. F. Goodrich, fitted to the nose undercarriage of a Boeing 727 jet transport. The second figure shows the shielded nosewheel which has been adopted for the Lear Jet executive aircraft. Some research into spray deflectors and special tyres has also been conducted in this country, by the De Havilland Aircraft Company (now Hawker Siddeley, Hatfield) using solid model wheels[5], by the Dunlop Rubber Company in conjunction with the Ministry of Aviation using full scale tests; and more recently at Bristol University by Roberts[2], also using solid model wheels. Although significant reductions to the spray have been found possible, these are not generally accompanied by reductions of the wheel drag, and in some cases an increase in the drag is caused by flow blockage at the chine, or impingement on the shield.

The experiments described in this report are concerned with an alternative method of improving the runway performance of aircraft in slush or wet conditions. The method consists of running a small auxiliary wheel ahead of the larger main wheel. This idea stemmed from the effective clearing action of the front wheel of a pair of wheels in tandem and the observation that the cleared track increased behind the wheel to two or three times the width of the wheel.

2. Apparatus

The investigation was carried out on the moving runway wheel test facility at Bristol University. This is described by Barrett[6,7]. In principle, the model wheel runs on an endless belt onto the surface of which a layer of water is ejected tangentially at the same speed as the belt. In this way the forward motion of a wheel on a fluid-covered runway is simulated, except that air motion relative to the wheel is not represented. A full description of the test conditions achieved and the degree to which the full scale conditions are scaled is included in Reference 7. In this investigation a 6" wide water layer with a nominal depth of 0.25" was used, with a smooth runway surface.

Some initial exploratory tests were carried out using a 3.0" diameter foam-filled rubber wheel mounted in front of a 9.0" diameter × 2.35" wide pneumatic tyre. For the main test series, the foam wheel was replaced by a 3.0" diameter pneumatic wheel.

The small wheel with its separate loading pan was carried on a beam freely pivoted on the axle of the main wheel, as shown in Figure 3. The whole assembly was mounted on a drag balance via a vertical sliding bearing which enabled loads to be applied to the main wheel. There was some coupling between the loads on the two wheels, for which allowance could be made. The horizontal distance between the wheel centres could be varied from 6.0" to 9.0". The geometry of the system and the forces involved are shown diagrammatically in Figure 4.

3. Tests Made

3.1 Exploratory work

The original tests using a 3.0" foam-filled auxiliary wheel were aimed solely at determining the workability of the system. The total drag of the tandem wheel combination was measured and was compared with the drag of each wheel when in isolation on the belt. The normal tyre conditions of 30 lb/in^2 inflation pressure and 200 lb load were used for the main wheel, while the auxiliary wheel carried a load of 15 lb. A wheel spacing of 6.0" was employed. An example of the results obtained is shown in Figure 5.

3.2 Drag measurements

Following the exploratory tests, a further series of drag measurements was made using the 3.0" diameter pneumatic auxiliary wheel. The water depth was 0.25" in all cases and the inflation pressure and load on the 9.0" diameter main wheel remained constant at 30 lb/in^2 and 200 lb respectively. Inflation pressures for the small wheel were 4 lb/in^2, 10lb/in^2 and 14 lb/in^2, and the corresponding loads to give the correct scale tyre deflection were 9 lb, 13 lb and 16 lb respectively. Horizontal distances between the wheel centres were 6.0" and 8.0". The total drag on the tandem wheel combination was measured, so also was the drag on the main wheel when alone on the belt. The results are shown for the 6.0" wheel spacing in Figures 6 - 8, and for the 8.0" spacing in Figures 9 - 11.

3.3 Spray measurements

Spray intensity measurements were made 5.0" behind the main wheel, for speeds of 60 ft/sec and 100 ft/sec. The inflation pressure of the small wheel was 14 lb/in^2 and the load was 16 lb. Spacing between the wheels was 6.0" and the water depth was 0.25". Conditions for the main wheel were as previously stated. The spray intensity distribution was also measured for the main wheel alone. The results are shown in Figures 14 and 15 for speeds of 60 ft/sec and 100 ft/sec respectively.

Spray intensity τ was defined as the ratio of the pressure measured by the spray intensity probe to the dynamic pressure of the water on the moving runway. Details of the probe and of the method of measurement are given in Reference 6.

4. Discussion of Results

4.1 Drag measurements

The initial experiments with the foam-filled auxiliary wheel amply demonstrated the drag reducing capabilities of the combination. For example, the results in Figure 5 show that, as the speed increased beyond 50 ft/sec, the drag reduction due to the presence of the auxiliary wheel increased steadily to reach a maximum of over 40% at 90 ft/sec. For the main wheel alone this speed marked the end of the steep rise of drag with speed and the onset of aquaplaning. At higher speeds, the percentage drag reduction decreased steadily as the drag of the combination continued to rise, while the drag of the main wheel alone was decreasing slightly. The continued rise with speed of the drag of the two wheel combination was due to the lack of aquaplaning. The aquaplaning speed of the small foam-filled wheel was greater than the maximum test speed, and hence it was able to maintain a clear path for the larger wheel.

The experiments with pneumatic auxiliary wheels indicate the effects of allowing the auxiliary wheel to aquaplane. Examination of the results in Figures 6 - 11 shows that the drag varied more erratically with speed than was the case with the foam-filled auxiliary wheel. The main irregularities coincided approximately with the aquaplaning speeds of the two wheels. In two cases the tests were curtailed at the higher speeds due to a pitching instability. This instability occurred at approximately the aquaplaning speed of the main wheel.

It was more prevalent at the lower tyre pressures of the auxiliary wheel and for the closer spacing of the wheels. The diagrams in Figure 12 show the nature of the instability. The cycle began with the auxiliary wheel, which was already aquaplaning, lifting clear of the water layer. This allowed a full flow of water to impinge on the main wheel tyre, which in turn lifted as the auxiliary wheel was falling back to the surface. The oscillation tended to build up very quickly, reaching amplitudes which necessitated stopping the water flow after only a few seconds. The maximum amplitude recorded was greater than 1.5" for the main wheel and approximately 2.0" for the small wheel which was restrained from lifting further by a cord attached to the nozzle structure. Although no attempt was made to cure the oscillation, it would be a simple matter to prevent, or heavily damp, the rotation of the deflector wheel and its support structure about the main axle. A similar instability has been observed on a four wheel bogie landing gear during tests by the NASA at the Langley Landing Loads Facility.

A comparison of the drag curves in Figures 6 - 11 shows that, after allowing for the local irregularities due to aquaplaning effects and variations in wheel rotation, the inflation pressure and the load on the deflector wheel had little effect on the results. At speeds above 70 ft/sec, there was also little to choose between the drags with the two different wheel separations. Below this speed, however, the 6.0" spacing gave slightly greater drag, probably due to greater impingement of spray on the main wheel.

In Figure 13 a mean value of the percentage drag reduction due to the auxiliary wheel is plotted against speed. The curve for the foam-filled auxiliary wheel is included for comparison, the two curves being similar in shape over most of the speed range. They differed somewhat at low speeds, but this may have been due to the averaging process carried out on the pneumatic auxiliary wheel results. The pneumatic auxiliary showed a slightly better performance, with a maximum drag reduction of nearly 50% at 90 ft/sec. At low speeds the drag of the combination was greater than the drag of the main wheel alone, but because the magnitude of the drag is small at these speeds, this would be of little consequence in operational use.

Despite the inconclusive nature of the results, it would seem logical to suppose that, in order to maintain a clear path through the fluid for the main wheel, the auxiliary wheel should be prevented from aquaplaning throughout the speed range. In practice, for a modern jet transport this would require an auxiliary wheel inflation pressure of 300 lb/in^2 or more. The development of such a tyre, with a diameter of about 12", and a maximum operating speed of 160 knots or more, should be within the capabilities of the aircraft tyre manufacturers.

4.2 Spray measurements

The results from the short series of spray intensity measurements showed a definite lowering and reduced lateral spread of the main spray plumes due to the action of the auxiliary wheel. Figures 14 and 15 compare the spray with and without the auxiliary wheel for speeds of 60 ft/sec and 100 ft/sec respectively. The reduction in height of the intense core of the spray plumes was such that, in practice, with a fuselage in the normal position relative to the nosewheels, impingement of spray would be insignificant. The maximum intensity values recorded with the auxiliary wheel in operation were, in fact, greater than with the main wheel alone, but they occurred low down immediately adjacent to the surface layer.

From spray intensity traverses for a single 3.0" diameter pneumatic wheel made in a separate investigation (Reference 7), a survey was made of the position of the inner edge of the spray envelope, 6.0" behind the wheel and 0.5" above the ground. This represented, for the tandem arrangement, the position at which the

width/

width of the main wheel tyre was a maximum. Under load the maximum width of the main wheel tyre was approximately 2.7" and this can be compared in the Table below with the width of the track cleared by the small wheel under various test conditions.

