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16. WATER DEPTH AND SLUSH DRAG INSTRUMENTATION

By W. W. H. Clarke, B.Sc., Ph.D., F.Inst.P.,
C.Eng., M.I.E.E., P.Eng.(Ont.)

Inertia Switch Limited

SUMMARY

The equipments which have been developed with the Ministry of Technology of Great Britain for measuring water depth on runways and for measuring the drag due to slush residue are described and their calibrations and application are outlined. The test evaluation programmes are assessed.

The forms in which information regarding runway conditions can be presented to the operational user are described and related to modern airport practice. In the case of water depth measurements the relevance of water depth instrumentation is discussed in the light of grooving techniques and of high rainfall rate possibilities and cross winds.

In the case of slush drag the importance of predicted drag and its effect on typical aircraft take-off distance is illustrated by theoretical calculation. Some attention is given to the nature of slush, and the significance of conditions in which enhanced drag may be encountered is examined.

INTRODUCTION

This paper is concerned with the description of two instrumentation systems, both connected with the sensing of phenomena on the surface of a runway. The two equipments described measure these two parameters – slush drag and water depth. They have been developed in support of the British Ministry of Technology programme.

The first of the instrumentation systems is for localised measurements of the depth of water on the runway and for presenting this information in the control tower – this system is called the Runway Surface Monitor. The second is an equipment involving a small aircraft wheel which is adapted to be propelled by a motor vehicle along a runway and which responds to the drag forces it encounters – this is called the Slush Drag Meter. It was known, before these concepts were developed, that the manner in which the data obtained by them could be used would require substantial correlation work with aircraft and substantial evaluation programmes of the systems themselves. However, the idea of direct measurement on slush and the closest parameter to the aquaplaning phenomena was felt to be an optimum starting point. The correlation work which has already been reported in previous publications has gone a long way towards enabling the relative usefulness of the two instrument systems to be understood. Other studies, particularly of runway grooving and porous surfaces (ref. 1), have created the situation usual in major engineering fields where alternative techniques exist so that the ultimate system designer may exert a choice based on the suitability to particular needs of the equipments he may desire to use and based on their cost effectiveness.

To provide the maximum relevance to this conference, each of the two equipments is dealt with in sequence by a description of the hardware and the method by which the parameters are measured. A description is given of the evaluation programmes of the instrument as a device in its own right, of the way in which it presents data, and of the interpretation of the data it provides in the light of the correlation work that has been carried out. Certain systems concepts which arise from the nature of the measured parameters are presented.

THE RUNWAY SURFACE MONITOR

Equipment

The schematic of the system is shown in figure 1. As can be seen in figure 2(a) a number of pointed metal probes are held under a dome which is designed to sit snugly on the runway surface, each probe at a different height above the lower surface of the housing in which it is contained (fig. 2(b)). Thus when the water, which is allowed to flow in under the dome through a channel, reaches a level at which it contacts one of the probes, a substantial change in the conductivity occurs and an electronic circuit causes a step change to occur which is fed into a signalling system. In order to eliminate effects of surface conductivity from the probe through the surrounding insulator a guard ring system is employed. The effect of water rising to the point where it touches the tip of the probe is a dramatic change in resistance, and this is large enough to actuate the switching of the electronic circuit, regardless of the degree of purity or contamination of the water involved. It is appropriate here also to say a word on accuracy. The point at which the water touches the tip of the probe is associated with a meniscus which forms as the water jumps up around the probe. Thus when the water recedes there is a difference in height of water between the contact making and the contact breaking, producing a difference of some 7 to 10 thousandths of an inch. It will be seen that this provides a safety time delay after a particular level has been reached, before the instrument will decide that the water has receded below that level. The control boxes (fig. 3) are designed to be fitted into manholes beside the runway. A miniature control circuit has also been devised which can be fitted into the sensing head. The control tower system can comprise a meter display (fig. 4) which supplies the operator with data on the individual water depth at each sensing head and also a recording system (fig. 5) such as the one installed at Gatwick.

Evaluation

In terms of evaluation this system has been used for a number of years at Gatwick and some features of the system have been changed. The main difficulties however have been waterproofing of cable junctions and alternating current pick-up in power cables and not in the fundamental concepts of the device. The overall accuracy of depth measurement is very good indeed, probably 1 or 2 thousandths of an inch consistently. However, the surveying problems of deciding the datum from which one is to measure depth must in most circumstances be of inferior accuracy. A system of water depth instrumentation has been in use in the trials at Wallops Island.

One meter with associated warning lamps is provided for each runway sensing head and the depth of water there is presented as step changes in the meter reading. At Gatwick the unit fits into the Air Traffic Controller's desk and can be readily interpreted by the Controller. Other warnings, such as ringing bells, can readily be provided from a system of this kind.

Data Presentation and Interpretation

Figure 6 shows a possible method of operational presentation of data in digital form, such that it could be offered to a computer programmed with the digested results of research into the behaviour of different kinds of aircraft in different depths of water. Whether such automatic use of the system would be desirable will depend on the reliance that can be associated with aircraft performance data as a function of depth of water and on the manner in which control of aircraft operation develops. The fact that it is feasible should be recognised at this time and should be related to the incontestable fact that any operating control must place the onus on somebody to take a "yes" or "no" decision – to land or not to land – to take off or not to take off. Such decisions will inevitably be better when based on the "best fit" to known physical characteristics, just as an artillery officer's responsibility to "decide the range of the target" grew into a methodology capable of better results and finally gave way to instrumentation.

Meteorological Aspects (Rain)

The charts obtained at Gatwick have been analysed and recorded for significant periods of time, and while the results are not primarily relevant to this instrumentation paper, it is noteworthy that

(a) In any six week period at least one occasion, and probably two or three occasions, will occur when runway sensing heads are showing significant water levels – usually two or three probes touching in any one head.

(b) Often one or more sensing heads will remain dry while others show water depth thresholds (i.e., there is a significant microstructure of rainfall over a distance that is small compared with runway size).

The relevance of water depth measurement is best shown by the following table which shows the incidence of extremely heavy rainfalls in England and Wales.

