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Available search effort of the WIG craft

Wydajność poszukiwawcza ekranoplanu

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Abstract

The article addresses an issue of expansion of maritime rescue systems with new components which are Wing-In-Ground-Effect Crafts (WIG craft). Due to operational characteristic, use of phenomenon of ground effect, WIG crafts are extremely economical and achieve relatively high speeds. In addition, they possess also amphibious features. This represents a huge potential for participation in search and rescue actions.

The article discusses the phenomenon of a ground effect and its operation performance benefits and limitations. The applications of the WIG craft for specific actions such as conducting search, medical transport, supply of equipment and crews, patrolling are specified.

The article analyzes the Search Effort of the WIG craft and marine search unit SAR-1500, actually used on Polish coast. The study consists in determining the relationship between the altitude of the observer, his speed and search width. Next the calculation of available search effort is conducted. The results enable to compare the ability of different types of the patrol units.

Słowa kluczowe: ratownictwo morskie, patrolowanie, efekt przypowierzchniowy

Abstrakt

Artykuł porusza kwestię rozbudowy morskich systemów ratowniczych o nowe komponenty, jakim są ekranoplany (jednostki WIG). Ze względu na charakter operacyjny, czyli wykorzystywanie zjawiska efektu przypowierzchniowego, ekranoplany są niezwykle ekonomiczne oraz uzyskują relatywnie duże prędkości. Dodatkowo wyróżniają się cechami amfibijnymi. Stanowi to o ich ogromnym potencjale możliwości udziału w akcjach poszukiwawczo-ratowniczych.

W artykule omówione zostaje zjawisko efektu przypowierzchniowego oraz wynikające z niego korzyści i ograniczenia eksploatacyjne. Wyszczególnione zostają także możliwości zastosowania ekranoplanu do konkretnych działań, takich jak prowadzenie poszukiwań, transport medyczny, dostarczanie sprzętu i ekip, patrolowanie etc.

W artykule przeprowadzono analizę wydajności poszukiwawczej ekranoplanu oraz obecnie stosowanej na polskim wybrzeżu jednostki ratowniczej SAR-1500. Badanie polega na wyznaczeniu zależności między wysokością położenia obserwatora i jego prędkością a szerokością pasa poszukiwań oraz obliczeniu dostępnej wydajności poszukiwawczej. Wyniki analizy pozwalają na porównanie osiągów różnych typów jednostek patrolowych.

Introduction

Successful maritime rescue system requires good equipment, trained people and efficient management. The issue of rescue service's resources depends among others on development of technology. In recent years faster and more functional units have become part of modern systems of emergency response.

Ships, pontoon boats, helicopters and airplanes are the most common units for search and rescue purpose. Each unit type has its own operating range, in which it's the most effective. This range may relate to external operating conditions, load capacity and equipment, appliance, maintenance costs, etc. Construction and testing of alternative vehicles leads to improvement and support of the existing rescue systems. An example of such unit is Wing-In-Ground-Effect Craft (WIG Craft).

The WIG Craft (also called the Ekranoplan or WISE – Wing In Surface Effect Craft) is a vehicle with aerodynamic shape of a hull, which moves at a relatively low altitude over a smooth surface (land, water, ice) using the phenomenon of the ground effect. To apply this effect effectively, the flight should take place at an altitude corresponding to about 1/3 of the wingspan of a vehicle, generally a few meters. The results of such flight are a huge fuel saving and a wide speed range. This range is within the limits of approximately 50–200 knots. Just these two parameters, the economy and operational speed, are huge potential in possibility of adopting the WIG crafts for search and rescue, and maritime transport [1].

