Toronto 26.3.78

National Research Council Canada
Conseil national de recherches Canada

TECHNICAL REPORT 1/78

ASSOCIATE COMMITTEE ON AIR CUSHION TECHNOLOGY

THE CASPAR ACV RESEARCH PROJECT
REPORT NO. 6
THE USE OF A NON-DIMENSIONAL QUANTITATIVE DESCRIPTION OF LIFT AIRFLOW APPLICABLE TO ANY ACV

BY

H.S. FOWLER

OTTAWA, CANADA

MARCH 1978

PRICE: $1.00

SUMMARY

Methods of describing lift airflow quantitatively are reviewed, and an improved system is derived, which accounts for cushion pressure and vehicle size, a non-dimensional hovergap, vehicle planform, and atmospheric conditions. It is shown that the hovergap is related to terrain roughness and porosity, and to the mode of operation of the vehicle. Existing vehicles of known adequate performance are seen to be in well-defined groups subject to this relationship, which is discussed briefly in connection with skirt drag.

TABLE OF CONTENTS

Summary		i
1.	INTRODUCTION	1
2.	LOW SPEED OVERLAND LIFT AND DRAG OF ACVs	1
3.	THE EFFLUX GAP HEIGHT	2
4.	PRELIMINARY CONSIDERATION OF TERRAIN EFFECT	6
5.	CONCLUSION	8
6.	REFERENCES	8
7.	ACKNOWLEDGEMENT	8

FIGURES

1	Typical Curve of Lift Airflow vs. Drag for an ACV over Rough Ground	1
2	Efflux Gap Height for Various Successful ACVs	4
3	Graph of Planform Factor vs. Aspect Ratio	5
4	Graph of Efflux Gap Height vs. Skirt Drag, from CASPAR Program Experiments	7

1. INTRODUCTION

For sometime it has appeared desirable to standardise a method of expressing lift airflow, which will allow a designer to extrapolate from a design which has proved successful to another larger or smaller vehicle, of different planform, travelling on different terrain.

Several methods of stating lift airflow have been proposed, and all have fallen short of this standard.

Basically, all methods stem from the concept of the airflow required to float the vehicle at some calculated but fictitious hovergap over level ground.

Two methods, the "flow per unit length of skirt perimeter.", and the "equivalent hovergap", are not non-dimensional, and are statements of a result rather than giving any relationship between the various quantities involved in the hovering process.

The Dyke/Trillo Cqc (Ref. 1) accounts for variations of atmospheric density and cushion pressure, but does not deal with variations of vehicle planform or size.

Following the work of Dyke, Trillo, Fowler and Cutts (Refs 2 & 3) it appears that Trillo's Cqc (based on an original proposal by Dyke) can be rearranged for greater convenience, and extended to account for variations in vehicle shape and size. With further experimental work, this modified expression can be written to include a suitable function to account for terrain roughness and porosity in any defined situation.

2. LOW SPEED OVERLAND LIFT AND DRAG OF ACVs

The relation between lift airflow and drag has been discussed at some length in Ref. 2 where it was shown that lift airflow, drag, terrain porosity and roughness are closely related. This relationship will be referred to again in the later section of this present report, but at present it will be stated simply that over a given terrain, the skirt interference drag (a more accurate term than skirt friction) depends on the hoverheight of the skirt hem above the ground. In fact this height may be positive (a visible gap) or negative (a dragging skirt) in actual operation. This is shown on a typical curve of lift airflow vs. drag in Fig. 1.

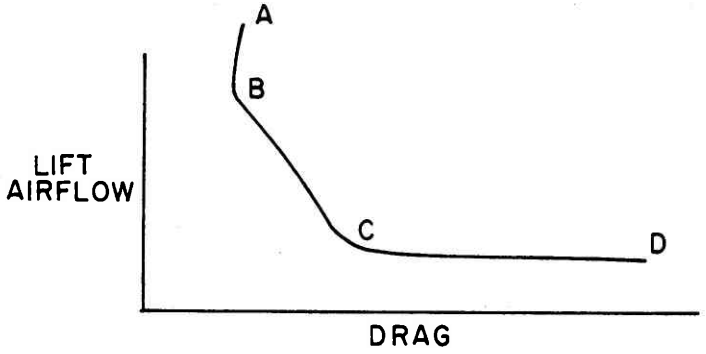


FIG. 1 Typical Curve of Lift Airflow vs. Drag for an ACV over Rough Ground

It is believed that the region AB corresponds to "full hover", when the skirt is completely clear of the ground, BC is a region in which skirt-terrain interference increases

(from B to C) as reducing airflow lowers the skirt even further onto the ground, until at C at C the hard structure makes contact and the vehicle behaves like a sled. This picture is considerably simplified, but is thought to be essentially correct. Such curves have been repeatedly obtained with the vehicles of the CASPAR program, over a wide variety of terrain.

