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REVIEW ON THE COST AND PERFORMANCE OF A WIGE CRAFT: A COMMERCIALIZATION PROSPECTIVE

Cheong Ming Yin, Surjatin Wiriadidjaja, Dayang Laila Abd Majid, Fairuz Izzudin bin Romli, Azmin Shakrine Mohd Rafie and Amzari Zhahir
Department of Aerospace Engineering, Faculty of Engineering, Universiti Putra Malaysia, Serdang, Selangor, Malaysia
E-Mail: memo4869@gmail.com

ABSTRACT

This study is prepared as an analysis on potential application and commercialization of the wing-in-ground effect craft (WIGE craft) as a new transportation system for domestic market. As the needs analysis and concept exploration phases commonly carried out within the concept development of a new complex system, this study may serve as validation answers to some basic questions such as "Is there a valid need for this new system?", "Is there a practical approach to satisfying such need?", "What performance is required?", and "Is there at least one feasible approach to achieving such performance at an affordable cost?". The analysis on potential of application and commercialization of WIGE craft would constitute a basis for making a decision as to whether or not to invest in a further development effort. The conducted analysis can be also considered as a "feasibility study", which in this case has been based on comparison of certain key features of a WIGE craft with those of other existing transportation vehicles that remain offering services as the "proven" alternative concepts. The key features of a WIGE craft should be in the first place in its capabilities, operational effectiveness, and in its performance requirements, which are supposed to achieve the most beneficial balance between capability, operational life, and cost. During the process of study, it has been found that a WIGE craft may fill in the gap between aircrafts and marine vehicles in terms of technological and operational advantages. However, the operational costs of WIGE craft have been found to be relatively higher if compared to those of other existing transport vehicles. Besides, as a matter of fact, a WIGE craft has never reached acceptance as mainstream transport vehicles, because apparently a WIGE craft contains inherent stability problem due to coupled effect of variation in angle of attacks and in altitude above the surface, which require a solid and generic solution. A further development effort beyond this current study would be the engineering development, which commences with the identification and reduction of development risks. Nevertheless, it can be stated that the development of a WIGE craft may give invaluable advantages in the development of new concept and technology.

Keywords: wing-in-ground-effect (WIGE), wing-in-surface-effect (WISE), wingship, ekranoplan.

INTRODUCTION

Petroleum has been one of the main export products from Malaysia. Crude oil of petroleum often found far away or under the deep sea. In order to get the crude oil of petroleum, offshore drilling is carried out. Normally, a working platform is built on the sea to carry out the drilling process. So, people working for the offshore drilling process, from operator to maintainer, they require to travel between onshore and offshore from time to time. Thus, a convenient transportation is required to bring people from onshore to offshore and vice versa. Helicopters and marine vessels are always used for personnel transportation and material movement between onshore and offshore. However, helicopters are expensive to operate while marine vessels are taking longer time. Therefore, it is found that there is another transportation that is potentially suitable for this job. It is known as wing-in-ground (WIGE) effect craft.

This study is prepared as an analysis on potential application and commercialization of the wing-in-ground effect craft (WIGE craft) as a new transportation system for domestic market. As the needs analysis and concept exploration phases commonly carried out within the concept development of a new complex system. Results of the study may serve as validation answers to some basic questions such as "Is there a valid need for this new system?", "Is there a practical approach to satisfying such need?", "What performance is required?", and "Is there at least one feasible approach to achieving such performance at an affordable cost?"

The analysis on potential of application and commercialization of WIGE craft would constitute a basis for making a decision as to whether or not to invest in a further development effort. The conducted analysis can be also considered as a "feasibility study", which in this case has been based on comparison of certain key features of a WIGE craft with those of other existing transportation vehicles that remain offering services as the "proven" alternative concepts. The key features of a WIGE craft should be in the first place in its capabilities, operational effectiveness, and in its performance requirements, which are supposed to achieve the most beneficial balance between capability, operational life, and cost [1].

