# Wing in ground vehicles operating as high-speed passenger ferries

*A feasibility and profitability study*

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# Table of contents

*The WIG vehicle presented on the front page is the Airfish-8. (Wigetworks, 2017)*

# Abbreviations

In order of appearance.

| | |
|---|---|
| WIG | Wing in ground |
| IMO | International maritime organization |
| ICAO | International civil aviation organization |
| MARIC | Marine design and research institute of China |
| PARWIG | Power augmented lift wing in ground vehicle |
| DACWIG | Dynamic air cushion wing in ground vehicle |
| FMEA | Failure mode and effect analysis |
| HAZOP | Hazard and operability study |
| SWOT | Strengths, weaknesses, opportunities, threats analysis |
| NPV | Net present value |
| IRR | Internal rate of return |

# Summary

Wing-in-ground (hereafter referred to as WIG) vehicles operate a few meters above water. The vehicles make use of the ground-effect (an effect where the drag is reduced, and the wings of the vehicles generate an increased lift). The unique speed and distance range of a WIG vehicle — a vehicle that, in functionality and appearance, sits somewhere between a ship and an aircraft — could be an ideal option for high-speed passenger transport on routes with 'medium' distances. That said, WIG vehicles have hardly ever been seen in civilian applications, such as high-speed passenger transport. This report answers the question: can WIG vehicles operating as high-speed passenger ferries, be feasible and profitable? This feasibility is assessed on the basis of literature research and real examples of WIG performance, functionality and profitability. Suitable routes and vehicles are selected based on criteria analyses. Using financial estimations, the profitability of two suitable WIG vehicles on two separate routes is investigated.

The specifications of recently built WIG vehicles and their design drivers are analyzed by performing a literature research. This information reveals that WIG vehicles have one main limitation: a low seaworthiness. It is then likely that this limits the seakeeping operability for a number of vehicles. To deal with this limitation, suitable vehicles are selected using a criteria analysis. The literature research shows that the WSH-500 and the Aron M80 both have a relatively good seaworthiness. The vehicles differentiate in size (48p & 6p). The costs of the vehicles are estimated by using general aviation cost estimation theory. A criteria analysis based on seakeeping operability and number of passengers and distance, shows two suitable routes: 'Buenos Aires – Montevideo' and 'Helsinki – Tallinn'. The potential demand for WIG transport on these routes is estimated by creating demand curves of transport. The strategy to market WIG transport on these routes is estimated by using a market research to gage the potential demand. A suitable strategy is to target the top niche of customers on these routes. The profitability is estimated by combining the suitable vehicles, cost of vehicles, routes and strategy. The net present value and internal rate of return is calculated for a number of cases that are explained in this paper. The cases vary mainly on the following aspects: vehicle, total investment and route.

In conclusion, WIG vehicles operating as high-speed passenger ferries can be feasible and profitable. The technology behind WIG vehicles has a technological readiness level of 8 out of 9. There are multiple, full-scale prototypes made and tested. Suitable vessels and routes have been selected to deal with the primary limitation that comes with WIG vehicles; they have low seaworthiness capabilities. The seakeeping operability rates of the selected vehicles and routes range between 91% and 100%. The net present value (NPV) and internal rate of return (IRR) of investments made in a WIG transport company can be positive in a number of cases. It can be seen that operating with the WSH-500 can be relatively more profitable than the Aron M80. Yet, the Aron M80 requires less investments. Furthermore, it is shown that the 'Helsinki-Tallinn' route has, in most cases, a higher net present value, than the 'Buenos Aires – Montevideo' route. Operating with the WSH-500, can be profitable, when the investments are €50 million or higher. Investments made can, in these cases, result into a NPV up to €145 million and an IRR up to 42%. Operating with the Aron M80 can also be profitable on both routes when the investments are around €50-100 million. Investments made can, in these cases, result into a NPV up to €99 million and an IRR up to 30%. In future research, it would be of use to improve the permissible wave height of WIG vehicles because this will result in an increase of operational areas. Furthermore, it is recommended to develop marketing, test and business plans for WIG transport. A stage gate system can be used for moving WIG transport from idea to launch.

# 1 Introduction

Wing in ground (WIG) vehicles are designed to fly a few meters above water by making use of the ground-effect. These vehicles have big technical advantages above traditional airplanes and vessels because they are more energy efficient in their speed range. Nonetheless, the WIG vehicles were hardly ever used in civilian applications. With the knowledge that WIG vehicles were first designed in the 1970's, it raises the question: has the technology and/or the market evolved in such a way as to make civilian applications of high-speed passenger transportation profitable?

WIG technology could be useful to transport passengers at high-speeds. This transportation method has the potential to be a progressive way of transport due to its unique speed and distance range capabilities. It is of importance to identify whether WIG vehicles (operating as high-speed passenger ferries) are feasible and profitable, before putting money and effort in to further investigation.

The goal of this research is to investigate whether WIG vehicles operating as high-speed passenger ferries can be feasible and profitable, and present the findings. This study will explore the variables and circumstances that improve the potential commercial future of the concept. A boundary condition of this research is that the application of the WIG vehicles is: high speed passenger ferry transport. Furthermore, the intended number of passengers will be around 5 to 50.

The structure of this report will be as follows. The second chapter reviews literature research; this literature research focuses on earlier studies regarding WIG vehicles. The third chapter describes a feasibility study of WIG vehicles. Chapter four will outline the basic concepts that have been selected and applied in this research. The costs of the concepts are described in chapter five. Chapter six assesses the potential demand of WIG transport on various routes. In chapter seven a profitability analysis is performed. Finally, conclusions and recommendations can be found in chapters eight and nine.

# 2 WIG vehicles in the literature

As the concept of WIG vehicles originates from around the 1970's, quite a lot has been written about this subject. This chapter describes what research has been done, where there are gaps in the studies. Clarity on this subject is essential to give a starting point for this research and to prevent repetition.

In this chapter the following questions are answered. What has been written about WIG vehicles? Are there gaps in the literature? Are there disagreements between studies? The following method is used in this literature research. First the relevant key words are defined. Thereafter, the literature is collected by making use of the database of the TU Delft. Thirdly the literature is judged on relevance and quality. Finally, the literature is processed to give answer to the mentioned questions.

Earlier studies are addressed per subject in paragraph 2.1. Gaps in, or between, literature are described in paragraph 2.2. This is then followed by the conclusion.

## 2.1 Collected literature

The literature research focuses on what has been written on the subject prior to this new research being produced. In this section the relevant literature is presented and is divided per subject. This is of importance to give a clear view on the collected literature. The general subjects are: what are WIG vehicles, the advantages and disadvantages, alternative technologies, applications of WIG, brief history, configurations and classifications, and recent developments. Each subject is elaborated upon in the next sub-sections.

Firstly, the relevant key words must be defined. The literature is collected by making use of the WorldCat Discovery database. This is an online cooperation of libraries all over the world including the library of the TU delft. If the collected literature is deemed relevant, the literature is processed to describe what research has been done and where there are gaps in the studies.

### 2.1.1 What are WIG vehicles?

A general description of what WIG vehicles are, is given in this paragraph. This provides an overview of how they work and what makes them unique.

WIG vehicles make use of the ground effect. This is an effect where the drag is reduced and the wings of the vehicles generate increased lift. The vehicles operate in ground effect at low altitude flights, between an altitude of 0 to 5 meters. The forward velocity is used to produce dynamic lift. In this way the lift dependent drag is reduced. It can be said that the closer the vehicle operates to the surface, the more energy efficient it becomes. The working principle is elaborated on in section 3.2.

The unique selling proposition of WIG vehicles, is that the speed range rests in between those of ships and airplanes. Notable is the fact that WIG vehicles are, in their speed range of 150-350 km/h, more energy efficient than both ships and airplanes. (Yun et al. 2010)

### 2.1.2 Advantages & disadvantages

Advantages and disadvantages of WIG vehicles are addressed by multiple sources. It is of importance to give a clear view of all the advantages and disadvantages addressed. The book of Yun et al. is used as a main source in this subsection (Yun, Bliault, & Doo, WIG Craft and Ekranoplan Ground Effect Craft Technology, 2010).

Nebylov (2001) distinguishes four advantages of WIG vehicles that are as follows:

a) absence of need of aerodromes
b) safety of exploitation due to a small altitude of flight and capability to land on water
c) ability to carry the payload of a very large weight and overall dimensions
d) the level of comfort for the passengers can be close to ship standard once in the air.

Hahn et al. argues that WIG vehicles have the potential to become the favorable transportation method for medium to long distances in coastal areas. (Hahn, Drewelow, Dewitz, Kolewe, & Lampe, 2014). As the potential of WIG vehicles is never realized it can be said that some disadvantages are quite important. Both Aminzadeh et al. (2017) and Nebylov (2001) argue that stability problems due to disturbances in wind and waves are essential. Aminzadeh argues further that unstable modes of WIG vehicles could lead to serious accidents and damages.

Yun et al. classify the disadvantages in “technical factors” and “operational factors”. The technical factors which must be addressed before WIG vehicles can be operational are: take off power needed, stability and aerodynamic efficiency. Rozhdestvensky & Kirill (2006) state that the technical problems have either been, or can be, dealt with. This indicates that the operational factors are key. The operational factors which need attention according to Yun et al. are terminals, maneuverability, safety, training, noise and economical profitability. All of the above technical and operational factors are elaborated on below.

The take-off speed of WIG vehicles is quite high. The takeoff speed is generally around 90 km/h state Fach et al. (2004). As the speed is high, the drag before take-off is high. This means that a high installed power is needed to get the vehicle out of the water. An option to improve the lift at lower speeds, so that the vehicle can take of earlier, is lift enhancement. When lift enhancement is used, technologies or elements comparable to those of surface effect ships or hovercrafts are used. Yun et al. describe that the installed power needed for take-off, will anyway become excess weight during cruise mode.

WIG vehicles have a high cruise speed. When wind gusts or waves occur, this will affect the longitudinal and transversal stability. To assure stability and safe operation at high-speeds two options can be used: a) an automated control system, b) a vehicle designed in such a way that it is statically stable and has a stable response to dynamic influences. A commercial automated control system for WIG vehicles has not yet been designed.

There is a compromise between aerodynamic efficiency and lift force during take-off. It is dependent on the aspect ratio of the wings — for example, the efficiency is high at a high aspect ratio. A high aspect ratio, however, also influences the lift force. The lift force decreases as the aspect ratio increases. Yun et al. states that a carefully chosen main wing plan and an extended wing design (with corresponding carefully chosen aspect ratios) will solve this problem.

WIG vehicles require terminals similar to hover ports. They must be located near coastal cities and they need a suitable water runway with a length of around 500-2000m and a width of 500m. An impression of a terminal similar to that of a hover port, can be found in figure 2.2.1.


*Figure 2.1.1 Impression of a WIG vehicle terminal (Aqualines, 2018)*

Maneuverability of WIG vehicles near other craft or quay side is difficult due to their protruding wings. This means that terminals need a good approach, and thrusters for floating maneuvering around and up to the slipways of the terminal must be designed. As the WIG vehicles operate at a high-speed, they should be operated to avoid collision. A good solution can for example be to maintain a safe distance to all other crafts of about 1-5 km. A special WIG lane can also be made.

WIG vehicles are new and are not yet commercially operated. This means that there is currently no training available for pilots or captains, and both have little experience in operating a WIG vehicle. An option available for the piloting of these vehicles, is to deploy aircraft or seaplane pilots. Furthermore, smaller WIG vehicles can be used as training vehicles.

Noise can be a limiting operational factor. The noise of WIG vehicles is comparable to that of small turboprop airplanes flying close to the water. It can be reduced, so that it meets acceptable criteria, by using ducted propulsors. Noise close to the terminals can be a factor for acceptance for both travelers and communities close to the terminals.

In the end, the economical profitability will be a key factor. It is known that WIG vehicles can exceed the efficiency of aircraft transport. It is proposed nevertheless that WIG transport is more suitable for short range routes of 150-400 km length. The mean reason for this is that aircraft transport is less efficient due to the frequent landing operations. It can be said that competing with aircraft transport in their speed range is hard due to the ongoing competing of low-cost airlines. (Yun et al. , 2010)

Another factor of influence worth noting, is  public reaction and acceptance. Fach et al. (2004) describes that the developments must continue in order to let the transport sector accept WIG transport step by step. Yun et al. states that market pull is only possible when there is a public acceptance. As the public acceptance is not yet available, this indicates that a market push is the only option to enable forward progression with these new vehicles.