Track Cleared by 3.0" dia Wheel at the Position of the Main Wheel

Test Conditions			Width of Cleared Track at Mainwheel Position i.e., z = 6" y = 0.5"		
Tyre Pressure p.s.i.	Wheel Load lb	Water Depth in	Wheel Speed 60 ft/sec	80 ft/sec	100 ft/sec
4	9	0.1	2.2"	2.4"	2.2"
4	9	0.16	2.6"	2.6"	2.0"
4	9	0.2	2.8"	2.6"	2.0"
14	16	0.1	1.9"	2.5"	2.6"
14	8	0.1	-	-	2.2"

Although the exact conditions of the tandem wheel tests are not represented in the Table, it can be inferred from the results that under most test conditions, the spray plumes were just striking the sides of the main wheel tyre. The cleared track tended to be narrower at high speed. This shows that the auxiliary wheel was not sufficiently far ahead of the main wheel in the spray tests. The intense spray regions close to the ground in the tandem wheel tests may have been the result of spray rebounding downward from the mainwheel. At each speed the shape of the main spray envelope for the pair of wheels differed from that of the small wheel alone, especially in the region close to the ground. This is a further indication that the spray was modified by impingement on the main wheel.

5. Conclusions

A method was examined for reducing the drag and spray from a wheel in slush or water and for eliminating aquaplaning. The method consisted of running the main aircraft wheel in the track of a small auxiliary wheel which acted as a deflector to the runway fluid. The following conclusions were drawn from the experimental results:-

(i) The auxiliary wheel considerably reduced the total hydrodynamic drag over the important part of the speed range. The maximum reduction of nearly 50% occurred just below the normal aquaplaning speed of the main wheel.

(ii) To eliminate aquaplaning of the large wheel, it was necessary to prevent the auxiliary wheel from aquaplaning by the use of very high inflation pressure.

(iii) The height of the intense region of the main spray plumes was considerably reduced by the auxiliary wheel.

The test series was very limited in scope and further work would be worthwhile to determine the optimum size, position and operating conditions for the auxiliary wheel.

The method would also appear to be applicable to twin side by side nosewheel undercarriages using two auxiliary wheels. Again, further experimental work is necessary to examine this application.

The performance obtained from the deflector wheel arrangement was somewhat similar to that obtained with air jet arrangements. The advantage over the latter is that no power is required from the aircraft. Other methods of spray reduction, such as tyre chines or spray deflector shields, could be incorporated on the auxiliary wheel to reduce the spray still further.

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No.	Author(s)	Title, etc.
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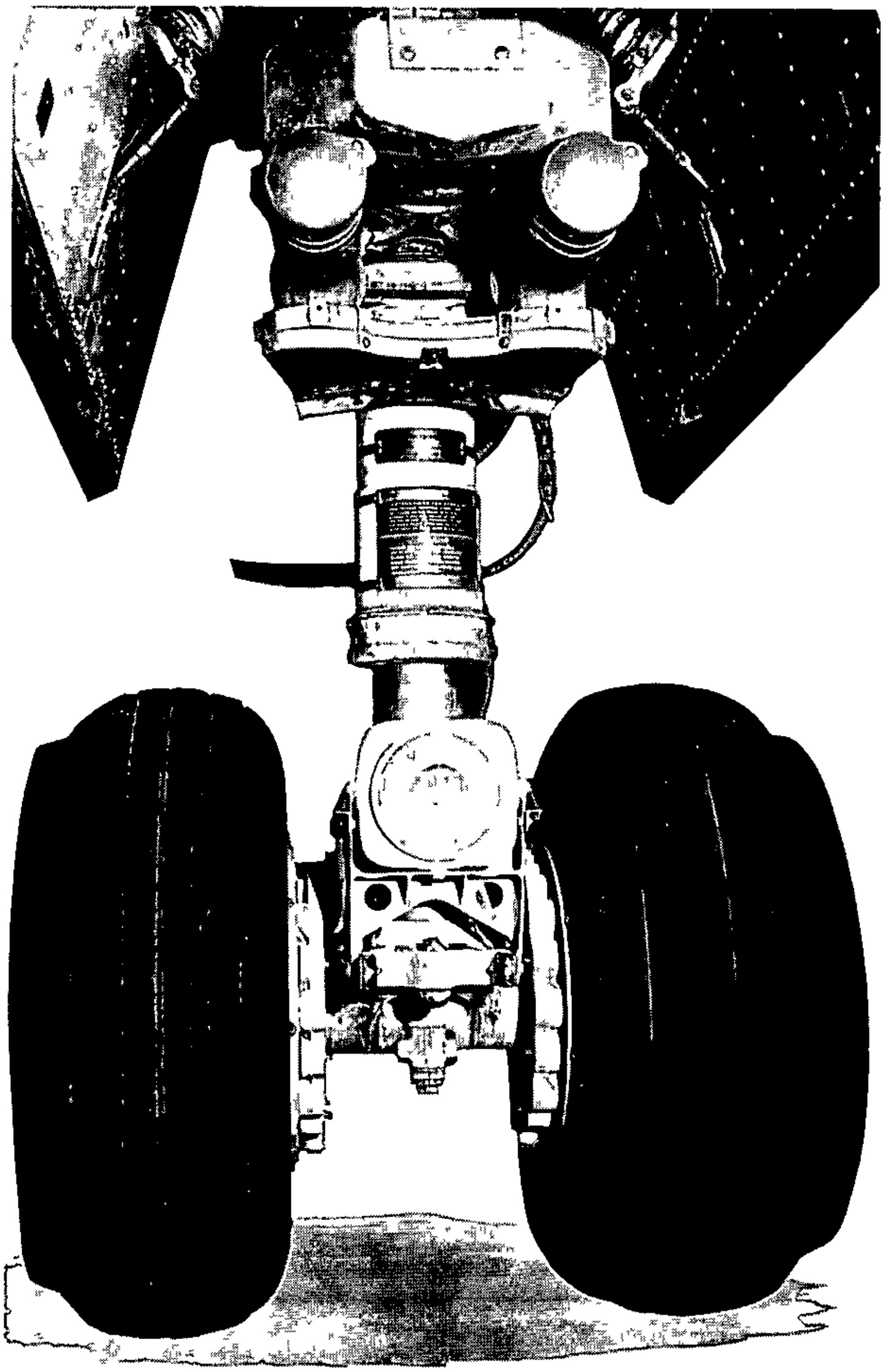
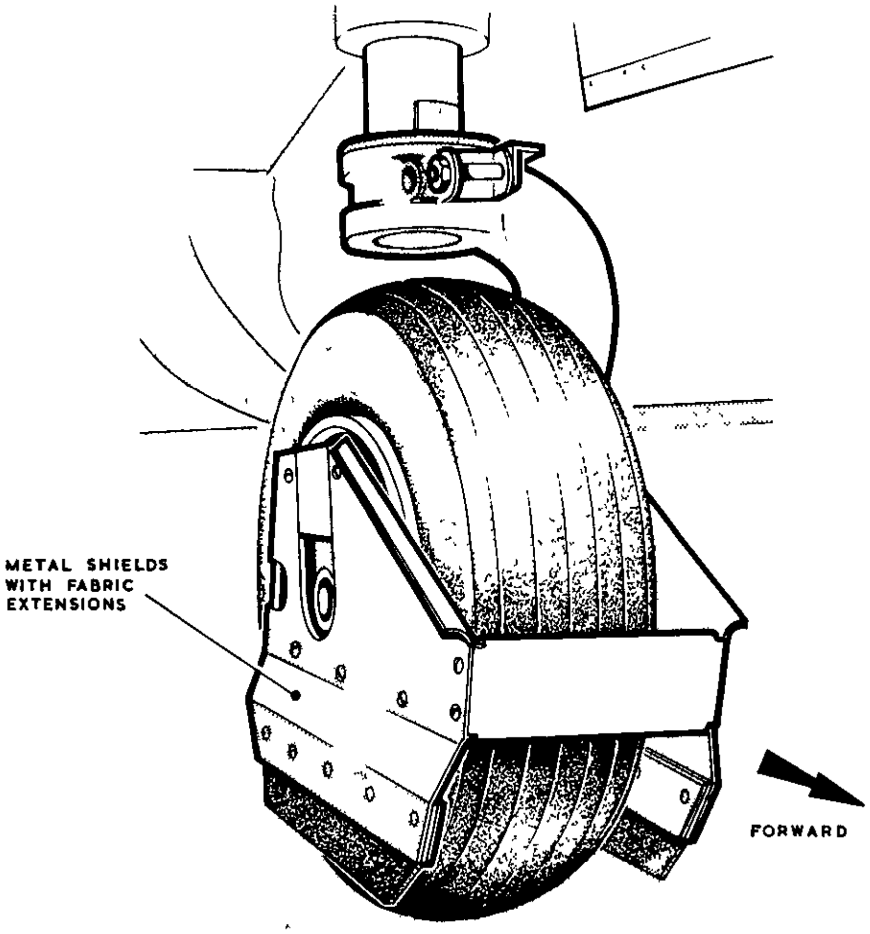
6.	Barrett, R. V.	Drag and Spray Measurements from a Small Pneumatic Tyre travelling through a Water Layer. Ministry of Aviation TILS. S & T Memo 11/63, December, 1963.
7.	Barrett, R. V.	Measurements of the Drag and Spray produced by Model Pneumatic Wheels moving through Water Layers. University of Bristol Ph.D. Thesis March, 1967.