Among other things, this report includes the theory of the efficiency of wings operating in ground effect and some background about the development of WIGE craft during all these time. Cost and performance characteristics of WIGE craft and its operational limitations, which are found on some developed WIGE craft are also discussed.

Some experimental and operational data that were obtained by WIGE's manufacturers or other WIGE's supporters, and resulted primarily from testing works on WIGE's prototypes are included in this report as well. Furthermore, this report also outline the discussion about the comparison between WIGE craft and comparative vehicles such as aircraft, helicopter and marine vessel for onshore and offshore operation in term of their performance, efficiency, speed, fuel requirement, and operation &maintenance costs.

BACKGROUND

Lifting bodies are objects that produce aerodynamic lift and drag in moving air. The most efficient shape in producing lift is a wing. A measure of aerodynamic efficiency of lifting bodies is represented by its lift to drag ratio (L/D). Theoretically, higher lift to drag ratio represents higher efficiency of the body. Movement of wing through the air produces a larger static pressure on the lower surface of the wing than that on the upper surface, and the different in pressure level will then produce a resultant force that points upward. When the produced resultant force is large enough to support the whole body weight of the aircraft, it can fly. Aircraft normally fly in a free stream which also means that the air around the wing is not bounded in any way [2].

The produced resultant forces that act on a moving wing may be thought of as a combination of lift and drag. The lift is defined as the resultant force that acts in the direction perpendicular to the vector of velocity of the wing while the drag force acts parallel to the direction of motion of the wing. The drag force itself is composed of pressure drag and frictional drag. The pressure drag has its origin in two phenomena. One is related to the lift, that is, to the work which must be expended to obtain lift. The force which necessitates the expenditure of this work is called the induced drag. The other part of the pressure drag is independent of lift, it is the wake drag [3].

WIGE craft is a type of craft that make use of a phenomenon called "ground effect" to fly. Ground effect is a common name that used to represent a phenomenon whereby a boundary is placed below or nearby the lower side of the wing. Thus, the lift of the wing will be increased while the induced drag of the wing will be reduced. As a result, the flowing of air around the wing is altered and cause a dense air cushion trapped between the wing and the boundary when the wing approaches the boundary. This results in an increase of effectiveness of the static pressure below the wing as dense air cushion and at the same time, increases the lift to drag ratio. In practice, the boundary that can be made use is the surface of earth which includes both ground surface and water surface. When the wing is nearer to the boundary, the effect will become more pronounced, and hence, it requires lesser power and fuels. Though these effects are only observed when the wing is close enough to the surface boundary but we still can say that the WIGE craft is more efficient than aircraft.

There are different names given to WIGE craft. Russian called it as an Ekranoplan or a Ram-wing craft, Greek knew it as an Arcopter. It also has other names such as a WISE (Wing-In-Surface-Effect) craft, a Wingship, an AGEC (Aerodynamic Ground Effect Craft), a GEM (Ground Effect Machine) and a Flaircraft. WIGE craft may be called as flying ships as well, because it flies just above the sea. High water resistance limits the speed of a conventional ship up to 80-120 kilometres per hour, even of fast marine vehicles such as hydrofoil ship and hovercraft. However, WIGE craft can cruise without high water resistance at the highest speed among marine vehicles because it employs the effect of the ground effect. By considering the density ratio between water and air, which is about one thousand to one, it is clear that the resistance to WIGE craft during operation above the water surface decreases considerably.

The technology of WIGE craft is still considered new and not matured yet. A WIGE craft contains inherent stability problem due to coupled effect of variation in angle of attacks and in heights above the surface, which require a solid and generic solution. The engineering and commercialization of WIGE craft should only be done when the problem is solved as well as the technology on WIGE craft is fully matured. Height stability of WIGE craft can be explained by the changes of height will cause what effect on lift. For example, the stable case can be said is achieved when a decrease in height will cause an increase on lift and vice versa. Then, the increased lift will be able to restore the original height of the WIGE craft. It has been proven that WIGE craft can be designed to be stable in term of height stability since it has been known that the lift force that acting on WIGE craft will increase when WIGE craft is getting closer to boundary [4]. Aside from what has been achieved, it is now required that the WIGE craft can be auto-piloted while maintaining self-stabilization in operating height. Without involvement of any pilot, it is known that WIGE craft can navigate its operation at constant speed in ground effect. However, the solution that generic by using auto-piloted is very expensive and further decrease the worthiness the commercialization of the commercialization of WIGE craft.

