SESSION I

CHAIRMAN'S COMMENTS - G.M. Parkes

As befits the first session of the symposium, the first two papers give a general picture of the last year's activities, the present status of air cushion technology, and its main fields of application. Mr. Fowler's paper covers the Canadian scene, and Mr. Rapson's, the British.

After this general survey, three important developments are discussed; a British study on the stability of Hovercraft, mainly on water, involving some most interesting model experiments; a Canadian research project on skirt material wear at low temperature; and a combined U.S.-Canadian full-scale program on air cushion landing gear for aircraft.

Here, then, is a broad survey of the current air cushion technology field, followed by three very varied and intriguing detailed samples. Later sessions will each delve more deeply into one selected aspect of the technology, overland transport and inland ferries, icebreaking, and marine operations.

A PROGRESS REPORT ON AIR CUSHION TECHNOLOGY IN CANADA 1975/76

H.S. Fowler
National Research Council of Canada

This will be a very short report, since much of the work will form the subject of detailed papers in the two days to come. However, I want to start the meeting by giving you an overall framework into which the later papers will fit.

It's widely considered that from first invention to an established industry usually takes about 30 years. The Air Cushion Vehicle was invented about 20 years ago in England as a sort of boat; it was tried here as a soft ground creeper about 10 years ago. I think we may beat the 30 year figure, and I certainly don't feel ashamed of the present status of the ACV - tenuous as it may be. I hope to show you a surprising lot going on, in a wide diversity of applications. I'm going to speak under several headings, starting at the Think Tank level, and ending at actual operations in the field, doing real work.

Starting then at the fundamental level, we have research at the Universities, Government laboratories, and the firms.

At Toronto University, there is a major effort to obtain a better understanding of the flexible skirt, and seal which holds the air cushion beneath the A.C.V. Sullivan is studying the stability of the skirt and Tennyson is studying the properties of skirt material - we have a paper from him later this morning. A driving simulator is also being built, to investigate the part the pilot plays.

At McGill and Carleton Universities, Yong and Kind are studying the way in which the A.C.V. generates its unfortunately characteristic dust or spray cloud; a feature we have got to eliminate, or at least control.

In the Government laboratories, notably the Department of the Environment and the National Research Council, work is going forward on the study of drag over rough ground and vegetation, the best methods of towing the vehicles, and skirt wear over rough ground. NRC has just published a fairly complete evaluation of the Multicell skirt system, and one of the segmented skirt systems is now going through the same process.

The firms have been getting on with some good research, also. I can mention studies on vehicle and skirt stability, the scaling up or down of skirt systems, the effect of high cushion pressure on roads, dust suppression, propulsion systems for heavy vehicles, - quite an impressive list. A lot of this work has been subsidised by the Federal Government, notably the Transportation Development Agency, the Department of Industry, the Department of the Environment, Transport Canada and the National Research Council of Canada.

One stage on from the fundamental level is Operational Research, and here the Provincial Governments have got into the act. The Alberta and Saskatchewan Governments and Research Councils, as well as the Ontario Government, have been actively studying the requirements and economics of the application of the A.C.V. in their provinces, notably in the All Season Ferry and Weak Highway Transporter roles. This very positive and serious interest is enormously encouraging to an industry just breaking out of its eggshell, and in the past year it has become clear that Provincial Transport Departments and Industrial groups are running economic and feasibility studies on major transportation problems with A.C.V. systems as a serious contender.

And please note that the keyword is SYSTEMS. An A.C.V. on its own is not enough; the whole transport system, including the routes, be they lakes, muskeg stretches, trails, roads of various classes, or whatever, has to be analysed.

The Federal Government has also been busy in the same field, as witness TDA's Harrison Report, and NRC's Troika Report and Engineering Proposal of required R&D in the A.C.V. field for the next three years, some of which is already being implemented.

However, you can't haul freight across muskeg on a pile of reports. What has the manufacturing sector been doing?

Frankly, not as much as we should have liked to see, - there have been thin times, and one death in the family.

We are sorry to have lost Hover-JaK, which has caused a serious hiatus in the Air Cushion Assist for on-road vehicles work, although some of their technology is surviving in Jones, Kirwan & Associates (JK&A). Bell are still with us, with their Voyageurs putting on a star turn as icebreakers (more of that in a moment) and the stretched Voyageur with the U.S. Army Engineers as the LACV30 fast amphibious lighter.

Mackley Hover Peterborough is showing the British flag from an Ontario base, and the performance of their parent company's A.C. Ferries on the Yukon has been outstanding.

And during the year a new group has been put together here in Calgary, - Hoverlift Systems Limited - their Rubber Duck looks like the prototype of a series of ferries and lighters, and I believe they are fitting some other strings to their bow as well.

The small machines. A year ago I read a paper on the "1/2 Ton Truck ACV" and said that it had not yet been built. It still hasn't been built in Canada, although the attempts at it are certainly much improved. Notably with the Canadian Cushion Craft "CASPAR" II. I must say that it looks as if Peter Winter's Tiger II in England may have hit that target.

Finally I must mention what is probably the biggest Canadian achievement in the field to day, the AC Icebreaker. This last winter, the Coastguard ran trials at Thunder Bay with an air cushion bow on a regular icebreaker, and at Montreal using a Voyageur as a high speed icebreaker on its own. The success of the operations has been quite amazing, but I will leave it to the Coastguard speakers tomorrow to describe it. The mechanism of the breaking is not yet well understood, but there is no doubt at all that the air cushion has advanced icebreaking technology more in the last couple of years than it has progressed the previous thirty.

So there you have a very brief picture of Canadian A.C.V. progress in 1975/76. The next two days of this symposium will fill it out in much greater detail, but at least I think I have shown that the A.C.V. is being recognized at last for what it is - a very demanding branch of engineering, needing a solid background, and also shrewd applications to the right fields. But in those fields, it is a way of transport promising great advantages.

1976 - A SIGNIFICANT YEAR FOR UK HOVERCRAFT

J.E. Rapson
Hovercraft Development Ltd.

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1. INTRODUCTION

History will show that 1976 was a significant year for British hovercraft. Although 1976 still has more than two months to run, the events to date are indicative of a high level of activity. The degree of "significance" may be judged by a number of parameters. It must be realised, however, that a particular activity may be significant due to its failure as well as its success, but happily the successes far outnumber the failures.

2. SALES OF CRAFT

The Southampton based firm of Hovermarine Transport Ltd. has continued to sell its HM.2 sidewall craft to overseas companies. So far this year eight of these craft have left the factory for delivery to five operators overseas. A significant feature during the year has been an increase in the size of the HM.2 fleets being operated. The Hong Kong & Yaumati Ferry Co. for example, now operate five HM.2's, one of which is of the latest stretched design. The company has formed an association with a Far Eastern group with the object of having sidewall craft produced in Japan.

Although some of the British Hovercraft Corporation's activities and future potential are concerned with military hovercraft, the company is currently building a new wide-bodied SR.N4 for Hoverlloyd to bring its fleet up to four SR.N4 Mk.2's. A contract was signed with British Rail for both of the Seaspeed SR.N4's to be lengthened. This will involve the addition of a 55 ft. long centre section which will increase the car carrying capacity from 32 to 59 cars and the passenger capacity from 254 to 400. The craft will continue to be powered by four marine Proteus gas turbine engines, but the propellers will be increased from 19 ft. to 21 ft. in diameter. Calculations and model tests have shown that the substantially increased payload will be carried with little change in performance in normal sea states. In addition the passenger comfort will be improved while the performance in extreme weather conditions will be increased. BHC is currently carrying out the design work and manufacture of the new centre section for the first craft. This is expected to be back in service in time for the 1978 summer season.

In the military field BHC has delivered three refurbished SR.N6 craft for the Egyptian Navy. It has also carried out a major refit to the first of the six BH.7 craft delivered to the Iranian Navy several years ago.

The firm of Pindair Ltd. at Gosport has specialised in the production of light inflatable hovercraft suitable for pest control, water and river authority patrol work, exploration and for military and para-military uses. Many of these have found uses abroad although in the UK Skima craft are used by the Centre for Overseas Pest Research, the Hydraulics Research Station, English China Clays etc.

3. <u>OPERATIONAL ACTIVITY</u>

The successes of the cross-Channel operation with SR.N4 Mks. 1 and 2 has been emphasised during the year. In times of financial stringency, two operating companies have shown their confidence in hovercraft as a means of carrying passengers and cars across the Channel by investing substantially in improvements to existing craft or the purchase of new craft. It was calculated that during September, Hoverlloyd and Sea-speed had between them clocked up 2 million miles on the cross-Channel service using five SR.N4's. About 9½ million passengers and 1½ million vehicles have been carried during this time. It is estimated that on the short sea routes across the English Channel 30% of all passengers and 26% of the total vehicles are carried by hovercraft. This achievement is perhaps even more remarkable when it is realised that the hovercraft being used were originally designed about ten years ago. Considerable improvements have been made to the craft during their time in service. This has largely resulted from a close working relationship between the operators, Hoverlloyd and Seaspeed, and the manufacturers, the British Hovercraft Corporation and has benefited from UK Government funds administered by the Department of Industry. During this period the regulating authorities, the Hovercraft Department of the Civil Aviation Authority and the Marine Division of the Department of Trade, have helped to ensure that the cross-Channel services maintain their record of safety. Both operating companies were forced to increase the fares charged but the new structures ensure that the fares are competitive with those of the conventional ship ferry companies. Seaspeed has substantially increased the numbers of crossings made compared with the previous year.

The operating company which has achieved the longest period of continuous running is Hovertravel Ltd. This company has continued its service across the Solent from Southsea to Ryde for the 11th year. A total of about 4 million passengers has been carried during this period. In the spring of 1976 Hovertravel substantially increased its activity on the Solent by taking over the running of the Southampton to Cowes route from the British Rail subsidiary, Seaspeed. The new service, Solent Seaspeed, is able to make the best use of the craft available by switching the higher capacity SR.N6's on to the route carrying the most traffic. There is a marked difference in the travelling habits of the two routes when comparing weekend with weekday activity. To this must be added the seasonal effects brought about by holiday traffic and sporting activities in the Solent. Hovertravel with its associated company, Hoverwork, are likely once again to be able to report profitable operations during the year.

Another operating company based on the Southampton area, International Hoverservices, passed a landmark during 1976. The company has been engaged by the Southampton based Shipbuilding Division of Vospers to ferry part of its workforce from the Isle of Wight to the mainland each day. In 1976 the company completed its fifth year of operation of this charter service and achieved a regularity amounting to approximately 98%. The service was initially operated with one HM.2 and was speedily increased with a second HM.2 Mk.3 as the demand increased. International Hoverservices have also operated a commercial service from Jersey, one of the United Kingdom Channel Islands, to the coast of France during the summer months. This operation seems likely to open up new routes for HM.2 craft which in turn could lead to the use of larger sidewall craft being developed by Hovermarine.

Hoverwork has used a lengthened version of the SR.N6 to carry passengers on a scheduled service from the centre of Algiers to an industrial exhibition.

4. NEW CRAFT

For the purposes of this review "new" is assumed to cover craft currently on initial trials as well as those in the design or prototype manufacture stage. One of the most significant new craft is the HM.5. This is being built by Hovermarine Transport Ltd. at their Southampton works and is due to be completed during 1977. It is designed to carry 140-200 passengers depending upon the layout and to maintain its specification performance in 1 m. seas. Although in some respects it may be regarded as a scaled up version of the HM.2, a considerable amount of model work and tank testing has been devoted to the concept. It will be one of the largest glass reinforced plastic structures in commercial production. The hull mould has been completed and the laying up of the first moulding is due to commence shortly. It is powered by diesel engines and propelled by water screws and will thus maintain the reputation for a quiet form of transport already enjoyed by other Hovermarine craft. Hovercraft Development Ltd. has helped to finance the design and construction of the first craft using funds advanced to it by its parent body, the National Research Development Corporation.

HDL has in a similar manner supported the development of two smaller amphibious hovercraft, the Air Vehicles Ltd. Tiger and the Pindair Skima 12. Both employ ducted fan propulsion and are powered by automobile engines. The Tiger is fitted with eight seats and the Skima with twelve seats. The first of the Tiger craft has an enclosed cabin and is constructed mainly of g.r.p. and plastic foam, whereas the Skima 12 has an open payload space which is provided with a fabric hood. The structure is light alloy surrounded by a large diameter inflatable structure. The Tiger has virtually completed its trials whereas the newer Skima 12 is still undergoing its overwater tests.

During 1976 Hovermarine designed and built its first stretched HM.2. This operation was carried out with virtually no publicity but the craft - designated a Mk.4 - was snapped up by the Hong Kong & Yaumati Ferry Co. to supplement its HM.2 Mk.3 fleet. The stretched craft has capacity for 92 passengers and has slightly more powerful diesel engines than those used on the Mk.3 craft. The company has adapted one of its HM.2 moulds so that it can be used for either Mk.3 or Mk.4 craft in future.

The Vosper Thornycroft company currently has under evaluation the VT.2 100 ton amphibious hovercraft. It will be remembered that this craft was developed from the VT.1 using the original hull of the VT.1 1-001 (Ref. 1). The original water screw propulsion powered by Lycoming gas turbines was replaced by a pair of variable pitch air propulsion fans mounted in ducts and driven by two Rolls-Royce Proteus gas turbines. This modification makes the craft fully amphibious and increases its speed capability. The uncompartmented cushion contained by an HDL loop and segment skirt, gives a relatively low drag with a comfortable ride in rough water. It has been shown that it is possible to repair or gain access to the whole of the skirt when the craft is resting on the beach or floating. The British Ministry of Defence have shown interest in the VT.2 for Mine Counter Measure duties due partly to the ability of amphibious hovercraft to survive under water explosions. Vospers believe that a craft like VT.2 should be close to being ideal in size to meet certain MCM roles.

Mention should also be made of two SR.N6 variants designed to reduce the noise level of this versatile craft. A twin propeller version was built by BHC and evaluated for military use. During 1976 this craft was put into service by Solent Seaspeed on the Southampton/Cowes route to provide a standby craft and extra capacity at the peak of the summer season. This proved to be very popular with the passengers due to the lower noise level both inside and outside the craft. Air Vehicles Ltd. manufactured a duct which was fitted to an SR.N6 after the propeller blades had been cropped. This also reduced the noise level of the craft appreciably.

The prospect for Channel hovercraft has been enlivened during 1976 by the decision to lengthen the two craft operated by Seaspeed and by the construction in France of the SEDAM N.500 craft. Two of these craft are due to go into service in 1977 in a joint Seaspeed/SNCF operation.

5. OTHER DEVELOPMENTS

The spate of developments for cross-Channel hovercraft has provided evidence of the confidence of both the operators and the manufacturers for the future. It is also encouraging to note that a new hoverport is in the process of being built within Dover Habour for the Seaspeed and the Seaspeed/SNCF service. The hoverport at Boulogne is to be improved with the standing area more than doubled and a new passenger terminal built. The terminals used by Hoverlloyd at Pegwell Bay and Calais were designed to handle a greater level of traffic than that associated with the two craft service originally operated. Nevertheless several improvements have been incorporated during recent years.

Developments associated with the Mackace enterprise also show a high degree of confidence in the future. The company has purchased a site for carrying out trials of its platforms and will soon have the whole of its British based activity at one site in East Hampshire. A new company has been formed in which the civil engineering firm of John Laing & Son Ltd. has joined with Mackace to form Transhore International Ltd. This company will specialise in the development and exploitation of hovering devices for transferring cargo from ship to shore.

An event which was significant but not encouraging was the failure of the firm of Sealand which specialised in the building of hovercraft in the 6-12 seater size range.

6. NOVEL USES OF THE HOVERCRAFT PRINCIPLE

Special attention should be given to uses of the hovercraft principle which are not exactly paralleled by the use of more conventional systems. In some cases a function can be performed which was either impossible without the use of the hovercraft system or was highly inconvenient and was, therefore, not usually attempted. Again 1976 has seen some significant developments in this field. For example, the moving of oil storage tanks on an air cushion, although no longer regarded as new, has become more widely accepted. Tank farms are now being laid down on the assumption that individual tanks can be moved around the site should this appear to be desirable. The Air Cushion Assist, known in the UK as the "On the Road Transporter", is in continuous use by the Central Electricity Generating Board for relieving the bending moments on bridges when carrying heavy indivisible loads. Before the end of 1976 it was estimated that the 1,000th bridge will have been crossed since the device was first put into service in 1967.

Hoverwork Ltd. have continued the use of SR.N5 and SR.N6 craft for seismic survey investigations. On shallow and tidal waters work of this nature is greatly speeded up by the use of self-propelled hovercraft, although a craft less sophisticated than the SR.N5/6 series would suffice for most of this type of work.

Another device which has proved its effectiveness during 1976 is the Water Skate. This is a concept developed by Air Cushion Equipment whereby water at about 87 lb/sq.in. is used to supply individual cushions for moving heavy loads over prepared surfaces (Ref. 2). Early in the year a 300 ton diving pontoon was launched using Water Skates and this was followed by the launching of another large structure weighing 1,800 tons by the same method. The water cushion concept is particularly useful for launching heavy loads into the sea where the leakage of the water from the cushion is no embarrassment and there is a plentiful supply to provide the cushion fluid. The units are relatively cheap and the power consumption is about 3% of that of a comparable air cushion device.

Mention has already been made of the interest shown by the Royal Navy in the use of hovercraft in the Mine Counter Measure role. Tests were carried out during the summer using both the Vosper VT.2 and a BHC SR.N4 Mk.2 chartered from Hoverlloyd. The Naval Hovercraft Trials Unit at Lee-on-Solent has been closely involved with the evaluation of these craft. The development of the MCM hovercraft concept by the Royal Navy has been carried on in conjunction with a joint team from BHC and Vosper.

One of the novel uses of hovercraft which attracted a great deal of attention during the year was the concept of using towed or self-propelled hover barges for transferring cargo from ship to shore in countries where port facilities were either non-existent or overcrowded. There is a tendency for some healthy scepticism to be shown when a new method is to be used for the first time in a competitive situation. For this reason novel devices may take several years to obtain general acceptance. This is well illustrated by the case of oil storage tank movements mentioned earlier.

The British cannot claim to have pioneered the use of hoverplatforms for icebreaking. This use, which was difficult to predict, has been developed in Canada. Some of the skirt sections used during the trials were, however, manufactured in the UK having been developed from earlier hovercraft or hoverplatforms.

7. GENERAL ACCEPTANCE OF HOVERCRAFT

In limited areas of the UK hovercraft are treated by the public as "just another form of transport". This is particularly noticeable in the Solent area. Apart from a high level of commuter travel between the Isle of Wight and the mainland in both directions, the SR.N6 hovercraft services are used for morning and afternoon shopping expeditions and during the summer for day trips to the Isle of Wight. In the area around the hoverports of Dover and Ramsgate the SR.N4 hovercraft seems to be the usual way of crossing the Channel. In addition, there is a considerable amount of traffic by day trippers in both directions. The Vosper Thornycroft commuters regard their HM.2 as a coach service.

In terms of commercial hovercraft there has during 1976 been increasing pressure applied for noise level reductions. The authorities and the various environmental protection societies have realised that in the case of the SR.N6 for example, alternative propulsion systems are available. It is appreciated, however, that the operating companies are not yet making sufficient profits to be able to have any of these alternative systems fitted to their existing craft. It is encouraging despite this that the operators and the authorities now seem to be working towards the same end.

A study has recently been made in which the effectiveness of commercial hovercraft and hydrofoils has been compared. The results of the study are shown in Figs. 1 and 2. It will be seen that in the smaller sizes of both types of craft, there is little to choose between them on the basis of the power installed for each unit of work achieved. As the work capacity of both types of craft increase the specific horsepower of hovercraft tends to improve while that of hydrofoils becomes worse. It will be noticed too that the larger capacity hovercraft are approaching passenger and car carrying ferries in terms of specific horsepower. The craft included on the graphs are those which are in commercial service or are due to be operational during 1977. It is realised that specific horsepower is not an infallible parameter for comparing different forms of transport. It does, however, have the merit that higher power requirements imply not only higher fuel consumption and operating costs, but also higher initial costs due to the greater installed power.

