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The Gimbal Fan Air Cushion Vehicle

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Abstract

In over two decades of research and development building sixteen conceptually different full-scale air cushion vehicles, my objective of attaining complete ACV controllability was achieved in the gimbal fan concept. Proper control of the ACV requires forces of propulsion magnitude available in all 360° from both ends of the craft. Given such powerful available forces, it is logical to use them for propulsion. In Aeromobile 16, the culmination of the work, two motor fans are mounted on gimbals at each end of the craft with freedom in two degrees. With fan shaft vertical, 100% of the power goes for lift. When tilted, part of the slipstream exits over the deck and produces powerful steering and propulsion thrust in the desired direction while maintaining lift. Other advantages inherent in gimbal design are personnel safety; quietness; reliability; low silhouette; low c.g.; low thrust line; low cost; exchangeable, mass-producible motor fans which can allow vehicle growth from one to four or more gimbals, which multiplies the reliability as well as lift, propulsion, and control effectiveness. Finally, having all engine and fan equipment at the extremes of the craft leaves the center unobstructed for payload on or off loading without trim changes.

Discussion

The gimbal fan is the solution to the problem of control which has frustrated the air cushion vehicle industry to date. In contrast to aircraft, control has come very late to the ACV. There were no aircraft until Wilbur Wright recognized the primacy of the control problem and with his brother did immense research on gliders. He had a good workable concept for control before attempting powered flight. In his remarks to the Western Society of Engineers in Chicago, September, 1901,he said, "Achievement of stability was the first instead of the last of the great problems in connection with human flight." Many refinements were added to the control system and flying technique in flights near Dayton after the first powered flight. The actuation and the technique of rudder use was learned by Orville in flights near Dayton after 1903.

In the ACV we have a stable base and freedom in only two degrees with no tendency on level solid ground to turn over. This is good, in that no lives are lost in experimenting with it; but bad, in that so much hardware has been built, so much investment has been made, and so many bankruptcies have occurred without producing adequate and sorely needed machines.

The absence of effective control is the limiting factor in widespread utilization of ACV's. The only successful ACV's are those in which their mission has been limited to level surface, such as over water. Even these "successful" air cushion craft are embarrassed by high winds and gusts, in attempting slow speed downwlnd travel, by weather cocking, by occasional plow-ins, and by overturning.

The first controlled, powered aircraft flight was 1903, and by 1914, the start of World War I, a mere eleven years later, there were successful, highly developed aircraft allover Europe and the U. S. A., in a burgeoning industry that has led to present day international air travel and private aircraft everywhere.

In contrast, I flew a man-carrying air cushion vehicle in the 1950's, and more than 20 years later, we are just learning how to control the machine; and the industry is in a very primitive state. There are no air cushion craft being mass-produced.

The opportunity for the adequate ACV is vast and untouched virgin territory. The civilian marine industry, now about four billion dollars a year, consists of craft with maximum speeds of about 30 m.p.h., usually less; very poor fuel economy; climate limited in the North to half the year utilization because of freezing water; craft aground in shallows and damaged by submerged floating objects; and craft unable to run up on a beach for access of loading and service. As yet undetermined is how big a market exists for the amphibious and overland ACV's.

How many of those marine customers, for some greater initial investment, would rather have a really good machine? We will not learn the size of the market until we can offer twice the speed and greater fuel economy, with freedom from "stove in" accidents from invisible submerged obstacles, and the ability to run on ice, in shallows, or over mud to beach the craft or return to the deep channel.

The lifting base problems have been solved by now. The ACV industry is able to provide the proper cushion containment and characteristics for specific vehicle designs and missions with low friction, stability, durability, and other desirable features.

But the ability to put the air cushion craft precisely where it must be and keep it there despite wind, wind gusts, slope and surface irregularities has not been demonstrated until now.

In our hundreds of flights in all types of weather and terrain over two decades, it has become obvious that adequate controllability of the frictionless air cushion vehicle requires control forces of the order of magnitude of propulsion. And the control forces must be available horizontally in all 360^0 vectors from points centering at both ends of an elongated vehicle. Given such powerful control forces of propulsion magnitude, it is logical to use them for propulsion as well as control. In tight maneuvering situations, there is no distinction between propulsion forces and control force.

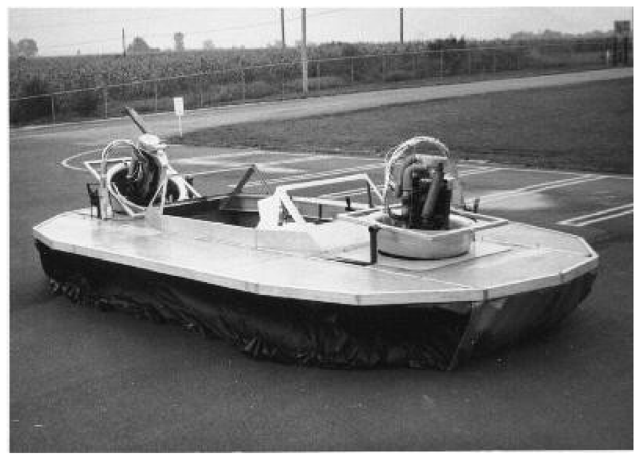
The air cushion vehicle has a unique motility unlike that of any surface vehicle, in that it is frictionless and totally unoriented as to direction of travel. This freedom of motion forwards, sideways, pivotally, or diagonally, is a valuable attribute, but exact controllability by the pilot is essential.

