S E C T I O N II

TECHNOLOGICAL AND MANUFACTURING DEVELOPMENTS

THE DESIGN, BUILDING AND EARLY OPERATION OF THE LA CRETE HOVERFERRY

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INTRODUCTION

The HL104 40-ton amphibious cable-operated hoverferry was ordered by Alberta Transportation in October, 1976, to provide an all-season service at Thompkins Crossing on the Peace River, excluding the period of time when the ice bridge is in operation, and the immediate break-up in the spring.

DESIGN

The philosophy around which the craft was designed was that of a simple steel fabricated structure, built in quickly demountable units which could be readily transported from one location to another on normal road transport. The hull structure is built in three sections which are pin-jointed together. The engines, fans, and winches are then located and bolted in place on the side wings of the hull, and the engine houses and control cabin are bolted over the power units. Finally the skirt is fitted, and the craft is moved onto the operating site where the guide - propulsion cables are installed. Site assembly should take approximately two to three days with a crew of six men.

HULL

As previously states, the hull is composed of three sections. The centre section has two box section pontoons running longitudinally through the craft, each divided into five watertight compartments. The pontoons are connected by intermediate frames, and corrugated decking above and below completes the section. This section forms the main load carrying portion of the hull.

Two side sections are built of decked frames, and these are designed to carry the skirt segments on the underside and the lift and propulsion machinery on the top. The remaining deck space can be used to accommodate passengers and light vehicles.

Power for lift and propulsion is provided by two Caterpillar 4308 PCTA Diesel engines, mounted as self-contained power packs on skid frames, for quick assembly and removal. The fans providing cushion air are driven through centrifugal clutches and Spicer couplings from the rear of the engine. The propulsion winches are hydraulically driven, the hydraulic pumps being mounted on the skid frame in front of the engine, and driven by an extension of the engine crankshaft.

Glass reinforced plastic engine houses cover the whole machinery package, and a control cabin is mounted on the top of one of the engine houses.

All controls and instrumentation between the power units and the control cabin are electric to ensure operation under all environmental conditions. Quick disconnect points are included at all transport joints to facilitate rapid assembly and break-down.

Two driving positions are provided with winch controls to enable the driver to face comfortably in the direction of travel at all times. Engine controls, instruments and switches for all lights and auxiliary functions are grouped in a central control panel situated between the two driving positions.

BUILDING

The three hull sections were constructed in Edmonton by a sub-contractor. On completion, these were transported to the Alberta Transportation Edmonton Repair Shops, where they were assembled, and the remainder of the equipment was installed. Following the installation of the machinery, the engines and winches and the wiring of the controls, a full test program was undertaken by Alberta Research Council to verify the design parameters of the craft.

During the test program the following performance capabilities were evaluated:

(a) Fan performance was checked using an inlet measuring duct temporarily attached to each fan.

(b) Overall winch line pull was evaluated by towing a large vehicle with a load cell in the tow line, and measuring line pull and line speed.

(c) Craft hoverheight was measured, relative to engine speed and fan inlet damper setting at no load, half load and full load conditions.

(d) Craft drag was measured over a range of speeds and payloads by winching over a selected area of pavement with load cells in the winch lines at the anchor points.

(e) Roll and pitch stiffness were measured by rolling and pitching the craft with a line attached to the outer edge of the craft, running through a block attached to a ground anchor. Line pull, and hence rolling moment, was measured for incremental increases in roll and pitch.

(f) An attempt was made to determine the gross weight of the craft by measuring cushion pressure and cushion area for the craft in the maximum all up weight condition.

Following the preliminary evaluation trials, the craft was steam cleaned, dismantled, and shipped to La Crete. The complete craft was accommodated on road vehicles as follows:

Centre Section	One (1) Vehicle
Side Sections	Two (2) Vehicles
Machinery and Skirt	Two (2) Vehicles
Engine Houses and Control Cabin	Two (2) Vehicles

OPERATION AT LA CRETE

The craft was reassembled at La Crete on a levelled area of ground adjacent to the operational site which had been prepared during the period in which the craft was assembled at Edmonton. After assembly, the craft was moved onto the slipway using two Caterpillar tractors, one to tow the craft and one for restraint. The cables were laid across the river using the existing ferry, threaded through the fairleads and winches on the craft and attached to the anchors.

The craft was operated across the river for driver familiarization prior to the continuation of the A.R.C. evaluation trials. In the second phase of the trials, the following additional functions are to be evaluated:

(a) Winch line pull under all operating conditions using load cells installed between the anchors and the cables.

(b) Fan output was measured during all operating conditions at no load, half load and full load.

(c) Roll and pitch stiffness were measured by vehicle displacement.

(d) Hoverheight relative to load, engine speed and fan setting were checked over water, and the off-cushion freeboard was established.

CONCLUSION

In operation the craft was found to be very easy to drive and to have a good response to all the control functions. Manoeuverability using differential winching speeds was good, and when crossing the river it was found that no adjustment of winch speed was necessary to maintain a matched speed between the two winches.

At the time of writing, some passengers and public vehicles have been carried on a random basis, although the ferry has not yet been put into full-time service. No experience of operation under any icing condition has yet been possible.

It is expected that the development and testing program jointly sponsored by Alberta Transportation, National Research Council and Alberta Research Council will continue through several seasons to prove operational capabilities.

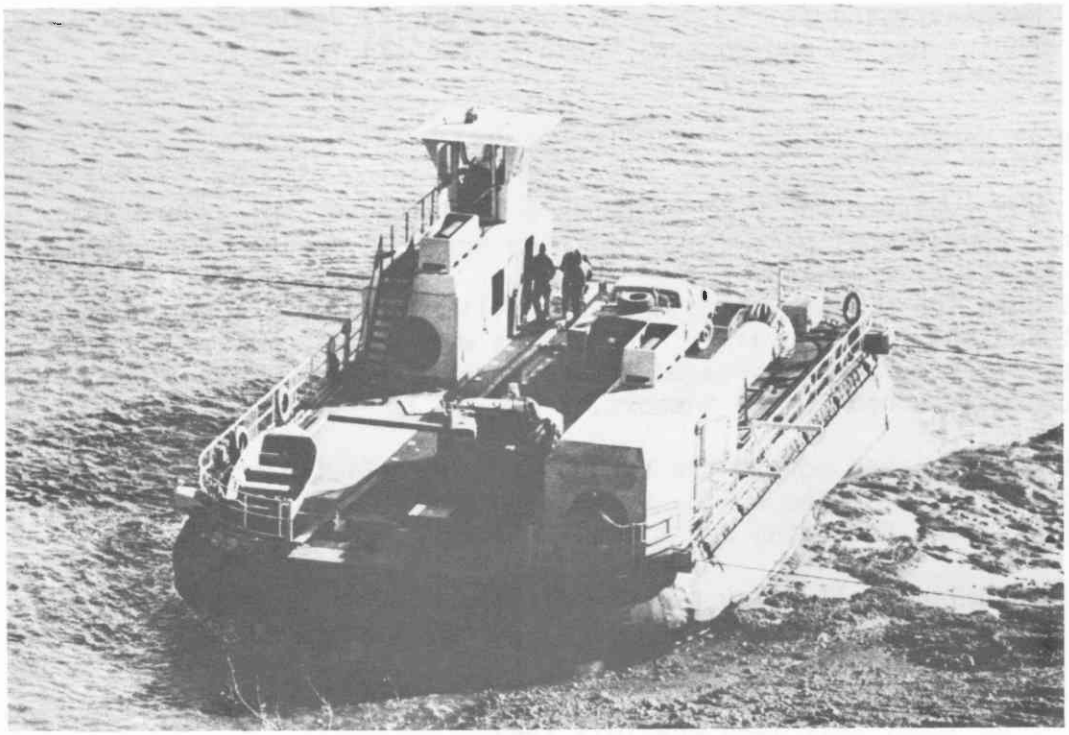


FIGURE 1 - The HL104 40-ton cable-operated hoverferry at La Crete, Alberta

PRAIRIE WEAK ROAD LOAD RELIEF PROGRAM

PART I

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Throughout the short history of the practical air cushion supported vehicle, random efforts have been made at applying the principle to the problem of relieving part of the load from the wheels or tracks of a heavily loaded transport vehicle, in order to permit operation over weak ground. It appears that the majority of these were developments in air cushion technology, for which a use was found when a practicable method had been achieved - a solution looking for a specific problem.

Experience in Canada has shown the application to be feasible and practicable, and it has become apparent that the time has come for determining the nature and extent of the problem, in order to optimize the solutions. Accordingly the Associate Committee on Air Cushion Technology (ACACT) of NRC proposed the initiation of a systematic program of studies, research and development in the subject, to be carried out jointly by NRC, industry and the Saskatchewan and Alberta Research Councils (SRC and ARC).

The first part of this program, a study to be carried out at NRC on the current and projected transportation needs, the effectiveness of air cushion technology in this field, and the possible alternatives, is the subject of this paper.

In order to contain the scope of the program within limits acceptable to all parties, it was defined as a "Prairie Weak-Road Load-Relief Program" although this would not preclude the application of the results obtained to problems outside this specific region.

A major problem confronting the Canadian haulage industry is the lack of first class solidly based all-year roads in the developing Northern and Prairie regions. Typically, in the Prairie Provinces, four billion tons of commodities of all types are transported annually, with a very large proportion of this amount on the road for at least a part of its journey. In addition, a large number of very heavy loads are moved, to service the construction and resource extraction industries. All these traffic movements, except those in the urban centres, are subjected to a so-called "half load season" during the spring thaw and early summer. Even with the reduced loads imposed, road damage during this season is considerable, and if loads are not reduced road maintenance costs will become insupportable. At the same time, disruptions in commodity flow caused by this phenomenon lead to economic problems for producers, carriers and users.

