An economic evaluation of air cushion vehicles in support of Arctic offshore oil development

D.F. Dickins (presented by J. Laframboise)

DF Dickins Associates Ltd., Vancouver, BC, Canada

RÉSUMÉ

Ce rapport donne les résultats d'une analyse technico-économique sur les aptitudes des aéroglisseurs (existants ou nouveaux) à fournir un support logistique à la mise en valeur des gisements pétrolifères récemment découverts à East Amauligak, dans la partie canadienne de la mer de Beaufort (Dickins and Dickinson, 1986). Une première étude technico-économique s'était penchée sur l'évaluation de deux aéroglisseurs au stade de l'étude conceptuelle et de quatre aéroglisseurs déjà en service, de type commercial. La présente évaluation économique compare des aéroglisseurs nouveaux et existants, utilisés avec un hélicoptère Boeing Chinook 234 MLR. Le scénario de base retenu a été le suivant : transport de 1 500 tonnes de marchandises et de 1 000 passagers par mois, l'année durant, sur une liaison longue de 43 milles marins reliant Tuktoyaktuk (T.N.-O.) au chantier.

L'étude a montré que l'aéroglisseur SR.N4 modifié, de fabrication britannique (actuellement en service), a été le seul capable de répondre aux critères fixés par Gulf concernant le transport de personnes et de marchandises, l'année durant. Un autre aéroglisseur, le AP.1-88, ne convient que pour assurer la relève du personnel en été. Quant aux nouveaux types d'aéroglisseurs, leur exploitation est de loin plus économique que celle de n'importe quel type d'aéroglisseur de charge existant, tout en ayant l'avantage supplémentaire d'être conçus pour opérer dans l'Arctique.

Il a été démontré que les principaux atouts d'un aéroglisseur sont les suivants :

1. Aptitude à évacuer tout le personnel du chantier en un seul voyage, en cas de situation d'urgence.

2. Aptitude à répondre aux demandes imprévues de transport de marchandises équivalant à plusieurs fois la capacité nominale prévue, et ce sans aucun véhicule d'appoint.

3. Insensibilité à la densité de charge, facteur critique d'efficacité dans le cas d'un hélicoptère.

L'étude arrive à la conclusion qu'un aéroglisseur peut assurer fiablement la desserte, l'année durant, du chantier d'East Amauligak, et qu'il permet de réaliser des économies annuelles de plus de trois millions de dollars canadiens de 1986, comparativement à l'hélicoptère mentionné.

AN ECONOMIC EVALUATION OF AIR CUSHION VEHICLES IN SUPPORT OF ARCTIC OFFSHORE OIL DEVELOPMENT

David F. Dickins

DF Dickins Associates Ltd.
Vancouver, Canada

SUMMARY

This paper is based on an engineering study and economic analysis of the capabilities of existing hovercraft and new hovercraft designs in support of future oil production development at the East Amauligak discovery in the Canadian Beaufort Sea (Dickins and Dickinson, 1986). Two new hovercraft designs were developed to a conceptual design stage, and four existing commercial hovercraft were assessed in the original study (proprietary). The economic evaluation presented here compares different combinations of new and existing hovercraft with a Boeing 234 MLR Chinook helicopter. Vehicles are compared on a common basis of having to move 1500 tonnes of cargo and 1,000 passengers per month, on a year round basis over a 43 nm. route between Tuktoyaktuk, N.W.T., and the drilling site.

Study results show that a modified British SR.N4 (used) is the only existing hovercraft capable of meeting Gulf's freight and crew transportation requirements on a year round basis. A second existing hovercraft, the AP.1-88 has potential as a summer crew change vehicle. New hovercraft designs offer greatly improved operating economics over any existing freight hovercraft, and have the advantage of being designed specifically for an arctic environment.

Hovercraft are shown to provide the following important advantages:

1. A hovercraft can evacuate the entire production facility in a single trip in the event of an emergency;
2. A hovercraft can meet transient cargo demands several times the design throughput without having to introduce additional vehicles;
3. A hovercraft is not sensitive to load density, a critical factor controlling helicopter efficiency.

The study concludes that hovercraft can provide reliable year round service to the East Amauligak production site at an annual cost saving in excess of 1986 $3 Million (CAN.), compared to a helicopter operation .

