SESSION 1

Concepts and Innovation

THE SEGMENTED AIR TRACK AMPHIBIOUS ALL-PURPOSE ALL-TERRAIN VEHICLE

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ABSTRACT

The state of the art of "All-Terrain Vehicles" is examined and found severely wanting. The concept of the Segmented Air Track is proposed as a possible true ATV. The configuration and structure of the SATC is explained and depicted in narrative and with listed advantages over the crawler tractor, the pneumatic tire, and the ACV. Four specific SATC vehicle designs are proposed and described, from a small four-passenger craft to a 50-ton payload tug for use in the Northern offshore oil fields to move the new 300-ton ACV oil rig transporters all year round. A possible solution to the weak road load relief problem is proposed in the form of an SATC conversion of the semi tractor-trailer truck tandem dual wheels to reduce ground pressure and increase flotation. Early calculations of air horsepower demand for four proposed SATC vehicles at various track pressures are provided.

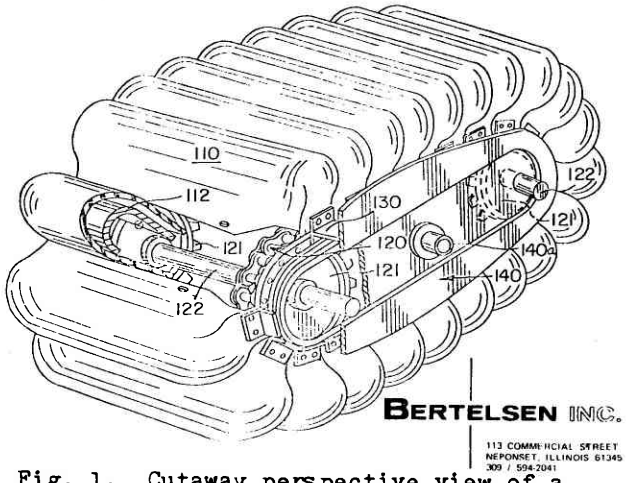


Fig. 1. Cutaway perspective view of a typical dual roller chain, dual pair sprocket Segmented Air Track Unit

At this writing, there is no "All-Terrain Vehicle"which will negotiate all conditions of surface up to 45 degree grades on land and travel on water in all weather, all seasons, all climates the world around. The tracked vehicle, "Snowcat," tank, crawler tractor, etc., are excellent on mud, snow, or sand, but are lost on water; the Rover or dune buggy gets stuck in loose sand, mud, and are also lost on water. The Army Duck does well on solid surfaces and makes slow headway on water, but gets stuck in mud; the Rollegon vehicle does well on soft surface, but capsizes in slipping off solid land or ice into water (Ref. 1); the ACV is fast on any level surface but cannot climb steep grades nor clear high obstacles and has inefficient low speed propulsion; the Archimedes screw vehicle performs adequately on water, ice floe, ice, but is destroyed on rocks, sand, etc. No combination of the above has produced a true "All Terrain Vehicle."

The Segmented Air Track Crawler (SATC), a concept as yet unrealized in hardware, is a proposed new modality of transport combining elements of the pneumatic tire, the crawler tractor, and the air cushion vehicle, possibly resulting in great versatility extending and enlarging the best features of each modality and obviating many of their limitations. It may become a true "All-Terrain Vehicle."

The basic SATC elements are shown in Fig. 1. It is an air cushion vehicle, the skirt segments of which are inwardly open and outwardly closed and are attached and sealed at each end to two roller chains running on four sprockets in orbital fashion like a crawler track. The roller chain also carries a seal which slides against a smooth plate attached to the main frame of the Air Track which mounts the sprocket shaft bearings. This sliding seal can be air lubricated through the slide plate perforations (see Fig. 2). This construction makes an air tight orbiting unit which can be variably pressurized by an external source to the desired degree and allows wide variation in the design height, length, and width of the crawler unit since, in contrast to the crawler track, air pressure, rather than bogies or rollers, carries the load.

The SATC promises to result in a vehicle less expensive than a conventional crawler and more expensive than a pneumatic tire or the simple ACV, but the probable capabilities of this tracked hybrid

and its probable advantages listed below fully justify the cost and the research and development needed to produce it. Again, there is no other "All-Terrain Vehicle" in existence or in prospect. If the SATC lives up to its potential, it will be a product useful in all sizes for many tasks in every part of the globe.

I. Air Track advantages over the conventional girderized roller crawler:

1. Less active machinery, eliminating rollers and their bearings, suspensions, etc.
2. Less first cost and maintenance and operating cost.
3. Greater length and width possible than in roller crawlers.
4. Lighter in total weight with less mass to accelerate positively and negatively.
5. Less internal friction.
6. Capable of higher speed.
7. Variable tread pressures for different tasks or running full or empty.
8. Exclusion of dirt, debris, and water from the mechanism by filter air under pressure, lengthening machinery life.
9. Flotation in water with sufficient volume/weight ratio.

II. Air Track advantages over pneumatic tires:

1. Lower silhouette for given ground contact area.
2. Single contact point vs. multiple points allowing less road flexion and self-cleaning tread.
3. Greater ground contact area, allowing lower ground pressure.
4. Variable ground pressure for different conditions or loads.
5. Greater efficiency of larger Air Tracks because of diminished relative peripheral seal length.
6. No practical limit to size of Air Track, whereas tires are now at technical and economic limit of size.
7. Less internal friction and heat generation.
8. Cheaper first cost, less material used per sq. ft. of traction area.
9. Field repairable without casing removal, compressors, jacks, cranes, etc.
10. Self-damping bounce, inherent shock absorption.
11. Puncture proof.
12. Higher salvage rate for slashed casing. A pneumatic tire would be scrapped; a segmented Air Track can have one or more segments replaced in the field.

III. Probable advantages of SATC over ACV's:

1. Powerful, positive propulsion, steering, braking and control with inherent yaw stability.
2. Steep grade climbing, hill holding, and side hill negotiation.
3. Greater pressures can be economically maintained with the smooth sliding seal and raceway as compared to open bottom ACV skirt with greater air gap dragging over uneven terrain.
4. No great efflux of base air emitted at ground level to stir dust, spray, and debris.
5. More compact units can be designed to make vehicles of massive load carrying capacity "roadable" at very low base pressure.
6. No erosion of the surface, no permeation of the substrate by cushion pressure, and no "sandblasting" of nearby objects occurs since the very small and economical seal efflux occurs well above ground level.
7. The SATC has inherent water flotation in the pressurized compartmented unit.
8. Effective, efficient propulsion and steering on water is inherent because of the great "paddle wheel" area of all moving base of the Air Track unit.
9. In contrast to the ACV, the skirt of which is dragged across rough, abrasive surfaces, there will be little relative motion of the Air Track segments against the ground except tractive effort slippage.
10. Much higher obstacle clearance will be possible with the SATC than with the ACV.
11. Greater economy of lift air power demand is probable even at higher base pressures because of the excellent prepared seal and race vs. the ACV skirt over uneven, varied, rough terrain. Air lubricated seals should reduce friction and wear to near zero.
12. Greater economy of propulsion power is almost certain with positive ground traction vs. the air propelled ACV at relatively low speed and therefore low air thrust efficiency.

USES AND APPLICATIONS OF SATC TECHNOLOGY

When developmental objectives such as sliding seal efficiency, durability, and reliability have been achieved, the applications of segmented Air Track technology are truly vast in types of vehicle, tasks, topographic, meteorologic, and geographic utility.

Proposed SATC Vehicle No. 1

A "Model T" four-passenger truly "All-Terrain" craft is a very real possibility (Figs. 3,4,5,6,7, 8,9, and Table I). Such a rugged utility craft, unlike its nearest rivals, the Cushman Trackster, the four, six, and eight wheel Rollegon vehicles, would be buoyant with full propulsion, steering, and land speed. Water speed of two MPH is the usual velocity for these extant craft. It is my belief that the Segmented Air Track will

achieve "hump speed" and climb out of its static buoyancy immersion depth to travel on the surface above 5-10 MPH, depending on the length of the craft. The descending leading edge of the Air Track segments will climb on the inertia of the bow water; its delay in moving away from the rapidly downwardly cascading segmented belt will force the nose of the craft upward. As the process of applying segment after segment a. faster than the water can yield continues, the entire craft will be lifted to and maintained on the surface as long as the track velocity is sustained. The improved efficiency and increased top speed per propulsive horsepower, if hump speed is achieved, is obvious. A corroborating analogy to this "hump speed" theory is the observed phenomenon of the non-buoyant snowmobile and its ability to skitter across a narrow open water area at high speed without observable sinking. All too many snowmobiles, however, have tragic outcomes on thin ice.

The proposed SATC has 100% gross weight buoyancy in each of its two widely spaced tracks which are designed to be only 50% or less immersed in full gross weight operation. The wide stance, nearly eight-foot beam, plus the great buoyancy of each track unit, should render the craft quite stable and capsize-resistant in sliding off sideways, for instance, from an ice shelf, or a sheer drop shore edge with the water level near or below the solid surface.

Proposed SATC Vehicle No. 2

An Articulated Tandem Dual Segmented Air Track Vehicle for carrying either moderate loads amphibiously, or massive loads on land with very low base pressures of 10 psi or less (Fig. 10, Table II). This roadable vehicle of eight foot maximum width has two articulated units with segmented Air Track belts seven ft. by seven ft. length and width, covering most of the entire bottom of the craft. As shown in Table II, the total base area carrying the load is 98 sq. ft. or 14,112 sq. in. At one psi base pressure the craft will carry 7.056 tons and float in water 27" deep. At 2 psi it carries 14.112 tons and floats 54" deep. At only 3 psi pressing on the ground this craft carries 21.168 tons and in water will be immersed 71". Beyond a gross weight of 21.168 tons or 3 psi, it is, of course, not longer amphibious but continues to carry more and more weight as the base pressure is raised. This small craft carries 70.56 tons of weight at the very low base pressure of 10 psi to bear on the ground, highway, sand, mud, snow, etc. It is a true All-Terrain Vehicle.