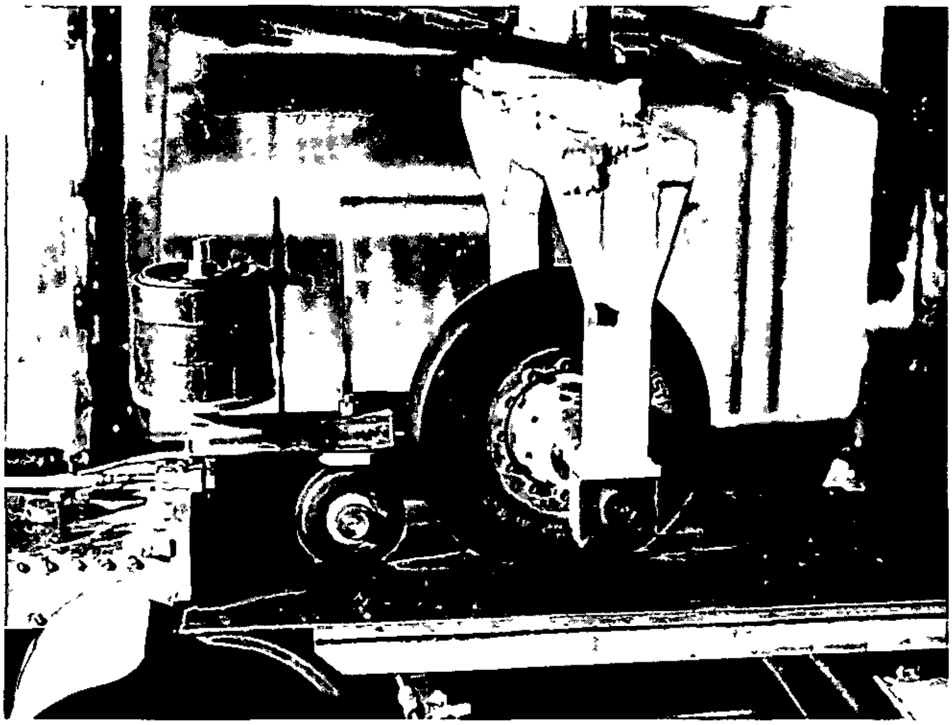


B F. Goodrich chine tyres, nose wheel and brake assembly, Boeing 727 aircraft.

FIG. 1.

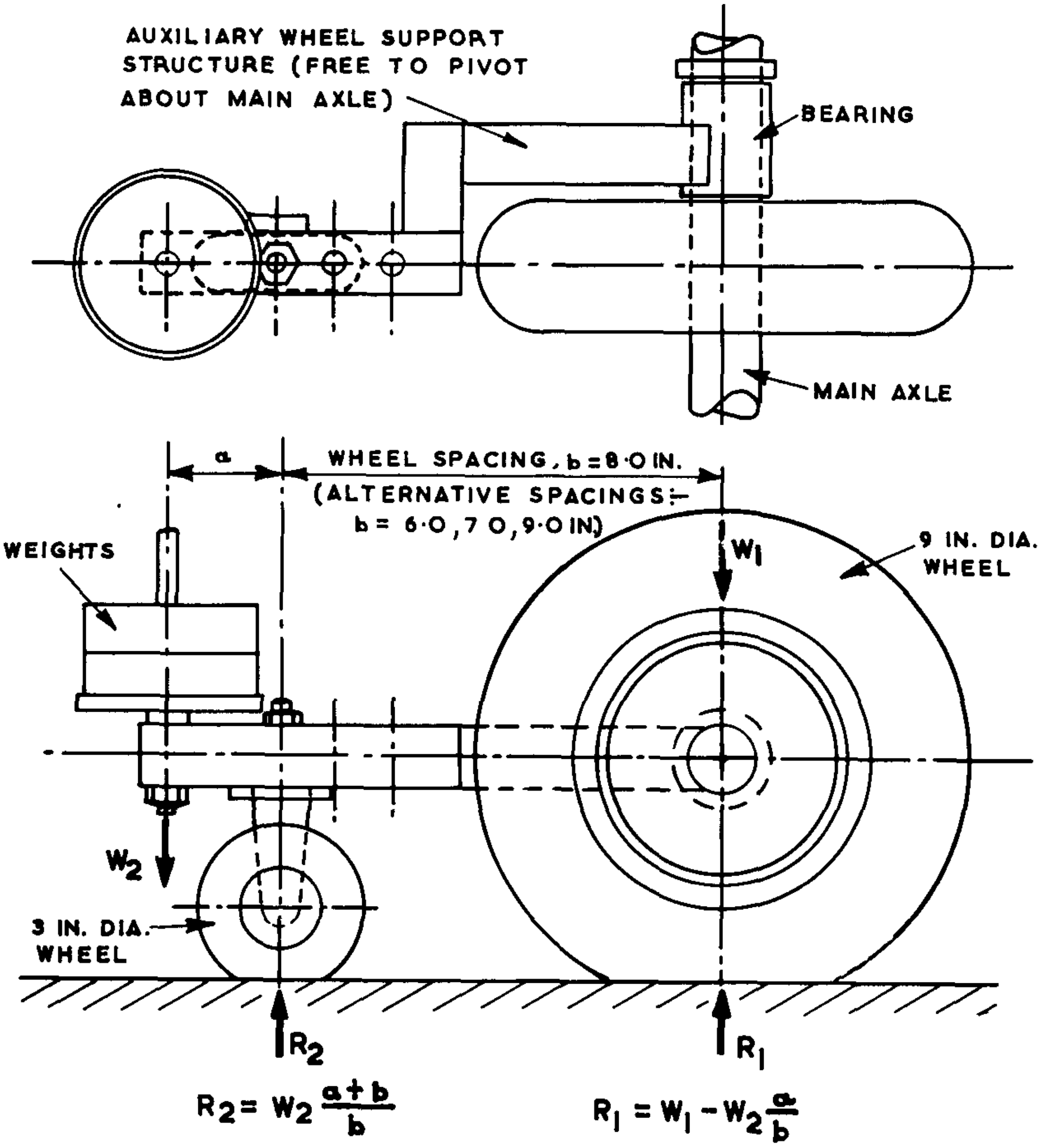


SPRAY SHIELD FITTED TO
NOSEWHEEL OF LEAR JET
EXECUTIVE AIRCRAFT
FIG 2



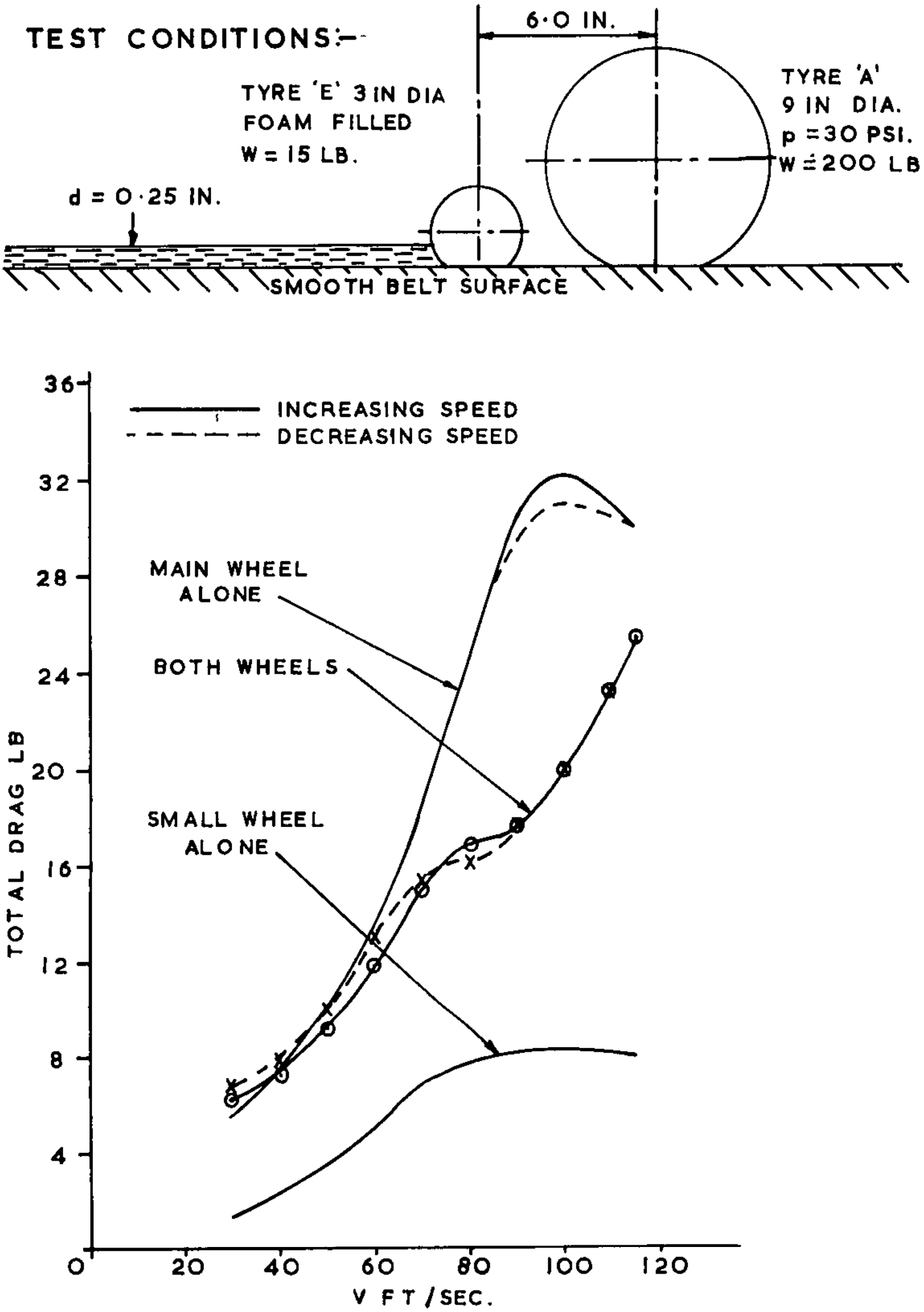
ARRANGEMENT OF MAIN WHEEL AND AUXILIARY WHEEL IN THE TEST SECTION.