In the field of small hovercraft, the activities of the Hoverclub of Great Britain have expanded considerably during 1976. The club arranges racing and other competitive events by amateur built craft. This has reached the stage at which at a good weekend meeting 40-50 craft may be competing. In such a collection of craft it would be unusual to find a single pair built to the same specification. Such a diversification of designs can only help to improve the effectiveness of small hovercraft. The UK Hovercraft Society has offered a prize in order to encourage Hoverclub members to concentrate on making light craft quieter.

During 1976 a number of manufacturers of small hovercraft have produced new craft which are being evaluated. The activities of Air Vehicles Ltd. and Pindair Ltd. have already been referred to but mention should also be made of the very efficient five seater craft produced by the Missionary Aviation Fellowship. This has been demonstrated as having a good performance and to be highly manoeuvrable and relatively quiet. The various two seater craft produced have improved greatly in appearance but it is generally realised that the state of the economy is likely to inhibit home sales and the companies will have to rely on exporting their craft.

8. TECHNOLOGICAL PROGRESS

The progress made by the principal manufacturing companies has been most ably and fully described (Ref. 3) by Mr. Wheeler in a paper presented to the AIAA/SNAME Third Advanced Marine Vehicle Conference, held only a month ago. Attention should perhaps be drawn to the programme of work being undertaken by BHC. In this it is confidently predicted that power and fuel savings for a hovercraft of given performance can be reduced by 40-50% (Ref. 4). Thus in the field of performance great strides are likely to be made in the next few years. On a more modest scale Hovercraft Development Ltd. has been working on improvements to the control systems of amphibious hovercraft.

It will be remembered that HDL maintained a strong research and development effort until 1967. Part of the programme involved the construction and testing of two experimental craft, the HD.1 and the HD.2 (Ref. 5). By 1967 plans were well advanced for the HD.3 which was to be a relatively deep cushioned craft to assess the practicability of producing smaller hovercraft to cope with a given sea state. This advantage could be used to improve the market potential for hovercraft. For example, the English Channel appeared to be the only route having sufficient traffic to justify using hovercraft of SR.N4 size. If, however, a smaller craft could be built having similar seakeeping qualities it could be used economically on less dense open sea routes.

A tank model had been built - Model 58 - which showed promising results. In subsequent years little effort was available for following up this work. In HDL it was felt that a craft having a cushion system similar to Model 58 would only be acceptable if it was also provided with an effective means for moving the cushion centre of pressure both laterally and in a fore and aft direction.

A c.p. shift system had been fitted to the HD.2 craft but it involved hydraulic actuators, levers, wires, a series of pulley blocks and fairleads underneath the hull. Some effort was, therefore, expended in devising a system with a minimum of working parts outside the craft. A basic layout to achieve this was designed about four years ago but it was not until the end of 1974 that it was possible to engineer this layout in such a way that the forces required to actuate the system were minimal. Working within a restricted budget the c.p. shift system was incorporated into a craft and testing began in the spring of 1976.

HDL had possessed for a number of years a two seater craft having an 8 in. deep cushion contained by an HDL loop and segment skirt. This craft was rebuilt using many of the parts and became HD.4. Figs. 3 and 4 show a General Arrangement of the craft and of the skirt system. The nominal depth of the cushion from the flat bottom of the craft to the segment tips is approximately 15 in. and the cushion beam is approximately 71 in. The corresponding figures for Model 58 were 12 in. and 60 in. When hovering over land the cushion depth of the HD.4 reduces to 13.4 in. Additional information on HD.4 is contained in Fig. 5.

The c.p., shift system is actuated by a single articulated stick in front of the driver. It operates in the natural sense in that movement to one side rolls the craft to that side and pitching is obtained by moving the stick in a fore and aft direction. Movement in a diagonal direction has the effect of depressing the appropriate corner of the craft. Since pitch attitude changes are achieved solely by moving the side skirts and the craft has a relatively short length of straight side, the effectiveness of HD.4's c.p. shift system in a fore and aft direction is limited. If the system were to be applied to a craft more rectangular in planform the pitch control could be improved. Static tests have to date been confined to the rolling mode although the pitch control has been used both dynamically and as a trimming device over water.

Fig. 6 shows the stiffness of the cushion system in roll. The applied rolling moment is expressed as the equivalent movement (as a percentage of the cushion beam) of the centre of gravity of the loaded craft. This "natural" stiffness of 0.40% per degree over the first 4 degrees of roll in each direction may be compared with the stiffness of 0.30% per degree of HD.2. Thus the simple open loop and segment skirt of HD.4 is comparable in roll stiffness with that obtained on the more complex skirt system of HD.2. Fig. 7 relates the roll angle achieved to the angular movement of the control stick. This figure is only applicable to the particular geometry chosen for the HD.4 system and can be varied to some extent according to the design parameters selected. Fig. 8 indicates the relationship between the stick angular movement applied and the external rolling moment which would be necessary in order to achieve the same angle of roll. Finally Fig. 9 shows the angle of stick movement necessary in order to restore the craft to level trim with the application of various amounts of external rolling moment. These last two curves suggest that the control may be more effective as a means for trimming out off-centre loads than as a means of rolling the craft.

HD.4 has so far undergone a limited amount of testing both over land and water. Fig. 10 shows the craft being rolled to starboard over water by the application of the stick alone. As was the case with HD.2 the operation of the roll control not only assisted the turning of the craft by redistributing the drag of the side skirts, but also ensured that the craft rolled into the turn. The geometry of the linkages have been chosen in this first phase of the HD.4 trials to give a reasonable angle of roll using stick forces which may easily be applied with one hand. The degree of pitch and roll control that should be sought is not obvious at this stage. Over land the static roll angle achieved was an unspectacular $3\frac{1}{2}°$. Over water this appeared to be somewhat greater and adequate as a dynamic control. Since the system may be used both as a static trim control and as a low inertia dynamic control, there may be a need to increase its effectiveness to give adequate ranges in both applications.

9. CONCLUSIONS

It is obvious that there is little room for complacency in the progress made in the exploitation of the hovercraft principle. It is always difficult to assess this in relation to other significant inventions. The rate of progress is greatly affected by world conditions and in particular, the presence or absence of military conflicts. In the case of hovercraft which are operated as an alternative to more conventional means of transport, the efficiency of the craft and the way in which it is presented to the public have a major influence upon its rate of adoption. At the other end of the scale, in the case of applications of the air cushion principle which enable difficult tasks to be performed for the first time, the period required to influence would-be users and purchasers is almost unpredictable. In this field some progress is being made.

It is clear that partly due to a shortage of suitable funding technical progress has been relatively slow. It is now becoming more obvious that the development of a new form of transport is likely to occupy at least two decades. The fact that some commercial operators can show a profit when using craft initially designed in the five years following the operation of the first man-carrying hovercraft is remarkable. Very great improvements were made in the first few years following the launch of the SR.N1 in 1959. Steady progress was made thereafter but it seems that we have now reached a point in 1976 when significant advances can be planned with confidence.

The author wishes to thank individuals and organisations for assistance in compiling this paper. Any opinions expressed are his own and do not necessarily represent the views of Hovercraft Development Ltd. or of the National Research Development Corporation.

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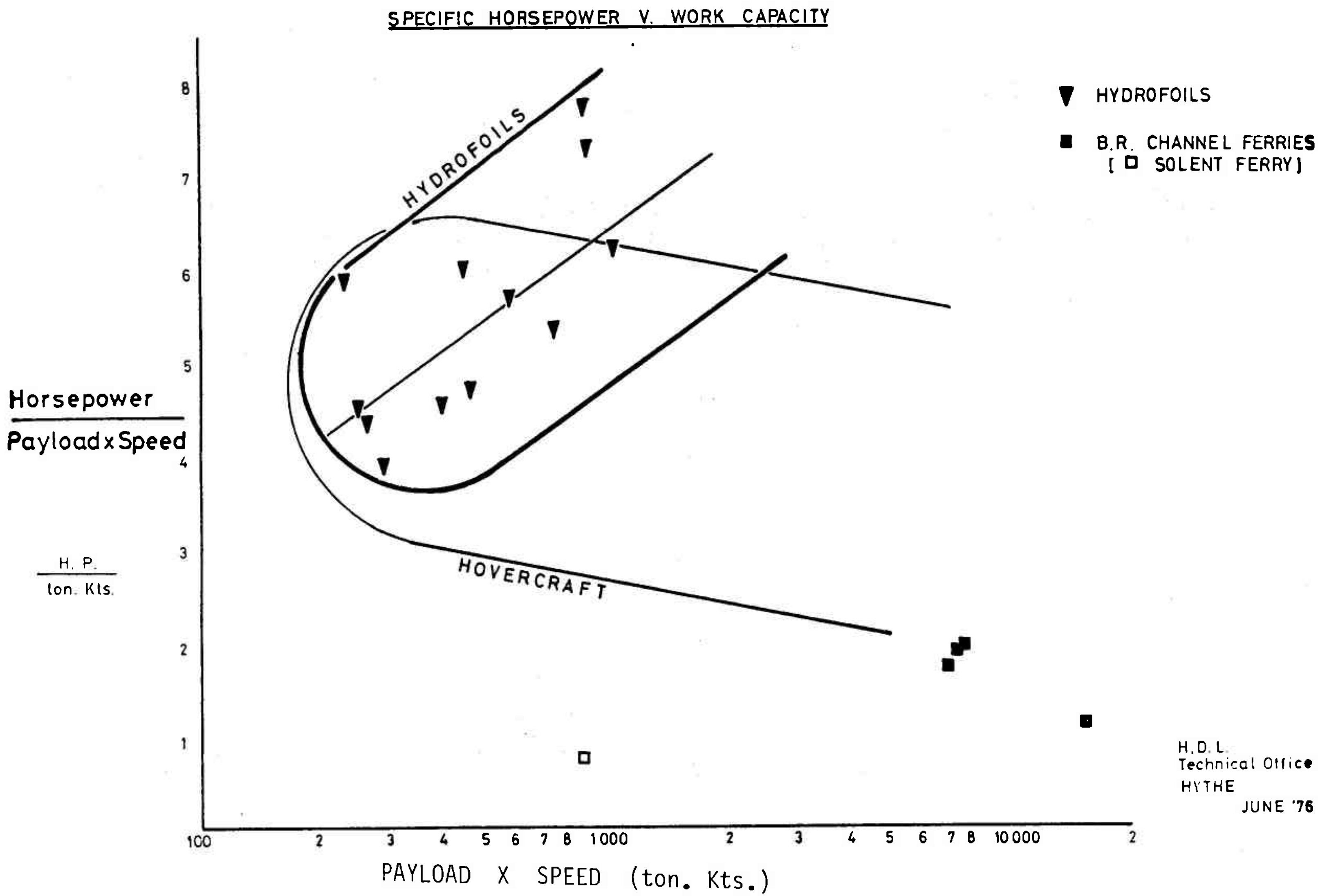

