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TECHNICAL REPORT 2/78

ASSOCIATE COMMITTEE ON AIR CUSHION TECHNOLOGY

THE CASPAR ACV RESEARCH PROJECT
REPORT NO. 7
THE DEVELOPMENT OF A SYSTEM AND EQUIPMENT FOR TERRAIN POROSITY MEASUREMENT

BY

H.S. FOWLER

OTTAWA, CANADA

MARCH 1978

PRICE: $1.50

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FIGURES

SUMMARY

The influence of terrain porosity on the operation of an air cushion vehicle is discussed, with regard to its ability to hover over the terrain, and to the drag resisting motion. This discussion is used to examine an existing terrain classification system, and to propose modifications to it to relate it specifically to ACV operation.

The design, construction, and calibration of a system for measuring this porosity are described, and an appendix gives such field test results as are available, and corresponding drag data for an ACV over the same terrain.

1. INTRODUCTION

(a) The Influence of Terrain Porosity on ACV Performance

The performance of an ACV as regards stability, load-carrying capacity, obstacle negotiation, drag and consequent thrust requirement, is directly related to the quantity of lift air available in the vehicle. If the vehicle operates over porous terrain, then a loss of lift air through this porous floor of the cushion occurs, and if the vehicle's lift air supply is only sufficient for the normal non-porous ground case, then the reduction in "useful" lift air will cause a reduction in performance. It is therefore necessary to measure the porosity of various types of terrain so that the lift air flow requirement of a vehicle can be increased over the normal "non-porous ground" design figure to permit satisfactory operation over such terrain.

(b) Terrain Description

So far, there does not appear to be a system of classification of terrain suitable to this specific purpose. However, Radforth's Field Description of Muskeg (Ref. 1) appears to cover many of the elements necessary, and will be used as a starting point. It classifies terrain in three respects - surface vegetation, topographic features, and subsurface characteristics.

Surface vegetation often forms a porous mat above the ground surface and it is through this that the major air loss probably usually occurs.

The (micro) topography of the ground surface often leads to poor sealing with the ACV skirt, and hence an above-design air leakage.

Finally, the nature of the subsurface structure can be porous in itself, as for example in a pebble beach, leading to some loss of lift air into the actual ground.

Measurement of the porosity of typical terrain, in conjunction with measurements of vehicle performance over it, should enable a classification of terrain in terms of lift air requirement, and also of vehicle drag, to be built up. This report discusses a system and the equipment for doing this.

It is hoped that this report will be regarded as one small step in the continuing process of discussion and evolution of a system of terrain classification and measurement in relation to its negotiation by ACVs, and to the design requirements of ACVs for operation over various terrains.

2. SKIRT/TERRAIN INTERACTION

This subject has been discussed by the present writer at some length in References 2 and 3. It is proposed that the interaction between skirt and terrain results in a temporary deformation of the skirt as it passes obstacles, and a temporary or permanent deformation of the terrain (vegetation or soil) as the skirt passes over it. The work done during the deformation process is a component of vehicle drag, and the deformed configuration of the terrain while the vehicle is over it will control the porosity and air loss. It is therefore essential to know what that deformation is, and to measure the porosity in this deformed terrain condition, particularly in the case of vegetation.

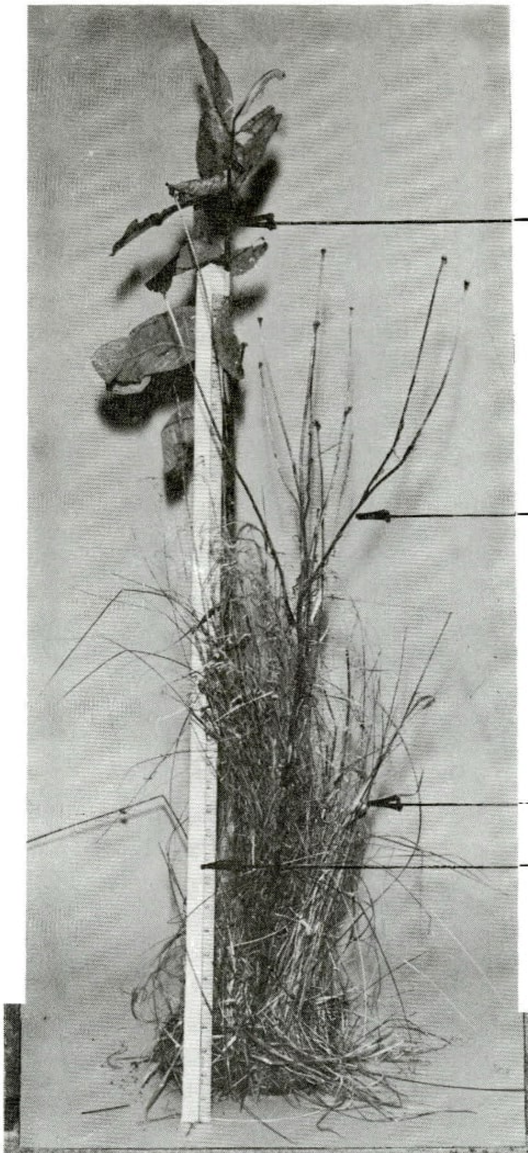
As an example, Figures 1, 3 and 4, show a clump of grass and milkweed on a clod of earth. In Figure 1 the undeformed vegetation is seen to reach to 1.0 m high at its weed peaks, with fairly dense grass rising to about 0.6 m. However, as Figures 3 and 4 show, when pushed over as it would be by an advancing skirt, the plants form a dense mat about 0.1 m high, overlaid by the upper stems and leaves lying flat on top. Figure 2 shows the path of bent-over plants left one minute after a single pass.