FIG. 3.



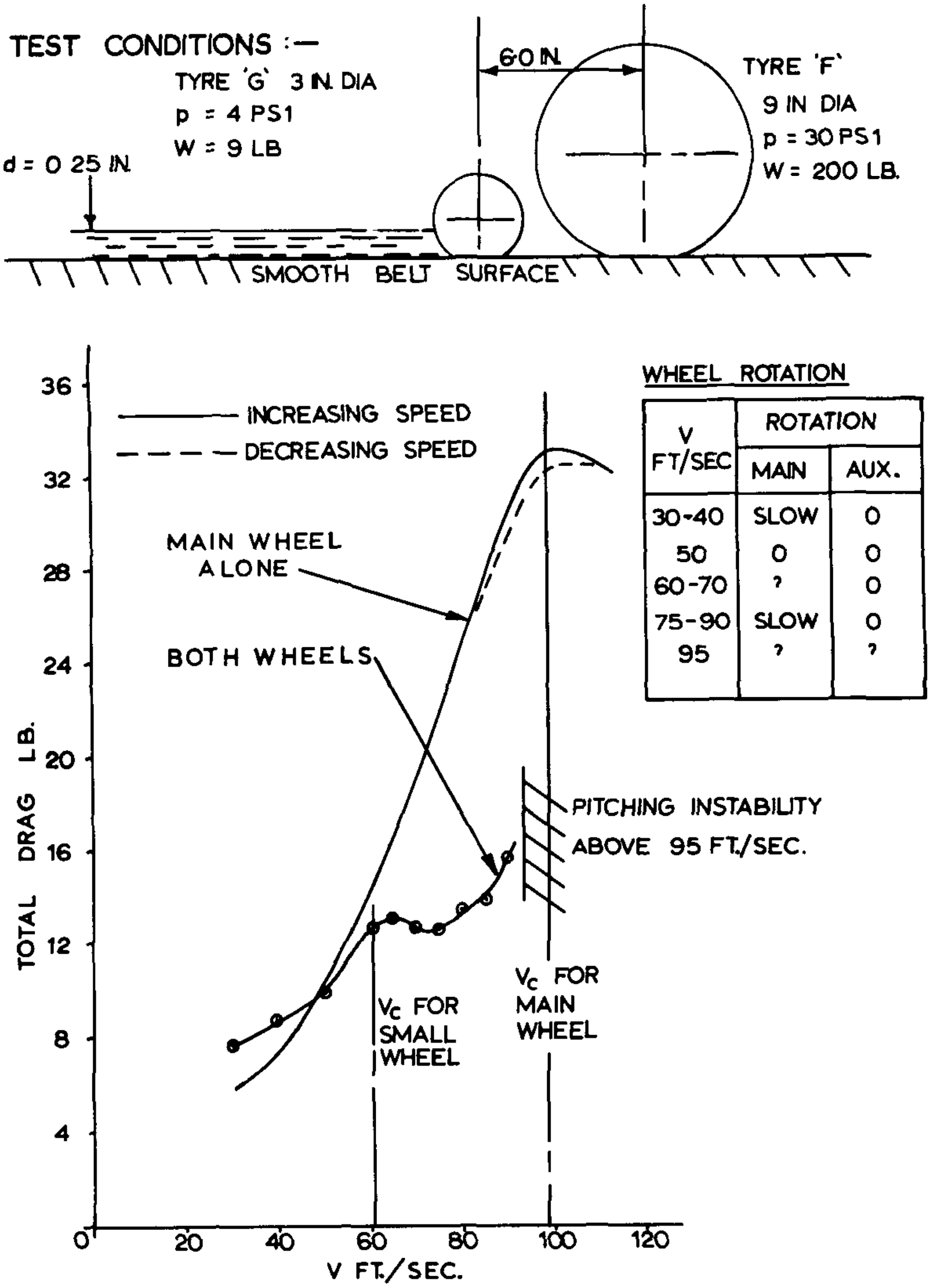
METHOD OF SUPPORTING AND LOADING AUXILIARY WHEEL

FIG. 4



EFFECT OF FOAM FILLED AUXILIARY WHEEL ON THE TOTAL DRAG VARIATION WITH SPEED

FIG. 5

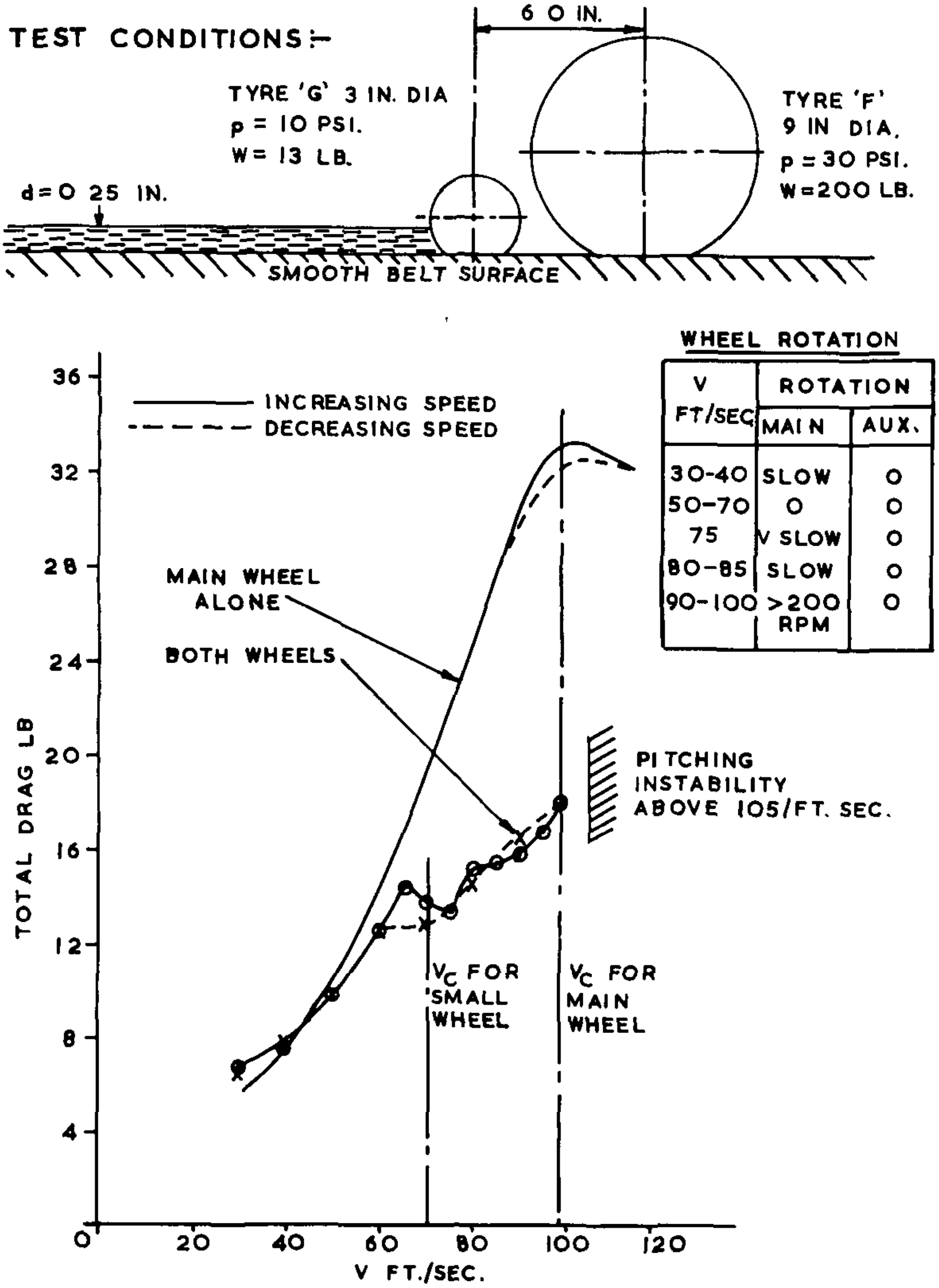


WHEEL ROTATION

V FT/SEC	ROTATION MAIN	 AUX.
30-40	SLOW	O
50	O	O
60-70	?	O
75-90	SLOW	O
95	?	?