Proposed SATC Vehicle No. 3

To illustrate the possibilities for growth of the SATC craft and to offer the offshore oil drillers in the Beaufort Sea an efficient tug for pushing or pulling their 300-ton ACV oil rig transporter, now under construction, on land and sea the year round (Ref. 1), we have proposed a 50-ton payload, 100-ton gross weight vehicle shown in Fig. 11; specifications are in Table III showing four 15 foot square area SATC units on each corner of the craft, each one of which would support 50% of the gross weight when fully immersed and any two of which would support 100% of the gross weight fully immersed, making the craft more stable than barges or conventional ACV's. The total movement of the immersed buoyant parts should provide tremendous paddle wheel propulsion and drawbar pull. On land the traction should be even greater. This too, huge as it is, is a true All-Terrain Vehicle. And this is not the maximum size nor load carrying capacity of the SATC concept. Theoretically, millions of pounds of SATC capacity can be built for amphibious operation.

Proposed SATC Vehicle No. 4

In 1977 (Ref. 2) David Eyre, Senior Research Scientist of the Saskatchewan Research Council, made a plea to air cushion designers to provide lift during the Spring banned period when heavy loads are forbidden on the public roads due to their weakened state during the Spring. To quote Ref. 2, "...there is one compelling argument in favor of such development /air cushion assist for prairies weak road load relief/--the number of potential users is one or two orders of magnitude greater than the total number of potential users of all other vehicle types." In other words, the market for such a device is huge, probably the largest of all ACV markets.

In the 1970's the National Research Council of Canada did extensive studies on air cushion lift assist of semi trailers and other techniques for load relief (Ref. 3). None was considered feasible with "conventional" ACV or extra wheels, Rollegons, etc. Four billion tons of commodities, ore, overlay, and other cargo cross Canadian prairies annually, most of it in semi tractor-trailers, and it slows drastically during the three months of each year as the Spring break-up occurs. This is a period when maximum equipment and materials movement should occur and is, therefore, a severe, continuing, unresolved economic deprivation.

In 1979 the author made two presentations (Refs. 4 and 5) which proposed the conversion of semi tractor-trailer tandem dual wheel sets to enclose them in a belt with peripheral seals, side pressure plates, and external air pressure supply to pressurize the unit to increase the ground contact area from 3 sq. ft. to 30 sq. ft. per tandem dual set to allow reduction of ground pressure to 10 psi or less instead of 75-100 psi.

Continued design work on the Air T Track concept has produced significant improvement in the crawler unit itself, such as the segmented track vs. the early belt design and the mounting of the track on roller chains for positive torque transmission, better track retention, and increased tensile strength. The substitution of inflated segments like ACV skirt "fingers" will allow greater "squash" and better acceptance of surface roughness. The sliding seal was moved radially inward from the periphery to the chain root center line, no longer subject to surface roughness, shorter in length, and stabilized by the rigidity of the roller chain (Figs. 1 and 2). Fig. 1 is an approximation of the appearance of SATC Vehicle No. 4 tandem dual wheel set conversion to Segmented Air Track, and Fig. 2 is a vertical transverse section drawing of a similar unit. Fig. 12 is a horizontal section drawing of the tandem dual set with the wheels removed and three sprockets substituted on the wheel mount studs to carry three roller chains on which both the track segments and sliding seal are mounted. Side pressure plates carry the stationary seal race against which the sliding seal presses, and it may be air lubricated through ports shown in Fig. 2 to reduce friction and wear, increasing durability. The existing dual wheel suspension, axle torque drive, and braking, of the tractor and trailer remain intact and effective.

If feasible, this SATC adaptation and retrofit to existing tractor-trailer units will eliminate the persistent, unresolved prairie weak road relief problem. It would also allow off-road operation of these rigs and overload condition on-road the rest of the year. To reiterate, this could be the greatest of all ACV markets.

CONCLUSION

We have only begun to experiment with orbiting SATC seals and can logically expect improved seal efficiency and less leakage through innovation of seal techniques. As ACV operators, we are accustomed to vast air volume flows at low pressure escaping from the base of our vehicle skirts when on cushion, and dedicate about one-third of the installed horsepower expenditure to lift air. In the Air Track with our early, first generation seals, we can expect a constant seal gap and therefore a graduating air supply demand increase with increasing track pressures and increasing Air Track vehicle size. The Air Track alone, in contrast to the ACV, allows base pressure to rise above one or two psi maximum.

Table IV shows calculated raw horsepower demands of each of the four proposed SATC vehicles described herein at track pressures ranging from one to 10 psi assuming a seal gap of 0.001 inch. This air gap is only an assumption and presumes no improvement over a mere smooth race with low friction seal materials sliding over it. Air lubrication is not considered, nor is any estimate of seal friction included with or without air lubrication. It is very early in Air Track art. The SATC is at about the same stage as the ACV was before the advent of the Bliss segmented finger skirt which produced at least an order of magnitude increase in lift efficiency.

The Segmented Air Track concept in any of its variations is hereby proposed for further R&D and field testing to determine the full range of its application and utility.

TABLE I Specifications of "Model T" Four-Passenger Segmented Air Track All-Terrain Vehicle: Gross weight, 3,000 lbs.; Empty weight, 2,000 lbs.; Payload, 1,000 lbs. Flotation (fully amphibious): in tracks @50% immersion, 4,800 lbs.; in Hull, 3,000 lbs. Track dimensions: overall length, 90"; overall height, 42"; width, 18". Power: 50 HP gasoline engine. Speed: on land, 20 MPH+; on water, 10 MPH+. Grade climbing: 45 degrees. Obstacle clearance: 16". Tread pressure on ground @3,000 lbs. gross wt.: 1.4 psi (area of tread contact 60" x 18" x 2 tracks = 2,160 sq. in.

TABLE II Capacities of Articulated Tandem Dual Segmented Air Track Vehicle (two 7'x7' crawler tracks carrying the vehicle, total 98 sq. ft. (14,112 sq. in.) weight bearing area:

PSI	Carrying Capacity	Flotation Depth
1	14,112 lbs. (7 tons)	27"
2	28,224 lbs. (14.1 tons)	54"
3	42,336 lbs. (21.2 tons)	71"
10	141,120 lbs. (70.6 tons)	--

TABLE III 50 Ton Air Track Tug Specifications: Overall Dimensions, Height on solid surface on cushion, 21 ft.; height on solid surface off cushion, kneeling, to well deck, 8 ft., overall, 17 ft.; Width, 38 ft; Length, 56 ft.; Well Deck and Cargo Bay dimensions: Depth, 6 ft., Width, 32 ft., Length, 45 ft.; Gross weight, 210,600 lbs. (105.3 tons). Flotation, Fixed permanent in structure, 220,000 lbs. (110 tons and 4.7 tons greater than gross weight); Maximum Air Track Buoyancy at 100% immersion, 421,200 lbs. (210.6 tons or twice the vehicle gross weight). Normal Air Track Buoyancy at 50% of track height immersion (25% of track length immersion), 210,600 lbs. (105.3 tons, equal to craft gross weight). Maximum Payload of full gross' weight, 114,600 lbs. (57.3 tons). Power: Four 1,000 HP Diesel engines. Tread Pressure on ground: 2 psi. Speed: On water,

two to 20 knots; on land, maximum 30 kts. Grade climbing: 45 degrees or whatever slopes traction will allow. Drawbar Pull (estimated): On water, 80,000 lbs. On land, 160,000 lbs. Maximum Obstacle Clearance, 8 ft.

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6. Liepman, H. W., and Roshko, A., Elements of Gas Dynamics, p. 139. (John Wiley & Sons, Inc., New York, 1957).

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TABLE IV		"Model T" Four-Passenger SATC #1	Articulated Tandem Dual SATC #2 Whole Bottom Area Tracks	50-Ton Payload Air Track Tug SATC #3	Semi Tractor-Trailer Tandem Dual Wheel Conversion to SATC #4
Total Seal Length		720"	720"	2,880"	800"
Total Seal Orifice A*		0.001"	0.001"	0.001"	0.001"
PSI $\left(\frac{P_o}{P_a}\right)$ in Air Track Chamber	A° Speed of Sound in Air Track Chamber ft./sec.	Seal Air Horsepower Required	Seal Air Horsepower Required	Seal Air Horsepower Required	Seal Air Horsepower Required
1	1128	0.89 HP	0.89 HP	3.57 HP	0.99 HP
2	1137	1.87 HP	1.87 HP	7.47 HP	2.08 HP
3	1147	2.93 HP	2.93 HP	11.73 HP	3.26 HP
4	1157	4.08 HP	4.08 HP	16.33 HP	4.54 HP
5	1165	5.31 HP	5.31 HP	21.24 HP	5.90 HP
6	1172	6.60 HP	6.60 HP	26.43 HP	7.34 HP
7	1181	8.00 HP	8.00 HP	32.00 HP	8.89 HP
8	1188	9.45 HP	9.45 HP	37.81 HP	10.50 HP
9	1195	10.98 HP	10.98 HP	43.92 HP	12.20 HP
10	1202	12.58 HP	12.58 HP	50.33 HP	13.98 HP

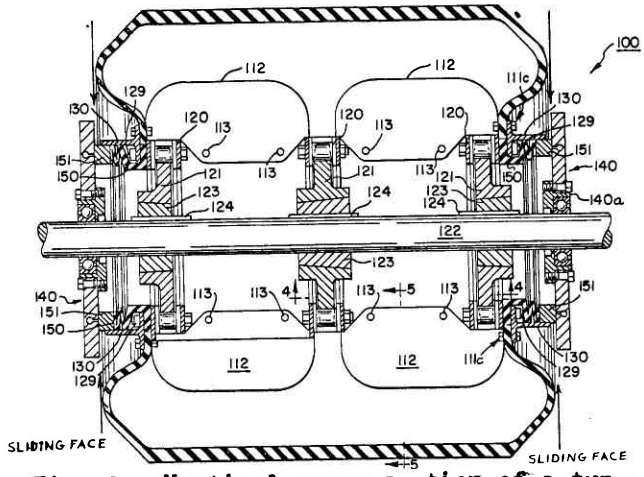


Fig. 2. Vertical cross section of a typical triple roller chain, triple pair sprocket Segmented Air Track Unit showing skid rests 112, slide plate 140 with air lubrication ports and sliding seal 151