The free frictionlessness of the ACV to move omnidirectionally in yaw axis rotation and horizontally becomes an increasing problem on non-level surfaces. Much force must be brought to bear on the freely suspended hovering vehicle merely to hold it on a hill. Furthermore, forces are needed to provide torque on the vertical axis around the center of gravity to maintain yaw orientation on hills and rolling terrain.

The ACV has weight, but it has little friction, and there is an inexorable downhill urge representing a fraction of its total weight, depending upon the slope of the grade. Force exceeding all possible inclined plane gravitational forces must be available to the pilot to maintain his vehicle on a hill and to climb that hill.

Moreover, maintaining the yaw attitude of the ACV on rough terrain is a more complex problem. As the craft proceeds over uneven surface, the front end may be on a right sloping surface, and the rear end on a left sloping surface, causing a powerful right turning moment in yaw axis. To counter this urge, the pilot must have at his disposal instantly forces exceeding all possible yawing urges. He must have force on the front end to make the front end go right or left at his will, despite terrain or wind. He must likewise control the rear end under all operating circumstances. He may require a powerful lateral force on one side on both front and rear simultaneously to maintain the craft on a side hill. If he then wishes to proceed along this side hill, he will require sufficient longitudinal force as well, for propulsion. Wind effects further complicate all control efforts. The magnitude of his required forces for control and those for propulsion are similar. Logically, both torque on the yaw axis and side force laterally on each end of the vehicle can be produced by originating thrust forces at each end of the vehicle.

The culmination of my work on ACV control is seen in the Aeromobile 16, which has two motor fans, one fore, one aft, on gimbal mounts with freedom in two degrees.



Aeromobile 16

When neutral (with fan shaft vertical), 100% of developed power goes for lift. When tilted slightly, part of the slipstream exits over the deck and provides powerful thrust in any direction while maintaining lift. Using two gimbal fans so mounted, there is available to the pilot instant control force in any yaw axis direction from each end of the craft. Full propulsive power (about 70% of developed power) can be brought to bear in any horizontal direction by tilting up both fans on parallel axes. Half of the total propulsive force arises from each end. The magnitude of the propulsion (or control) force is metered by the degree of gimbal fan tilt. Up to 90° tilt is possible for maximum horizontal thrust, and it can be instantly applied and just as quickly cut off or turned in a new direction. There is no need for vertical tail surfaces which are so troublesome in variable winds, causing severe weathercocking.

The twin gimbal ducts provide a fully self-sufficient ACV system for all conditions of operable terrain and wind, providing propulsion and control of both ends of the craft, plus the benefit of multi-engine reliability: either gimbal fan will lift and propel the craft; and since each has its own fuel, electrical system and servos, it is possible to continue most missions with a single engine operating.

Other advantages of gimbal ACV's are as follows:

1. The thrust line of the gimbal fan is low, avoiding pitching or rolling moments and the tendency to "plowin." On the contrary, the gimbal force is instantly available to prevent plowin or heeling over, should it occur from high drag on the skirt or wind forces. The silhouette of the craft and its center of gravity are very low. The center of the gimbal powered ACV is totally free of machinery, since all engines, fans, etc., are at the extremes of the craft, leaving the center hold or center deck area free for payload at the center of lift. No trim problems result from on or off loading payload from center of lift in the gimbal fan air cushion craft.

2. The gimbal fan unit when mass produced would be inexpensive as are outboard motors. It is a quick change to unplug and disconnect a gimbal unit and exchange it for another one. The production outboard engines powering the Aeromobile 16 have parts and service obtainable world-wide. The engines are marinized for fresh or salt water, and have proved their ruggedness and reliability.

2. In conditions where lift air is lost through permeable substrates such as gravel, vegetation, and brush, it is very useful to have 100% of engine power usable to supply pure lift air; and it is possible to "rock" a gimbal fan craft off a hang-up by pulsing full lift-thrust vectors back and forth by gimbal tilting in any direction, vertical to horizontal.

4. The turning circle of a gimbal ACV can be tightened by centripetal radial force, which is impossible with any other propulsion-control system.

5. Training operators of gimbal ACV's is much simpler than "conventional" craft with only limited rudder in slip stream vectoring, weak "puff ports," etc. Much less judgment is necessary to stay out of trouble with powerful, constant and positive force instantly available in all directions.