INTRODUCTION

This paper is based on a 1986 study carried out for Gulf Canada Resources Ltd. of Calgary. That study was conceived as an independent evaluation of hovercraft capabilities in support of oil production development at the East Amauligak discovery site (Figure 1). Initial terms of reference provided by Gulf Canada are indicated in Table 1.

Table 1: East Amauligak Support Requirements

Location and Routing

From	Tuktoyaktuk, N.W.T.
To	East Amauligak
Distance	43 nm
Operating Period	Year Round

Cargo Description

Offshore Monthly Tonnage	1500 tonnes (Dry)
Total Personnel Transfers	1000/month (each direction)
Maximum Preferred Resupply Intervals	20 Days (cargo) 5 Days (passenger)
Largest Indivisible Payload	10 tonnes
Emergency Evacuation	150 people

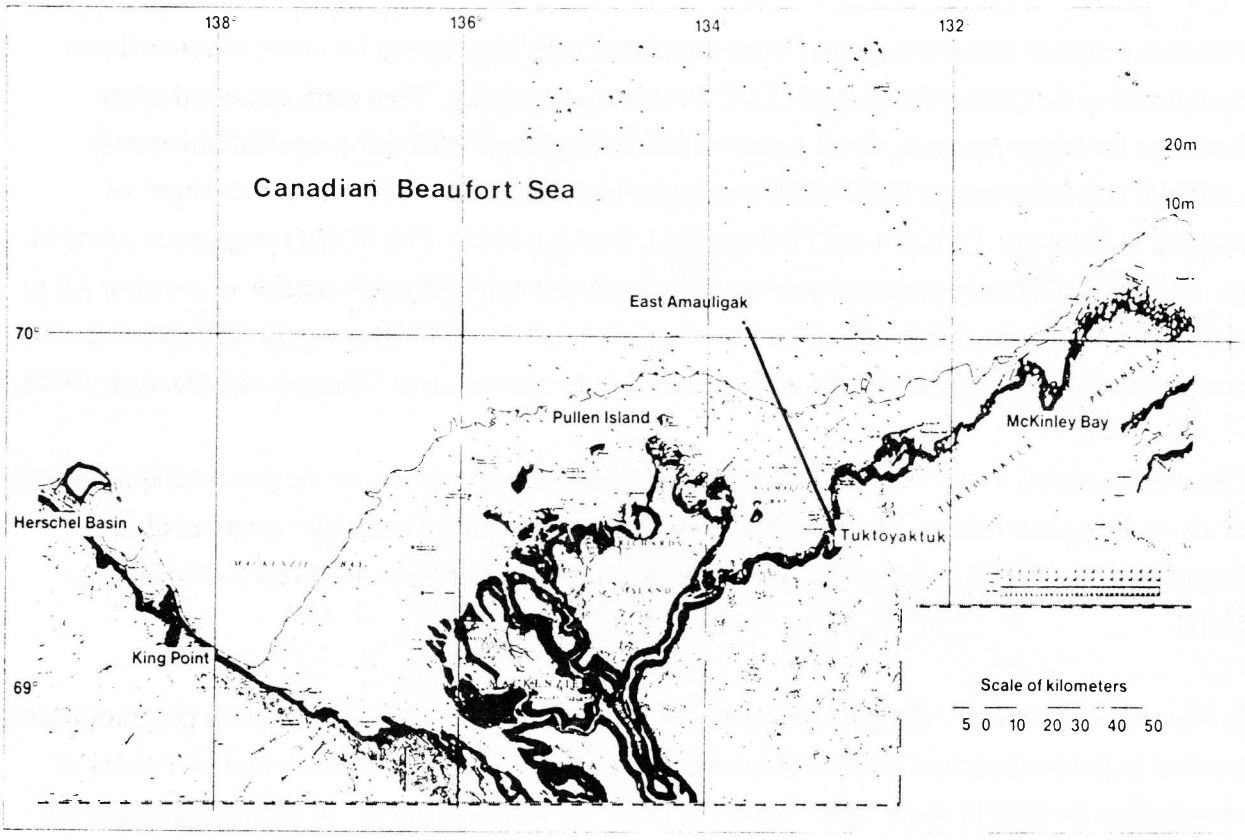


Figure 1: Beaufort Sea location map showing transportation routes to East Amauligak.

It was recognized at the outset of the study, that given the limited availability of suitable hovercraft, the development of new design concepts would be required to fully satisfy Gulf Canada's requirements. The following background summarizes previous experiences with arctic hovercraft which formed a basis for this study. A detailed review of the history of arctic hovercraft operations is provided in Dickins (1985).