Duration, min	Frequency	Rate, in./hr	Depth in the time interval, in.
2	1/year	2.72	0.09
	1/5 years	4.24	0.141
	1/20 years	5.57	0.186
5	1/year	2.00	0.18
	1/5 years	3.19	0.265
	1/20 years	4.30	0.357
10	1/year	1.41	0.23
	1/5 years	2.36	0.39
	1/20 years	3.29	0.55

Typical rainfall intensity is likely to be achieved within the stated times (duration) on any one day within the given return period. The actual duration of the storm will normally be much longer.

These figures are based on a modification of Bilham's original formula by Holland and are derived from data from stations in England and Wales, mainly situated on airfields.

These heavy rainfalls may of course be preceded by rain at a somewhat lower rate making excessive water depths all the more certain. It is known that cross winds cause two effects of importance in relation to aquaplaning risks. Firstly, there is a tendency for cross wind to hold water on a slope by offsetting the run-off effect – programmes to measure this more precisely are under way. Secondly, in aquaplaning conditions with cross wind an aircraft can run into trouble at the edge of the runway more readily than it may run off the end. Grooving provides a reservoir for initial rain and a sideways bleed to relieve the hydrodynamic pressure under the tyre. Reliance on it in icing conditions may prove misplaced. Again it seems likely, in the light of present concepts, that grooving provides an increase in the speed at which a given tyre at a given pressure will aquaplane and not a total solution.

THE SLUSH DRAG METER

Equipment

The prime element of the slush drag meter is a wheel which moves slightly against a linear spring restraint (fig. 7). The drag forces cause the wheel to be thrust back stretching the springs and to move the potentiometer to an extent proportional to the force applied to the wheel in the horizontal plane.

The wheel in its frame may be mounted in a special stand together with the instrumentation box (fig. 8) and with a spare wheel. It may be moved about by one man without difficulty (fig. 9).

Figure 10 shows the wheel in its frame on the Land Rover with the lead weights in position. The pressure normally used in this tyre is about 40 psi which is as high as it is convenient to go in the small wheel. The deflexion of the tyre is typical of aircraft usage and is achieved by putting 300 lb of lead weights on the loading trays. The purpose of putting the wheel in front of the vehicle pushing it is to avoid the impingement of any slush thrown up by the wheels of the propelling vehicle onto the measuring wheel. Also, by placing the wheel in front, it attacks virgin slush. The potentiometer transducer provides a voltage proportional to drag. The wheel is also equipped with a contactor which closes the circuit once for every wheel revolution.

The instrumentation box shown in figure 8 provides on dials and counters the elapsed time, the distance travelled by the wheel, and the integrated drag (i.e., drag force in pounds times the time). Thus the distance and the integrated drag can be divided by the time after a known run and the average velocity and the average drag obtained. Another meter reads instantaneous drag, though this is only intended as a guide to prove that the equipment is working.

It may seem a complicated way of going about a simple problem to provide these kinds of integration. However, a moment's reflection will enable one to appreciate that the drag in any given magnitude of slush is not a linear function of speed. The drag does not accurately follow a square law either, but its counterpart has been determined in plain water for a number of special cases in a test programme taking a considerable period of time. These results are shown in figure 11(a) and (b). It is impractical to try to drive a vehicle at a controlled fixed speed particularly in slushy conditions, and this would be necessary if it were desired merely to integrate the drag and rely on the hypothesis that the vehicle speed was known.

Evaluation

The evaluation of the slush drag meter began with a programme intended to show that it was stable when driven over rough ground, through water troughs, and through sand representing the kind of resistance to movement which might be expected of slush. These tests were then followed by a calibration process because it was decided that the the correct method of calibration would be to refer all measurements of drag to the equivalent depth of water which would cause the same drag at the same speed. For this reason, trials were done in a water trough and, for convenience, the water trough was so arranged that the vehicle propelling the test wheel need not put its own wheels in the water. This reduced the drag on the vehicle as a whole and allowed each test run to be carried out at a more consistent speed. These curves in figure 11 are a digest of the test data. Variations of drag in fixed depths are shown as a function of speed, and by interpolation the variation of drag with water depth at different fixed speeds has been determined.

Data Processing

Full interpretation of these data, of which a great deal has been obtained in a fairly extensive Ministry supported evaluation programme, has resulted in a complete calculator for use with the slush drag meter. It is possible to set into the calculator, shown in figure 12, the time, the integrated drag, and the distance travelled, and the water depth nearest to that which would provide the drag which has been encountered can be read. Thus the calculator directly determines a water equivalent depth (W.E.D.) which correlates with the work under way to measure the drag effects on various aircraft types of various depths of water.

Slush and Its Characteristics

Most of the work to date (refs. 2 and 3) confirms the concept that the drag exerted by slush is the same as the drag it would exert if it were melted. Hence the water equivalent depth deduced from the slush drag meter calculator should be expected to equal the actual quantity of water in the slush. However, there is also evidence (ref. 4) that there may be some conditions of slush in which significantly greater drag than the "water content drag" occurs. Because this is a relatively little understood phenomenon, a discussion of its characteristics is contained in the appendix. If this phenomenon occurs on ordinary airfields with slush residues it is almost certainly associated with refreezing of the slush matrix and particularly with keying of the slush to frozen ground. It is thought that at high speeds, with the tendency of tyres to override the slush, the enhancement factors would disappear. It is also likely that in some conditions of slush, the effects of higher tyre pressure would eradicate the phenomenon. Nevertheless, an examination of the critical data for the variation of the melting point of ice with pressure shows that it takes over 300 atmospheres to reduce the melting point by 2.5° C. Thus, since temperature depression is fairly linear with pressure, the tyre pressures currently in use are only capable of reducing the melting point of ice by a small fraction of a degree Centigrade.

Fortunately, the slush drag meter will not give an optimistic interpretation of enhancement drag; it may, when it encounters enhancement drag, give an unnecessarily pessimistic view. However, if enhancement drag is rare then it will not often give a pessimistic result, and if it is less rare in operating conditions than in research conditions (usually done with artificial slush in warm weather), due allowance will be made for it by the slush drag meter readings. This would not be the case with methods of weight sampling of slush residues. The phenomenon can, for present operational use of slush drag meters, be treated as irrelevant because there is no likelihood that a dangerously optimistic interpretation of runway conditions could be given by the instrument. The case for fixed force enhancement drag rests quite simply on work done by the tyre pressure over the area of the track being equated to the (maximum) enhancement drag times the horizontal travel of the vehicle.

