Review on the Development of Wing-In-Ground Crafts

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ABSTRACT: This paper focuses on the development of Ground Effect Craft (GEC). The ultimate objective of this paper is to comprehensively outline all publicly disclosed and well-known GECs. The scope of this paper encompasses a review of the design challenges and architectures associated with GECs that have been prevalent for more than 60 years. It delves into research, development, and enhancements of existing GECs throughout their history. In conclusion, considering current technological advances, GECs present substantial opportunities and potential to evolve into a viable mode of transportation, effectively bridging the gap between aircraft and ships. The incentive to overcome the economic challenges associated with fabricating and operating GECs is worthwhile, encouraging exploration and development toward a commercially viable GEC.

Keywords: Ground Effect Craft (GEC) aerodynamics; ekranoplans; hoverwing.

1 Introduction

A Ground Effect Craft (*GEC*) is an aircraft flying in close proximity to the ground or other flat surfaces. The International Maritime Organization has designated it as a marine vessel (IMO)[1]. By placing a non-compressible surface near an airfoil, flying a *GEC* would be similar to always driving an aircraft in landing or take off which will lead to crash. However, the benefits gain due to this phenomenal outweighs its downsides and this statement is widely stated in many books and publishing papers. A design of three-dimensional 3 dimension airfoil profile immersed in an appropriate flow will produce usable force (lift) from a pressure imbalance. Because of this phenomenal, the 3 dimension airfoil will have low pressure above and high pressure below 3 dimension airfoil surfaces. The air will flow around the 3-dimension airfoil tip as a result of pressure equalisation,

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creating air vortices as shown in Figure 1. This spinning vorticies of air created an energy loss adversely yields no useful advantages. Therefore, it must be reducing to stimulate the aircraft efficient.

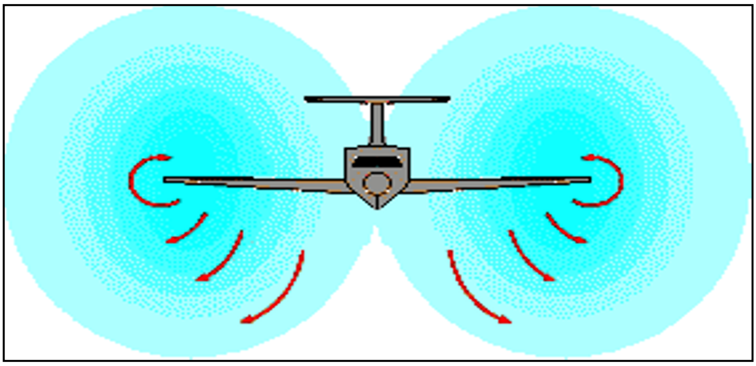

Fig. 1. An air flow around aircraft on free flow flight [2]

Figure 2 showed the energy wasted by 3-dimension airfoil tip vorticies is reduced by the surface interference with the lateral air flow hence reducing the induced drag.
Due to the effect/benefit is proportional to span, this phenomenon is also known as the Span Dominated Surface Effect. Theoretically, there will be no tip and vortex if the 3-dimension airfoil is infinitely long. A smaller aircraft produces a smaller vortex than an average aircraft, hence flying near to the surface will result in less vortex reduction.

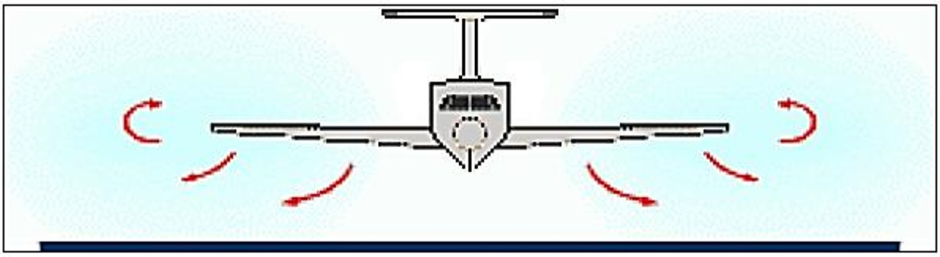

Fig. 2. Tip Vortices Drag Reduction (Span dominated ground Effect)

As shown in Figure 3, the location of the maximum suction is represented by the green region over the 3-dimension airfoil surface and the maximum pressure location is represented by the red region on the lower surface of the 3-dimension airfoil. The yellow region represents atmospheric pressure, whereas nonyellow region seems to be focused closer to the 3-dimension airfoil leading edge which normally would be around ¼ of chord. This is also typically referred to the center of lifting force. The streamlines show the air being disturbed or drag.

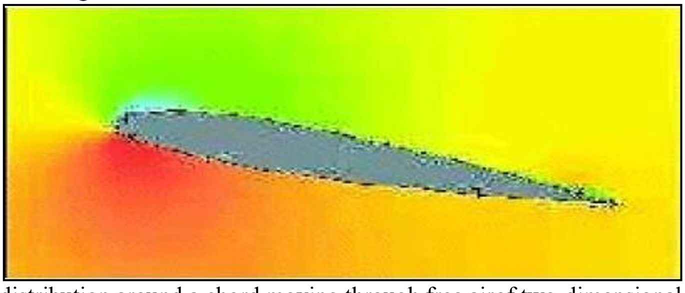

Fig. 3. Pressure distribution around a chord moving through free airof two-dimensional depiction. [2]

During ground effect phenomenal, the air flow under the 3-dimension airfoil becomes restricted due to interferences by the ground surfaces. The air flowin this phenomenal can be categorized into 3 inter-related effect. The air flow over the upper surface experiences less positive pressure gradient which result in making the air flow slower over the upper surface (see green region over the 3-dimension airfoil in Figure 4). At lower angle of attack, the separation (stall) is likely to occur due to the impact on pressure gradient. Secondly, the red region beneath the bottom surface indicated an increase in pressure, and it had moved aft on the 3 dimension airfoil, closer to the centre. A lateral shift of the aerodynamic centre will occur if the top surface lift is reduced and the lower surface lift aft portion is increased. A pitch down moment will transpire to aircraft designed to balance in free flight when it transit into ground effect. Conversely, an aircraft will experience a pitch up moment when tran out of ground effect despite the fact that it was designed to balance in ground effect.