FIGURE 1 - Comparison of contemporary hovercraft hydrofoil and ship ferries

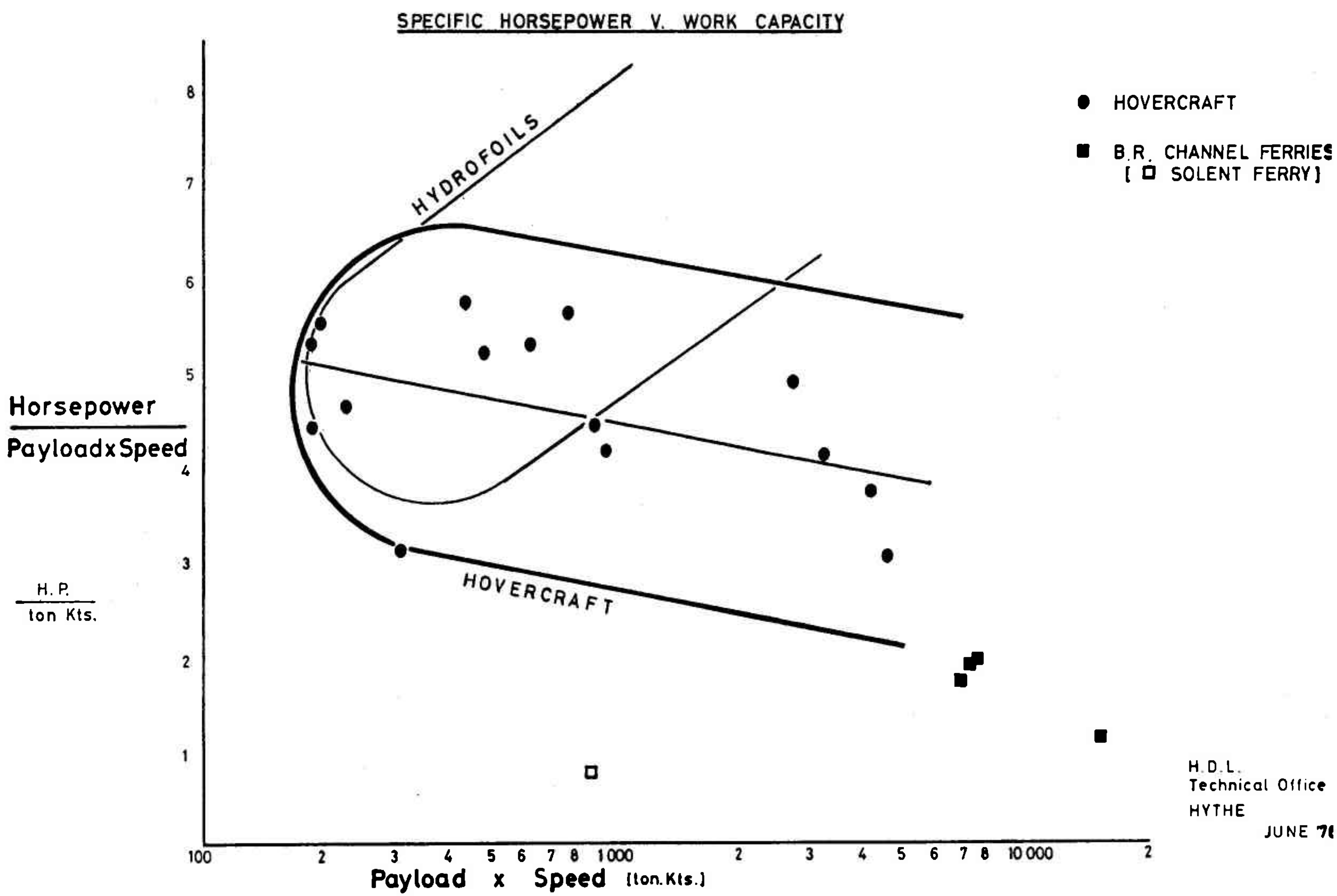

FIGURE 2 - Comparison of contemporary hovercraft hydrofoil and ship ferries

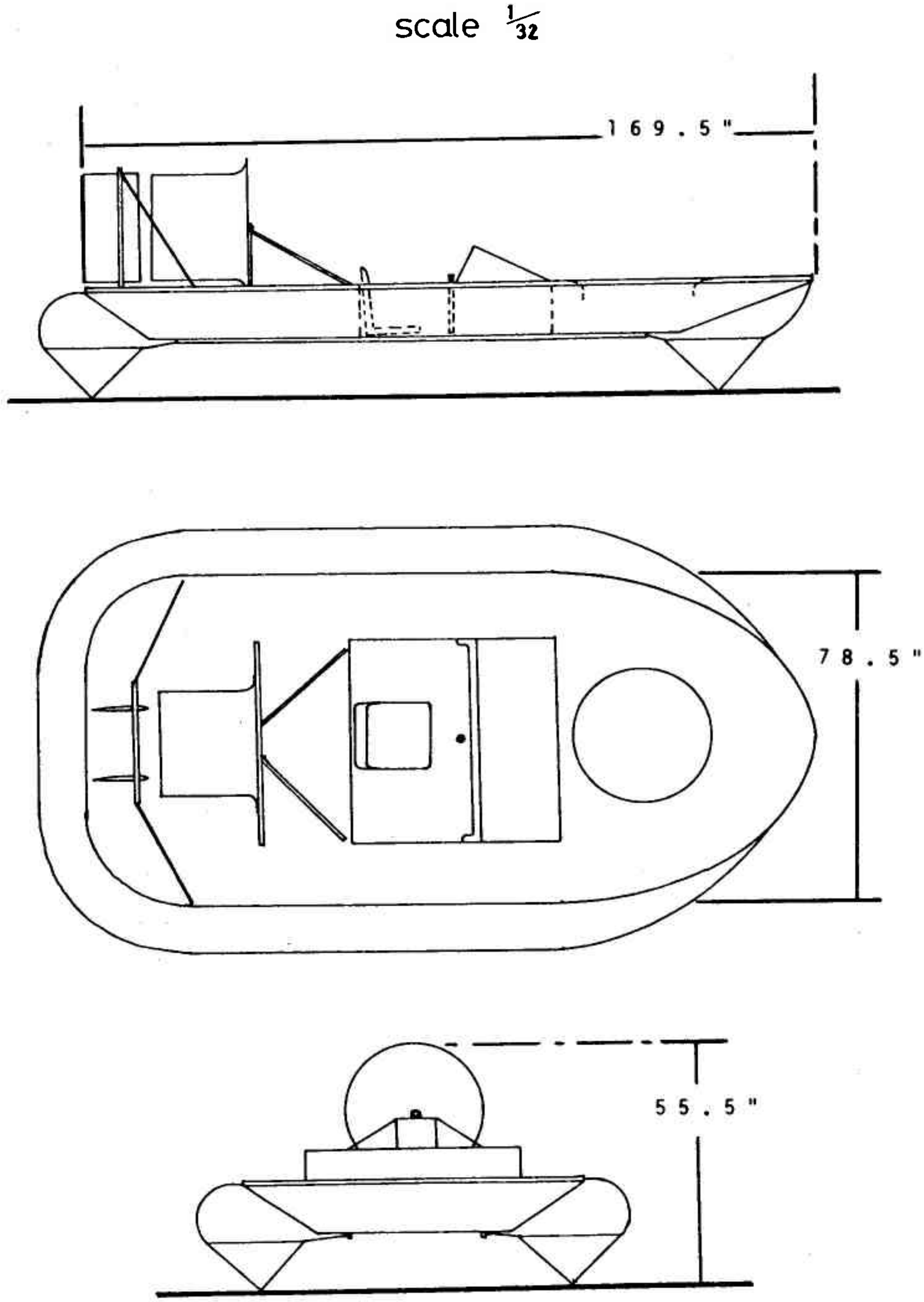

FIGURE 3 - General arrangement of HD4b

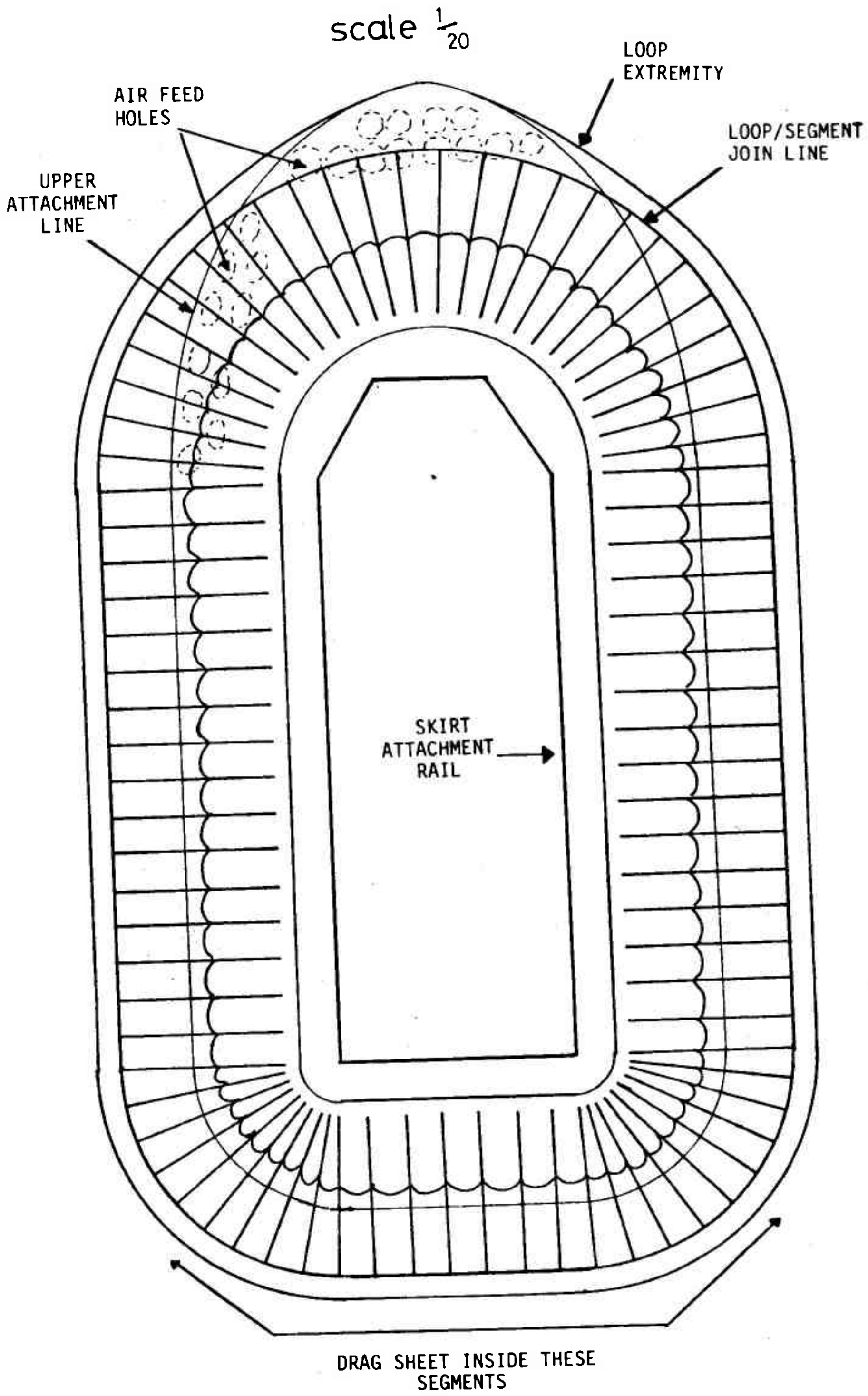

FIGURE 4 - HD4 skirt detail

Type H.D.L. H.D.4 b	Versions Ducted fan	Special features Balanced c.p. shift system in pitch and roll

Normal A.U.W.	Length	Beam	Height -	Cushion Depth
691 lb.	169·5"	78·5"	Hovering: 55·5" At rest: 44"	13·4"

Configuration
Single axial lift fan feeding air into bow loop through 32 x 4" dia. holes in horseshoe formation extending back 60" from bow.
Single ducted fan aft.

Construction
4mm & 1 5mm plywood on 1" & ½" sq. framing.
Structure depth 13·6".
Planing angle 35° reducing to 20° on bow centreline

Payload accommodation
2 seat cockpit amidships.

Engines	Power
Lift. Villiers 8E 197 c.c.	9·0 max.
Prop. Kyoritsu KEC 225 225 c.c.	11·0 max.

Control
2 vertical rudders 16" chord x 24" HT in fan slipstream.
C.P. shift in pitch & roll.

Transmission Lift - Direct.
Prop - Toothed belt reduction 1: 1·39

Propulsion
Breeza fan in duct
23" dia. 5 blades @ 30°

WEIGHTS :
Structure :
Machinery :
Equipment :
Skirts :
Furnishings :
Crew :

Empty : 508 lb.
Fuel 4 Galls: 29 lb.
Payload : 154 lb.

A.U.W. (Normal): 691 lb.

Overload :

Lift
Multiwing fan
23·5" dia. 10 blades @ 30°

Cushion Uncompartmented open loop & segment.
Length - 132" effective - 145" overall
Beam - 71·25"
Area - 65·5 sq. ft.
Mass Flow -
Pressure - 10·55 lb/sq.ft.

Seal Open loop & segment with trailing sheet over open faces of rear segments.
Material Loop 6 oz. nylon
Segments 1·5 oz.nylon
Segment- Length 12" Pitch 5.4"

PERFORMANCE (normal A.U.W.)

Hump speed kts. 7	Static T/W 0·1
Cruise speed kts.	Range
Max. speed kts.	Endurance

Entry speed kts.	Turn Radius	Nominal 'g'	Exit speed kts.

Wave ht.	Wind Vel.	Speed kts.

Solid obstacle clearance 11·5"
Continuous gradient

ECONOMICS Assumptions:
First cost: Life:
Service Speed: Passenger Seating: Freight:

D.O.C. £/HOUR	Utilisation 1000 Hr.	Hr.
Depreciation		
Interest		
Insurance		
Craft maintenance		
Machinery maintenance		
Fuel and oil		
Crew		
Total D.O.C.		

First cost/ton A.U.W.
First cost/seat
First cost/Payload-ton-knot
D.O.C./seat - N.M.
D.O.C./payload ton - N.M.

Buoyancy 5 dinghy buoyancy bags: 600 lb.
Landing systems 4 plywood pads 2" deep

Parameter	Stiffness	Damping	C_{DA}
Roll			
Pitch			C_{DW}
Heave			

HISTORY: First operated:
Number produced:
Routes Operators

Remarks:

Sources H.D.L.

Issue No. 1
Date 8.9.76

H.D.L. D.S. No.

FIGURE 5 - HDL hovercraft data sheet

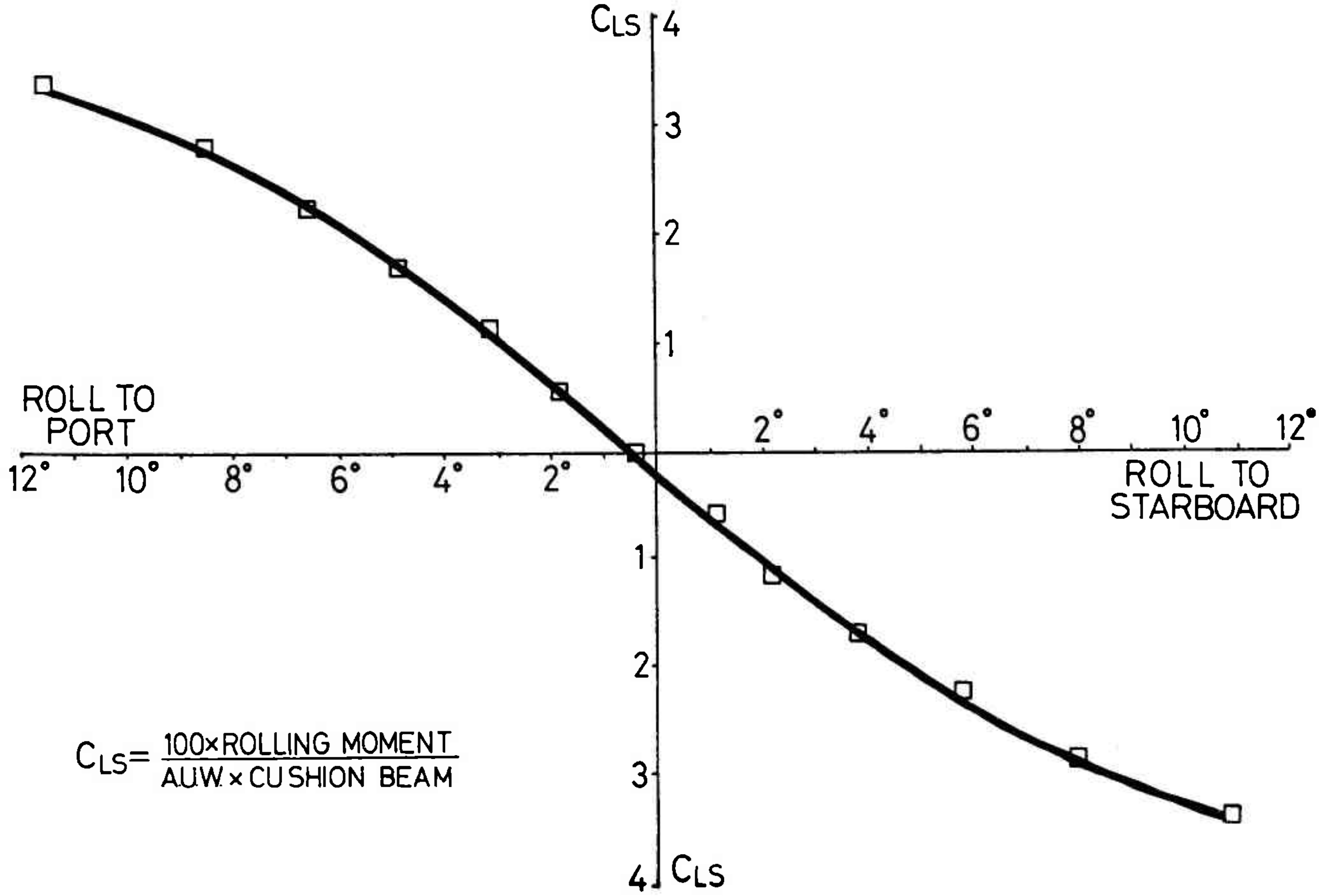

FIGURE 6 - HD4 roll stiffness on land

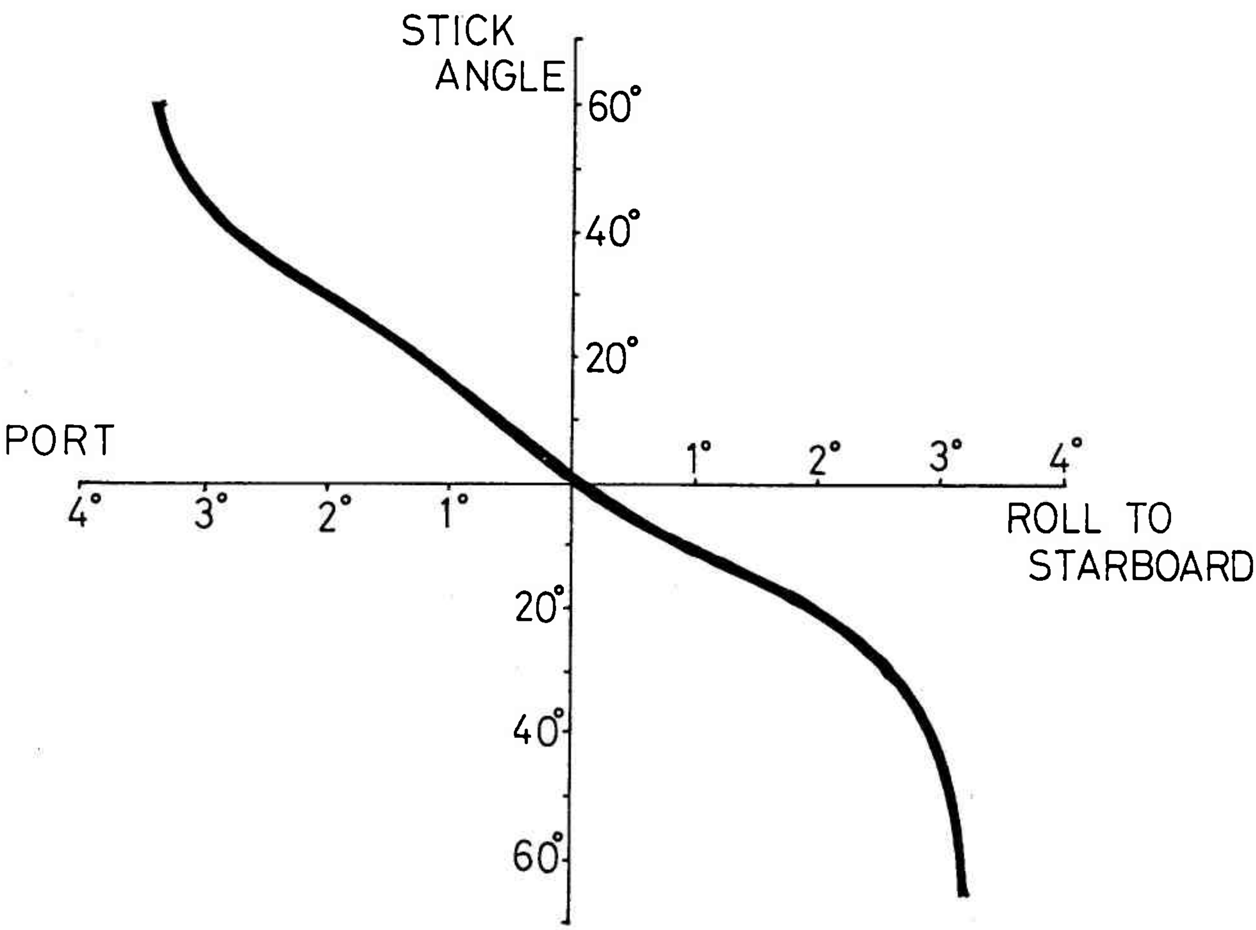

FIGURE 7 - HD4 stick angle v. roll angle

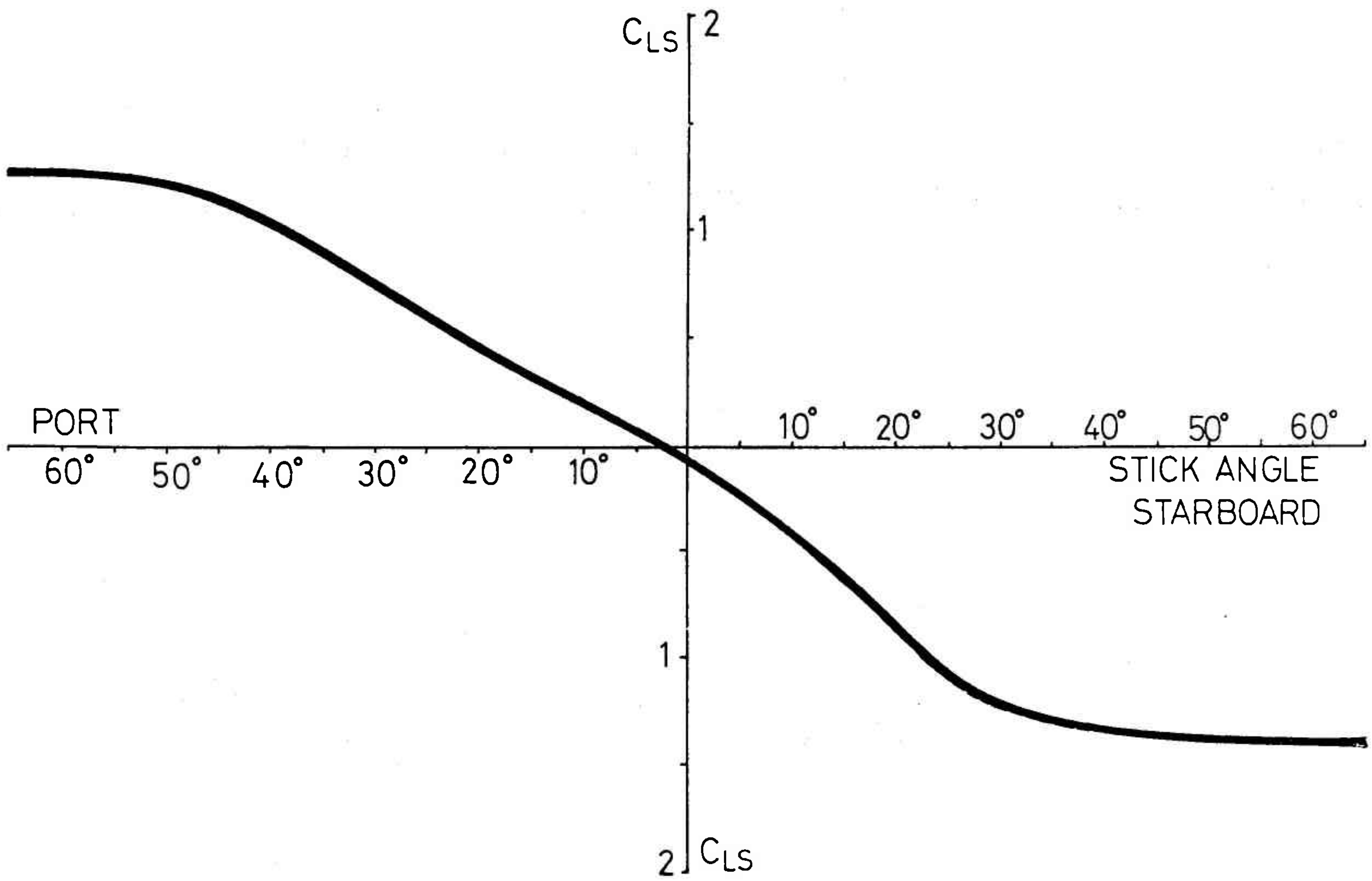

FIGURE 8 - HD4 C.P. shift v. control stick angle craft rolled

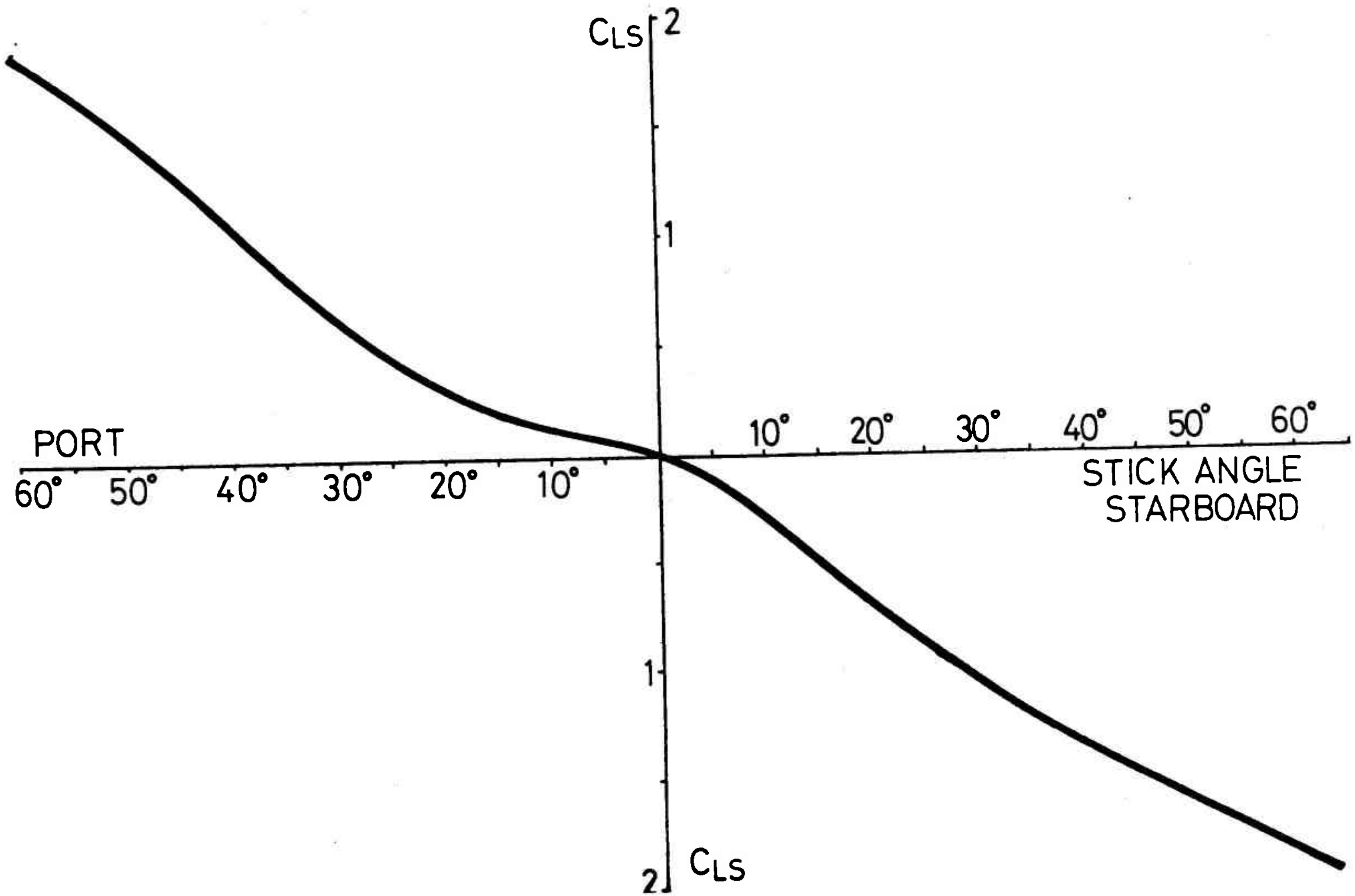

FIGURE 9 - HD4 C.P. shift v. control stick angle craft level

FIGURE 10 - HD.4b Rolled to Starboard over Water

A REVIEW OF THE REPORT OF THE ARB SPECIAL COMMITTEE ON HOVERCRAFT STABILITY AND CONTROL

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Civil Aviation Authority
Airworthiness Division
Hovercraft Department

SUMMARY

This paper briefly describes the capsizes which have occurred to commercial sized hovercraft and which led the Airworthiness Requirements Board (ARB) to form, in April 1973, a Special Committee to investigate hovercraft stability and control. The Special Committee reported their findings to the ARB and their report was published as CAA Paper 75017, some topics of which are reviewed in this paper.