In 1935, the concept of WIGE craft was started by T. Kaario, a Finnish engineer, who built the first WIGE craft known as a Wing-Ram. This idea was followed subsequently by Troeing, a Swedish engineer in the end of the 1930s. In late the 1950s and early 1960s, the practical realization of the WIGE's concept was made by R. Alexeyev, a renowned scientist of the former USSR as a precursor of the WIGE craft. In 1966, the KM (510 tonnes), a full size WIGE craft, nicknamed the Caspian Sea Monster was created by him. KM was the largest flying machine in the world at that time and remains the largest of WIGE craft till now. So, research and development of the WIGE craft were pioneered by the Russian. However, the situation becomes difficult for the Russians to further develop the WIGE craft since 1991 because the budget of the Russian Navy reduces drastically with the breakup of the Soviet Union. Russian WIGE craft are technically feasible but they are inadequate for civil use from an economic standpoint.

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Meanwhile, in 1964, the research of WIGE craft in Germany started by H. Fischer and A. Lippisch and they developed experimental WIGE craft, which are X-112, X-113 and X-114. In the USA, in 1984, Steven Hooker, an aeronautical engineer and an analysis of US intelligence, has pursued a full scale WIGE craft and founded his own company, Aerocon, to develop a huge WIGE craft, the so-called Wingship. Consequently, Hooker put forward five thousand tonnes of WIGE craft which have fifteen hundred cargo capacities. However, the US Defense Advanced Research Project Agency (ARPA) ended it up half-heartedly in doubt about its feasibility [5].

In connection with such a huge WIGE craft, Boeing recently announced that a concept aircraft that officially called the Pelican Ultra Large Transport Aircraft, might be the largest aircraft to ever fly. The craft has a normal cruising altitude of only twenty feet because it flies using ground effect. It will have a wingspan of 150 meters carrying up to 1400 tons of cargo. On the other hand, smaller WIGE craft have been developed for recreational and civilian uses since the 1980s. In addition, the research and development of WIGE craft have been continuing in many countries, such as Australia, China, Germany, Japan, Korea (Republic of), Russia, Taiwan and the United States. However, even though discussions, research and development for WIGE craft are done vigorously in the world, actual commercialization of WIGE craft in real earnest has not been realized up to date.

FEASIBILITY STUDY

Economic reasonableness of WIGE craft

Without a doubt that, when a new type of transportation is about to be introduced into the market, cost-effective analysis have to be carried out in order to determine whether the new transportation has economic reasonableness. This is important because no one wants an inefficient transportation. To examine this matter, the Gabrielli and von Karman diagram can be used. They are the first researchers to theorize comparative cost-effective studies of specific power required for propulsion of vehicles. This method is a classical but useful method to analyze the efficiency of a transport medium. The definition of specific resistance is the maximum installed power of a vehicle divided by the product gross weight and multiplied by its velocity. The Figure-1 represents the specific resistances of vehicles in a diagram according to Gabrielli and von Karman [6]. The centerline in the diagram shows the state-of-art technology, a target that is wanted to be achieved at a certain speed with a desired payload and at a minimum power. It is defined that when the specific resistance of a certain type of transportation is closer to the centerline, the transportation will be considered to have higher efficiency. For example, the specific resistance of helicopter is larger than that of commercial airplanes.

