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### An approximate method of extrapolating overwater ACV model drag measurements to full size

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#### **Publisher's version / Version de l'éditeur:**

<https://doi.org/10.4224/40003553>

*Laboratory Technical Report (National Research Council Canada. Division of Mechanical Engineering. Engine Laboratory); no. LTR-ENG-122, 1983-05*

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PAGES 8  
PAGES \_\_\_\_\_

FIG. 2  
DIAG. \_\_\_\_\_

TABLES 1  
TABLES \_\_\_\_\_

**REPORT  
RAPPORT**

**LABORATORY / LABORATOIRE**

REPORT LTR-ENG-120  
RAPPORT \_\_\_\_\_

DATE May 1983  
DATE \_\_\_\_\_

LAB. ORDER 21746  
COMM. LAB. \_\_\_\_\_

FILE 3515-1  
DOSSIER \_\_\_\_\_

FOR  
POUR

REFERENCE  
RÉFÉRENCE

LTR -ENG-122

An Approximate Method of Extrapolating Overwater ACV  
Model Drag Measurements to Full Size

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SUMMARY

The estimation of the drag of an air cushion vehicle (ACV) over water is a difficult process, since the total drag is due to a combination of several aerodynamic and hydrodynamic mechanisms.

This report sets out an approximate method by which total drag measured in model tests during motion in the displacement ("sub-hump") regime through to the planing ("above-hump") regime may be extrapolated to values for the full-scale craft.

CONTENTS

SUMMARY ..... i

CONTENTS.....ii

LIST OF FIGURES.....ii

1.0 INTRODUCTION..... 1

2.0 METHOD..... 1

3.0 SIMPLE RULE FOR ESTIMATION OF MAGNITUDE OF DRAG..... 5

4.0 TABLE 1, REQUIRED DATA..... 6

5.0 REFERENCES..... 7

LIST OF FIGURES

Fig. 1 TYPICAL CURVE OF SPEED VS. DRAG..... 8

Fig. 2 TYPICAL CURVE OF  $\left( \frac{\text{SPEED}}{\text{HUMP SPEED}} \right)$  VS. DRAG..... 8

## 1.0 INTRODUCTION

The conversion of model ACV drag data to full scale is a difficult problem, as the several sources of drag (aerodynamic, momentum, wavemaking, etc.) obey different laws (Reynold's, Froude's, etc.). There are rigorous treatments of these, but that of wavemaking drag in particular is extremely complex, particularly at low speed. In the case of rough water tests, the problem becomes even more complex.

Having due regard for the relative magnitudes of the various drag causes, the following approximate method gives reasonable results for smooth water tests.

## 2.0 METHOD

2.1 The model is towed at a range of speeds over smooth water and the total drag, the lift air flow, the cushion pressure, model total weight, model speed, and model skirt dimensions (length, beam), are measured. The model beam should be less than  $1/3$  of the width of the channel, and the water depth should be greater than the length of the model, unless specific "shallow water" tests are required. It is emphasised that the model should be towed from the point at which thrust is normally applied (e.g. the hub of the vehicle's propulsion fan) and not from some convenient point such as the bow of the craft. This will ensure the vehicle sitting at the correct trim angle, which will have a major influence on the measured drag.

2.2 The aerodynamic drag is calculated over the speed range.

$$\text{Aerodyn. Drag} = \frac{1}{2} \times \text{Air Density} \times \text{Speed}^2 \times \text{Frontal Area} \times C_D \quad (\text{I})$$

and is in force units (newtons).

The value of  $C_D$  for various ACVs with the usual amount of deck clutter and square stern varies from 0.38 for an SRN5 down to 0.32 for a very simple hull. A value of 0.25 was reported for one craft with a fine stern and aft air intakes giving some boundary-layer control. Unless known otherwise, a value of 0.35 should be used. The frontal area of the craft is that above the waterline, and is calculated for the static case in the present approximate method. How much area is contributed by a ducted thrust fan is an arguable question. It is probably reasonable to account for struts, hub, and duct wall area, omitting the through-flow area of the duct. In anycase, only those parts seen in a frontal silhouette view are accounted.

2.3 The lift air momentum drag is calculated over the speed range. This is the drag due to raising the momentum of the air inhaled by the lift system until it is moving forward inside the craft at craft speed. This is not usually recaptured as it leaves the craft, since the air is normally emitted equally in all directions around the hull.

$$\text{Momentum drag} = \text{Mass flow of lift air (kg/sec)} \times V(\text{craft speed, m/s}) \quad (\text{II})$$

and is in force units (newtons)

2.4 The curve of test values of total drag against speed is plotted, and by subtraction the curve of water drag (wave-making, friction, spray drag, etc.) is plotted. [Fig. 1]

2.5 The curve of water drag against speed is replotted against  $\left(\frac{\text{speed}}{\text{hump speed}}\right)$ . "Hump speed" is so called from the

hump in the drag curve at the speed at which the craft accelerates from the displacement mode to the planing mode.