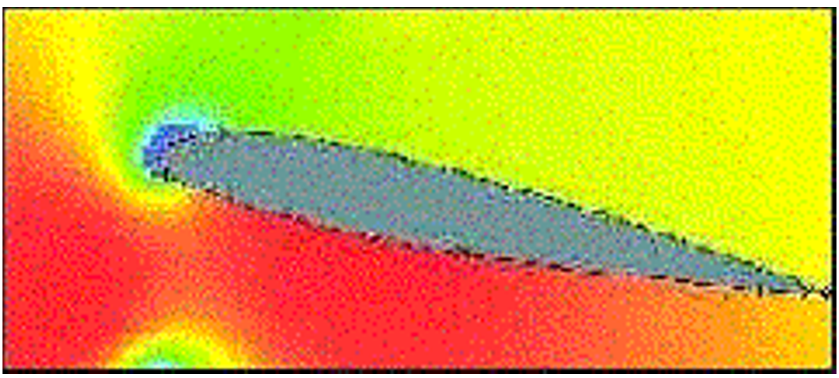

Fig. 4. GEC lift with the Wing in ground effect pressure graphic [2]

When span wise air flow is restricted, tip vortices are reducing and the 3 dimension airfoil will function as though it were an infinite 3 dimension airfoil. Within close proximity to the surfaces, there is some air entrapment beneath the 3-dimension airfoil and reduces the lower surface flow of chord, hence static pressure is increased. The upper surface flow effect has been decreased due to the reduced Lower Surface flow. As a result, at a lower angle of attack (AOA) the top Surface flow separates from the 3-dimension airfoil would transpire in free air. Occasionally, in accordance with 3-dimension airfoilprofile, there may be a venturi between the 3-dimension airfoil and the ground thus accelerating the air flow underneath the 3 dimension airfoil. The benefit of the air being trapped may be outweighed by the flow's negative effect on lift. Under exceptional circumstances, it even has a negative net aerodynamic lift. It is also worth noting, more energy loss will occur when pressure is lost due to the layer of air beneath the 3-dimension airfoil is compressed by the high pressure directly below it. Adding the non- compressible surfaces will stop the movement of downwash.

As shown in Figure 4, when compared to a 3-dimension airfoil in free flow, the ground effect 3-dimension airfoil produces nearly twice as much lifting force. It is broadly regarded that this effect is inversely proportional to elevation, h and directly related to the cord length, x, and is known as Ram Effect, or Cord dominated ground effect. As a result, a similar-sized *GEC* craft should be able to carry approximately twice as much weight as their body weight.

Despite the fact that ground effect will create more impediment, circumvent the venturi effect, increasing lift and reducing drag will increase *GEC* craft efficiency. For both aircraft and *GEC* craft, the center of effort, CE and the center of gravity, CG are located in the same plane. From Figure 3 and 4, it is safe to assume that the CE location of free flight is about 25% of its 3-dimension airfoil chord and turn to 45% of its 3-dimension airfoil chord when the same 3 dimension airfoil transiting into ground effect zone. This is because the front nose tries to pitch up when the craft departs from the ground and the CE travels forward on the 3 dimension airfoil. A *GEC* operating in ground effect zone will have a devastating outcome in these circumstances. A *GEC* needs a horizontal stabilization to compromise this challenge. On a side note, the Joerg tandem 3-dimension airfoil design is an exception of this problem since the front and rear 3-dimension airfoil supported the craft. During takeoff, the front 3-dimension airfoil reduces lift by moving into free air thus becoming stabilizing force for the craft and the rear 3-dimension airfoil remains in ground effect mode at the same time. As a result, there is no need for additional horizontal stabilizer. Regrettably to this day knowledge, this type of *GEC* become unstable as it is transiting outside ground effect zone.

As opposed to that, the Lippisch reverse delta 3 dimension airfoil shape incorporated with small horizontal stabilizer is more conducive to stability. The single, low aspect ratio, square 3-dimension airfoil such as ekranoplans need a large horizontal stabilizers since it's affected by a similar problem. In addition, S shape aerofoil profile is used in stabilizing the craft. It is unfavorable to use S shape profile since it is possible to develop a venturi effect therefore should never be used in extreme ground effect.

2 GEC Design Challenges

High speed sea transport has been the main society's development since centuries ago. During the last half century, due to increased demand for both work and leisure travel, the rapid proliferation of fast passenger transit ships around and between numerous coastal cities has become a notable phenomenon. For that reason, the study of *GEC* craft has continued to this day in order to improve transportation capacity. However until now not even one *GEC* craft has ever reached satisfying acceptance as mainstream transport vehicles [3]. It is by the author assumption that the reason behind this is because *GEC* craft need a high power capacity in order to take off thus affecting the investment and operational cost. The second reason would be when *GEC* craft travel in ground effect, it tends to have pitch up moment (longitudinal stability). This resulting in control difficulty and potential accident such as back flip and crash might be possible to occur. Such cases will need a pilot to take over the craft manually. Another reason worth to highlight is the original research country such as Russia stopped *GEC* craft development (or possibly still continue but in secrecy due to it is a military research) resulting in the technology itself lack in open publications forothers to continue this research.

2.1 GEC Craft Different Architectures Implementation

To solve longitudinal stability problem, most *GEC* are designed to have huge tail unit located far away from the central main 3-dimension airfoil and relatively high such as airplane, composite and Lippisch types as shown in Figure 5. The tail size of the best craft ranges from 22 to 30 percent of the primary 3-dimension airfoil area [6]. This type of arrangement requires a relatively huge fuselage which reduces the lift to drag ratio, L/D. It is widely known in aerodynamic study that the best option to increase L/D is to increase the Aspect Ratio, AR of the airfoil. However, there is an opinion that a low AR is sufficient for a *GEC* to operate and has the possibility to performsharp turning maneuvers at high roll angle without any contact from water surfaces.

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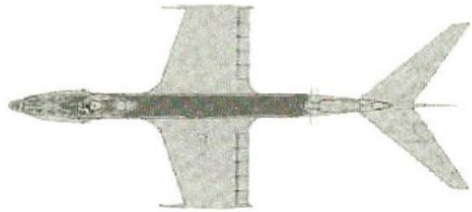
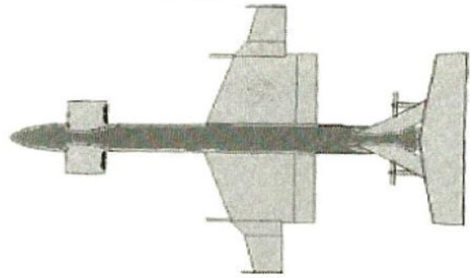
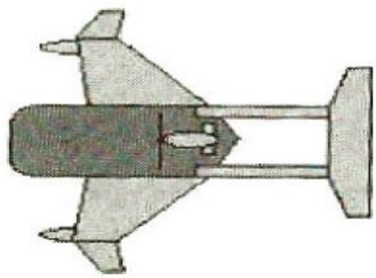
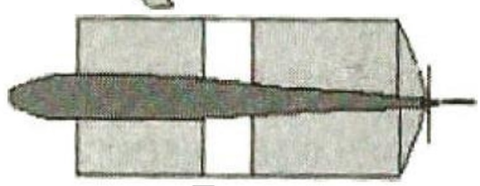
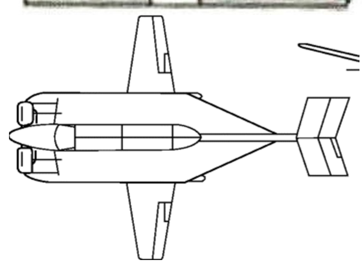
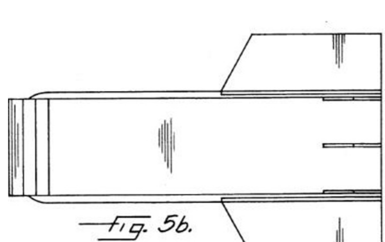
Orlyonok	
CompositeWing	
Lippisch	
Tandem	
Ivolga	
Bixel	