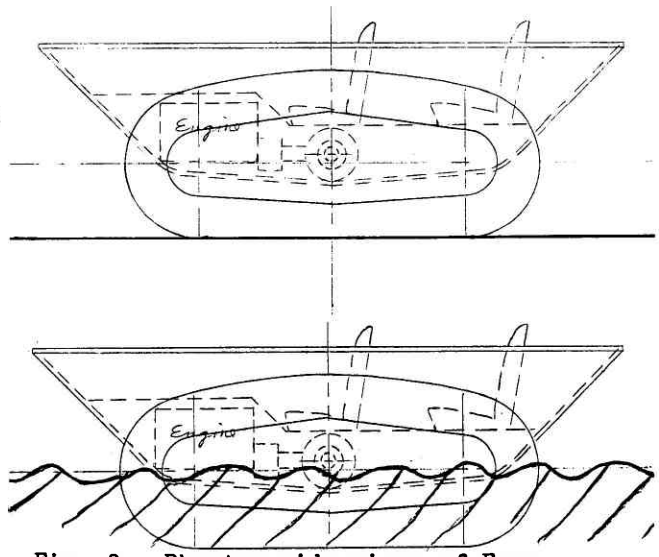


Fig. 3. Phantom side views of Four-Passenger Dual Air Track chassis only, without canopy, shown on land and in full amphibious operation in water in hydrostatic Air Track buoyancy

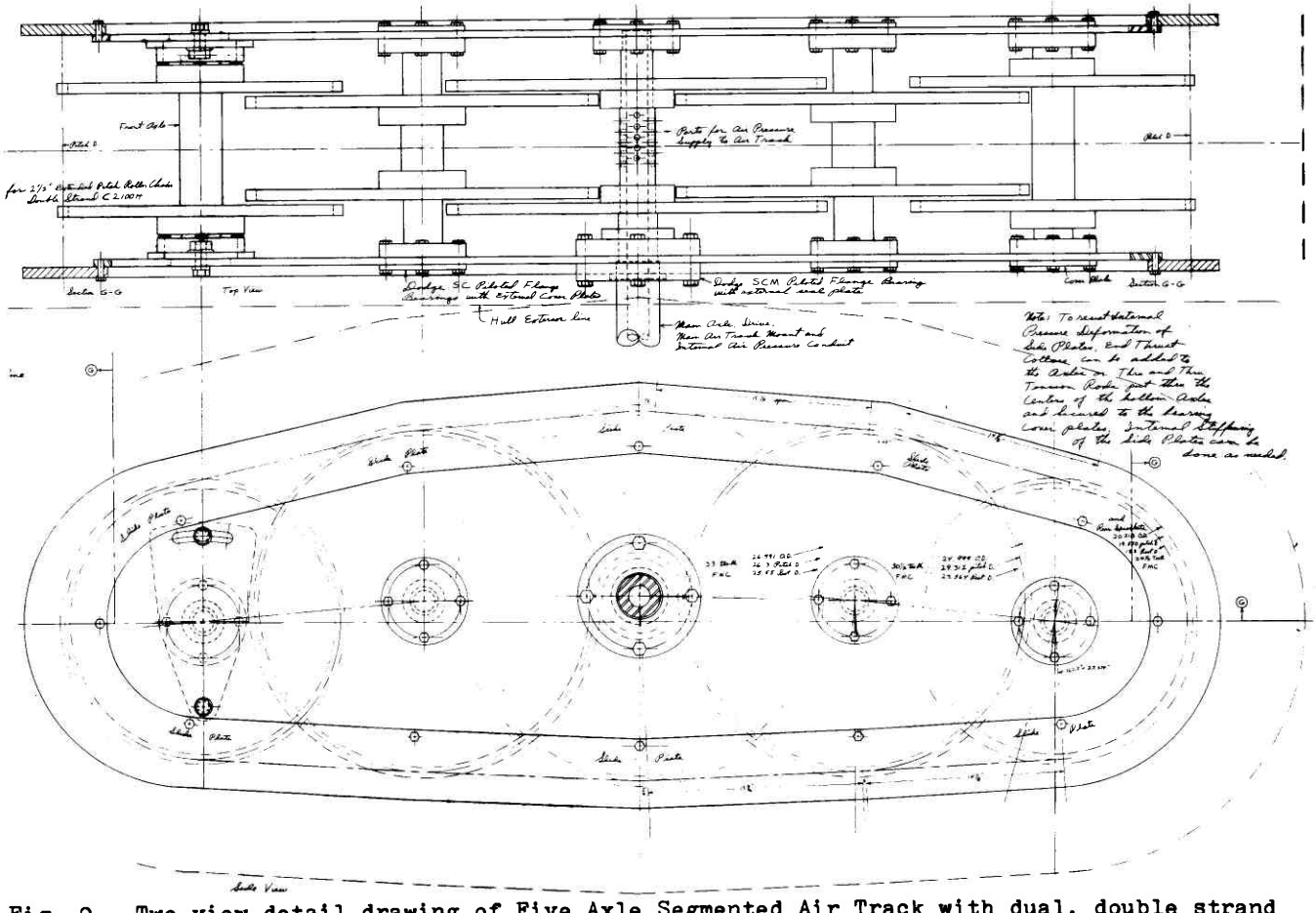


Fig. 9. Two view detail drawing of Five Axle Segmented Air Track with dual, double strand roller chain segment and seal mount.

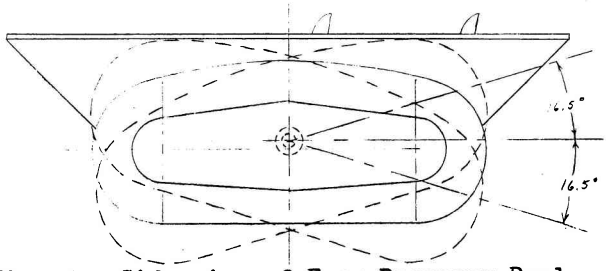


Fig. 5. Side view of Four-Passnger Dual Air Track chassis showing 33° total track oscillation range.

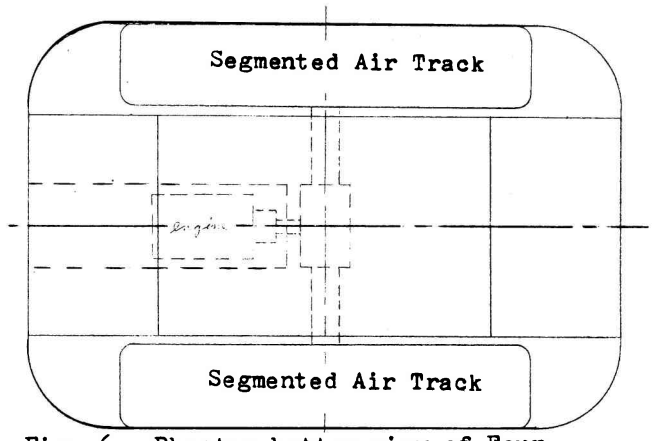


Fig. 6. Phantom bottom view of Four-Paseenger Dual Air Track illustrating track area, engine, transmission and drive.