It is therefore to be seen that although in region BC the skirt is to some extent touching the ground, there is still considerable airflow, and hence a theoretical hovergap, which actually accounts for leakage between segments, etc, may be calculated under the known skirt perimeter. Even though this hovergap is a very theoretical concept, and is primarily a measure of airflow, it would seem to bear a direct relation to the height of the skirt above a mean ground surface, or the amount of interference between the skirt and an uneven surface. It is therefore a useful concept to be kept in mind for the consideration of drag.

3. THE EFFLUX GAP HEIGHT

To return now to the consideration of a standardised description of lift airflow, the following analysis from first principles is presented. Based on the simple axiom that "what goes in must come out, — somewhere", it treats the total lift airflow into and out of the underhull cushion area. The fact that a craft "hovering" at low lift airflow with its skirts dragging on the ground (and hence a "negative hovergap" in practical terms) still has a positive airflow is accounted for largely by leakage between skirt segments or fingers. Thus in such a case the airflow calculation still demands an efflux area, and since this is most conveniently expressed as the product of skirt hem perimeter and a fictitious "efflux gap height", the analysis will lead to this latter quantity. The preceding Section 2, and subsequent experimental evidence presented and discussed in Section 4, suggest that this quantity has some claim to reality, and is a helpful concept rather than a mere analytical abstraction.

$$\text{Lift airflow} = \text{Efflux area} \times \text{Efflux velocity}.$$

$$= \text{Skirt perimeter} \times \text{Gap height} \times \text{Discharge coefficient} \times \text{Efflux velocity} \qquad (1)$$

$$\text{Velocity} = \sqrt{\frac{2 \times \text{Dynamic Pressure}}{\text{Density}}} \qquad \text{(from Benouilli's Theorem)}$$

$$= \sqrt{\frac{2}{\text{Density}}} \times \sqrt{\text{Cushion gauge pressure}} \qquad (2)$$

$$\text{Cushion gauge pressure} = \frac{\text{Vehicle total weight}}{\text{Footprint Area}} \qquad (3)$$

Combining equations 1, 2, and 3, we have that:—

$$\text{Lift airflow} = \text{Skirt Perimeter} \times \text{Gap height} \times \text{Discharge Coefficient} \times \sqrt{\frac{2}{\text{Density}}} \times \sqrt{\frac{\text{Total Weight}}{\text{Footprint Area}}} \qquad (4)$$

We will symbolise for brevity:—

Lift airflow	=	$Q\ (m^3/s)$
Skirt perimeter	=	$L\ (m)$
Efflux gap height	=	$h\ (m)$
Discharge coefficient	=	C_D
Air density of day	=	$\rho\ (kg/m^3)$
Total vehicle weight	=	$w\ (N)$
Footprint area	=	$S_c\ (m^2)$
Cushion pressure	=	$P_c\ (Pa)$

So that equation (4) may be written:—

$$Q = L \times h \times C_D \times \sqrt{\frac{2}{\rho}} \times \sqrt{w} \times \frac{1}{\sqrt{S_c}} \qquad (4)$$

This equation may now be recast in a more useful form as follows:—

$$Q = \frac{L}{\sqrt{S_c}} \times h \times C_D \times \sqrt{\frac{2}{\rho}} \times \sqrt{w}$$

Since $S_c \times P_c = w$, $\quad \therefore \frac{w}{S_c P_c} = 1 = \frac{\sqrt{w}}{\sqrt{S_c}\sqrt{P_c}}$

$$\therefore Q = \frac{L}{\sqrt{S_c}} \times h \times C_D \times \sqrt{\frac{2}{\rho}} \times \sqrt{w} \times \frac{\sqrt{w}}{\sqrt{S_c}\sqrt{P_c}}$$

$$\therefore Q = \frac{L}{\sqrt{S_c}} \times \frac{h}{\sqrt{S_c}} \times C_D \times \sqrt{\frac{2}{\rho}} \times \frac{w}{\sqrt{P_c}} \qquad (5)$$

Returning now to reality, it is well known (and clearly demonstrated in Fig. 2) that various classes of air cushion vehicles operate at considerably different values of lift airflow, expressed here as values of "h".