Background

Previous research and development work associated with large heavy lift arctic hovercraft was completed in the United States by SOHIO Petroleum Company. This work consisted of an intensive four year program which included full scale trials of both self-propelled hovercraft (Jeff(A)) and hoverbarges (ACT-100), model testing, analytical studies, and evaluations of existing technology. (Walden and Dickins 1983, Dickins 1984). The SOHIO program resulted in the design of a 300 ton (nominal) payload air propelled arctic hovercraft capable of clearing 2.5 m obstacles. The basic design principles developed through the SOHIO program were subsequently used to develop a family of related arctic hovercraft design concepts (Tangren and Dickins, 1986).

Canadian research into hovercraft operations over ice has concentrated on the practical applications of air cushion icebreaking. Much of this work has been conducted under the auspices of the Canadian Coast Guard and the Transportation Development Centre in Montreal (Laframboise, 1981).

In Finland, Wartsila OY Helsinki Shipyard completed an arctic hovercraft research program which resulted in the construction of several specialized test vehicles, and the production of a series of hoverbarges for ship to shore lightering in the arctic (to Soviet licence). In addition, a single self-propelled hovercraft ferry was produced for service over smooth ice in the Finnish Archipelago, the "Larus."

Hovercraft have been used in both trials and regular service in the Canadian Arctic since 1966. The Northern Transportation Company Ltd. operated a commercial hovercraft charter operation in the Mackenzie Delta from 1974 to 1977 using modified SR.N6 craft. Recent experiences with hovercraft in the Beaufort Sea include the Jeff(A) 170 tonne craft at Prudhoe Bay from November 1983 to July 1984 (Dickins, 1984), and the Wartsila Larus 100 tonne machine based at Tuktoyaktuk since September 1984 (Wainwright and Makinen , 1986).

OPERATING ENVIRONMENT

Hovercraft operating along a route from Tuktoyaktuk to East Amauligak will encounter a wide range of ice and climatic conditions dependent on time of year and distance offshore. These conditions can be grouped on a seasonal basis according to changes in the most important environmental parameter: sea ice (stability, thickness and roughness).

Season	Proportion of Year %	Months	Critical Features of the Offshore Environment for Hovercraft Operations
Winter	44	Jan-May	- Shear Zone Ice Ridging - Stable Landfast Ice
Spring	12	Jun-July	- Moving Pack Ice
Summer	19	July-Sept	- Shallow Open Water - Fog
Fall	25	Oct-Dec	- Breaking Ice - Ice Rubble - Structural Icing

A wide range of ice regimes including solid landfast ice, severe ridging zones, and moving young ice will be encountered by hovercraft operating during the winter. The operating environment will have a major effect on both speed and fuel consumption depending on time of year and ice conditions. Over shallow open water and thin ice, the sharp rise in wave drag with increasing velocity will limit the operating speed to ten knots or less in deep water (over 10 m) and 6 knots or less in shallow water (less than 5 m).

The heavy lift designs proposed in this study are powered for optimum performance over ice thicker than 60 cm. In order to achieve cruising speeds in excess of 20 knots over water or thin ice, the vehicles would require over four times the propulsion power specified for ice operations.

Once the ice cover exceeds about 60 cm by early December, the hovercraft will begin to ride on top of the ice without causing catastrophic breaking of the sheet. As the ice continues to grow to more than 1 m, the hovercraft will leave only minor cracking in its wake. Drag over a relatively solid ice cover is not strongly dependent on vehicle speed, allowing the vehicles designed in this study to cruise comfortably at 20-25 knots. The maximum recommended winter cruising speed will depend less on power available, than on the prevailing weather conditions, and ice roughness along the route. Safety considerations, including the risk of collision with extreme ice features, will be the primary cause of speed restrictions.

ECONOMIC EVALUATION

The original study evaluated thirteen case studies in terms of the total annual cost of meeting the specified transportation requirements. This section presents summary results from a number of the favoured options which emerged from the detailed analysis.

The economic evaluations involved a number of critical assumptions outlined below.