This study was carried out to determine whether it is technically and economically feasible to reduce road damage whilst maintaining full load transportation during the critical season. Because of the similarity of the problems involved, the study has also included the problems of hauling very heavy unit loads over weak surfaced or rough graded roads, and has consid-

ered whether similar technologies can be applied to local agricultural transportation.

Air cushion solutions to the agricultural transport problem were found to be technically feasible, but their economic and operational aspects appeared to be significantly against such developments at this time, and this aspect of the study was temporarily abandoned. It is considered that the subject could be reviewed again when substantial advances have been made in either of the other two fields.

The study showed that there was a technical feasibility of achieving the objective by several methods in both the remaining cases. For the highway commodity haulage problem it was strongly indicated that some form of air cushion assist was the most economic and operationally the most satisfactory solution, provided that certain well-understood problems of air cushion operation on roads could be solved quickly.

The two most fundamental problems are the economic one of skirt wear life, and the "social" one of dust and spray dispersion by the cushion air-flow.

The transportation of agricultural and mineral commodities in the Prairie Provinces is an enormous business, a large proportion of which is carried out by specialized fleets of trucks and semi-trailer units. A very large body of statistical data is available, indicating a steady increase in this activity, the 1975 total being in the order of 4×10^9 tons of goods removed.

A fundamental problem, when operating away from the main urban centres, is the provision of adequate roads for this traffic, particularly the trade-off between first cost and maintenance cost. The standard method is to build weak but relatively cheap roads and accept the high maintenance and renewal costs which result. These are kept to acceptable values by load-restrictive regulations, which are adjusted to suit the seasonal variations in strength of the ground supporting the roads.

This restriction imposes economic constraints on the producers, transporters and processors of these commodities, which have a significant effect on the final market price to the consumer, and on local employment patterns and continuity. Any method of overcoming these restrictions without increasing road maintenance costs will have potentially very high rewards.

One very significant economic factory is that the transporting agencies will be most likely to bear the cost of the technological improvements involved, but that they stand to gain least in the overall economic improvement. Some of their increased cost will obviously be borne by the other members of the commodity chain, from producer to consumer, but some will have to be taken by the road authorities, to be derived from the saving in maintenance costs. A system of permit incentives might be one way of encouraging the adoption of the necessary technological changes by the transport fleet operators.

The movement of very heavy specialized loads, usually of high density, is a continuing and expanding activity in the development of Northern Canada, particularly in the resource extraction industries. Very little statis-

tical information is available on the range of loads involved, or the distances and types of terrain traversed.

In order to study the feasibility of alternate methods to those in use, an arbitrary limit of 80-ton to 300-ton payloads has been set, for journeys from 10 to 50 miles. Terrain variations from paved road to rough graded track of 10 psi bearing strength are assumed.

For the heavy load haulage problem, the superiority of the air cushion approach was less clear, because of the very wide variations of load dimensions and terrain qualities which could be encountered, and it was apparent that the further development of very specialized wheeled and tracked vehicles could not be ruled out.

One aspect of the overall problem was clearly emphasized by the study. A considerably improved knowledge of the mechanism of road failure is needed, to support the statistical data presently used for evaluating loading capacity on the roads. There is a need for analysis and practical research in the areas of lateral and longitudinal load distributions, footprint pressures, and the actual effects of a large air cushion on the road structures.

Mr. Fowler will now discuss some of the technical aspects of the study.

PRAIRIE WEAK ROAD LOAD RELIEF PROGRAM

PART II

TECHNICAL PROBLEMS OF THE AIR CUSHION ASSISTED TRAILER (ACAT)

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The ACAT is basically a normal wheeled vehicle, with the addition of a nearly frictionless device to take some load off the wheels.

The design philosophy at present is that the weight of vehicle and load, up to almost the acceptable wheel-load limit for the road to be travelled, is borne on the wheels. The vehicle can then carry additional load ("overload") which is supported by the near-frictionless air cushion, and does not increase the wheel loading.

This raises some interesting technical considerations, which I should like to discuss briefly.

1. STEERING, TRACTION, BRAKING

The steering, traction, and braking of a vehicle are dependent on the friction which can be generated between its wheels and the road, which is proportional to the total weight on the wheels. In the ACAT these forces are therefore dependent on the wheel-supported ("basic") weight.

However, the inertia forces resisting steering, traction, and braking are proportional to the total (basic + overload) weight. The control effectiveness of an A.C. assisted vehicle will therefore be reduced in proportion to the amount of air-assist.

If as an extreme example the overload equals the basic weight, then the inertia forces are proportional to twice basic weight, and the control forces to once basic weight, so that maximum hill climbing or accelerating ability will be halved, while minimum cornering radius or stopping distance will be doubled.

The distribution of weight and air assistance between tractor and trailer, and between the several axles, complicates this relation slightly, but it is basically true.

In effect, we have concluded that a 20% overload, which probably almost doubles the freight load, is a useful target, and does not cause the handing characteristics to deteriorate too badly.

Looking at Figure 1, we see that the load on the front wheels is not altered appreciably by air-assist, so steering is unaffected except by

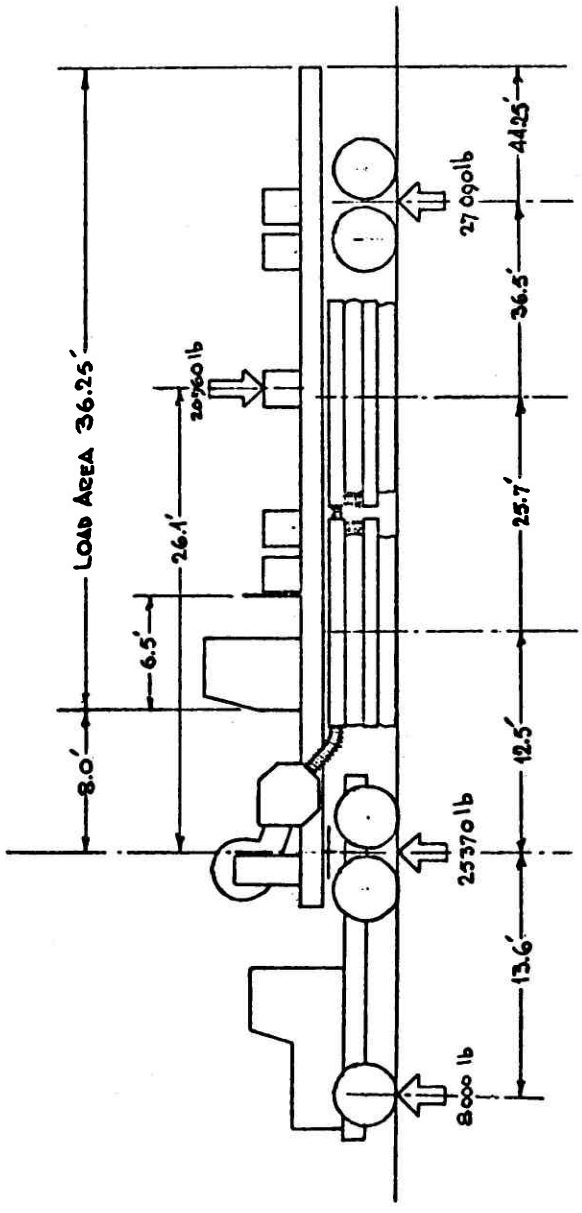


FIGURE 1 - Load Distribution on typical air cushion assisted trailer (ACAT)

jack-knifing of the rear end, which is brought on primarily by skidding of the rear wheels, due often to excessive braking. It will therefore be essential to provide the best anti-skid controls on the braking system, and train the driver to accept the somewhat different handling of the ACAT.

It does, however, seem that a useful load-increase can be obtained without paying too great a price.

2. DUST CLOUD GENERATION

Any vehicle raises a dust cloud on a dusty road. This appears to have been forgotten by many lawyers who sit in offices and make transportation regulations. One wonders if they have ever tried to drive along a prairie road behind a truck in the dry season.

However, present-day ACVs raise dust better than other vehicles, and this is not acceptable.

In a head-wind an ACAT with a conventional skirt is likely to blind following traffic, in a tail-wind it will blind its own driver.

In terms of erosion, the amount of soil is probably not serious. Existing "dust-skirts" keep large-particle dust (50 microns diameter and upwards) down and dump it back in the road. The fine dust, (10 microns and less) the so-called "face-powder" is extremely difficult to trap, and hangs in the air as a cloud for many minutes, obscuring the view but removing only a very small weight of soil from the ground.

Ways of eliminating these dust clouds are being sought. Dr. Yong at McGill is studying the electrical properties of the fine road-dust, and Dr. Kind at Carleton is looking at the detailed erosion mechanism under the edge of the skirt.

The humidity has a great deal to do with these dust clouds. Figure 2 shows the cloud generated by an ACAT on a dry day, while Figure 3 shows a very similar vehicle over a sandy area after a spell of more humid weather. I don't think we can afford to run a water spray truck in front of each ACAT, or wait for rainy days, but there are certainly some possible solutions in view.

3. OTHER EFFECTS ON ROADS

The passage along a road of an air cushion lift pack supporting a heavy load might affect the road in two general ways; by surface damage and by damage to the sub grade. The former has been studied and reported in fair detail in Reference 1, the latter is much less well understood, at any rate by the ACV community.



FIGURE 2 - Dust Cloud Generated by an ACAT
on dry soil



FIGURE 3 - Lack of Dust over Slightly Damp Soil

A. Surface Damage

In order to obtain sufficient lift from an air cushion pack small enough to fit under a trailer, the cushion air pressure is considerably higher than the ½/1 psi normal in free-flying ACVs. The lowest useful values are likely to be about 2 psi, and cushion pressures of up to 10 psi have been tested. In the first place, this leads to very high air escape velocities under the skirt edge, (up to 1000 ft/sec) which will erode any loose road surface severely. Small gravel flies on a low trajectory and peppers the ankles quite severely at twenty feet.

