Notes on AGARD Meeting on Air-Cushion Vehicles and Subsequent Visits to Hovercraft Development Ltd. and Saunders Roe

by

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Memo 65-1

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Supported Under D.R.B. Grant Number 9551-12

and Canadair Ltd.

Montreal May, 1965

1. INTRODUCTION

With the financial support of D.R.B. and Canadair Ltd., I attended the lecture series 'An Introduction to the Aerodynamics of Ground Effect Machines', presented two papers during the subsequent Seminar on Problems in Hovercraft Design and Operation, and chaired one of these sessions. Three days were then spent in England, in the company of Mr. Derek Jones of Canadair Ltd., visiting Hovercraft Development Ltd., and Westland Aircraft Co., Saunders Roe Division.

Machines which are sustained close to the earth by means of increased air pressure extending over little more than the projected plan area of the vehicle, are termed 'hovercraft' in the U.K. (although they do more than merely hover) and 'ground-effect machines' in the U.S.A. (even though this term also embraces low-flying aircraft). The latest term 'air-cushion vehicles' is clearly more satisfactory. Nevertheless hovercraft was the name most often used during the seminar, for the British are currently well ahead in this branch of technology. Much detailed information on the geometry of flexible skirts, the detailed arrangement of the jets and the methods of design were withheld from the meeting, particularly by Saunders Roe. Nonetheless the lectures by Dr. H. R. Chaplin of David Taylor Model Basin and Mr. A. Ford of the Naval Air Development Center U.S.A., were most useful in putting into perspective the importance of the various branches of knowledge relevant to the design of these vehicles. For example the importance of the efficiency of the internal ducting, and the fan, was made clear. The series of lectures ended with a comprehensive preliminary design study of a complete air-cushion vehicle, and included prediction of the performance over rough water as well as smooth.

2. LECTURES

Dr. Chaplin gave the following lectures:

Introduction

Types of machine

Plenum

Peripheral Jet

Sidewall

Recirculating

Ram

Important Parameters

$$\text{Specific power} = \frac{\text{Power}}{(\text{weight})(\text{forward speed})} = \frac{P}{WV}$$

$$\frac{\text{Cushion gauge pressure}}{\text{Jet total gauge pressure}} = \frac{\Delta p}{p_t}$$

$$\text{Cushion Discharge Coefft} = \frac{\text{Volume flux}}{\sqrt{\frac{2\Delta p}{\rho_a}}\,(\text{area of air gap})}$$

$$= \frac{Q}{\sqrt{\frac{2\Delta p}{\rho_a}}\left(S_g\right)}$$

With increasing $\frac{S_g}{S}$, where S is the plan area of machine, the optimum value of $\frac{V}{\Delta p}$ increases for operation over land. Hence cushion pressures have tended to decrease with the advent of flexibles and the reduction of S_g.

Air Cushion Mechanics

Thin Jet theory.

Exponential theory - favoured.

Off-design performance with cross flow (underfed and overfed operation)

Compressors

Radial-flow compressor neglecting swirl and with small 'advance ratio'.

Internal Efficiency

Assuming that all dynamic pressure through the compressor is lost (probably leads to the choice of oversize compressors).

Matching to compressor characteristics.

Cushion Contributions to Stability

Static and dynamic heave stability over a sinusoidal ground.

Pitch and roll stability for plenum chamber.

Seakeeping

Statistical description of water waves.

Flexible Skirts and Trunks

Pneumatic and web stabilization of trunks.

Open skirts.

Cringing, or flying, trunks.

Ploughing as an explanation of recent SRN 5 overturning.

Mr. Ford lectured on :

Drag — With particular reference to side-wall craft (captured air bubble).

Wave drag for constant pressure machine.

Aerodynamic drag coefficient,

Based on frontal area ~ 0.35

Based on plan area ~ 0.10

<u>Air Propellers</u>

Actuator-disc theory for shrouded and unshrouded propellers.

Simple blade-element theory without rotary inflow.

<u>Performance Criteria</u>

Breguet range formula.

Karman-Gabrielli figure of merit.

Corresponding payload figure of merit.

<u>Sidewall Craft</u>

Static instability of immersed plenum.

Notes were issued for these lectures and are available at McGill University and at Canadair Ltd.

3. SEMINAR

A. Jaumotte

"Analyse Expérimentale de la Répartition de Pression dans le Coussin d'Air"
Université Libre de Bruxelles; Belgium

B. G. Newman

"Third-Order Mixing Theory for Curved Jets Applied to an Air-Cushion Vehicle with Annular Jet"
McGill University; Canada

Mixing theory applied to Wald-Thunholm theory.