1. EARLY CALM WATER CAPSIZES

To set the scene, the brief descriptions from Reference 1 on the capsizes that have occurred on U.K. commercial type craft are repeated. Figure 1 puts the capsizing story into perspective. The first flight of the SR.N1 was made in 1959, and the first flight of the SR.N5 was made in April 1964. The SR.N5 cabin was lengthened by four window bays, to make the SRN6 which first hovered in March 1965. It should be borne in mind during the discussion that follows, that since their first flights the SR.N5 and SR.N6 have accumulated over 29,000 and 162,000 type operating hours respectively.

The first major capsize and only known sidewall craft capsize, occurred in December 1964, to an American research craft, the XR-1. The first SR.N5 capsize was in April 1965, when the craft overturned following a plough-in, during a pirouette on glassy calm sea conditions. Entry speed into the pirouette was approximately 40 kts, the actual overturn occurring, at or near, the beam-on hump speed of 7 kts. It was found afterwards, that the stability keel, had been split along its entire length. The next N5 capsize came soon after in May 1965 and again resulted from a plough-in. This was caused by gross mishandling of the controls by a driver under instruction. Again, the sea was calm with no wind. It should be noted that a total of fourteen people escaped from these two capsizes without serious injury. Action was immediately taken by BHC to establish the circumstances of the capsizes by a design and model test investigation. The basic objective of this work was to reduce all aspects of plough-in severity by reducing the jetted skirt drag and suction effects. This was achieved, see Reference 2, by the addition of external strakes on the skirt with air ventilating holes. Combinations of these modifications were extensively flight tested by BHC, who carried out over 60 deliberate plough-ins during their test programme. The final modification was satisfactorily demonstrated to surveyors from the Air Registration Board, U.S. Coast Guard and Japanese Ministry of Transport. In addition, the concept of limiting the yaw angle for various speeds was introduced by BHC, and is still very much in use today, see Figure 2.

The third SR.N5 capsize occurred off Calshot to a military craft in July 1966, during a 180° stop turn to port. Although the skirt on this craft had been modified with strakes and air lubrication it was in poor condition, due to being deliberately operated to an extended maintenance schedule for military reasons. In addition, the yaw-speed conditions were being exceeded. Sea was again glassy calm with no wind.

It should be noted, that all the N5 capsizes described, were in glassy calm sea conditions and were of a plough-in type, resulting from initially high speed, high yaw angle, turn or pirouettes. It was considered that the yaw-speed limiting condition, if observed, together with improvements in skirt design resulting in the fingered skirt, should eliminate any further calm water capsizes. In passing, it should be noted, that the fingered skirt could sustain over twice the adverse moment, before it tucked-under, than the original jetted bag skirt.

In the meantime, for the rough water end of the scale considerable experience and confidence in the seagoing qualities of the N5 and N6 type craft, was being gained by the manufacturers, BHC, the Air Registration Board and operators all around the world. Weather conditions for craft operations were initially limited to five feet significant seas and 20 knot winds and these values were quoted in the craft operating manuals. As a result of further extensive experience and testing the limiting wind speed was increased by the Air Registration Board in December 1966 to 30 knots forward of the beam and 25 knots abaft the beam.

2. SR.N6 ROUGH WATER CAPSIZE INVESTIGATION

We now span a period, of some six years, since the Calshot capsize, to March 1972, when SRN6-012 capsized off the entrance to Portsmouth Harbour. This accident occurred in severe weather conditions and although 22 people escaped, five people lost their lives.

Figure 3 shows the general situation. Craft 012 left Ryde for Southsea and capsized approximately 400 yards from the Southsea base. At the point of capsize the mean wind was approximately 30 knots, gusting to nearly 45 knots. The wind was blowing on the craft starboard beam and in almost direct opposition to the 2-1/2 to 3 knots tidal stream coming out of Portsmouth Harbour. There was consequently a short steep sea with waves, estimated at the time, to be six to eight feet high and up to sixty feet long. Figure 4 summarises the information on the accident provided by eye witnesses who included an N6 Commander who was watching the craft approach.

After the accident, BHC worked practically day and night to try and establish the cause, by means of model tests and theoretical analyses. Almost immediately they published Service Bulletin No. 163, which drew attention to the danger of decelerating with sideways motion, particularly, when using low turbine rpm. This was followed a few days later by Bulletin No. 168, which described in full scale terms the results of the model tests. It was found, that the craft could, occasionally, be made to overturn in breaking wave conditions eight to nine feet high and sixty feet long. These are unusually steep waves, but they could occur in certain conditions of wind, tide and sea bed. It was not found possible to overturn the model, in similar short steep waves, five to six feet high. The model test method is indicated in Figure 5 and shows the model placed beam into the waves, and pulled through them at the critical beam hump speed of seven knots. A 40 knot wind force was simulated, by an off-set CG position and the towing method was such that the model was subjected to snatch loads representative of gusts.

The results showed that when the model was operated at normal turbine speeds, of 17 to 18,000 rpm, it was not possible to overturn the craft in repeated tests. Also, if the engine power was completely cut at the most critical moment, so that the side structure was buried in the water, no overturning was achieved. However, if the power was reduced from 18,000 turbine rpm to 14,000 at the critical moment, the model could be made to overturn, in approximately 1 in 15 occasions. This 1 in 15 occasions would only be made to occur, if the craft was almost exactly beam to sea, and drifting sideways at the critical speed. If the model was 20° off the beam condition, no overturning could be made to occur.

It should be emphasized that these were the preliminary results of a general set of overturning model trials. Deliberately severe conditions, compatible with those observed at the time of the accident, had been chosen to quickly find a condition that would reproduce the overturning. The key factor appeared to be a partial reduction of turbine speed at a critical moment, and it appeared from the model tests, that wind strength and asymmetric craft loading were quite secondary effects. Even so, overturning could only be produced occasionally.

3. HD2 MODEL TESTS

The Department of Trade and Industry financed a programme of model tests, to be carried out by BHC on various craft and on the HD.2 research craft, designed and built by HDL. This craft hull had been designed to have planing type surfaces round the complete craft periphery. An isometric view of the hull and air feed arrangement into the loop-segment skirt is shown in Figure 7.

The report, Reference 3, on the HD.2 model tests was published for a restricted circulation by BHC. Figure 6 reproduces Figure 5 from that report, and shows the roll angle variation with beam-on towing speed measured over calm water with an adverse rolling moment, equivalent to 5,300 lb. feet full scale applied. The resulting curve clearly shows a sharply defined critical speed region around 6-1/2 knots where either overturning, under the model test conditions, or severe skirt scooping occurred. The sensitivity of this speed region can be judged by the position of the test points at six knots and seven knots on the edges of the critical region. The fundamental question is, what makes the model unstable at 6-1/2 knots yet completely stable at 1/2 knot either side of this value? Unfortunately this question cannot be completely answered at present as a complete theoretical analysis is difficult, due to the lack of precise knowledge of the contact lengths and actual Froude Numbers involved.

For example, theoretical curves for the cushion wavemaking drag show that Froude Number is very critical in the six to seven knot region. With leading skirt contact the beam could effectively be increased to 16.0 feet compared with a design cushion beam of 14-1/2 feet. This gives Froude Numbers of 0.44 and 0.525 at six and seven knots respectively, with wavemaking coefficients of 0.85 and 2.84, since these Froude Numbers are just above the first hollow, and just below the main hump. Hence for a speed change of only one knot the wave drag coefficient increases by a factor of nearly 3.5. Also an examination of water surface elevations of these speeds, computed by NPL, Reference 4, suggests that wetting drag would have partly transferred from the side skirts to the bow and rear skirt between these Froude Numbers.

4. ARB SPECIAL COMMITTEE

Now, the test work being carried out was mainly related to establishing the limits on existing types of craft, and the results obtained would not necessarily be in a form which could assist the CAA with drafting hovercraft design and test requirements.

The CAA and ARB therefore decided to form a Special Committee to examine all aspects of hovercraft capsizing with a view to improving the relevant British Hovercraft Safety Requirements (BHSR's). The Special Committee held its first meetong on 10th April 1973 and the committee members listed in Figure 8 shows that the CAA was fortunate in having a great wealth of hovercraft talent at its disposal. The Committee met over a period of some two years and their report to the ARB was published as CAA Paper 75017.

The report broadly discusses some of the capsizes that have occurred to date, and some of these have been described in the first part of this note. For the capsizes in rough water, it was suggested that there may be a limiting wave height peculiar to each type of craft below which, capsizing, if not impossible, is extremely unlikely to occur. This is tentatively put forward on the SRN6 model test experience only. Naturally, this concept, if correct, is of great importance to Safety Authorities, but the difficulty remains in establishing its validity and the maximum safe wave height and steepness for various craft types.

The Committee reviewed the factors which could affect capsizing, but did not feel justified in attempting to put recommended values for all the factors. It was considered that a basic research programme was necessary in order to establish suitable combinations of the numerical values required.

Despite this, an attempt at analysing the capsizing sequence was made, and in order to simplify the analysis, the following sequence was assumed to occur in each over-water capsize from the on-cushion position -

i) Initially the craft is on-cushion and operating normally.

ii) A situation and/or a manoeuvre occurs causing leading skirt tuck-under.

iii) The hard structure of the craft makes a dynamic impact with the water surface.

iv) The actual capsize occurs.

Leading skirt tuck-under is, therefore, the most significant factor in the sequence as a necessary although not in itself sufficient condition for this form of capsize. Probably the most important single feature leading to skirt tuck-under and possible capsize when travelling beam-on is reduction of the lift engine power.

Some analysis of skirt tuck-under, as described already for the HD2, is contained in the report. In this respect the Committee was fortunate in being able to draw upon the results of an analysis on hovercraft safety, being carried out by BHC under contract to the Department of Trade and Industry. Figures 9 and 10 were derived from this work and are included in the Committee's report. Figure 9 lists the design factors affecting the leading sideskirt tuck-under boundary. The range of current practice is quoted but these values should not be regarded as design rules or limiting values. The same comment applies to Figure 10 which lists other design factors affecting the craft's reserve against capsizing, again up to the skirt tuck-under point.

Various conclusions and recommendations are made in the report on the design, model and full scale testing and operational aspects to minimise the risk of capsizing.

The Committee recognised that many problem areas had been highlighted and therefore further general research was recommended, not only to increase basic data and knowledge, but also to enable better theoretical techniques to be formulated. Accordingly, a general research programme based on the Committee's recommendations has been formulated by the CAA, BHC and others in the hovercraft industry. This will be put to the Ship and Marine Technology Requirements Board in the near future and it is hoped that research funding will be provided.

To sum up, the Special Committee's Report is not, by any means, the last word on hovercraft capsizing. It should be regarded more as a foundation on which further research and development can build the knowledge required to design and operate hovercraft more safely in the future.

5. REFERENCES

1. CAA Paper 75017 "Report on the ARB Special Committee on Hovercraft Stability and Control" Airworthiness Technical Note No. 112, June 1975.

2. W.A. Crago "Problems Associated with the Use of Skirts on Hovercraft". Institute of Mechanical Engineers, Proceedings 1967-68, Volume 182, Part 2A.

3. B. Clarke "Model Tests to Investigate the Safety of the HD.2 ACV in a Yawed Condition". Report No. X/O/1682, March 1973. BHC EEL (Restricted circulation. Prepared under contract for the Department of Trade and Industry.)

4. Dr. R.G. Standing "Hovercraft Wave Profile Computer Results". NPL Project 40.52.

6. ACKNOWLEDGEMENTS

The author would like to thank the Canadian Aeronautics and Space Institute for its invitation and the CAA for its permission to present this paper. It is, however, stressed that any opinions expressed are his own and do not necessarily reflect the views of the CAA, the ARB Special Committee, any hovercraft company, government department, or individual. The author is indebted to the Departments of Trade and Industry and to the British Hovercraft Corporation for their permission to present Figures 2-5 inclusive and material in the text of the paper. Special thanks for their helpful assistance are due to Mr. T.F. Arlotte and Mr. D.G. Gerry of that company.

June 1st 1959	SRN1 first free hovering trials
April 11th 1964	SRN5 first flight
December 8th 1964	XR-1 capsize
March 29th 1965	SRN6 first flight
April 8th 1965	SRN5-001 capsize in Alesund Harbour
May 11th 1965	SRN5-007 capsize in San Francisco Bay
July 8th 1966	SRN5-005 capsize off Calshot
March 12th 1972	SRN6-012 capsize off Southsea