The hump speed is calculated as:

$$\text{Hump Speed} = K \sqrt{\ell} \quad \text{m/s} \quad (\text{III})$$

where K is a constant between 1.4 and 1.8, (theoretically 1.76). The value K for the experiments in question can be found from the peak of the hump in the drag/speed curve, and is assumed to be the same for the full-sized case.

$\ell$  is the cushion length of the craft (in metres). The speed values in Fig. 1 can now be converted to  $\left(\frac{\text{Speed}}{\text{hump speed}}\right)$

values, and the curve replotted, as in Fig. 2.

2.6 From knowledge of the components of the water drag, the factors controlling them, and their probable relative magnitudes, it has been argued that this drag can be expressed approximately in terms:

$$\text{Water drag} = \frac{1}{2} \times (\text{water density}) \times \text{Speed}^2 \times (\text{opposed underwater area}) \times C_{DW} \quad (\text{IV})$$

where the water density =  $1000 \text{ kg/m}^3$  at standard temperature,  
opposed underwater area = cushion beam x immersion depth (in  $\text{m}^2$ ) and  $C_{DW}$  = Water drag coefficient.

The opposed underwater area is going to vary in a manner difficult to quantify as the craft rises through the maximum wavemaking situation into the planing mode. This problem is handled in the following manner. The area is calculated in the static case, as:

$$\text{Area} = \text{cushion beam (in metres)} \times \text{cushion pressure (in metres of water gauge)} \quad (\text{V})$$

This area is assumed to remain constant, and the  $C_{DW}$  value is assumed to vary to compensate. Thus, at a number of speeds, the water drag is read from Fig. 1, and  $C_{DW}$  is calculated at each speed from equation IV above. These values of constant area (appropriately scaled from model to full-size) and varying  $C_{DW}$ , are then assumed to hold true at the same values of  $\left(\frac{\text{speed}}{\text{hump speed}}\right)$  in the full-sized craft.

2.7 The value of hump speed in the full-sized craft is then calculated, and at the same values of  $\left(\frac{\text{speed}}{\text{hump speed}}\right)$  as were calculated in the graphs of model performance, the full size craft speeds are calculated, and using the appropriate values of speed and area, the values of water drag are found, and plotted.

2.8 Finally, at the chosen full-size values of speed, lift air flow, and above-water area, the full-size values of aerodynamic and momentum drag are calculated and added to the water drag to give the appropriate full scale total drag curve, finally plotted against speed.

### 3.0 SIMPLE RULE FOR ESTIMATION OF MAGNITUDE OF DRAG

As an extremely simple rule-of-thumb for estimating magnitudes of drag, at up to 15 m/s full-scale speed, the full-scale drag will be of the order of:

model drag x full-scale weight

model weight

or model drag x  $\left( \frac{\text{full-scale length}}{\text{model length}} \right)^3$

4.0 TABLE 1

Required Data

	<u>Model Scale</u>	<u>Full Scale</u>	<u>Units</u>
1. Measured total drag at range of speeds	✓		Newtons
2. Lift airflow (Mass Flow)	✓	✓	kg/s.
3. Vehicle speed	✓		m/s
4. Above-water frontal area	✓	✓	m <sup>2</sup>
5. C <sub>D</sub> aerodynamic	0.35	0.35	-
6. Air density (standard day)	1.230	1.230	Kg/m <sup>3</sup>
7. Cushion length "L"	✓	✓	m
8. Cushion beam	✓	✓	m
9. Hump speed (from model drag curve)		✓	m/s
10. K value for hump speed (model and full- size are same)			-
11. Full-size hump speed calculated using same K value.		✓	m/s
12. Water density	1000	1000	kg/m <sup>3</sup>
13. Cushion pressure	✓	✓	m water gauge
14. Opposed under-water area (static value, assumed constant)		✓	m <sup>2</sup>

5.0 References

1. "Status of Hydrodynamic Technology as Related to Model Tests of High Speed Marine Vehicles" [particularly "section 3.6, air cushion vehicles", by Stevens, Martin J., and Prokhorov, Sergei D.] David Taylor Naval Ship Research and Development Centre, Bethesda, Maryland, 20084, U.S.A. Report No. DTN SRDC - 81/026. July 1981.
  
2. "Overland and Amphibious ACV Design Data Relating to Performance", by Fowler, H.S., National Research Council of Canada, Report No. ME-245, April 1979.