T. A. de Roquefort

"The Problems of a Jet Against the Ground. Rheoelectrical Solution in the Hodograph Plane."
France

Elegant solutions in the hodograph plane. Probably superseded by the work of Ehrich.

A. J. Alexander

"Some Effects of Forward Speed on Cushion Pressures"

The University of Liverpool; U.K.

Attempt to predict variation of pressure underneath the machine in forward flight. Experimental results.

P. E. Colin

"Measurement of Air Cushion Pressure with Forward Speed in the Wind-Tunnel"
von Karman Institute; Belgium

Ingenious method for obtaining moving ground by mounting model sideways on end of a large pendulum. Comparison with tunnel results.

F. G. Maccabee

"Research Programme on Air Cushion Vehicles at the Loughborough College of Technology"
Loughborough College of Technology; U.K.

A. M. Hall

"Some of the Work at General Dynamics on Air Cushion Vehicles"
General Dynamics/Electric Boat; U.S.A.

Description of the Electric Boat machine, which is about to fly.

R. D. Hunt	"Operational Experience at H.D.L." Hovercraft Development Limited; U.K. Description of machine with trailing side curtains of ingenious design.
I. L. Keiller	"Some Comments on Hovercraft Research at R.A.E. with particular Reference to Overland Operation" Royal Aircraft Establishment; Bedford U.K. Modifications and tests on Norman-Britten CC2 overland and without skirts. Specifications for control.
G. G. Connor	"Experience Gained by Briston Siddeley in the Hovercraft Field" Bristol-Siddeley Engines Ltd.; U.K.
B. G. Newman	"Cushion Drag" McGill University; Canada Cushion drag is sink drag due to jet entrainment.
A. F. Bingham	"Some Aspects of Hovercraft Stability" Vickers Limited; U.K.

	Film showing difficulty of getting through the hump speed with forward C.G. position.
A. Kiedrzynski	"Optimisation d'un Avant-Projet de Véhicule à Coussin d'Air au Point de Vue de la Puissance" Universite Libre de Bruxelles; Belgium Optimization based on all-up weight and not payload unfortunately.
H. R. Chaplin	"An Argument for Nuclear Powered Ground-Effect Machines" David Taylor Model Basin; U.S.A. Gradual decrease of weight per H.P. for nuclear powerplant and increase of size of air cushion vehicles indicate that a 1000 ton, 100 knot machine might be attractive in the future.
N. Hogben and J. T. Everest	"Some Research on Hovercraft Hydrodynamics" National Physical Laboratory; U.K. Definitive information on wave drag for plenum chamber machine with air gap.

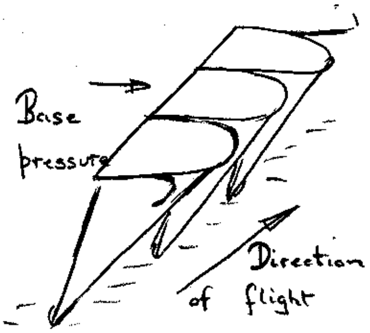
A. G. Ford "Froude Number Considerations in Captured Air Bubble Optimization" U.S. Naval Air Development Center; U.S.A.

Summaries of these papers, the figures (slides) and an edited version of the discussion will be published as an Agardograph and edited by the convenor, Mr. P. E. Colin, VKI Institute, Brussels.

4. <u>VISIT TO HOVERCRAFT DEVELOPMENT LTD., HYTHE, SOUTHAMPTON</u>

Mr. Jones and I met Mr.R.L.Trillo who had arranged the visit. It is interesting to note that the company is mainly financed from royalties on the sale of their patents.

<u>Facilities</u>	Open-air towing tank for 'floating' models with random-wave maker. Static test stands for 250 m.p.h. train with cushion pads (200 psf, annular jet without flexibles) There are presumably other aerodynamic facilities which we were not shown.
<u>Machine</u>	H.D.1, 10 tons, 60 ft. long, 17 ft. wide, 24 psf cushion pressure. 170 H.P. for lift, 450 H.P. for propulsion. 35 knots over smooth water. An interesting machine in which the side curtains are trailed over the surface. Apparently up to 10% of this curtain can be damaged without noticeably affecting the performance. The side curtains are formed in a series of independent folds each of which can be replaced without jacking up the machine. There are no flexible curtains underneath the machine and no



stabilizing jets. The rear jet is novel and the details were not revealed.

Theoretical Work

Barratt has developed an inviscid theory for thick jets, which is similar to that of Wald and Thunholm. He has also obtained a theoretical solution for the wave drag of hovercraft of various plan shapes in both deep and shallow water (J.F.M. 22, 1965). The theory appears to be inaccurate when the wave slope exceeds about one in seven, and therefore the humps in the drag curve at lower Froude numbers are ignored.

