DESIGN OF GROUND EFFECT VEHICLES

by

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AFTER several years of experience in operating full scale ground effect vehicles over all kinds of terrain under a wide variety of conditions, certain design requirements have become apparent.

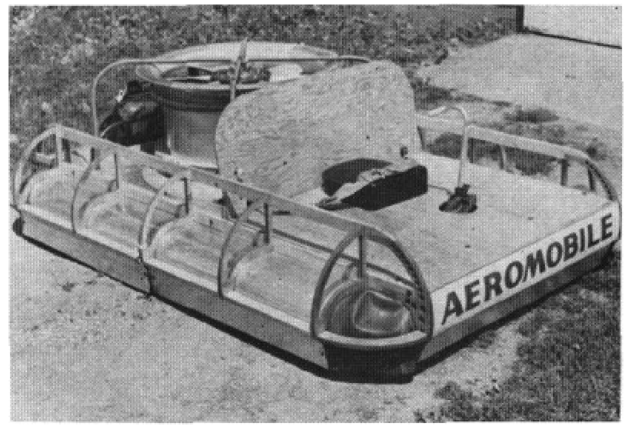
Of basic importance to the success of any given ground effect vehicle are simplicity of design, efficiency, stability, controllability, and several auxiliary features such as flotation and dust, spray and snow deflection.

SIMPLICITY

The irreducibly simplest design of the ground effect vehicle is that of single engine and single fan. Failure liability, first cost and maintenance are all minimized in the single motor fan vehicle. For the small machine as contrasted to large ocean going GEV, further elaboration of mechanism is unnecessary.

EFFICIENCY

Maximum efficiency is attained when the greatest possible thrust augmentation is obtained per horse power. Very early in ground effect design these machines were considered to be properly almost pure pressure operated and very thin jets were recommended. The mass flow and thrust, the very thing which was to be "augmented" by ground effect, was cut down. An efficient GEV must have a large mass flow of air to obtain the largest possible reaction lift further augmented by pressure beneath the base. Large mass flow is most efficiently obtained through a large multiblade fan turning slowly and, to avoid constriction and back pressure, the jet area should be large.



Aeromobile GEV

STABILITY

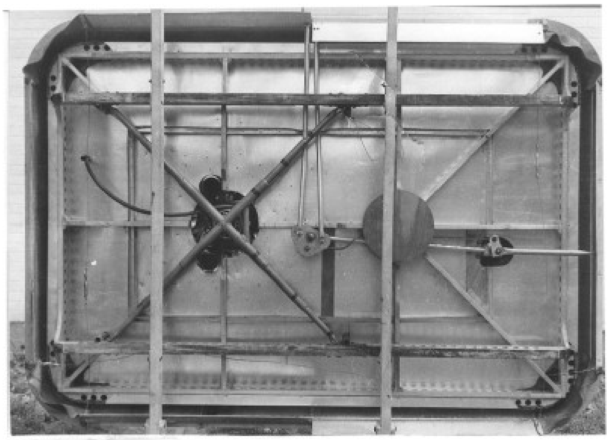
Stability in pitch and roll in the GEV becomes an acute problem when altitude rises over 10% of the base diameter. The single plenum chamber machine is unstable in pitch and roll in this region and higher. The peripheral jet GEV can be stabilized by large mass flow through its periphery. Reaction produces an upward force at the widest possible base and is stabilizing. The peripheral jet GEV with thin jets, and consequently low thrust, (using motor fans rather than jet engines) is relatively unstable because the major lift force (pressure) is exerted through the geometric center of the base. The thin jet, low reaction thrust peripheral jet machine teeters on a central lift vector with its center of gravity above the pivot point.

The plenum chamber and the peripheral jet machines can both be stabilized by compartmentalization of the base. By having four plenum chambers, or four center bodies surrounded by jets, the vehicle stands on four legs instead of one.

The most critical area is roll stability in the GEV which is longer than its width. Unstable rectangular or oval machines tend to lie on one side or the other. Any negative angle put on the peripheral jet is destabilizing in the small machine. Inward deflection of the jet is also critical in altitude and not sufficiently rewarding of increase in altitude or weight lifting to warrant consideration. The most efficient and stable design is with large area vertical jets with high volume passing straight through.