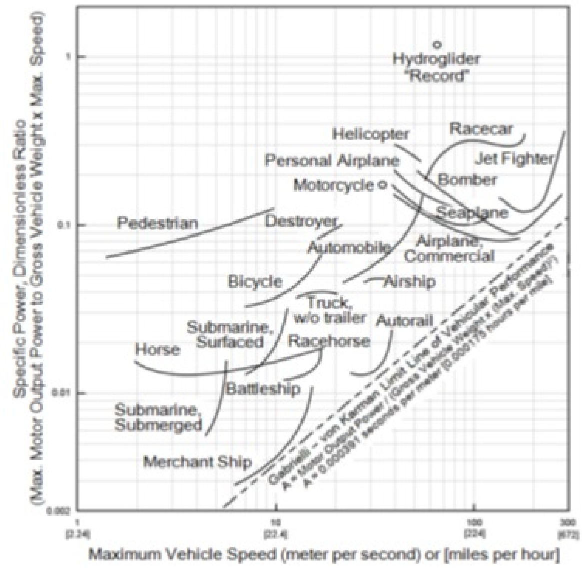

Figure-1. Specific resistance of single vehicles [6].

Thus, it would mean that the efficiency of commercial airplanes is higher than that of the helicopters since the specific resistance of helicopter is further from centerline. The above diagram also shows a wide range of specific resistance between various types of vehicles [7].

From the diagram, it can be observed that the specific resistance of the WIGE craft is located between the merchant ship and commercial airplane. In other words, WIGE craft have a potential to fill the gap between ships and aircraft. Aside from that, Gabrielli and von Karman diagram can be modified in various ways. One of the modified diagrams is shown in Figure-2, which illustrates the power required for different types of transportation. As it can be seen from this figure, a WIGE craft shows greater efficiency as compared with that of the others.

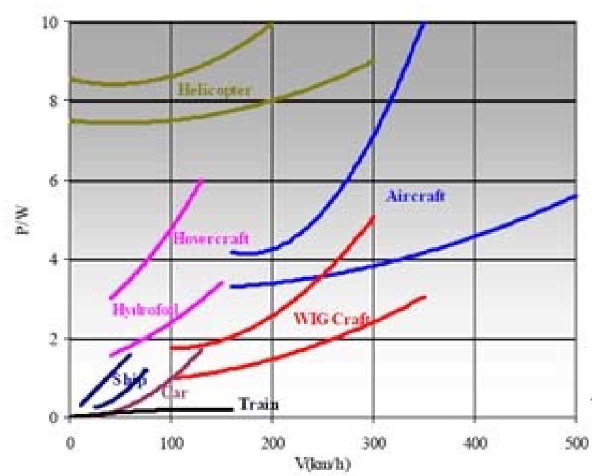

Figure-2. Required power for transport vehicles [8].

When examining the economic efficiency of transportation vehicles of known payload ratios, it is found that though the payload ratios of some vehicles are high, their speed are quite low such as in ships, while the other payload ratios are comparatively low but they have considerably high speed such as WIGE craft and airplanes. Definitely, the speed of vehicles is also an important economic parameter aside from the payload ratio.

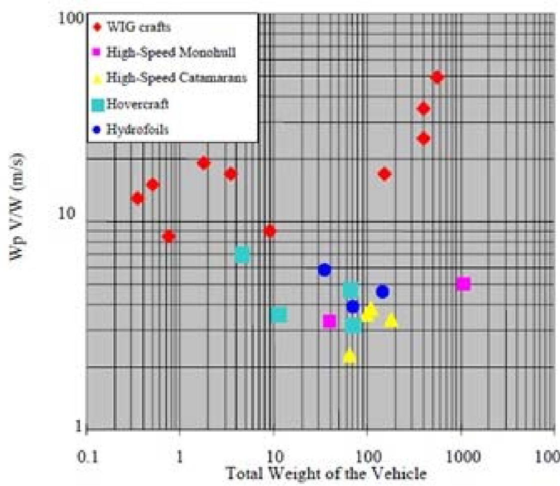

Figure-3. Productivity of HS marine vehicles [9].