International Maritime Organization classifies three types of WIG units, dividing them by their operating nature. IMO Type A is a small vehicle that can move only in an interaction of a ground effect. IMO Type B, vehicles are generally larger in size, capable of moving away temporarily from the ground effect, jumping over an object or continuing the flight on determined altitude, but not exceeding a height of 150 meters. Type C is an ordinary aircraft (regulated by ICAO[1]), performing flying above an altitude of 150 meters, but also suitable for operating in a zone of a ground effect [2].

a)

b)

Fig. 1. a) WIG craft for passenger use type A, FS-8; b) WIG craft for patrolling and rescue aims, type B, Aron-7 [3, 4]
Rys. 1. a) Ekranoplan pasażerski typu A, FS-8; b) ekranoplan patrolowo-ratowniczy typu B, Aron-7 [3, 4]

[1] ICAO – International Civil Aviation Organization.

Figure 1 shows two examples of the latest design solutions [3, 4]. Figure 1a: FS-8 passenger WIG Craft Type A, crew – 10 persons (capacity 800 kg), maximum flight speed – 86 knots, optimum altitude – 3 meters, range – 300 Nm, maximum flight time – 4 hours, average wave height during taking off up to 0.5 m, during flight – up to 2 m [3], Figure 1b: Patrol and rescue craft of Korean production Aron-7 WIG Type B, crew – 5 person, maximum flight speed – 108 knots, range – 430 Nm, optimum altitude – 5 m, patrol flight – 150 m, average wave height during take-off up to 1.5 m during flight up to 2.5 m [4]. These and other WIG crafts are currently used on a small scale in the passengers or cargo transport and patrolling of a coast, among others in Korea, Australia, USA, Canada, Germany and other countries.

Phenomenon of the ground effect

The effect occurs when a sufficiently large and fast object is moving in proximity to the surface. During the movement (flight), the air flowing upper convex part of the wing has a longer way to go, than the air flowing under its bottom along the flat part. Therefore, the speed of air flowing over the wing is higher and thus lower is the pressure. The resulting pressure difference causes a local extra lift upward (perpendicular to wind direction). Under the wings, a gap of compressed air is being created. This is an artificial high pressure zone also called a dynamic air cushion. The area of overpressure affects the entire surface of the wing, causing lift multiply by about 75%. Remaining in the ground effect zone provides maintaining the obtained speed [4].

Using the ground effect enables to obtain a relatively high speed, while low fuel consumption. In terms of the maximum attainable speed, the WIG craft can be located between marine vessels and small airplanes or helicopters. In comparison to maritime units WIG crafts fuel consumption is up to about 80% lower and compared to the air units about 50% lower.

Capabilities and operating limitations

Due to the moving mode of WIG crafts clear limitations of application can be distinguished, as well as the tangible opportunities named. The main advantages include: speed, efficiency, safety and low environmental impact. Low maintenance costs and short amortization periods are next features. Low fuel consumption also means less pollution of air and water. If the WIG craft moves through inland areas such as along rivers, no impact on flora and fauna is recorded. The vehicle does not touch water surface, does not produce any waves, so cannot destroy the fragile edges of riverbeds. Application of closed-circuit cooling systems in engine significantly reduces risk of water pollution.

Fuel savings result in increased operating range of the craft. Depending on size and destination of the unit, the range is between a few hundred to even a few thousand miles. The WIG crafts can be equipped with auto-stabilized systems and lack of rolling and pitching significantly affects comfort. A low altitude of flight and a possibility of launching in emergency or failure contribute to increasing level of operational safety. It presents a big advantage for search and rescue actions as well. Constructing vehicles with technically advanced composites and materials makes the craft practically unsinkable.

Depending on the unit size and its individual structure, one can point out their key performance:

– flight speed of ca. 50–200 kn;
– flight range: 200–2000 Nm;
– fuel consumption equal to approximately half fuel consumption for aircraft and only about 1/5 for marine units;
– flight possible in zone of the ground effect and also at higher altitudes;
– possibility of launching, beaching, landing at the airport;
– possibility of flight over a flat surface of land, water, ice.

So far none of the existing sea or air vehicles was built as universal transport device. Each kind of vehicle operates only within specified limits or certain hydro-meteorological conditions. Their operational capabilities determine their chance to be used in particular situation.