Assumptions Used in the Economic Analysis

Helicopters

1. Only the Boeing Chinook is considered in this study . Although other helicopters, (e.g., AS332L and S-61) can meet the passenger requirements, no other helicopter is capable of meeting freight requirements without employing two machines.
2. An annual utilization up to 2500 hours is feasible with one helicopter (Boeing uses 1800 h)
3. Travel times are calculated on the basis of 130 kt with internal load and 85 kt (average) with multiple hook sling loads. Six minutes of dead time are added to each end of a one way trip.
4. The number of trips are based on an average freight load factor of 85%, i.e., the helicopter lifts 85% of its rated capacity on average. Payload/range curves are based on -10°C temperature conditions (data provided by Boeing).

Assumptions Used in the Economic Analysis (cont.)

5. Fixed and variable annual costs are calculated on Boeing worksheet forms (1985 Dollars) using the following factors:
   - depreciation over 10 years to 0% residual;
   - hull and liability insurance at 6% per annum;
   - average flight crew salary $75,000/year X 6;
   - maintenance overhead, administration and non-revenue flight costs discounted (see note below);
   - fuel costed at 90¢/Litre (actual 1985 costs in the Beaufort Sea).

   Note: As per Boeing cost sheets, maintenance labour is considered a variable (or direct) cost item at 5 man hours/flight hour ($30 hour salary).

Hovercraft

1. New design heavy lift hovercraft described in this study will not be used to carry passengers during the summer period (July to November) owing to the excessive travel time (6 hours one way). An economical existing hovercraft (AP.1-88) is dedicated to summer passenger use in costing the overall annual passenger + cargo cases.

2. All hovercraft winter travel times are calculated based on an average block speed of 25 kt over a distance of 49 nm (15% allowance for detours around critical ice ridges).

3. Heavy lift hovercraft summer travel times are calculated based on an average speed of 7 kt along a straight line route.

4. Existing hovercraft summer travel times are based on an average open water cruise speed of 45 kt (SR.N4, AP.1-88).

5. Fuel weights on departure are sufficient to provide 10 hours endurance in winter and 20 hours in summer (new heavy lift designs). Payloads are adjusted accordingly.

6. Fuel costs year round are based on a cruise power condition of 95% to lift and 50% to propulsion. An exception is the SR.N4 existing craft which assumes maximum continuous cruise power in open water.

7. Fixed annual hovercraft costs are based on similar guidelines as to the helicopter, (i.e., depreciation, crews and insurance.) An exception is that maintenance crews for hovercraft are considered as a fixed cost item. The total annual cost of flight and maintenance crews is estimated at $900,000.00.

Capital costs of existing hovercraft are based on quotes received from the manufacturer or owner. The AP.1-88 is in production in the U.K. and offered during the original study at a 1986 cost FOB Cowes of $3.58 Million (Canadian). Two SR.N4's were offered used by the owners, (Hoverspeed Limited) on an "as is" basis. Additional equipment and modifications to suit the craft for Beaufort operation (including skirt replacement, spares, winterization of systems and structural changes to allow craning of loads onboard) were costed to arrive at the following capital cost estimates for an "Arctic SR.N4": $8.3 Million (CAN. 1986) for summer open water operation only, and $11.5 Million for year round operation (exclusive of delivery charges by ship and barge from the U.K to the Beaufort Sea).

Hourly variable (or direct) hovercraft costs for new designs include the following components:

Fuel	@ 90¢/1 (assume fuel s.g. as 0.83)
Engine Overhaul	Replacement Cost/Estimated TBO*
Prop Overhaul	Replacement Cost/TBO
Skirt Replacement	Based on an average segment wear life of 500 h (reduced by 15% to account for accidental damage)
Spares and Materials	Nominal $250/h

*Time Between Overhaul

The SR.N4 variable operating costs were calculated in a similar fashion except skirt wear and fuel consumption were estimated separately for summer and winter use. Winter rates were arrived at by using skirt cost criteria developed for the new designs factored to account for differences in number of segments. Summer skirt costs were arrived at by using quoted BHC values (approximately $1/foot of hem length/hour) .

Hourly operating costs for the AP.1-88 vehicle were derived from actual experience in U.K. service (High Speed Surface Craft July-August 1985).

The variable costs are summarized below for three new designs of hovercraft, and two existing hovercraft, the AP.1-88 and SR.N4.