Secondly, the higher air pressures can force air down through cracks in a deteriorated asphalt or concrete surface if the vehicle is moving slowly or hovering. This can lead to a bubble of compressed air spreading under the road surface, and lifting slabs of pavement into the air up to thirty feet away.

Thirdly, when the cushion air is compressed it is also heated abiabatically, and unless it is cooled deliberately, the air temperature in the cushion will rise to quite high levels ($40^{o}C$ at 10 psig).

During normal travel this will have no effect on a road surface, but after five minutes' static hovering, asphalt is melted and blown away from under the skirt edges.

Finally, if a high pressure skirt is provied with stellite wear plates to prevent it abrading where the air pressure forces its hem onto the road, (as in the Heavy Lift trailers of the British Electricity Board) many passes would soon scar the road surface severely.

All the above effects suggest strongly that a successful ACAT will not have a skirt of normal "hovercraft" design, certainly if it is to operate at much above 2 psi. Alternative skirt arrangements are therefore under serious study.

B. Sub Surface Damage

Apart from abrasive, erosive, and "bubble lifting" effects on the road surface, the influence of the air-supported load on the road as a multilayered structure have to be considered. These effects, as far as the present writer is aware, are less well assessed, and are likely to vary completely with the nature of the sublayer, which will, of course, alter drastically with the season.

Bekker and others have analysed the action of wheel or track loading on homogeneous soils, but a good theoretical treatment of the multilayered case does not yet seem to be available. In essence there are two extremes. In the first case, one could liken a hard road on an unfrozen loam or muskeg base to

a thin brittle sheet on a cushion. When heavily loaded, the surface would crack due to local shear failure, but the sub-layer would not be damaged. In this case the air cushion assist should be useful, in spreading load and reducing local pressures.

In the second case, a road over hard-frozen muskeg could be likened to an elastic sheet over a brittle foam. Here it is likely that the surface might survive, but that the total load would crush the foam. In this case, the total load of the vehicle would be equally damaging, however supported.

At the present state of our investigations one can merely state this framework, and remark that it is being studied, with a view to assessing the terrain and seasons in which air cushion assist would be beneficial.

4. SKIRT WEAR

The combination of physical property requirements of skirt material are unique to the ACV, and the development of skirt sheeting has been long, slow and costly. There are now very good materials available, but these have been developed to obtain the properties required mainly by marine ACV "hovercraft". It is becoming clear that this is not the best combination of properties for an on-road ACAT skirt. In particular, far higher resistance to abrasion is required in the on-road case.

It has been clear for some time that there are two possible approaches to the ACAT design along conventional lines. One is to design for a large visible airgap under the skirt, so that there is no ground contact and hence no skirt wear. This demands a very large airflow, and hence a very large blower installation. It is a possible solution for low-pressure lift packs, but even then the blower and engine are likely to absorb a large proportion of the payload increase.

The other extreme is to use a small, high pressure blower, and seal the skirt to the ground relatively effectively by putting some sort of abrasion-resistant hem on it, which the cushion air pressure will force into the road surface, on which it will slide along. This is done in the case of the British Heavy Load Transporters, but here the air cushion sees only very limited use, in actually traversing bridges at slow walking pace. At other times it is brailed up and inactive. Even so there has been much work needed to find seal-pads which will resist this limited amount of abrasion, and at low speed. The abrasive wear is certainly proportional to the distance travelled, and experiments at NRC lead me to believe that it is also proportional to the speed, if not to the square or even cube power of the speed.

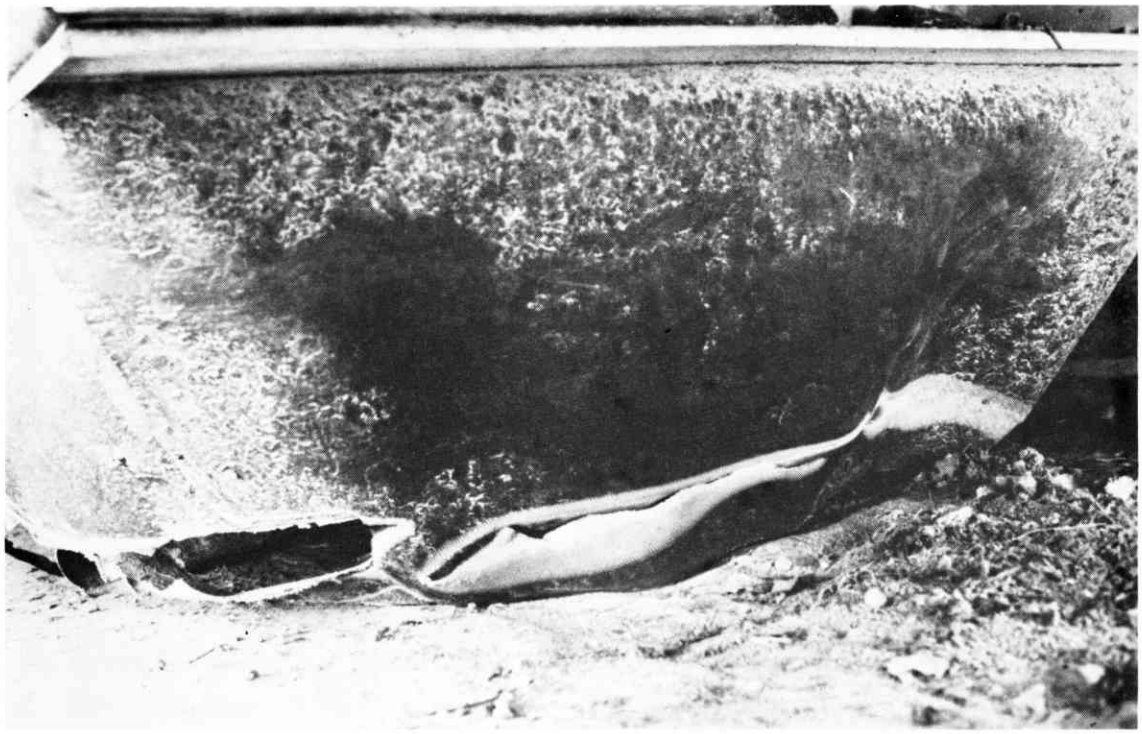
As an example, on one of our ACVs operating over a concrete airfield runway, half an hour's operation at 20/25 mph caused drastic wear, worse then that caused by about 20 hours' operation at 5 to 10 mph.

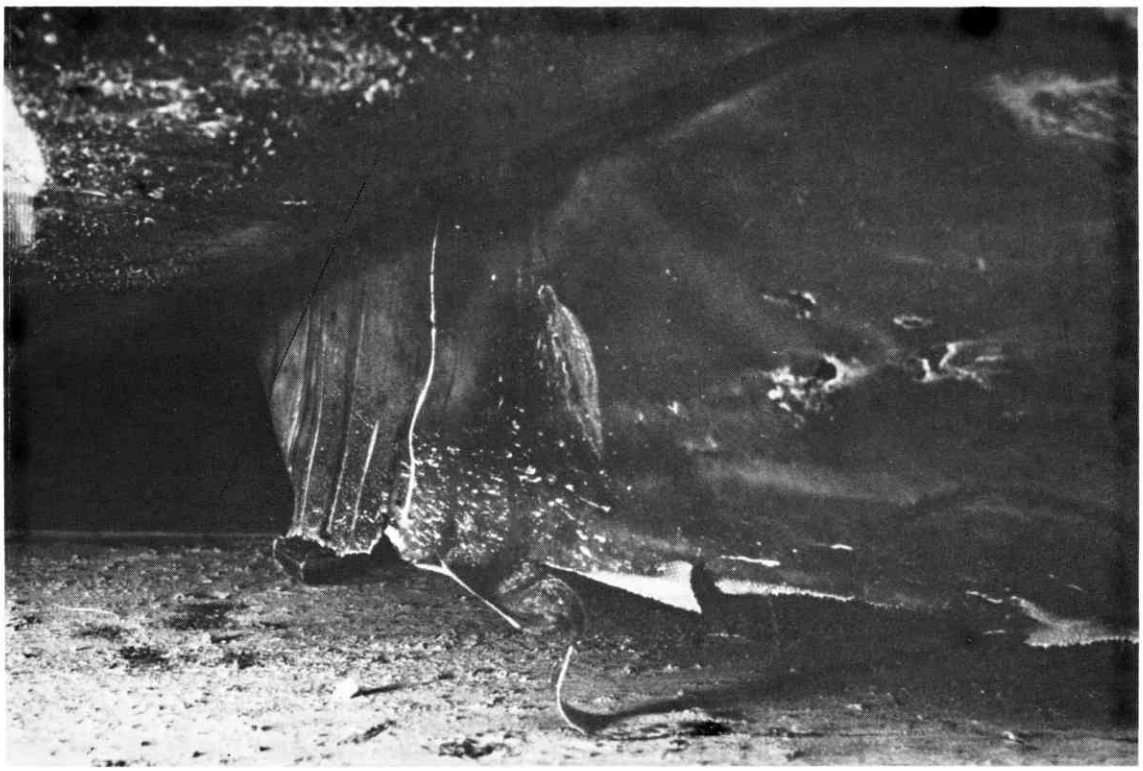
The kind of abrasive wear on a skirt running over concrete road and gravel road at up to 30 mph for a total of 20 miles is shown in Figures 4 and 5. The skirt material was .090" thick. In the tests mentioned previously, material .020" thick was abraded right through in half a mile over concrete at 20 mph.