Another useful measure to demonstrate economic efficiency of transport vehicles is the so-called transport productivity. Transport productivity is defined as the payload ratio multiplied with the speed. The Figure-3 illustrates, that the transport productivity of WIGE craft is beyond all comparison with other high-speed marine vehicles such as hovercraft and hydrofoils. So, it is obvious that WIGE craft have an advantage over the whole range of weight compared with other high-speed marine vehicles. Therefore, this figure can prove the development of WIGE craft as a new innovative transportation.

When determining the economic parameters of vehicles, it is important that the fuel consumption of vehicles be included because this is a direct characteristic that affect the performance of vehicles. Table-1 shows fuel consumption efficiency of several aircraft and the Russian Ekranoplan MPE-200 (WIGE craft). Aircrafts and the WIGE craft are selected because they have about similar payload and this is important so that comparison of fuel consumption is more accurate. From the table, it can be seen, that though Q_{pass} and Qt_{load} of a WIGE craft are comparatively high, the Qt_{weight} of WIGE craft is still quite competitive if compared with the modern civil aircraft. It can be concluded from the same table that weight efficiency of the WIGE craft is lower than that of current aircraft. This is due to WIGE craft require extra power required for take-off and additional equipment for safety at sea operations.

Table-1. Comparison of fuel efficiency [10].

Type	Q_{pass}	Qt_{load}	Qt_{weight}
Boeing 707-320C	31.3	334	8.54
Aerobus A 310-300	33.9	339	4.98
Aerobus A 300 B4	34.0	329	8.54
WIGE MPE-200	47.0	466	7.71

where, Q_{pass} = gram of fuel / 1 passenger 1 km (fuel consumption in order 1 passenger x 1 km),Qt_{load} = gram of fuel / 1t of load 1 km (fuel consumption in order 1t of load x 1 km), Qt_{weight} = liters of fuel / 1t of weight 100 km (fuel consumption in order 1t of total weight x 100 km)

Aside from comparing the WIGE craft with aircrafts, the Figure-4 shows the fuel consumption of WIGE craft as compared with other high-speed marine vehicles. When comparing with high-speed marine vehicles, it can be said that fuel consumption of WIGE craft is comparatively high. This is one of the reasons of why WIGE craft is not commercialized yet because fuel consumption efficiency of WIGE craft needs to be more improved.

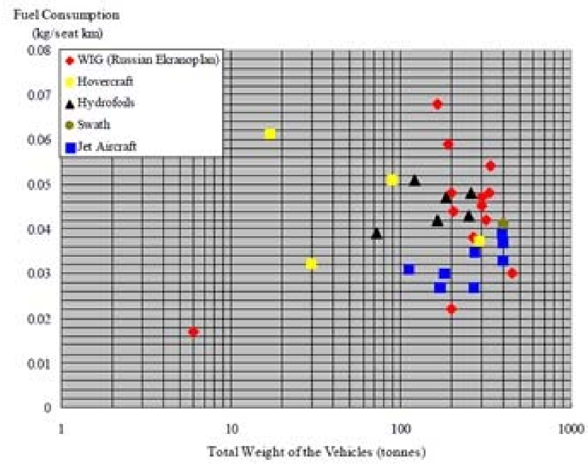

Figure-4. Fuel consumption of hs marine vehicles vs. total weight [9].

Cost analysis

Cost analysis is important to determine the possibility of commercialization of WIGE craft. In order to commercialize WIGE craft into the market, it is important to analyze the cost of craft and operation cost and compare with the other competing transportation such as aircraft and conventional ships. Though it is proven that the efficiency of the WIGE craft is higher when the size of WIGE craft is bigger, but the full scale WIGE craft is still difficult to be developed under present circumstances. So, it is desirable that the cost analysis is done for WIGE craft operation that is relatively small size as compared with existing types of transportation.