Fach et al. state that the permissible wave height during takeoff and landing is the most limiting factor. They argue that the permissible wave height during landing and takeoff ranges around 5% of the wingspan. Another variable is the wave height during cruise mode or in ground effect mode. During cruising, the permissible wave height is about 10% of the wingspan (Fach, Fischer, Kornev, & Petersen, 2004).

### 2.1.3 Alternative technologies

Several alternative technologies are mentioned in the literature. It is important to get to know the basics, the advantages and disadvantages of those alternative technologies. With this information a general background overview is formed. The advantages and disadvantages of three alternative technologies are described in this subsection.

Gee mentions three alternative technologies to the WIG technology (Gee, 1992). These are hydrofoils, surface effect ships and hovercrafts. A comparison of the alternative technologies is presented in table 2.1.1.

Hydrofoil vehicles fly above the water by using foils. The foils are located beneath the hull and generate dynamic lift in water. This is shown in figure 2.1.2 (Darling, 2016). As the hydrofoil is still in the water, high hydrodynamic lift but also profile drag occurs. The advantage of using hydrofoils is that the hull resistance is reduced, and a relatively high-speed is achieved. The downside of using hydrofoils is cavitation on the upper surface of the hydrofoils. This cavitation occurs above 85 km/h and limits the service speed. A disadvantage of hydrofoils is that it makes designs complex and expensive to build. It has to be said that surface piercing hydrofoils are respectively somewhat simpler. Finally, hydrofoils have a relatively low payload in comparison to other high-speed marine vehicles. Similar to other high-speed marine vehicles, hydrofoils have medium to poor performance in heavy seas if the waves touch the hull.

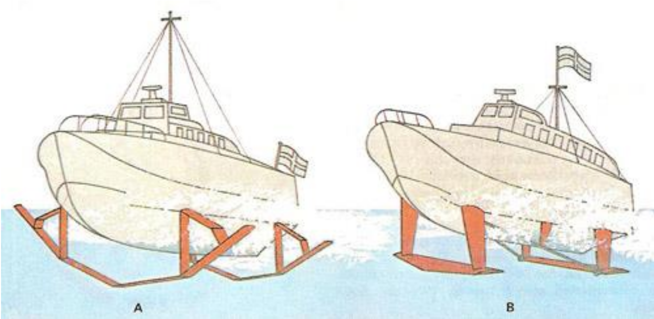


*Figure 2.1.2 Illustration of two hydrofoil types – Surface piercing (left) & fully submerged (right) (Darling, 2016)*

The working principle behind surface effect ships (SES) is that air underneath the ships lifts them out of the water. This is being achieved by trapping exhaust gasses and air under the ship. The sidewalls at the side of the ship and the skirts in the front and back prevent the air to escape. As the air is trapped underneath the ship, static lift is created, and thus hydrodynamic resistance is reduced. An impression of a surface effect ship is shown in figure 2.1.3. A big advantage of surface effect ships is that they can attain high-speeds when compared against classical vessels due to a low hydrodynamic resistance. The reduction of the hydrodynamic resistance is caused by the air cushion. The mitigation of motion in rough seas, as the vessel is partly lifted out of the water, is another advantage. That said, this advantage turns into a major disadvantage if the significant wave height reaches about twice the height of the cushion. The motions at high-speed simply become too large if the sea state is rough. A disadvantage of surface effect ships is that the skirts wear out quickly and must often be replaced. The resulting effect is that the maintenance costs are relatively high. (Yun & Bliault, High performance marine vessels, 2012), (Frouws, 2012)

The hovercraft, also known as air cushion vehicle (ACV), floats completely above the surface and does not use any buoyancy. Yun et al states that their most important attributes are the amphibious qualities rather than their high-speed. The working principle behind the hovercraft, is that it pumps air into a cushion cavity similar to surface effect ships. An impression of a hovercraft is shown in figure 2.1.3.

The air in the cushion cavity creates static lift. An advantage of hovercrafts is that they are very versatile — they can operate on beaches and on land. The downside of hovercrafts, however, is that they behave poorly in waves. In calm waters, the service speeds can reach up to 110 km/h, whereas service speeds may drop between 30 and 75 km/h in waves. This is the result of dynamic vertical motions which cause a significant added resistance. (Yun & Bliault, High performance marine vessels, 2012), (Frouws, 2012)

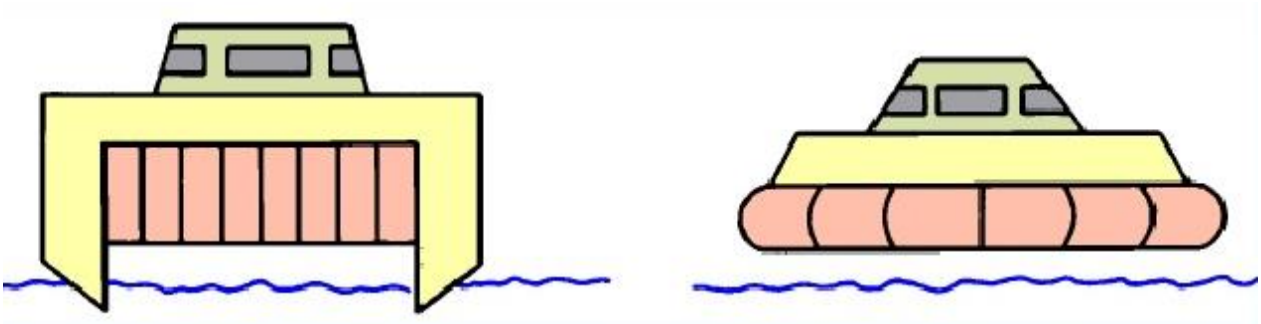

*Figure 2.1.3 Illustration of surface effect ship (left) & hovercraft (right) (Darling, 2016)*

*Table 2.1.1 Overview of high-speed transport vehicles (Frouws & own work)*

| | **Hydrofoil** | **Hovercraft** | **Surface effect ship** | **WIG vehicle** |
|---|---|---|---|---|
| **Max speed** | 90 km/h | 110 km/h | 110 km/h | 185-650 km/h |
| **Seaworthiness** | When the waves become higher than the struts, they will hit the bottom of the hull. If the speed of the vessel is too high, the foils could break the wave surface. | Bad if the sea state is rough. The motions simply become too big to stay above the surface. | Bad when sea state gets higher than sea state 3. | Bad during landing and take-off due to high impact motions. Good once in the air. The seaworthiness generally depends on the shape and weight. |
| **Vertical movement at sea** | Performs well at calm sea-states, when waves impact on the hull, motions become large. | Depending on the wave height, usually good until the waves become too high and it starts slamming against the vessel. | Depending on the wave height, usually good until the waves become too high and it starts slamming against the vessel. | Perfect. |
| **Maneuverability** | Long hulls provide fine course keeping but have a long rotating radius. | Can turn in all degrees, but it has 'lag' as the surface does not counteract the movement of the vessel. | Good as the surface effect ship can have a rudder in the part which has water contact. | Limited during take-off and landing. |
| **Cargo capability** | Bad, low payload capabilities. | Good, large deck area. | Good, large deck area. | Good, high payload capabilities. |
| **Operability** | Limited by high waves which can impact the hull. | Limited by high waves. | Limited by high waves. | Limited by high waves during landing and take-off. Behavior depends on wingspan and weight. |

### 2.1.4 Applications of WIG

WIG vehicles can be used in several applications. All the possible applications are described together with their advantages and disadvantages to give a clear view on the scope of this research. It must be noted that the scope of this research is non-exhaustive in the sense that it only focuses on the *application* as high-speed passenger ferry. In this subsection, the applications suitable for WIG vehicles are explored. The described applications are: High-speed passenger ferry, leisure, crew supplier, military transport and military missile launcher.

A high-speed passenger ferry carries passengers across the water. Mostly on a regular line basis. Applications as ferry range from smaller ferries or taxis with a capacity of about 8 to 15 passengers, to bigger ferries with capacities up to 450 passengers.

Another civilian application can be in the form of leisure. Both as taxi to leisure yachts, or purely as yachts. Smaller WIG vehicles could even be stored inside superyachts, like speed boats.

WIG vehicles could also be used in the application of crew supplier. Supplying crew to coastal areas where windmills or oil platforms are situated could be possible, provided that the significant wave height is within an allowable range.

Different to the civilian market, there is the military market. In this market, it is common to see higher costs of research as well as those costs being allocated to specific projects. WIG vehicles as part of a military force could generally operate in two applications: one as transporter of troops or material, the other as missile launcher. In both applications, the key advantage for assault is that WIG vehicles fly under the radar and are hard to detect. When a WIG vehicle is applied as missile launcher it has the benefit that the rocket trajectory, the chance of detection, and the response time, is reduced.

In figure 2.1.4, the radar sight and shadow are shown (Aviation Academic, 2014). WIG vehicles can easily fly under the radar i.e. operate in the radar shadow. This means that WIG vehicles can almost only be seen within the radar horizon which has a radius of about 28-46 km. In future research, it can be useful to investigate other suitable applications for WIG vehicles in more detail.

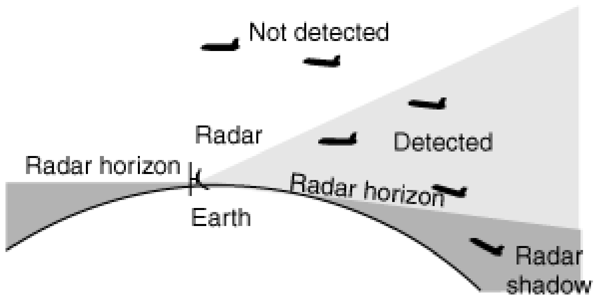


*Figure 2.1.4 Illustration of radar sight (Aviation Academic, 2014)*

### 2.1.5 Brief history

The development of WIG vehicles started in the 1960's. To give a clear general overview on the developments since then, a brief historical summary is given. As several countries made their developments quite uniquely, the developments are divided by country. This subsection elaborates on the developments per country. Yun et al. (2010) is used as a primary source in this subsection.

Development of WIG vehicles in the USSR started around 1960. The scientist Alexeyev wanted to build faster and faster hydrofoil vehicles. Together with his team, he produced the first series of WIG vehicles in the period 1961-1964; the SM-1 through to the SM-5. After the successful completion of this series, bigger prototypes of WIG vehicles were designed up to 550 ton. One of the most famous prototypes was the Caspian Sea Monster. This WIG vehicle was designed to carry personnel and material over the black sea and was the biggest WIG vehicle ever made. As the projects became more expensive, smaller WIG vehicles began to be made for training purposes. In parallel with the other developments, a WIG vehicle used as missile launcher was ordered by the soviet navy. This project resulted in the development of the Lun-class in 1983. After the disintegration of the Soviet Union, the development of WIG vehicles came to a halt due to a lack of funds. However, because of an accident with the "Comsomoloz" submarine in 1989, in which the crew could not be rescued, the need for a rescue WIG vehicle arose. In 1991, a project started to create search and rescue WIG vehicles based on the Lun-class vehicles. To date, this project has not been completed. (Yun et al. 2010)

China has also been investigating the WIG technology since the 1960's. China focuses more on the power augmented and dynamic cushion WIG vehicles. This technology can be seen in the use of ducted propellers at the bow of the WIG vehicles.

In the 1960's, the German scientist Alexander Lippisch developed an alternative configuration to the Russian rectangular wing Ekranoplans. The configuration was characterized by the reversed delta wing configuration. He started his research under contract of the German ministry of defense. His models were made of composite materials and were thus light weight. The models could fly in ground effect mode and were capable of flying up to a height of 800m during the test trials in 1971. Following this success, the German ministry of defense (in combination with the VFW/Fokker aircraft group) supported developments that were to follow.

The models X-113 and X-114 were created. These models turned out to be successful too and designs for the X-117 15 seat WIG vehicle were made. After that, a32-seat passenger ferry design was created. After the liquidation of the Fokker aircraft group in 1997, the complete design database was sold. The company, Flightship, bought the database — together with the X-113 prototype for DM 12 million. Flightship worked together with the scientist Fisscher on the development of the FS-8 (dragon commuter) and the FS-40 (dragon clipper). The construction of the FS-8 prototype was completed in February 2001. The FS-8 got IMO certification as a high-speed craft. The company Flightship came in, in 2002 and by 2003, were in financial problems due to the high investments required for prototype certification. These problems arose before the vehicles or the product of transportation could be sold, and revenues could be made. The database and prototypes of Flightship were thereafter purchased by Wigetworks. The company Wigetworks now continues to develop the commercial viability of the concept. A noticeable point is that Wigetworks renamed the FS-8 to Airfish-8 — it is unknown why Wigetworks did this. (Yun et al. 2010)

### 2.1.6 Classifications of WIG vehicles

WIG vehicles are classified into three categories by the International Maritime Organization (IMO). The three types of classifications are described in this subsection, as well as the limitations of these rules.