Fig. 5. Different lifting surfaces of *GEC*

Low AR also increases the efficiency of Power Augmented Ram (PAR) system. For a composite 3-dimension airfoil type as shown in Figure 5, it is designed to have side 3 dimension airfoil of high AR located above the primary 3 dimension airfoil and along the span, the airfoil is separated into two pieces. In cruising mode, one 3-dimension airfoil is used for the PAR system and the other is employed to generate lift. Due to this arrangement, the AR increases by two or three to five times and possibly higher. Noted that the derivative đh/ đU also increases as the limitation of AR increase [4]. This reduces the "Binding" between the *GEC* and the level surfaces. This can also cause the *GEC* to jumps in a vertical direction due to wind gust or thrust increase.
For a lippisch type the primary 3-dimension airfoil is created with a load of little pressure by using a variety of anhedral, tapered cord, and forward sweep as shown in Figure 2.0. Such a *GEC* is comparatively steady when flying. The propulsion system can be installed towards the tail or above the hull. Adding dihedral to the outer winglets increases stability and control in high altitude ground effect situations [5]. As shown in Figure 2.0, tandem 3 dimension airfoil type has two endplates connecting them, creating a streamline flow channel. This arrangement improves the use of ground effects and the static stability of the motion of the *GEC* ship over choppy water and while landing in weaving circumstances. As shown in Figure 2.0, the Ivolga type *GEC* is equipped with a conventional aviation control system, including a tailplane, fin, rudder, and 3 dimension airfoil ailerons [7]. Flaps are located at the back of the 3 dimension airfoil and slender side buoys in catamaran configuration are attached to the frontal plane of the central 3 dimension airfoil. This type of *GEC* possesses Both lengthwise and transverse steps are required for optimal hydrodynamic performance, especially in take off mode.
Finally for Bixel type, it utilises both hovercraft and ground effect technology. Bixel craft are flat double-dimensional airfoils that can travel at a safe distance over water or land masses. [8]. The flat double 3-dimension airfoil has a retractable 3-dimension airfoil and capable of longer time hovering and remain at faster velocity before transition into true flight. It also incorporated with a hovercraft air containment wall mounted at the bottom of the body which allows the craft to be lifted out of the water. The air containment wall is a structure with a flat bottom. This gives a water ski effect for emergency stopping and landing [9]. Bixel also has a thin air fence attached to the inside of the containment wall. This allows it to operate at zero degree Angle of Attack, AOA in a hovercraft mode. For maneuvering control, Bixel craft flight control used conventional aircraft type and mounting two or three large stabilizers with a rudder at the rear of the body.

2.2 GEC Development Operational Issues

Up until now *GEC* are not yet commercially operated. The reason lies on its operational challenges in development. Yun et al stated that *GEC* disadvantage can be classify into "technical" and "operational" factor. We will first need to discuss about technical factor before getting to operational factor.
For a technical factor, the takeoff speed of a *GEC* is high as a result of to hydrodynamic drag. This indicates that the *GEC* need to begin takeoff at lower speed. In order to overcome it a 'lift enhancement' capability need to be apply into the craft. Technologies on par to those elements are surface effect ships and hovercraft. The transversal and longitudinal stability of *GEC* will also be affected when wind gust or waves occur during high cruise speed. This means that the *GEC* will have maneuverability problem and need a manual handling from pilot. As such a commercial automated system for *GEC* is still not available [10]. Another technical factor worth mentioning is the trade-off between aerodynamic efficiency and lift force during take-off. It is dependent on the aspect ratio (AR) of the airfoil. A high AR will increase aerodynamic efficiency but decreases lift force. For operational factor, *GEC* require terminal similar to hover port. The hover port must be

located near coastal cities and a suitable water runway with a length of 500m to 2000m and width of 500m is needed. Since *GEC* is not yet commercialize, there is no training available for pilot.[11,12] A Boeing pilot and a ship captain may have a little experience in operating *GEC*. Other operationalfactor would be the noise produced by the *GEC*. It is comparative to a small turboprop airplanes flying closer to water surface [13]. This will affect the acceptance level of tourist and communities nearby the terminal. Public reaction and acceptance will also influence the development of *GEC* since it is a new type of transportation compares to establish airplane and other marine transportation. Lastly, economical profitability will be the last key factor. *GEC* as transportation is more suitable for a short range route of less than 400km. Aircraft transport is less efficient due to repeated landing operations. Yun et al said that competing with aircraft transport in their speed range is difficult due to the competing of low cost airline.[14]

2.3 Theory of Rigid Wing Section

The first understanding in flight aerodynamic is the elements of flight. There are four forces that makes it up which is lift, weight, drag and thrust. These four forces also counteract against each other. An observer on the ground andan observer within the aircraft can both quantify the aerodynamic force for anaircraft in steady flight. Hence in frame of reference motion, the aircraft is stationary and the air moves at a velocity **-V**. This simplifies prediction of aerodynamic force since it can be measured in wind tunnel or computed by a numerical solution. [15]

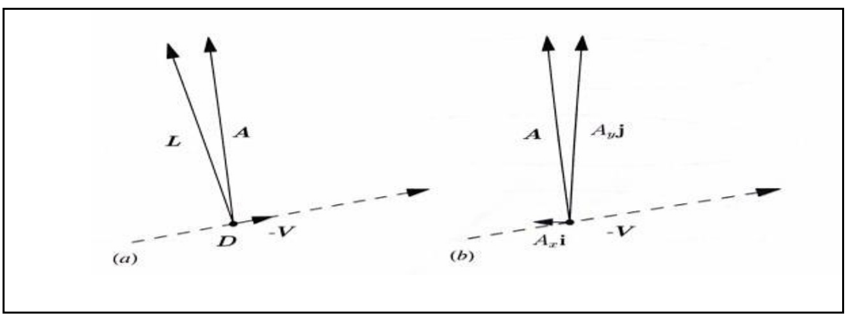


Fig. 6. Lift and Drag as Cartesian Component [15]

Figure 6 shows a lift **L** and drag **D** component in cartesian mode. Aerodynamic force **A** can be resolved into a perpendicular component force such as;

$$\boldsymbol{A} = \boldsymbol{L} + \boldsymbol{D} \textit{ and,} \boldsymbol{A} = \boldsymbol{Ax\, i} + \boldsymbol{Ay\, j}$$

The ***D*** *is* opposed to the direction of motion or parallel to the direction of theairstream relative to the aircraft **-V**.