The salient factors in this discussion can be summarized as follows:

Water content drag = Drag from melted slush

(For example, drag from 0.65 in. of water is equivalent to water content drag from 1 in. of slush with a density of 0.65.)

$$\frac{\text{Actual drag}}{\text{Water content drag}} = K = \text{Enhancement drag factor}$$

For 1 in. slush ($\rho = 0.65$), K values measured at 30 mph on March 31 and April 1, 1965, were 1.35, 2.6, 3.6, 1.15, and 3.2.

Reduction of melting point due to pressure:

Pressure of over 300 atmospheres is required to reduce the melting point by 2.5° C.

Therefore, a pressure of 225 psi would reduce the melting point approximately 1/8° C.

Fixed force enhancement:

$$(\text{Work done vertically})_{\text{max}} = \text{Area} \times \text{Pressure} \times \text{Depth}$$
$$\equiv \text{Drag}_{\text{fixed}} \times \text{Travel}$$

Area = Travel × Track width

Therefore, the maximum fixed force enhancement at 40 psi is 30 lb in 1/4 in. of slush for a 3 in. width wheel.

Aircraft Performance

Having discussed drag force and enhancements it is advisable to see how much effect exists in a typical case. The case chosen is hypothetical and comprises an aircraft of nominal 75 000 lb weight powered by two Avon engines giving a thrust of 15 000 lb corresponding to 0.2g at zero velocity and with an assumed 90 mph take-off speed. A level of water or slush with residual force at take-off of 6000 lb is supposed and the curves in figure 13 are for enhanced drag conditions with fixed force laws. Four cases have been computed in terms of take-off distances in the appendix.

The effects of fixed force enhancements (at 30 mph) are very serious in distance-travelled time. However, if the enhanced measurement is the yardstick, then a safe interpretation ensues.

CONCLUSIONS

The primary conclusions from the work described are as follows:

The measurement of water depth may be accomplished accurately with simple inexpensive equipment and the data presented readily to the Air Traffic Controller.

The drag due to slush may be measured accurately and converted to the equivalent depth of water which would exert the same drag.

The known depth of water may be related to the threshold depths at which various aircraft types (with specific tyre pressures) will begin to aquaplane.

From the measurement of drag coefficients for various aircraft types in known water depths, the water equivalent depth (W.E.D.) predicated by the slush drag meter can be used to predict take-off distance for a particular aircraft in the measured conditions.

Two equipments have been developed which measure basic parameters of aircraft environment and which can take their places against the background of increasing knowledge of the behaviour of aircraft on the ground in wet and winter conditions.

While the two instrument systems described are in a state of readiness for operational application, they must be considered against the following as yet unanswered questions:

Where rainfall statistics and slush incidence are known, what are the criteria for operational acceptability of brief periods of known operation, predicated by the use of accurate knowledge of water depth and slush drag? How does one compare this acceptability with possibly more complete solutions involving runway grooving and total slush removal?

How do the overall operating costs compare and should additional tyre wear from grooving be brought into consideration?

How do the risks, due to increased tyre hazard because of grooving, compare statistically with the risks of occasional need to allow landing (or take-off) in known aquaplaning water depths?

Is there really such a thing as total slush removal to the point where no measurement is desirable?

It is felt that these two equipments proffer a philosophy for wet and winter operations, related to improved safety in the present environment of aircraft and runways.

ACKNOWLEDGMENTS

Throughout the work which my firm has carried out in this area I and my colleagues have been constantly aided and advised by the Officer of the Ministry of Technology responsible for this work in the United Kingdom – Mr. R. W. Sugg – whose help has been greatly appreciated.

I should also like to mention that the rainfall statistics have been contributed by permission of the Director General, Meteorological Office (Copyright – Controller, H.M.S.O.).

APPENDIX

ENHANCEMENT DRAG

Test Data Obtained With Slush Drag Meter in Sweden

These trials took place at Bromma Airfield with the cooperation of the Swedish Authorities on March 31 and April 1, 1965, and the weather conditions were fairly constant; that is, humidity $< 50\%$, temperature 3° to 8° C during the day. The density of the slush was approximately 0.65 throughout the work. No other equipment was used to measure drag, but comparative measurements of the density of the respread slush were made throughout the tests.

Relationship between the wheel drag measured and the drag which occurs in a water depth equal to the water content is the most important single factor. One inch of slush with density 0.65 is equivalent to 0.65 in. of water. From its water calibrations the drag that the wheel should experience in 0.65 in. of water is

Speed, mph	Drag, lb
10	1.30
20	5.2
30	11.7

Corresponding selected Swedish data follows. The left-hand side of the table contains the measurements made and the right-hand side converts the drag to what it would be in 1 in. deep slush at the nearest of the three speeds listed (linear variation with depth and square law variation with velocity assumed). The value of K finally tabulated is the ratio of the drag measured to the water content drag.

Run	Depth, in.	Speed, mph	Drag, lb	Nearest speed, mph	Equivalent drag at nearest speed and in 1 in. of slush, lb	K
March 31, 1965						
12	1.25	18	28.5	20	28.0	5.4
14	1	17.6	19.0	20	24.5	4.8
16	1.75	18.1	61.0	20	42.5	8.2
17	1.75	19.4	68.0	20	41.5	8.0
22	1.0	28.0	13.7	30	15.4	1.34
28	1.0	27.4	25.5	30	30.5	2.6

APPENDIX

Run	Depth, in.	Speed, mph	Drag, lb	Nearest speed, mph	Equivalent drag at nearest speed and in 1 in. of slush, lb	K
April 1, 1965						
5	1.0	27.0	34.3	30	42	3.6
12	2.0	10.3	67.0	10	31.5	24.2
15	1.0	9.3	6.0	10	7.0	5.4
19	1.0	31.6	15.0	30	13.5	1.15
22	1.0	10.3	9.6	10	9.0	7.0
23	1.0	30.2	38.0	30	37.5	3.2

The value of K ranges from 1.15 to 24.2, and since the highest K values relate to lowest speeds, the inference that the enhancement decreases as speed increases is born. However since the highest K values are also at the greatest depths, it may be that more slush than in proportion to depth is 'worked' in the deeper cases because of track residue.