The International Maritime Organization (IMO) classifies the WIG vehicles into three classification-types. An illustration of the types is shown in figure 2.1.5. The types of classification are described below. (Yun et al, 2010)

A. *Craft not capable of operation without the ground effect.*
B. *Craft capable to increase its altitude limited in time and magnitude outside influence of the ground effect in order to over fly a ship, an obstacle or for other purpose. The maximal height of such an "over flight" should be less than the minimal safe altitude of an aircraft prescribed by International Civil Aviation Organization (ICAO).*
C. *Craft capable to take-off from the ground and cruise at an altitude that exceeds the minimal safety altitude of an aircraft prescribed by ICAO.*

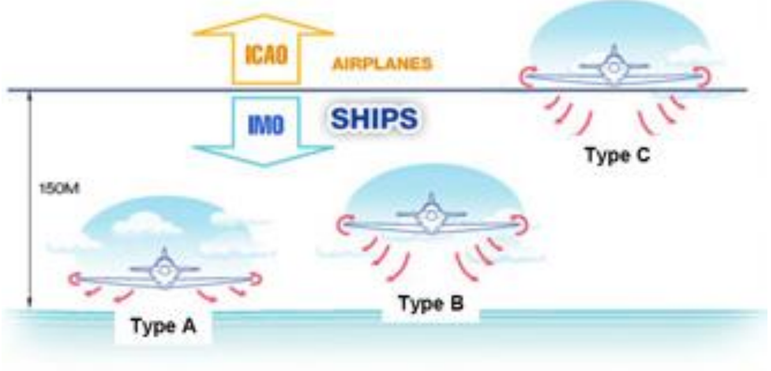


*Figure 2.1.5 Illustration of WIG classification types A, B & C (Fischer & Zagklis, WSH-500, 2013)*

The WSH-500 and the Flightship 8 (also called Airfish-8) are known to be classified as type A vehicles. This indicates that it is possible to get a classification by the IMO. (IMO numbers: 9590436 and 9267340)

### 2.1.7 Wing configurations

There are several wing configurations of WIG vehicles. The configurations are described in this subsection. Special attention is given to the stability aspects of the configurations. To give a general idea which WIG vehicle matches with which configuration, the distribution of wing configurations of typical WIG vehicles is presented below.

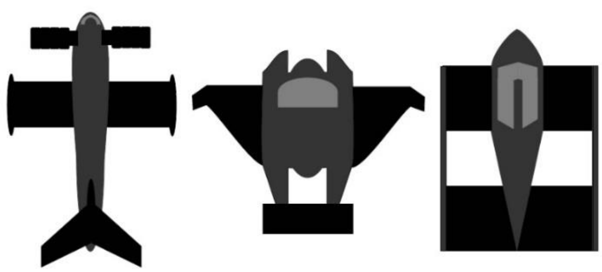

*Figure 2.1.6 Illustration of wing configurations*
*Ekranoplan (left), reversed delta wing (mid) & tandem (right) (Tataroko, 2007)*

There are, in general, three wing configurations. These are: Ekranoplan, reverse delta wing and tandem wings. The wing configurations are shown in figure 2.1.6. On the left, the Ekranoplan configuration is shown. The wings of the Ekranoplan are considerably shorter and squarer than any comparable aircraft. To maintain stability, a high aft-placed horizontal tail is required. In the mid of the figure, a reverse delta wing is shown. This configuration is said to be the most energy efficient. It is characterized by the reversed delta wing. On the right, a tandem configuration is shown. The tandem configuration can be distinguished by its large wing length/beam ratio. This configuration is mainly used in smaller hobby models because of the good stability aspects. The downside of this wing configuration is, however, more drag and the interference between the wings.

In some wing configurations, large wings or double wings are added to the design. These wings have similarities to aircraft wings. The wings have the advantages that they give more lift and make the rate of the lift force vs ground distance more constant. The disadvantage of the wings, is that more drag is induced.

The wing configurations are quite important for the stability of the vehicles. The forces and moments acting on the wing and tail plane must be in equilibrium. The Ekranoplan have the disadvantage that when they fly too high, the force on the wing will suddenly decrease due to the abrupt end of the wing. This means that the relation of aerodynamic lift force to the ground distance can suddenly decline. The reversed delta wing does not have an abrupt end of its wing. That is why the relation of the aerodynamic lift force to the ground distance remains steadier. This improves the stability of the vehicles. The same principle is applied when wings, double wings or tandem wings are added. The disadvantage of these more stable options is that those extra wings induce more drag. In figure 2.1.7, the forces acting on a WIG vehicle are shown. In figure 2.1.8, the aerodynamic lift force in relation to the ground distance is presented.

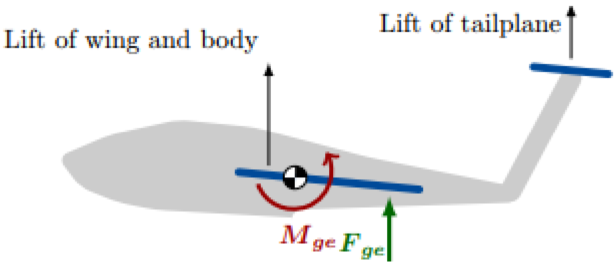


*Figure 2.1.7 Illustration of force and moment acting on WIG vehicle in ground effect (Hahn et al. 2014)*

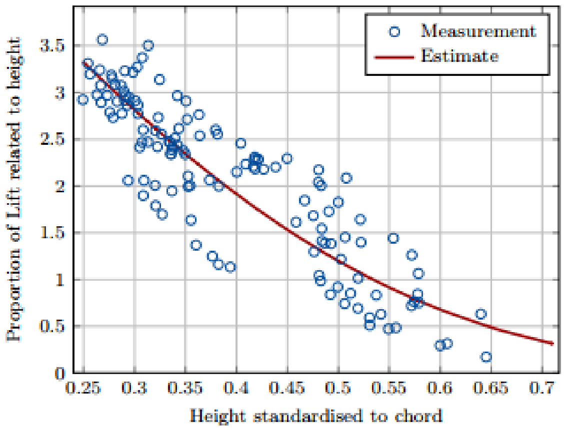


*Figure 2.1.8 The relation between the aerodynamic lift force to the ground distance (Hahn et al. 2014)*

*Table 2.1.2 Overview of wing configurations of typical WIG vehicles (own work)*

| | Configuration | | | Addition | |
|---|---|---|---|---|---|
| Vehicle: | Ekranoplan | Reversed delta | Tandem | Wings | Double wings |
| KM | x | | | | |
| Orlyonok | x | | | | |
| Volga 2 | x | | | | |
| Lun | x | | | | |
| Airfish 3 | | x | | | |
| Strizh | x | | | | |
| TAF VIII-5 | | | x | | |
| Hydrowing | x | | | | |
| XTW-2 | | x | | | |
| Hoverwing 2vt | | x | | | |
| Aquaglide 2 | x | | | | |
| Airfish 8 | | x | | | |
| Haenarae-X1 | x | | | | |
| Aron 7, M50 | x | | | | |
| Orion 12, Ivolga, EK-12, CYG-11 | | x | | x | |
| Bavar 2 | x | | | | |
| Burevestnik-24 1 | | x | | | x |
| WSH-500 | | x | | | |
| Orion 14, EK-14 | | x | | x | |
| Orion 20 | | x | | x | |
| Xiang Zhou-1 | x | | | | |
| Aron M80 | x | | | | |

In table 2.1.2, the wing configurations of general WIG vehicles are shown. The vehicles are sorted by year built.  As can be seen, most of the configurations have either a Ekranoplan or a reversed delta configuration. It can also be noted, that adding extra wings or double wings, has become more popular over time.

### 2.1.8 WIG characteristics

General characteristics of typical WIG vehicles are presented in research of Fach et al (2004). These characteristics give an idea of the dimensions of the vehicles. In this section are the characteristics presented.

Typical characteristics of WIG vehicles up until 2004, are presented in table 2.1.3. The characteristics are collected and presented by Fach et al. (2004).

What is notable in the characteristics, are the large differences in size and displacement. What can also be seen is that the speed of the larger vessels is higher.

*Table 2.1.3 Overview of typical WIG vehicle characteristics (Fach, Fischer, Kornev, & Petersen, 2004)*

| *WIG craft* | *Length (m)* | *Span (m)* | *Power or thrust* | *Displacement (kg)* | *Speed (knots)* | *Number of people* | *Permissible wave height* |
|---|---|---|---|---|---|---|---|
| *Airfish – 3* | 9.9 | 7.5 | 55 kW | 760 | 73 | 2 | 0.3 |
| *Airfish – 8* | 17.2 | 15.2 | 345 kW | 4300 | 86 | 8 | 0.5 |
| *Hoverwing – 2VT* | 10.6 | 10.6 | 78 kW | 1150 | 67 | 2 | 0.5 |
| *KM* | 98.0 | 38.0 | 8×9.5 tonne (PAR)+2×10.5 tonne (cruise) | 500 000 | 297 | — | 3.5 |
| *Orlyonok* | 58.0 | 31.5 | 2×10.5 tonne (PAR)+15.0 tonne (cruise) | 140 000 | 216 | 150 | 1.5 |
| *Lun* | 73.8 | 44.0 | 8×13.5 ton | 400 000 | 297 | — | 2.5 |
| *Volga 2* | 11.6 | 7.6 | 220 kW | 2700 | 65 | 8 | 0.5 |
| *Strizh* | 11.4 | 6.6 | 235 kW | 1630 | 108 | 2 | 0.5 |
| *TAF VIII-5* | 19.8 | 8.5 | 1.200 kW | 9200 | 95 | 15 | — |
| *XTW-2* | 18.5 | 12.7 | 440 kW | 4000 | 81 | 12 | 0.5 |
| *Aquaglide* | 10.5 | 5.9 | 162 kW | 2100 | 81 | 4 | 0.3 |
| *Hydrowing VT01* | 9.9 | 7.8 | 88 kW | 1050 | 65 | 2 | 0.4 |

### 2.1.9 Recent built WIG vehicles

Several WIG vehicles have been built since the collection of typical WIG vehicle characteristics by Fach et al in 2004. This section describes and presents recent (2004-2017) built WIG vehicles. The vehicles are addressed in a chronological order.

The particulars of the recently built WIG vehicles are shown in table 2.1.4. Sources: Aron (2018), Wingship brochure (2018), (Horak, 2018), (Alexeev's hydrofoil design bureau, 2018), (Romanenko, 2018), (Telegraph co uk, 2010). Caution must be applied with the used sources in this subparagraph, as most of the sources are not substantiated with scientific literature.

*Table 2.1.4 Overview of recent built WIG vehicle characteristics 2004-2017 (own work)*

| *Wig craft* | *Length [m]* | *Span [m]* | *Power or Thrust [kW]* | *Displacement [kg]* | *Speed [km/h]* | *Number of people* | *Permissible wave height [m]* | *Type* | *Year built* |
|---|---|---|---|---|---|---|---|---|---|
| *Burevestnik-24 1* | 14 | 14.5 | 2x 335 | 3600 | 240 | 24 | - | C | 2004-2013 |
| *Aron 7, M50* | 10 | 12.9 | 186 | 1400 | 165 | 4+1 | 1.2 | B | 2007 |
| *Haenarae-X1* | 12.3 | 11 | 2x 75 | 1500 | 120 | - | - | A | 2007 |
| *Orion 12, Ivolga, EK-12, CYG-11* | 15 | 12.5 | 2x 243 | 3700 | 185 | 10+2 | - | A | 2009 |
| *Bavar 2* | 8.43 | 5.89 | - | - | 185 | 2 | - | B | 2010 |
| *WSH-500* | 29 | 27 | 2x 1000 | 17 100 | 185 | 50 | - | A | 2013 |
| *Orion 14, EK-14* | 13.1 | 12.3 | 2x 358 | 4200 | 250 | 12+2 | - | A | 2014 |
| *Orion 20* | 19.13 | 19.78 | 3x 490 | 9250 | 185 | 12 +1 t | - | A | 2015 |
| *Xiang Zhou-1* | 12.7 | 11 | - | 2500 | 185 | 7 | - | B | 2017 |
| *Aron M80* | 12.2 | 13.6 | 560 | 3100 | 185 | 6+2 | 1.8 | B | 2017 |

The Burevestnik-24 is a 24-passenger, type C WIG vehicle. It can fly both in and out of ground effect mode. The company behind the model is named sky and sea group. What is interesting is that most of the team members have a military or cosmonautic background. In 2004, the company started test flights of the first version. The company conducted the test flights of the 7$^{th}$ version in 2013. The latest model is shown in figure 2.1.9. The company named this model the HSA-7. (Romanenko, 2018)