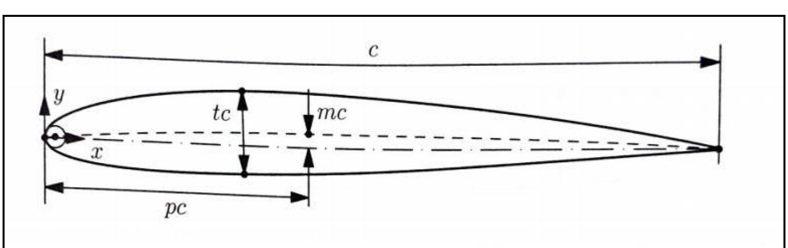


Fig. 7. Naca 2412 wing section. [16]

Figure 7 shows a Naca 2412 3 dimension airfoil section as exemplary aerofoil. 3-dimension airfoil section can be characterized by;

- Chord.
  Has a direction, position and length. Chord described the aerodynamic properties of a profile and therefore should be precisely defined.
- Camber.
  Maximum distance from the chord. Usually denote from camberline between upper and lower chord surfaces.
- Chord length, c
- Maximum thickness ratio, t
- Maximum camber ratio, m
- Chord wise location of maximum camber, p

Another important element in aerodynamic flight is **Aspect Ratio**. It is described as the ratio of overall 3-dimension airfoil span to the average chord. [17] The formula for 3-dimension airfoil geometry aspect ratio is:

$$\text{Aspect Ratio} = \frac{Span}{Mean\ Chord} = \frac{Span^2}{Area}$$

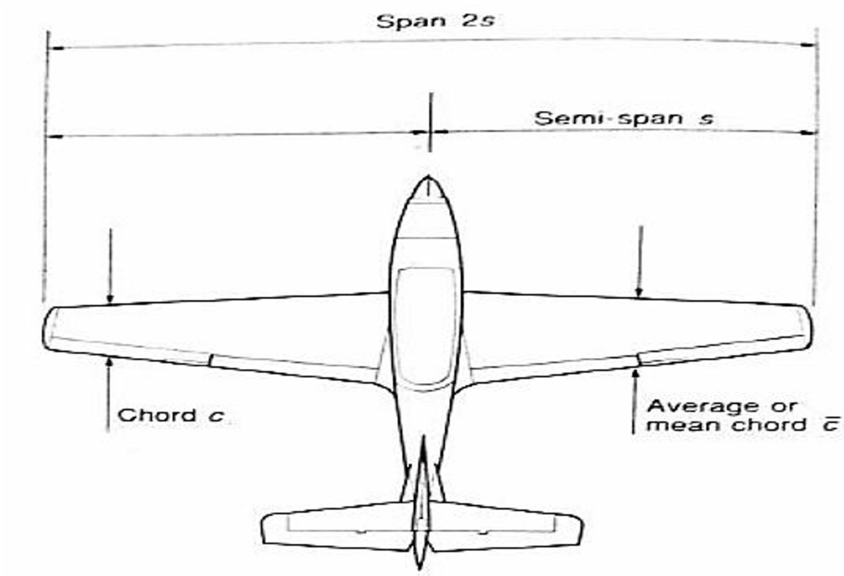


Fig. 8. Dimension Airfoil Geometry

Many of previous studies of 3-dimension airfoil section have been limited to rigid 3-dimension airfoil [17]. For a rigid 3-dimension airfoil section, lift is typically achieved due to Newton third law of motion principle and coanda
effect. The third law of motion of Newton states that there is an equal and
opposing force for every action force. Based on this law, lift is generated when 3 dimension airfoil are tilted upward, pushing air downwards so the 3 dimension airfoil get pushed upwards. For coanda effect, lift generated when an air particle that approached aerofoil surface were force downward due to higher pressure at the top of the air particle. This phenomenal makes the air particle to always attach to aerofoil surfaces on a steady flight.[18,19] According to Bernoulli equal time argument, 3 dimension airfoil is none other than a half of ventury tube hence assuming that the air moving over the rigid 3

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dimension airfoil section moved faster than air below the 3 dimension airfoil to meet aft at the same time resulting in low pressure above and high pressure below the 3 dimension airfoil thus generating lift. This has become an argument and many oppose Bernoulli claimed such as Prof. Holger Babinsky from University of Cambridge and Nasa Scientists.[20]

2.4 Effect of Flat Plate and Membrane 3 Dimension Airfoil

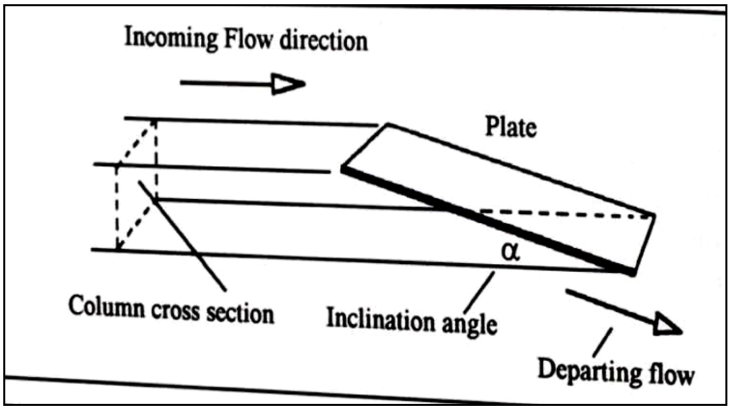

Fig. 9. Newton Flat Plate

The air flow passing through a flat plate held at an angle of inclination as shown in Figure 9 is considered to be the pioneer fundamental knowledge in aerodynamic study Newton's third law of motion states that an upward lift on a plate should equal a downward momentum that results [21]. The vertical velocity component at the plate trailing edge is equal to incoming air velocity times since the angle of downwash. However, at this point Newton’s interest was solely on how lift is generated hence the interference between flat plate and ground surface was discovered many decades later.

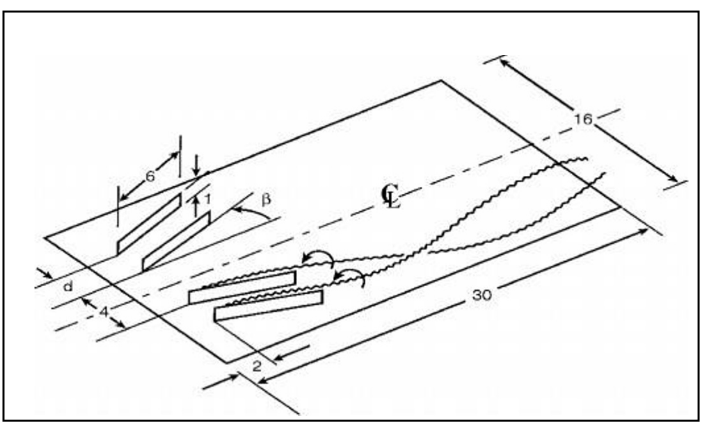

Fig. 10. Flat-plate model with the vortex generators [20].

Today the studies involving flat plate aerodynamics on free stream are widely published in many sites. Unfortunately, the publication studies of flat plate on ground effect conditions are still limited. Still there are few attempted to study on the flat plate ground effect such as Darwin L.[22,23] Garcia and Joseph Katz. Joseph and Darwin in their study attempted to find out The effects of vortices trapped between a flat plate and a ground plane in a wind-tunnel experiment. Their intention was to study the flow behavior when a vortex generator,

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VG was embedded on the vehicle floor on a ground surface near collusion as shown in Figure 10. As a result, the VG created more aerodynamic load and it is clearly showed in the data that the larger VG incidence resulted in stronger vortices and more lift, which effect in general, increases with reduced ground clearance.[24,25] As shown in Figure 11, the initially high lift force decreases as the height to chord, h/c value increased.

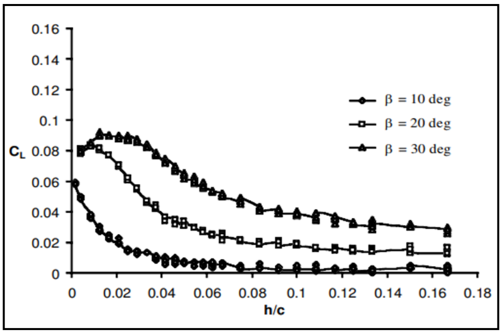

Fig. 11. Effect of VG yaw angle on the flat-plate lift [21].