FIGURE 1 - Significant Dates

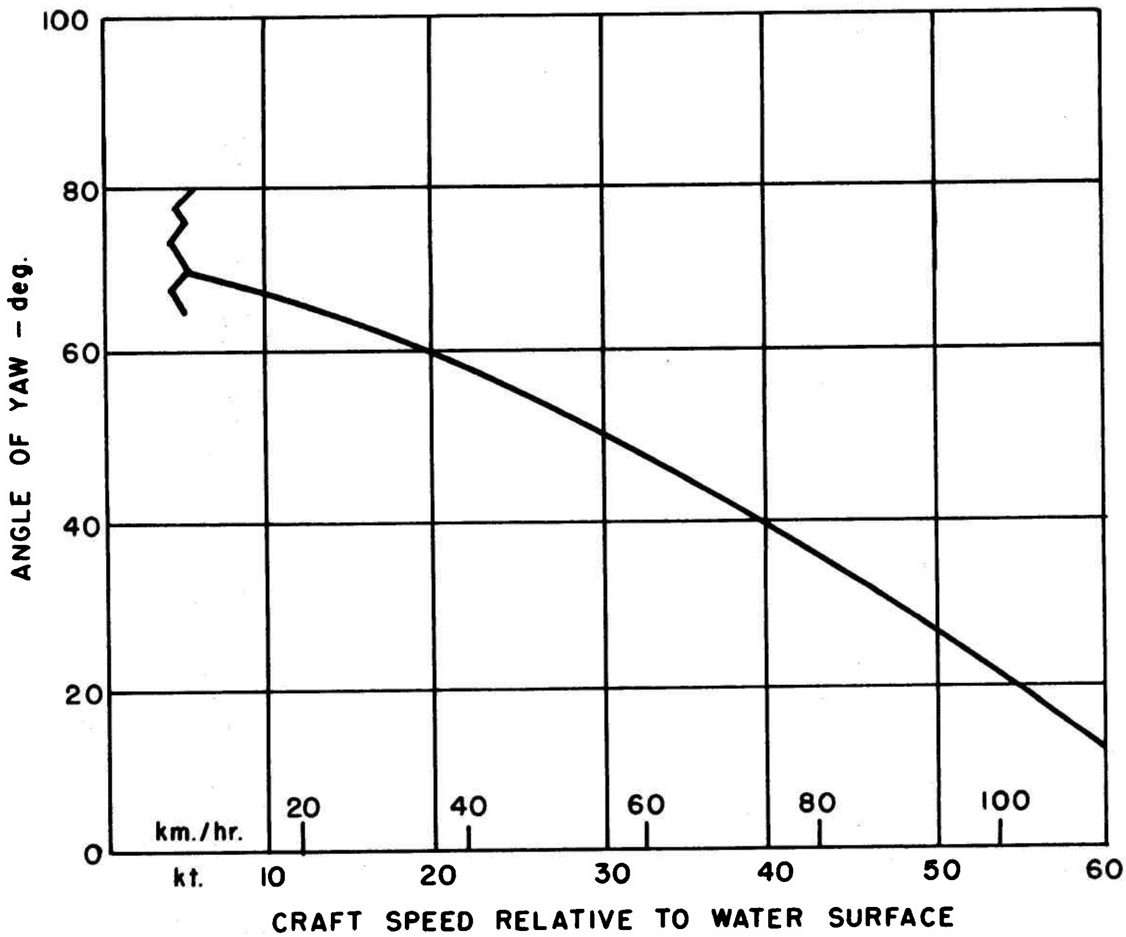

FIGURE 2 - Speed v. Yaw Angles

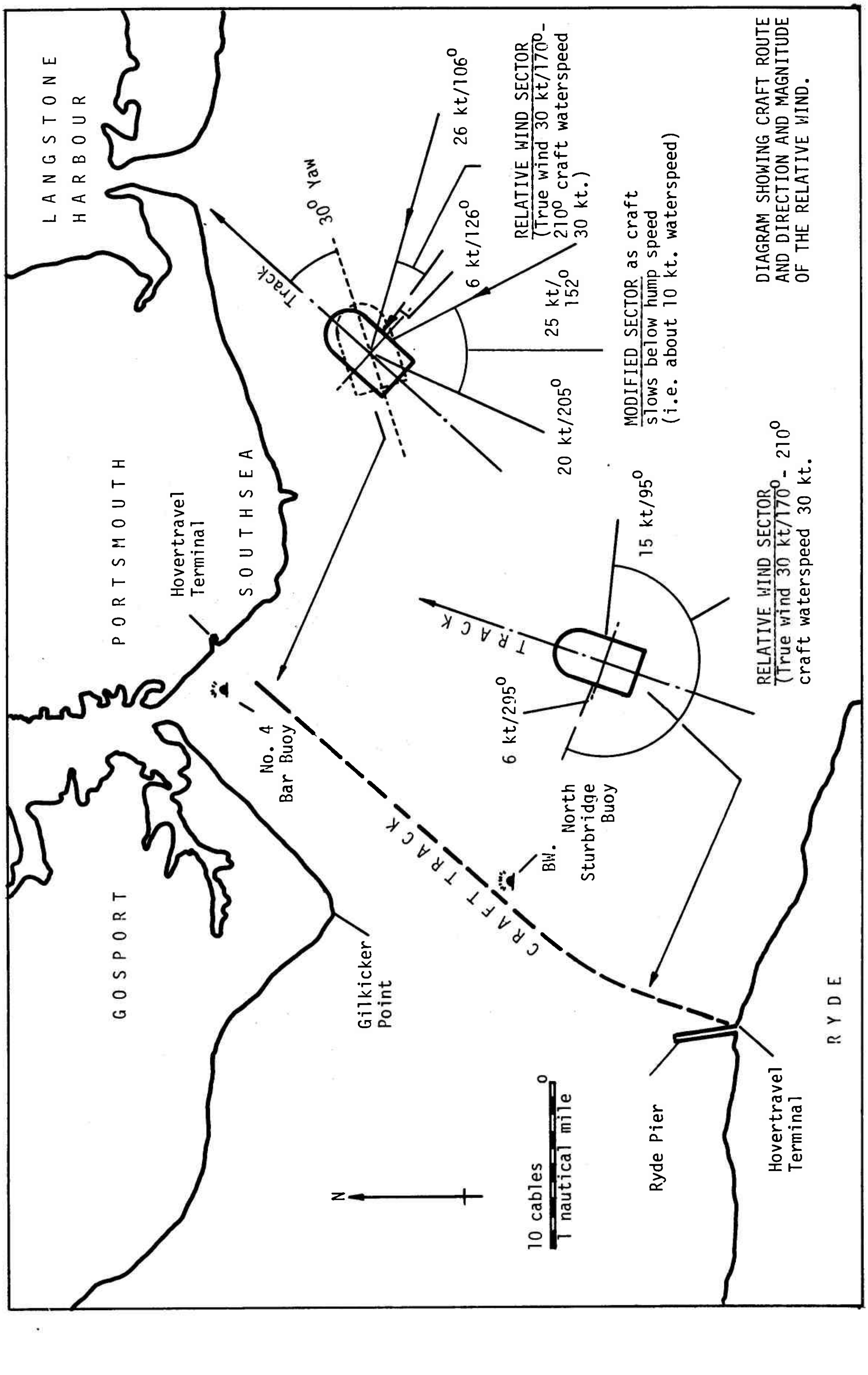
L A N G S T O N E
H A R B O U R
P O R T S M O U T H
S O U T H S E A
Hovertravel
Terminal
G O S P O R T
Gilkicker
Point
R Y D E
Ryde Pier
Hovertravel
Terminal
No. 4
Bar Buoy
BW.
North
Sturbridge
Buoy
C R A F T   T R A C K
Track
30° Yaw
26 kt/106°
6 kt/126°
25 kt/
152°
20 kt/205°
RELATIVE WIND SECTOR
(True wind 30 kt/170°-
210° craft waterspeed
30 kt.)
MODIFIED SECTOR as craft
slows below hump speed
(i.e. about 10 kt. waterspeed)
15 kt/95°
T R A C K
6 kt/295°
RELATIVE WIND SECTOR
(True wind 30 kt/170° - 210°
craft waterspeed 30 kt.
DIAGRAM SHOWING CRAFT ROUTE
AND DIRECTION AND MAGNITUDE
OF THE RELATIVE WIND.
10 cables
1 nautical mile
0
N

FIGURE 3

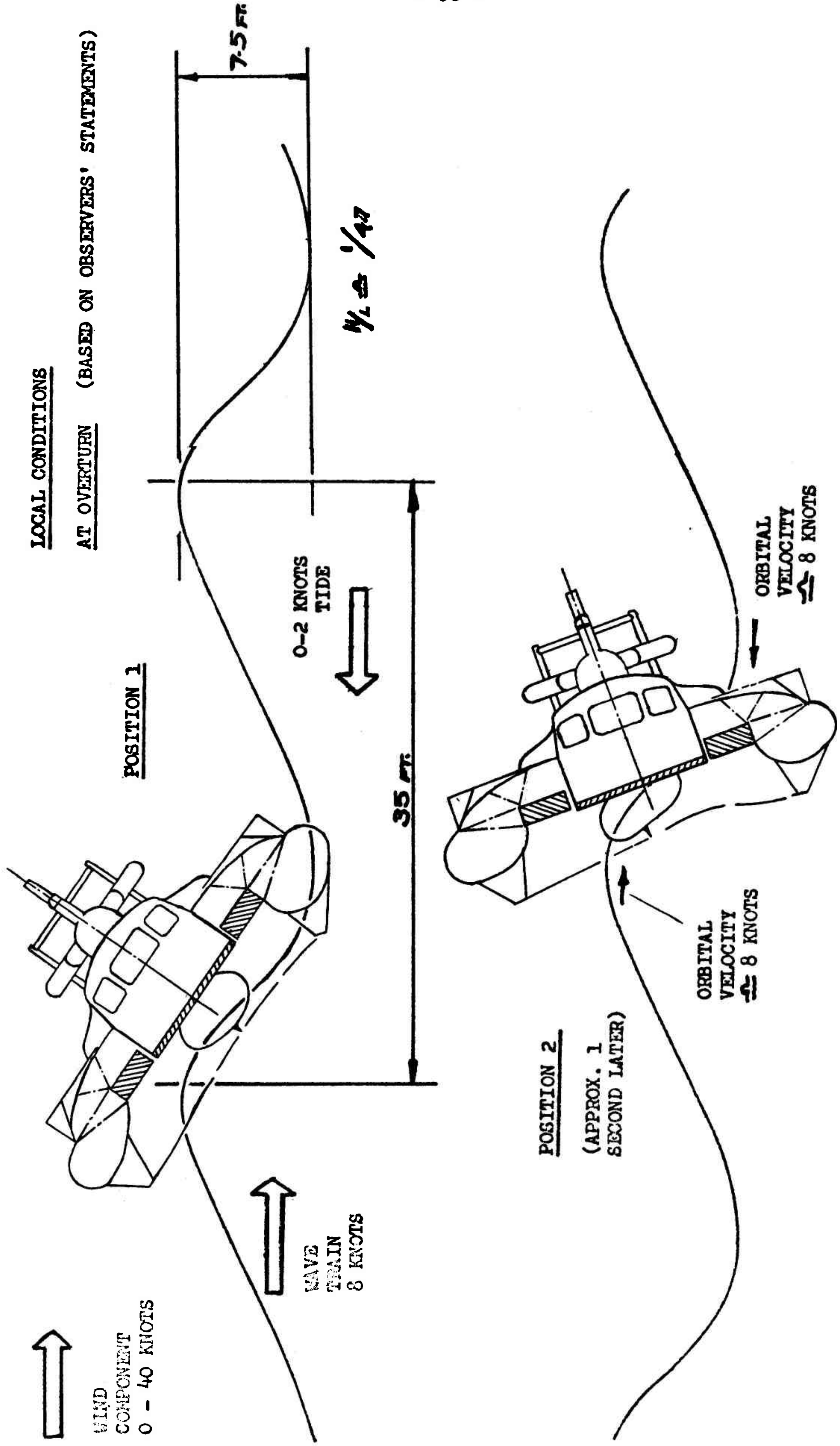
LOCAL CONDITIONS
AT OVERTURN (BASED ON OBSERVERS' STATEMENTS)
7.5 FT.
H/L ≏ 1/4.7
POSITION 1
0–2 KNOTS
TIDE
35 FT.
ORBITAL
VELOCITY
≏ 8 KNOTS
ORBITAL
VELOCITY
≏ 8 KNOTS
POSITION 2
(APPROX. 1
SECOND LATER)
WAVE
TRAIN
8 KNOTS
WIND
COMPONENT
0 – 40 KNOTS

FIGURE 4

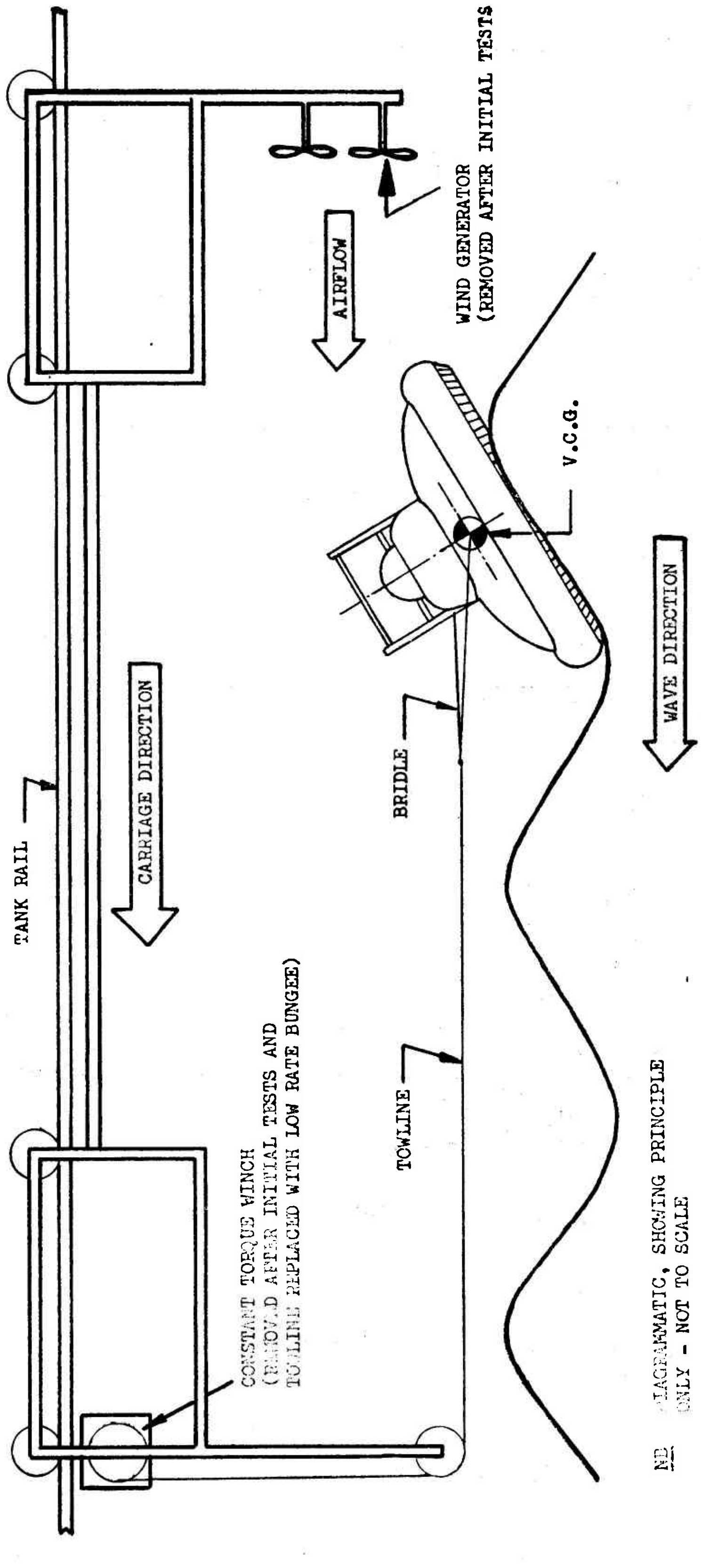

FIGURE 5 - Diagram of Beam Towing Rig 1/75 Scale Model 105

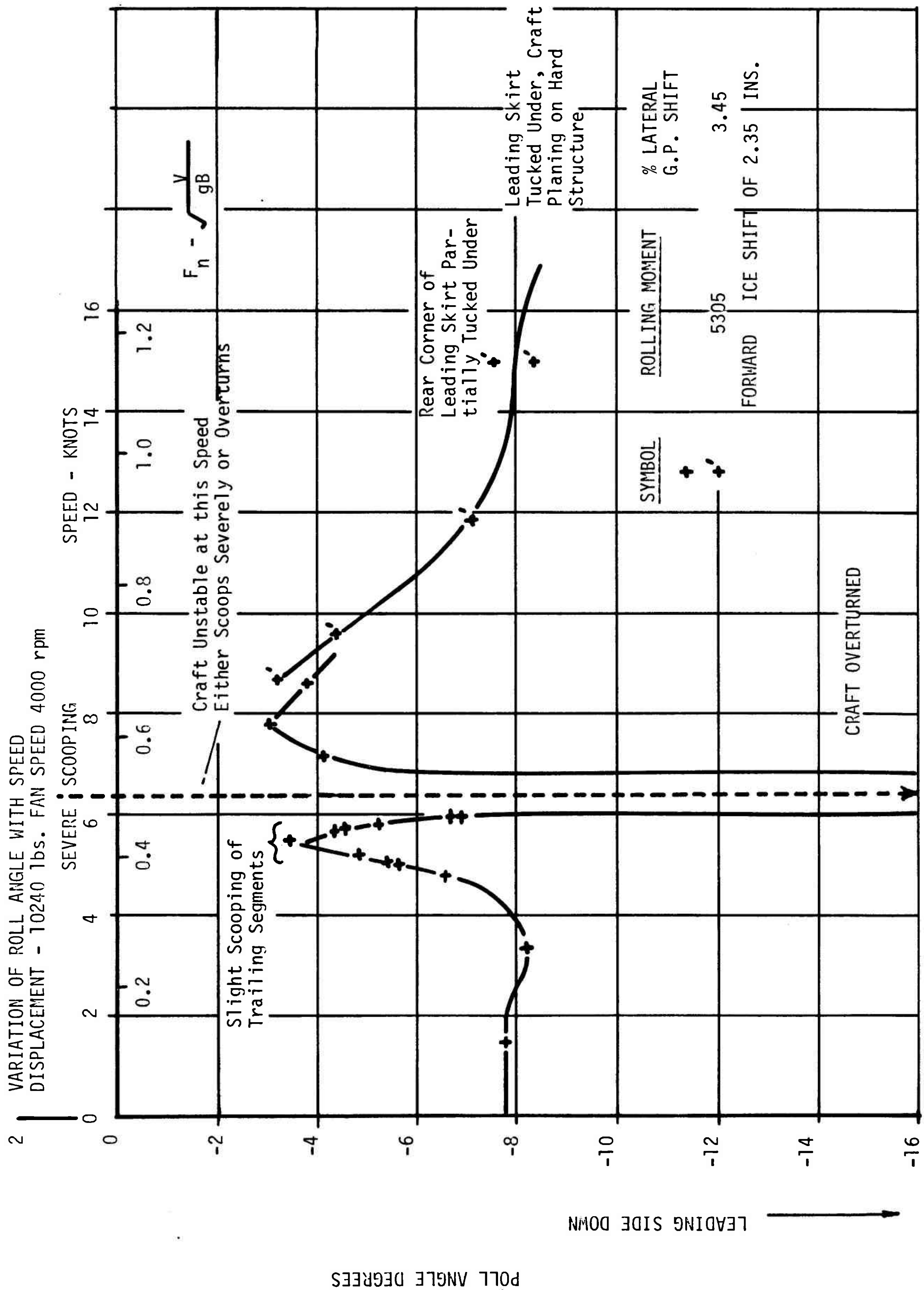
VARIATION OF ROLL ANGLE WITH SPEED
DISPLACEMENT - 10240 lbs. FAN SPEED 4000 rpm
SPEED - KNOTS
$F_n = \frac{V}{\sqrt{gB}}$
SEVERE SCOOPING
Craft Unstable at this Speed
Either Scoops Severely or Overturns
Slight Scooping of
Trailing Segments
Rear Corner of
Leading Skirt Par-
tially Tucked Under
Leading Skirt
Tucked Under, Craft
Planing on Hard
Structure
SYMBOL
ROLLING MOMENT
% LATERAL
G.P. SHIFT
5305
3.45
FORWARD ICE SHIFT OF 2.35 INS.
CRAFT OVERTURNED
LEADING SIDE DOWN
ROLL ANGLE DEGREES

FIGURE 6

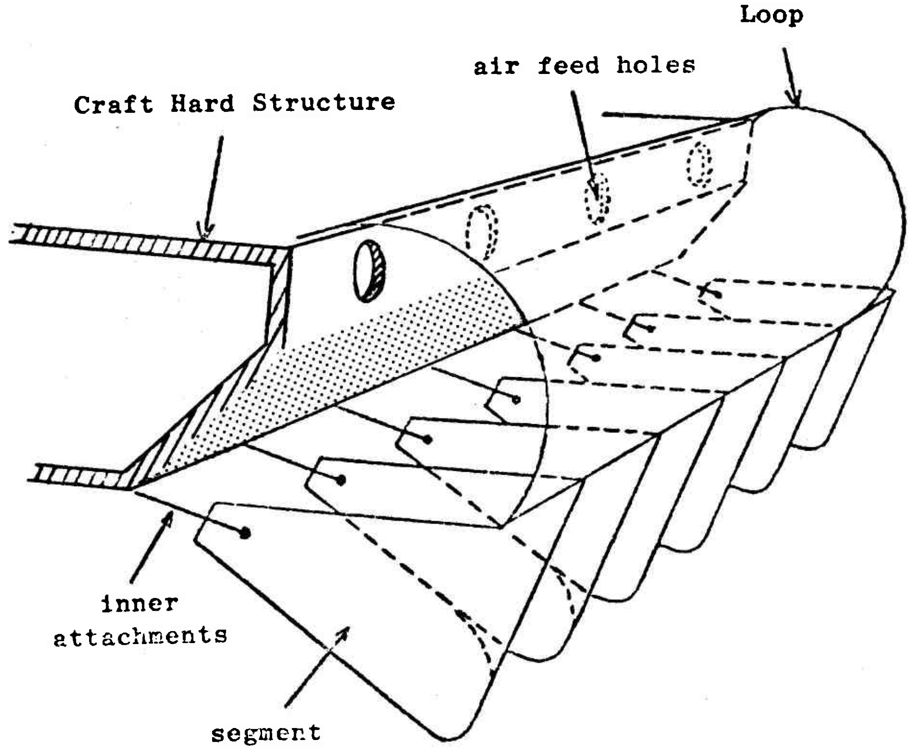

FIGURE 7 - HD2 Hull and Air Feed Arrangement

Mr. C. Mudie (Chairman)	ARB Hovercraft Committee
Mr. T.F. Arlotte	British Hovercraft Corporation Ltd.
Mr. A.E. Bingham	Vosper Thornycroft Ltd.
Sqn. Ldr. J.R. Blatch	DOI (RR3)
Mr. J.E. Rapson	Hovercraft Development Ltd.
Mr. J.R. Richardson	NPL Division of Maritime Science
Captain C.G. Sadler	DOT Marine Division
Mr. E. Tattersall	Hovermarine Transport Ltd.
Mr. R.L. Wheeler	British Hovercraft Corporation Ltd.
Mr. J.W. Addington	CAA
Mr. J.G. Wraith	CAA

FIGURE 8 - List of Committee Members

Sectional Geometry Parameters	Comment	Current Practice
$\frac{z_H}{x_H} = \frac{\text{Hinge vert. spacing}}{\text{Hinge horiz. spacing}}$	High value favourable	0·15 to 1·0
$\frac{p}{x_H} = \frac{\text{Bag perimeter}}{\text{Hinge horiz. spacing}}$	High value favourable at lower pressure ratios (p_B/p_c)	1·75 to 3·5
$\frac{b}{x_H} = \frac{\text{Cushion beam}}{\text{Hinge horiz. spacing}}$	Low value favourable	5·0 to 7·5
Percentage finger depth	Low value favourable, in theory, but some minimum value (> 20%) probably optimum in practice, due to better drag characteristics of finger than bag, even on purely beam-on considerations	
Overall Skirt Geometry and Craft Parameters		
Compartmentation	Centre keel, with differential pressure in roll favourable, unless p_B/p_c for leading sideskirt becomes low and z_H/x_H and/or p/x_H are low.	
$\frac{H_{SK}}{b} = \frac{\text{Skirt Depth}}{\text{Cushion Beam}}$	Low value favourable	0·10 to 0·20
$\frac{p_B}{p_c} = \frac{\text{Bag pressure}}{\text{Cushion pressure}}$	High value favourable	1·0 to 2·0
C_Δ = Cushion loading	High value favourable	0·01 to 0·03
$\frac{b.t.c}{H_{SK}} = \frac{\text{Buoyancy tank clearance}}{\text{Skirt depth}}$	High value favourable	0·8 to 1·1
$\frac{b}{l_e} = \frac{\text{Cushion beam}}{\text{Effective cushion length}}$	Low value favourable, in conjunction with H_{SK}/b and C_Δ but only $\sqrt{b/l_e}$ is as powerful as these.	0·4 to 0·75
Wetting drag coefficient	Low value favourable, but unlikely to be very different from model value, i.e. of order 0·01.	