As mentioned before, WIGE craft is put between aircraft and ship in many different aspects. Therefore, an assumption that states the direct operating costs of WIGE craft is in between aircraft and ship is made. By the way, it is provided that the cost to operate WIGE craft is higher than aircraft and this might be the case that the commercialization of WIGE craft is not achieved until now. Since there is only a little reliable base on presumption of WIGE craft, it is quite complicated to estimate the price of WIGE craft. So, the price of WIGE craft will be estimated by formula [11], which is found on aviation statistics to determine the price of aircraft.

Total Operating Cost (TOC) consists of direct operating costs (DOC) and indirect operating costs (IOC) according to [12]. The DOC includes costs required to operate a craft such as price of a vehicle, maintenance cost, fuel cost and crew cost while the IOC includes costs that account for secondary items such as administrative and general costs, facilities and indirect personnel.

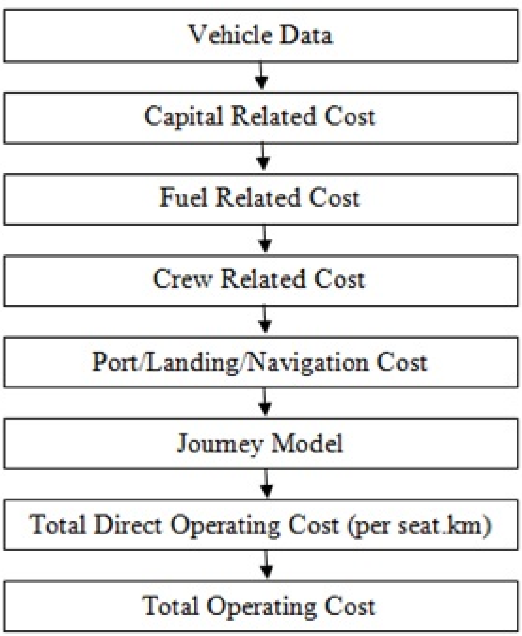

Figure-5. Main elements and procedure of operating costs [14].

The main elements and procedure of analysis of direct operating costs is illustrated as shown in figure 5. However, in practice, all costs are always changing and depend upon the price of elasticity of external economic and market environments [13]. For example, changes of price of oil can influence the operating costs of WIGE craft. Since the operating costs are mutable depending on various cost factors, the purpose of doing cost analysis on WIGE craft and compared with other types of similar transportation, is to study whether WIGE craft is viable to be commercialized.

Although various methods have been applied to estimate the operating costs, the Rozhdestvensky and Kubo's formula is used to calculate the direct operating costs (per seat.km).

$$DOC = \left[\left\{\frac{1-r_v}{A} + r_{ins} + r_{int}\right\} + r_m\right] \times \left(\frac{K_s}{N_p \cdot V_s}\right) \times \frac{1}{T_a} + \left(\frac{C_{fu} \cdot M_f}{R.N_p}\right) + \left(\frac{S_c \cdot N_c}{V_s \cdot N_p}\right) \times \frac{1}{T_a} \qquad (1)$$

where,
r_v = rate of residual value
A = amortization (years)
r_{ins} = annual rate of insurance
r_{int} = annual rate of interest
r_m = annual rate of maintenance
K_s = price of the vehicle
N_p = number of passenger
V_s = speed of vehicle (km/h)
T_a = annual utilization (in hours)
C_{fu} = price of fuel per kg, including lubricant
M_f = mass of fuel
R = range (km)
S_c = average yearly crew cost per person
N_c = number of crew

$$T_a = n_a \times \left(\frac{t_d}{t_r + {L_R}/{V_s}}\right) \times \frac{L_R}{V_s} \qquad (2)$$

where,
n_a = annual number of operating days
t_d = number of operating hours per day
t_r = terminal hours per service
L_R = length of route

Basically, the cost factors above are set to: r_v is 0.1, r_{int} is 0.05, r_m is 0.03, A is 14, r_{ins} is 0.01, C_{fu} is 0.4 USD/kg, n_a is 320 days, t_d is 12 hours, t_r for aircraft is 0.5, t_r for fast ferries is 0.67, t_r for small size WIGE is 0.25 and t_r for large size WIGE is 0.42. Since the price of WIGE craft cannot be estimated without reliable information, then the price can be calculated by using the following formula originated from aviation statistics.

$$K_s = 3.7 \times 10^5 \times 0.8730 \times N_p \times P(N)(USD) \qquad (3)$$

where P(N) is factor of number of built vehicles, if the number of vehicle is sufficiently large, P(N) is 1.