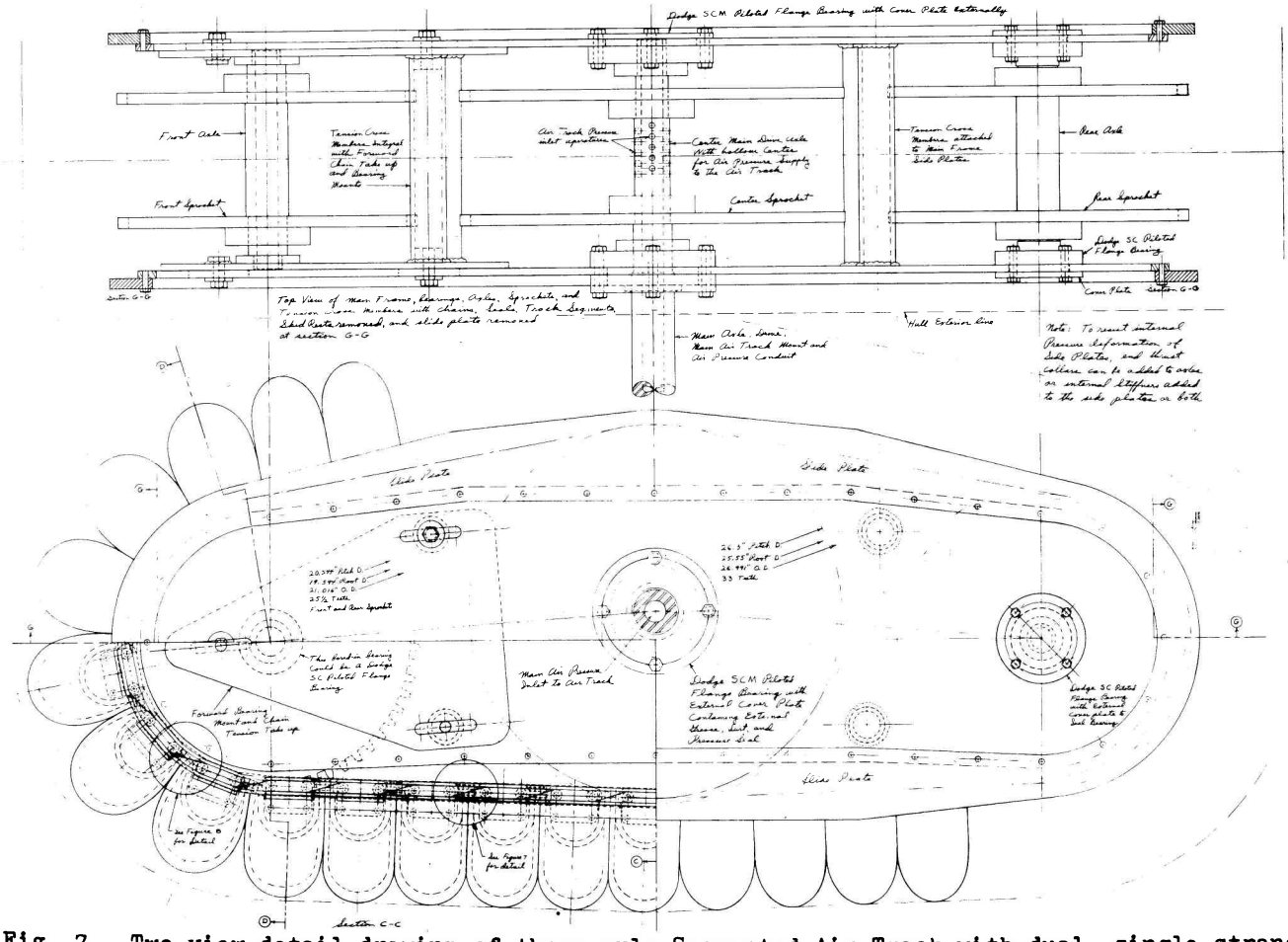


Fig. 7. Two view detail drawing of three axle Segmented Air Track with dual, single strand roller chain segment and seal mount

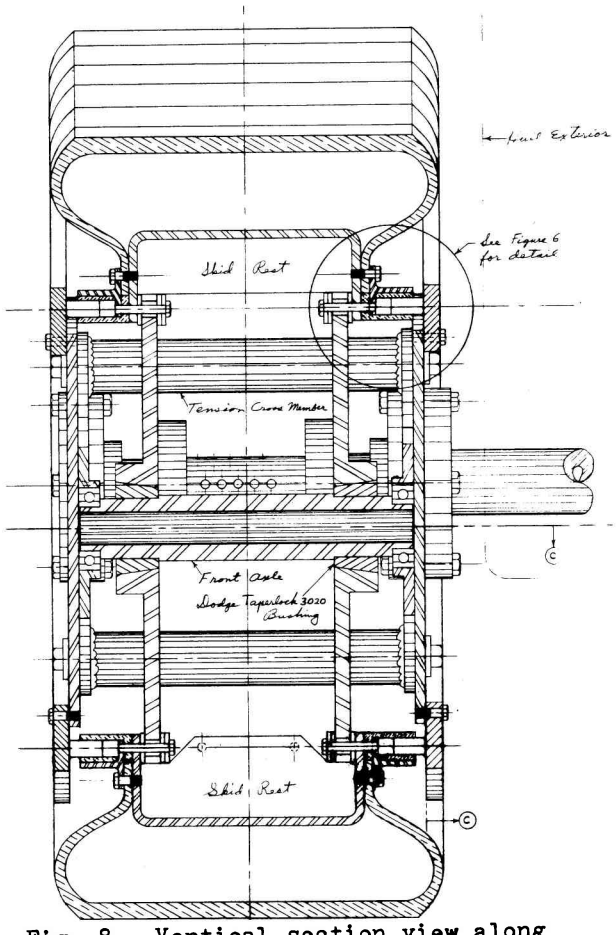


Fig. 8. Vertical section view along section D-D of Fig. 7

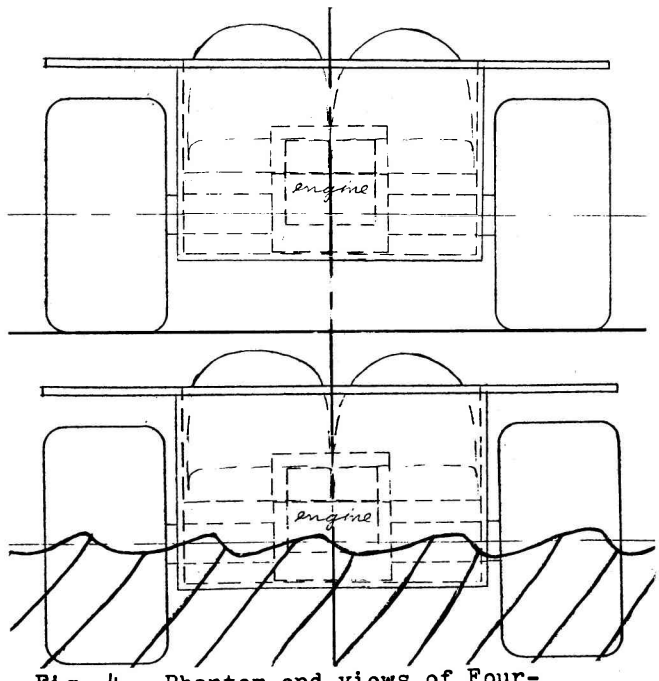


Fig. 4. Phantom end views of Four-Passenger Dual Air Track chassis shown on land and in hydrostatic Air Track buoyancy in water

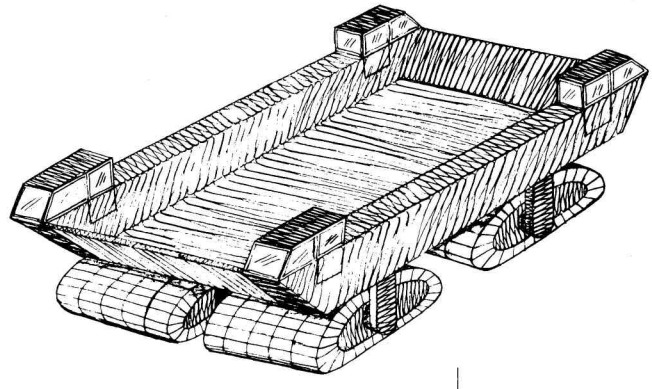


Fig. 11. 50 Ton Payload Air Track Tug

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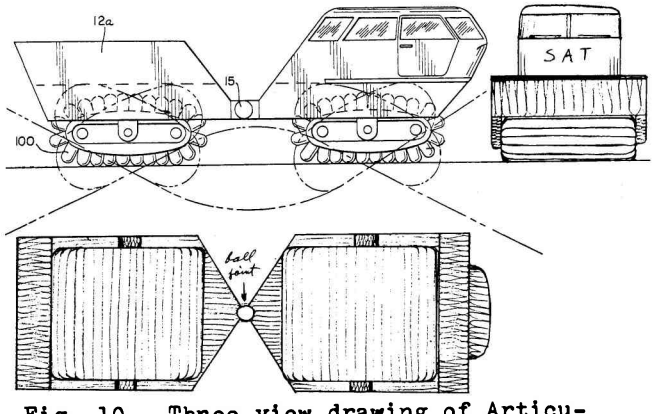


Fig. 10. Three view drawing of Articulated Tandem Dual Segmented Air Track Vehicle with near total base area Air Track

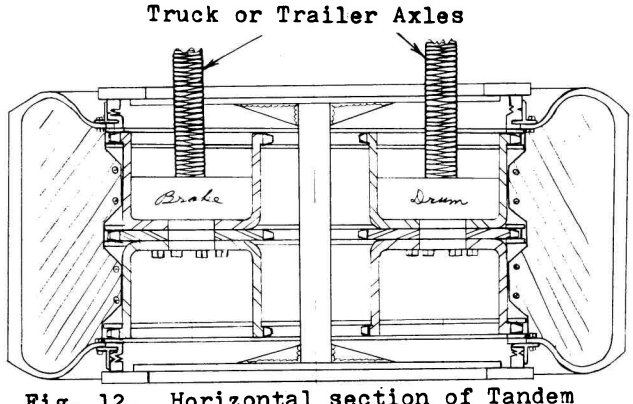


Fig. 12. Horizontal section of Tandem Dual Semi Tractor-Trailer wheel set conversion to Segmented Air Track Crawler

COASTAL SHALLOWS AND THE NUCLEAR DETERRENT: AN ALTERNATIVE BASING MODE FOR THE MX MISSILE

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I.

The recent Congressional decision not to appropriate funds for the "dense-pack" system proposed by the Reagan Administration for the MX missile has thrown into sharp focus a critical problem at the heart of our national security. Most members of Congress, and much of the public, seem to agree that the MX missile is necessary for maintaining the U.S. strategic deterrent in top form; by replacing older and less efficient missiles in the U.S. strategic arsenal, the MX would add significantly to the continued credibility of the American deterrent. The problem, however, is that so far no acceptable method for basing the MX has been found.

The "dense-pack" system, for instance, suffers from serious flaws which no amount of political pressure by the Administration can obscure. First, its reliability and effectiveness are highly questionable, which explains why most of the Joint Chiefs have harbored grave reservations about it. Moreover, the serious questions revolving around the system's reliability are almost intrinsically unanswerable since it would be impossible to test the system under conditions resembling those of a massive Soviet nuclear attack. A second flaw has to do with the great risks involved in concentrating all the MX forces in a few limited areas; were the Soviets to succeed in developing techniques for frustrating the system, it would take only a few of their missiles to destroy or incapacitate a large component of the U.S. strategic arsenal.

Strategically, as well as morally, "dense-pack" suffers from two other major defects. It places before Soviet planners the alluring temptation of figuring out a way to destroy the U.S. land-based deterrent through one giant knock-out blow or a small number of skillful, well-targeted attacks. And "dense-pack" would insure that any such attack, even if it turned out to be a mistake and failed to eliminate the MX, would still destroy much of the U.S. heartland and the large urban centers of the Midwest and the eastern United States. Prevailing West-East winds would carry the nuclear fallout across these areas, destroying, perhaps irreparably, the rich agricultural and industrial resources of the nation and leaving tens of millions dead. This last problem, not unique to "dense-pack", is one that needs to be reassessed as the country looks for innovative ways to deploy its updated nuclear deterrent.