*Figure 2.1.9 The Burevestnik-24 (7$^{th}$ version) (Romanenko, 2018)*

The Aron M50 is a B type WIG vehicle with a passenger capacity of 4+1. The vehicles are made by a south Korean company named Aron 7 flying ship Ltd. Yun et al. (2010) states that a number of M50s are in operation with Korean services and for taxi services to a luxury resort. The M50 model has a small aircraft engine. The Aron M50 is shown in figure 2.1.10. (Aron, 2017)

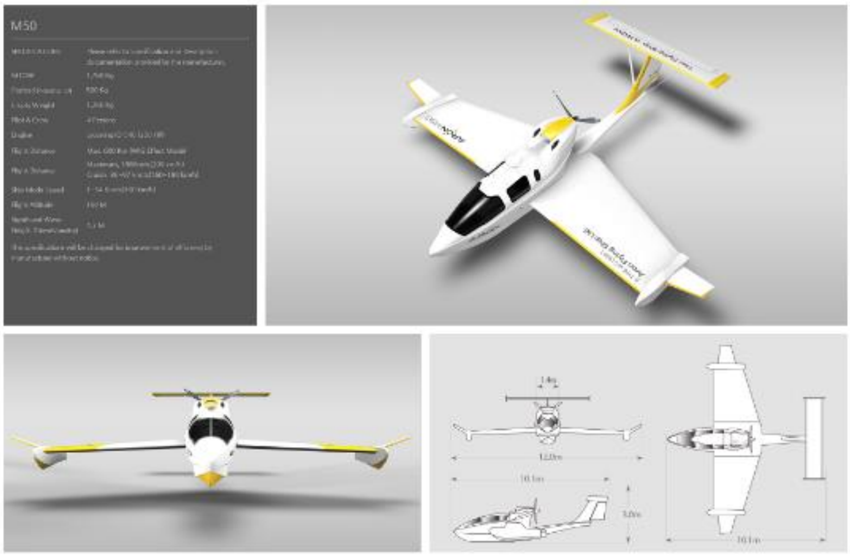


*Figure 2.1.10 The Aron M50 (Aron, 2017)*

The Haenarae-X1 is type A WIG vehicle. It is a small half-sized vehicle of a 20-person WIG vehicle. The vehicle is made with subsidies of the south Korean ministry of commerce, industry and energy. Although not much information can be found on the project, it is, however, clear that no prototype was made of the final 20-person vehicle. Below, shoes only the half-sized prototype (figure 2.1.11). (Pangor, 2011)


*Figure 2.1.11 The Haenarae-X1 (Pangor, 2011)*

The Orion 12 is a type B WIG vehicle with a capacity to carry 10+2 people. It is a model out of the Russian Orion project. The project delivered several WIG vehicles based on the design of the Ivolga. The models abbreviate from each other in size. Multiple versions of the model are made since 2009. The model has been copied by a Chinese company called 'Yingge' and renamed CYG-11. Figure 2.1.12 shows the CYG-11. (Yingge, 2017)


*Figure 2.1.12 The Orion-12 (Yingge, 2017)*

The Bavar 2 is a type B WIG vehicle with a capacity to carry 2 people. Iran unveiled 12 of these small WIG vehicles in 2010. The vehicles are designed to carry out patrol missions. The Bavar 2, is shown in figure 2.1.13. Telegraph.co.uk (2010)

*Figure 2.1.13 12 The Bavar 2 (Telegraph co uk, 2010)*

The WSH-500 is an A type WIG vehicle, with a capacity to carry up to 50 people. The vehicle is developed by Wingship technology corp. This company has been quite operative in the years 2007-2013. In these years, the WSH-500 was developed and tested. No big news flashes regarding this company have been seen since 2013. The WSH-500 is shown in figure 2.1.14. (Wing Ship Technology Corp. Ltd., 2016)

After the building process of the WSH-500 in 2013 not much is heard of the company. Zagklis states that the major shareholder shipyard DSME, couldn't fund the project with additional funds in 2013. This, together with the postponing of the sea trials due to a major ferry accident in South-Korea, became too big of an obstacle to continue the final certification needed for commercial operation. The construction and basic specifications of the WSH-500 are certified by the Korean register. (Zagklis, 2018)


*Figure 2.1.14 The WSH-500 (Wing Ship Technology Corp. Ltd., 2016)*

The Orion 14 is a type A WIG vehicle with a capacity to carry 12+2 people. It is a larger version of the Orion 12. The Orion 14 and Orion 20 are shown in figure 2.1.15 and 2.1.16. (Horak, 2018)

The Orion project is presumably run by the Ekranoplani.ru association. The association consists of developers and is a non-profit organization with the goal to assist socio-economic development. The association consists of governmental projects but notably also the sky and sea group, the developers of the Burevestnik-24 model. (Ekroplani association, 2010)


*Figure 2.1.15 Orion 14 (L) and Orion 20 (Magra, 2016)*

The Orion 20 is a type A WIG vehicle with a capacity to carry 20 people or 12 people + 1 t cargo. The vehicle is a result of the Orion project. In 2015, the Orion 20 stalled and crashed during a test operation. There were no casualties, but the vehicle was heavily damaged (Karelia, 2015). A general arrangement of the Orion 20 is shown in figure 2.1.16. (Ekroplani association, 2010)

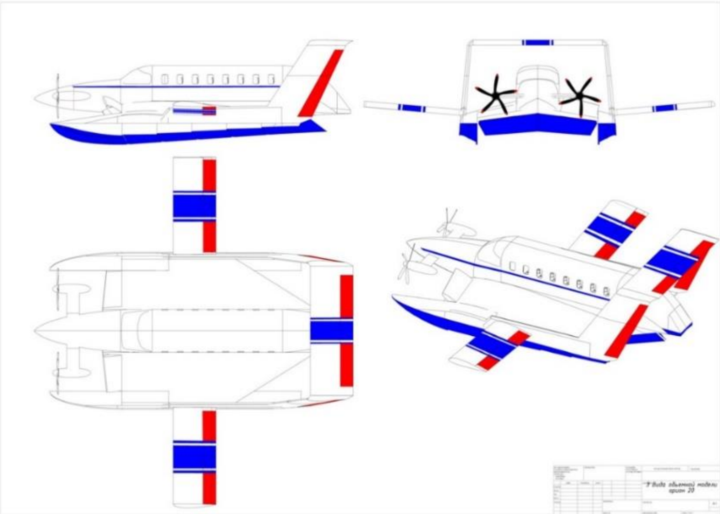

*Figure 2.1.16 General arrangement of the Orion 20 (Ekroplani association, 2010)*

The Xiang Zhou 1 is type B WIG vehicle with a capacity to carry 7 persons. It is a result of a joint venture project, between China and Russia. The project has been operative since 2013 until present day and has a budget of CNY 5 billion (640 million euros). The Xiang Zhou 1, allegedly completed its debut flight on 11 December 2017. There is little information available on both the project and the vehicle. The available information states that the vehicle can seat 7 passengers and is 12.7 meters long. The Xiang Zhou 1 is shown in figure 2.1.17. (Lan, 2017)


*Figure 2.1.17 The Xiang Zhou 1 (Lan, 2017)*

The Aron M80 is a type B WIG vehicle which can carry 6+2 persons; it is the big brother of the Aron M50. What is notable in the specifications presented by the producer is that the vehicle has a remarkable high permissible wave height of 1.8 m. The vehicle is powered by a small aircraft engine. The Aron M80 is shown in figure 2.1.18. (Aron, 2017)

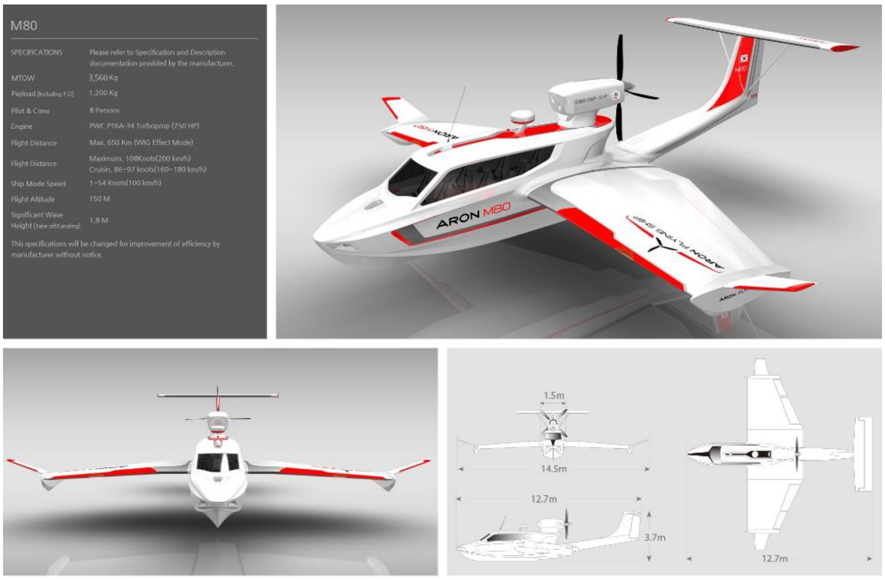


*Figure 2.1.18 The Aron M80 (Aron, 2017)*

## 2.2 Gaps in literature

Some gaps in the literature are found in the collected literature. The gaps are described in this subparagraph to give a clear view on the subjects which are worth researching.

The gaps in or between literature written about WIG vehicles can be divided per subject. The general subjects are:

a) lack of economical information (price and costs)
b) no reasoning why commercial operating never lifted off
c) comfortability is hardly never mentioned as disadvantage in scientific research.

Economical information is hard to find. Some estimated prices of WIG vehicles are mentioned on news sites. However, caution must be applied as the reliability of these sources is not determined. Information regarding operational costs is also hard to find. Multiple sources argue that due to the high fuel efficiency, the operating costs are low, but any supporting numbers regarding the total operating costs are hard to locate.

What's more, it is also difficult to find much literature or supporting research on why WIG vehicles were never successfully operated commercially. The only non-scientific source found regarding this subject is the economist.com. It investigates the reasons why soviet prototype WIG vehicles were never commercially operated. An article on the website describes that the fuel consumption of the soviet WIG vehicles simply was too high to consider commercial operation. (Economist.com, 2007) This leaves the question: why were the later developed WIG vehicles were not operated commercially? Rozhdestvensky & Kirill (2006) state that the technical disadvantages are not the problem. So, could the lack of commercially operating lead back to the lack of profitability?

It is stated by Fach et al. (2004) that the most limiting factor of the WIG vehicles is the permissible wave height. It is hereby not mentioned that the resulting motions are too high, or that the comfort is too low. Therefore, it is not defined what permissible is. In a video of the Airfish-8 (Science, 2018), the take-off and landing is can be seen. The wave height during landing is estimated to be around 0.5m significant by (Koning, 2018). From what can be deduced from the video, it seems that the landing and take-off is quite bumpy and the passengers are uncomfortable.

## 2.3 Conclusion

The history, working principle and the technical advantages and disadvantages of WIG vehicles are described in the researched literature. Gaps in the literature are created by the lack of a comparison of recent developments, as well as of any economical information about costs and price. A comparison of the models since 2004, is made to bridge the first gap. Costs and prices will be determined later in this research. There are not that many contradictions in the literature, though characteristics of vehicles can differ a bit per source.

The development of WIG vehicles started in the 1960's. It had a stall in the 1980's due to the fall of the USSR and a lack of funding. Development of WIG vehicles is nowadays growing again. The main principle of WIG vehicles is that they make use of the ground effect to create more lift. They take off and land on water and fly a few meters above water. The unique selling point of WIG vehicles is that they operate in the speed and distance range between ships and aircrafts.

The six advantages of WIG vehicles are:

a) absence of need of aerodromes
b) safety of exploitation due to a small altitude of flight and capability to land on water
c) ability to carry the payload of a large weight and overall dimensions
d) the level of comfort for the passengers can be close to or even better than ship standard
e) high fuel efficiency and f) classification as fast vessels.

Ten disadvantages are:

a) high take off power needed
b) stability problems
c) low permissible wave height during landing and takeoff
d) need for terminals
e) low maneuverability
f) no training available
g) high noise levels
h) lack of economical experience.

What is notable is that there are several different WIG vehicles built in recent years (2004-2017), yet the characteristics of the vehicles differentiate from one another. As could be seen, the large number of recently built WIG vehicles indicates that there is money available for the development of WIG vehicles.