The Nature of Slush

The fact that serious enhancement of wheel drag can take place with a particular slush requires explanation. However, the best that can be attempted here are hypothetical suggestions. Slush is, generally, a mixture of ice crystals, air, and retained water. Enhancement of drag must comprise an increase in the force required to push it out of the way and ergo must be related to the strength of the ice crystal matrix. Additionally, the matrix may be bonded to the (frozen) ground, and there may be air in it but no water. Alternatively, the water might, just conceivably, be of such purity that it can be supercooled and freeze instantly when it is disturbed. Allowing for slush to embrace the condition of being significantly below 0° C there is a case for regarding it as a material with a very great range of strengths, that is, from a sloppy substance in its frequent melting state, indistinguishable from water except in its inability to run away quickly, to a strong ice matrix capable of supporting tyre pressure.

To a marginal extent tyre pressure increase should work to eradicate enhancement, but if it is tenable that enhancement only occurs at "slush" temperatures significantly below 0° C, the pressures available will not do more than shift the initiating temperature for enhancement drag by a small fraction of a degree Centigrade $\left(300\right.$ atmospheres gives -2.5° C, and since the phenomenon is reasonably linear, 225 psi $\equiv -\frac{1}{8}^\circ$ $\left.\mathrm{C}\right)$.

Apart from providing a working hypothesis, these considerations lead to a fairly simple theory for wheel drag in enhancement conditions. It is logical that a constant force (invariant with speed) is required to crush the matrix, so that a simple theory may depend on a fixed force addition to the approximate square law dependent water drag term. This may be modified to some slight extent by the forces exerted by the adjacent matrix on the displaced material. The extremely large enhancements measured at very low speeds are supporting evidence for a fixed force concept.

Fixed force enhancement would involve

$$F = F_o + \rho C_{DS} V^2 d$$

where

F = Total drag force

F_o = Fixed term due to matrix strength

ρ = Density of slush

C_{DS} = Drag factor for the drag meter wheel

V = Velocity of test

d = Depth of slush

and from which F_o and $\rho d C_{DS}$ can be determined by drag measurements at two speeds V_1 and V_2. The corresponding total drag forces F_1 and F_2 are written

$$F_1 = F_o + \left(\rho d C_{DS}\right) V_1^2$$

$$F_2 = F_o + \left(\rho d C_{DS}\right) V_2^2$$

This would then allow the effect on aircraft to be predicted.

A fixed force law in enhancement conditions may be related to the work done by a tyre in crushing slush out of the way of the wheel track through the distance represented by the slush thickness, which cannot be more than the work done by tyre pressure over the whole area of the tyre. If the slush is stiffer than the tyre pressure, less drag will be exerted since the wheel will ride up. Consider for the slush drag meter a nominally 3 in. wide track crushing optimally resistant slush with a 40 psi tyre pressure. Thus, an area of $3l$ sq in. (l = Travel) representing a force of $120l$ lb will have been worked through a distance of say d inches (d = Slush depth). This may be equated to the work done over horizontal travel (i.e., $l \times$ Maximum drag form in lb). Hence 120d lb represents a maximum fixed force drag (i.e., 1/4 in. of slush can exert a maximum drag of 30 lb due to its structural strength).

Effect on Aircraft

The drag coefficients of wheels of different size may be measured in water and a conversion ratio established.

APPENDIX

$$C'_{DS} = \text{Aircraft wheels factor}$$

Then for a fixed force law

$$F_{A/C} = F_o \frac{C'_{DS}}{C_{DS}} + 2\left(\rho d C_{DS}\right) \frac{C'_{DS}}{C_{DS}} V^2$$

The factor 2 arises in the second term because it is commonly assumed that impingement drag is equal to wheel drag and total drag is equal to 2 × wheel drag. It would be wholly unreasonable to assume that enhancement occurs in impingement, hence the form of the equation. The effects of these considerations are discussed in the main text in the section on "Slush and Its Characteristics."

The distance calculations were obtained by integration of the net thrust equations.

Case	Assumptions	Distance to reach speed of 135 ft/sec
1	Thrust gives 0.2g, falling linearly to 0.173g at 135 ft/sec as per thrust curve	1554 ft
2	Net acceleration = $0.2g\left(1 - \frac{2}{15}\frac{V}{135} - \frac{8}{15}\frac{V^2}{135^2}\right)$ (i.e., it falls to 0.067g at 135 ft/sec with drag term $\propto V^2$) The supposed operation of an aircraft in the worst case with 1/2 in. of slush (on the water content theory)	2403 ft
3	Net acceleration = $0.2g\left(1 - \frac{2}{15}\frac{V}{135} - \frac{12}{15}\frac{V^2}{135^2}\right)$ (i.e., equivalent enhancement or wheel drag × 0.2 and V^2 dependence maintained)	4583 ft
4	Net acceleration = $0.2g\left(1 - \frac{2}{15}\frac{V}{135} - \frac{8}{15}\frac{V^2}{135^2} - \frac{3.5}{15}\right)$ Fixed force theory Enhancement × 8.8 at 45 ft/sec or Enhancement × 3 at 90 ft/sec	4641 ft

These represent particular curves in figure 13.

Thus, there is little difference between take-off distances for cases 3 and 4 which represent wheel drag enhancement times 0.2 with V^2 dependence maintained and wheel drag enhancement of fixed force form but times 8.8 at 45 ft/sec.

It is important that quite modest further increases in slush depth involved will make much longer take-off distances occur and where the drag curve intersects the thrust curve at the take-off speed the distance approaches infinity.

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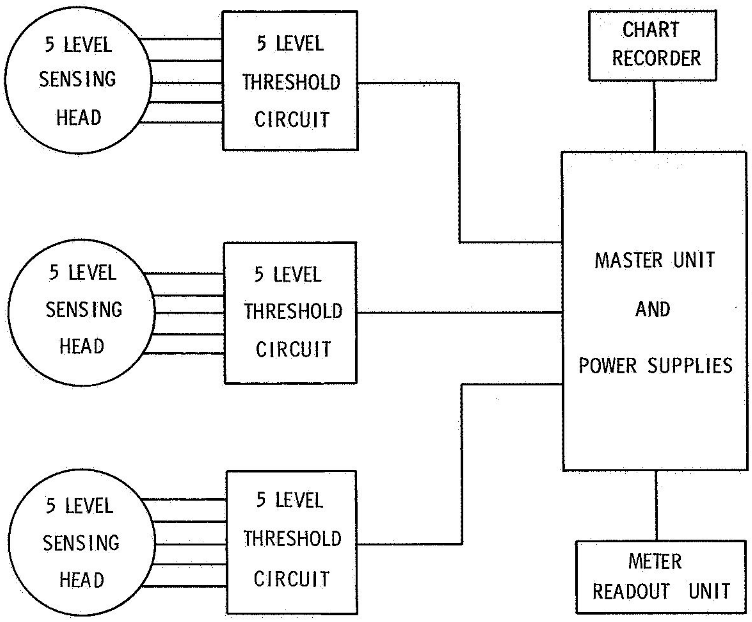


Figure 1.- Block schematic of a typical installation of the runway surface monitor.