Table 2: Variable Operating Costs

Craft Type	Payload (tonnes)	Passengers	Variable Operating Costs $/tonne-h	$/Pass - h	Total $/hour
New Design (Diesel)	276	N/A	$18.90	N/A	$5206.
New Design (Gas Turbine)	314	N/A	21.70	N/A	6816.
New Design (Diesel)	98	N/A	38.00	N/A	3737.
SR.N4 (Summer)	80	282	71.00	21.00	6021.
SR.N4 (Winter)	80	282	65.00	19.00	5491.
AP.1-88 (Summer)	10	100	38.00	3.84	384.

Notes: 1. New design costs are for winter over ice operations.
2. SR.N4 is modified for arctic operations.
3. AP.I-88 skirt clearance is not sufficient for offshore operations over rough ice.

Overall results of the economic evaluations for selected vehicles and mixed vehicle fleets are summarized in Table 3 below (costs in $ CAN 1986). Hourly fuel costs are included separately as an indicator of relative consumption, an important factor in an area where all fuel is presently imported on a summer sealift.

Table 3: Summary Economic Evaluations

Selected Case	Utilization (annual hours)	Fuel Costs $/hour	Overall Annual (Fixed + Variable) Total ($ Millions)	$/tonne -km
Helicopter Boeing 234 LR	2500	$1400	11.8	15.20
Mixed Fleet (1)	620	2160	8.4	10.90
Mixed Fleet (2)	1900	1500	10.3	13.30
Mixed Fleet (3)	680	2300	8.2	10.60
New Design (1)	500	2160	7.0	9.00
New Design (2)	1600	2800	8.4	10.85
SR.N4	803	3000	7.3	9.40

Notes: Mixed Fleet Compositions

(1) New Design 276 Tonne Payload Diesel craft for cargo (summer and winter) and passengers (winter only) in combination with AP.1-88 for passengers (summer only)

(2) New Design 98 Tonne Payload Diesel craft for cargo (summer and winter) and passengers (winter only) in combination with AP.1-88 for passengers (summer only)

(3) New Design 98 Tonne Payload Diesel craft for cargo and passengers during winter months and an arctic modified SR.N4 for cargo and passengers during the summer.

New Designs

(1) 276 Tonne payload diesel craft year round (cargo operation only)

(2) 98 Tonne payload diesel craft year round (cargo operation only)

Helicopter costing assumes that a single Boeing 234 can achieve an average 7 hour daily utilization and makes no allowances for weather delays (see further discussion of helicopter limitations below).

The results shown in Table 3 can be summarized as follows. The most economical year round transportation system over the East Amauligak to Tuktoyaktuk route utilizes a modified SR.N4 available on the used market. The next most economical system utilizes either a single new design operating year round, or the same craft operating on a seasonal basis in conjunction with an SR.N4. The variable hourly costs saved by replacing a 7 knot hovercraft with one capable of 45 knots in open water are sufficient to pay for the increased fixed annual cost associated with the additional hovercraft.

The mixed craft fleet makes optimal use of each hovercraft type in the environment for which it was designed (i.e., the SR.N4 in open water and the new heavy lift design over ice). In addition, the mixed fleet offers the added security of a back-up machine in the event that one is damaged or grounded for mechanical reasons. The propulsion modules on the SR.N4 (propellers and gearboxes) are compatible with those proposed for the new design making spares inventory much more economical.

As expected, the smaller new design option with its much inferior payload efficiency (Table 2) is the most expensive mixed fleet hovercraft option. Interestingly, even the worst case hovercraft option is still more economical than a single Boeing Chinook. The favoured hovercraft all cargo options (New Designs (1) and (2) in Table 3) are between $2.5 and 3.4 million (25 to 33%) per year cheaper than the helicopter system. In these evaluations, the hovercraft were costed on an extremely conservative basis to compensate for the lack of long term operating data in an offshore arctic environment. In contrast, the helicopter was assumed to achieve high levels of efficiency in terms of the load carried on each flight and the number of hours daily utilization.

Hovercraft have two major advantages over helicopters in an all cargo operation:

First, the helicopters lift capacity will not be fully utilized if a container is filled with low density material. Slinging additional containers to make up the load will result in a greatly reduced cruising speed. The overall transportation cost is highly sensitive to variations in container loading, as shown in Figure 2. In contrast, the hovercraft shows no dependence on container load density in the 100 to 50% range. Both of the new hovercraft designs

proposed in this study have sufficient deck area to accept the number of containers necessary to make up a full load on every trip.