The main difficulties of the WIG craft application include: flight over diversity surface (e.g. jumping over obstructions), seaworthiness (limited sea state and wind speed), size of unit (wide wingspan), and navigation in dense traffic. Jumping over the objects may be associated with leaving the ground effect. Larger WIG crafts possess such abilities, but this often increases fuel consumption.

The hydrometeorological conditions are another problem of flight over water. When a wave is too high, an air gathered under the wings of a vehicle could move in a brough and thus introduce instability in flight. The smallest WIG crafts can take off by sea state up to 2°B and the main flight influenced by the ground effect may take place by sea state of 3°B, the biggest crafts are able to take off from sea state of 4–5°B, and the main flight is possible even by 6°B.

For very large WIG crafts, due to their wide wingspan, manoeuvring over water in a harbour can be problematic. But the solution to this situation may be craft's stationing at a nearby airport or going out to the beach. However, due to the development of relatively high-speed, the WIG crafts flying at low altitude in dense vessel traffic can introduce additional risk of collision.

Potential applications in the maritime sector

There are numerous possibilities of using the WIG craft in the maritime sector. The intention of introducing them into existing systems is not to replace the currently used vehicles which are proven conventional sea or air units, but to support and supplement some branches of transport.

The group of commercial applications encloses passenger transport, cargo transport on a small scale, as well as a branch of tourism and sport industries. The second group comprises non-commercial use which can include search, rescue, environmental monitoring, patrolling and protecting the coast. The third group includes special tasks such as transfer of crew, amphibious transport, research, etc.

For purpose of search and rescue, depending on the type of WIG unit, the following functions and tasks can be listed:

– conducting search of missing crafts and persons;
– evacuation of crew and passengers form ships in distress, submarines, aircrafts, mining and drilling rigs and other ocean facilities;
– medical transport from ship, e.g. ice-covered areas;
– delivery of pollution and fire preventing equipment, rescue teams;
– environmental monitoring, e.g. in terms of oil spills;
– limiting of oil spills (e.g., developing booms), especially in early stages of rescue operation;
– reaching out crafts and crews trapped in shallows or in ice;
– rescue assistance.

The main determinant which of the functions can be carried out by the WIG craft is its capacity and type. The largest WIG crafts type C, up to several tens of meters in length, are capable to transport equipment and rescue teams on a distance of several hundred up to several thousand miles.

It allows to reach out ship in distress far off the coast. Another function for these units can be patrolling flights conducted on higher altitudes.

It is possible to design a system which will increase the operating range of the WIG craft. The system consists of two units. The mother transporting aircraft and the daughter WIG craft type B. In this arrangement, the WIG craft could be installed in the hull of the aircraft. After reaching the scene of the incident, the WIG craft slides near threatened units and provide assistance. By taking the advantage of aircraft transport, the fuel stores of the WIG craft can be saved and used for operation on the scene and return ashore.

Smaller WIG units of type A and B can be used, in the range of their autonomy, for the purposes of searching, patrolling, monitoring and transport off coastal waters. On the Baltic Sea, in particular in the summer time, the WIG's will find application in early stages of search operation. Due to the high speed the crafts can reach the scene much faster than conventional vessels. Early commenced search action will also increase the chance of recovery of survivors.

Comparison of rescue units in search actions

The search actions include searching of persons in water, life saving appliances or vessels. The main threat of person over board is hypothermia. Therefore, the time to reach the person by rescuers is usually most important factor for his chances of survival. Early commenced action increases the probability of finding a survivor in good physical condition.

Figure 2 presents the comparison of different types of marine rescue units in terms of attainable speed range in which they can operate during the action. The approximate values of speed are assumed to create the graph. The WIG crafts, which are a transitional form between seaborne and airborne units, have a similar speed range to helicopters and small airplanes. Simultaneously, they are about 3–5 times faster than conventional merchant ships or maritime rescue vessels. WIG crafts of type A and B operate generally in the range up to 100 knots, while the type C and up to twice times faster.