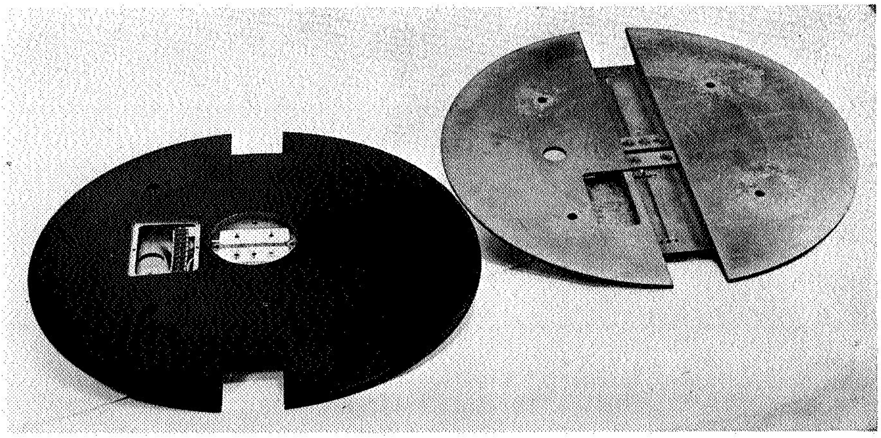


Figure 2(a).- Pointed metal probes in runway surface monitor.

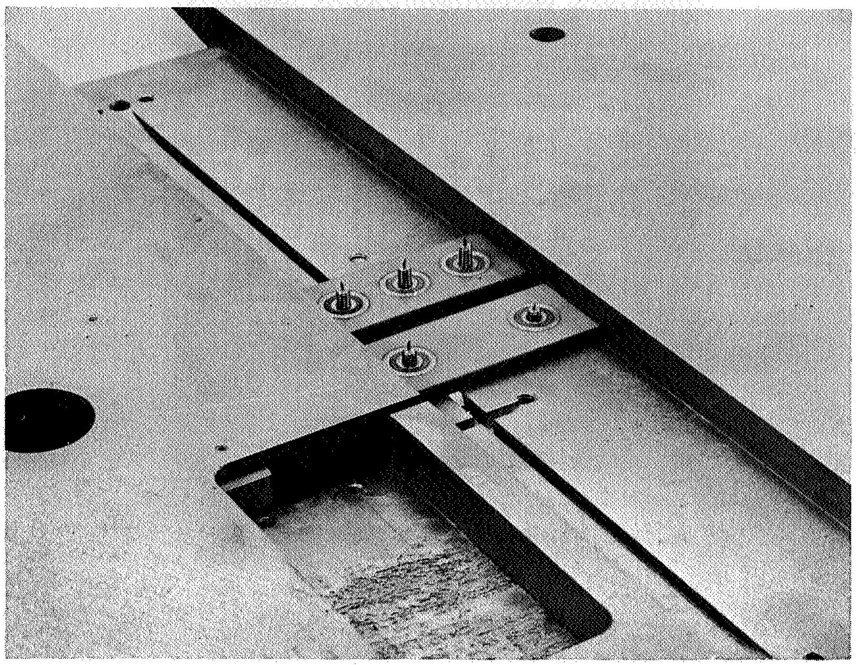


Figure 2(b).- Probes of different height in runway surface monitor.

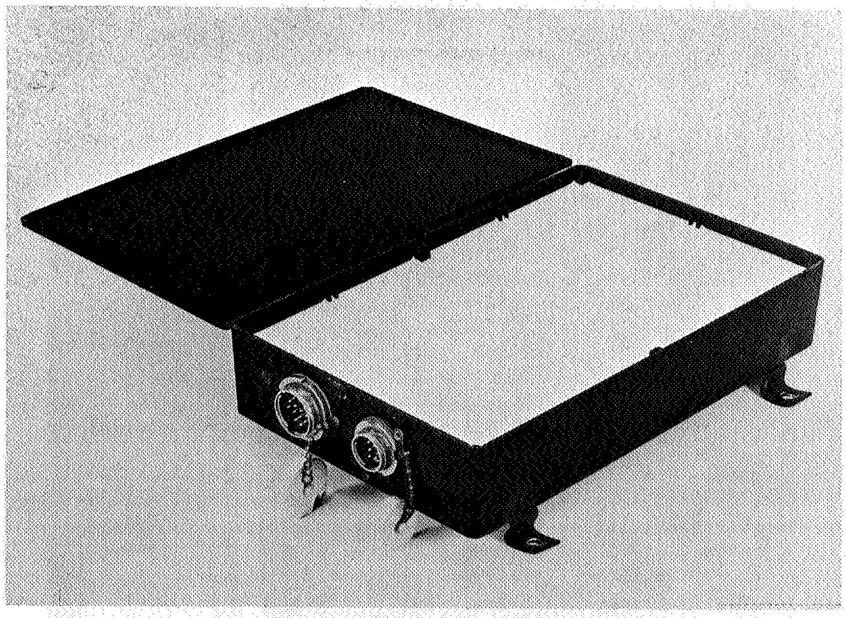


Figure 3.- Control box for runway surface monitor.

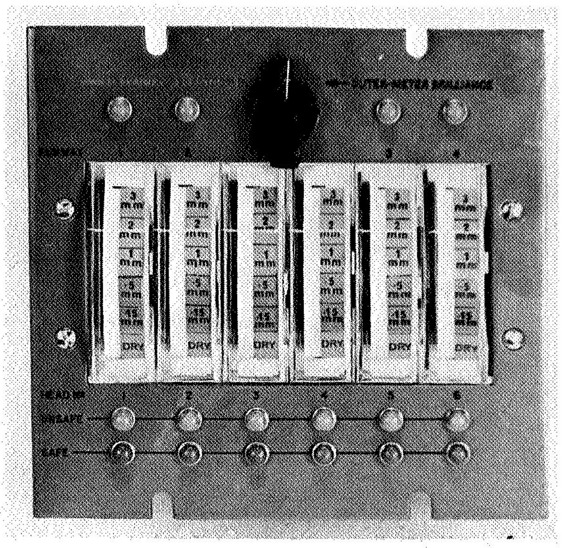


Figure 4.- Meter display.