In the high speed marine "hovercraft", the very high value of h is designed partly to reduce skirt drag and wear by minimising (within practical limits) skirt/wave contact, and partly to offset the results of "wave-pumping".

The low speed over-water/mud-flat A.C. ferry barge operates at an extremely low h, since it has only small frictional and sealing demands to contend with.

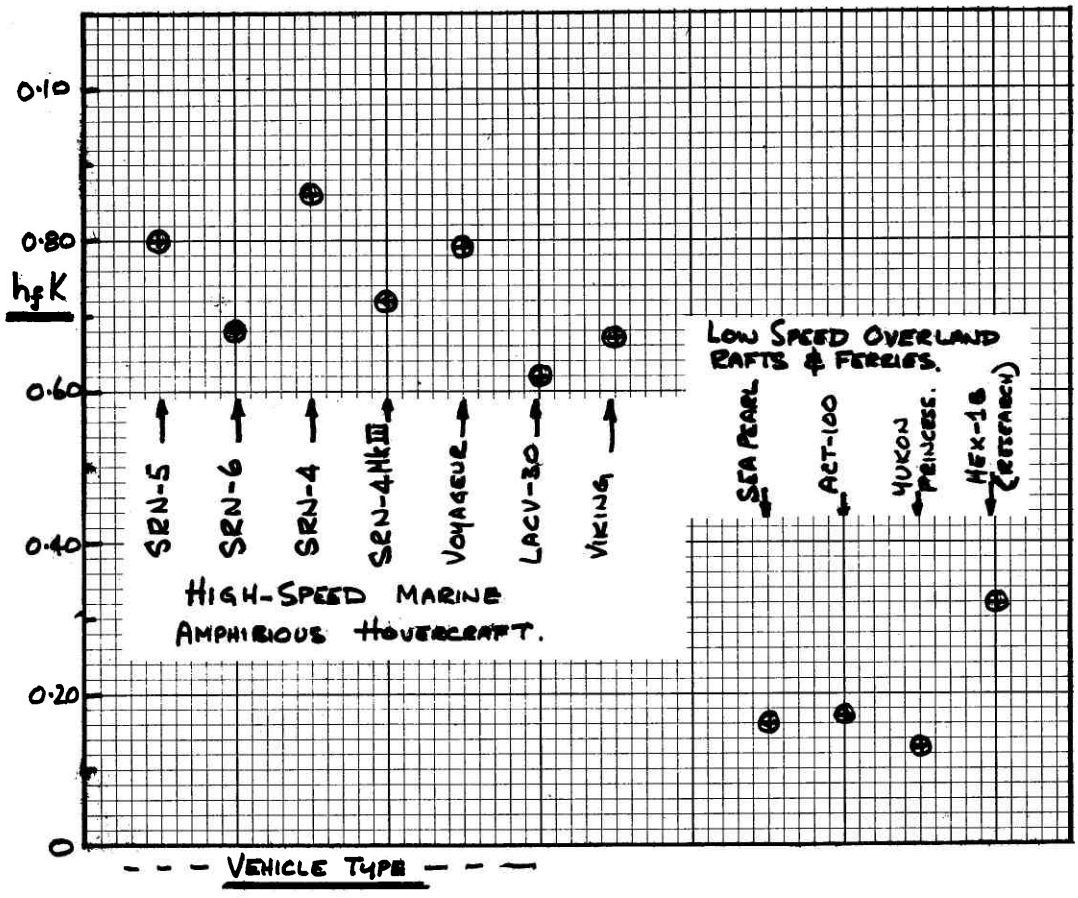


FIG. 2 Chart of Installed Lift Air Capacity of Various ACVs

Experiments with the CASPAR vehicles and other scattered clues lead us to believe that operation over notably rough ground or porous vegetation at low speed, or high-speed operation over flat ground, will require larger values of h, but still not up into the marine "hovercraft" range.