If the plant leaves are long and broad they may fold down to form a relatively non-porous "skin" over the base mat, and even permit a fairly light ACV to glide over them at extremely low air flows, like a sled, or like the "air boats" used in the Florida Everglades swamps. However, when the stems are round and reedy, without much leafage, they act as a grid, and allow lift air to leak profusely into and through the base mat, and thence to escape. In this case the air available to maintain the cushion is seriously depleted, and the hovering performance greatly reduced. While not strictly the subject of the present study, it is also clear that the drag will rise sharply owing to the work required to push over the vegetation, (the so-called "bush-bashing" drag).

When attempting to study the deformed configuration of the terrain, several aspects have therefore to be considered.

(a) If vegetation is present, its deformation due the passage of the vehicle must be simulated, and the thickness and porosity of the resulting mat must be measured. In this measurement some account of the ratio of area to perimeter of the sample measured must be taken, since the area controls the input flow, while the perimeter (as a sort of porous fence) has a strong influence on the outlet. This assumes that the air flows down into the mat over its top horizontal surface, and out through the thickness of the mat horizontally around the test area perimeter.

(b) If vegetation is not present but the soil surface is not smooth, then any damage to the surface must be simulated, involving a consideration of its flexibility, plasticity, or brittleness, after which the leakage flow between skirt and uneven surface,



CLUMP OF VEGETATION IN UNDISTURBED UPRIGHT POSITION.

FIG. 1.

VEGETATION BENT DOWN AFTER PASSAGE OF ACV (HEX-1B) DURING DRAG EXPERIMENTS [1 m. HIGH GRASS & WEEDS]. FIG 2.

CLUMP OF VEGETATION BENT OVER. FIG 3.

CLOSE-UP OF POROUS MAT AT BASE OF BENT CLUMP.

[SCALE IN INCHES] FIG 4.

ORIGINAL TABLE

ADDITION FOR ACV PURPOSES

Summary of Properties Designating Nine Pure Coverage Classes						Obstacle to Traverse by ACV	Porosity to Lift Air	Compressed Height at 3000 Pa
Coverage Type (Class)	Woodiness vs. Non-woodiness	Stature (approx. height)	Texture (where req'd)	Growth Habit	Example		$m^3/s/m^2$ at 3000 Pa	$\frac{\text{Compressed height}}{\text{Original height}} \times 100\%$
A	woody	15 ft. or over	--	tree form	Spruce Larch	Impassable	--	--
B	woody	5 to 15 ft.	--	young or dwarfed tree or bush	Spruce Larch Willow Birch	Passable only by large powerful vehicles	--	--
C	non-woody	2 to 5 ft.	--	tall grass-like	Grasses	Passable except by very small vehicles	Varies with leaf form, probably very porous	10% *
D	woody	2 to 5 ft.	--	tall shrub or very dwarfed tree	Willow Birch Labrador tea	Passable with difficulty	Very porous indeed	Estimate 75%
E	woody	up to 2 ft.	--	low shrub	Blueberry Laurel	Passable except by small vehicles	Very porous indeed	Estimate 75%
F	non-woody	up to 2 ft.	--	mats, clumps or patches, sometimes touching	Sedges Grasses	Easily passable	Probably moderately porous	Estimate 50% Short Grass * and Clover
G	non-woody	up to 2 ft.	--	singly or loose association	Orchid Pitcher plant	Easily passable	Probably moderately porous	Estimate 50% Short Grass * and Clover
H	non-woody	up to 4 in.	leathery to crisp	mostly continuous mats	Lichens	Very easily passable	Probably only slightly porous	Estimate 75%
I	non-woody	up to 4 in.	soft or velvety	often continuous mats, sometimes in hummocks	Mosses	Very easily passable	Probably only slightly porous	Estimate 75%

ITEMS MARKED * SEE TEST RESULTS IN SECTION 5a plus that through any subsurface porosity (as for example through a pebble bed) must be measured.

(c) In some cases, both (a) and (b) above will be involved simultaneously, although it is likely that the vegetative cover will prevent any damage to the surface beneath.

3. A SUGGESTED TERRAIN DESCRIPTION SYSTEM

Using Radforth and MacFarlane's Muskeg Classification (Ref. 1) as a base, a first attempt will now be made to classify terrain for ACV purposes, in the present instance with reference to lift air flow. Their Table 1, giving 9 classes of vegetal cover, is reproduced on page 5, with an additional section, based on the preceeding discussion, describing porosity and vehicle resistance. It seems likely that the resulting table would not be restricted to muskeg.

Radforth and MacFarlane's Table 2, giving 16 classes of topographic features, is obviously entirely muskeg oriented. It is reproduced below, followed by a more widely applicable table developed on the same lines, but including data comparable to Radforth's Table 3, dealing with subsurface constitution.