EFFECT OF THE AUXILIARY WHEEL ON THE TOTAL DRAG VARIATON WITH SPEED.

FIG.6

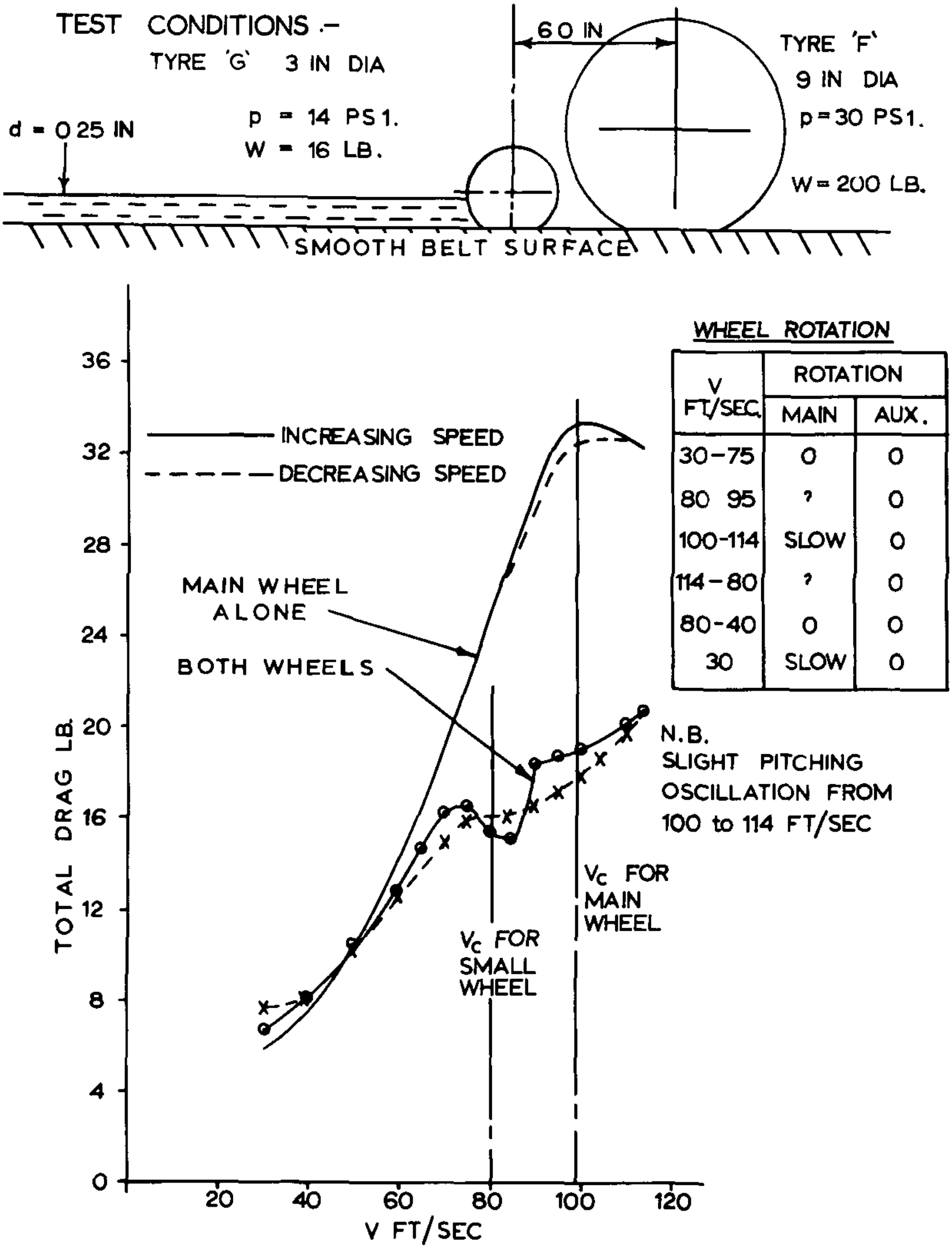


WHEEL ROTATION

V FT/SEC	ROTATION	
	MAIN	AUX.
30-40	SLOW	O
50-70	O	O
75	V SLOW	O
80-85	SLOW	O
90-100	>200 RPM	O

EFFECT OF THE AUXILIARY WHEEL ON THE TOTAL DRAG VARIATION WITH SPEED

FIG. 7

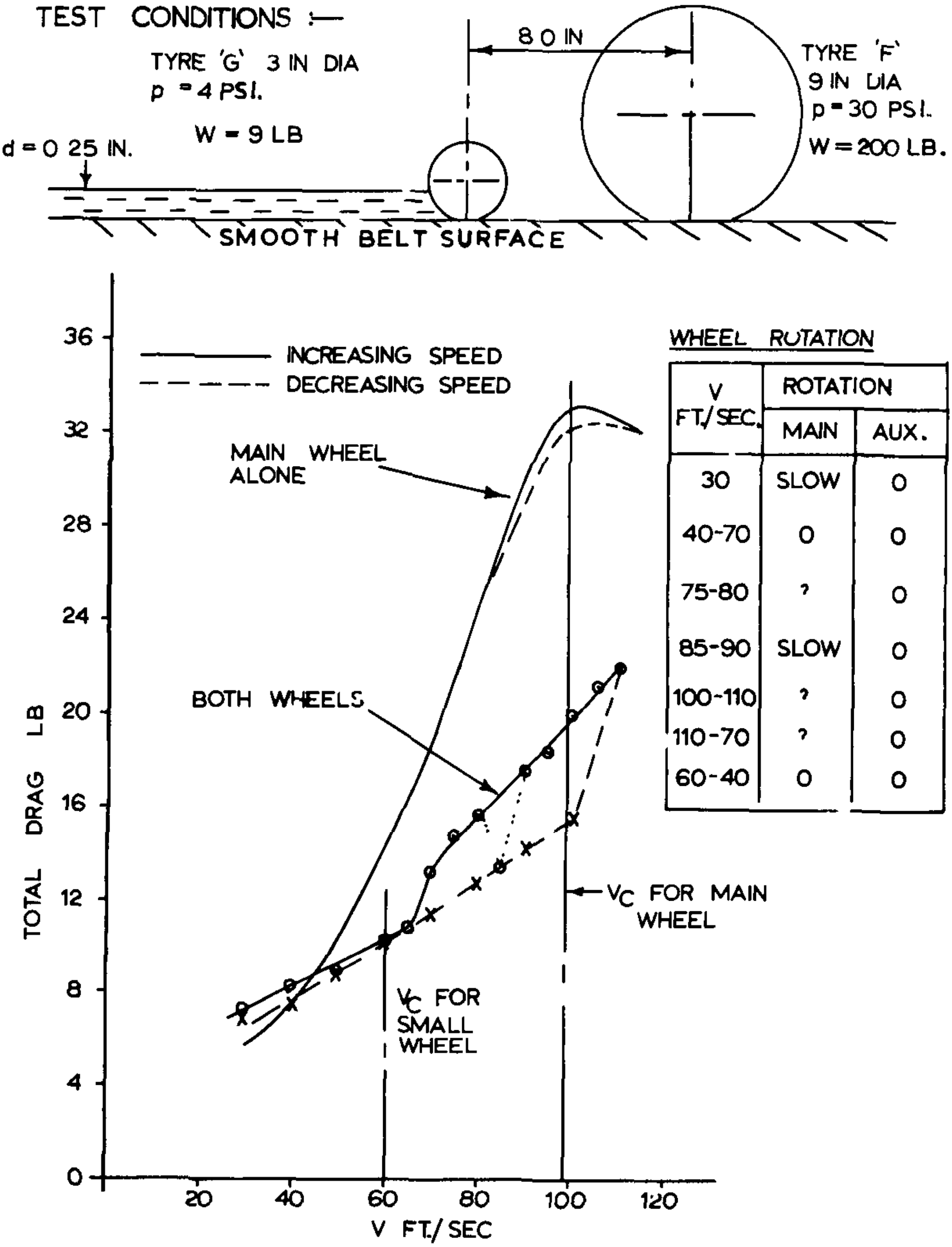


WHEEL ROTATION

V FT/SEC.	ROTATION	
	MAIN	AUX.
30–75	0	0
80 95	?	0
100-114	SLOW	0
114–80	?	0
80-40	0	0
30	SLOW	0

EFFECT OF THE AUXILIARY WHEEL ON THE TOTAL DRAG VARIATION WITH SPEED.