One such innovative alternative is to base a portion of the MX arsenal aboard a number of high-speed surface ships that would operate in that area of our territorial waters known as the coastal shallows. The technology for building medium-sized vessels capable of carrying and firing two or three MX missiles and reaching speeds equivalent to 50 and 60 m.p.h. is already available. Moreover, unlike "dense-pack" and other proposed basing modes, the effectiveness and reliability of this system could be tested under conditions closely resembling those of an enemy attack. It would not be necessary to wait for a real nuclear barrage to find out if the key elements of the system work. These elements are: first, the advantage enjoyed by a launching platform moving at high speeds in a random direction against a direct hit or partial incapacitation by incoming enemy missiles; and second, the platform's reactive capacity to launch its own missiles accurately and while in motion.

Mobility would be the most valuable advantage, and one which this particular system would capitalize on with the utmost effectiveness. Some proposed basing modes for the MX, such as multiple underground tracking, incorporate mobility but only during the transportation stage; launching takes place at a fixed position. On the other hand, airborne basing modes, while providing mobility at both stages of transportation and launching, do so only by sacrificing target accuracy. A high-speed surface ship could serve simultaneously as a moving transport and launcher without sacrificing target accuracy. The most important component of target accuracy is keeping continuous track of the exact location of the launching platforms. Through advanced satellite reconnaissance and communication technologies it is possible for a surface vessel to maintain an accurate reading of its own position. These technologies could be complemented by an extensive, but inexpensive, network of buoys in coastal shallows which, when combined with already existing shore-based position stations and regular coastal landmarks, would enable the vessel to ascertain its exact location at all points. Target accuracy would be preserved.

The immense value of maintaining mobility from the storage and transportation stages all the way through launching cannot be overemphasized. It is a commonplace that moving targets are more difficult to find and attack than fixed ones, and that this difficulty increases with the speed of the movement. Speed advantage scales as a quadratic function. For example, a 2-knot advantage over 10 knots is as 12 to 10 or 144 to 100, almost a 50% improvement. The small advantage accrued by a single additional knot of speed can well mean the difference between, on the one hand, destruction or incapacitation by incoming enemy missiles, and

survival on the other. Thus, a launching platform whose movement is fast enough to cause a ten-mile miss by an enemy warhead has reduced the probabilities of its incapacitation from almost 100% to about 2.5%.

Two further advantages should be underlined. Firstly, there is dispersion. By distributing a number of MX missiles among a number of mobile launchers the risk of their total incapacitation is considerably lower than if they were concentrated in a single area. Secondly, an enemy attack on these MX's would not necessarily entail vast destruction of the nation's population, cities, industry, and ecological system.

II.

The coastal shallows offer an excellent basing area in several respects. A sea-going mode of transportation and launching is likely to be much more energy-efficient than either land or airborne ones. Like airborne systems, but unlike land systems, a water-based platform also can move randomly along an almost infinite number of "tracks" in ever-changing directions, thereby gaining a degree of freedom of mobility unavailable to any land-based mode. The choice of the coastal shallows preserves these advantages proper to sea-going systems, while incorporating some of the benefits of land-based ones. Vessels in the coastal shallows are fairly well protected from enemy attack submarines and bombers, and they can enjoy close logistical, technical and directional support from shore bases.

Coastal shallows can be best described as those waters within U.S. jurisdiction whose depth ranges up to 60 feet or 10 fathoms. Of the vast area encompassed by the coastal shallows, about 90,000 square miles represents the total surface realistically available to medium-sized vessels capable of carrying and launching the MX, and requiring a depth zone of 20 to 60 feet. Accurate surveys of these waters are available, making possible safe navigation even under adverse weather conditions.

A planing-hull vessel would be the most capable of combining the characteristics necessary for an MX water transport-launcher: speed, capacity to carry at least two missiles, and full operational capabilities for coastal shallows. The technology of planing hulls has advanced considerably since the early designs of Campet around the turn of the century. It was another Frenchman, Tellier, who built the first stepped bottom planing hull craft in 1908. The stepped hull allowed air to be fed from the hull's sides into the planing surface aft. This method of bringing air to the planing surface as a lubricant worked well in smooth waters, but in rough seas the air path from the hull's sides could be cut off by waves or the craft's own rolling motion, resulting in increased planing surface drag and lower speeds. In 1915, Muller-Thomamuhl attempted to solve this problem by a design using a blower that would provide a continuous air supply to the planing surface.

Subsequent improvements in craft design and power plant technology have made possible the attainment of ever higher speed records, as the following table indicates:

1939	141 m.p.h.
1950	160 m.p.h.
1952	178 m.p.h.
1955	200 m.p.h.
1963	276 m.p.h.
1967	285 m.p.h.
1978	319 m.p.h.

This increase in speed has been a function of the greater engine power available to the craft designer. Indeed, planing hull vessels are more efficient in translating greater power into higher speed than hovercraft, hydrofoil and conventional surface or subsurface ships.

The recent development of Wave-Forming Keels has cleared the way for solving the main problems that had limited the usefulness of planing-hull vessels. These problems were the maintenance of a constant air supply to the planing surfaces and the difficulties associated with slamming loads in rough seas, and severe restrictions on the craft's size and carrying capacity which are typical of air-cushion and hydrofoil vehicles. The Keels themselves are simple, free-flooding structures located on the bottom of the planing hull for the purpose of adding planing lift to the craft. The air path from the aft area of the Wave-Forming Keel provides a reliable supply of air for lubricating the hull's surface under any sea conditions. When the load structure is aligned with the transverse bulkheads of the hull's bottom, multiple Wave-Forming Keels stiffen the craft's longitudinal framing system, thereby allowing high impact slamming loads in rough seas, and permitting increases in the vessel's size and load capacity to comply with the deployment requirements of at least two MX missiles.

Concept Model
Wave-Forming Keel Ship

2, LM - 2500's = 50,000 H.P.
Ship = 625 Tons Max.
500 Tons, Operational

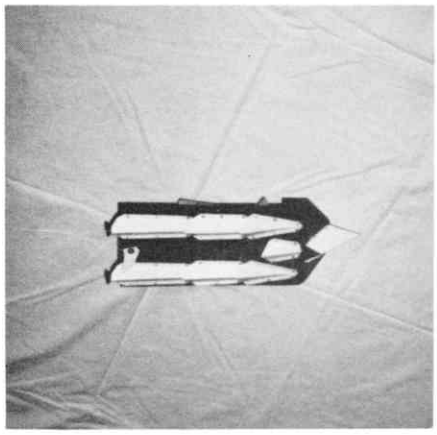
Design Factors

$\frac{\text{Weight}}{\text{Power}} = \frac{25\#}{1\ \text{H.P.}}$

Orlop Size

$\frac{B}{L} = \frac{1}{2}$ B = 50'
L = 100'
Draft = 3.5'





The logistics of a coastal shallows MX fleet would be simple and economical by comparison with many other proposed MX basing systems. Fuel for the ships could be stored in selected buoys that would serve the additional functions of position-keeping points and anchoring stations. Crew changes, and the supply of food, water and repair parts would not always require entry into port; because the ships would be operating close to shore, their logistical support could be flown in by helicopter in many cases. The various functions of supplying and protecting the ships, navigating them, and taking responsibility for the maintenance and operation of the MX missiles could be intelligently allocated among the naval and air branches of the armed forces, so as to avoid intra-service rivalry and preserve the Air Force's considerable investment in the MX project. During most of their duty cycle the MX carriers would move at low, fuel-efficient speeds. High speeds would be used only during regular training exercises or a presidentially-directed alert.

The capacity to carry the MX and launch it while moving at high speeds is the heart of this concept. Even submarines have to slow their motion or stop altogether in order to fire their missiles with accuracy. Moreover, to launch their missiles submarines also must reduce their depth, risking exposure and attack. The probability of an enemy warhead incapacitating a Wave-Forming Keel vessel moving at 100 knots is five times less than for a motionless craft. Finally, no other system proposed for basing the MX would have a lesser fallout impact on the nation's population and resources in case of enemy attack. The deployment of a portion of the MX force in the coastal shallows along the lines suggested here would give to one of the key legs of the U.S. strategic triad a degree of mobility, dispersion, and structural flexibility that could only enhance our defense posture and contribute significantly to the national objective of peace through strength.

REVIEW OF NASA ACLS RESEARCH

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ABSTRACT

An experimental investigation was conducted to evaluate a method of maintaining stability of an air cushion vehicle and also to evaluate several concepts to brake and steer an ACLS-equipped vehicle. The investigation used a modified airboat equipped with an air cushion landing system. The pressure relief door stability concept was characterized by the ACLS pressure time histories. The pressure relief doors vented excess cavity and lobe pressures and consistently maintained vehicle heave and pitch stability. Braking concepts were characterized by the average deceleration of the vehicle. Reduced lobe flow and cavity venting braking concepts were evaluated in this program. The cavity venting concept demonstrated the best performance, producing decelerations on the test vehicle on the same order as moderate braking with conventional wheel brakes. Steering concepts were evaluated by recording the path taken while attempting to follow a prescribed maneuver. The steering concepts evaluated included using rudders only, using differential lobe flow, and using rudders combined with a lightly loaded, non-steering center wheel. The latter concept proved to be the most accurate means of steering the vehicle on the ACLS, producing translational deviations which, while two to three times higher than those from conventional nose gear steering, were still felt to provide reasonably precise steering control for this type vehicle.

INTRODUCTION

As aircraft become larger and heavier, design of systems to support them during takeoff and landing becomes more demanding. Today, some aircraft are restricted from operations on certain runways due to the possibility of damage to the runway surfaces. Providing adequate flotation for a heavy aircraft can incur large weight penalties. The C-5 landing gear, for example, weighs some 52,000 lb (231 kN) (approximately 7% of total gross weight) including the gear doors and their associated structure (reference [1]). Conventional landing gear requires an aircraft structure to withstand high localized loads; conventional landing gear also generally precludes operating on low strength or unprepared surfaces.