At present, it seems reasonably likely that special hauls of 50 or 100 miles could be achieved, at the price of a simple skirt to be discarded after the one trip, and at a speed of 10 mph or so.

Beyond this, we are thinking of quite a fundamental change in concept - possibly laying down a continuous track on the road and running a skirt on this, - which almost amounts to an ACV suspension inside a caterpillar track.

In summary, certain well-documented problems peculiar to the ACAT have been discussed, in the light of which the development of such a vehicle is going to be a major task. However, work is in progress on these problems, and it is hoped to show results in the foreseeable future, since the need for road loading relief for heavy industrial freight is acute.





FIGURES 4 & 5 - Abrasive Damage to
early experimental ACAT skirts

TRACTION PROPELLED ACV

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ABSTRACT

The paper represents a summary of the development of a traction propelled air cushion vehicle. Initially the various methods of traction propulsion are identified and compared. A brief theory of traction propulsion is then presented followed by a discussion of the interaction of the propulsion system with other vehicle sub-systems. The pertinent features and performance characteristics of the vehicle are described with specific focus on the craft's modularity and 'off-the-shelf' component method of fabrication. The paper concludes with a survey of potential applications and identifies several problem areas.

INTRODUCTION

The development of surface effect vehicles technology has been rapid and at times spectacular. It has taken approximately six decades for aviation to progress from the first man carrying aircraft to the present three hundred passenger air buses. In the surface effect vehicle field the first manned craft was operated in the fities. Today, two hundred ton craft are routinely operational while craft of thousands of tons are in the design stages. The surface effect vehicle is unique among transportation systems.

By its very nature the surface effect vehicle does not readily fit into any of the traditional disciplines of aeronautical, mechanical, or naval engineering. Technology from these and other disciplines must be intergrated and judicious trade offs made in the development of a successful craft. The air cushion vehicle is not only amphibious but a multi-terrain craft. The vehicle and its subsystems are exposed to a severe and hostile environment ranging in extremes of temperature, corrosive and abrasive atmosphere, and terrain interactive loads. Yet the technology of the craft and its systems has invariably been begged, stolen, or borrowed from disciplines where design inputs are more uniform or at least more predictable. It is perhaps this hasty or ill-conceived technology transfer that may be the reason why the surface effect vehicle has not achieved the success that was initially projected. The earlier fervor and belief that the surface effect vehicle would be an answer to all of man's transportation problems has been tempered by realistic technical evaluations. It has been realized that surface effect craft are specialized vehicles and can perform certain missions exceptionally well. However, pushed off design,

their performance decays rapidly. The situation is analogous to the helicopter. It is the only aircraft capable of sustained hovering flight and thus, in order to justify the high capital and operating costs, vertical flight must be a stringent platform requirement. So also the surface effect vehicle, all terrain or amphibious capability and high speed must be important mission requirements before these craft show an advantage over existing modes of transport.

In recent years there has been detected a trend towards hybridization not only of surface effect vehicle platforms but towards the craft subsystems as well. Various combinations of cushions, wings, wheels, tracks, and foils have appeared either in proposal stages or prototype development. The thrust of hybridization is to eliminate undesirable characteristics of various pure configurations while retaining their advantageous qualities.

This trend in hybridization has also permeated into surface effect vehicle subsystems not the least of which is the thrust generating element. The multi-terrain operation of the vehicle often poses stringent and conflicting propulsion requirements, which, in many instances, cannot be satisfied by any one type of thrustor. When the thrust generating question is combined with other considerations such as stability and maneuvering the overall picture assumes some considerable complexity. It is the purpose of this paper to explore one type of propulsive system, the surface impulse propulsor (SIP), and to examine its salient features.

SURFACE IMPULSE PROPULSION

Surface effect vehicle thrust generators can be classed into three general categories (Figure 1). In the first group are thrustors which accelerate surrounding media such as air or water. Thrustors that accelerate stored media either continuously or sporadically as in burst thrust modes, form the second group while systems that rely on traction are in the third group. Included in the last group are electromagnetic accelerators such as linear induction motors and linear turbines.

In addition to the physical differences the various thrustors exhibit differences in their performance characteristics. Of major interest is the question of efficiency. Systems that exchange momentum with the surrounding media and obtain thrust by imparting velocity to a propulsive stream have their efficiency determined by the propulsive jet to vehicle velocity ratio. The larger this ratio the more energy, in its kinetic form, is left in the propulsive jet and hence a lower efficiency. It is thus desirable to employ thrust generator systems that minimize the jet/vehicle velocity ratio. While surface effect vehicles may be designed for high speeds, i.e., 100 knots, they nevertheless operate for a major portion of their mission time at considerably lower flight velocities, i.e., less than 50 knots.

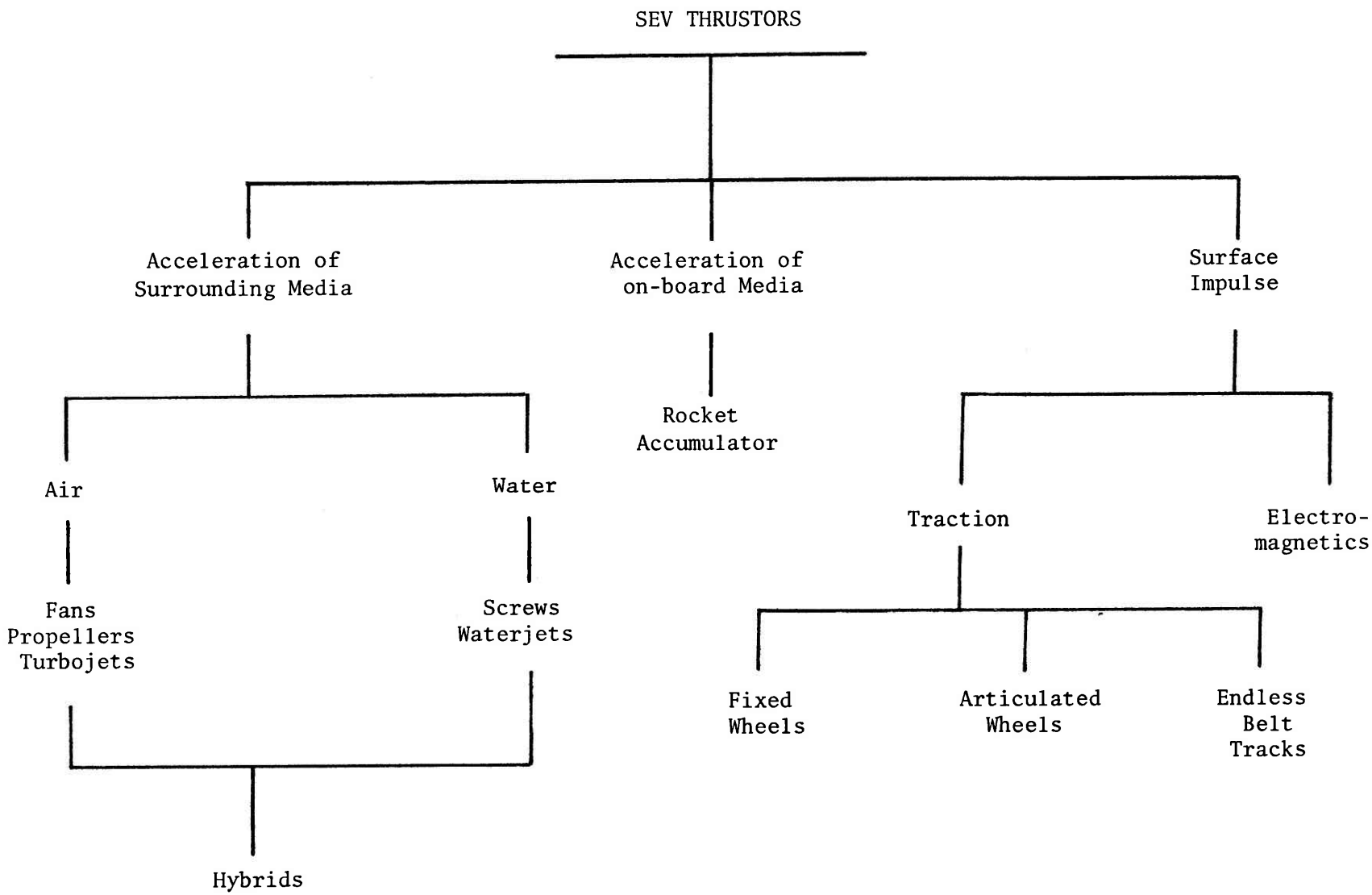

SEV THRUSTORS
Acceleration of Surrounding Media
Acceleration of on-board Media
Surface Impulse
Air
Water
Rocket Accumulator
Traction
Electro-magnetics
Fans Propellers Turbojets
Screws Waterjets
Fixed Wheels
Articulated Wheels
Endless Belt Tracks
Hybrids

FIGURE 1

This creates a dilema. For these speeds and for a given thrust level the designer has two limiting alternatives. One is to select a propulsor of practical size and accept substantially lowered propulsive efficiencies, while the other is to strive for a thrustor of desirable efficiency but accept large diameter propellers with their associated problems. While propeller efficiencies of 80%+ are achievable in the laboratory and under ideal and matched conditions it is doubtful that on an air cushion vehicle operating at forty knots under crosswind conditions a propeller can exceed 40%. The performance degenerates still further when the effects of spray and dust are incorporated. A similar argument is valid for marine surface effect vehicles propelled by waterjets or high performance marine propellers. In practice efficiencies over 50% are difficult to achieve. It appears that the direct transfer of aircraft and marine thrust generator technology will not yield the results expected of it when it is applied to surface effect vehicles.