As mentioned before, WIGE craft is mediates between aircraft and ship both functionally and economically. Since development of WIGE craft is still on initial stage and long distance transportation by WIGE craft is not proven technically yet, so, a route of 200km is suited for the model. The specification of vehicles is stated in Table-2 in the appendix column.

Vehicle models that are used for analysis are as below:

- WIGE craft 1: 34 passenger seats, notional specification with power at 1/3 that of Saab 340
- WIGE craft 2: 50 passenger seats, based on Raketa-2 specification

- WIGE craft 3: 150 passenger seats, based on A.90 Ekranoplan specification
- Saab 340 aircraft: 34 passenger seats
- Saab 2000 aircraft: 50 passenger seats
- 74m NGA fast passenger ferry: 450 passenger seats
- 38m Austal catamaran ferry: 430 passenger seats

Operational constraints and commercial risks of WIGE craft due to seaworthiness may arise and affect the accuracy of the cost analysis. Aside from that, the nominal speed of the vehicles does not same as the effective speed particularly in short distance and this further influence the accuracy of results. Furthermore, inaccurate moderation of the cost factors also affects the reliability of the analysis. However, in order to have a basic understanding on cost analysis in examine the direct operating cost of vehicles, it is good to practice the calculation on cost analysis. The table 3 from appendix shows the results obtained.

CONCLUSIONS

In a nutshell, general economic efficiencies on WIGE craft have been analyzed. In order for WIGE craft to be successful in commercialization, it goes without saying that the price of craft and operation cost should be examined and compared with those of competing means of transportation such as conventional ships and aircraft. Albeit Hooker aggressively maintains the beneficial factors and the need for developing full scale WIGE craft as a mega transport concept competing with conventional container ships. It is too early to discuss and analyze detailed operating costs. Although there is no doubt that efficiency is higher when size of WIGE craft is larger, but it is difficult to develop and commercialize such kind of full scale WIGE craft with current technology. It seems that commercialization of the WIGE craft is obviously prone to arise through operation of small-scale craft. So, it is desirable that an analysis of the cost is done on WIGE craft that is relatively small size as compared to other existing types of transportation.

The previous part shows that in many aspects, WIGE craft is put between aircraft and ship. Thus, the direct operating costs of WIGE craft can be assumed is mediated between aircraft and ship. It could be the case that commercialization of WIGE craft is not accomplish at this stage since provided that the cost of WIGE craft operations is higher than aircraft. Due to that reason, the cost should be interpolated between aircraft and ship with a view to commercialize WIGE craft.

It is obvious that the gap between ship and aircraft can be filled by WIGE craft. By referring to several Karman-Gabrielli diagrams, theoretically, WIGE craft seems to have enough economic reasonableness when comparing to other vehicles. In addition, both in terms of payload ratio as well as transport productivity of the WIGE craft show satisfactory results in order to commercialize the WIGE craft. Since the fuel efficiency of the WIGE craft shows negative results, further researches are required to improve the fuel efficiency of WIGE craft. But still, it can be said that the WIGE craft is worthy to be further investigated and commercialized.

Useful tools for the evaluation of economic efficiency which are different values of transport effectiveness and the transport factor of WIGE craft show relatively high efficiencies among other vehicles. Aside from that, the seaworthiness which gives direct practical utilization effects on WIGE craft can be relatively accepted. Other than the above, in order to improve these efficiencies, size and speed of WIGE craft also play an important role. It is sure that the WIGE craft is in an insusceptible position out of other vehicles and it has theoretical economic reasonableness to be commercialized.