TABLE II (Ref. 1)

TOPOGRAPHIC FEATURES

Contour Type	Feature	Description
a	Hummock	includes "tussock" and "nigger-head", has tufted top usually vertical sides, occurring in patches, several to numerous
b	Mound	rounded top, often elliptic or crescent-shaped in plan view
c	Ridge	similar to Mound but extended, often irregular and numerous; vegetation often coarser on one side
d	Rock gravel	extensive exposed areas
e	Gravel bar	eskers and old beaches (elevated)
f	Rock enclosure	grouped boulders overgrown with organic deposit

TABLE II (Ref. 1) Continued

Contour Type	Feature	Description
g	Exposed boulder	visible boulder interrupting organic deposit
h	Hidden boulder	single boulder overgrown with organic deposit
i	Peat plateau (even)	usually extensive and involving sudden elevation
j	Peat plateau (irregular)	often wooded, localized and much contorted
k	Closed pond	filled with organic debris, often with living coverage
l	Open pond	water rises above organic debris
m	Pond or lake margin (abrupt)	
n	Pond or lake margin (sloped)	
o	Free polygon	forming a rimmed depression
p	Joined polygon	formed by a system of banked clefts in the organic deposit

Since this report deals with terrain porosity, and not obstacle crossing, the following table does not include slopes or obstacles such as mounds, steps, river banks, or trenches, although these are indeed terrain obstacles and often cause severe air loss.

TABLE III

POROSITY DUE TO TOPOGRAPHIC AND SUBSURFACE FEATURES

No.	General Class	Sub Types	Examples	Porosity $m^3/s/m^3$	Seriousness of obstacle due to porosity
1.	Smooth Non Porous	a) Hard non porous	Hard sand, clay, roads, rock surface	Probably zero	None
		b) Soft non porous	Mud, soft earth,	Probably near zero	V. Slight
		c) Loose non porous	Fine sand, snow		Can be impassable due to erosion by efflux jet, creating voids
2.	Smooth Porous	a) Cracked hard ground	Polygons	?	Slight/moderate
		b) Hard "pebble beds"	Beaches, Gravel beds, Gravel roads	?	Slight/ impassable
3.	Rough Non Porous	a) Rough hard ground	Ploughed fields, Trafficked dried mud, or ice	Due to poor seal	Slight/serious depending on skirt type and scale of roughness
4.	Rough Porous	a) Rough ground with large voids	Broken rocky ground, Broken ice	?	Likely to be serious or impassable

As has been discussed in some detail in Ref. 3 and more particularly Ref. 4, the drag of an ACV appears to be directly dependent on the lift air quantity, at least over the normal design range for low speed overland vehicles, where the skirt is to some extent in contact with the terrain. It is therefore clear that the data just discussed will have a considerable bearing not only on the ability of the ACV to hover in a stable way on the terrain, but also on the drag experienced in moving it across the terrain in question. This is on account of both the friction of rough ground over which the vehicle is hovering with more than designed skirt contact, and also the "bush-bashing" drag in much of the vegetation described above. The actual snagging of a rough rocky surface must also be accounted for.

Referring again to Ref. 4, it is noted there that there are two methods possible for accounting for the increase of lift air flow due to terrain porosity. Either the one standard Efflux Gap Height can contain a function k which describes the porosity or the terrain, or a suitable Efflux Gap Height can be assigned to each type of terrain, eliminating the k. This matter must await further experimental data and discussion.

4. A TERRAIN POROSITY MEASURING SYSTEM

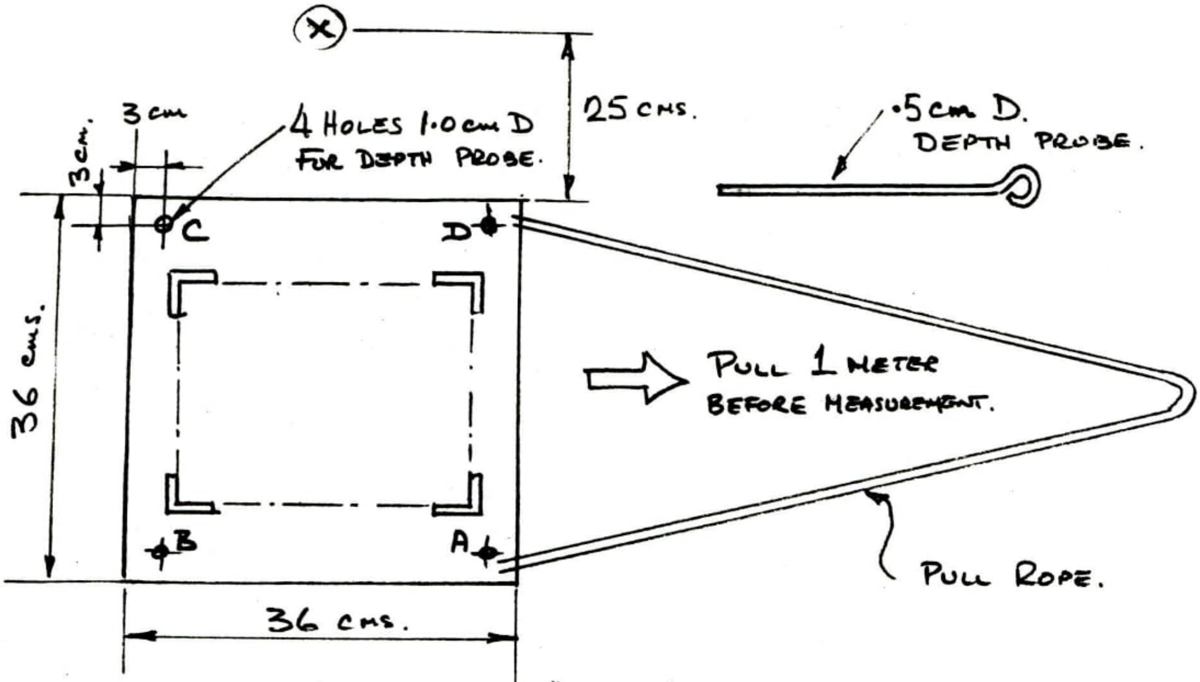
From the preceding discussion it is clear that a measuring system is required which will impose itself on any terrain with a disturbance similar to that of an ACV, and then measure the porosity shown to a lift air supply by that terrain. Such a system has been designed and built in the Engine Laboratory of NRC, and a few preliminary tests of one element were made before the 1977/78 winter closed in and modified the vegetation being tested.