An air cushion landing system (ACLS) offers possible solution to these problems. An ACLS makes use of an inflatable airbag with peripheral jets at the ground tangent. High volume, low pressure air is introduced into the airbag and exhausts through the jets. Typically an ACLS covers a large area; consequently the ground bearing pressure required to support even a large aircraft is very low. Low bearing pressures provide the capability to operate on a variety of surfaces, both prepared and unprepared, and may extend to amphibious operations.

At least two aircraft, the Lake LA-4 Amphibian and the de Havilland CC-115, have been fitted with an ACLS on an experimental basis. Lacking conventional ground contact, however, these aircraft were difficult to control and stop, particularly at low forward speeds when aerodynamic control surfaces were ineffective (reference 2). Small inflatable "pillows", located between the airbag and the ground, were incorporated into both designs to provide brakes and differential braking for steering. This still did not eliminate the inherent sideslip and yaw an ACLS is susceptible to. Testing of these aircraft emphasized the need for new control techniques. An ACLS is also susceptible to instabilities in heave, pitch, and roll (references 3 and 4). These problems must be overcome to provide adequate ground handling properties for ACLS-equipped vehicles.

The purpose of this paper is to present the results of an experimental program conducted at the NASA Langley Research Center to evaluate a method of maintaining stability of an air cushion vehicle and also to evaluate several concepts for braking and steering a vehicle equipped with an ACLS. In this investigation, candidate braking and steering systems were installed on a modified airboat fitted with an ACLS. Braking concepts were evaluated by measuring the distance required to stop from brake application speeds up to 45 ft/sec (14 m/sec) on concrete and grass surfaces. Steering concept tests were conducted at speeds up to 27 ft/sec (8 m/sec) while attempting to follow an "S" shaped path painted on a runway and recording the vehicle's ground track. Deviations from the test path were represented by maximum and average error terms.

APPARATUS

Airboat

The vehicle used in this investigation was a modified airboat shown in figure 1. The basic airboat was equipped with an Avco Lycoming O-540 aircraft engine which supplies about 500 lb (2 kN) of thrust at full throttle. Engine thrust was



Fig. 1 Test vehicle on ACLS

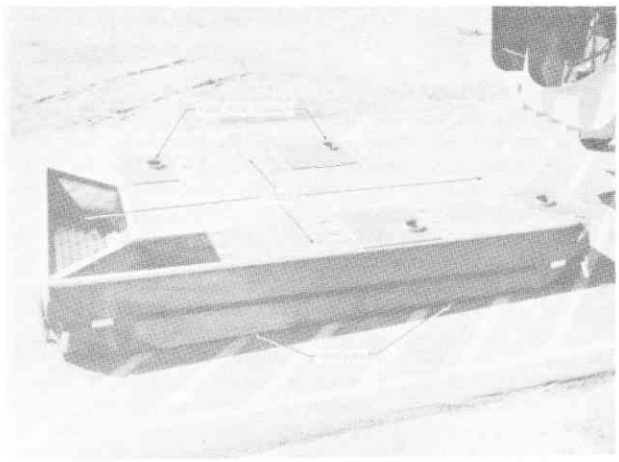


Fig. 2 Multi-lobed airbag

used in conjunction with highly effective dual rudders to provide forward and turning motion for the vehicle. These large rudders were effective only when thrust was applied since they were directly aft of the propeller. Retractable landing gear using the struts, wheels, tires, and brakes from a light twin aircraft were added to the airboat and provided a means of obtaining baseline braking and steering data. An auxiliary power unit (APU) and a hub turbine fan were used to power the ACLS. The vehicle was approximately 22 ft (6.7 m) long, 12 ft (3.7 m) wide, and weighed approximately 5500 lb (24 kN) including operator and observer.

Air Cushion System

The air cushion system for the test vehicle consisted of the APU, hub turbine fan, plenum, and airbag. The APU is a gas turbine engine which provided bleed air to drive the hub turbine fan. High temperature (400°F (204°C)), high pressure (18 psig (12 kPa)) drive air from the APU caused the hub turbine to rotate, drawing in ambient air through its tip fan. At full speed (about 20 000 RPM) the hub turbine fan combined flow rate was approximately 120 ft^3/sec (3.4 m^3/sec) and this air flow was exhausted into the plenum, where air temperatures were stabilized and the flow was evenly distributed by feedhoses to the airbag lobes. The airbag used on the vehicle is shown in figure 2 and consisted of four separate lobes rather than the single annulus commonly found on an ACLS. Each lobe was fabricated by "laying up" an open weave of KEVLAR fabric (about 6 fiber bundles per inch) into a truncated circular shape and spraying it with polyurethane. The orifices in the bottom of each lobe were created by preventing the polyurethane from adhering to the fabric in those areas. The individual lobe design provided the capability for obtaining differential pressures between lobes of the airbag system. The air flow through the orifices located at the ground tangent provided air lubrication for the system. The airbag was 14.5 ft (4.4 m) long and 8.5 ft (2.6 m) wide, leaving an area in the center of the arrangement measuring 9.5 ft by 3.5 ft (2.9 m by 1.1 m). This area is referred to as the cavity. Each lobe had a 1.25 ft (0.4 m) radius in cross-section except for a flat cover. In normal operation the covered cavity (indirectly fed by the lobe orifices) maintained a pressure of approximately 0.4 lb/in^2 (0.3 kPa), while each of the lobes maintained a pressure of about 0.8 lb/in^2 (0.5 kPa).

Test Area

The tests for this investigation were conducted on an inactive concrete runway at Langley Air Force Base. The portion of the runway used measured 150 ft by 1400 ft (46 m by 427 m). The runway had a transverse slope of 1%. In addition, grass areas adjacent to the runway were used during some of the braking concept tests. Surface conditions for all tests were dry, and winds were negligible.

Instrumentation

Cavity and lobe pressures were measured by pressure transducers during the stability tests. During the braking tests a trailing wheel was used to measure brake application speed and stopping distance. Parameters measured during each steering test included velocity, heading angle, and yaw angle. Heading measurements were recorded from a rate gyroscope coupled with an integrator. Yaw angle measurements were recorded from a continuous turn potentiometer mounted on the pivot of the trailing wheel.

STABILITY, BRAKING, AND STEERING CONCEPTS

Stability

The concept for maintaining stability of the vehicle involved using a pressure relief door located in the appropriate area. This door consisted of a plate mounted on studs with concentric springs. The springs were precompressed so that when the pressure behind the door was nominal it would remain closed but when the pressure began to rise it would force open the door and vent the excess pressure, preventing the vehicle from becoming unstable. One pressure relief door was mounted in the roof of the cavity and another in

the top of the rear lobe to prevent heave and pitch instability respectively.

Braking

Several different concepts for stopping the vehicle were evaluated. Initially, however, two sets of tests were performed to get baseline data. First, a set of braking tests was conducted with the conventional landing gear as installed on the vehicle and with the ACLS inoperative. A second set of tests was conducted with the vehicle free to slide on the operating ACLS, relying only on air drag and airbag/ground friction to bring it to a stop. This set of tests defined the lower boundary of the ACLS braking performance envelope.

The first ACLS braking concept was to use reduced air flow to three of the airbag lobes. Butterfly valves located in the feedhoses between the plenum and the side and rear lobes could be adjusted from the cockpit to reduce the air flow into these lobes. This technique increased the friction between these airbag lobes and the ground. Full pressure was maintained in the forward lobe to prevent the airboat from pitching nose down during the braking effort.

The second ACLS braking concept involved venting the cavity. The normal cavity pressure provided approximately 40% of the total lift force for the vehicle. Venting this pressure caused all of the vehicle weight to shift to the lobes which deflected and increased friction thereby stopping the vehicle. To accomplish venting, a door in the top of the cavity (the same one used for heave stability) was coupled to an electrically actuated air cylinder. This door is shown in figure 3.

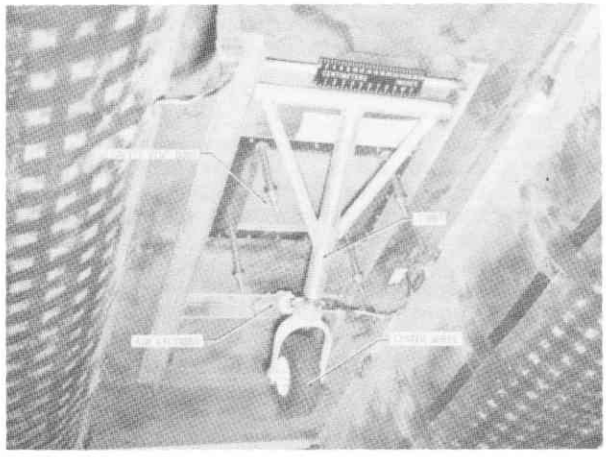


Fig. 3 Cavity vent door and center wheel

When activated, the cylinder retracts and the door is opened approximately 3.5 inches (0.09 m). The door measures 1.25 ft by 1.25 ft (0.38 m by 0.38 m) and represents approximately 4% of the total cavity area.

Steering

Steering tests were conducted using four different techniques. The first used conventional nose gear steering on the tricycle landing gear combined with rudders and with the ACLS inoperative to define a baseline for comparison of steering while supported by the ACLS. Second, a series of tests was conducted on the air cushion using the rudders alone as the steering technique. Since the rudders were effective only while thrust was maintained, the operator was instructed to apply thrust and yaw as necessary to accomplish the maneuver and maintain speed.

The third series of tests relied on differential lobe flow to maneuver the vehicle. For this technique the butterfly valves in the side lobe feedhoses were adjusted to allow one side lobe to receive less flow, thus creating an asymmetric friction condition to change the vehicle heading. During these tests the rudders were not used.