The only other alternative to the air propeller or ducted fan for the propulsion of an amphibious surface effect vehicle is traction propulsion. This blinding flash of the obvious bears some examination. While not a new concept, the propulsion of ACVs by tracks or large low pressure tires is being examined with renewed interest. The principles involved in traction propulsion or 'surface impulse propulsion' (SIP) as is the present more common name, are quite complex and in many phases empirical in nature. The theory of tire and track thrust generation is rather extensively treated by Bekker (1, 2, 3). However, for completeness, some of the more elemental aspects are included herein.

The net tractive force or draw-bar pull that a wheel-ground system develops is dependent on the contact area, load on the system, and the terrain properties. Bekker (1) presents a qualitative description of the mechanism of traction. A wheel loaded by a vertical weight deforms and generates a footprint on contact area. The shape of the footprint is a function of, in addition to the applied load, the free unloaded tire configuration; i.e., diameter, height, and width.

Perhaps the more difficult element to grasp in the traction question is the terrain properties. Not so much in the laboratory, but in the real world the surface is not only non-homogeneous but its properties vary with depth. Reference 2 addresses two limiting soil conditions. The first case concerns, a 'plastic' surface. In general this is wet clay or snow and gains its cohesion through the intergrain bonding of capillary forces. This cohesion value does not change to any great extent with the applied load. The second case considered is that of a dry powdery terrain where the surface particles are loose and free to move about. In this case however, the resistance to sliding is determined by friction laws and is related to the applied normal load.

The real situation of course is considerably more complex. However, it is reasonable to combine the above cases and form a gross thrust equation for an actual terrain.

$$T_g = Ac + W\tan \phi$$

Where c - coefficient of cohesion
ϕ - friction angle

There is one additional factor that needs to be examined before the net thrust of a wheel-terrain system is established and that is the wheel resistance to motion. Here also there is no escaping complexity. Bekker in Reference 3 states that "this aspect appears to be beyond solutions with a workable analytical model." The resistance phenomenon involves wheel sinkage and, in extremely fluid surfaces, i.e., mud, wave patterns similar to those experienced in motion of bodies on a water surface.

Estimate for the motion resistance of a deformable (Pneumatic) wheel is approximately given (from Reference 3) as

$$R_m = R + R_i$$

where (i) R_i is the resistance due to the elastic internal material deformation

$$R_i = Wu/p_i^a$$

(ii) R is the motion resistance caused by compacting and sinkage of the wheel.

$$R = \frac{b(P_i - P_c)^{n+1)/n}}{(K_c + bK_\phi)^{1/n}(n+1)}$$

In the above equations u and a are empirical constants while b is the wheel width. K_c and K_ϕ are soil constants.

The thrust developed by a rolling powered wheel can be given as:

$$T = T_g - R_m$$

$$= Ac + W\tan \phi - R - Ri$$

Surface impulse propulsion over a firm surface does not appear unreasonable and in fact, has been developed to a relatively advanced degree in the all terrain and snowmobile vehicle fields. Wheel propulsion over water or extremely liquid surface is, it would seem, another matter. One form of surface impulse propulsion over a liquid surface is, of course, the paddle wheel which has been in existence for a long time indeed. In its unarticulated form this system has relatively low propulsion efficiencies. The major reason for the low performance is the local

surface turbulence generated by the off axis entry and exit of the paddles. Spray generation and surface ventilation of the suction side of the blade represent losses. One solution to this question is the articulation of the blades such that the water entry and exit is performed in a vertical orientation. This, of course, involves considerable system sophistication in addition to increased weight and possibly decreased reliability. Disposition of cleats or paddles on a track (endless belt) or on a large diamter wheel would tend to decrease the losses, however, not eliminate them.

A relatively recent and novel development is the addition of flexible membranes or webbing between unarticulated paddles arranged on a rotating wheel (Figure 2). With internal pressurization a type of pseudo blade articulation is achieved. Before water entry, the flexible surface in convex in configuration due to the higher interval rotor pressure. As the blade enters the fluid the membrane adjusts as dictated by local dynamic pressures. In this process the ventilation of the suction side is prevented and the blade water entry is relatively clean. When fully immersed the membrane forms a concave scoop or a traction cleat. A similar situation occurs on blade exit. As the membrane leaves the water surface it reverts back to its convex form and serves to spill the fluid off the paddle thus preventing the generation of spray.

It is this capability of controlling the rotor internal pressure and hence the stiffness or contour of the interblade membranes that make the surface impulse propulsor a hybrid system and truly an alternate propulsion scheme to the air propeller. Not only do the membranes improve propulsive efficiency and provide a buoyant system but by adjusting the internal rotor pressure the operator can taylor the wheel's traction effort to the particular terrain. For instance, over a compact surface the pilot can select sufficiently high internal pressure which will insure that the membranes are always convex - these then act as treads or cleats. Over a highly fluid surface the rotor internal pressure is lowered and the paddle blades act as the cleats (Figure 3).

While this concept of surface impulse propulsion is in the formative stages of development it may be worthwhile to take note of some preliminary results. The thrust/horsepower ratio for SIP is in the neighborhood of 20-40$\#_f$/hp while values for air propellers range from 2-5$\#_f$/hp (5,6). The question of efficiency is always controversial; however, for similar constraints it appears that SIP propulsive efficiencies of over 80% are readily achievable (5,7) while, as pointed out earlier, air propeller efficiencies of 50% are difficult to realize under actual operating conditions. The traditional rule of thumb of 33% cushion power and 66% thrust power is not valid for SIP surface effect vehicles. The major power demand point on an air cushion vehicle propelled by a traction device becomes the fan lift system.