Fig. 12. Microlight flying with membrane 3-dimension airfoil

Figure 11 shows a micro light equipped with fabric 3-dimension airfoil. Fabric 3-dimension airfoil or membrane 3-dimension airfoil has been an application in many engineering fields including parachute, hang glider, and micro light [26]. It is known to be flexible and impervious [27]. Membrane 3 dimension airfoil elasticity property plays a significant part in its aerodynamic performance. Theoretically membrane 3-dimension airfoil operates by adjusting the shape of its 3-dimension airfoil in accordance to the flow environment [28]. Membrane 3 dimension airfoil operates at low Reynold number and has an unsteadiness due to flow separation at high incident. Manipulating the membrane 3 dimension airfoil adaptability is known to improve the aircraft performance. Unfortunately, the aerodynamic of membrane 3-dimension airfoil is still largely unknown and the publishing studies on it are limited.[29]

2.5 Aerodynamic Performance and Stability of GEC

Generally, an aerodynamic performance includes the lift (Cl) and drag (Cd) capability of a *GEC*. Where these capabilities will always be measured with 3-dimension airfoil aerofoil angle or angle of attack (AOA) such as Cl vs AOA and Cd vs AOA. A satisfy aerodynamic performance is achieve by having thenumber of Cl as high as possible and a low number of Cd.[30]

Another aerodynamic performance that needs to be highlighted is its stability. It is defined as the ability of an aircraft to correct its position for conditions that act on it. There are two types of aircraft stability and they are static and dynamic. For each stability there is a positive, neutral and negative stability respectively.

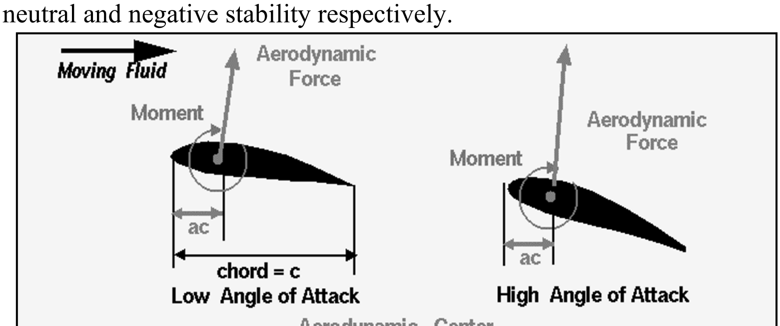

Fig. 13. Aerodynamic center acting on airfoil [31].

Aerodynamic center also have a significant contribution to *GEC* stability. As shown in Figure 13, aerodynamic center is the single point of drag and lift force acting on aircraft 3 dimension airfoil. Also called as center of pressure, normally it is located about 25% of 3 dimension airfoil chord .dIt forms a pitching moment when its location does not vary with the aircraft center of gravity. Aerodynamic center location does not move with angle of attack. Instead its location migrates based on the pressure distribution over the 3 dimension airfoil surfaces. Theoretically when one considered an airfoil at angle of attack, the pressure variation around the airfoils can be determined and the aerodynamic force and center of pressure can be calculated.[32,33]

A *GEC* uses ground effect phenomenon caused by the presence of a ground boundary below the surface of the 3 dimension airfoil. The boundary modifies the airflow around the 3 dimension airfoil, increasing 3 dimension airfoil lift and decreasing induced drag. The lift to drag ratio increases as a result of the overall effect. This ratio is a measure of an aircraft's efficiency that can be represented as the amount of thrust necessary to propel a plane of a given weight. When a 3 dimension airfoil operating in ground effect zone, the 3 dimension airfoil tip vortices will reduce the downwash velocity and the 3 dimension airfoil tip vortex-induced speed reduced the induced drag. The *GEC* flies closer to the ground and the lift generated by the 3 dimension airfoil increases with the drag decreasing as the tip vortices are suppressed and the craft becomes more efficient in flying closer to water and ground surfaces. The flow obstruction between the underside of the 3 dimension airfoil and the ground increases the pressure on the 3 dimension airfoilslower surface, creating lift. Aerodynamic center or centers of pressure location were influence by the pressure surrounding the surfaces.[34,35] Therefore, its location migrates further from its original position when flying outside ground effect zone. This phenomenon disturbed the pilot handling capability and may require special control system or specific type of 3 dimension airfoilto solve this problem. For a *GEC*, being able to fly outside of ground effect zone is crucial in order to avoid sea wave and high obstacle in a long travel.[36]

Longitudinal Stability

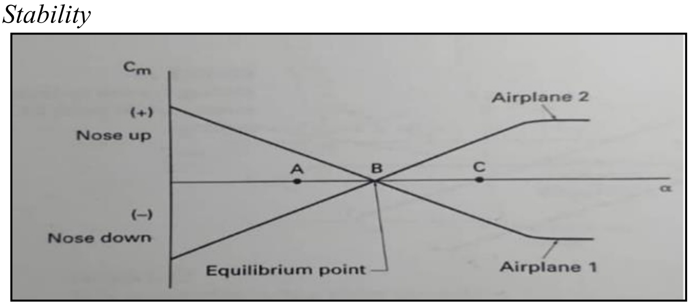

Fig.14. Aerodynamic center acting on airfoil [37].

As shown in Figure 14, to have a static longitudinal stability the aircraft pitching moment must have a negative slope.

Which is; ɖCm/ ɖɑ

In addition to having a negative slop, one must also have a positive intercept to trim at positive angle of attack in which;

$$Cm0 > 0$$

We've concluded that variables involving products of the drag coefficient and either vertical displacements of the vehicle centre of gravity can be ignored when analysing longitudinal stability. Hence as shown below, the pitching moment about the centre of gravity can written as;
The tail is usually symmetrical so we assume that Cm0t = 0.

$$\mathrm{C}_{m\mathrm{cg}} = \mathrm{C}_{m0_w} + \mathrm{C}_{Lw}\left(\frac{x_{\mathrm{cg}}}{\bar{c}} - \frac{x_{\mathrm{ac}}}{\bar{c}}\right) - \eta\frac{S_t}{S}\mathrm{C}_{Lt}\left[\frac{\ell_t}{\bar{c}} - \left(\frac{x_{\mathrm{cg}}}{\bar{c}} - \frac{x_{\mathrm{ac}}}{\bar{c}}\right)\right] + \mathrm{C}_{mf}$$