It therefore appears reasonable to admit that the discharge coefficient C_D is that for flow between a skirt hem and flat ground, (0.61 according to standard text books such as Lamb's Hydraulics, or sharp-edged orifice data) while h_f is the efflux gap height over flat nonporous ground at low speed, while a factor K (or possibly a group $K_1 K_2$ etc.) represents the increase of h due to terrain porosity, uneveness, high-speed operation, wave pumping, etc. This factor will be discussed later; at present it will simply be included in the final equation (5) and the results presented in Fig. 1 given in terms of the factured efflux gap height $h_f K$.

$$Q = \frac{L}{\sqrt{S_c}} \times \frac{h_f K}{\sqrt{S_c}} \times C_D \times \sqrt{\frac{2}{\rho}} \times \frac{w}{\sqrt{P_c}} \qquad (5A)$$

In equation (5A) it is apparent that the various terms have real physical significance.

The term $\frac{L}{\sqrt{S_c}}$ is related to vehicle planform, or aspect ratio, and a graph relating aspect ratio to this term, applicable to any rectangular vehicle is shown in Fig. 3. This curve is to be used in evaluating equation (5).

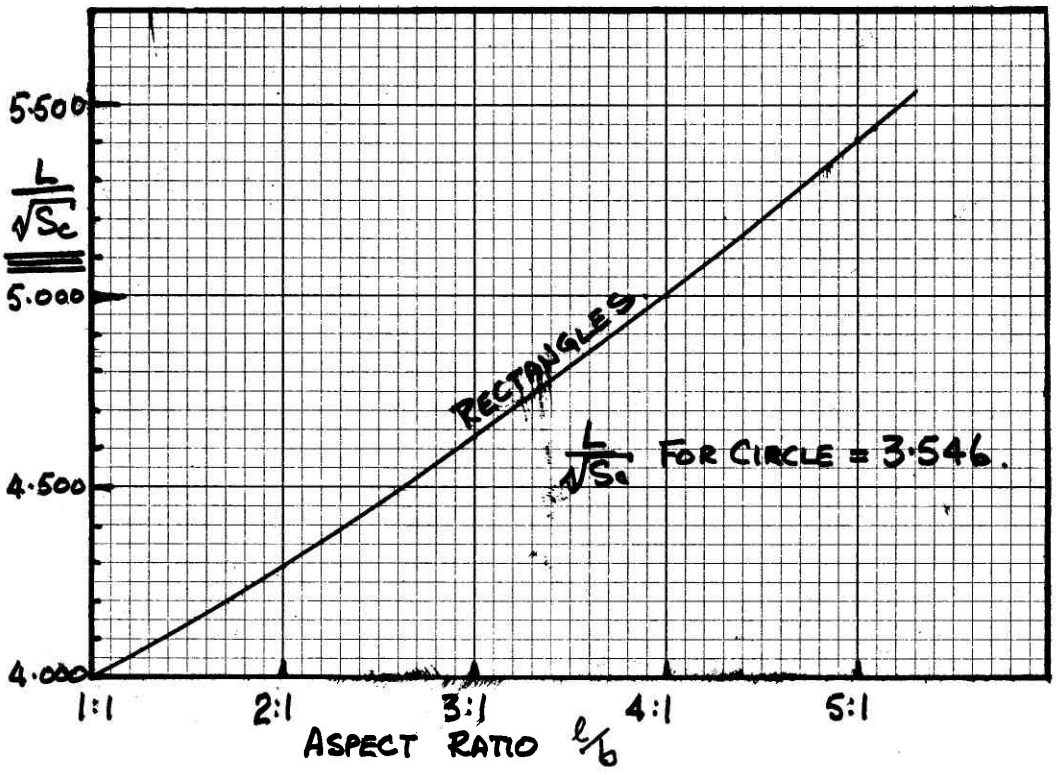


FIG. 3 Graph of $\frac{L}{\sqrt{S_c}}$ vs. Aspect Ratio

The term $\sqrt{\frac{2}{\rho}}$ describes the atmospheric conditions, and is of surprising importance in designing and testing a vehicle for use in the arctic, or on a hot high-altitude plateau.