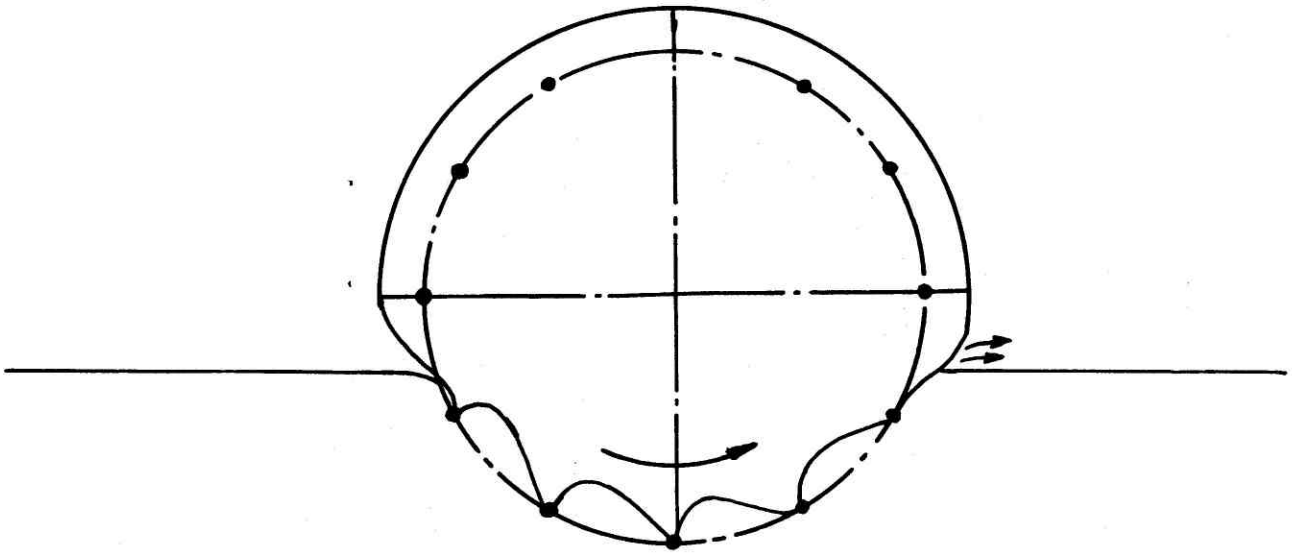


FIGURE 2

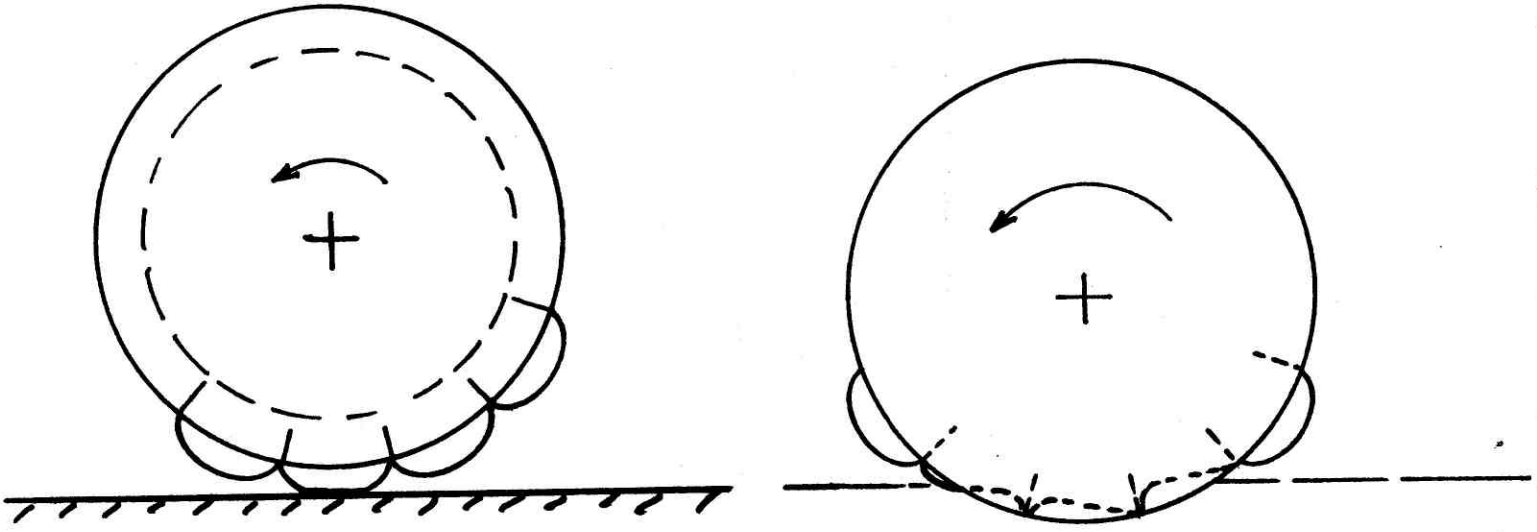


FIGURE 3

TRACTION PROPELLED ACV

It may be worthwhile at this point to examine the impact of surface impulse propulsion on the air cushion vehicle and its subsystems and to discuss some of the advantages and disadvantages of this mode of thrust generation. The most obvious aspect of SIP, as far as the vehicle is concerned, is the fact that an additional variable has been introduced into the lift system considerations. Thrust developed by a traction system depends on the normal load placed on the wheels, tracks or rollers. Thus surface effect vehicles where the thrust generating traction system is on-board the craft have the option of distributing the total weight between the SIP unit and the air cushion proper. Furthermore, the number, location and articulation (steerable) of traction wheels is relatively flexible. If, for a given traction system size, the major portion of a vehicles weight is supported by the propulsor, then stability, manoeuvering, and grade climbing capability are significantly improved. However, foot print pressures are high as well as propulsion system weights and in all likelihood wear rates. On the other hand if the cushion supports the major portion of the weight or at least the payload weight, then improved stability and manoeuvering is retained. However, foot print pressures and traction system weights are low, a desirable aspect from the view of wheel sinkage and tangential thrust production. The question of wheel/cushion load distribution is complex and beyond the intent of this discussion. Our interest is primarily in a true air cushion vehicle propelled by traction.

There are two general locations for the traction system and two mounting methods. The wheels can be located inboard, in the cushion area, or outboard, external to the ACV platform (Figures 4 and 5). The axle of the wheels can be fixed to the structure or mounted on a trailing link arm. Either configuration can have yaw or steering control. For a given cushion height or obstacle clearance capability the fixed axle configuration requires substantially larger volume (Figure 6). The trailing link suspension can accept smaller diameter wheels but will likely suffer periodic loss of contact with the surface due to the system inertia (Figure 7). The question of inboard or outboard wheel or roller location appears to be governed by accessability. Accessability is an important parameter. The traction system, both at the surface contact region (where the rubber meets the road) and the high torque power input at the axle, are high wear elements. Service and replacement access are essential. Inboard traction locations afford access only through the deck, a highly undesirable situation. Outboard location not only simplifies the ACV platform itself but also provides service, maintenance, and replacement accessability. Futhermore, outboard placement provides the opportunity for modularity and system growth and updating.

There are a number of desirable characteristics associated with SIP. Compared to air propellers the vehicle is substantially quieter. The on deck area is uncluttered and lends itself to the placement of modular payloads or superstructures. If provisions exist for load sharing between the cushion and the SIP system then the vehicle has a limited

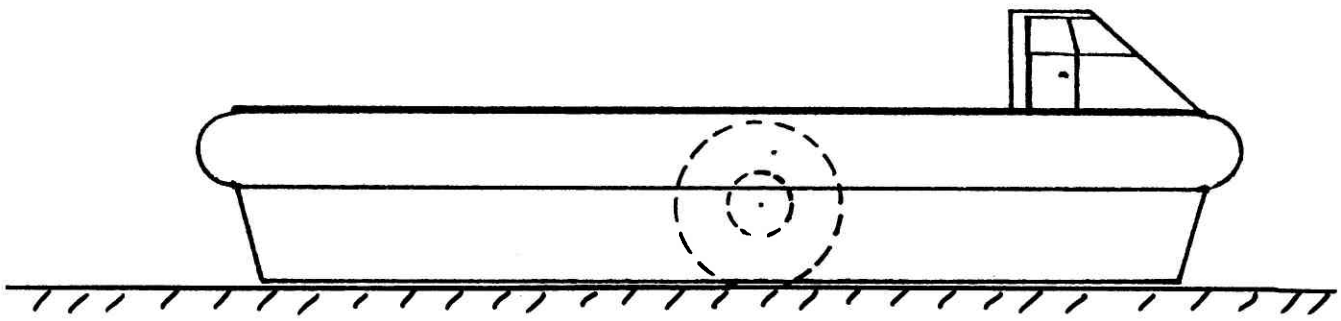


FIGURE 4

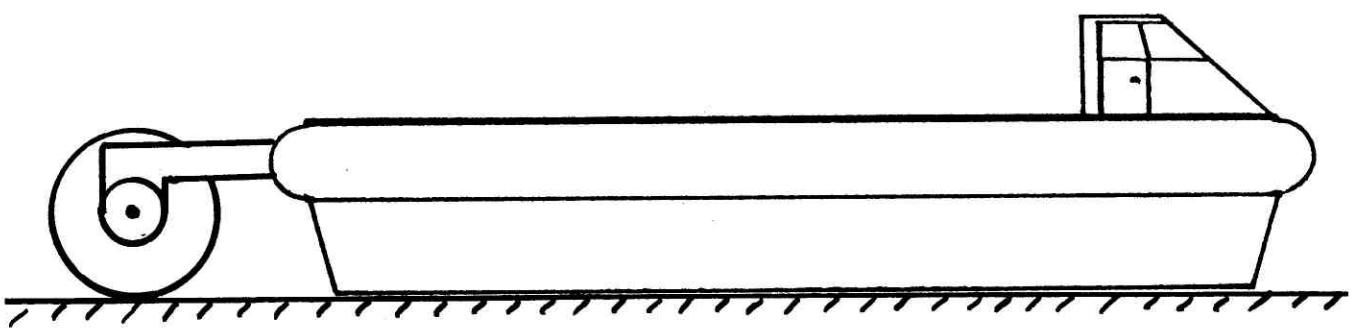


FIGURE 5

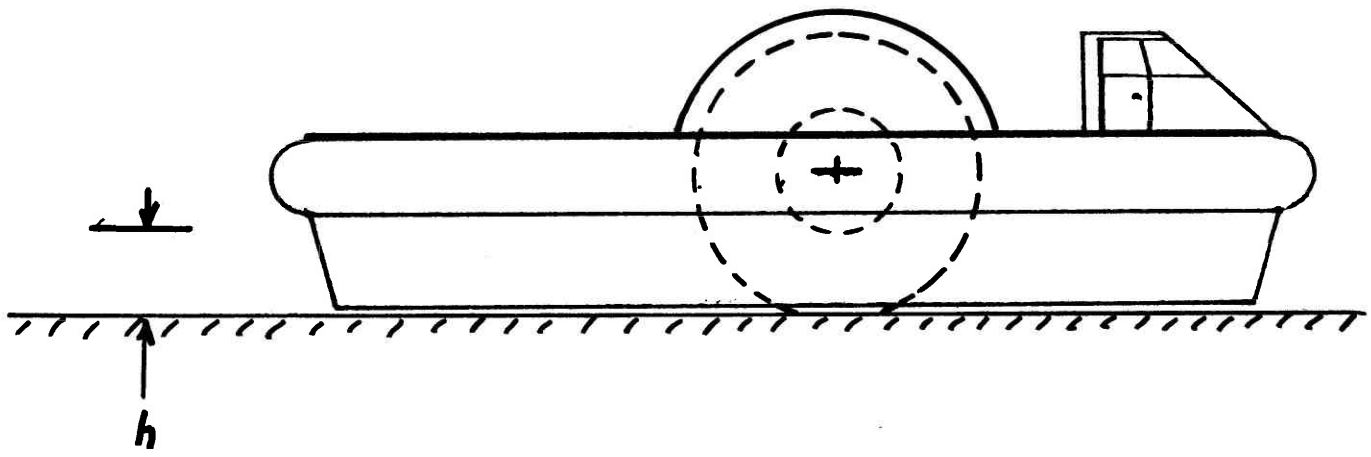


FIGURE 6

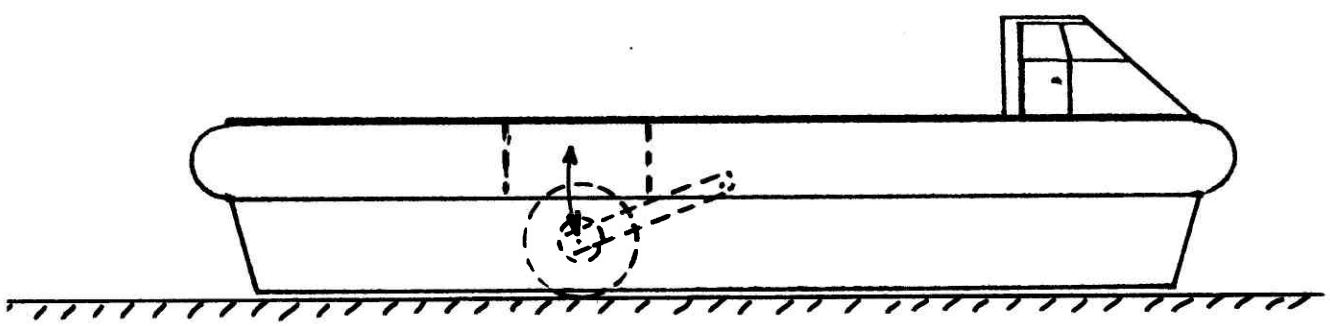


FIGURE 7

'get-off' capability, a highly desirable aspect in ridge and obstacle groundings. Finally, by judicious placement of the traction elements, stability, manoeuvering, and grade capability are improved.