Gaps in the literature are due to the following:

a) lack of economical information (price and costs)
b) no reasoning why commercial operating never lifted off
c) comfortability in high waves not mentioned as disadvantage.

# 3 Analysis of technical feasibility

It is important to know whether WIG vehicles operating as high-speed passenger ferries can be technically feasible. By conducting a feasibility research, limitations of the technology can be considered in the further research. In this chapter, the technical feasibility of WIG vehicles operating as high-speed ferries is analyzed.

## 3.1 Method of testing technical feasibility

To conduct the feasibility study in an efficient and structural way, it is essential to have a clear methodology. The  one-off methodology will be outlined below.

To begin with, the working principle, limitations and technical disadvantages are described. There is a particular focus on how to improve the limitations and technical disadvantages. Literature of old and new technologies are used together to prove the feasibility per disadvantage and limitation. Secondly, a risk assessment is performed to identify and evaluate the risks. A failure mode and effect analysis (FMEA), as well as a hazard and operability study (HAZOP) are performed. Thirdly, the technological readiness level of WIG technology is estimated to assess the feasibility. Lastly, a conclusion is given.

## 3.2 Working principle

The working principle is described hereafter, to provide an understanding of its role within WIG vehicles. The WIG effect is caused by the following two main physical phenomena (the main source used in this subparagraph is Yun et al., 2010):

- The flow between the wing and the surface over which a vehicle is flying is blocked when it is flying in ground-effect. The pressure underneath the wing is higher which increases the lift. In figure 3.2.1 is a WIG effect and out of ground-effect shown.
- The down wash velocity caused by the wing tip vortices, is reduced when a vehicle is flying in ground-effect. The decrease of down wash when flying in ground-effect has the result that the lift and effective aspect ratio are increased. An illustration of this effect is presented in figure 3.2.2. The left figure illustrates the wing tip vortex, when a vehicle is flying outside the ground-effect modus. The right figure illustrates the wing tip vortex, when a vehicle is flying in ground-effect modus.

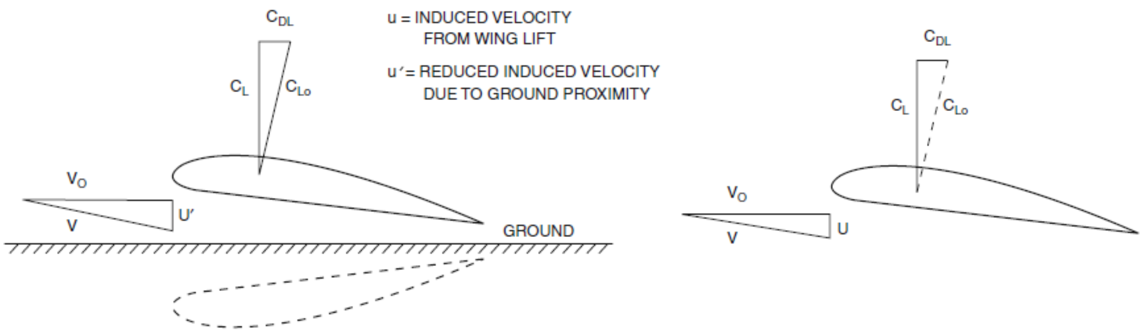


*Figure 3.2.1 Illustration of wing in (L) and out of ground effect (R) (Yun et al. 2010)*

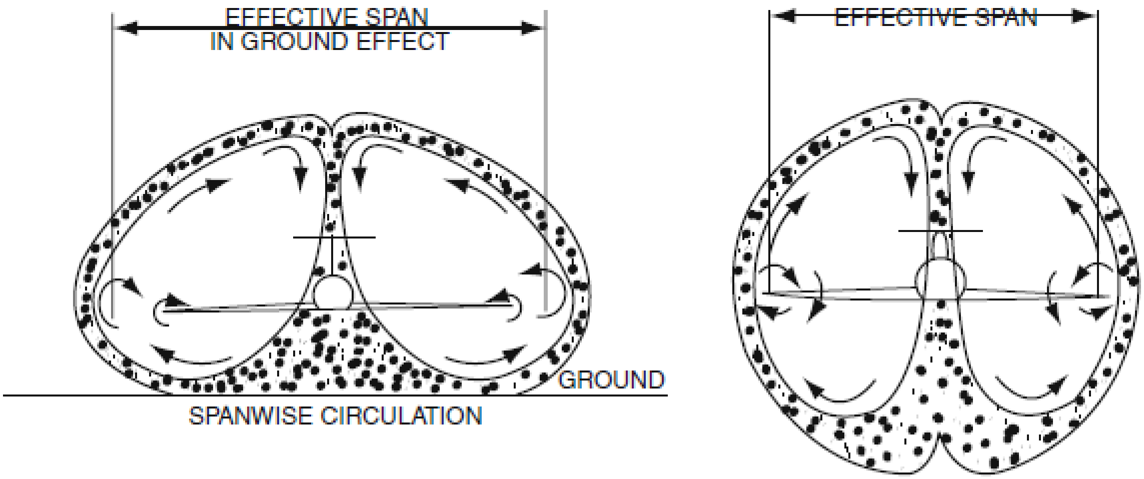


*Figure 3.2.2 Illustration of down-wash and lift induced drag in (L) and out (R) of ground effect (Yun et al. 2010)*

A WIG vehicle has three modes of operation. The vehicle starts in the displacement mode, it then goes into planning mode, then into flying mode. The vehicle acts as a hydroplane in-between the modes. The hydrodynamic pressure during this transition is very high. It will act on the lower part of the hull and induce a large hump drag during takeoff. It must be noted that the hump drag during the takeoff, is bigger than the drag during cruising. The hump drag is therefore the parameter which controls the size of the power system.

## 3.3 Seaworthiness

Yun et al. (2010) and Fach et al. (2004) name the seaworthiness as the main limitation of WIG vehicles. They state that the permissible wave height during landing and takeoff is a critical limitation. This limitation is described in further detail below. Firstly, the permissible wave height is analyzed on an empirical basis. Thereafter, a comparison is made with sea planes. Lastly, technologies are addressed which can improve the permissible wave height.

### 3.3.1 Empirical estimate of seaworthiness

Fach et al. (2004) state that the seaworthiness is determined by the size, in a similar fashion to conventional ships. They give a rule of thumb and state that the wave height should not exceed 5% of the wingspan during takeoff and 10% of the wingspan while cruising economically.

It must be noted that caution must be applied with the empirical rule of thumb of Fach et al. (2004). It is unclear what source the rule of thumb is based. Assumed is that it is based on a database of WIG vehicle specifications.

Typical characteristics of WIG vehicles are shown in table 2.1.4. The permissible wave height is shown for each WIG vehicle in the last column. For WIG vehicles with a wing span smaller than 15.2m, the permissible wave height has a maximum of 0.5m (Fach et al. 2004). It also must be noted that the definition of permissible wave height could differ per developer.

The maximum wave height at an emergency landing, is a factor which needs to be taken into account for safe operation. Fach et al. (2004) states that if the WIG vehicle is designed to cruise over higher waves, the structure can be designed to allow an emergency landing in up to 20% of the wingspan, without endangering the passengers of the vehicle.

### 3.3.2 Seaworthiness of seaplanes

The characteristics of seaplanes during landing and takeoff are similar to those of WIG vehicles. During cruising mode, the seaplanes cruise above the cruise heights of WIG vehicles (150m for type C). It is interesting to look at these characteristics and the permissible wave height, so that similarities can be drawn.

There are two types of seaplanes: floating planes and flying boats. Floating planes can take off and land on waves up to a height of approximately 0.3m. The maximum wave height at which flying boats can land and take off, are higher than flying planes. This maximum wave height relation is given below, it is dependent on the gross weight. The maximum wave height is, for example, calculated for a 4 person Lake Buccaneer, a flying boat with a gross weight ($W_G$) of 1220 kg. It must be noted that the maximum wave height is not the significant wave height (explained in section 4.2). (Gudmundsson, 2013)

$$H_w \approx 1.25 * \ln(W_G * 2.20462) - 8.6414 = 1.35\ (4\ persons)$$

The following symbols can be noted in the formula: $H_W$ = Maximum wave height [m], $W_G$ = gross weight [kg].

This relation corresponds to specifications previously given of maximum wave heights of flying boats. The specifications range to about 3m for large boats. One flying boat, the Shin Meiwa US-1A, even has limited operational capacities in sea state 5 (Odedra, Hope, & Kennel, 2004). This flying boat is shown in figure 3.3.1. The Havilland Canada DHC-3 is shown in figure 3.3.2. This is a floating plane, it has two floaters. In conclusion, the shape (i.e. the type of seaplane) and weight are the most important contributing factors to the permissible wave height of seaplanes. It is also clear that permissible wave heights up to 3m can be achieved for large flying boats because they are heavy. It is not clear which level of comfort is reached in these waves. The key similarities with WIG vehicles which can be drawn are weight and shape.


*Figure 3.3.1 Flying boats: Shin Meiwa US-1A (L) and Lake Buccaneer (R) (Odedra, Hope, & Kennel, 2004)*

*Figure 3.3.2 Floating plane: De Havilland Canada DHC-3 (Looijen, 2010)*

### 3.3.3 Improvement: Hydraulic suspension

The seaworthiness of a WIG vehicle may be improved by making use of a hydraulic suspension.  This subsection will explore the application of hydraulic suspension in the marine industry (the Nauti-craft).

The hydraulic structure underneath the boat dampens the boat's pitch and roll. It does this with a so-called passive reactive system. The technology implemented on a maritime application is invented by the company Nauti-Craft (Goldberg, 2017) and two models have been developed so far. A catamaran and a quadmaran. The quadmaran is displayed in figure 3.3.3.


*Figure 3.3.3 Quadmaran with hydraulic suspension (Goldberg, 2017)*

The Nauti-craft 8M quadmaran has a measured top-speed of 75 km/h. Nauti craft state that for a 26m boat, the wave height of which comfort is reached is 1.5-1.7m, yet for a 26m boat with hydraulic suspension, the wave height of which comfort is reached, is 2-2.5m. This is an increase in permissible wave height of around 40 %. The 26m boat with hydraulic suspension, the NautiStrat 26 WFSV, is shown in figure 3.3.4 (Rood, 2016).

The hydraulic damping of motions could be interesting to reduce the endured takeoff and landing motions of WIG vehicles because some WIG vehicles have similar two floater designs. If the 40% increase of permissible wave height could also be used in WIG vehicles, this could be beneficiary to broad workable areas.

Rijkens (2018) argues that an active reactive system — as seen on the NautiStrat 26WFSV — is probably quite heavy. This will increase the weight of the WIG vehicle, which will in turn reduce the fuel efficiency. Therefore, a passive reaction system may be more desirable.

*Figure 3.3.4 Catamaran with hydraulic suspension. (Goldberg, 2017)*

### 3.3.4 Improvement: Wave prediction

Wave prediction technology is used on vessels to predict the character of waves. A vessel can adjust speed and range to reduce the impact motions. The motions of WIG vehicles during landing and takeoff could be reduced by using wave prediction technology. This effect of this technology, when applied to WIG vehicles, will be considered in the subsection below.

A wave radar developed by Naaijen (2017), forecasts the dangerous waves approaching in the following5 minutes. This technology could be useful if it works in high-speed operation. The wave radar could, in such a case, provide a forecast on the waves exceeding a certain height in front of the WIG vehicle. In combination with an automated control system, the speed and pitch of a WIG vehicle van be adjusted to reduce the impact motions.

### 3.3.5 Improvement: Wave barriers

Wave barriers reduce the wave height behind it. They can increase the seakeeping operability of WIG vehicles because it is stated by Fach et al. (2004) that the wave heights during landing and takeoff are critical. In this section, a short description and a first cost indication is given.

Wave barriers reduce the intensity of wave action. The barriers create sheltered waters behind them. When using WIG vehicles in sheltered waters they encounter smaller waves and endure smaller motions.

As sea dikes and wave barriers are fairly common, rough costs estimations are easy to find. The costs of a new sea dike of 1 , with regular maintenance costs, are about 0.62 M€/km. Adding 1m dike in a rural area costs about 0.52 M€/km state Hillen et al. (2010). This gives a first indication that wave barriers are affordable, compared to the ship prices of 0.6-20 million euro, mentioned in the literature research. A wave barrier is shown in figure 3.3.5. What can be seen is that the wave heights on the right are lower than the wave heights on the left.

*Figure 3.3.5 Illustration of wave barrier (motionelements, 2018)*

## 3.4 Aerodynamic efficiency

The tradeoff between lift and aerodynamic efficiency is a technical disadvantage. This section will analyze the disadvantages and look at possible solutions.