FIG. 8

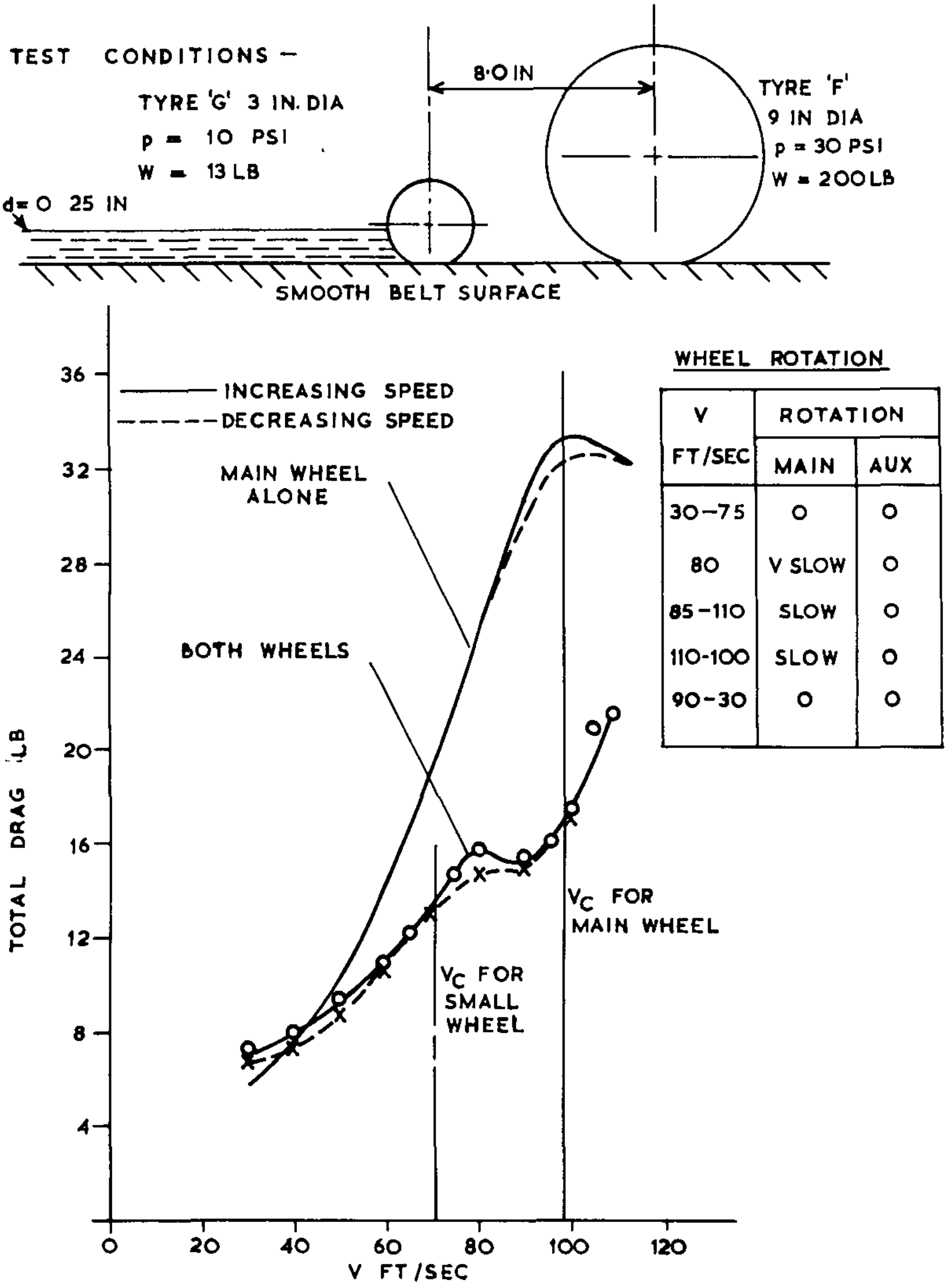


WHEEL ROTATION

V FT./SEC.	ROTATION	
	MAIN	AUX.
30	SLOW	O
40-70	O	O
75-80	?	O
85-90	SLOW	O
100-110	?	O
110-70	?	O
60-40	O	O

EFFECT OF THE AUXILIARY WHEEL ON THE TOTAL DRAG VARIATION WITH SPEED.