From the cost point of view the SIP system may have certain advantages also. In general traction systems are transplants from the terrain vehicular technology where the system first costs range from $1.50 to $2.50 per pound instead of aircraft technology where costs run $10.00 per pound and up. It is reasonable to expect that operating cost would also be comparable to the technology level.

Unfortunately a traction propelled surface effect vehicle may be size limited. This observation is primarily based on the fact that SIP systems are slow rotational speed and extremely high torque devices. This necessitates not only heavy wheel assemblies but also heavy power transfer shafting and gearing as well as substantial support structures. Some preliminary calculations indicate that for inboard mounted SIP systems the propulsion machinery weight fraction approaches 40% for a vehicle designed for a three ton payload. In the case of outboard, articulated, SIP system, where the traction motor, drive, and cockpit are mounted on the traction wheels themselves, the weight limitation is not as severe. Vehicles of fifty ton payloads appear possible.

There then appears to be a break-off point at two to four ton payloads below which relatively low level technology craft are possible. These would employ internal combustion prime movers costing approximately $10-$15 per horsepower. Larger craft of higher power requirements would necessitate gas turbine prime movers running $100-$175 per horsepower.

SIP MANNED MODEL

To gain an insight into the various aspects of surface impulse propulsion and to identify practical operational parameters a manned traction propelled model was designed and fabricated. It was not the aim to produce an air cushion platform for a specific mission, but only to establish a reference base and to provide a vehicle on which various SIP systems can be tested and evaluated.

The cental element of the vehicle is the air cushion platform unit (Figure 8). For simplicity and versatility this component was configured with the 'jupe' seal system. The seals are compartmented for stability. Vertical curtains divide the figure eight cushion area lengthwise and beamwise. Cushion air is supplied by a squirrel cage centrifugal fan which is driven by an eight horsepower Briggs and Stratton internal combustion engine.

The traction components are mounted outboard of the air cushion region and are free to move in the vertical plane (Figure 9). Directional control is achieved by a tiller steering arrangement which controls the rear wheel yaw angle (Figure 10). The traction drive wheel is also

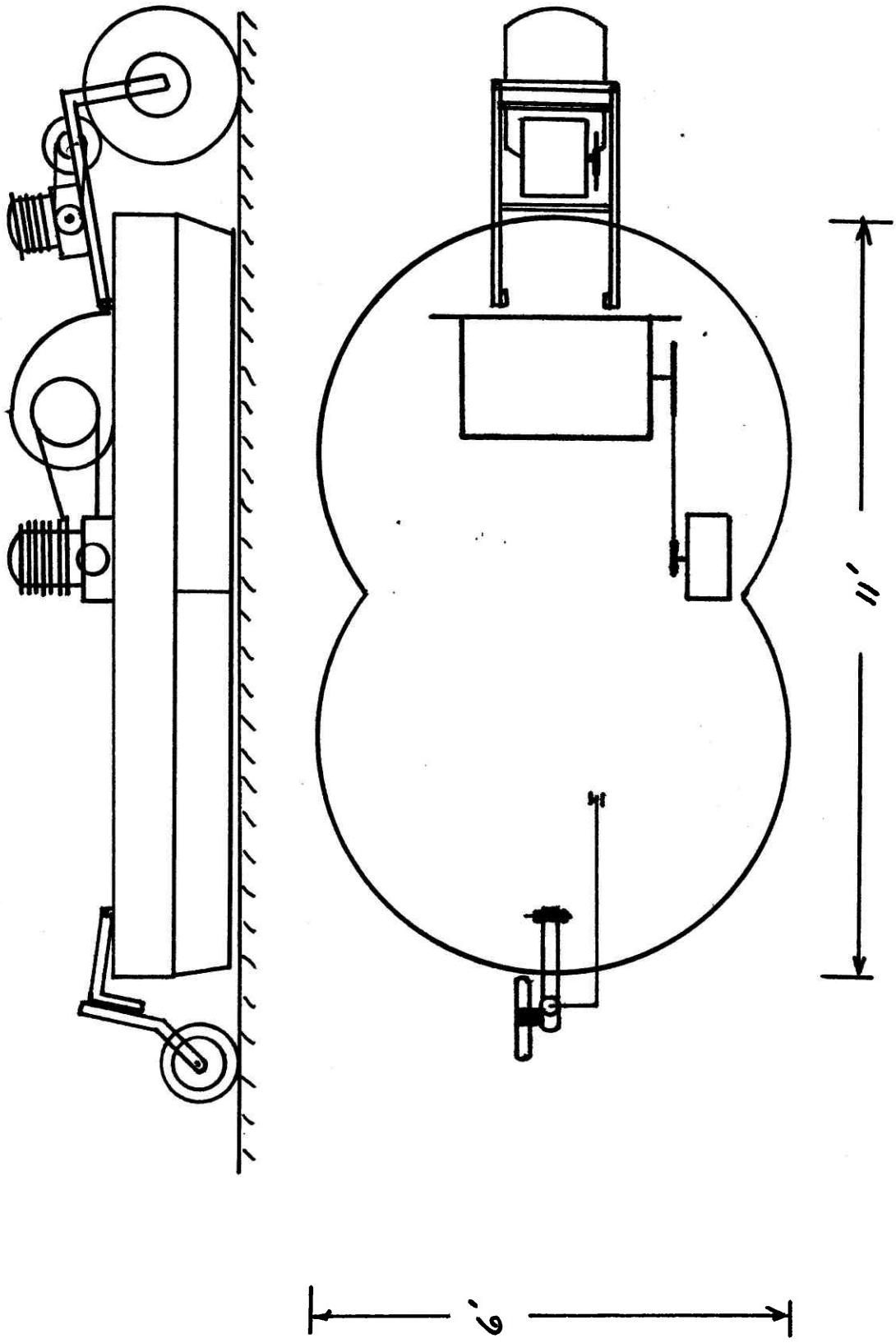


FIGURE 8

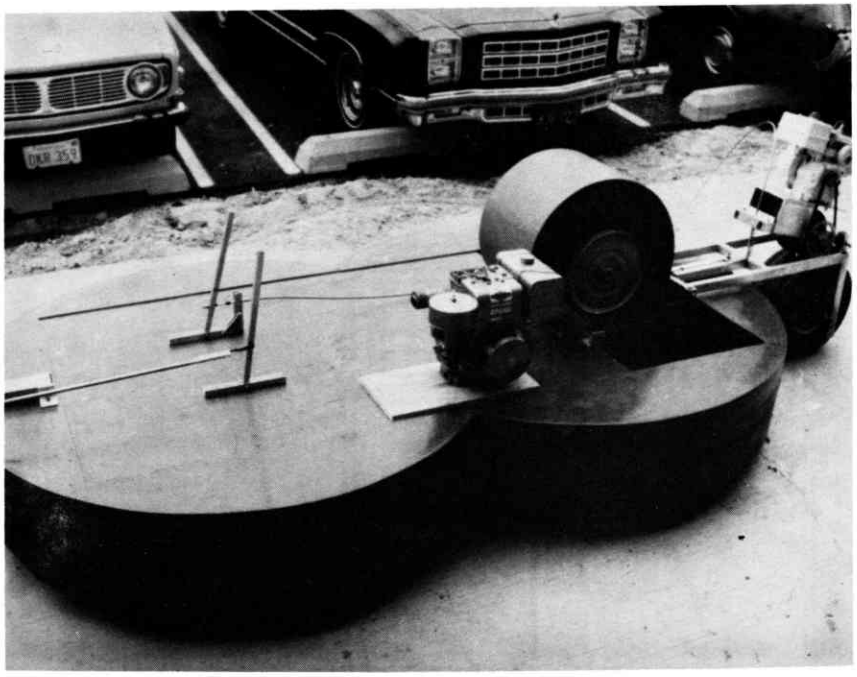


FIGURE 9

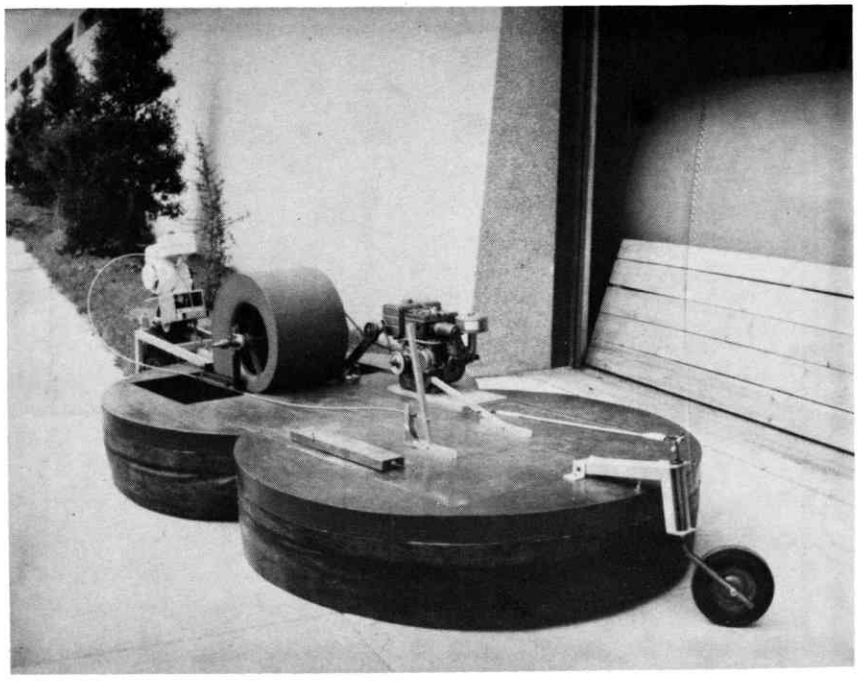


FIGURE 10

mounted on a pitch articulated arm; however, it is not steerable. The propulsion engine is superimposed on the drive wheel structure and engages the drive wheel through a friction drive (Figure 11). Contact between the drive wheel and the engine friction drive is controlled by a 'flexcable' from the pilot station. Both steerable tail wheel and the traction drive wheel articulation arms can be locked in the down position, thus providing mobility and vehicle transfer capability.