The aerodynamic efficiency is a compromise between efficiency and lift force during take-off. This compromise is dependent on the aspect ratio of the wings. The aspect ratio is the ratio of the span to the mean chord of a wing. Yun et al. (2010) state that a carefully chosen main wing plan and extended wing design (with corresponding, selectively chosen aspect ratios) will solve this problem.

Research on the aerodynamic efficiency is performed by MARIC. This is a Chinese institute that has a WIG development program. The program researched the aerodynamics of WIG airfoils. It performed model tests in wind tunnels. The tests measured the longitudinal aspects of eight wing profiles in ground-effect mode. The tests resulted in the design of an optimal wing in DACWIG configuration and optimal aspect ratios. Yun et al. (2010) state that the best way to deal with the tradeoff in aerodynamic efficiency, is to use a main wing with a AR = 0.5-0.8 and AR = 3-4 for the extended wing. (Yun et al. 2010)

## 3.5 Installed power

It is a disadvantage that there is a relatively high required installed power needed for takeoff which is not needed for cruising. Below, the required power of WIG vehicles will be described, as well as why it is a disadvantage, and then how to reduce said installed power.

Power is required during takeoff and cruising. It is highest during takeoff because the vehicle has to get out of the water and a high hydrodynamic drag occurs in this phase. After takeoff, the hydrodynamic drag disappears. An option — so that the vehicle can take of earlier — is lift enhancement. (Yun et al. 2010)

### 3.5.1 Improvement: Hydro ski gear

The installed power can be reduced by enhancing the lift and reducing the takeoff speed. A technology which enhances this lift is hydro ski gear.

A hydro ski gear can be seen in the design of some WIG vehicles. Yun et al. (2010) state that this feature is first seen on the Orlyonok to improve the hydrodynamic properties and to absorb wave slamming during landing and takeoff. In this subsection, the basic principle behind this technology is explained.

In the first stage of landing, the skies contact the water; they bounce over it. The skies rotate on their attachment point on the vehicle and there is no contact between the water and the hull. In the second stage, the skies give lift due planing. They also reduce the impact loads. Lastly, the hull of the vehicle contacts the water. The hull gives lift as a result of displacement. The hydrodynamic resistance slows the vehicle down and the vehicle is landed. During takeoff, the order of the stages is vice versa.

Hydro ski gear can be seen in the design of WIG vehicles. An illustration of the EP-15 with hydro ski gear is shown in figure 3.5.1. (Aqualines, 2018)

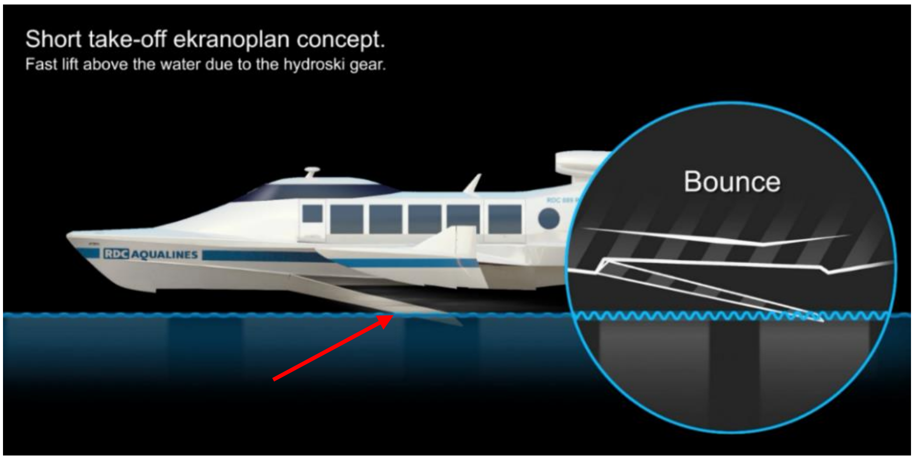


*Figure 3.5.1 Illustration of EP-15 (hydro ski gear is indicated with arrow) (Aqualines, 2018)*

In figure 3.5.2 is the side view of a Lun-class WIG vehicle presented. The hydro ski gear is indicated with a red arrow. (Yun et al. 2010)

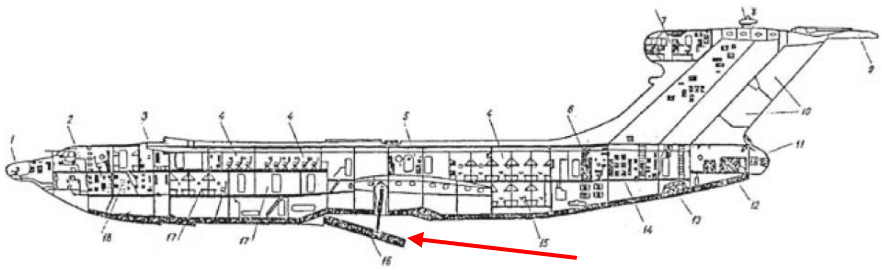

*Figure 3.5.2 Side view of Lun-class (hydro ski gear is indicated with arrow) (Yun et al. , 2010)*

In figure 3.5.3. a picture of the CYG-11 is shown. Hydro ski gear can be seen underneath the vehicle. (Yingge, 2017)

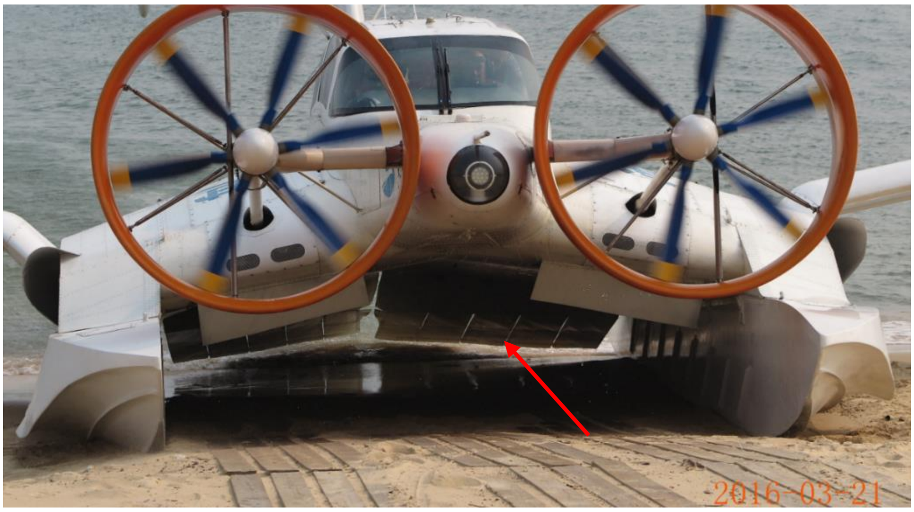


*Figure 3.5.3 Picture of Orion 12 (hydro ski gear is indicated with arrow) (Yingge, 2017)*

The formula below is used to estimate the lift of the hydro skies seen in the CYG-11. The estimated values are given in table 3.5.1. Width and length of the surface of the skies are estimated using figure 3.5.2. The lift coefficient is estimated by using a theoretical flat plate lift coefficient curve. This curve is shown in figure 3.5.4 (Brown, 1957). The figure shows the lift coefficient on the y axis. The trim [$^{o}$] is shown on the x-axis.

$$F_L = C_L * \rho * S * \frac{v^2}{2} = 95\ kN \text{ (Mantle, 2016)}$$

The symbols are as follows: $F_L$ = estimate of lift of hydro skies [kN], $C_L$ = lift coefficient [-], $\rho$ = density [kg/m$^3$], S = wetted surface [m$^2$], v = speed [m/s].

Estimated is that the lift is 95 kN at a speed of 75 km/h. This means that the hydro skies can lift 9700 kg out of the water at this speed. Caution must be applied with this estimate, as the lift is based on an undisturbed water surface.

*Table 3.5.1 Variables determining lift (own work)*

| Variable | Estimate | Unit |
|---|---|---|
| Lift Coefficient | 0.5 | - |
| Trim | 15 | $^{o}$ |
| Density | 998.0 | kg/m3 |
| Length | 0.3 | m |
| Width | 3.0 | m |
| Speed | 20.57 | m/s |
| Speed | 75 | km/h |
| Lift | 95 | kN |

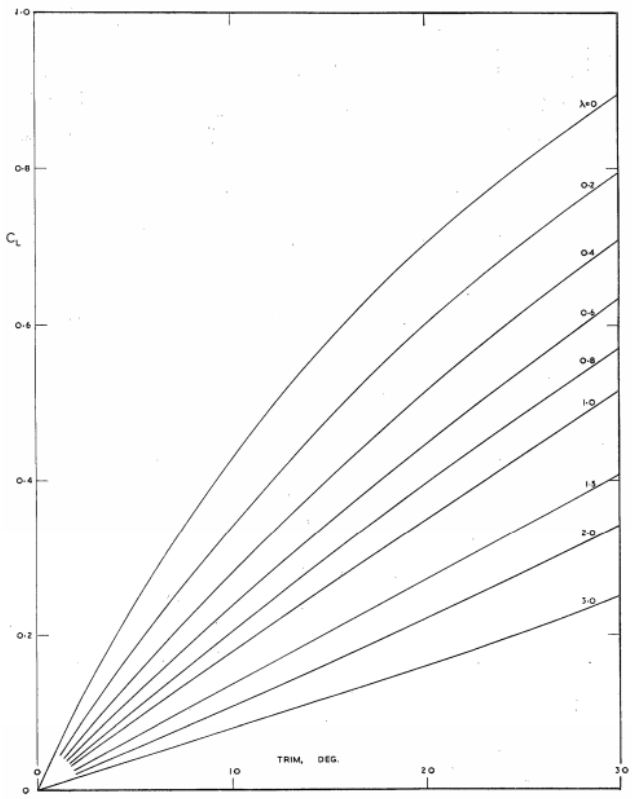


*Figure 3.5.4 Lift coefficient curve of flat-plate (Brown, 1957)*

### 3.5.2 Improvement: Power augmented lift

The required installed power can be reduced by enhancing the lift and reducing the takeoff speed. A technology which enhances the lift is power augmented lift WIG (PARWIG). This is an existing technology. The technology is described below.

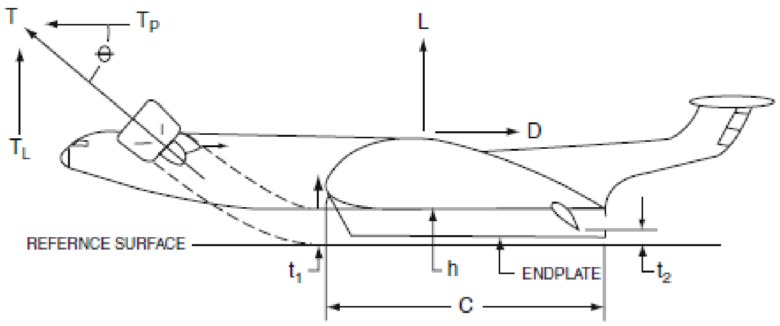


*Figure 3.5.5 Illustration of power augmented lift WIG vehicle (Yun et al. , 2010)*

Power augmented lift WIG vehicles have a pair of ducted propellers or turbofans mounted on the front of the vehicle to provide pressured air underneath the wing. This is in place to decrease the takeoff speed and the seakeeping, by creating a high lift force that leads to a reduced hump drag. In figure 3.5.4, the illustration of a PARWIG is shown. (Yun et al. 2010)

### 3.5.3 Improvement: Dynamic air cushion

Dynamic Air Cushion WIG vehicles (DACWIG) enhance the lift to reduce take off speed. It is an existing technology invented by MARIC. The technology is described below.

DACWIG vehicles have one or two tandem wings with a large cushion length/beam ratio. The vehicles have endplates on their wings to create a cushion of air underneath the wings at low speeds. The DACWIG vehicles are characterized by having deepened sidewalls or buoys. In figure 3.5.5, an illustration of a DACWIG is shown. Three modes of operation are illustrated. The large length/beam ratio can also be seen. (Yun et al. 2010)

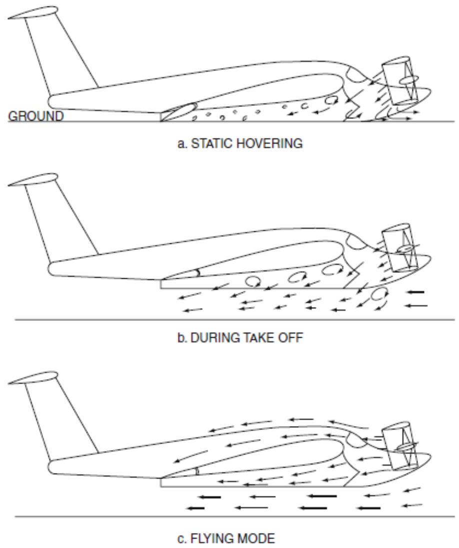


*Figure 3.5.6 Illustration of dynamic air cushion WIG vehicle (Yun et al. , 2010)*

### 3.5.4 Improvement: Hydrofoils

Hydrofoils can be used to reduce the speed at which the hull is lifted out of the water and therefore can reduce the hydrodynamic drag and reduce the installed power.