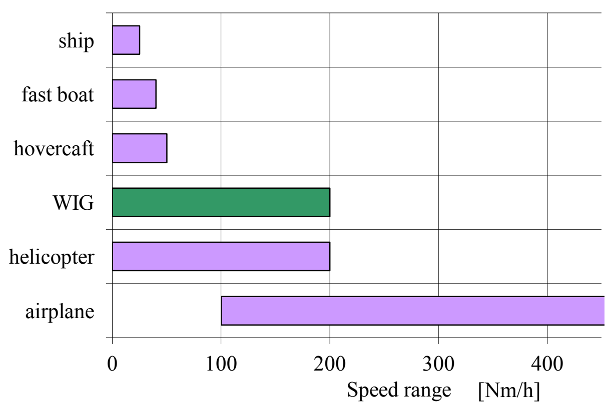

Fig. 2. Comparison of operational speed ranges for different types of rescue units

Rys. 2. Porównanie operacyjnych przedziałów prędkości dla różnych typów jednostek ratowniczych

The operating speed of the search unit is one of the elements determining its suitability for SAR actions. The high speed of the WIG craft can be useful especially for search actions.

The parameter specifying the productivity of the vehicle in search actions is called *Search Effort Z*. This parameter defines "a measure of the area, a search facility can effectively search within the limit of search speed *V*, endurance *T* and sweep width *W*" [5]. Search effort is expressed in units of surface and is base element for further search plan calculation.

The analysis of the parameter *Z* conducted below is done to assess the suitability for search action of a small WIG craft in comparison to the maritime rescue unit SAR-1500. For the calculation four speeds 20, 30, 50 and 80 in altitude range 2–10 meters were adopted. The first two speeds will represent abilities of rescue units SAR-1500, the last two speeds will represent average performance of WIG crafts.

Altitude of observation and Sweep width

Sweep width *W*, the width of the search is defined as "a measure of the effectiveness with which a particular sensor can detect a particular object under specific environmental conditions" [5]. The value of this parameter in a particular situation affects current visibility, size of search target, as well as search altitude and speed. Other important factors determining detection ability are object's contrast on background of sea or sky, observer fatigue, vibrations, etc.

Recommended sweep widths are to be found in IAMSAR Manual. The search units are divided into two groups: merchant ships and air crafts. For the second group designated search widths include observer's altitude, as opposed to first group. However, small differences of elevation impact on the observation's range and viewing angle of the sea surface especially by high speed as well.

On small merchant vessels observer is located at the altitude up to several meters above the water level. For the large ships it is up to 30–40 meters in height. Maximum visibility range of these units is different. Altitude of the observer affects the ability of detection and should be taken into account when determining the search width, especially when applying significant search speed differences.

The parameter W is essential element allowing effective planning of search action. This value has to be chosen according to prevailing meteorological conditions at sea. A small search target, man in water could partially or completely "disappear" in brough, while a relatively large waving. In this case, the angle of observation, resulting from the altitude, is a key factor in detecting form a distance. Extended search width enables faster passage through the area, but may cause omission of search target on the edges of search tracks. The tracks arranged to close will result in loss of time and reduction of search effort. The reason for that is fact that some sectors of search area will be sweep several times.

In order to create a table of recommended sweep width, depending of the search altitude and speed, the model of inverse cube has been used. The formula (1) below is the result of integration function of likelihood of detecting a target by a search unit moving linear motion. Sweep width is proportional to the square root of altitude and inversely proportional to the square root of speed [6].

$$W = 2\sqrt{\frac{2\pi kh}{V}} \tag{1}$$

where, k – detection factor, h – search altitude, V – search speed.

Detection coefficient k includes factors that reduce the probability of detecting an object. For further analysis the coefficient k assumed equal one.