Vehicle operations begin with decoupling of wheel lockdown arms (Figure 12). This in effect lowers the central air cushion platform through its full seal height. At this point the traction system supports its own weight plus the weight of the traction engine. Start up of the lift engine and fan system raises the platform on to its cushion and engagement of the traction wheel friction drive establishes forward motion. Operations to date have concentrated on debugging the system and establishing procedures for experimentation. Development of a testing and development program is continuing.

In conclusion Figure 13 is presented to illustrate one concept of a SIP system applied to a large air cushion transporter. The hover platform has clear decks suitable for modular payloads, while the propulsion system, including its command station, is separately contained and supported by the traction rollers.

REFERENCES

1. Bekker, M.G., "Off-The-Road Locomotion", University of Michigan Press, 1960.

2. Bekker, M.G., "Theory of Land Locomotion", University of Michigan Press, 1955.

3. Bekker, M.G., "Introduction to Terrain Vehicle Systems", University of Michigan Press, 1968.

4. Kearsey, J.A., "Rollercraft", Chartered Mechanical Engineer, July 1972.

5. Triem, J., "Surface Impulse Propulsion", Private Communication.

6. Quady, J., "Tangential Flow Systems", Rohr Industries Communication.

7. Dandini, A., "Hydrosphere", Desert Research Institute.

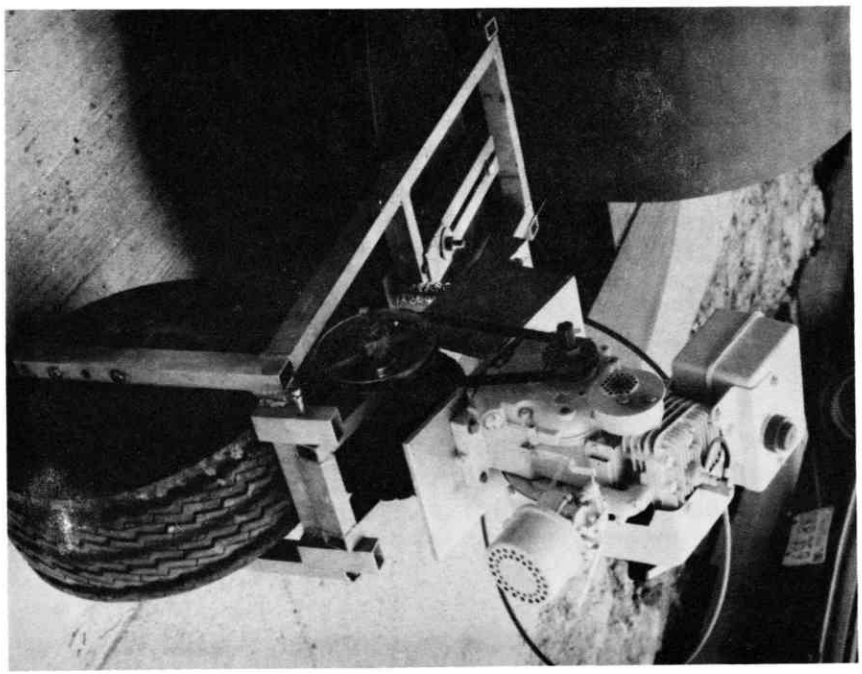


FIGURE 11

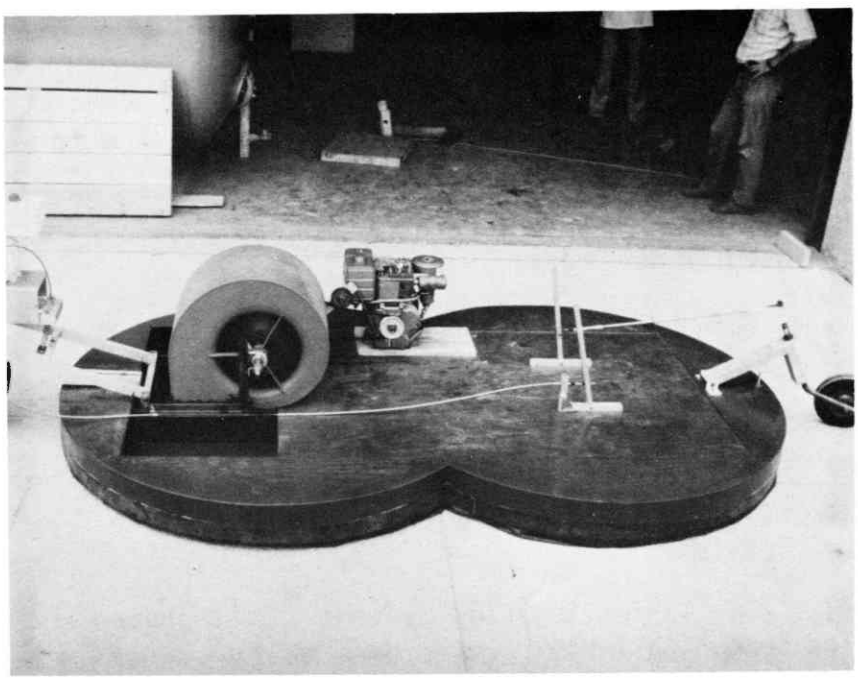


FIGURE 12

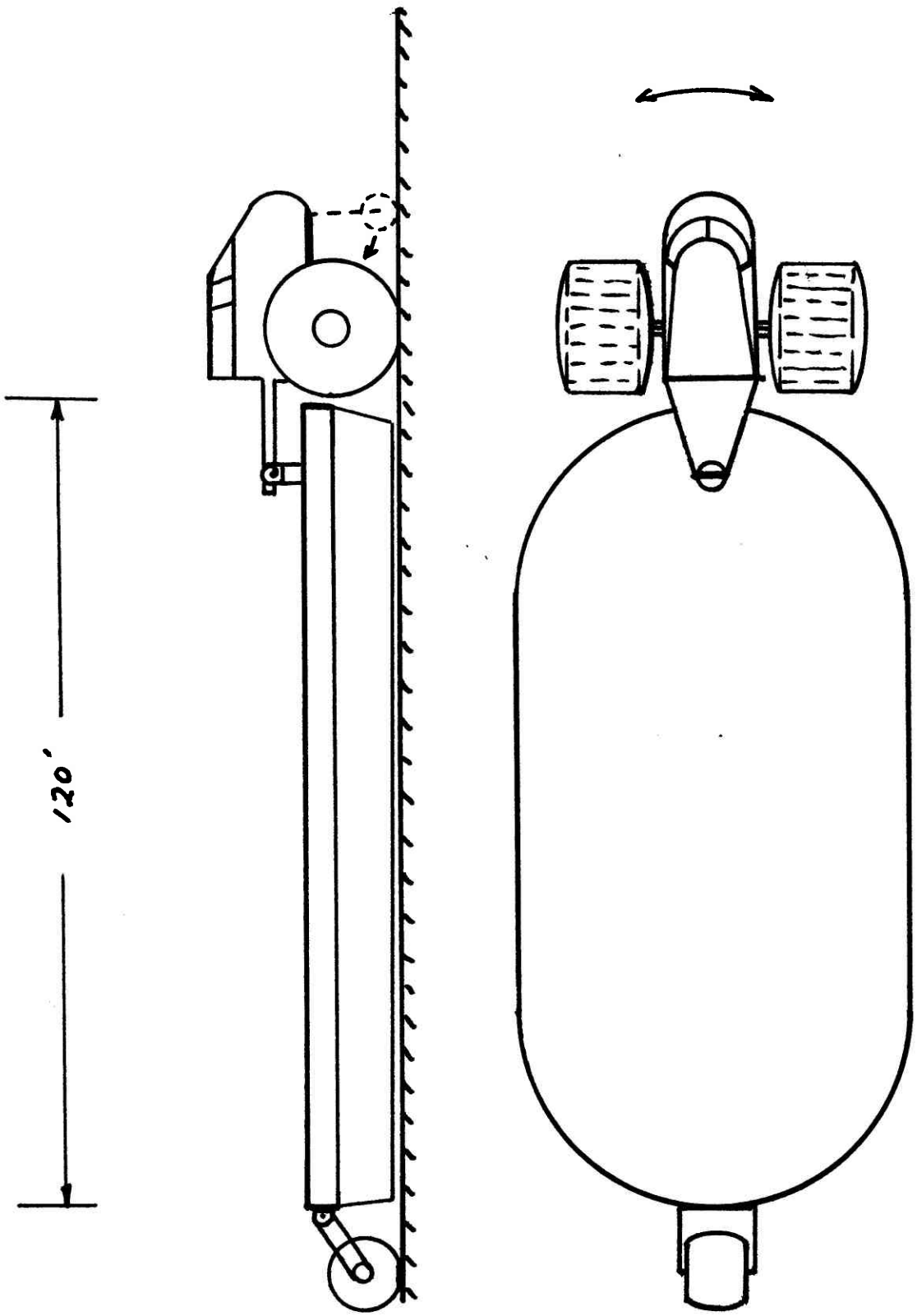


FIGURE 13