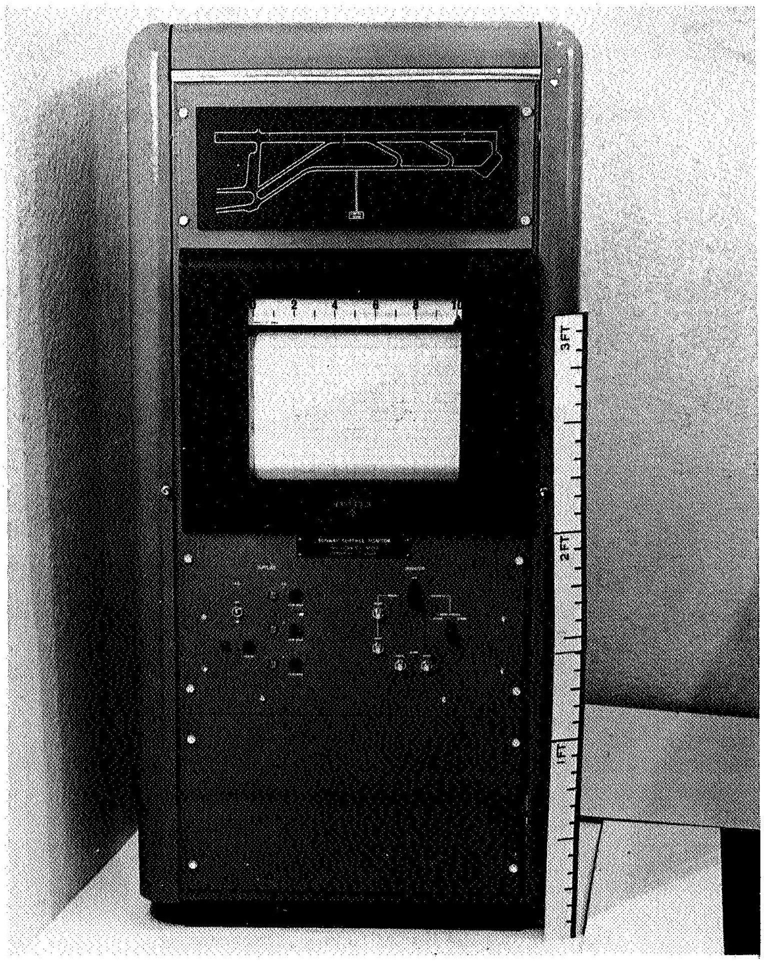
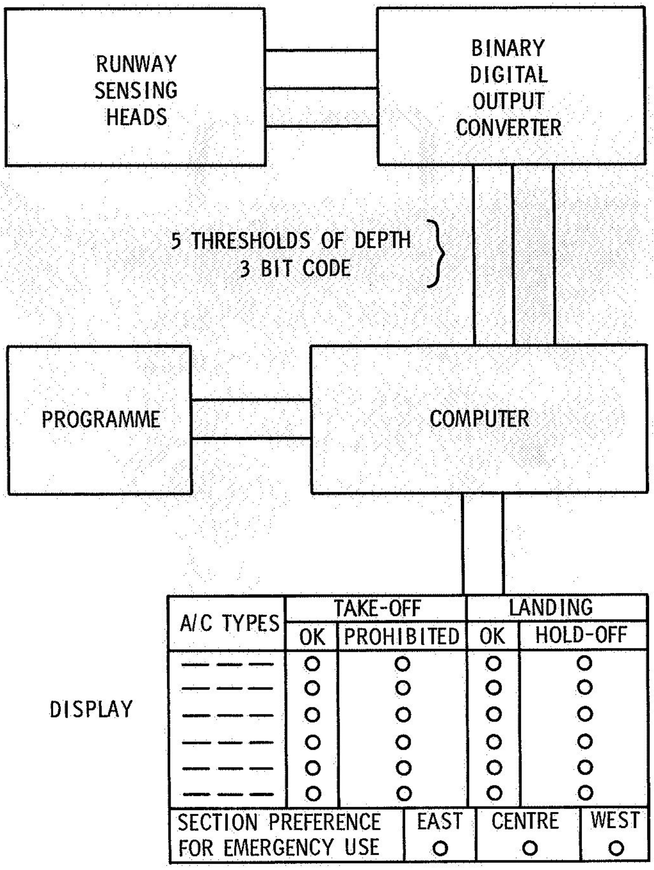


Figure 5.- Recording system.



A/C TYPES	TAKE-OFF		LANDING	
	OK	PROHIBITED	OK	HOLD-OFF
———	○	○	○	○
———	○	○	○	○
———	○	○	○	○
———	○	○	○	○
———	○	○	○	○
———	○	○	○	○

SECTION PREFERENCE FOR EMERGENCY USE	EAST	CENTRE	WEST
	○	○	○

Figure 6.- A method of data presentation.

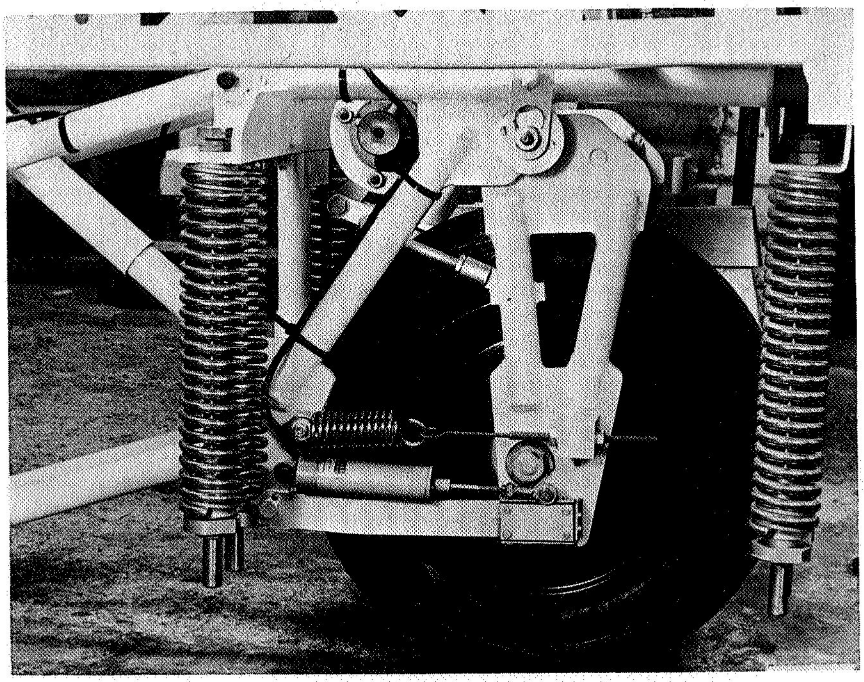


Figure 7.- Wheel in slush drag meter equipment.