2.6 Ground Effect Phenomenal

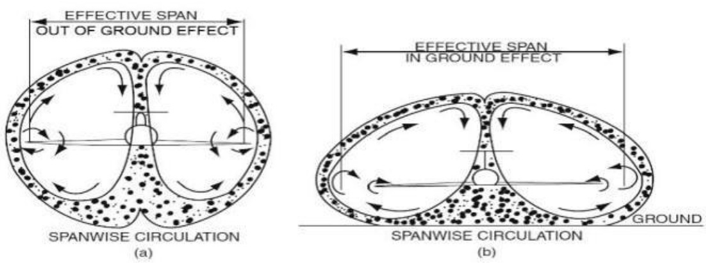

Fig. 15. Wingtip vortex difference without (a) and with (b) ground effect

Ground effect is known as a phenomenon caused by the presence of a ground boundary below the surface of the 3 dimension airfoil. By altering the airflowaround the 3 dimension airfoil, the boundary boosts 3 dimension airfoil lift and reduces induced drag. The overall effect is an increase of the lift to drag ratio. This ratio is a measure for the efficiency of an aircraft that can be expressed as the amount of thrust that is required to propel an aircraft on a certain weight. [38]When a 3 dimension airfoil operating in ground effect zone, the 3 dimension airfoil tip vortices will reduce the downwash velocity and the 3 dimension airfoil tip vortex-induced velocity reduced the induced drag . As shown in Figure 7, as the tip vortices are reduced and the *GEC* becomes more adept at flying near water and land surfaces, the lift produced by the 3 dimension airfoil increases and the drag decreases as the craft descends. The flow obstruction between the underside of the 3 dimension airfoil and the ground increases the pressure on the lower surface of the 3 dimension airfoil, increasing the lift. According to subsection 3.3 above, center of pressure location was influence by the pressure surrounding the surfaces. [39,40]Therefore, its location migrates further from its original position when flying outside ground effect zone. This phenomenon disturbed the pilot handling capability and may require special control system or specific type of 3 dimension airfoil to solve this problem. For a *GEC*, being able to fly outside of ground effect zone is crucial in order to avoid sea wave and high obstacle in a long travel.

3 Introduction to GEC

Since the early days of aviation, the ground effect has been known where experimental Ground effect Craft (*GEC*) were built in Scandinavia before the Second World War. The Russian Rostislav Alexeiev and German Alexander Lippisch was two individuals that contributed to the first series of *GEC* development. These two individuals while having a different background have encountered the same problems and have come out with a different solution. Alexeiev who has a background as a ship designer has thought that the *GEC* as a hydrofoils boat with its 3 dimension airfoil just above the surface. For Lippisch, based on his background as an aeronautical engineer, he was interested by the possibility of increasing the efficiency of aircraft flying nearer to the surface.[41,42]

3.1 Experimental GEC

In Russia, there have been two significant efforts to increase ship speed during the twentieth century. The initial project, which was launched in the 1940s, sought to lessen wave resistance when travelling quickly. The second initiative was in 1950s and aimed to glide the marine craft above water by lifting it out of water surfaces completely.

Fig. 16. SM

The first experimental *GEC* is the SM-1 and was designed by Alexeyev together with his team in 1960. SM-1 has a twin 3-dimension airfoil in a tandem arrangement and a gross weight of 2.8 tons as shown in Figure 3.0. SM-1 has a tandem 3 dimension airfoil at the centre and rear and a 20-meter- fuselage in the shape of a cigar. [43]The primary 3-dimension airfoil and tail haveside plates in the shape of 3-dimension airfoil tip floats put on them to lessen tip vortices and improve the craft's L/D ratio. SM-1 had a three crew and was flight tested on calm water at 200 km/h on July 22 1961. SM-1 exhibits unsteadiness in pitch during the trial as a result of its rear 3 dimension airfoil operating directly in the erratic slipstream of the forward 3 dimension airfoil. SM-1 crashed in Jan 1962 from engine failure when it climbed maneuvers.[44,45]

The second configuration was designed after SM-1 and named as SM-2 in March 1962 as shown in Figure 17. It is similar to SM-1 except that in this new arrangement, in ground effect mode, the ship was supported by one main 3-dimension airfoil, and to maintain long-term positive stability, asecond horizontal tail stabiliser was placed at the top of the vertical fin.[46] SM-2was damaged in a hanger fire and was given the name SM-2P after modification of installing rectangular tail with a high mounting 3 dimension airfoil and new jet engine. This SM-2P configuration was stable in-flight test.

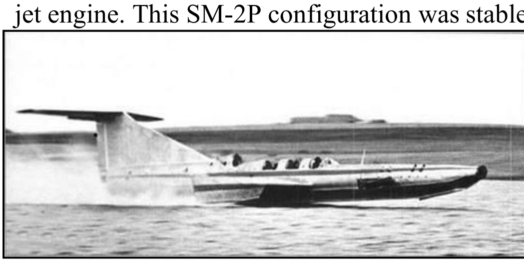

Fig. 17. SM-2

Fig. 18. SM-3

Later in 1962, SM-3 was developed and has a longer, low AR of main lifting 3-dimension airfoil and smaller tail as shown in Figure 18. It has a three crew in an enclosed cockpit and right in the front of the fuselage, the primary engine was relocated. The exhausts from the engine jet were blown underneath the main 3 dimension airfoil. SM-3 shows insufficiency forsteady flight in yaw stability when flying above 1.5 meter. It is clear at this point that low AR of the main 3 dimension airfoil was only appropriate for low ground clearance concept.[47,48] Later on, SM-3 was stop and change to the SM-4 in 1963 as

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shown in Figure 19 Based on the design of the SM-2, the SM-3 used a bigger jet engine in the bow to power the lift-enhancing system. As a result of SM-4's outstanding performance, the design bureau was inspired to create the KM, a very large *GEC* (also known as "Caspian Sea Monster" by the west) in late 1963 (see Figure 20). A 1:4 test model of KM was built in the same time called SM-5.

Fig. 19. SM-4

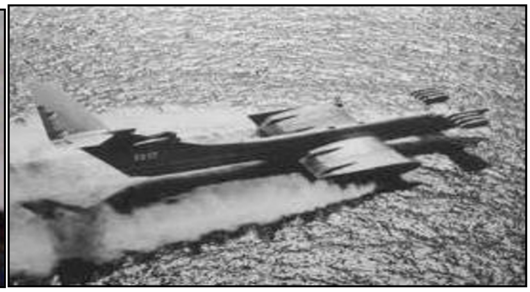

Fig. 20. KM a.k.a Caspian Sea Monster

Another noteworthy experimental *GEC* to mention is the Buchon-1. It has the velocity of 200 to 250 km/h, the vehicle length is 13 meter and has a 0.5 to 3 m of an altitude range. The Buchon-1 is mainly for commercialization applications and civilian transport. It is incorporated with reverse delta 3 dimension airfoil form and a 3 dimension airfoil section of S shape camber line. Due to blended 3 dimension airfoil shape, its fuselage produces more lift and horizontal stability. The canard also helps during the takeoff and landing producing a high AOA at low velocity.[49,50] The canard also generated positive lift during takeoff and landing. Buchon-M1 also embodied an elevator and rudders which effective even in slow forward speed. The propulsion system is located in a spray-free area and has a catamaran hull, which decreases hydrodynamic drag and boosts system durability. Figure 21 show the Buchon-M1 configurations produce in Russia.

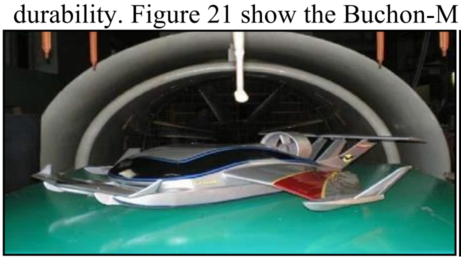

Fig. 21. Buchon M-1 model during 3-dimension airfoil tunnel test in Russia

Fig. 22. CSSRC PARWIG

At the China Shipbuilding Scientific Research Center, or CSSRC, more than 40 miniature PARWIG models were created in the late 1960s for testing purposes. Both the towing tank at CSSRC in Wu-Xi and the wind tunnel at MARIC in Shanghai were used to test out these models. The creation of a full-size craft in the late 1970s was made possible by the success of this test.[51,52] Figure of PARWIG is as shown in Figure 22.