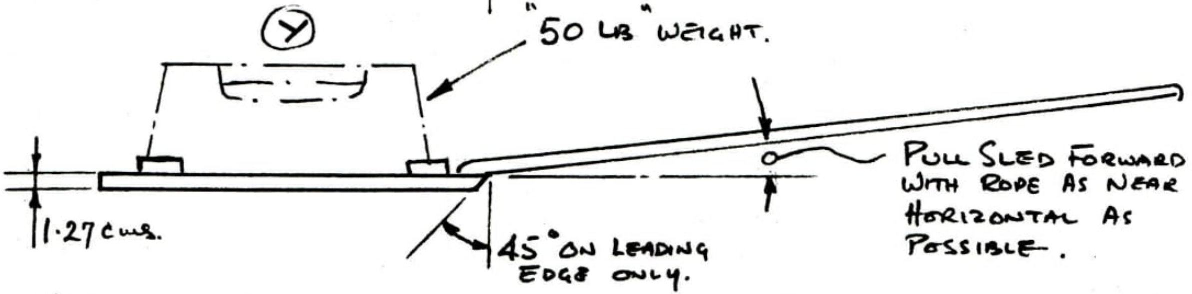
The system consists of two items, one to simulate and measure the effect of the ACV skirt and footprint on the terrain, (the "Squasher"), and one to be set up in accordance with this measurement and then used to measure the porosity (the "Puffer"). This system has been designed to be used in conjunction with ACV tests over the same terrain. So far, only the Squasher has been used over vegetation which has been traversed by an ACV. The Puffer has been calibrated, but has not yet been used over vegetation. The system is therefore not yet developed and validated.

a) The Squasher (Figure 5)

This device consists of a plywood sled 36 cms x 36 cms, on which is placed a weight which will generate a footprint pressure (sled weight + added weight/sled area) equal to that of the ACV in question. In the case tested a 222 newton (50 lb) weight was placed on the sled, which weighed 5 N, producing a footprint pressure of 1750 Pa (17.5 cms water gauge).

SQUASH-METER. [CASPAR PROGRAM]

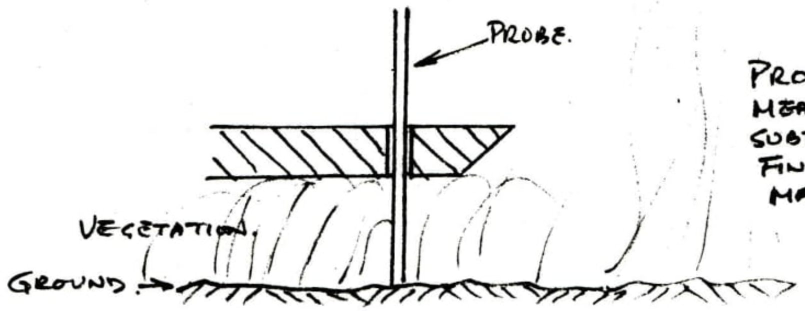




PULL SLED FORWARD WITH ROPE AS NEAR HORIZONTAL AS POSSIBLE.

UNDERSIDE & EDGES OF SLED COVERED WITH POLYETHYLENE SHEET, TO PERMIT EASY SLIDING OVER VEGETATION.

MEASURE HEIGHT OF UNDISTURBED VEGETATION AT (X) & (Y)



PROBE LENGTH TO DECK MEASURED AFTER WITHDRAWING. SUBTRACT DECK THICKNESS TO FIND THICKNESS OF VEGETATION MAT.

AREA = 0·130 m^2. WEIGHT = 232 Newtons.

∴ FOOTPRINT PRESSURE = 1785 N/m^2.

VARY WEIGHT TO GIVE FOOTPRINT PRESS. CORRESPONDING TO A.C.V. BEING CONSIDERED.