The last steering concept studied made use of a lightly loaded, non-steerable, free rolling wheel mounted in the airbag cavity near the fore and aft center of gravity. The 10 inch (0.3 m) diameter wheel was attached to the strut and air cylinder assembly shown in figure 3 and was loaded vertically to approximately 200 pounds (0.9 kN) (4% of vehicle weight) by pressurizing the air cylinder. This wheel was used in conjunction with the rudders to produce the yawing moments necessary for steering.

TESTING TECHNIQUES

Stability

The testing technique used for stability studies involved inflating the airbag while on the conventional gear and then retracting the gear to lower the vehicle onto the air cushion and recording the pressure time history. These tests were conducted with no forward speed.

Braking

The testing technique used during braking studies involved running the vehicle down the test runway until the desired speed was reached, applying brakes, and measuring the distance required to stop. At brake application, the forward thrust was eliminated, and the trigger on the sensing unit was activated to begin measuring the elapsed stopping distance. If the test involved braking over grass, brake application would begin after the airboat had crossed the threshhold of the runway and was running over grass.

For each braking concept, brake application speeds ranged from approximately 15 ft/sec (5 m/sec) to 45 ft/sec (15 m/sec). In general, four tests at each speed were conducted so that representative stopping distances could be obtained.

Steering

To evaluate the performance of the steering concepts, the vehicle was maneuvered along an "S" shaped path painted symmetrically about the centerline of the test runway. Each straight leg of the maneuver was 100 ft (30.5 m) long and 50 ft (15.2 m) out from the centerline, joined by 100 ft (30.5 m) radius arcs.

Steering tests were conducted at approximately 8, 15, and 22 ft/sec (2, 5, and 7 m/sec). For each concept, several tests were run at

similar speeds with the most representative runs presented in this report.

RESULTS AND DISCUSSION

Stability

Shown in figure 4 is a photograph of the pressure relief door in the top of the rear lobe to prevent pitch instability. Before installing the

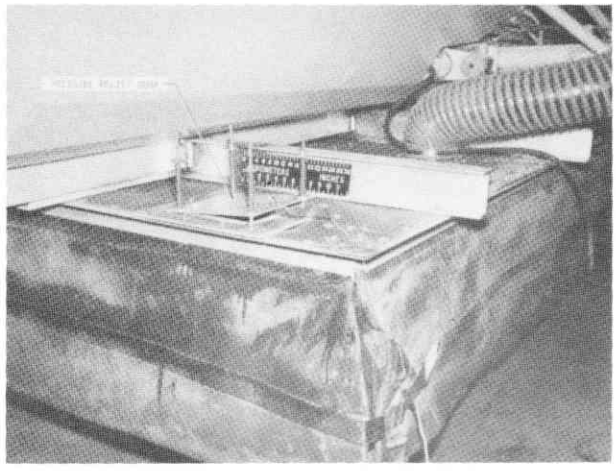


Fig. 4 Pitch pressure relief door

door the vehicle was so unstable in pitch that just lowering the vehicle onto the air cushion using the retractable gear was enough to trigger the divergent instability as shown in figure 5.

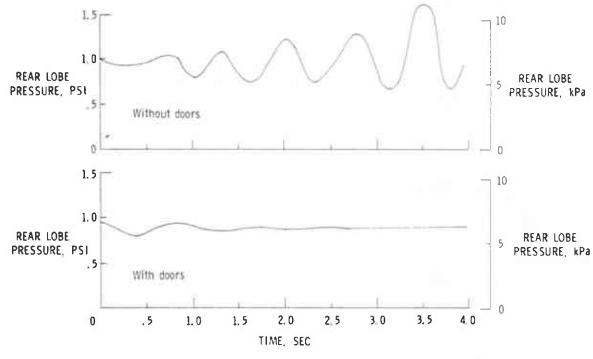


Fig. 5 Rear lobe pressure time histories

However, after installation the door maintained pitch stability and, as seen in the figure, even a large initial pitch perturbance (weights dropped off of the rear of the vehicle) was damped out quickly. The pressure relief door concept worked similarly in the cavity to prevent heave instability.

Braking

Brake application speed and stopping distance for each of the braking tests are presented in Table 1. Also tabulated is the average drag coefficient (deceleration) for each concept. The average drag coefficient appears to increase with speed, and this trend is attributed to the aerodynamic drag on the vehicle which is a function of velocity squared. Each braking concept was characterized by a single value average drag coefficient, $\bar{\mu}_d$. This single value is defined as the inverse of the slope of the least-squares linear curve fit to the relationship between stopping distance and the square of the brake application speed, divided by 2g.

The tests employing conventional wheels and brakes (ACLS not in use) developed an average drag coefficient of 0.22 on the concrete surface. This coefficient is consistent with routine aircraft landing decelerations and provides a basis for comparison with other braking concepts. The operator was instructed to maintain a "comfortable" deceleration and to avoid locked wheel skids; thus this drag coefficient does not represent a maximum braking effort. Tests employing conventional wheels and brakes were not conducted on grass due to its soft surface.

To define the magnitude of the combined effects of aerodynamic drag on the vehicle and the drag created at the airbag/ground interface, tare tests were conducted on concrete and grass surfaces with the ACLS in use, but using no braking effort. On concrete the tare $\bar{\mu}_d$ was 0.05 and on grass $\bar{\mu}_d$ was slightly higher at 0.09. This behavior would be expected because the blades of grass made contact with the airbag, creating an additional drag force. Operating on grass also partially vents the cavity, increasing friction. The values of $\bar{\mu}_d$ in Table 1 for each ACLS braking concept include the appropriate tare value.

Tests were also conducted to evaluate the friction coefficient between the airbag material and concrete or grass surfaces. To do this, weights up to 80 lb (0.36 kN) were placed on a square of the airbag material measuring 0.75 ft by 0.75 ft (0.23 m by 0.23 m) and pulled along the ground. A spring scale was used to measure kinetic pull force. On concrete, the friction coefficient was 0.42 and on grass this coefficient was 0.54. The higher value on grass may be largely attributable to the irregular surface. Neglecting air drag on the vehicle, these values represent the maximum available μ_d without air lubrication for any braking concept.

On concrete the reduced lobe flow braking concept produced a $\bar{\mu}_d$ of 0.10. On grass, a $\bar{\mu}_d$ of 0.14 was demonstrated. The cavity venting braking concept produced a $\bar{\mu}_d$ of 0.21 on concrete and a $\bar{\mu}_d$ of 0.36 on the grass surface. These two concepts are among the first to be attempted at large scale. A concept similar to cavity venting, referred to as suction braking, has been demonstrated at model scale by Bell Aerospace Company. Instead of simply venting cavity pressure, Bell created a negative cavity pressure for braking and reported decelerations as high as 2 g's (reference 5).

The reduced lobe flow braking concept performed only about half as well as the conventional wheel braking and only took advantage of about 25% of the maximum available friction coefficient. The cavity venting braking concept demonstrated the capability to perform nearly as well as the conventional wheel braking and took advantage of about 50 to 70% of the maximum available friction

coefficient.

Eighteen tests using the reduced lobe flow concept were conducted on concrete and some airbag wear and occasional tears in the material (which were repaired) were observed. Eleven tests using the cavity venting concept were conducted on concrete and very little airbag wear was observed and no tears developed. Neither braking concept produced any observable wear on the airbag during tests on the grass surface.

Steering

Data from the steering tests are presented in figures 6-9. For brevity the concepts will all be compared at one speed (nominally 15 ft/sec (4.6 m/sec)). The solid "S" shaped curve in each plot represents the test path, and the sequence of triangular symbols denote the actual ground track and orientation of the vehicle. The location and orientation of the symbols was obtained by playing back the steering data into a desktop computer and integrating the velocity vector using small time steps to give a plot mapping the track of the vehicle.

To define a baseline steering performance for the vehicle, a test was conducted using the conventional gear with nose gear steering in conjunction with the rudders (ACLS not in use). The actual and attempted steering paths for the vehicle at an average speed of 19.0 ft/sec (5.8 m/sec) are shown in figure 6. The average deviation for this test was only 3.5 ft (1.1 m) and the maximum deviation was 7.6 ft (2.3 m).

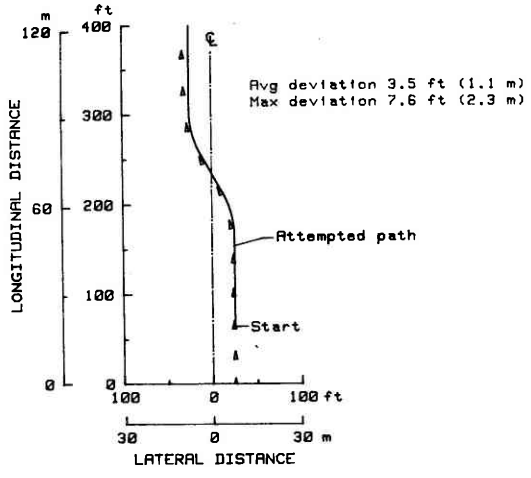


Fig. 6 Nose gear steering performance

A test using the rudders only steering concept at an average speed of 17.1 ft/sec (5.2 m/sec) is presented in figure 7. This plot shows that there was a significant response lag (approximately 5 seconds) during the steering maneuver as indicated by the time between the steering inputs which altered the vehicle heading and the onset of lateral translation of the vehicle. Also shown are yaw angles up to about 30°. The average deviation for this test was 8.6 ft (2.6 m) while the maximum deviation was 27.2 ft (8.3 m). These deviations are three to four times greater than for the conventional nose gear steering.