Second, an operation using a single helicopter is severely limited in terms of the maximum monthly cargo volume which can be moved over a 43 nm distance. The helicopter reaches an upper attainable limit at about 2,000 tonnes/month at an extremely optimistic utilization of 9 hours a day. Beyond this tonnage, a second helicopter will be needed, resulting in a dramatic increase in annual cost from about $12.1 to 16.5 million.

A hovercraft system provides for greatly expanded cargo volumes without the need for additional vehicles. For example, a single SR.N4 making one round trip per day can move 2,400 tonnes/ month, far in excess of the tonnage requirements specified in this study. The smaller new design proposed in this study can move over 2,900 tonnes/month, and the intermediate craft in excess of 7,500 tonnes/month.

Figure 3 shows the effect of adding additional helicopters or hovercraft as their individual cargo limits are reached. The cost differential between hovercraft and helicopters becomes even more pronounced at higher tonnage volumes than the values considered as the baseline reference in this study. For example, with a 2,200 tonnes/ month requirement, the annual costs of the overall transportation system increase to the following values (compared with Table 3):

Table 4: Annual Overall Transportation Costs at 2,200 tonnes/month

Boeing 234 MLR	$17.1 Million
SR.N4 Hovercraft	$ 8.7 Million
458 Tonne (AUW) New Design	$10.5 Million
845 Tonne (AUW) New Design	$ 7.9 Million