FIGURE 5

The sled is placed on the vegetation, and pulled forward 1 meter by a light rope in the front corners. It is then considered to simulate an ACV skirt and cushion which has advanced and squashed the vegetation with the appropriate force.

A 4 mm diameter rod is then used as a depth probe to determine the height of the sled above hard ground, as it sits on the mat of squashed vegetation. The probe is pushed down through a hole in each corner of the sled in turn, until it meets the ground under the vegetation. Knowing the 1 cm thickness of the sled, the height is quickly determined, and the arithmetic average height (of the four corners) calculated.

At two points, one each side of the sled and one sled-width away, the height of the undisturbed vegetation is measured.

A "Squash Factor" is then calculated, as

$$\text{Squash Factor} \equiv \frac{\text{Squashed Height}}{\text{Undisturbed Height}} \times 100\%$$

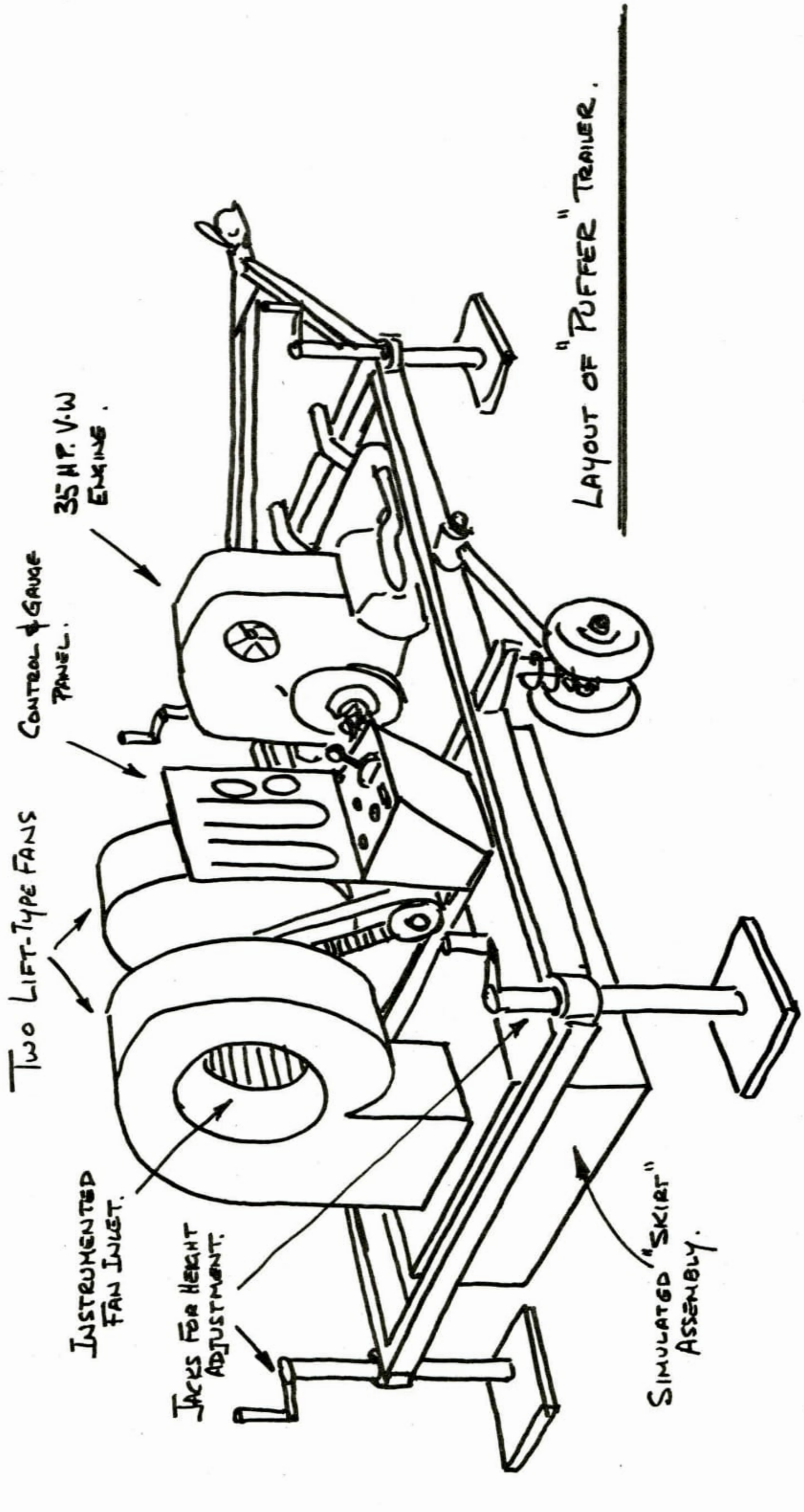
This is done for five points in a representative area of the vegetation, and an arithmetic Average Squash Factor arrived at, together with an Average Squashed Height, which is required for the Puffer experiment.