The direct operating costs of WIGE craft have been analyzed and compared with those of aircraft and fast ferries by introducing Rozhdestvensky and Kubo's formula in order to determine economic reasonableness of WIGE craft from practical standpoint. Due to the large difficulty to estimate the price of the WIGE craft without any reliable information, the prices of WIGE craft have been firstly estimated by the formula originated from aviation statistics, then all factors of Direct Operating Cost (DOC) of WIGE craft have been compared to those of aircraft and fast ferries and finally, maximum price of WIGE craft, which found to be similar to aircraft, has been deduced. The maximum price of WIGE craft has tremendous impact on the direct operating costs of WIGE craft and has weakens the commercial competitiveness of WIGE craft.

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REFERENCES

[1] Alexander Kossiakoff William N. Sweet Samuel J. Seymour and Steven M. 2011. Biemer. Systems Engineering Principles and Practice, 2nd Edition, John Wiley &Sons, Inc., New Jersey, USA.

[2] Liu Pengfei. 2015. "WIGE (wing-in-ground) effect dual-foil turbine for high renewable energy performance." Energy, Vol. 83, pp. 366-378.

[3] Theodore von Karman. 2004. Aerodynamics – Selected Topics in the Light of their Historical Development. Dover publications, Inc., New York, USA.

[4] Jamei Saeed *et al.* 2014. "Static Stability and Ground Viscous Effect of a Compound Wing Configuration with Respect to Reynolds Number." Advances in Mechanical Engineering Vol. 6, pp. 685-410.

[5] Park, Jin Hyoung, Deok-Ho Kim and Min-jee Kang. 2012. "Safety requirements for Wing-In-Ground (WIGE) craft." OCEANS, 2012-Yeosu. IEEE.

[6] Gabrielli G. and von Karman TH. (1950, October). What price speed? Mechanical Engineering, Vol. 72, No. 10, pp. 775-781.

[7] Jeff Radtke. 2011. Comparing Vehicle Payload Kinetic Energy Benefit to Thermal Power Cost Ratios for Ships, Pipelines, Trains, Airships, Planes and Personal Vehicles Including Bicycles, Motorcycles, and Automobiles Powered by Electric Motors and IC Engines. pp.27-33.

[8] Green W. J. 1997. The imminent future of ultra-fast ferries is off the water: Breakthrough design offers better efficiency & maneuverability. Paper presented to the International Conference on Air Cushion Vehicles and Wing-In-Ground Effect Craft sponsored the Royal Institution of Naval Architects in London, 3-5 December.

[9] Rozhdestvensky K.V. 1995. Ekranoplans: Flying ships of the next century. Proceedings of International Symposium for Twenty-First Century Flying Ships. (pp. 47-70). Sydney: The Institute of Marine Engineers (Sydney Branch).

[10] Sinitsyn D. and Maskalik A. 1996. The Ekranoplan is a new type of high speed water transport which can be used in all seasons. Proceedings of Ekranoplans and Very Fast Craft, (pp.152 -161). Sydney: The Institute of Marine Engineers (Sydney Branch).

[11] Rozhdestvensky K. V. and Kubo S. 1997. A Parametric analysis of a flying wing configuration in extreme ground effect. In: proceedings of International Symposium and Seminar for the Safety of High Speed Craft (pp.78-96). London: Royal Institution of Naval Architects.

[12] Amyot J. R. (Ed.). 1989. Hovercraft technology, economics and applications. Amsterdam: Elsevier Science Publishers B.V.

[13] Stopford M. 1997. Maritime economics. London; New York: Routledge.

[14] Taylor G.K. 2000. Wise or Otherwise? The Dream or Reality of Commercial Wing in Ground Effect Vehicles. Paper presented at the Proceedings of GEM 2000 International Conference, St. Petersburg, Russia.