6. Ducted fans are inherently quieter than open blades and are safer to personnel also. Thrust per unit horsepower is much higher in ducted fans than in centrifugal thrusters, and fan diameters are smaller per unit thrust than those of unshrouded propellers.

7. Gimbal ACV's have growth capacity. We have flown 55 hp. and 125 hp. single fan vehicles with payloads of 500 and 1,000 lbs., respectively and twins up to 1,500 lbs. payload with 250 hp. installed power. With three or four gimbal fans installed in an air cushion vehicle, up to 6,000 lbs. payload or 20-30 people could be accommodated. Reliability and control effectiveness multiplies with each additional power unit installed.

Further growth beyond piston engine gimbal ACV's would logically be turbine powered gimbal fans. Bypass turbine fans would be feasible for large craft using any number of turbofans in gimbals of thousands of horsepower each. Medium to very large amphibious craft with gimbal fans would have fingertip, instant deployment of tons of force in any direction, so very necessary to safe operation of large air cushion craft.

The gimbal fan integrated lift, propulsion, and control system, When designed into an ACV of any size, type, or mission, will provide the appropriate lift or force modality needed to render the craft controllable under all operating conditions. In more than 20 years of experience exploring many control systems in sixteen full-scale vehicles, only the gimbal concept has achieved adequate control of air cushion vehicles.

Gimbal at 80° Tilt

Appendix 1. Aeromobile 16 Specifications

BERTELSEN, INC.

Neponset, IL 61345

Structure length:	24' 5”
Inflated Length:	24' 8”
Structure width:	14' 2”
Structure width, power off, folded:	7'6"
Inflated width:	18 ft.
Height to deck power off: ---------------------------------- on cushion:	 2'8" -- 48"
Height to top of engines power off: ---------------------------------- on cushion:	 5'8" -- 7 ft.
Base area:	260 sq. ft.
Gross weight base loading:	19 lbs./sq. ft.
Cushion height (belly clearance):	16''
Empty weight:	3,500 lbs.
Gross weight:	5,000 lbs.
Useful load:	1,500 lbs.
Power:	Two 99 cu. in. two-cycle Mercury outboard engines, 125 hp. Each - total 250 hp.
Fans:	Two 40" diameter axial flow fans

Gimbal:	Two 48" diameter shrouds
Fuel capacity:	Two 24 gal. tanks, total 48 gals
Cargo bay:	6' wide x 11' long x 2'3" deep; 151.8 cu. ft. below deck
Deck area Total: ---------------------------------- Between gimbal fans:	299.3 sq. ft. -- 12' x 14'3"; 171 sq. ft.
Flotation Fixed foam type: ---------------------------------- Cargo bay displacement: ---------------------------------- Total flotation:	3,000 lbs. -- 148.5 cu. ft., 9,266 lbs. -- 12,266 lbs
Electrical system - 12 volt:	two 12 volt alternators, two 12 volt batteries

Appendix 2. William R. Bertelsen Papers

"Experience with Several Man-Carrying Ground Effect Machines," Princeton Symposium on Ground Effect Phenomenon, Princeton University, October 21-23, 1959

"Aeromobile," Winter Meeting, American Society of Agricultural Engineers, December 15-18, 1959

"The Design of Ground Effect Vehicles " Canadian Aeronautical Journal' Vol. 6, No. 6, June, 1960

"1,500 M. P. H. Family Cars?" *Popular Science Monthly*, August, 1961

"Aeromobile, Arcopter, Aeroplow, Airtrack, and Other Uses of Ground Effect," Winter Meeting, American Society of Agricultural Engineers, December 13-15, 1961

"The Ultimate Vehicle," Initial Lecture to the Research Symposium on Air Cushion Craft, Department of Engineering, University College of Swansea, Great Britain, July 21-23 1964

"Aeromobile," National Safety Congress, Chicago, 1964

"The Evolution of Integrated Lift Propulsion and Control in the Aeromobile Air Cushion Vehicle " Third Symposium on Air Cushion Technology, Canadian Aeronautics and Space Institute, Montreal, Canada, 1969

"The Air Cushion Vehicle in a Mass Transit System," Ninth Symposium on Air Cushion Technology, Canadian Aeronautics and Space Institute, October 21, 1975, Ottawa, Ontario, Canada

Appendix 3. William R. Bertelsen
Air Cushion Vehicle Patent Patents, U.S.

3,074,499	Air Track Crawler
3,074,764	Air Track Crawler
3,095,938	Air Track Crawler
3,322,223	Arcopter GEM
3,512,602	Air Track Crawler
3,572,614	Aircraft (Arcopter VTOL)
3,712,406	Ground Effect Vehicle (Aeromobile No.1)
3,827,527	Gimbal Ground Effect Vehicles
3,845,716	Surface Effect Vehicle and Guideways Therefor