NOTE: The above statements and numerical ranges, which reflect design practice for several current craft, are provided for general guidance and not as design rules or limiting values. An overall configuration involves a compromise choice of all the factors, and may be satisfactory even if one or more factors are at the least favourable end of the range. A system of overall assessment is duscussed in Refernce 4.

FIGURE 9 - Design Factors Affecting
Leading Sideskirt Tuck-under Boundary

Parameter	Comment	Current Practice
$7 \quad \frac{\partial(\Delta p/p_c)}{\partial \phi} - \frac{h_G}{b}$ = Differential pressure rate less CG height moment parameter	A high value is favourable in this context, but will be offset by an adverse adjustment to the tuck-under merit if hinge spacing and bag perimeter ratios are not good (unless initial pressure ratio is high).	–0·3 to 0·6
$\frac{b.t.c}{H_{SK}} = \frac{\text{Buoyancy tank clearance}}{\text{Skirt depth}}$	The importance of this parameter is modified by the size of the 'drag moment' parameter, but a high value is favourable.	0·8 to 1·1
$\frac{h_G/b}{C_\Delta} = \frac{\text{CG height ratio}}{\text{Cushion loading parameter}}$	Drag moment parameter. Low value favourable.	10 to 25
$\frac{p}{x_H} = \frac{\text{Bag perimeter}}{\text{Horiz. hinge spacing}}$	Affects beam increase. High value favourable.	1·75 to 3·5
$\frac{p_B}{p_c} = \frac{\text{Bag pressure}}{\text{Cushion pressure}}$	Affects bag pressure moment. High value favourable.	1·0 to 2·0
$\frac{b}{x_H} = \frac{\text{Cushion beam}}{\text{Horiz. hinge spacing}}$	Relates skirt contact moment to cushion beam dependent and other moments. Low value favourable.	5·0 to 7·5

NOTE: The above statements and numerical ranges, which reflect design practice for several current craft are provided for general guidance and not as design rules or limiting values. An overall configuration involves a compromise choice of all the factors, and may be satisfactory even if one or more factors are at the least favourable end of the range. A system of overall assessment is discussed in Reference 4.

FIGURE 10 - Design Factors Affecting Craft's Reserve against Capsizing (up to Tuck-under Point)

LOW TEMPERATURE EFFECTS ON THE ABRASION BEHAVIOUR OF COATED FABRICS

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A.A. Smailys, Research Assistant
University of Toronto
Institute for Aerospace Studies

ABSTRACT

Coated fabric materials typical of those used in ACV skirt systems were subject to abrasion at temperatures varying from 75°F to -30°F for varying lengths of time. Abrasion resistance was measured in terms of the amount (mass) abraded, the maximum depth of wear and the residual tensile strength as a function of temperature. These results were then compared with data obtained at room temperature.

INTRODUCTION

Since the early fifties when Christopher Cockerell first promulgated the idea of placing a layer of air between a boat and the surrounding water to reduce skin friction, the concept of air cushions has come a long way. Still the full potential of air cushions is far from being fully realized. What started at first with two tin cans and a vacuum cleaner has now developed into hovercraft varying from single passenger types to sizes capable of carrying large multi-ton cargos. The idea of air cushions is also being applied to such things as hovertrains, landing systems for aircraft, moving heavy loads over soft ground or bridges that cannot sustain large point loads and mine-detecting apparatus that stays at least six inches off the ground. Yet it is doubtful that the use of air cushions could have gone beyond the first few prototype hovercraft that were built if it were not for the introduction of a flexible skirt to the hovercraft in 1959. Besides increasing the obstacle clearance of the hovercraft hard structure, the flexible skirt reduced the power required to maintain the air cushion and thus made the hovercraft economically feasible to operate. With the skirts, the hovercraft's performance was improved remarkably and with the reduced power requirement, the size of the hovercraft grew steadily. It is also the skirt concept that is making possible such things as the landing system for aircraft, which will then be "fully invented" according to Thomas Edison who once said, "The airplane will remain only half invented until the day it can take off and land without runways".

With the increasing use of air cushions, and thus skirts, the conditions under which the skirts have to survive vary considerably. Hovercraft now operate anywhere from the hot jungles of South America to Canada's cold Arctic. Despite such a wide range of temperatures to which the skirt material is subjected, no investigation (to the best of our knowledge) has been carried out on the effect that temperature has on the abrasion resistance of skirt materials, although some studies have been done at room temperature (see Ref. 1 for example). Therefore this report should provide some useful guidance to those concerned with the effect of low temperatures on the abrasion behaviour of skirt materials, particularly in terms of their residual strength.

The first skirt materials manufactured consisted of a cotton weave that was coated with natural rubber. Since then, the manufacture of skirt materials has advanced to the use of various weaves of different materials including such ones as 'basket', 'rip-stop', and 'twill' weaves utilizing materials that are typically nylon, but also include polyester, nomex, PRD 49, fiberglass and even stainless steel. The modern materials used for the elastomeric matrix are synthetic rubbers such as neoprene, nitrile and butyl, for example. The material investigated in this report consisted of a 'basket' weave of nylon (two different weights) with a matrix of polychloroprene rubber.

MECHANISM OF ABRASION

The mechanism of abrasion that occurs depends on the conditions under which the friction unit operates. The simplest type of abrasion is wear which generally occurs when there is friction between rigid materials. The process that takes place in this type of abrasion results from sharp edges on the rough surface of the abradant wearing away the surface layer of the material. For this to occur, not only should the abrading surface and the material be rigid but also the friction between both must be above a certain critical point. This type of abrasion can be recognized by the presence of scratches on the surface of the material in the direction of abrasion.

Another type of abrasion is called "wear by roll formation". This occurs when a highly elastic material is abraded by a surface that is not very rough. There must also be a relatively high coefficient of friction between the two surfaces. In this type of abrasion, the elastic material being abraded is stretched by the abrading surface. If, however, the material does not have the strength to reach the point where the two surfaces begin to slip, it will crack perpendicular to the direction of the force. This then results in the gradual tearing of the material. The material that is torn off then starts to wind into a roll due to the relative motion between the two surfaces. Once these rolls of material are torn off, new ones are formed by the continuous tearing of the material. This type of wear usually requires the material being abraded to have a low tear strength. For the case of rubber, the heating created by the friction may reduce the tear strength of the rubber sufficiently to produce this wear mechanism. In some instances, "resinification" of the surface of the rubber results, thus increasing the friction between the two surfaces. The resinification of rubber is characterized by the surface becoming tacky.

The surface of a material that has been subjected to wear by roll formation is coarse and has lines of abrasion perpendicular to the direction of motion of the abrading surface. The most obvious indicators of this type of abrasion are the rolls of material that may still be clinging to the abraded surface.

EXPERIMENTAL TECHNIQUE

Materials Tested

To study the effect of low temperature on the abrasion behaviour of coated fabrics, two materials were chosen to be tested. These were designated as AR2 and AR3 in order to be consistent with Sowerby (Ref.1) who had tested samples of the same materials previously at room temperature. Both of these are used primarily as skirt materials for hovercraft. AR2 and AR3 were made of a 'basket' weave of nylon coated with a blend of polychloroprene and natural rubber. The AR2 fabric had a total thickness of .054 inches and AR3 was .126 inches according to the manufacturer's specifications. However, on measuring the thicknesses of both materials, it was found that they varied from these values. Therefore, in order to have maximum accuracy in the data, each specimen was measured individually before testing. The specifications obtained from the manufacturer are shown in Table 1 and the averages of the actual properties measured are shown in Table 2.

Since both the materials AR2 and AR3 have directional properties and all previous testing was done in the warp direction, then for comparative purposes these tests were also conducted in the warp direction. It should be noted that these results are also applicable to the fill (cross-wise) direction in terms of abrasive resistance of the elastomer coating although tests involving the residual strength of the material are directionally dependent.

Testing Apparatus

The complete set-up of the abrasion apparatus is shown in Figure 1. This apparatus had originally been used for testing specimens at room temperature (Ref. 1) and consisted of a plexiglass drum which was covered with an abrasive surface against which specimens were abraded by revolving the drum. The abrasive used was Tri-M-ite 80E Silicon Carbide sandpaper which was attached to the drum by means of several metal plates that were screwed down on to the edges of the sandpaper as can be seen in Figure 2. The material to be abraded was then held against the drum by means of a "Bulldog" clip attached to the top of the specimen and another to the bottom of the specimen with a two ounce weight on it. The weight was there to maintain a constant pressure on the specimen. To keep the specimen from moving to the sides, the wire to which the weight was attached was threaded through a hole in a part of the structure so that it could only move in the vertical direction as can been seen in Figure 2. The drum was then driven at 430 RPM by a 1/2 hp electric motor by means of a belt drive. This rotational velocity corresponded to a linear abrasive velocity of 18 mph.

The pressure under which the specimen was abraded can be calculated from the geometry of the configuration shown in Figure 3. Assuming that the only force on the specimen was created by the weight W, the pressure between the specimen and the abrasive surface is given as

$p_c = \frac{W}{Rb}$. By using the values given in Figure 3 and assuming that ℓ_c is a straight line, p_c was estimated to be 0.012 lb/in^2. The fact that p_c is a constant means that the abrasion should be uniform over the contact area, which in reality does not occur as will be discussed later.

In order to perform the abrasion tests at low temperatures, the enclosure was insulated with two to four inches of styrofoam keeping one side removable for easy access to the drum and the specimens. To measure the temperature inside the chamber, two indoor-outdoor thermometers were placed with the "outdoor" sensors mounted inside the chamber at mid-height adjacent to the specimens being tested.

The chamber was cooled down to the desired temperature by using liquid nitrogen. This was accomplished by applying compressed nitrogen from a gas bottle to the tank containing the liquid nitrogen at pressures varying from 1 to 5 psi, depending on what temperature was desired in the test. The tank was sealed off with a rubber stopper so that as the pressure was applied through one hose at the top, the liquid nitrogen was forced out another hose to the chamber to be cooled. This hose was then split into two separate sections by means of a Y joint, and each end was attached to an end of a copper pipe. The copper pipe, which had orifices along the bottom edge, was positioned inside the chamber and as the liquid nitrogen entered the pipe from both ends, the pressure built up thus forcing out cold gas and liquid into the chamber. The temperature was thus controlled by varying the pressure applied to the tank of liquid nitrogen.

To measure the maximum depth abraded on each specimen, a micrometer was used. In addition, profiles were made of the abraded surface using a linearly variable displacement transducer (LVDT) apparatus shown in Figure 4, which was capable of measuring surface deviations as small as 0.0005 in. Figure 5 presents a set of typical abrasion surface profiles which are clearly non-uniform across the specimen width.

Prior to testing the samples to determine their residual tensile strength, each was cut into the standard ASTM "dog-bone" shape to ensure that the specimens failed in the abraded area and not close to the gripping jaws of the test machine which so often happens. The tensile machine used was a Tinius-Olsen Universal Testing Machine with an accuracy of ±1/2 lb. on the 600 lb. scale and ±2 lbs. on the 2400 lb. scale.

Test Procedure

Before the abrasion testing began, all of the specimens were prepared by cutting the material into strips 1-1/2 in. wide by 9 in. long. Since there were no standards set up for abrasion testing of coated fabrics at low temperatures in ASTM D751-73, the technique followed was that used by Sowerby (Ref. 1) in the tests conducted at room temperature. Although different weights were employed on the specimens to supply various contact pressures in these tests, only the two ounce weight was used in order to have constant conditions for the tests at various temperatures. To do the abrasion testing, four specimens (two of AR2 and two of AR3) were placed in the grips and the chamber was then closed and cooled to the desired temperature. The specimens were maintained at that temperature for a period of time to allow them to cool before subjecting them to abrasion. The specimens were then abraded from ten minutes to two hours at temperatures ranging from room temperature (75°F) down to -65°F. The abrasion data for one and two hours at room temperature were taken from Sowerby's results (Ref. 1).

Problems Encountered

During the abrasion process, problems of heating of the AR3 specimens due to friction were encountered which did not occur in the AR2 specimens. These difficulties were prevalent at 30°F and less at 0°F, while at -30°F the heating problem disappeared.

Problems with the abrasive clogging up with rubber and becoming less abrasive as time went on also occurred, particularly at the higher temperatures. However, the rubber could be easily removed from the abrasive by gently rubbing a cloth over it and when the abrasive seemed to lose its roughness, it was replaced (which was every few runs). The loss of abrasiveness, however, was small so that it should not be a significant factor in the final results obtained.

RESULTS

Properties Before Abrasion

The properties of the materials tested as given by the manufacturer are shown in Table 1. On examining the specimens, slightly different values were obtained for the thickness then quoted by the manufacturer. In addition, Sowerby had found that the strength also varied from the nominal stated properties. Thus, for purposes of our calculations, the values used were those given in Table 2. Note that prior to abrasion testing, each specimen was individually measured to determine its actual thickness and the values quoted in Table 2 represent averages.

Abrasion Resistance

The maximum depth of abrasion at different temperatures that occurred in both materials is shown in Figures 6 and 7 as a function of time for both materials AR2 and AR3, respectively. Their relative abrasion resistance at various temperatures (i.e. compared to their room temperature behaviour) is also plotted in Figures 8 to 11 in terms of the abraded mass and maximum depth of wear. Note that although substantial scatter in the data exists, the general trend is towards reduced abrasive wear as the temperature is lowered. The rate of wear probably asymptotes to some nominal constant value beyond a certain temperature due to the transition from a "soft" elastomer to that of a "brittle" material behaviour.

Strength of Abraded Material

All of the specimens were tested to determine their ultimate tensile strength after abrasion and the results were plotted in a non-dimensionalized form in Figure 12 for both materials AR2 and AR3. Most of the data obtained fell within the bounds which were obtained for the abrasion tests at room temperature (see Figure 13). This shows that the relationship between the maximum abraded depth and the residual tensile strength remains the same regardless of the temperature at which the abrasion was done or the mechanism of abrasion (this will be discussed later). For both of these cases, however, the tensile strength tests were conducted at approximately the same temperature (room temperature) so that these curves do not take into account the changes in the tensile strength that may occur with temperature. However, the temperature correction can readily be estimated by obtaining tensile failure data for P_o (the virgin or unabraded specimen strength) as a function of ambient temperature.

TYPE OF ABRASION

As discussed previously, the mechanism of abrasion varies with the material being abraded and the surrounding conditions. In the abrasion of material AR3, both types occurred, namely abrasive wear and wear by roll formation. Differences in the abrasion behaviour of elastomers in particular depend strongly on the temperature. At 75°F, the abrasion was mainly "wear by roll formation" with some abrasive wear. However, as the temperature was lowered, more and more abrasive wear took place. At 0°F, degradation was mainly due to abrasive wear for the short test time of .17 hours but for the longer duration tests, it was about half of each. At colder temperatures, it was all "abrasive wear" with no change observed with the length of time that the specimen was abraded.

The variations that occurred from one type of abrasion to another with temperature were due to the fact that as the temperature was decreased, the stiffness of the rubber material increased. For abrasive wear to take place, the material being abraded must be stiff and for wear by roll formation, the material must be highly elastic. At room temperature the elastomer coating was highly elastic but as the temperature decreased, the elasticity also decreased until at some temperature, the material becomes stiff and brittle. This change in the elasticity of the material results in the change from one mechanism of abrasion to another.

The effect of the lenth of exposure time on the type of abrasion experienced by the material arises from local heating at the interface between the coated fabric and abrading drum. In our tests, no attempt was made to cool the interface as can occur with an actual ACV due to the escaping air. Thus, with the frictional heat build-up, the elastomer surface can become soft and tacky, depending on the ambient temperature. At sufficiently low temperatures, the surface temperature does not appear to increase to such an extent as to cause roll formation and abrasive wear of the brittle material occurs over long periods of time. Varying the coating thickness also has a strong effect on the abrasion behaviour at room (or elevated) temperature conditions, as can be seen in Figures 6 and 7.

CONCLUSIONS

The data obtained showed that temperature has a definite effect on the abrasion resistance of elastomer coated fabrics, lower temperatures resulting in substantially less wear. This effect is the same whether the abrasion is characterized in terms of either the mass loss or maximum depth of wear. Any differences that do appear can be mainly attributed to the fact that the pressure was not uniform over the contact area during testing as evidenced by the observed non-uniform wear profiles.

Temperature also has an effect on the mechanism of abrasion. At temperatures above $0^{o}F$, "wear by roll formation" predominates while below that temperature, abrasive wear takes place. This is also influenced by local heating at the interface which can produce increased abrasion, depending on the ambient temperature.

For design purposes, the strength curve given in this report can be utilized to determine the effect of abrasion on the residual tensile strength of an elastomer coated fabric, independent of how the abrasion was incurred by the material. This abrasion design curve can be regarded as characteristic of coated fabrics and any temperature effects or other environmental degradation can be taken into account by obtaining appropriate tensile failure data on the material in its unabraded state.*

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* The residual strength curve (shown in Figures 12 and 13) was based on different thickness materials. However, the elastomer coatings on each side of the fabric for any given material were nominally equal such that the following relation $t_o = t_f + 2t_e$ (where t_f = fabric thickness) holds approximately true.

REFERENCES

1. "Abrasion Study of Coated Fabrics", by C.I. Sowerby, B.A.Sc. Thesis, University of Toronto, Division of Engineering Science, Faculty of Applied Science and Engineering, 1974.