$\frac{w}{\sqrt{P_c}}$ considers both the cushion pressure and the total weight of the vehicle, and might be called a "loading" term, while the term $\frac{h_f K}{\sqrt{S_c}}$ defines the efflux gap in a non-dimensional manner.

The convenience of equation (5A) to a designer is therefore apparent, since it enables him to see at a glance the effect of juggling the several variables open to him in meeting a particular requirement, and at the same time ensures that by using a value of $h_f K$

appropriate to the terrain and operational mode specified he will produce a vehicle with adequate hovering performance by currently accepted standards.

4. PRELIMINARY CONSIDERATION OF TERRAIN EFFECT

As was mentioned in Section 3 above, it is hoped ultimately to define the additional factor K by which the Efflux Gap Height for smooth nonporous terrain and low speed operation should be multiplied to account for different types of terrain and operational modes.

To bring these remarks into sharper focus, the curves of Fig. 4 show the trend of test results on the CASPAR vehicles to date. These trends, which cover the some 15 curves, each plotted on a number of test runs, show the general characteristics of the hypothetical curves sketched in Fig. 1.

The upper left-hand side vertical leg represents the true hover regime at high lift airflow, the diagonal band shows the range of flow in which increasing skirt/terrain interference occurs with reducing lift airflow, and the horizontal band at bottom right represents the quasi-sled operation at low flows.

It is clear that taller and more porous vegetation enters the skirt/terrain interference zone at higher lift-airflows, and it is also apparent that the hard non-deformable roughness of jagged ground causes much higher drag than the softer vegetation although a higher airflow is needed to traverse the latter.

Figs 2 and 4 have been plotted on a scale of $h_f K$, without attempting to separate these factors. At the present stage the value of h_f pure and simple, for the smooth low speed case, is debatable. It is not clear whether one should use point A, B, C, or an arbitrary 1% Drag point. Furture testing will be directed in an attempt to obtain a sufficient mass of reliable data to enable a proper decision to be made on this point, and values of K for various terrains and operations to be established.

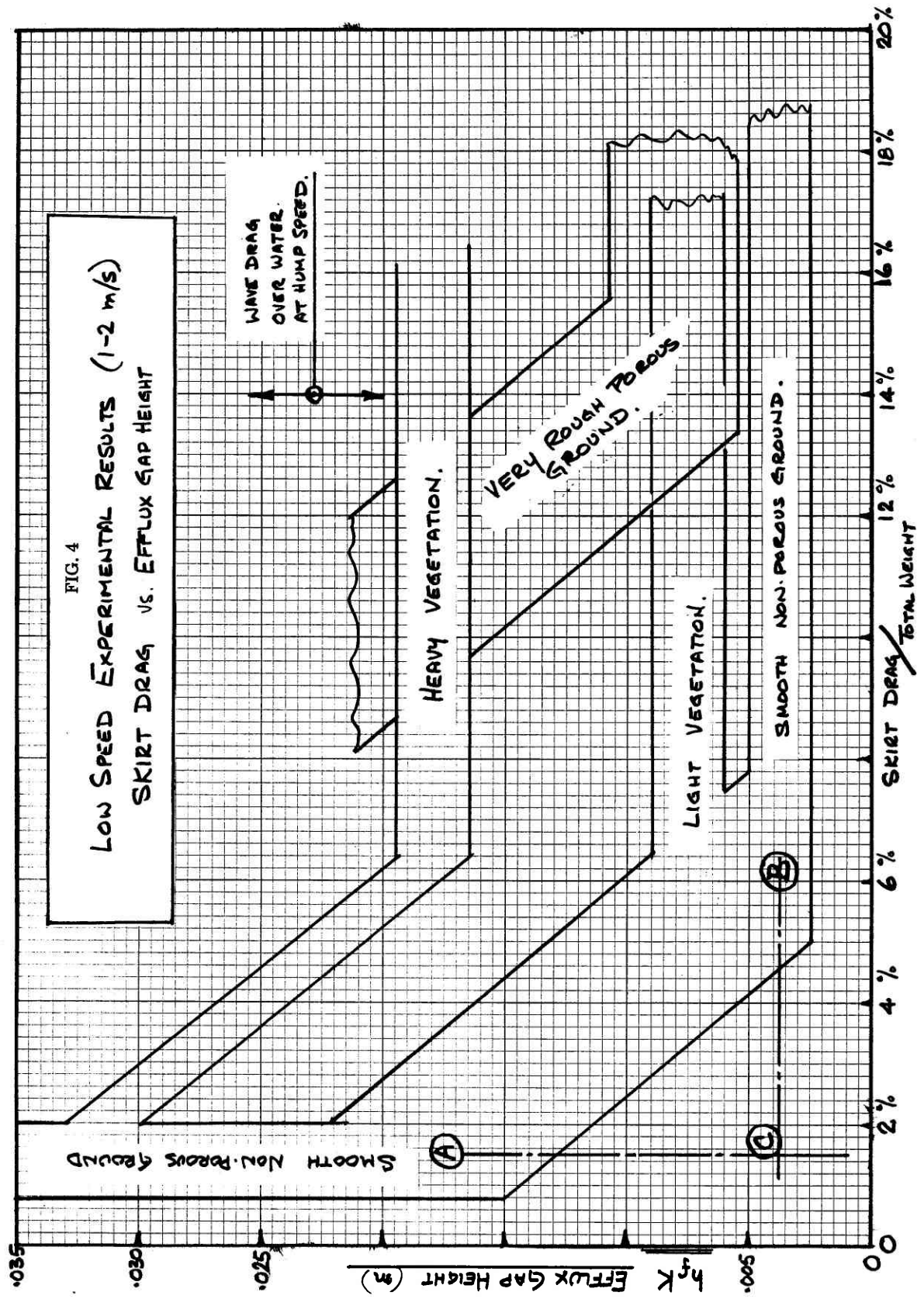
Purely by way of example, if one were to assume the point C in Fig. 4 to establish the value of h, then one could point on the same figure and also on Fig. 2 to values of K, chosen rather arbitrarily as being in the middle of the sloping band to represent an optimum choice between installed blower weight and propulsion requirement. Such values would include:—