Hydrofoils are applied to the prototype X-114. A picture of the prototype is shown in figure 3.5.7. A design proposal of another WIG vehicle with hydrofoils is shown in figure 3.5.8. The problem with the X-114 prototype (equipped with hydrofoils) was that it was quite dangerous. When the vehicle landed there was a negative pitch angle. As a result, the hydrofoils pulled the vehicle into the water. The application of hydrofoils on WIG vehicles was subsequently abandoned. Yun et al (2010) state that the cavitation barrier, the complicated retraction mechanisms and the dangerous characteristics prevent a practical application.

*Figure 3.5.7 The X-114 equipped with hydrofoils (Yun et al. 2010)*

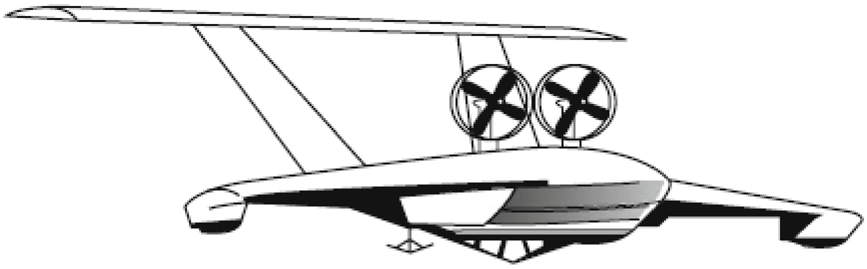

*Figure 3.5.8 Design proposal equipped with hydrofoils (Yun et al. 2010)*

## 3.6 Longitudinal stability

The longitudinal stability of WIG vehicles can be a technical disadvantage. Fach et al. (2004) describes that most of the accidents with WIG vehicles occurred due to a loss of longitudinal stability. The stability problems, together with improvements are described in this paragraph.

WIG vehicles have a high cruise speed. When wind gusts or waves occur, this will affect the longitudinal and transversal stability. To assure stability and safe operation at high-speeds, two new technologies can be used: a) an automated control system, b) a stall prevention system.

### 3.6.1 Improvement: Automated control systems

An automated control system can be used to assure stability and safe operation at high-speeds. A commercial automated control system has not been designed yet. (Yun et al. , 2010) But, this technology is developing fast. Automated control systems are designed for many other options in recent years. The development in this technology raises opportunities for automated control systems that can be used in WIG vehicles.

### 3.6.2 Improvement: Stall prevention system

Seawind, a small leisure airplane, makes use of a stall prevention system. WIG vehicles could use such a system too. De Swart states that all traditional aircrafts have a stall warning system built in and are designed to be passively stable (de Swart, 2018). The stick of the aircraft controls will start shaking when the nose must be lowered or power must be applied (Irwin, 2015).

## 3.7 Risk assessment of operating WIG vehicle

There can be several failure modes and operating risks involved in the operating of a WIG vehicle. To identify and evaluate failure modes and risks, a risk assessment is performed. The results are described in this hereafter.

Failure modes in design and operation are identified and evaluated according to a failure mode and effect analysis (FMEA). Both a hazard and an operability study are conducted, to address ways to deal with the risks. The risks are presented in a risk register, which acts as repository for all the identified risks.

*Table 3.7.1 Failure mode and effect analysis on a WIG vehicle (own work)*

| | DESCRIPTION OF FAILURE | | | EFFECT OF FAILURE | | |
|---|---|---|---|---|---|---|
| **#** | **Failure mode** | **Cause** | **Mechanism** | **On the system** | **Impact** | **Probability** |
| 1.1 | Propulsion fails | Insufficient maintenance | Wear | Loss of propulsion; Emergency landing | Major | Low |
| | | Insufficient fuel | Human error | | | |
| 1.2 | Electrical equipment fails | Short circuit | Human error/ Over heating | Blackout; Emergency landing | Major | Low |
| | | Fuse failed | Wrong voltage | | | |
| 1.3 | Control fails | Insufficient maintenance | Wear | Loss of control, loss of stability, Stalling, Crash | Severe | Low |
| | | Wrong handling | Human error | | | |
| | | Inadequate settings | Computation error | | | |
| | | Inadequate settings | Human error | | | |
| 1.4 | Hull fails | Inadequate design | Impact | Sinking, loss of stability | Major | Low |

Four failure modes are defined in the FMEA. The failure mode with the highest impact is the failure of the control system, this is presented in table 3.7.1. The strategy to cope with this failure mode is given in the risk register in table 3.7.4.

In table 3.7.2, the hazard and operability study is shown and eight risks are described. The risks are also added in the risk register in table 3.7.4. As can be seen, the risk with the highest impact is the risk of collision.

The study shows that the consequence of most of the risks is an emergency landing. The impact of an emergency landing is not too severe, as WIG vehicles can land in waves up to approximately 20% of their wingspan (Fach et al. 2004).

The risk of collision with a ship is high. The action to deal with this risk is to operate on a WIG lane. Fach et al. (2004) state that in order to avoid an obstacle, a temporary increase in height is possible. The kinetic energy of the cruise speed is used in this avoidance maneuver. It is questionable whether this avoidance maneuver is acceptable for the public. Therefore, it is not mentioned as an action.

*Table 3.7.2 Hazard and operability study of WIG vehicle operation (own work)*

| | GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCE | PROBABILITY | IMPACT |
|---|---|---|---|---|---|---|
| 2.1 | None | No deployment | Bad weather | Delay | Low | Minor |
| 2.2 | | No fuel | Defect in measuring equipment, human error | Emergency landing | Low | Major |
| 3.1 | Less | Less deployment | Bad weather | Low comfort | Low | Minor |
| 3.2 | | Less control | Control system failure | Emergency landing | Low | Major |
| 3.3 | | Less fuel | Defect in measuring equipment, rupture in tank | Emergency landing | Low | Major |
| 3.4 | | Less stable | Control system failure, human error | Emergency landing | Low | Major |
| 4.1 | Low | Low speed | Engine failure, human error | Emergency landing | Medium | Moderate |
| 5.1 | More | More ships | Busy waterway | Collision or gain height | Medium | Severe |

*Table 3.7.3 Risk matrix (own work)*

| PROBABILITY \ IMPACT | Insignificant | Minor | Moderate | Major | Severe |
|---|---|---|---|---|---|
| **Very high** | Medium | Medium | High | Extreme | Extreme |
| **High** | Low | Medium | High | High | Extreme |
| **Medium** | Low | Medium | Medium | High | High |
| **Low** | Low | Low | Medium | Medium | Medium |
| **Very Low** | Low | Low | Low | Low | Medium |

*Table 3.7.4 Risk register (own work)*

| | DESCRIPTION | PROBABILITY | IMPACT | RISK | STRATEGY | ACTION |
|---|---|---|---|---|---|---|
| 1.1 | Propulsion fails | Low | Major | Medium | Mitigate | Inspections will be conducted before operations. They can be similar to those of aircrafts. Cameras could also be used. |
| 1.2 | Electrical equipment fails | Low | Major | Medium | Mitigate | Inspections will be conducted before operations |
| 1.3 | Control fails | Low | Severe | Medium | Mitigate | Redundant emergency system and inspections will be conducted before operations |
| 1.4 | Hull fails | Low | Major | Medium | Mitigate | Inspections will be conducted before operations |
| 2.1 | No deployment due to bad weather | Low | Minor | Low | Accept | No operations. Proper planning. |
| 2.2 | Out of fuel | Low | Major | Medium | Mitigate | Redundant fuel measure system and manual inspections will be conducted before operations. Proper planning and training. |
| 3.1 | Less deployment due to bad weather | Low | Minor | Low | Accept | Limited operations |
| 3.2 | Control partly fails | Low | Major | Medium | Mitigate | Inspections will be conducted before operations |
| 3.3 | Low on fuel | Low | Moderate | Medium | Mitigate | Redundant fuel measure system and manual inspections will be conducted before operations |
| 3.4 | Stability partly fails | Low | Moderate | Medium | Mitigate | Inspections will be conducted before operations. Design for failure. |
| 4.1 | Speed is too low | Medium | Moderate | Medium | Mitigate | Inspections will be conducted before operations. |
| 5.1 | Collision with ship | Medium | Severe | High | High | Laying out WIG lane. Selecting right type of WIG. |

## 3.8 Technological readiness level

Before bringing a technology to the market, the technology must be ready from a technical point of view. As it is quite complicated to select and quantify whether a technology is ready, a technology readiness level index is used. This level of “readiness”, in relationship to WIG technology, will be explained below.

Model tests, and full-size prototype tests, with the WIG technology are performed (Yun et al. 2010). This means that according to the NASA scale of technology readiness, the level is eight out of nine. Problems are known, plans, options and actions to resolve the problems are also known. In figure 3.8.1, a technology readiness level index is presented. The index shows the different levels and describes them. The technological readiness level of WIG technology is indicated in the figure with a red arrow. (EARTO, 2014).

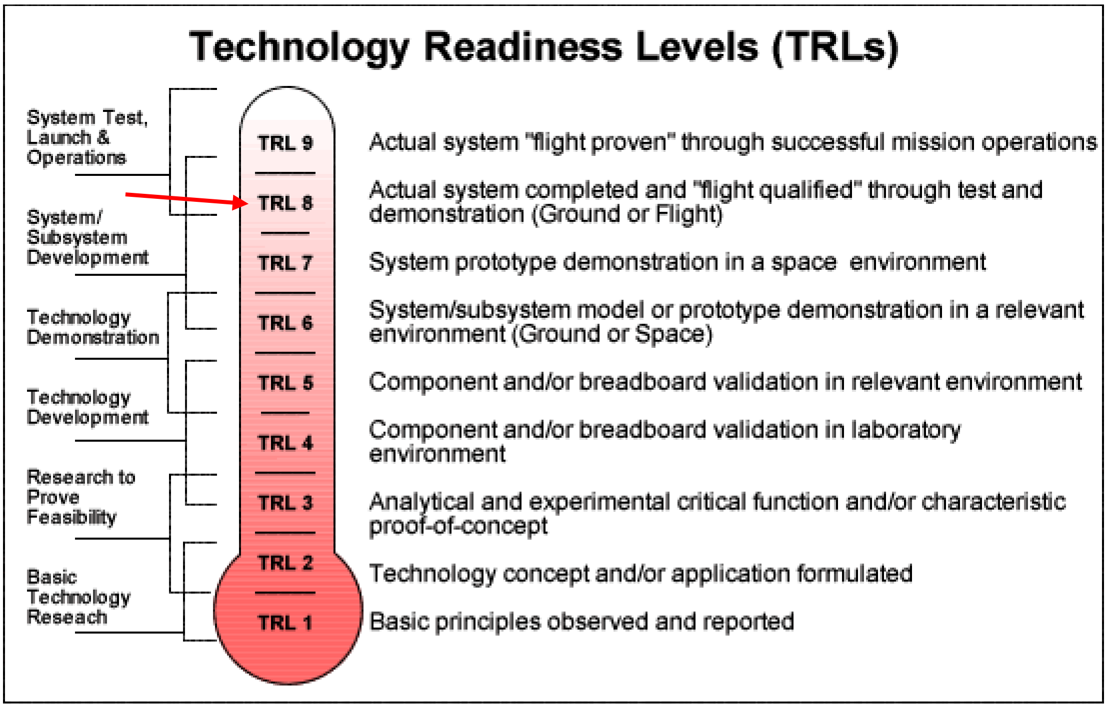


*Figure 3.8.1 Technology readiness level index (WIG technology is indicated with arrow). (EARTO, 2014)*

## 3.9 Conclusion

The technical feasibility of WIG vehicles is proven. Rozhdestvensky & Kirill (2006) state that the technical feasibility is not a problem because all technical problems can be dealt with, model tests are performed and full-size prototypes are built. Yun et al. (2010) state that all of the technical disadvantages must be brought to attention, but can subsequently be dealt with. Yun argues that an elegant option to address the technical disadvantages, is through making use of new technologies.