From the assumption the WIG crafts operate on the height above the water equal to 10–30% of span of their wings. The observer occupies position a few meters above the surface. A similar situation is on rescue unit SAR-1500. So, for further calculation the altitude range of 2–10 meters were adopted. The analysis includes study of search effort of rescue unit SAR-1500 searching with speed of 20 and 30 knots, as well as search effort of WIG craft searching with speed of 50 and 80 knots. The analysis doesn't include sweep width variations resulting form size of the object or weather conditions limiting visibility. The results should be treated as output values for further modification.

Table 1 summarizes the results of sweep width obtained by applying the inverse cube model. Rows represent altitude of the observer, columns correspond to the tested speed. The obtained values are presented with an accuracy of 0.1. The table shows that increasing of observation's height will expand the sweep width.

Table 1. Sweep width according to the inverse cube law, variable altitude and speed of search

Tabela 1. Szerokość pasa poszukiwań według modelu odwróconego sześcianu, zmienna wysokość i prędkość poszukiwań

h \ V	20 kn	30 kn	50 kn	80 kn
2 m	1.6	1.3	1.0	0.8
4 m	2.2	1.8	1.4	1.1
6 m	2.7	2.2	1.7	1.4
8 m	3.2	2.6	2.0	1.6
10 m	3.5	2.9	2.2	1.8

Theoretically, each additional meter of elevation up to 10 meters expands the search width about 2–3 cables for the slower units (SAR-1500) and about 1–2 cables for faster crafts. If the observer is located 6 meters above water level, then depending on his speed, recommended sweep widths are from 1.4 Nm ($V = 80$ kn) to 2.7 Nm ($V = 20$ kn). Simultaneously, it can be seen that increasing the velocity four times (20–80 kn) effects restricting of sweep width by half ($W_{80}/W_{20} \approx 0.5$).

Calculating the Search Effort

As mentioned above, the search effort depends on speed, endurance and sweep width and is a product of these factors. Speed is the velocity maintained during a search. For analyzed case, four speeds corresponding to the craft' performances were adopted. Endurance is a "productive" search time interval available for the unit. In case of searching conducted by visual observation the daylight time is also taken into account. The time which has lower value is assumed for further calculations. Additionally, the amount is usually reduced by 15%. Spare time is used among others for navigating turns at the end of search legs. In the analyzed situation available time is set at seven hours and daylight time at six hours. Real amount of time used for sweeping the designated area is called *Search Endurance*. In accordance with the IAMSAR procedure, the sweep width should be corrected by weather factor, fatigue factor and speed factor (aircrafts). In analyzed situation these factors don't change the width. For this reason they were omitted.

Table 2 shows the calculation sheet of the search effort parameter. Rows correspond to a particular factor, columns represent the value of these factors for studied crafts and their speeds. The values of altitude and speed presented in table 1 were used to complement appropriate fields.

Table 2. Calculation of parameter *Search Effort Z* for analyzed crafts, based on IAMASR vol. II. Appendix L "Total Available Search Effort Worksheet"
Tabela 2. Kalkulacja parametru wydajności poszukiwawczej *Z* dla analizowanych pojazdów, na podstawie IAMSAR vol. II. Załącznik L „Total Available Search Effort Worksheet"

Parameter	SAR-1500 (1)	SAR-1500 (2)	WIG (1)	WIG (2)
Search Speed V [Nm/h]	20	30	50	80
Available Time	7	7	7	7
Daylight Time	6	6	6	6
Search Endurance T [h]	5.1	5.1	5.1	5.1
Altitude [m]	6	6	6	6
Sweep Width W [Nm]	2.7	2.2	1.7	1.4
Search Effort Z [Nm^2]	280.0	342.9	442.7	560.0

On all four crafts simulated observers are located at altitude of 6 meters above water level. Rescue units SAR-1500 are searching with speed of 20 and 30 knots. Within 6 hours these crafts are able to scan area of 280 and 343 Nm^2. Sweep widths are respectively 2.7 and 2.2 Nm. Search effort of the faster unit is 22.5% higher then slower unit ($W_{30}/W_{20} = 1.225$). At the same time interval the WIG crafts moving with speed of 50 and 80 knots, despite of sweep width reduction down to 1.7 and 1.4 Nm, are able to scan the area of 443 and 560 Nm^2. Increase in effort between the crafts is 26% ($W_{80}/W_{50} = 1.26$).