The experiment described above has been carried out in conjunction with drag tests of HEX-1B and HEX-4 over a range of vegetation, from short-cropped grass to heavy deep grass and weeds. Repeatable and consistant results were obtained, and are shown in Appendix 1.

b) The Puffer (Figure 6)

This, the major component of the system, consists of a mobile trailer on which is mounted a Volkswagen engine driving a pair of lift fans, which blow into one of three interchangeable "skirt" assemblies. These "skirts", rigid sheet steel rectangular structures whose area is known accurately, are held in vegetation by the use of jacks at the height above hard ground determined by the Squasher experiment. The air flow pumped through the given footprint area (of 2:1 aspect ratio) by a range of cushion pressures is then measured by readings from calibrated throat tappings in the fan inlet bellmouth. Either one or both fans can be used, to give a large operating range.

The trailer is shown in Figure 6. It has been calibrated for air flow measurement by bolting a large box on the fan outlets, instead of a skirt assembly. The box had a series of 5 standard sharp-edged orifices 17.8 cms diameter in its walls, and provision



Layout of "Puffer" Trailer.

FIGURE 6

for blanking these off. Runs with increasing numbers of orifices open, each run covering a number of fan rpm values, while readings were taken of fan inlet throat depression and of orifice pressure differential, enabled the true flow corresponding to each fan inlet throat depression to be calculated. In future tests a simple inlet throat depression reading from a pair of manometers installed on the trailer will show the air flow through the porous vegetation beneath the "skirt" of known area, at the cushion pressure displayed on a pressure gauge mounted beside the manometers.

Three skirt assemblies, of areas in the ratio of 1:2:4 have been provided, to explore any anomalies in the air flow as related to the cushion area/(cushion perimeter x squashed height) ratio.

The fan flow calibration is shown in Figure 7.

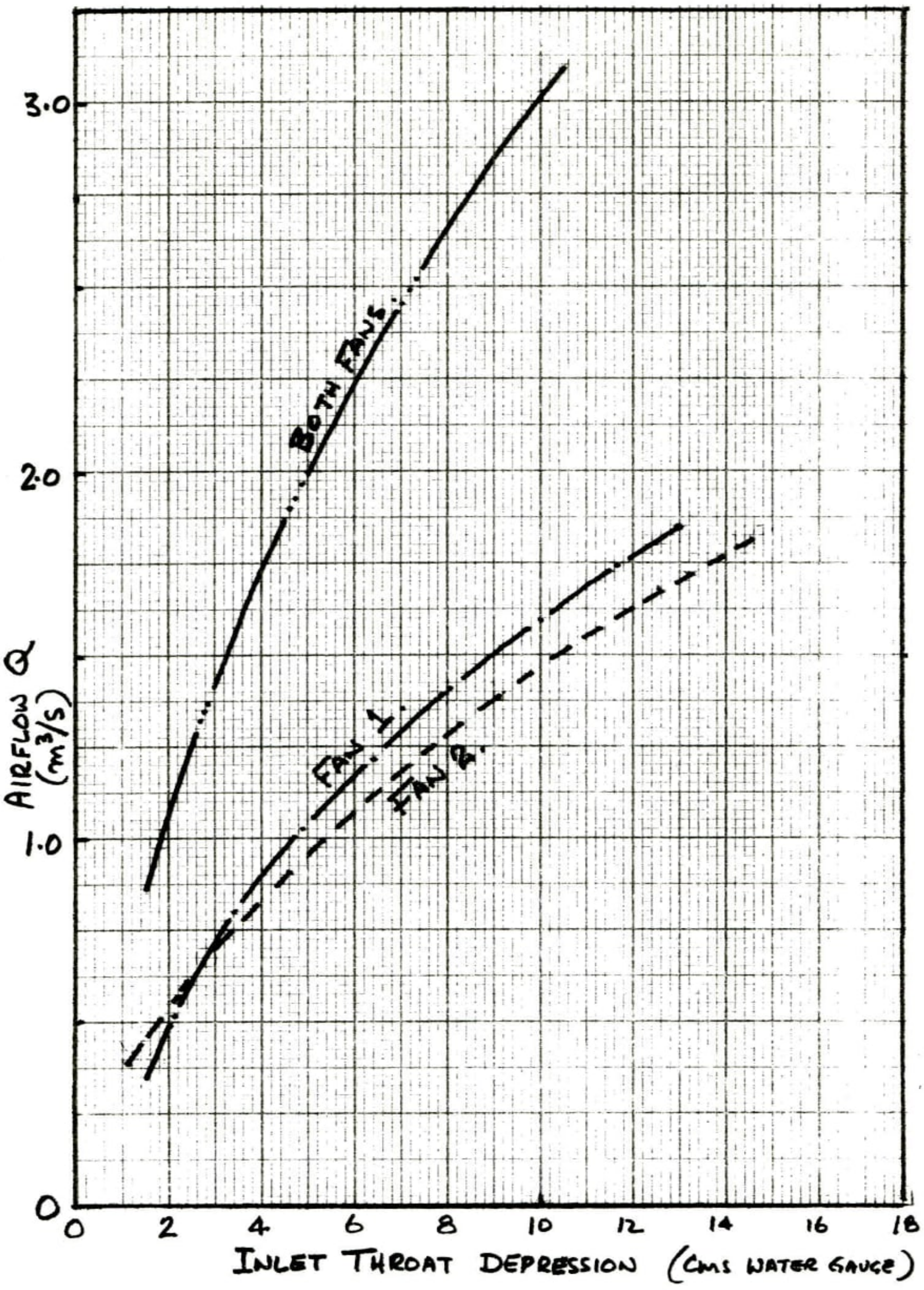
Despite intensive efforts, the construction and calibration of the Puffer were completed just as the ground and vegetation showed signs of freezing for the winter. Since a reasonable amount of testing will be required to learn the technique of operation and to gain a proper understanding of the results, it was decided to postpone this until time was available for a careful program over good vegetation in the spring.