GEV shown here in flight

Stability in yaw in the GEV can be achieved by a vertical tail surface, but the introduction of weather cocking and the necessity of crabbing in cross winds rule out its use. A single yaw axis auto-pilot is a means of achieving yaw stability, but the best means for personal vehicles would be to operate them in shallow grooves. Existing highways can be enlarged in capacity, at very low cost, by grading the



An underside view of the Aeromobile GEV. Note the linkage and cable arrangement for the six jet control flaps.

grooves into the shoulder and ditch and resowing to grass for GEV. Groove travel will accomplish stabilization of the vehicle in yaw, cheapen highway construction, and make possible, ultimately, the complete automation of personal transportation.

Lack of inherent stability in yaw, is not, however, a serious fault if good controllability is obtained. In many operational conditions sideways or diagonal travel is advantageous.

CONTROLLABILITY

The GEV, unlike the aircraft, is forced to meet the rigors of the terrain on its own "ground". The fixed wing craft or helicopter operator will select a proper runway with correct wind direction and climb to altitude on his own terms and then tackle a mountain or hill. However, the frictionlessness of the operating medium, although good on level surface, is detrimental to the GEV on hills because inexorable gravity forces the machine to the lowest possible point.

It is, of course, possible to add thrust from auxiliary sources such as propellers, air bleed jets, ducted fans, rockets etc to force the machine uphill and to brake them against tobogganning downhill. In addition to the weight, cost and fuel cost of these auxiliaries, they have the disadvantage of not acting through the center of gravity in all directions and thus causing extraneous roll, pitch or yaw motions.

It is possible to make the GEV rise vertically like a VTOL up a sheer cliff with the addition of sufficient power and with disregard of the efficiency of the unmodified base out of ground effect. It should be possible, therefore, to force the machine up an inclined plane with its principal lift source by tilting it uphill. The additional force required to move it uphill would be from zero to full gross weight as the angle of the plane rises from zero to 90°.

The proper place for additional forces for grade climbing would seem to be through the main lifting base where existing controls can assure moments of force acting in 360^0 directly through the center .f gravity without unwanted torque. By installing sufficient power in the single motor fan unit, the cheapest, simplest and most controllable propulsive force can be obtained.

Consider the operation of the machine in strong cross winds or in negotiation of side hills. In cross winds a continuous extra power bleed must be done by the non-tilting GEV merely to maintain the hovering or travelling machine steady relative to the earth or its path. On side hills, the machine which cannot tilt opposite the hill will require large amounts of power just to maintain it on the hillside and more to lift and propel it.

Control of tilt is important for several other reasons aside from obtaining propulsion and control through the main power source and lifting base. Reverse thrust for braking is also obtained by rearing up the nose of the craft. Very powerful and fully controlled braking force is obtained.

Trim of eccentric loads by tilt control will prevent listing and consequent motion in the direction of list. A listing machine requires power bleed in some form to counter the tendency to drift.

The ability of a GEV to take a tight turn depends on its production of an inwardly directed radial force to prevent tangential motion. Tilting is the best means to produce this force and is the means that aircraft have used since the Kitty Hawk biplane. Control of pitch, roll and yaw is as essential to the GEV as it is to any other aircraft.

OTHER DESIGN REQUIREMENTS

Inherent flotation to enable safe travel over water and allow resting on water is absolutely necessary for all GEV. Dust, spray and snow deflectors or "fenders" must be permanently designed into these craft because they and their occupants tend to get dirt, water or snow thrown onto them in large quantities. Water runs off, but dust and snow build up and tend to load down the machine. The deflectors may be simple plane surfaces some distance above the bottom of the vehicle and extending out about the same distance horizontally.

Safety harness for all passengers must be provided because of rapid accelerations possible in operating these craft.

The GEV is at once the simplest possible land vehicle and the most versatile amphibious machine. It behooves the designer to keep it unencumbered with excessive complexity and highly capable and efficient to fulfill its promise of great utility.