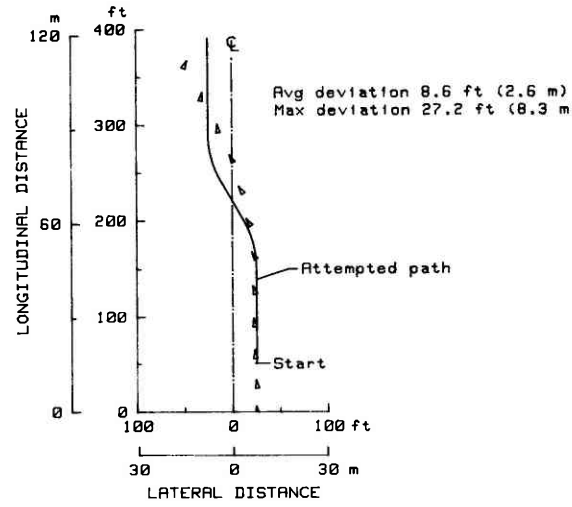


Fig. 7 Rudders only concept performance

A test using the differential flow steering concept at an average speed of 13.8 ft/sec (4.2 m/sec) is presented in figure 8. This test indicates that this concept was not able to execute the desired steering maneuver. The ACLS vehicle appeared to be more sensitive to the 1% runway transverse slope than to the steering inputs. Average and maximum deviations for this test were 22.2 ft (6.8 m) and 50.5 ft (15.4 m) respectively.

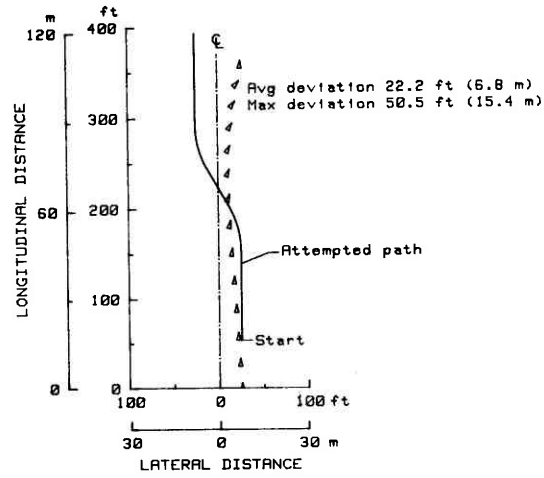


Fig. 8 Differential lobe flow concept performance

The final test utilized the center wheel combined with rudders to steer the vehicle. Figure 9 shows a test run at an average speed of 14.7 ft/sec (4.5 m/sec). The first turn was executed with little error; however, the operator was not able to yaw the vehicle to the right

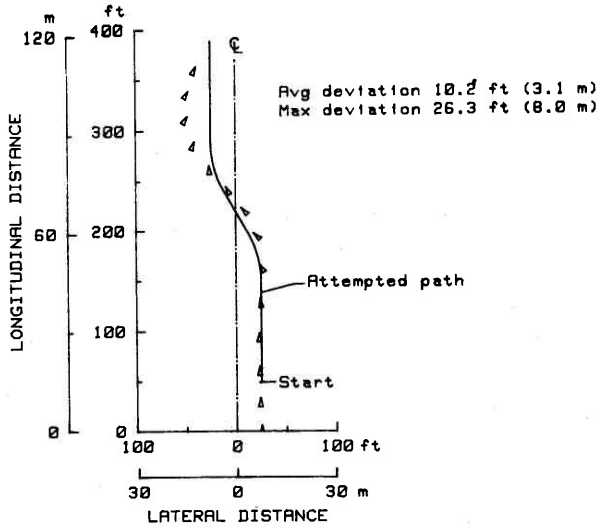


Fig. 9 Center wheel concept performance

rapidly enough to stay on course and consequently spent the rest of the test attempting to get back to the test path. The average and maximum deviations for this test were 10.2 ft (3.1 m) and 26.3 ft (8.0 m) respectively.

CONCLUDING REMARKS

An experimental investigation was conducted at the Langley Research Center to evaluate a method of maintaining stability of an air cushion vehicle and also to evaluate several concepts to brake and steer a vehicle equipped with an ACLS. The investigation used a modified airboat equipped with an air cushion landing system and with a conventional retractable tricycle landing gear. The pressure relief door stability concept was evaluated by recording lobe pressure time histories. Braking concepts were evaluated by measuring the distance required to stop from an initial speed and representing them as an average deceleration. Steering concepts were evaluated by attempting to follow a path painted on a runway and recording the actual ground track taken. Average and maximum deviations from the attempted path were calculated.

The pressure relief door concept proved to be a very satisfactory way of maintaining stability of an ACLS-equipped vehicle. A door installed in the rear lobe completely eliminated the tendency for the vehicle to undergo divergent pitch instability, while a similar door installed in the cavity eliminated heave instability.

The ACLS braking concepts were compared to the braking performance provided by the conventional landing gear and brakes. The reduce lobe flow concept, which used butterfly valves located in the airbag feedhoses to control the air flow, produced approximately half of the deceleration provided by the conventional system. The cavity venting braking concept, using a door located in the cavity to vent pressure, demonstrated decelerations nearly as high as the conventional technique.

The steering concepts were compared to the steering performance provided by conventional nose gear steering combined with rudders. Differential lobe flow steering proved to be ineffective. Significant lateral translations with this concept are not achievable. Using the rudders only for steering control resulted in considerable response lags, large yaw angles, and translational deviations three to five times greater than those using the conventional steering technique. Using the rudders only concept in conjunction with a lightly loaded, non-steering, free rolling center wheel proved to be a much more accurate means of steering the vehicle. The steering deviations were reduced to between two and three times that of the conventional nose gear steering.

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TABLE I - SUMMARY OF BRAKING CONCEPT TEST CONDITIONS AND RESULTS

CONCEPT	SURFACE	SPEED ft/sec	SPEED m/sec	STOPPING DISTANCE ft	STOPPING DISTANCE m	μ_d	$\bar{\mu}_d$
CONVENTIONAL WHEEL BRAKING (ACLS not in use)	CONCRETE	14.6	4.5	24	7.3	0.14	0.22
		14.6	4.5	19	5.8	0.17	
		14.5	4.5	22	6.7	0.15	
		14.6	4.5	22	6.7	0.15	
		14.6	4.5	15	4.6	0.22	
		29.3	8.9	62	18.9	0.22	
		29.3	8.9	56	17.1	0.24	
		29.3	8.9	57	17.4	0.23	
		29.3	8.9	72	21.9	0.19	
		29.3	8.9	72	21.9	0.19	
		44.0	13.4	159	48.5	0.19	
		44.0	13.4	137	41.8	0.22	
		44.0	13.4	135	41.1	0.22	
		44.0	13.4	131	39.9	0.23	
		44.0	13.4	118	36.0	0.25	
NO BRAKING (ACLS in use)	CONCRETE	16.0	4.9	122	37.2	0.03	0.05
		15.1	4.6	96	29.3	0.04	
		14.2	4.3	99	30.2	0.03	
		14.8	4.5	93	28.3	0.04	
		15.7	4.8	97	29.6	0.04	
		29.9	9.0	288	87.8	0.05	
		28.7	8.7	302	92.0	0.04	
		29.0	8.8	317	96.6	0.04	
		24.8	7.6	324	98.8	0.03	
		30.0	9.1	299	91.1	0.05	
		44.0	13.4	543	165.5	0.06	
		42.5	13.0	538	164.0	0.05	
	GRASS	7.2	2.2	9	2.7	0.09	0.09
		7.6	2.3	12	3.7	0.07	
		7.8	2.4	12	3.7	0.08	
		15.4	4.7	59	18.0	0.06	
		16.0	4.9	48	14.6	0.08	
		16.2	4.9	45	13.7	0.09	
		17.4	5.3	64	19.5	0.07	
		24.8	7.6	142	43.3	0.07	
		28.7	8.7	115	35.1	0.11	
REDUCED LOBE FLOW (ACLS in use)	CONCRETE	14.7	4.5	45	13.7	0.07	0.10
		14.4	4.4	46	14.0	0.07	
		13.9	4.2	43	13.1	0.07	
		14.1	4.3	49	14.9	0.06	
		15.0	4.6	43	13.1	0.08	
		14.7	4.5	45	13.7	0.07	
		28.9	8.8	140	42.7	0.09	
		29.3	8.9	141	43.0	0.09	
		30.8	9.4	151	46.0	0.10	
		29.8	9.1	153	46.6	0.09	
		30.0	9.1	154	46.9	0.09	
		29.3	8.9	148	45.1	0.09	
		43.9	13.4	283	86.3	0.11	
		44.0	13.4	312	95.1	0.10	
		44.7	13.6	327	99.7	0.09	
		43.0	13.1	306	93.3	0.09	
		44.0	13.4	305	93.0	0.10	
		44.0	13.4	307	93.6	0.10	
	GRASS	12.5	3.8	19	5.8	0.13	0.14
		14.5	4.4	23	7.0	0.14	
		14.7	4.5	23	7.0	0.15	
		15.0	4.6	34	10.4	0.10	
		15.7	4.8	26	7.9	0.15	
		17.6	5.4	37	11.3	0.13	
		18.9	5.8	46	14.0	0.12	
		22.3	6.8	59	18.0	0.13	
		23.2	7.1	65	19.8	0.13	
		23.6	7.2	58	17.7	0.15	
CAVITY VENTING (ACLS in use)	CONCRETE	13.2	4.0	12	3.7	0.23	0.21
		15.1	4.6	19	5.8	0.19	
		17.2	5.2	20	6.1	0.23	
		21.3	6.5	28	8.5	0.25	
		27.7	8.4	59	18.0	0.20	
		28.9	8.8	58	17.7	0.22	
		29.0	8.8	60	18.3	0.22	
		42.2	12.9	142	43.3	0.19	
		43.3	13.2	132	40.2	0.22	
		44.6	13.6	140	42.7	0.22	
		46.7	14.2	180	54.9	0.19	
	GRASS	15.0	4.6	15	4.6	0.23	0.36
		15.1	4.6	11	3.4	0.32	
		15.4	4.7	15	4.6	0.25	
		15.5	4.7	9	2.7	0.41	
		16.1	4.9	12	3.7	0.31	
		22.4	6.8	19	5.8	0.41	
		24.5	7.5	22	6.7	0.42	