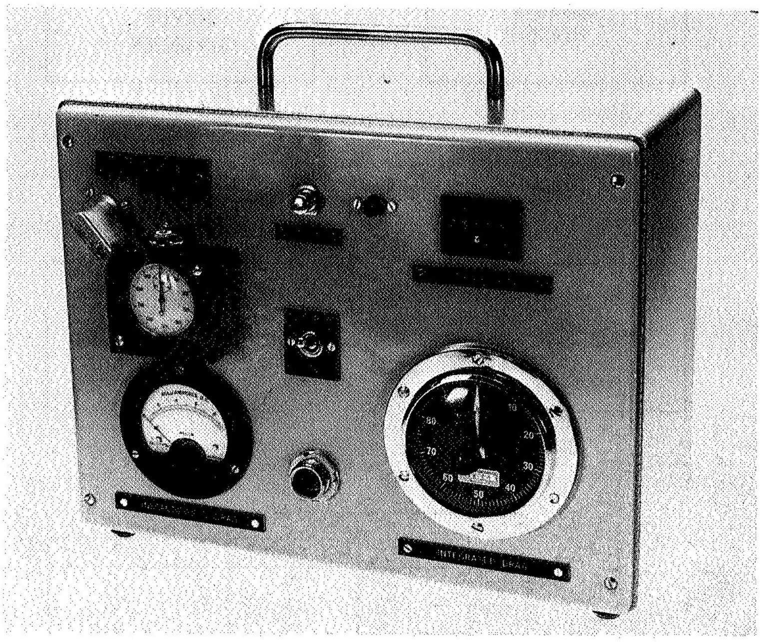


Figure 8.- Instrumentation box for slush drag meter.

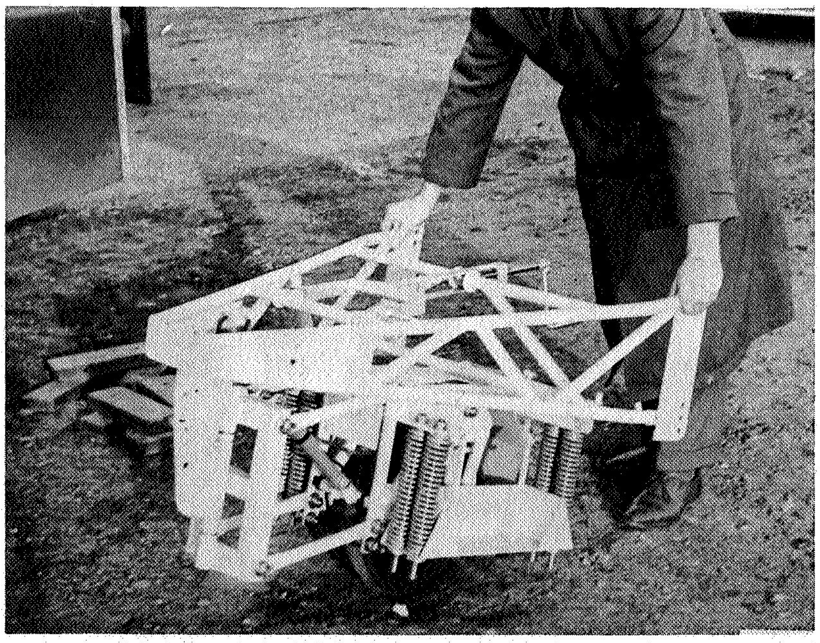


Figure 9.- Wheel in frame, with lead weights removed.

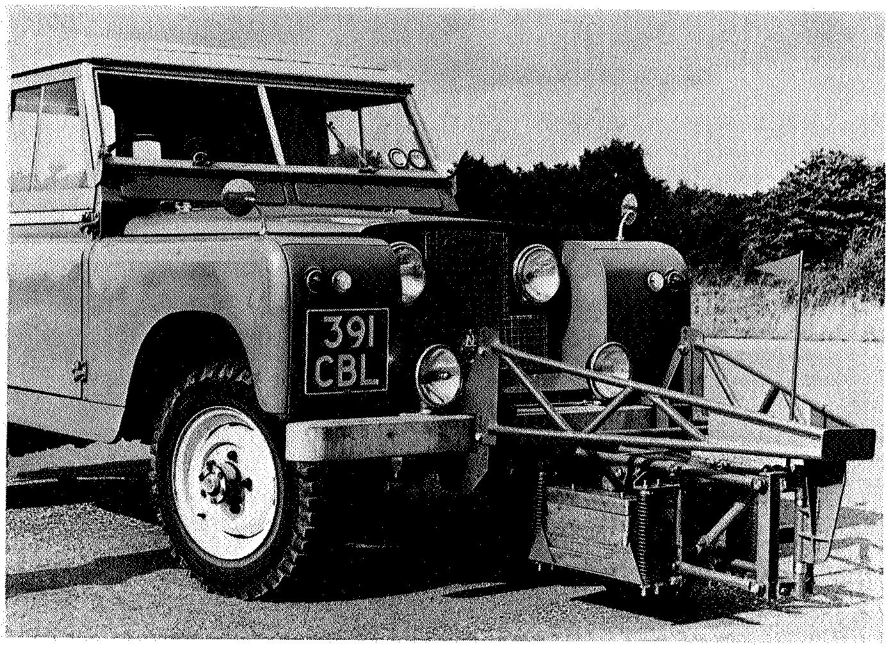
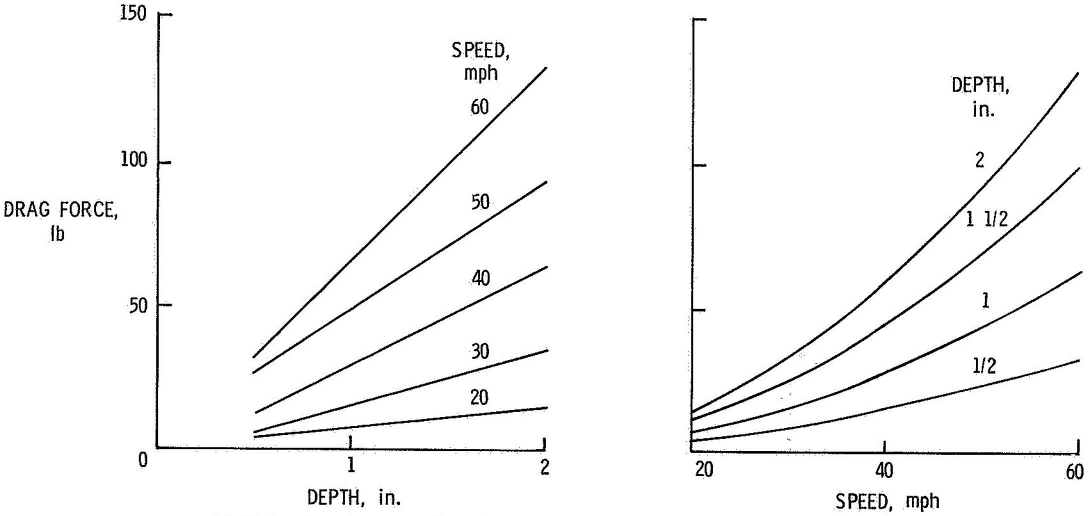