In Germany, the development of experimental *GEC* was started by Dr.G.W Jorg. He began by adopting a negative delta 3 dimension airfoil configuration to promote ram air cushion beneath the 3 dimension airfoil. In his early experiment, Due to this layout has higher efficiency, improved stability, and reduced total resistance, the single ram air 3 dimension airfoil was replaced with two identical parallel 3 dimension airfoil arranged in tandem. After several years of development took place, The Tandem Airfoil Flair, TAF Boat was designated as a ship or boat by the German Ministry of Transport. Figure 23 shows the primary configuration of TAF VIII-3.[53]

Fig. 23. TAF VIII-3 photo

Fig. 24. Prototype of Bixel craft by Charles Bixel

An American enthusiasm, Charles G. Bixel patented his own *GEC* design in 1989. It is defined as combination of flying hovercraft and ground effect vehicle design. This craft is a flat double 3 dimension airfoil design for small, medium and large cargo that allows travel from low to medium to high speed on land and water. It is a low AR capable of traveling at a speed of 150 to 200 knots in ground effect zone at a safe distance above the water . Bixel claimed that this vehicle is 250 percent more efficient than modern aeroplanes, 15 times faster than cargo ships, and capable of flying over land masses for ocean-to-ocean and Inland Lake or river access, as well as any terrain. The patent Bixel drawing is as shown in Figure 25.[54] The flat 3-dimension airfoil with low aspect ratio allows this craft to fly in the ground effect zone at a height four times greater than at which conventional planes can fly in the ground effect zone. Another reason for using the flat 3 dimension airfoil design is manufacturing costs. Fabrication of chambered airfoil 3 dimension airfoil is costly, but flat box structures are substantially less expensive. Figure 24 shows the *GEC* prototype made by Charles Bixel conducting test on open sea.

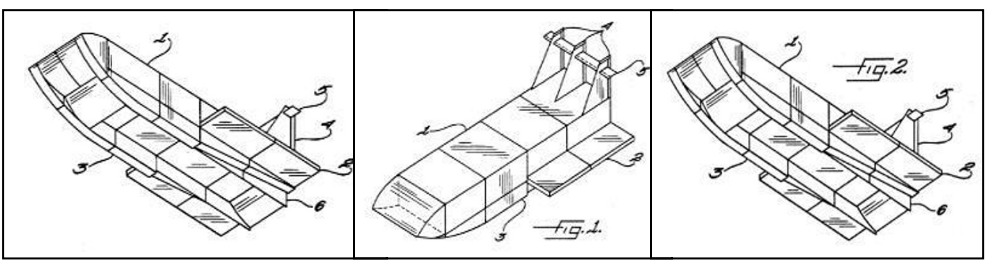

Fig. 25. Patented Bixel craft.

3.2 Large Russian Ekranoplan

Initially *GEC* that being design by Alexeiev has two wings and it was set as a tandem 3-dimension airfoil. The first full scale of *GEC* from the Design Bureau was a tandem craft SM-1, but after that the tandem concept was soon rejected in favors of ekranoplan design. Having a high take off speed, rough ride quality and poor maneuverability is the reason why the tandem concepts were rejected.[55]

Fig. 26. Lun type enkranoplan

SM-2P was the first ekranoplan built in 1962 and has featured low aspect ratio 3-dimension airfoil, high T-tail, and also the aerodynamics ofthe 3-dimension airfoil that will assist at takeoff.
All these designs are to decreased speed and load at takeoff and made the craft amphibious to accommodate Power Augmented Ram, PAR-system. As shown in Figure 3.10, the 400 lun that was built in 1987 is the most recent large ekranoplan with missile launcher on top of the hull. After that the second craft were created and being renamed Spasatel. After the collapse of Soviet Union, it has become impossible for the Russian to keep developing or keep maintaining the big ekranoplan.[56]

3.3 Small Commercial Prototype GEC

Small type of *GEC* has more opportunities in commercialization purposes whether in tourism, logistic and human transportation. For that reason, the design bureau started focusing on smaller ekranoplan for non-military use. InRussian, the design bureau started focusing on smaller ekranoplan for nonmilitary use. Since the dissolvent of Soviet Union, Volga Shipyard has been the one to continue producing enkranoplans and smaller enkranoplan for nonmilitary use is still under development. The development of eight seat Volga 2 was introduced in 1985.
Alexander Lippisch the German scientist, also known as a father of delta 3 dimension airfoil who designed the ME 163 rocket powered delta 3 dimension airfoil airplane, develop the X-112 *GEC* with inversed delta 3 dimension airfoil and T-tail in 1963. This design has proved to be stable, efficient in ground effect and was successfully tested. Soon the six seat X- 114 were develop by German company called Rhein Flugzeugbau as shown in Figure 27.

Fig. 27. The Rhein Flugzeugbau X-114 in flight .

Later Hanno Fischer completed two models. Figure 28 shows the two- seater Airfisch 3[44], and the six-seater FS-8. The FS-8 was to bedeveloped by Fischer Flugmechanik for a Singapore-Australian joint venture called Flightship.

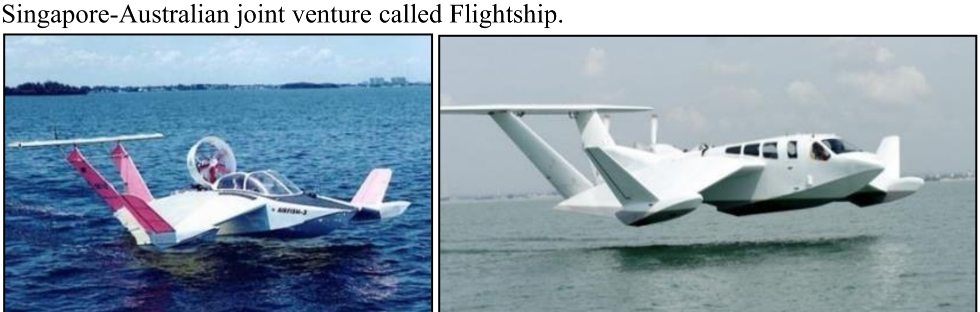

Fig. 28. The Air Fisch 3 and Air Fisch 8 develop by Hanno Fischer

From 1060s to late 1969s, The America conducts several ground effect machine configurations as part of a defence development programme with the aim of creating a fast marine vehicle. However, high speed SES and then hovercraft for amphibious attack. In early 1970s, American chooses to develop large high speed SES rather than other concepts. This programed was cut short after by the mid-east fuel crisis and their intention was switchto other programed such as nuclear-powered submarine.

A company called Wingship Inc. created the concept design for the Hoverplane in the 1990s. It combines *GEC* technology that is already in use with conventional technology. The main body of the hoverplane is shaped like a shallow catamaran, and the front and back are sealed with semi-rigid skirts. By forcing air into the chamber, it works., so that the main body wouldbe able to maneuver on the water like SES.