5. CONCLUSION

The effect of terrain porosity on the performance of an ACV has been considered in the light of available experience, and a rational explanation proposed.

An initial attempt has been made to set up a system of classifying terrain specifically with regard to the porosity aspect of ACV operation.

Finally a description is given of a terrain porosity measurement system for field use, which has been designed, built, and calibrated. The few available results are shown, and when further field work has been completed it will be reported in the CASPAR report series.



FAN CALIBRATION OF "PUFFER"

FIGURE 7

6. REFERENCES

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3. Fowler, H.S. "CASPAR Research Project Report No. 3, On the Drag of ACVs Overland" Tech Report 1/75, NRC Associate Committee on Air Cushion Technology

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7. ACKNOWLEDGEMENT

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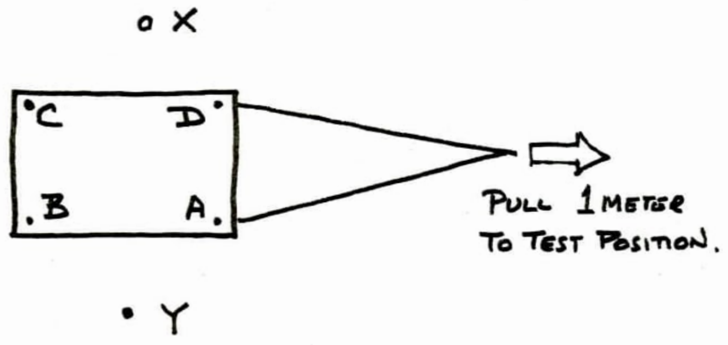
APPENDIX 1

SQUASH FACTOR AND DRAG MEASUREMENTS ON VEGETATION

a) Squash Factor Measurements Made Over Three Vegetated Areas at Rockcliffe Airport - September/October 1977

(i) Short grass, clover, and dandelion mix, on flat hard earth, north of Aeronautical Museum. Mowed at intervals. This was a rather sparce, bristly, springy growth, about 10 cms high, and presented almost negligible resistance to both HEX-1B and HEX-4 vehicles, except in occasional thick patches which were not measured in this experiment.

Three sets of readings were taken, at sites about 10 meters apart, with the readings located relative to the sled as shown in the plan below.



Footprint pressure = 1800 Pa - Measurements in cms

Site	A	B	C	D	X	Y	Average A-D	Av. X-Y
1	2.5	0.5	2.0	2.0	8.9	7.6	1.75	8.3
2	2.8	2.0	1.8	1.5	7.9	8.1	2.03	8.0
3	3.1	2.5	2.3	2.0	9.4	9.9	2.48	9.7
						Average	2.09 = x	8.67 = y

$\therefore$ Average Unsquashed Height = 8.7 cms

$\therefore$ Average Squashed Height = 2.1 cms

$\therefore$ Squash Factor = $\frac{2.1}{8.7} \times 100 = 24\%$

(ii) Moderate length grass and clover on lumpy meadowland, south of west end of live runway (09). Mowed only at rare intervals. This was a relatively lush, rich growth, about 18 cms high, and presented some difficulty to driving HEX-4, but little to HEX-1B. Four sets of readings were taken, and the results summarised below.

At footprint pressure = 1800 Pa

Average Unsquashed Height = 17.0 cms
Average Squashed Height = 3.6 cms

$$\therefore \text{Squash Factor} = \frac{3.6}{17.0} \times 100 = 21\%$$

(iii) Tall thick growth of reedy grass, milkweed and golden rod on swampy ground, east of the threshold of runway 27. Never cut. Three readings were taken in an area primarily covered in reedy grass and milkweed, and one set in a golden rod clump. The grass formed a thick mat of leaves when bent over by sled or ACV, and would seem rather non porous. The golden rod was stiffer to bend, and formed a very open-work lattice of stems about 0.6 cms diameter, probably with a high porosity. All tests were at 1800 Pa footprint pressure.

For Reedy Grass: Average Unsquashed Height = 115.0 cms
Average Squashed Height = 9.4 cms