FIG. 9

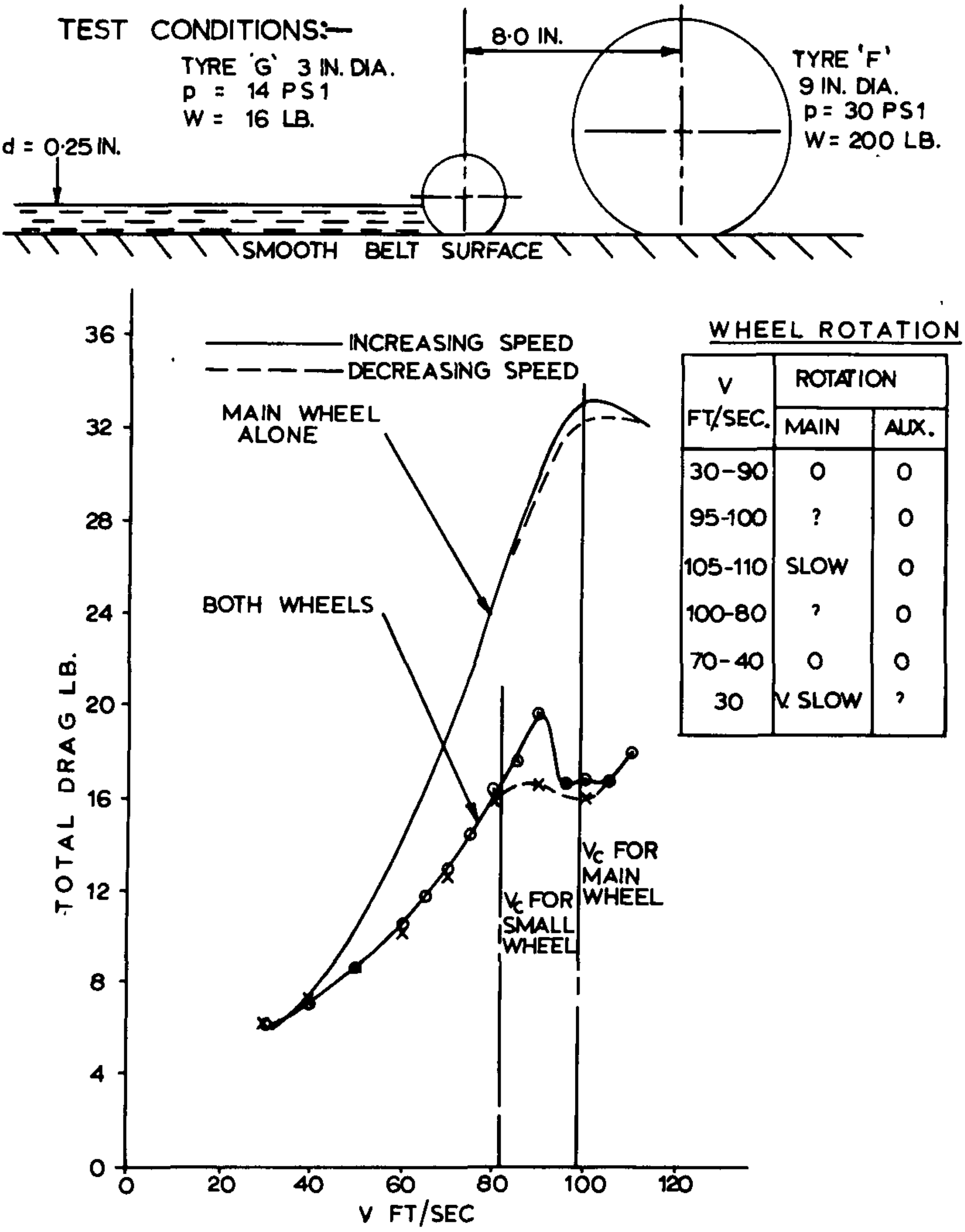


WHEEL ROTATION

V FT/SEC	ROTATION	
	MAIN	AUX
30–75	O	O
80	V SLOW	O
85–110	SLOW	O
110-100	SLOW	O
90–30	O	O

EFFECT OF THE AUXILIARY WHEEL ON THE TOTAL DRAG VARIATION WITH SPEED

FIG. 10

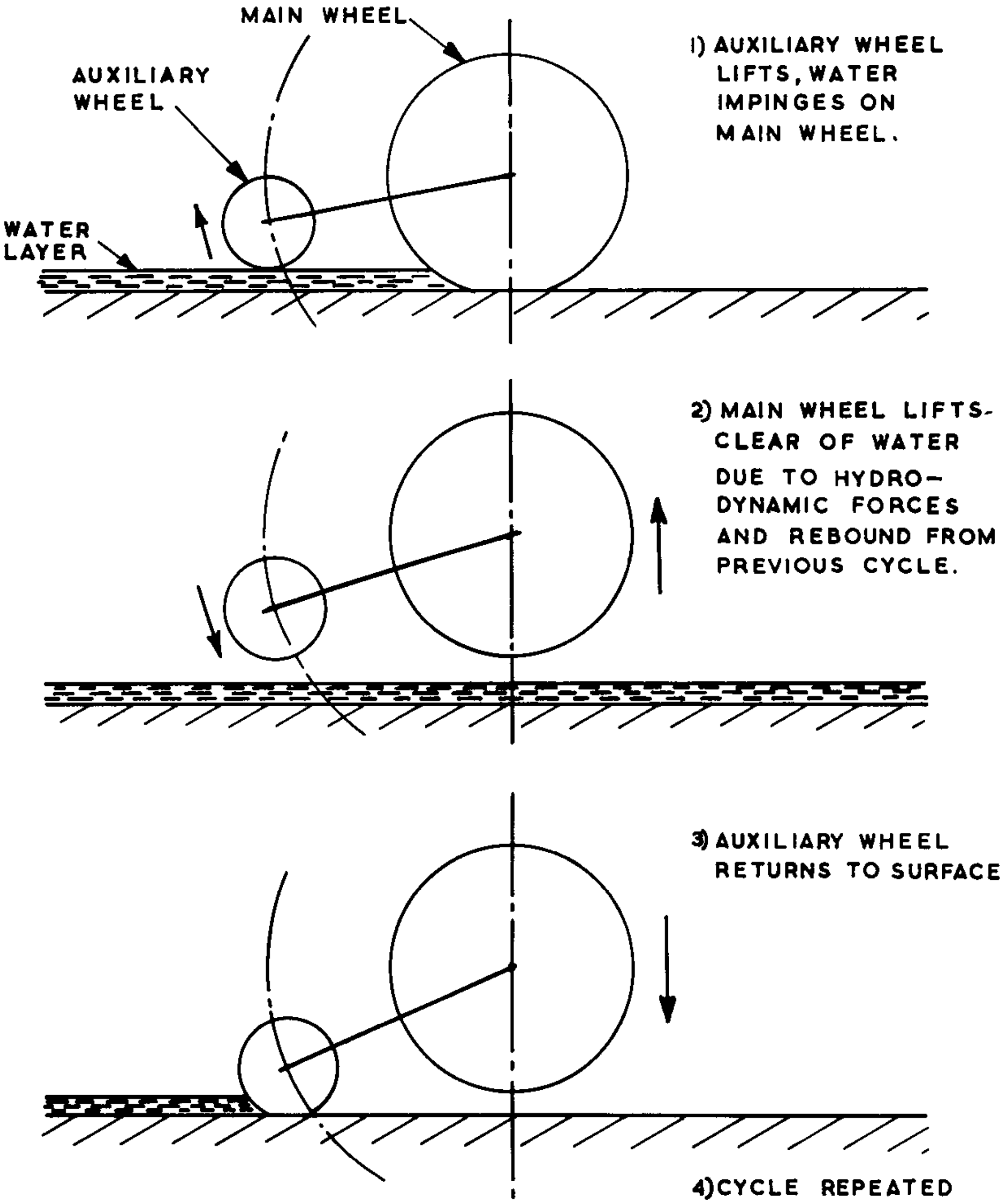


WHEEL ROTATION

V FT/SEC.	ROTATION MAIN	ROTATION AUX.
30–90	0	0
95-100	?	0
105-110	SLOW	0
100-80	?	0
70-40	0	0
30	V. SLOW	?

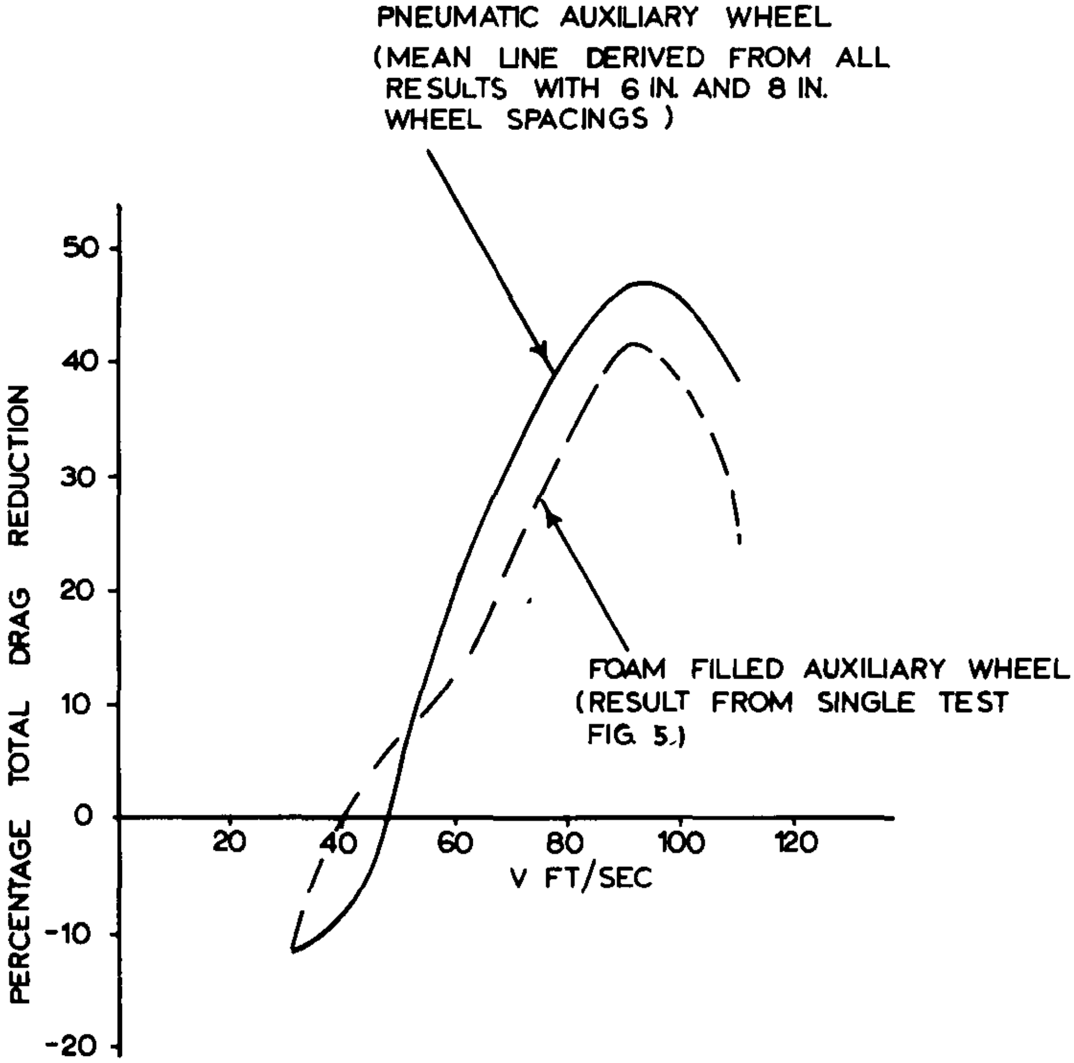
EFFECT OF THE AUXILIARY WHEEL ON THE TOTAL DRAG VARIATION WITH SPEED.