NOTATION

d	maximum depth of abrasion
d_{rt}	maximum depth of abrasion at room temperature
m_a	specimen mass after abrasion
m_{rt}	specimen mass after abrasion at room temperature
P_a	ultimate tensile strength of abraded specimen
P_o	ultimate tensile strength of unabraded specimen
t_e	thickness of rubber coating
t_o	original total thickness of specimen
T	time of abrasion

TABLE 1

Designation	AR2	AR3
Colour	Black	Black
Coating	Polychloroprene blend	Polychloroprene blend
Fabric	Nylon	Nylon
t_o (in.)	.054	.126
P_o (lb./in.)	450 (min.)	800 (min.)
w (oz./sq.yd.)	43	100

TABLE 2

Designation	t_o (in)	t_e (in)	P_o (lb/in)
AR2	.0543	.004	560
AR3	.1306	.024	855

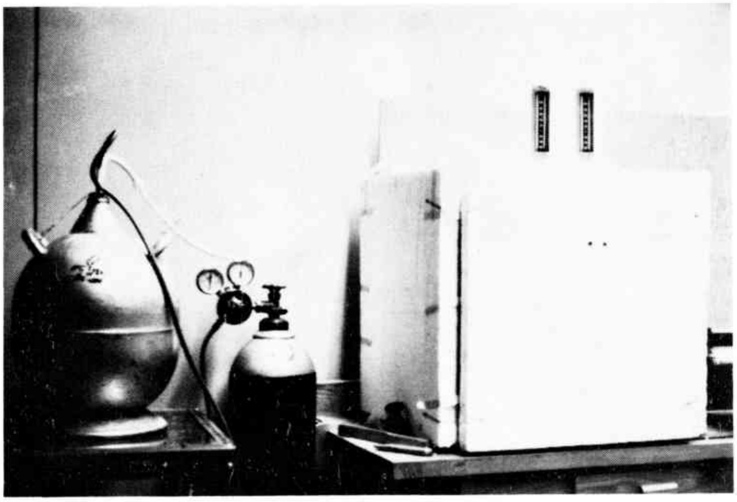

FIGURE 1
Abrasion Apparatus

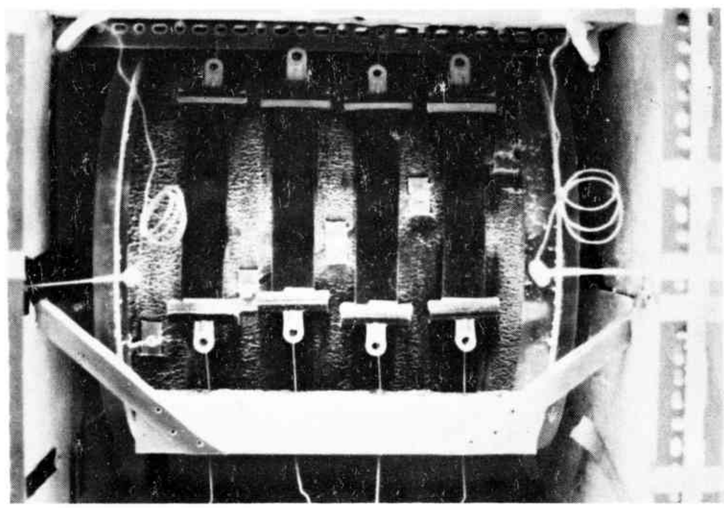

FIGURE 2
Abrasion Drum and Specimens

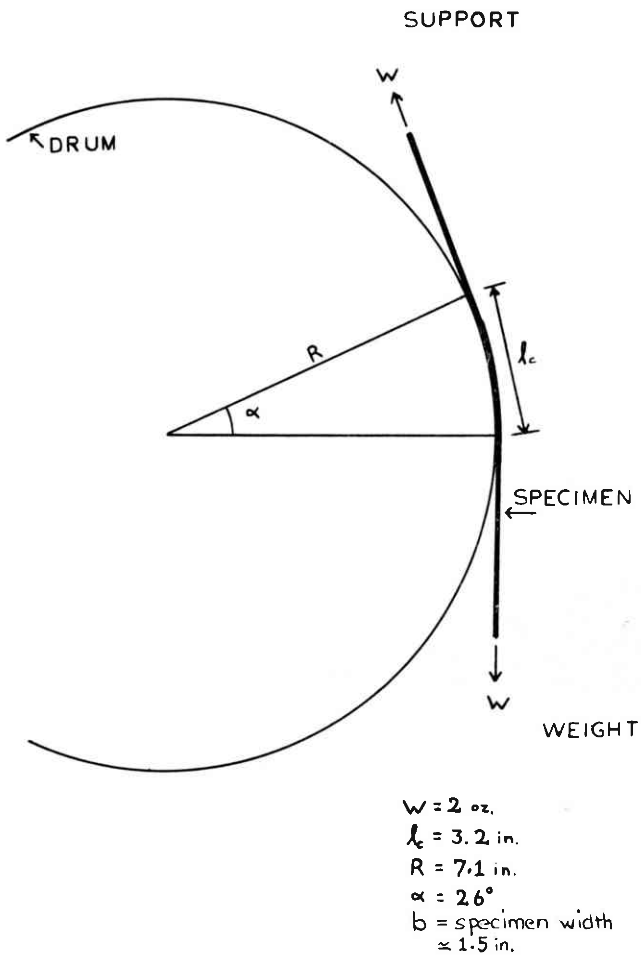

FIGURE 3
Geometry of Abrasion

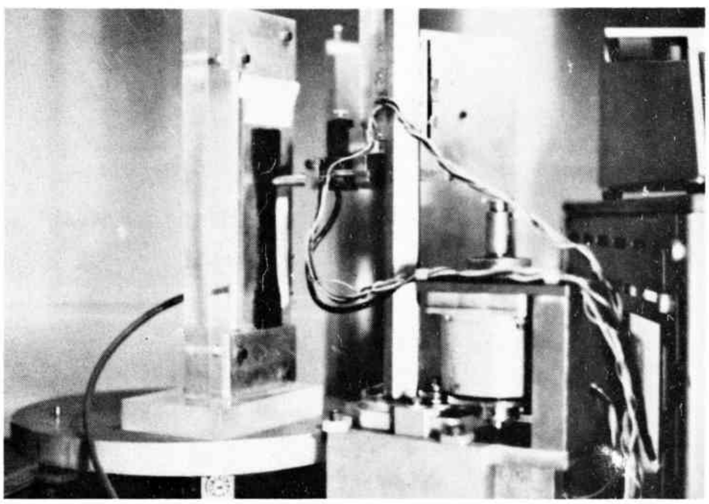

FIGURE 4
Profiling Apparatus (LVDT)