A five-seater *GEC* Aron-7 were developed by Korean company namely Aron Flying Ship Ltd as shown in Figure 29. It has a length of 10.8 meter and a wingspan of 12 meter. Aron-7 is equipped with Lycoming 540 engine and produces about 300 bhp. The takeoff speed is 100 km/h and cruising speed of180 km/h. Aron 7 were intended for marine tourism, rescue and military applications (see Figure 29).

Fig. 29. Five-seater Aron-7 GEC.

Fig. 30. CYG-11, joint venture development between China and Russian

Started at late 1960s, China joint venture with the Russian. Together they have developed a GEC called CYG-11 (see Figure 30) by a company called Hainan England *GEC* Manufacturing Co, Ltd. The appearance and technical characteristic similar to the Russian Wig craft called Ivolga. It can reach a cruising speed of 250 km/h and mileage of 1500km. CYG-11 capacity is 12 passengers and the maximum weight is 1200kg.

In 2010, Iran announced that Bavar 2, a fixed-3 dimension airfoil *GEC* producing a low radar signature capable of flying undetected while carrying out patrolling mission are to be given the Iranian Navy. 11 of these *GEC* were delivered to the navy fleet on the same day. There is close resemblance between Bavar 2 and Eska-1. The craft has a seating capacity of one to two. Videos footages of assembly process and the craft flying are widely availableon Internet. These craft are suggested to be aerodynamically stable based on the video footages.

3.4 Small Individual Initiatives

Separate from the major commercial endeavour projects during the past ten years, a number of enthusiasts began to build *GEC* for their own purposes. The ACV pioneer Bob Windt created the first successful design. . The Weber brothers were another enthusiast and they constructed their own GEC with tandem 3 dimension airfoil designs. Another enthusiast was RudyHeeman from New Zealand which we will discuss further in the next chapter.

In tourism, recreational Hoverwing can be used as substitute forboat and ships. It is also a much faster recreational transportation compare to boats and ships. It will also provide a new attraction for tourists since the vehicle is flying rather than going on river and sea.

3.4.1. UH18 SPW and UH19 XRW

Design and develop by Universal Hovercraft, a leading for innovative, high-speed hovercraft and solution worldwide. The development of UH18 SPW hoverwing were introduces by combining two technologies, hovercraft and ground effect creating a hovercraft that can fly called Hoverwing. Later on Universal Hovercraft developed UH19 XRW as the upgrade version of previous one. UH18 SPW specification were not written in any published journal and article making its aerodynamic performance remain unknown although it has been successfully to hover, fly, easy maneuverability and achieved sufficient stability during flight test. Figure 31 and Figure 32 shows the UH 18 SPW and UH 19 XRW respectively [51].

Fig. 31. UH 18 SPW by Universal Hovercraft [52].

Fig. 32. UH 19 XRW by Universal Hovercraft [53].

3.4.2. New Zealand Rudy Heeman

A New Zealand mechanic and enthusiasts, Rudy Heeman developed a successfully tested hoverwing after spending 11 years of building it. His hoverwing can reach an optimum height of 1.5 meter above the water and a top speed of 98 km/h. The hoverwing is powered by a modified Subaru engine and the body was made mostly from fiber glass. Figure 33 shows the Rudy Heeman hoverwing .

Fig. 33. Hoverwing developed by New Zealand Mechanic, RudyHeeman [55].

3.4.3. New Generation and Conceptual Future GEC

Fig. 34. The New Orlan. A conceptual Design.

Over the last years, inspired by the monster craft during the cold war, Russian has started to develop a new generation of GEC. The new Orlan craft will be a descendant of the so-called 'Caspian Sea Monster,' a now inoperative vehicle that flew across the sea at speeds of up to 400 mph. According to Russian Deputy Prime Minister Yuri Borisov, the Orlan which currently under develop will be ready by 2027. It is part of armament program for 2018-2027 and carrying missile armament. The Orlan craft is currently under development by the Alekseyev Central Hydrofoil Design Bureau, based in Nizhniy Novgorod, Russia. Figure 34 show theconceptual Orlan GEC by Russian.

4 GEC Potential Market

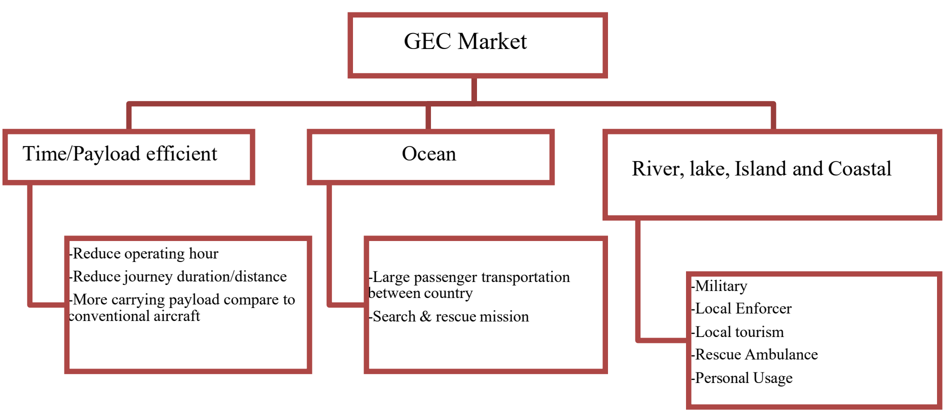

Fig. 35. GEC potential Market

Even in the future, GEC will not be able to replace any forms of maritime vehicles or aeroplanes. Although it might be an alternative vehicle to the existing transportation options.

All types of GEC, small and large, will be developed and upgraded, from type A to type C. GEC has a potential market in nations and places where water transportation plays an important part in local transportation and has to be extended as shown in Figure 35. There are rivers, lakes, islands or coasts. There is also a trend toward reducing operating hours and route length/distance across water.

The earth's water covers 70% of its surface, leaving 30% for land. Some countries are made up entirely of islands or are made up of multiple islands. Basically, GEC is water based

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vehicle, its routes is where there are actually people requiring fast transport at either end over water. In other areas, a rapid ferry revolution is also required to speed up local over-water transportation. The Sunda Island chain (Indonesia or Malaysia) and China's Eastern Coast are two possible places. Taylor GT considered East Asia/Australasia, the Caribbean, and Europe to be three appealing regions for GEC. . They perform a number of economic functions that enable them to facilitate products of varying degrees of sophistication.

5 Conclusion

For many centuries man has been wanting to travel around the worlds faster. New generations of ships are often faster than the ones they replaced. To make the speed improvement possible, new technologies were introduced. Higher speeds were achieved with hovering and air cushion vehicles such as microlights, hoverwings and GEC. There were several ship transportations like ferries and boats. Such traveling vehicle cannot travel faster because of the hydro drag.

In tourism, a GEC can be used to act as different alternative of transportations to ferries and boats. It also can be used as pilot studies in aircraft or militaries pilot. With the concept of microlights, hoverwings and GEC, these might be the best concept solution to achieve faster long travel and cost-effective maintenance and price of a GEC. The ability to overcome the economic challenge of fabricating and operating GEC will certainly be more palatable and enticing as tangible outcome translated in terms of profit in dollars and cents.

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