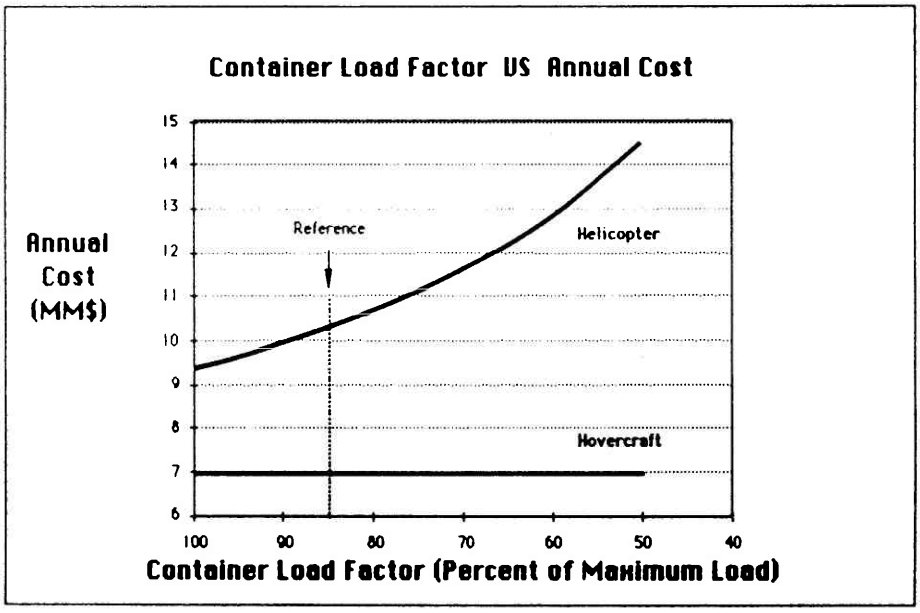


Figure 2: Effect of partial loads on overall annual cost

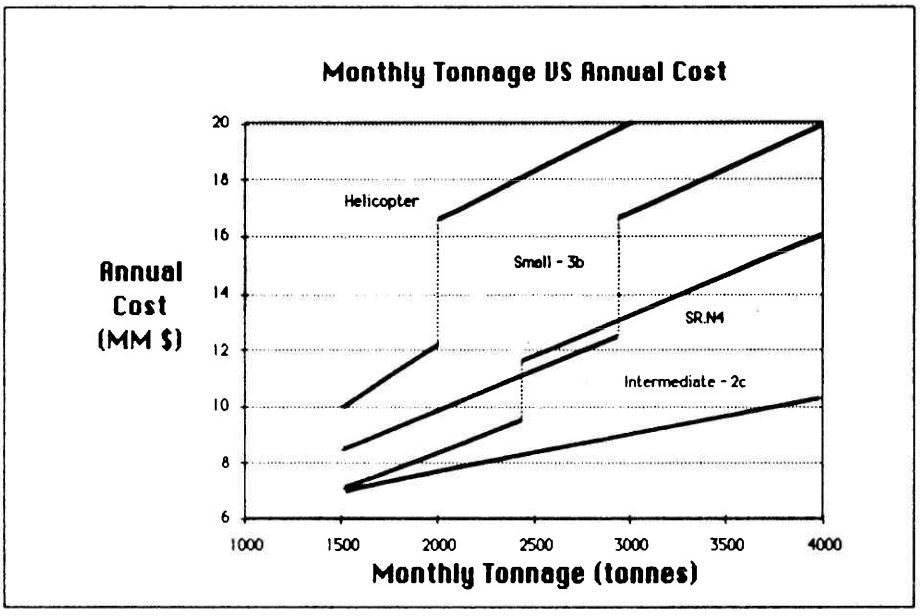


Figure 3: Effect of increasing cargo demand on overall annual cost. Steps in the curves occur at the point where a second vehicle is required. *Small* and *Intermediate* refer to new hovercraft designs.

RECOMMENDATIONS AND CONCLUSIONS

The results of this study show that hovercraft can be seriously considered as a viable alternative to heavy lift helicopters on the Tuktoyaktuk to East Amauligak route. Preliminary economic analysis indicates that significant annual cost savings will result from using hovercraft in place of a Boeing Chinook. The relative cost advantages of hovercraft become even more pronounced as tonnage volumes increase, or if two machines are considered necessary for reasons of safety and redundancy.

The proposed new design will be most effective from November to June when it is able to operate over relatively solid ice at a reasonable speed. The most efficient utilization of hovercraft will be achieved by using each vehicle in its intended design role (i.e., the N4 and/or AP.1-88 for high speed open water or thin ice operation, and the new heavy lift design for moderate speed winter operation over ice thicker than two feet).

ACKNOWLEDGEMENTS

The author wishes to acknowledge the contributions of a number of individuals and organizations who participated in the original study:

Anthony Dickinson (co-author of the original report) ;

Robert Tangren for evaluating power requirements of the new design concepts, and developed the basic arrangements showing overall configuration and machinery layout;

Hovercraft Consultants Limited (John Rapson and Malcolm Cox) for developing the conceptual designs for skirt systems, for providing estimates of skirt operating and capital costs, and for assessing the potential of a modified SR.N4 for arctic operations;

Peter S. Hatfield Limited (Vancouver) for developing and costing the hulls for the new design concepts and for producing detailed general arrangement drawings;

Derek Hardy of British Hovercraft Corporation (now retired) for assisting in evaluating the technical feasibility of proposed SR.N4 modifications;

David Wise of Hoverspeed Ltd. for providing information on the SR.N4's;

Roy Pallant of GEC Diesels Inc. (Vancouver), Frank Hayden and Michael Drinkwater (Paxman Diesels, Colchester U.K.) for providing specialized technical support;

Gulf Canada Resources Ltd., Calgary for allowing publication of the economic analysis component of their study.

REFERENCES

Dickins, D.F. and Dickinson, A., "Evaluation of Hovercraft for Support of Beaufort Sea Production Development", proprietary report to Gulf Canada Corporation, Calgary, April 1986.

Dickins, D.F., "Arctic Hovercraft: Lessons Learned and Future Prospects", in Proceedings - Arctic Offshore Technology Conference, Anchorage, September 1985.

Dickins, D.F., "The Jeff(A) Test Program", in Proceedings - 1984 CACTS International Conference on Air Cushion Technology, Vancouver, September 1984.

High Speed Surface Craft, July - August, 1985 (AP.1-88 operating costs)

Laframboise, J.E., "The Transportation Development Centre Contribution to Air Cushion Technology", in Proceedings - 15th Canadian Symposium on Air Cushion Technology, Toronto, September 1981.

Tangren, R.F. and Dickins, D.F., "Design Studies for a Diesel Powered Heavy Lift Air Cushion Vehicle", in Proceedings - Fifth International Symposium on Offshore Mechanics and Arctic Engineering, Tokyo, 1986.

Wainwright, J. and Makinen, E., "First Winter's Experience with the Air Cushion Vehicle *Larus* in the Beaufort Sea", in Proceedings - International Polar Transportation Conference (IPTC86), Vancouver, May 1986.

Walden, J.T., and Dickins, D.F., "Review of an Air Cushion Vehicle Program for Offshore Arctic Operations", in Proceedings - 7th International Conference on Port and Ocean Engineering Under Arctic Conditions, Helsinki, April 1983.