Comparing WIG crafts to SAR-1500 units the increase in search effort can be determine as a range 29–100% ($W_{50}/W_{30} = 1.29$; $W_{80}/W_{20} = 2$). Lower limit is ratio of WIG (1) and SAR-1500 (2), upper limit is ratio of WIG (2) and SAR-1500 (1).

Figure 3 presents the relationship between speed and search effort for the altitude of 6 meters. Graph clearly shows the increase in field size proportional to growing speed.

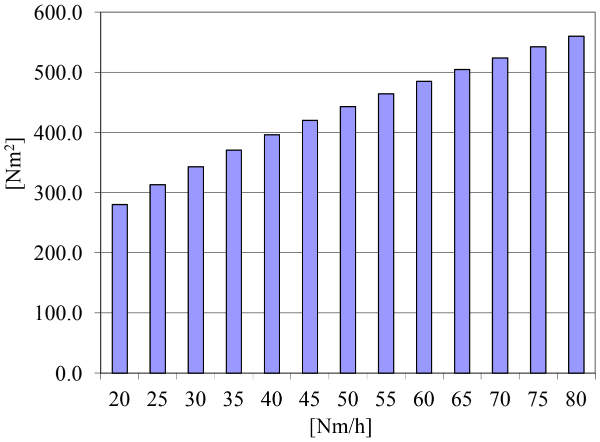

Fig. 3. Search effort for speed range of 20–80 knots, altitude of the observer 6 meters
Rys. 3. Wydajność poszukiwawcza w zakresie prędkości 20–80 węzłów, wzniesienie obserwatora 6 metrów

The obtained results allow to draw the following conclusion. There is a close correlation between altitude of observation's point, speed and search width. While sweeping the sea surface at particular elevation, speed growth leads to restricting of search width. It means that the search tracks covering area should be arranged closer each other. However, this restriction doesn't adversely affect the search effort parameter. The relationship is opposite. The increase in speed at a constant elevation of the eye, causes enlarge in swept area.

Search for a target by WIG craft may be more effective than by fast rescue unit SAR-1500. Due to high search speed an object can be found earlier, which gives survivors better chance for recovery. For this reason WIG crafts within their operational limitations and abilities may be complement to rescue systems.

Conclusions

The WIG crafts are vehicles linking many advantages of other conventional rescue units. Relatively high speed, ability to land on the water, cargo capacity, fuel economy, low environmental impact are the most important features of the WIG crafts. Their application for search and rescue may be limited by hydro-meteorological conditions. Especially, the WIG crafts characterized by low seaworthiness can not be applied in every situation.

The search effort of rescue unit depend the most on the search speed. The increase in speed by constant altitude enables sweeping bigger area. The observation point on WIG craft and SAR-1500 is similar, but due to different speed the sweep widths are dissimilar. Despite of smaller sweep width resulted from higher speed, the WIG craft can search larger area in the same time interval. For the analyzed speed of 20–80 knots the search effort growth between these types of rescue craft is assigned in range of 0.29–1.0.

The conclusion is that WIG crafts type A and B may support search operation, particularly in coastal waters with great efficient and may be used for patrolling, monitoring and medical transport. Maritime Search and Rescue Service, Maritime Regional Unit of Border Guard, Maritime Authority, Sea Fisheries Inspectorate are Polish institution which could use these WIG crafts in their operation at sea. In combination with other maritime rescue units larger WIG vehicles may create global rescue system. Their main functions will be search, rescue and transport.

Inclusion of the WIG crafts in rescue operations will increase the efficiency of maritime rescue systems. In this way, it will be possible to respond much more quickly and effectively in emergency situations for life, property and environment.

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