5. VISIT TO WESTLAND AIRCRAFT LTD., SAUNDERS ROE DIVISION, COWES, ISLE OF WIGHT

This visit was made at the invitation of the Chief Designer, Mr. R. Stanton-Jones. We met Messrs Crago (in charge of all Fluid Mechanics), Elsley (Aerodynamics), Crewe (Hydrodynamics) and Perry (Hydrodynamic Test Facilities).

Facilities

Medium size, low speed, open-jet wind tunnel.

Two testing tanks, one with high speed carriage. (Rather interestingly these tanks are also used commercially to test yacht hulls)

Two-dimensional test rigs

Radio-controlled model of SRN4 8 ft. long with flexible skirts. 2 - 5 HP two-stroke engines for lift and propulsion. Front and rear pylons are actuated independently in pairs. Conventional model aircraft radio-controlled links, about seven of them.

Machines

	Wt. Long Tons	Length Ft.	Beam Ft.	Total Power H.P.	Max Speed Over Calm Water Knots	Max Step Clearance ft.
SRN2	27	65.3	29.5	3,260	70	
SRN3	37	77	30.5	3,900	70	3.5
SRN4	~160	128	82.5	13,900	60 in. 4-5 ft. waves	
SRN5	6.7	39.1	22.8	900	70	3-4 ft.
SRN6	8.2	48.5	23	900	64	3-4 ft.

At least twenty five SRN 5 and 6's are currently being built. These machines are compartmented underneath by flexible skirts. Side force and yawing mount are produced by lifting the side trunks at low forward speeds.

Saunders Roe operate their machines with from 3 to 6 ins. daylight clearance over smooth water. They are capable of higher speeds than HD1 (70 knots c.f. 35 knots) and moreover have slightly better specific powers (0.25 c.f. 0.30). Skirt life is about 2000 hours, and the machine has to be jacked up to change the skirts and trunks.

6. CONCLUSIONS

I have returned from this visit firmly convinced that air-cushion vehicles with flexible extensions are here to stay. In my opinion they will eventually be used in the Canadian North, and over our rivers and lakes, but it is difficult to foresee how extensively they will be used and how useful they will prove to be. The sooner we compare, with the existing methods, their ability to move people and freight in northern regions, and in all seasons, the better.

It is interesting to restate the conclusions of the meeting on air-cushion vehicles in Ottawa which was organized by the Aerodynamics Committee of N.R.C. (15th meeting, Sept. 1963). The following applications were suggested:

1. Military: Navy
   - (a) ASW, including operation over ice.
   - (b) Transportation in northern areas over water, ice, snow and muskeg.

   Army
   - (c) River crossing of troops and supplies.
   - (d) Amphibious, overbeach, transportation of troops and supplies.
   - (e) Operation in mine fields.

   Air Force
   - (f) G.E.T.O.L. for assault and transport aircraft.

2. <u>Civil</u>
   - (a) Commuter services e.g. Victoria-Vancouver, Lakes, P.E. Island.
   - (b) Northern transportation.

(c) Lakehead transportation along St. Lawrence throughout the year.

(d) Agriculture - crop spraying in muddy fields.

(e) World's Fair.

(f) Pleasure speedboat (with side walls).

1 and 2 (b) are specifically Canadian and there is an urgent need for first-hand experience. We must not delude ourselves into imagining that a paper study will suffice. I would suggest that an interservice work team should be formed which is strongly supported in the field by operational research scientists, in order that the experience which is gained can be more meaningfully analysed. It is to be hoped that such an undertaking is already being planned.

The meeting also concluded that supporting research was required on:

(a) Wheel traction in boggy terrain, and the effect of unloading the wheels.

(b) Power required to overcome hump drag, particularly in shallow water.

(c) Stability near the hump speed.

(d) Required rigidity of skirted vehicles.

(e) General stability of skirted vehicles.

(f) Performance of recirculating curtains, including mixing.

(g) Erosion in recirculating ducts.

(h) Rough-water drag, with emphasis on the ram wing.

With the possible exception of (b), work is still needed in these areas.

It seems that sidewall machines may be useful for replacing boats up to say 30 or 40 knots, although amphibious trailing skirt machines like H.D.1 may be even more useful at these speeds. For higher speeds it seems that some daylight clearance is desirable and it is in this area that a flexible recirculating machine (with 'flying' recirculating ducts) would be competitive with the peripheral-jet machine with flexible trunks. The additional drag due to water entrainment requires investigation, particularly for operation over rough water, and of course the degree of flexibility must be comparable to that of the Saunders Roe machines.