h_f = .004 (0.4 cms efflux gap height)

K =

Light vegetation 3	Heavy vegetation 6
Marine operation (Low speed) 4	Marine operation (High speed) 19

It must be emphasised that these figures are given merely for illustration of the proposed approach and should not be accepted as useful data.


FIG. 4
LOW SPEED EXPERIMENTAL RESULTS (1-2 m/s)
SKIRT DRAG VS. EFFLUX GAP HEIGHT
WAVE DRAG OVER WATER AT HUMP SPEED.
HEAVY VEGETATION.
VERY ROUGH POROUS GROUND.
LIGHT VEGETATION.
SMOOTH NON-POROUS GROUND.
SMOOTH NON-POROUS GROUND
A
B
C
.035
.030
.025
.005
0
2%
4%
6%
12%
14%
16%
18%
20%
$h_f K$ EFFLUX GAP HEIGHT (m)
SKIRT DRAG / TOTAL WEIGHT

5. CONCLUSION

In view of the importance of predicting the required lift airflow for a new design of ACV, it is proposed that the Efflux Gap Height should be adopted as a standard. It is believed that experience will enable K factors appropriate to various terrains and operational modes to be specified, and that this system will be applicable to vehicles of any size and planform.

6. REFERENCES

1. R.L. Trillo, "Marine Hovercraft Technology". Leonard Hill Books Ltd., London, 1971.

2. H.S. Fowler, "The CASPAR ACV Research Project Report No. 3, On the Drag of ACVs Overland". NRC Associate Committee on Air Cushion Technology, Technical Report 1/75, February 1975.

3. T.P. Cutts, "The Development of a Non-dimensional Lift Air Coefficient for ACVs". NRC ACACT Technical Report 2/75, April 1975.

7. ACKNOWLEDGEMENT

This report has been complied, and much of the data generated, under the CASPAR program, operated by the National Research Council of Canada. The program is partially supported by grants from Transport Canada (Transportation Development Centre and ACV Division, Canadian Coast Guard) and from the Defence Research Board.

The writer also wishes to acknowledge the assistance of Mr. R.G. Wade in generating much of the data shown in Fig. 2, and in continual discussions on the subject.