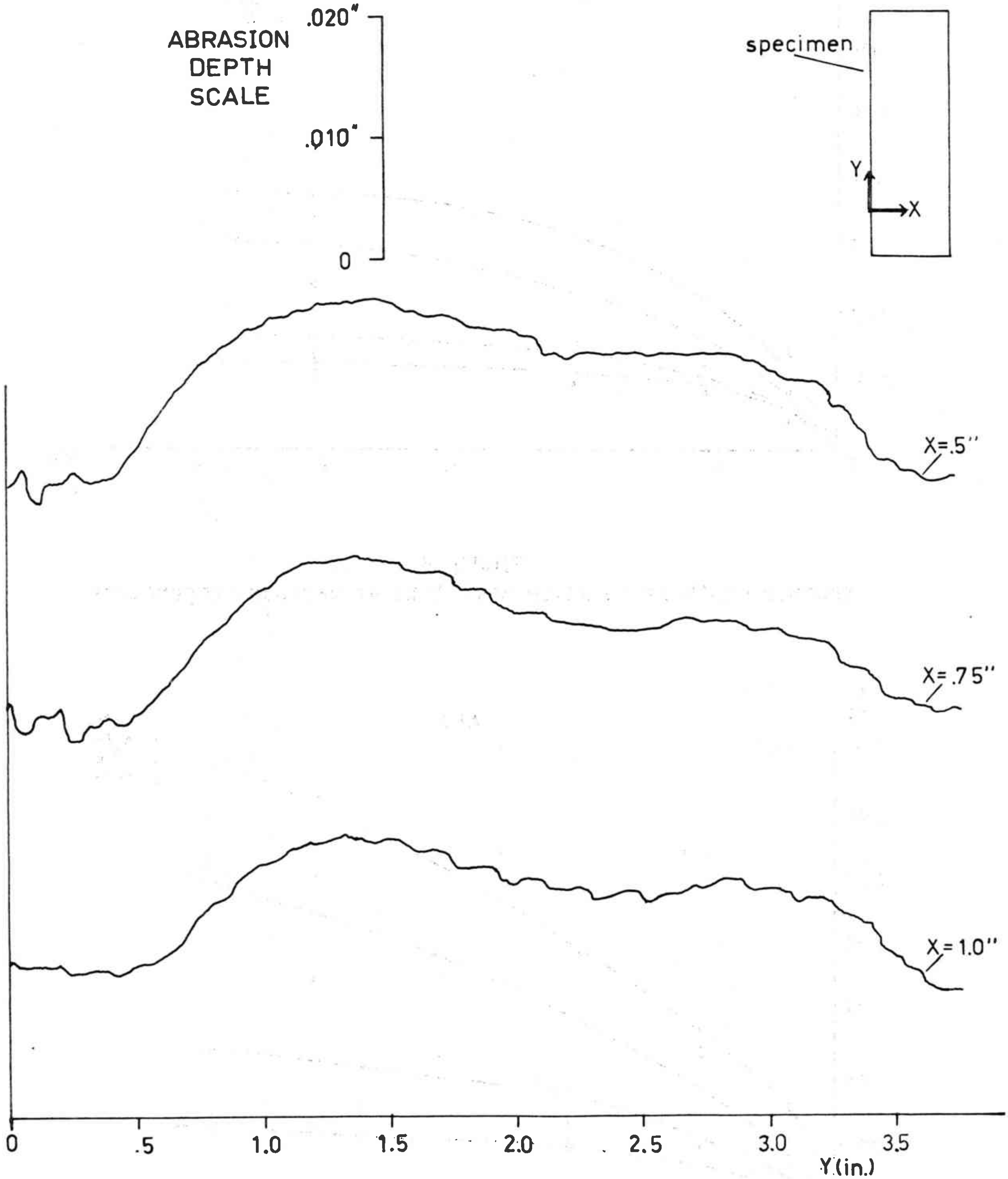

FIGURE 5

Typical Profile - AR2

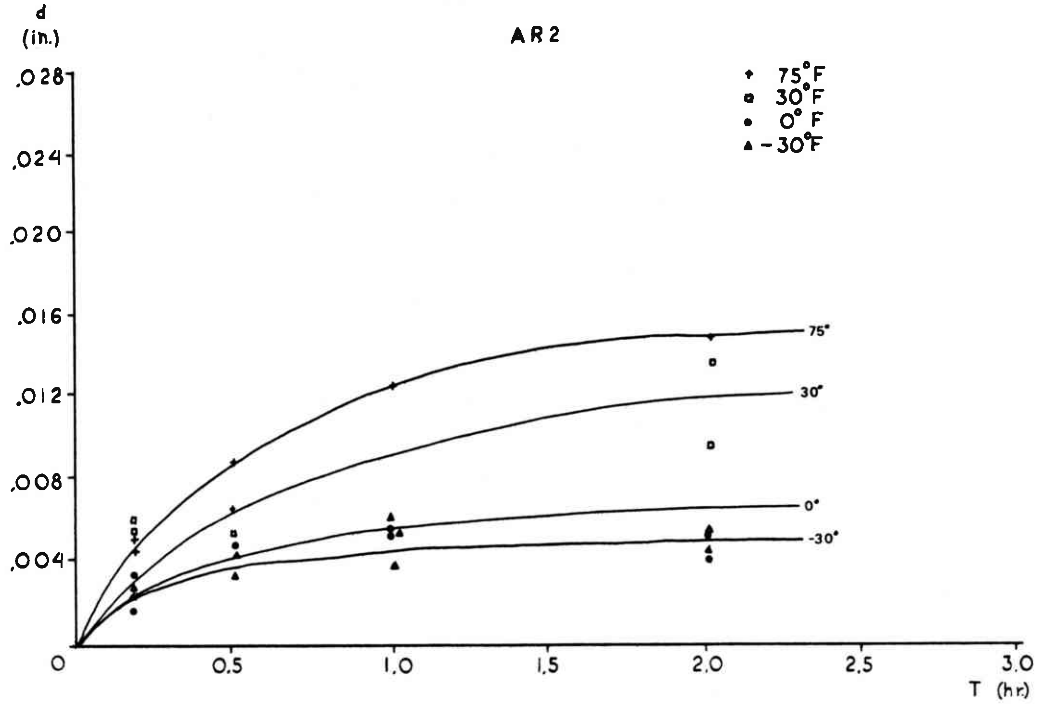

FIGURE 6
Maximum depth of abrasion with time at various temperatures

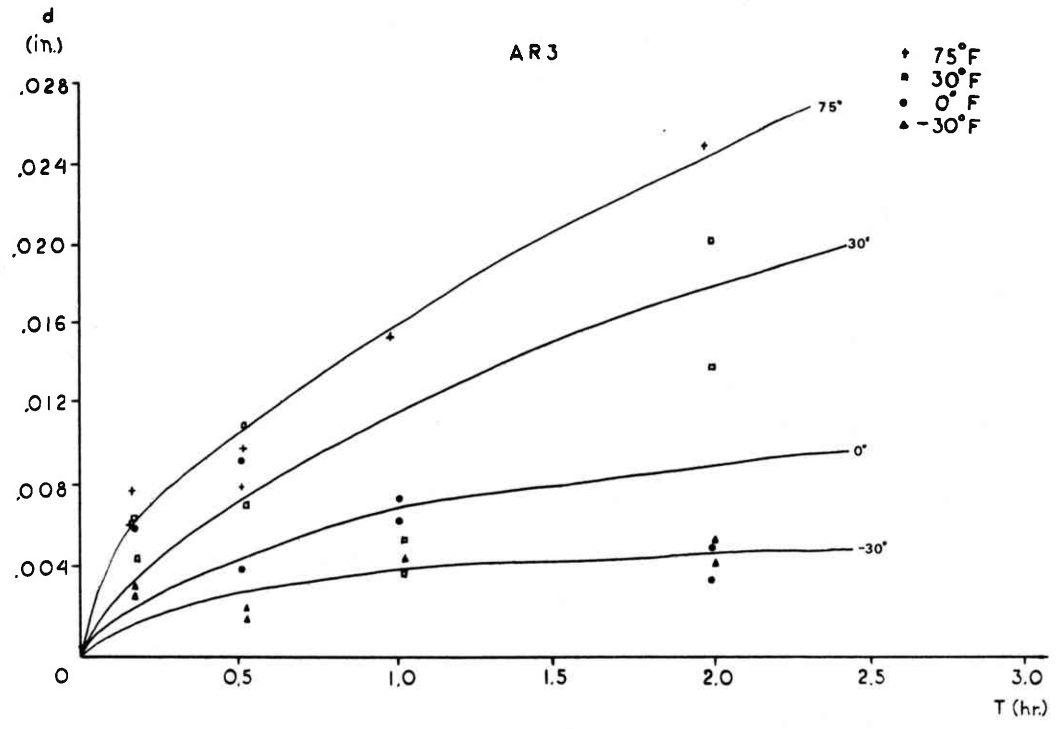

FIGURE 7
Maximum depth of abrasion with time at various temperatures

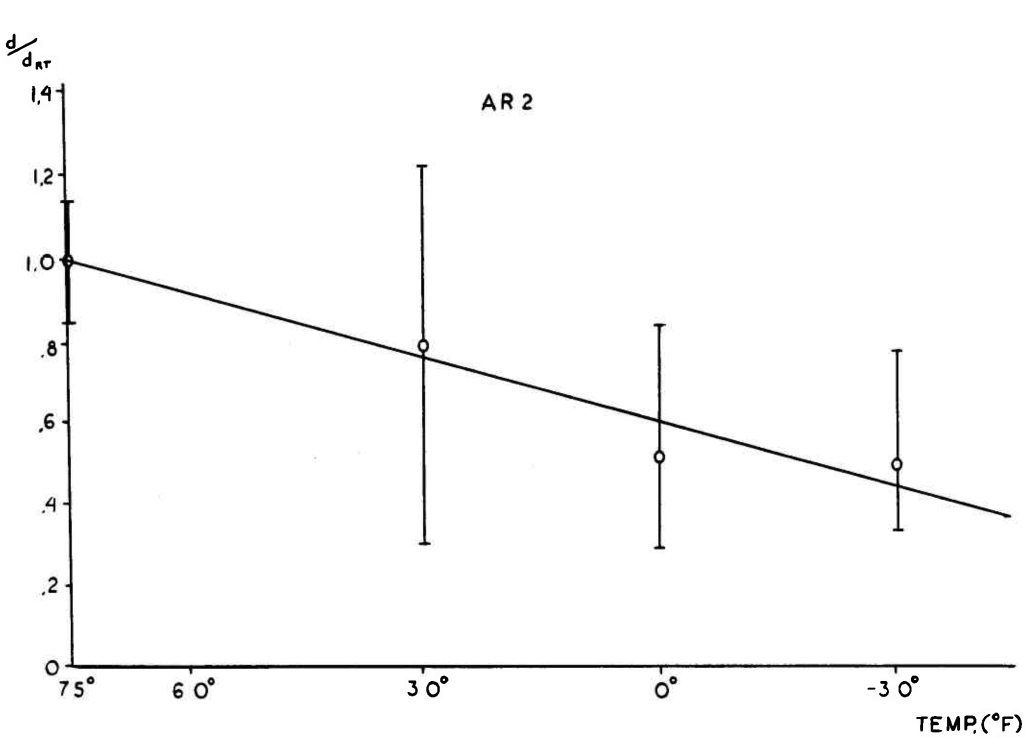

FIGURE 8
Effect of temperature on abrasion resistance

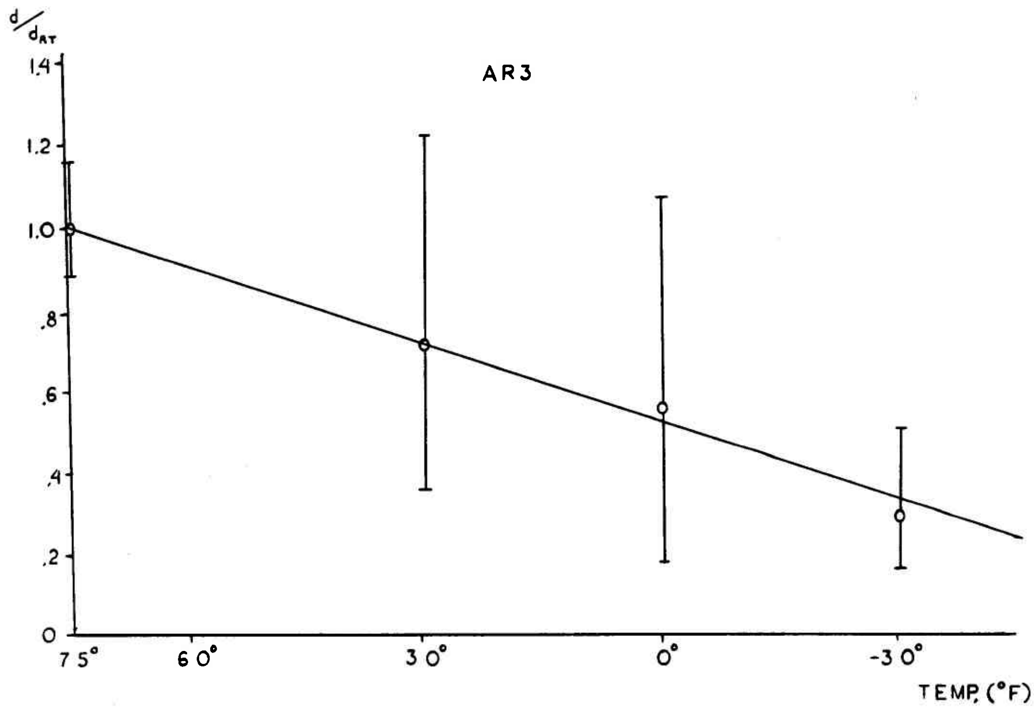

FIGURE 9
Effect of temperature on abrasion resistance

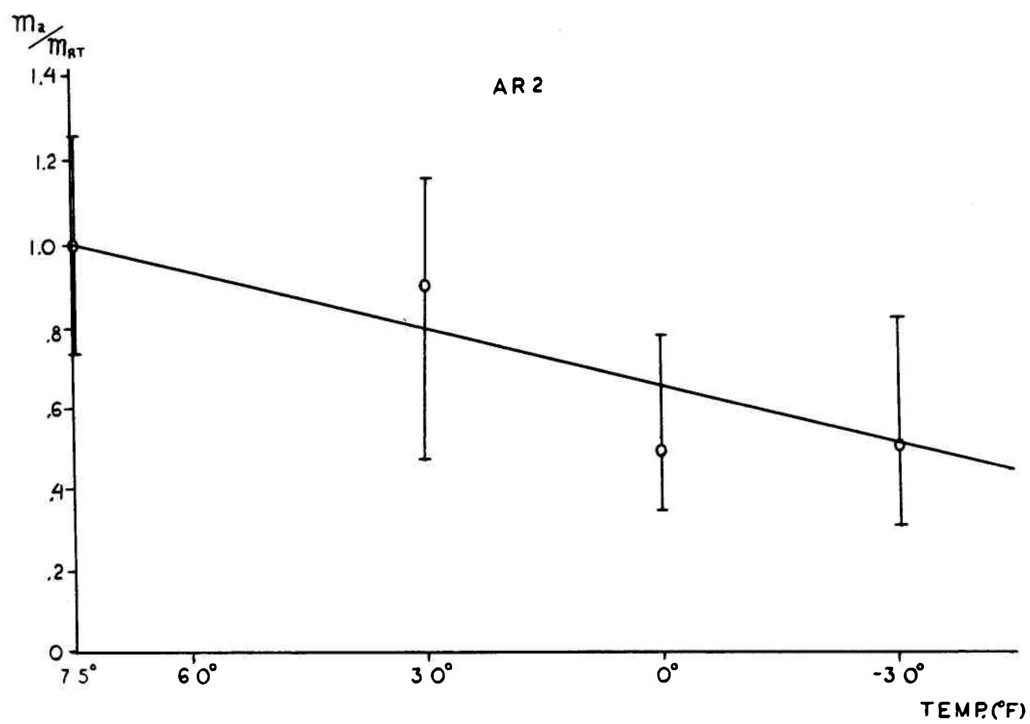

FIGURE 10
Effect of Temperature on Abrasion Resistance

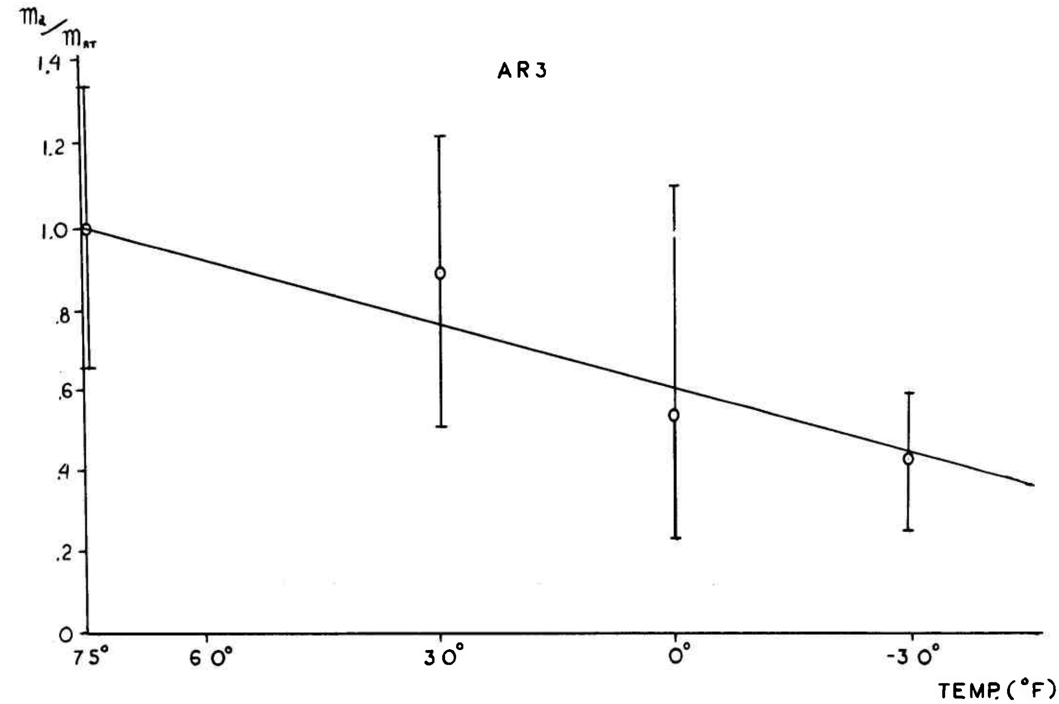

FIGURE 11
Effect of Temperature on Abrasion Resistance

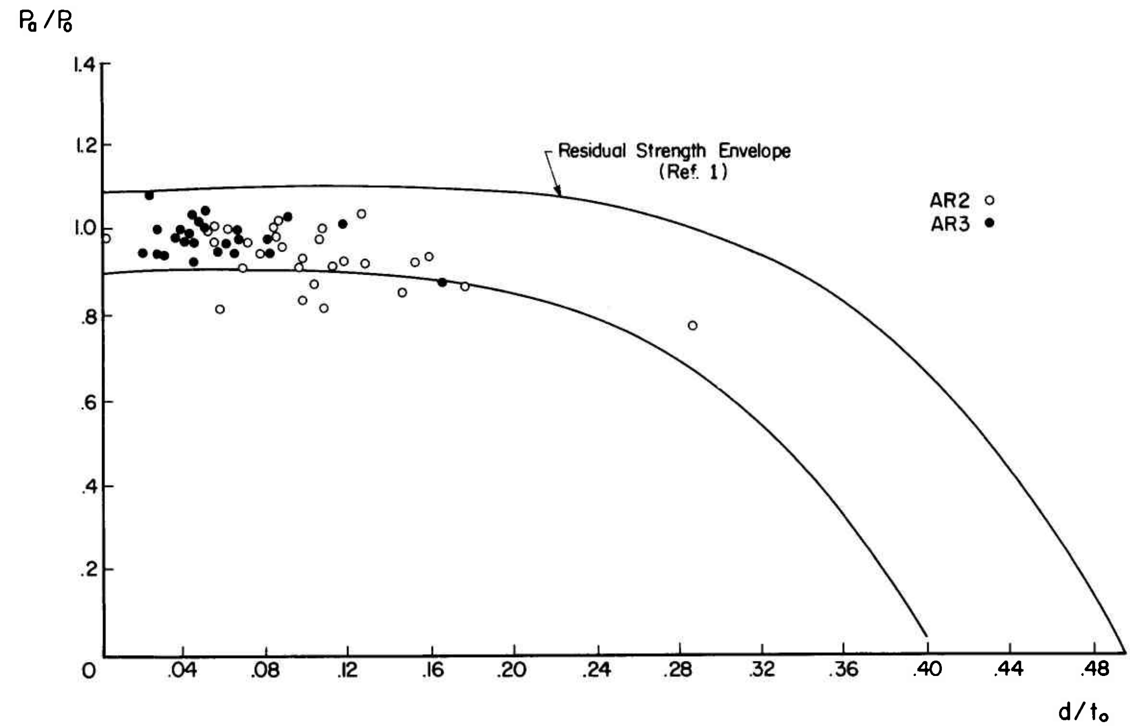

FIGURE 12
Decrease in strength with thickness fraction abraded

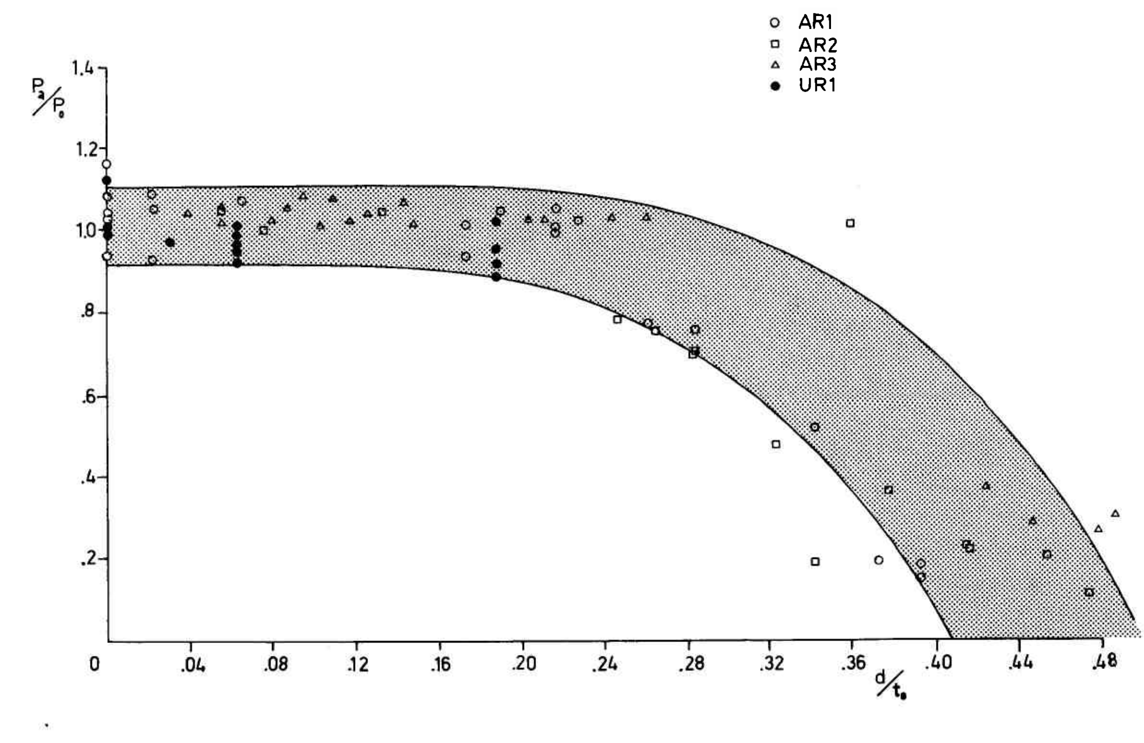

FIGURE 13
Decrease in strength with thickness fraction abraded

TESTS ON THE AIR CUSHION LANDING SYSTEM BUFFALO AIRCRAFT

Captain Tom Clapp
United States Air Force

The Air Cushion Landing System or ACLS Flight Test Program is being conducted by the U.S. Air Force's Systems Command at Wright-Patterson Air Force Base in Dayton, Ohio. The program is jointly sponsored and funded by the Canadian and American governments. During the talk, I will describe the program objectives, describe the system, summarize what we've done and where we are going, and point out some advantages and problem areas.

PROGRAM OBJECTIVES

The objectives are to demonstrate the ACLS principle on a medium size, short take off and landing or STOL transport, to develop the system, to determine operational limits and identify problem areas. Finally, all of the above are being used to develop ACLS design criteria.

THE SYSTEM

The air supply for the trunk is generated by two engines, one on each side of the fuselage. The air is ducted through a diffuser duct and into the trunk. The trunk is of one-piece sandwich construction with a built-in, two-way elastic stretch. Inflated, the trunk measures 14 feet by 32 feet with a footprint of 240 sq. feet. The system is operated at a trunk pressure of 340 PSF which yields a nominal cushion pressure of 135 PSF.

A gas turbine engine mechanically drives a two-stage fan which compresses air for the trunk. Diverter vanes permit the fan air to be exhausted aft in a thrust mode or down into the trunk in the cushion mode.

When the air supply is shut off, the elastic trunk retracts and hugs the contour of the aircraft to yield a streamlined cruise configuration. When air pressure is directed to the trunk, it expands to its inflated shape. Six sets of cushion trim ports, three on each side, are used to vent air from the trunk into the cushion cavity and thereby control the trunk pressure - fan flow relationship as well as cushion pressure. The trunk also has 6800 small holes in the ground tangent area to provide the air bearing. Six parking bladders, three on each side, are used to park the aircraft. The bladders, located inside the trunk, are inflated and the trunk is then deflated around them and the aircraft settles onto the bladders. Cushion brakes are also incorporated with inflatable pillows inside the trunk which inflate proportional to pilot pressure on the brake pedals and push the skid pads onto the ground to provide braking friction.

PROGRAM ACCOMPLISHMENTS

In the flight test program, the ACLS capability has been demonstrated by take offs, landings and taxiing on hard surfaces, grass and snow. Limited obstacles such as craters and steps have been traversed and cold weather effects of the elastic trunk have been examined. The STOL mode of operation has been demonstrated and landing sink rates up to 8 ft/sec (480 ft/min) at a 6^{0} nose up pitch attitude have been demonstrated. This condition is felt to be equal to or more severe than STOL landing conditions.

FUTURE GOALS

We are about to become operational after installing the third trunk. Various types of tests are planned for this new trunk.

A static water test will be conducted to ensure that the aircraft/ACLS will perform an acceptable static hover on water. This is a prerequisite to water operations. If a turboprop engine failed while on the water, we could not take off and a static hover would be required until a boat could tow the aircraft to land. Water touch and go landings with a progressive slow-down in the landing runout down to 20 or 30 knots checking maneuverability and controllability at each lower speed will also be conducted. Then would come water to land and land to water transitions which are the real proof of the water tests. Another series of tests will be obstacles consisting of logs or stumps to one and one half feet in height and craters or ditches to four feet deep by nine feet wide. Any remaining test time will be devoted to demonstrations of the system, supplementing data from previous tests, and/or investigating solutions to trunk flutter and heave problems which are described later. The test program is scheduled to end in March of next year.

SYSTEM ADVANTAGES

Advantages of the ACLS are its ability to operate from unprepared or battle damaged areas. This greatly increases the mobility of an aircraft. An ACLS aircraft has a superior crosswind take off and landing capability as it can operate in a crabbed attitude where a conventional aircraft cannot (except for a crosswind landing gear such as on the B-52). The demonstrated landing sink rates of 8 ft/sec are considerably greater than that experienced in a normal landing. The impact from these landings was comparable to a smooth touchdown in a conventional aircraft. The trunk absorbs most of the impact energy and that not absorbed is spread out over the whole planform of the trunk. This absorption accounts for the reduced aircraft fatigue and ground loads.

Aircraft requiring high flotation landing gear, such as the C-5A or an extremely high gross weight aircraft, could realize a significant weight savings by replacing the landing gear with an ACLS. High flotation gear are very heavy as they require more wheels to distribute the greater aircraft weight. As an example, the Boeing 707 has ten tires and the C-5A has 28.

The battle damage capability is obvious when one considers that with 6800 holes already in the trunk, what difference will a few more holes make? As an example, just before we replaced the No. 2 trunk, there was a football sized hole in the trunk and full system pressure could still be maintained.

PROBLEM AREAS

Some effort has been expended during the flight test phase of this program dealing with technical problems. Foreign Object Damage or FOD has been one of the biggest problems to date. The air supply engines have centrifugal particle separators which work well for the heavier debris but heavy grass tends to clog the inlets. The T-64 turboprop engines are much more susceptible to ingestion resulting from loose dirt, snow and grass being kicked up by the cushion air and sucked into the engine inlets. This is not necessarily an ACLS problem but an aircraft design consideration. We have to be very careful of the area in which we operate. The ingestion problem could be solved by protecting the existing engine installation from the harsh environment with a particle separator to remove the debris from the air. Another option for future ACLS aircraft would be to relocate the engines to a position where the inlet air would be cleaner. A particle separator could also be included.

Another problem is a dynamic flutter of the trunk or buzzing which occurs primarily on hard, smooth surfaces such as asphalt or concrete. When flutter occurs, part or all of the trunk has a high frequency vibration which shakes the whole aircraft and is an unacceptable operating condition. A mechanical fix to the flutter problem solved the flutter but induces a vertical heave or bounce which was unacceptable. Hence, we can only operate on grass or other than a hard surface until these problems are solved.

The aircraft has poor directional control and low roll stiffness at low speeds. Below the flight control effectiveness speed of about 50 knots, the only turning control available is differential power and brakes. This makes the task loading on the pilot to taxi the aircraft much higher than on an aircraft with conventional landing gear.

The low trunk life, in terms of inflation hours, that this program has experienced would not be practical for a production system. A trunk life of what surface ACV's realize would be desirable instead of the just under 50 inflation hours that our No. 2 trunk has logged.

In summary, the ACLS definitely increases an aircraft's capabilities and the feasibility has been demonstrated both on the XC-8A and a LA-4 Light Amphibian. However, improvements are required in the present system. Recommendations for future ACLS designs can be made from the experience gained with the XC-8A.

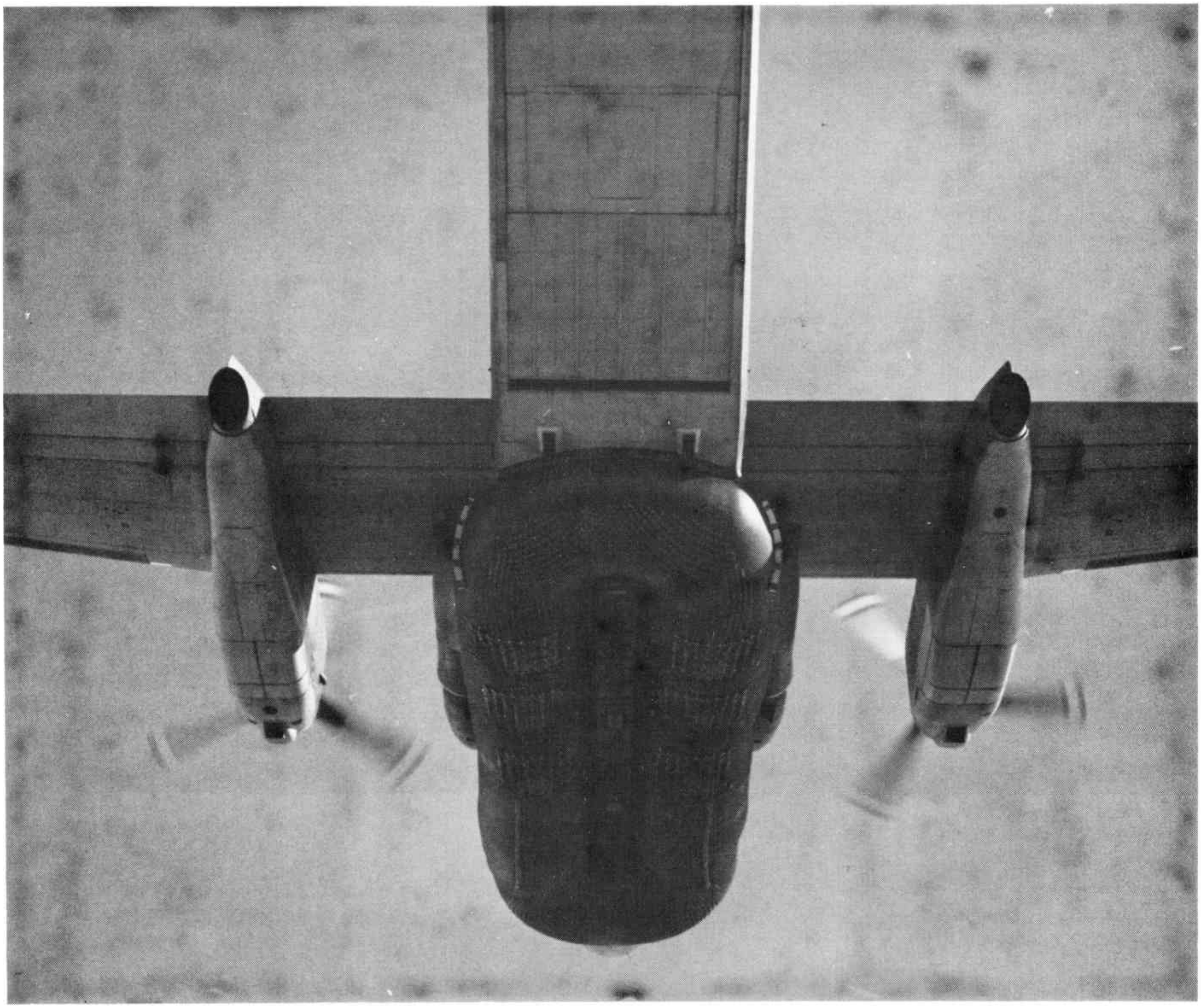

FIGURE 1

In flight, inflated view of trunk system of ACLS equipped XC-8A Buffalo. Items of interest in photo:

1. Approximately 6800 holes in ground tangent area.
2. Six brake skids, three on each side i.. mid to aft section of trunk.
3. Added strakes on aft sides to improve directional stability of the aircraft with the trunk inflated in flight.
4. Added strakes, forward of brake skids, running longitudinally to damp trunk flutter or buzzing.

FIGURE 2
XC-8A taking off from grass surface at Wright-Patterson