Figure 10.- Wheel in frame on Land Rover.



(a) Water drag as a function of depth at different speeds.

(b) Water drag as a function of speed at different depths.

Figure 11.- Calibration curves for slush drag meter.

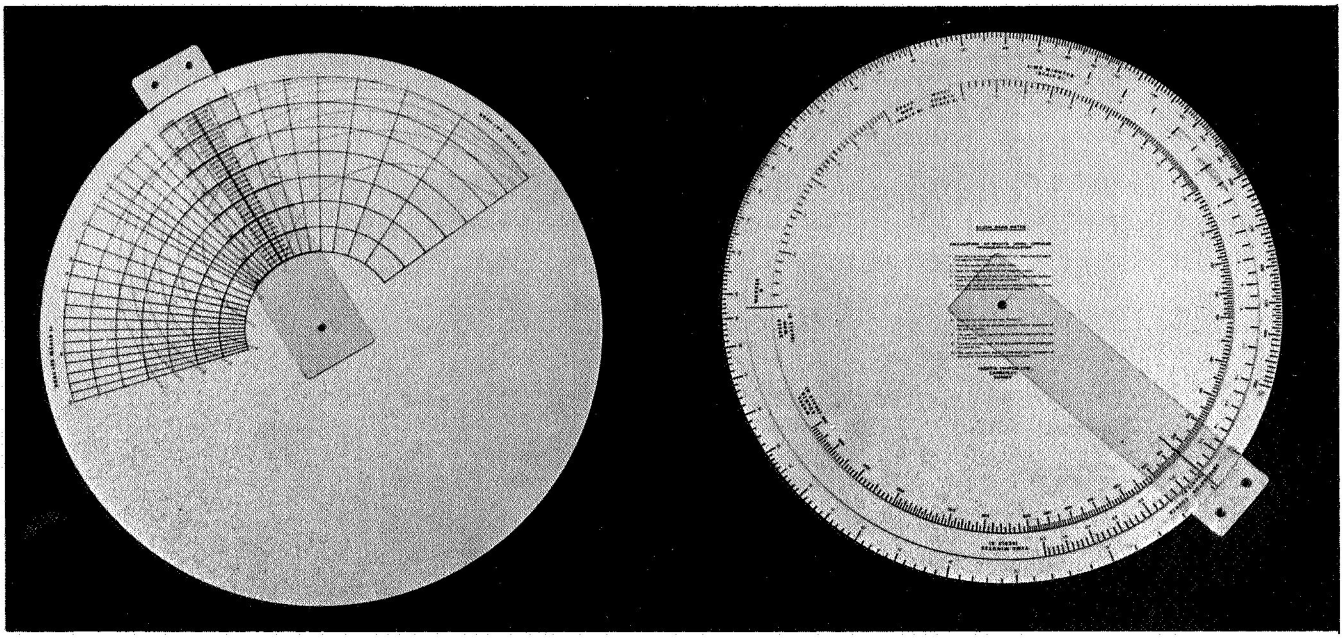


Figure 12.- Calculator for slush drag meter.

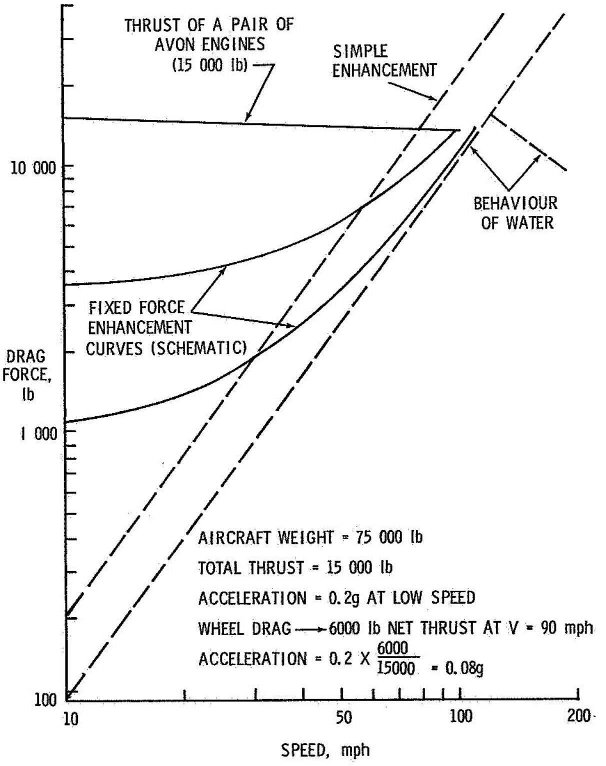


Figure 13.- Effects of drag force and enhancements on aircraft performance at take-off.