$$\therefore \text{Squash Factor} = \frac{9.4}{115.0} \times 100 = 8.2\%$$

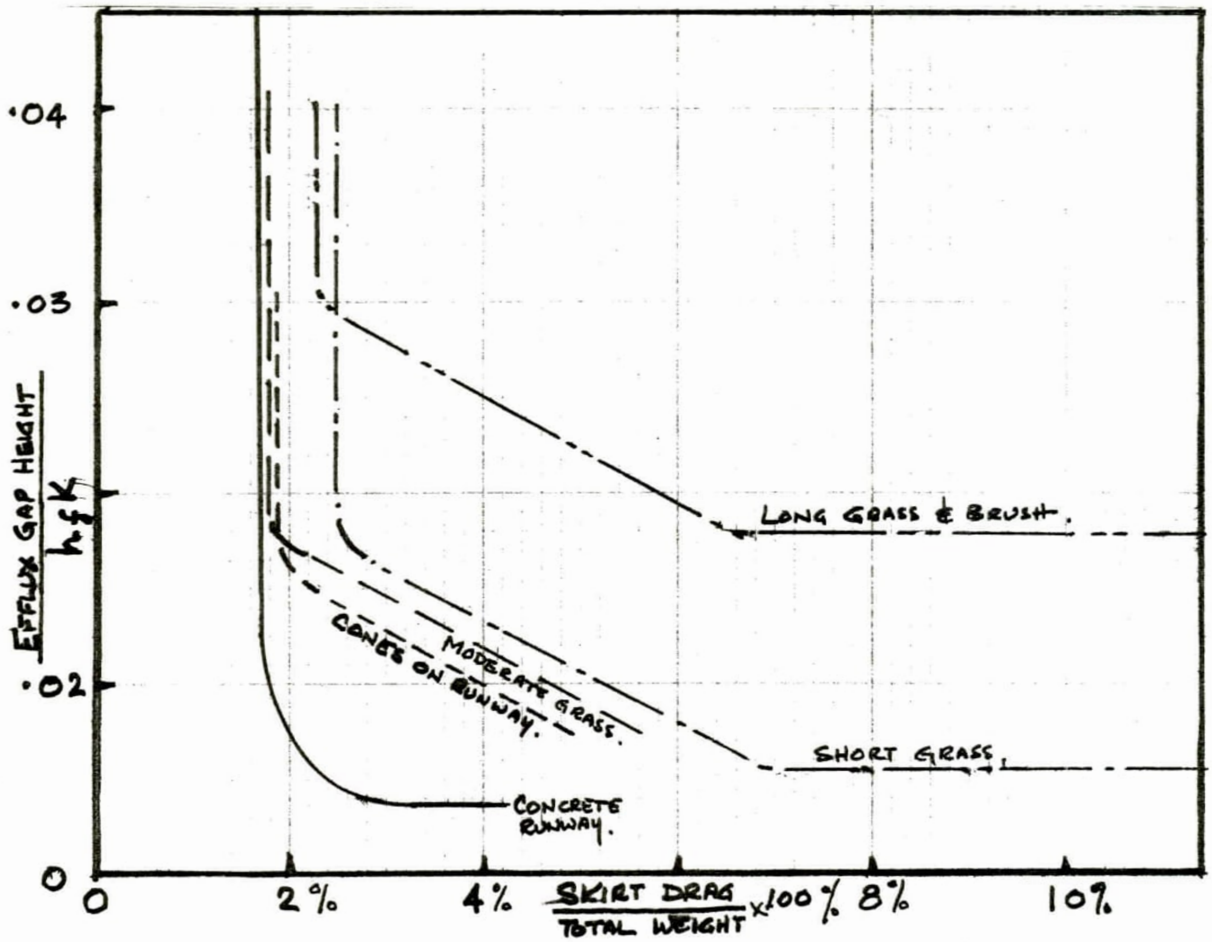
For Golden Rod: Average Unsquashed Height = 122.0 cms
Average Squashed Height = 14.7 cms

$$\therefore \text{Squash Factor} = \frac{14.7}{122.0} \times 100 = 12.1\%$$

b) Drag Measurements on Research ACV HEX-1B Over Bare and Vegetated Terrain

Drag measurements at a range of lift air flows were made with HEX-1B, wearing an HDL segment skirt, over concrete runway, the same runway with concrete cones bolted to it, and the three grass surfaces described in Appendix 1. The vehicle was towed at about 2 m/s. Lift air flow vs. drag curves are therefore available (see below) for a non-porous flat surface, a non-porous surface likely to cause air loss due to poor skirt sealing over its unevenness, and three vegetated surfaces of varying porosity and frictional properties.

It is clear from these curves that simple porosity is by no means the only factor affecting the performance of the vehicle over vegetation.



SKIRT DRAG vs. EFFLUX GAP HEIGHT (PROPORTIONAL TO LIFT AIR FLOW)
FOR HEX-1B AT 2 m/s OVER TERRAIN OF VARYING POROSITY

For example, the curves for a rough (coned) runway and for stiff short grass on hard earth are very similar, and suggest that a friction-type drag is increasing linearly as reducing air flow lowers the skirt onto a rough ground surface.

On the other hand, longer grass and very heavy grass/brush show quite a different characteristic. The vegetation appears to bend over and provide a surface on which the skirt can slide relatively easily, until the porosity absorbs the major part of the lift air flow and the vehicle becomes a sled. The "long grass/brush" curve shows far higher drag values, but this is probably due to a large "bush-bashing" component used to bend the vegetation down as the vehicle contacts it.

It was very interesting to note that when the smaller research vehicle (HEX-4) was run over the same terrain, similar results were obtained except that in the long grass/brush case the vehicle moved with unexpected ease. Finally it became clear that it was riding as a pure sled over the vegetation, and that virtually no lift air was needed. Curves for this vehicle are not shown in the present report, since the drags recorded were so small that scatter made them unsatisfactory, and the scale effect of grass height vs. skirt height is still under study.