FIG. II



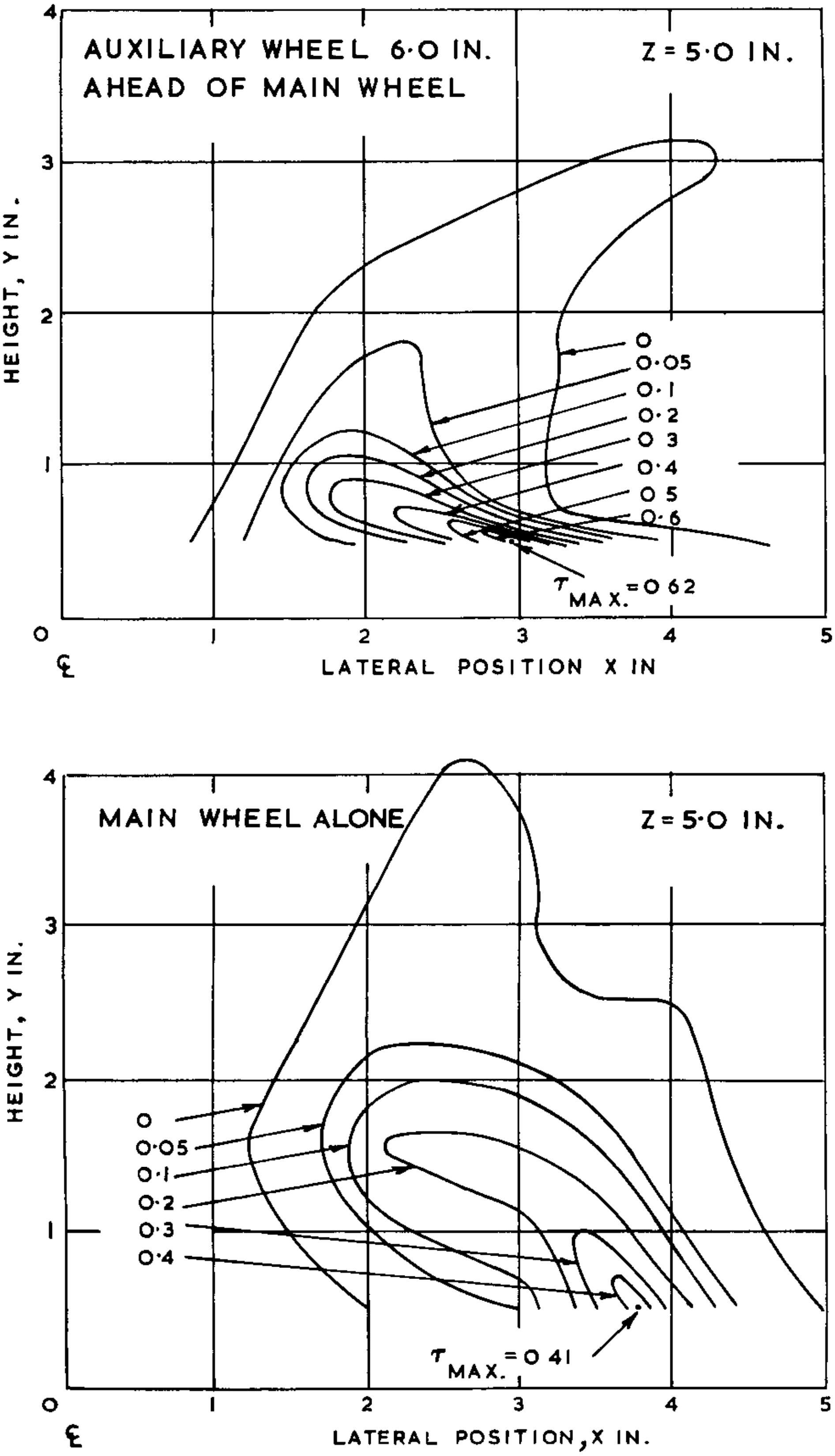
PITCHING OSCILLATION EXPERIENCED UNDER CERTAIN TEST CONDITIONS

FIG. 12



PERCENTAGE REDUCTION IN TOTAL DRAG DUE TO THE AUXILIARY WHEEL.

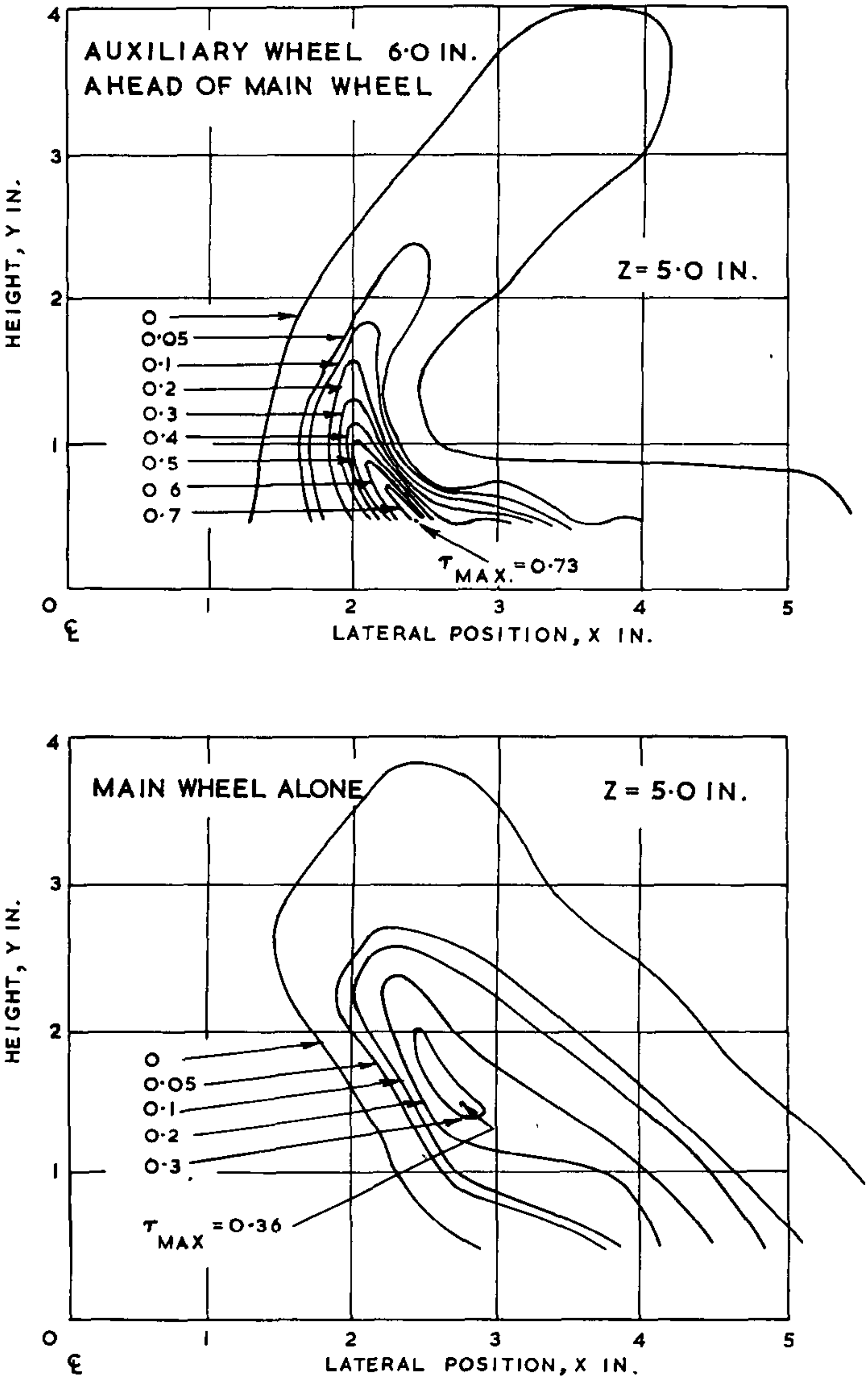
FIG. 13



COMPARISON OF MAIN SPRAY INTENSITY DISTRIBUTION WITH AND WITHOUT AUXILIARY WHEEL, AT V=60 FT/SEC.

MAIN WHEEL-9 IN. DIA, TYRE 'F', $p = 30$ PSI, W 200 LB.
AUXILIARY WHEEL - 3 IN DIA, PNEUMATIC TYRE, $p = 30$ PSI. $W = 16$ LB
SMOOTH BELT SURFACE, $d = 0{\cdot}25$ IN. N B CONTOURS ARE OF CONSTANT, τ

FIG. 14



COMPARISON OF MAIN SPRAY INTENSITY DISTRIBUTION WITH AND WITHOUT AUXILIARY WHEEL, AT V=100 FT./SEC.

MAIN WHEEL-9 IN DIA., TYRE 'F', p = 30 PSI, W 200 LB
AUXILIARY WHEEL-3 IN DIA, PNEUMATIC TYRE, p=14 PSI W=16 LB
SMOOTH BELT SURFACE, d=0 25 IN NB CONTOURS ARE OF CONSTANT, τ

FIG.15

A.R.C. C.P. No.1206
July, 1971

Barrett, R. V.

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Total/

DETACHABLE ABSTRACT CARDS

Total wheel drag was reduced by the auxiliary wheel except at very low speeds, the maximum reduction of nearly 50% occurring just below the normal aquaplaning speed of the main wheel.

Aquaplaning of the main wheel only occurred after the auxiliary wheel had aquaplaned. This could be prevented by using a very high auxiliary wheel tyre pressure.

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