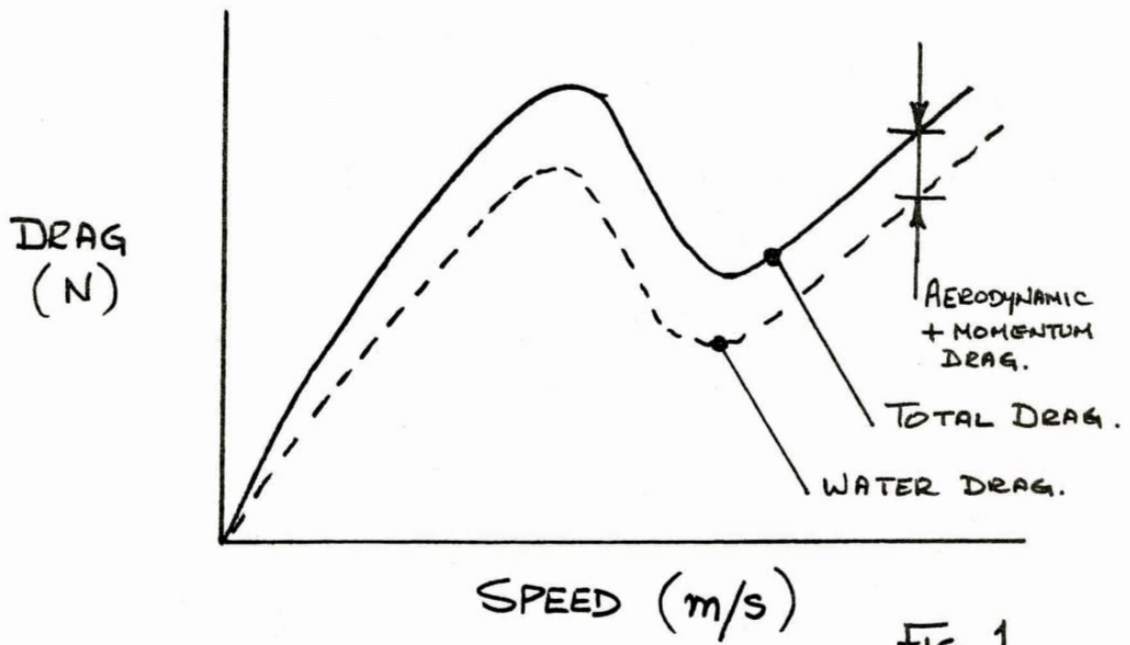


FIG. 1.

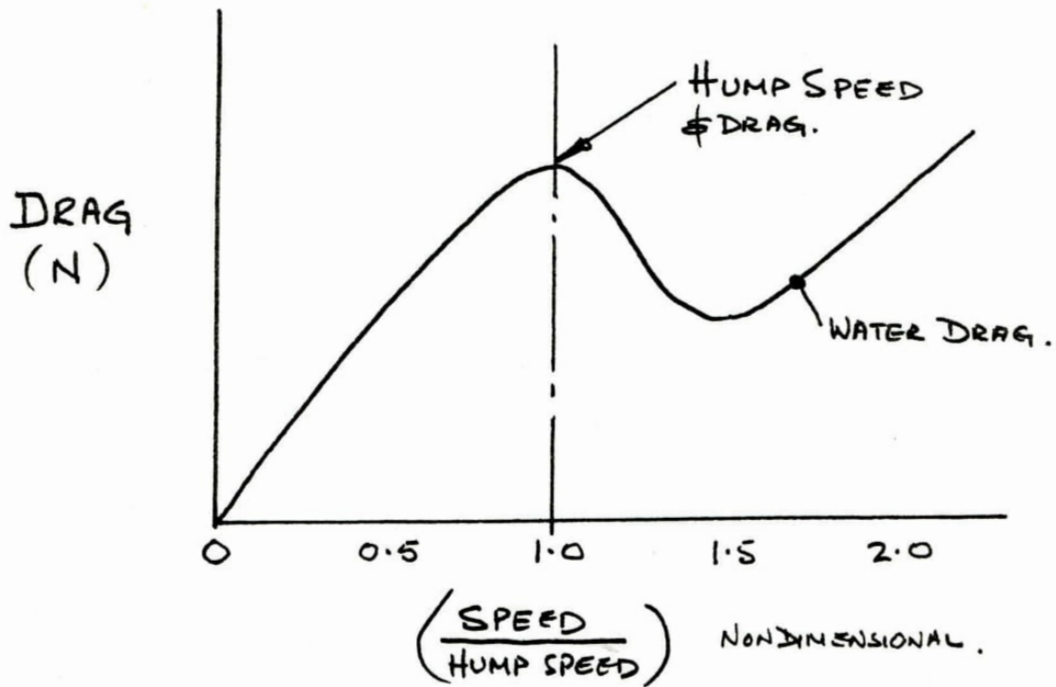


FIG. 2.