WIG vehicles admittedly have one main limitation: seaworthiness. This permissible wave height during landing and takeoff is low. The waves induce motions on the vehicle during these modes. A rule of thumb, given by Fach et al. (2004), states that the wave height should not exceed 5% of the wingspan of WIG vehicles during takeoff and landing. Other sources state that the permissible wave height of WIG vehicles is dependent on the weight and design of the vehicle.

Flying boats have similar ranges of permissible wave heights as WIG vehicles. The most important similarities, regarding the permissible wave height, are both the contributing factors: weight and shape. Gudmundsson (2013) presents a formula for which the wave height of flying boats is dependent on the gross weight.

A promising technology which can improve the seaworthiness of WIG vehicles is the use of a hydraulic suspension. Designs for hydraulic suspension are available in the marine industry. The hydraulic suspension is placed underneath a vessel, and dampens the vessel's pitch and roll, with a passive reactive system. Vessels equipped with a hydraulic suspension can handle an increase of 40% in permissible wave height, at which the same level of comfort is reached. Hydraulic suspension for WIG vehicles might thus be an interesting direction for further research.

There are three technical disadvantages: 1) tradeoff in aerodynamic efficiency and lift force, 2) high required installed power needed for takeoff, 3) longitudinal stability can be hard to regulate. Yun et al. (2010) state that aerodynamic tests have been performed by MARIC and resulted in an optimal wing profile. The installed power can be reduced by enhancing the lift and reducing the takeoff speed. Automated control and stalling systems can be used to improve the longitudinal stability.

Risks involved in the design and operations of WIG vehicles are evaluated by selecting the right strategies and actions. The result of the risk assessment is that a collision with a ship is the highest risk.

WIG technology has a readiness level of eight out of nine. This is assessed by making use of a technological readiness levels index. The level eight out of nine means that an actual system is completed, and the technology is qualified by tests and demonstrations. There is only one level higher with proven commercial operations.

# 4 Choice of concepts

Different WIG vehicles can be chosen to base the profitability study on. This chapter analyses recently built WIG vehicles (2004-2017) on the following technical aspects: seaworthiness, passenger capacity and efficiency. Based on that, a set of most suitable WIG vehicle(s) is chosen to be used for the further research.

## 4.1 Methodology

The expected output of this chapter is a set of concepts which can be used in the profitability study. To determine and specify the concepts as good as possible, a methodology is used. This methodology is described below.

Firstly, the following topics are described: seakeeping operability, reliability, operational cycle and general design of logistics. This information is used to estimate the requirements of the concepts. Thereafter, a database with the specifications of WIG vehicles is presented. The database is used to compare the WIG vehicles with each other based their specifications. Lastly, a set of the most suitable WIG vehicles is chosen. This is being done by looking at the requirements: seaworthiness, number of passengers and efficiency.

The selection in this chapter is based on  technological aspects. Later, when the cost of the vehicles is known, there will be further commentary on the profitability of the concepts..

## 4.2 Seakeeping operability

The seaworthiness of a WIG vehicle is dependent on the permissible wave height of the vehicle. In this section, is the influence shown of the permissible wave height of WIG vehicles on the seakeeping operability rate on a number of routes. It is important that this is considered, as is stated that the seaworthiness is the most limiting factor of WIG vehicles. First off, the definitions regarding seakeeping operability are described. Thereafter, the impact of seaworthiness on the seakeeping operability is elaborated on.

It is useful to be familiar with definitions regarding the seakeeping operability of WIG vehicles. General definitions are described below.

- The significant wave height represents the average of the highest one-third of waves.
- The mean wave height represents the height of a wave which appears on average the most.
- The permissible wave height is a specification of a vehicle which represents the maximum significant wave height for which landing/takeoff is possible.
- The seakeeping operability rate is defined as the percentage of days for which the significant wave height is lower than the permissible wave height.

A statistical wave distribution is shown in figure 4.2.1. In the same figure, the distribution is presented as  all the waves' heights plotted, vs their appearance over a certain period of time. The mean and significant wave height are also presented in the  same figure.

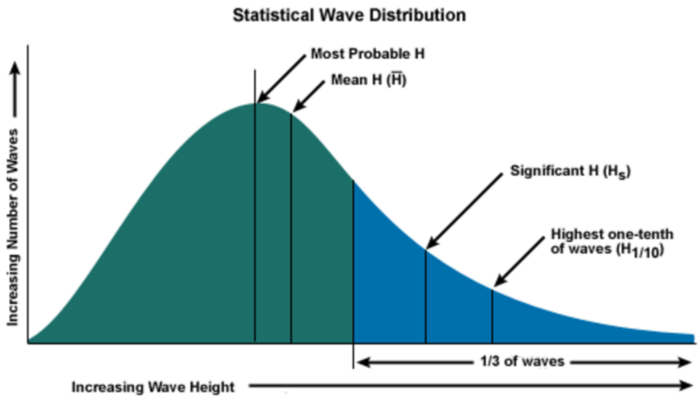


*Figure 4.2.1 Standard statistical wave distribution (Collins, 2014)*

The seakeeping operability rate of a WIG vehicle on a route is dependent on the permissible wave height of the vehicle and the occurring significant wave height. The seakeeping operability rate on a selection of routes is calculated as follows:

1) The wave height data of a number of routes is gathered using data of Copernicus (year 2017) (Copernicus, 2018)
2) The significant wave height is calculated per route and per day.
3) The seakeeping operability rate is calculated by the formula presented below.

$$Seakeeping\ operability\ rate\ [\%] = \frac{number\ of\ days\ (permissible\ wave\ height > \ significant\ wave\ height)}{total\ number\ of\ days}$$

In figure 4.2.2, the seakeeping operability rate of a number of routes is plotted against the permissible wave height. The selection of the presented routes is shown in section 6.5. What can be seen in the figure is that the operability rises for each route, as the permissible wave height increases. The variation of seakeeping operability rate per route is striking. The 'Buenos Aires – Montevideo' route stands out in the figure because it has a relatively high operability rate.

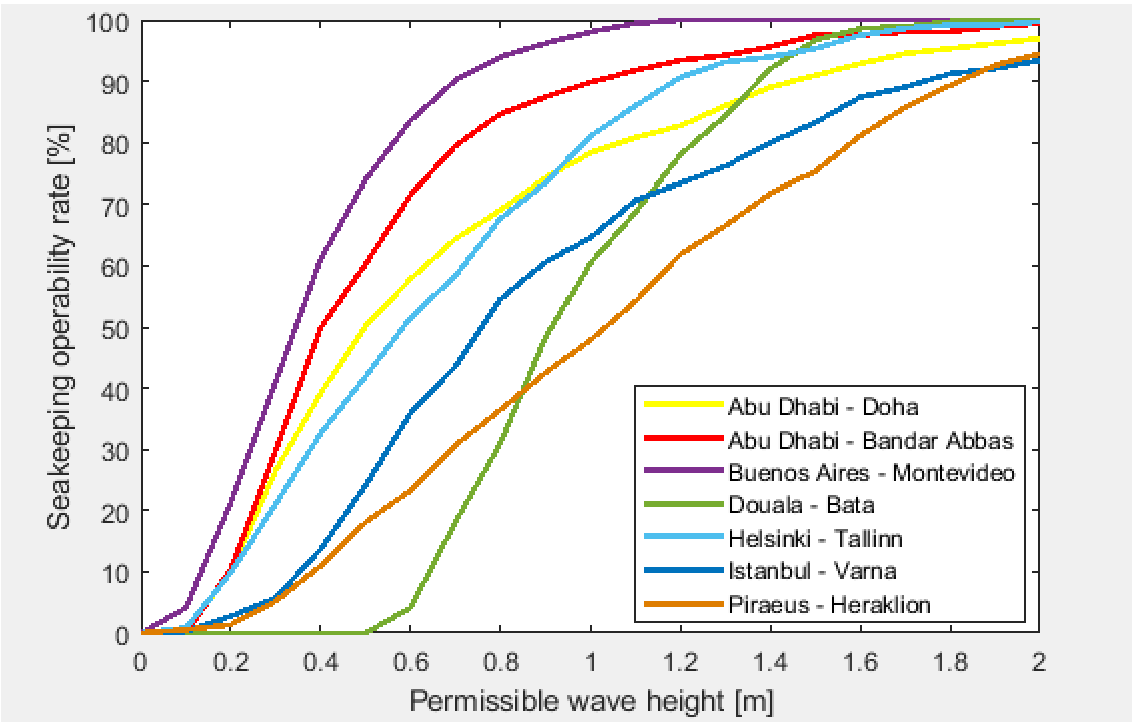


*Figure 4.2.2 Seakeeping operability rate of suitable routes vs permissible wave height (own work)*

Fach et al. state that the wave heights at takeoff and landing are most critical (Fach et al. 2004). The variable permissible wave height during takeoff and landing is therefore used in the calculation of the seakeeping operability rate.

The seakeeping operability rate does not take into account that the significant wave height can change while operating. Allowing a buffer zone to account for weather changes could prove to be a valuable solution to this issue. In future research, it would be useful to take weather changes into account. Furthermore, the comfort of the occupiers is not fully accounted for; for example, comfort is likely to be high when the permissible wave height is far greater than the significant wave height. Likewise, the comfort level is likely to be lower when the permissible wave height is almost equal to the significant wave height.

Concluding, the permissible wave height of a WIG vehicle can be of big influence on the seakeeping operability rate. The higher the permissible wave height of a vehicle, the higher the seakeeping operability rate.

## 4.3 Reliability

It is of importance to know the reliability of WIG vehicles to estimate its influence. This section will contextually explore the definition of "reliability" and will then compare WIG transport against aviation transport, with said reliability in mind.

Reliability is, in theory, defined as the degree of consistency of a measure. It is often expressed in time of delay or percentage as a result of faults and failures. (Shuttleworth, 2017)

A comparison between the reliability of WIG transport and aviation transport is made because there is no specific reliability data of WIG transport available. Aviation transport is chosen because it has a similar market and data is available and accessible.

Wyndham (2012) states that a dispatch reliability of 98% is standard in the aircraft transport business. He continues that it should be at, or near, 100%. An aircraft is compromised when it has a (technical) problem and cannot takeoff within 15 minutes of the departure time.

## 4.4 Operational cycle

A general operational cycle is given in this section. As the operational region is not known at this point, the operational cycle is given at a basic level. In future research, it could be useful to determine the operational profile per region.

The literature research demonstrated that there can be a time advantage over other transportation methods when the distance of a route is between 50-350km. A WIG vehicle can be faster than regular boats and faster than aircraft transportation, depending on the location of the aerodromes.

Table 4.4.1 illustrates an example of an operational cycle for a route with a distance of 344km. The duration of this trip will be 120 minutes. The stages are presented in the table.

*Table 4.4.1 Illustration of operational cycle (own work)*

| | | Duration [min] | Speed [km/h] | Distance [km] |
|---|---|---|---|---|
| Departure | Harbor maneuvering | 2 | - | 0 |
| | Leaving harbor | 3 | 18 | 1 |
| Transit | Crossing at operational speed | 111 | 185 | 342 |
| Arrival | Entering harbor | 3 | 18 | 1 |
| | Mooring | 1 | - | 0 |

## 4.5 General design of logistics

WIG vehicles normally land and takeoff on water. The literature research revealed that some recently built WIG vehicles can also land on an ice terrain. This section gives a general description of the logistics needed to land and takeoff on water and ice.

The logistics on both terrains have two components: a runway and a terminal. The runway is typically 500-2000m long (Yun et al. 2010). Looking at aircraft principles, the runway is shorter for smaller vehicles, and longer for bigger vehicles. The terminal on a water terrain can be made of a quay and a plastic (polyethylene) pontoon. An example is given in figure 4.5.1. The embarking of the Aron M80 is shown in this figure. The rest of the terminal can be arranged by keeping general weather conditions in mind.

*Figure 4.5.1 Illustration of WIG vehicle quay (Aron, 2017)*

A terminal on an ice terrain can be quite small, as a modular pontoon or quay is not needed. A ramp to cover the distance to the ground can be handy. Some vehicles such as the burevestnik-24 and the Orlyonok have such a ramp built in at the stern of the vehicle.

This research does not take into account that WIG vehicles can be designed to land or takeoff on land. Assumed is that this can reduce the feasibility of WIG transport. This has multiple reasons:

a) *The duration of transport is likely to be longer.*
WIG vehicles which can land or takeoff on land need landing strips. It is likely that these landing strips cannot be situated as close to cities as landing strips situated on water.

b) *The investments are likely to be higher.*
The building of landing strips requires significant investments.

c) *The startup duration and costs are likely to be higher.*
It is likely that regulations and residents prevent or delay the building of landing strips or wave barriers near cities.

## 4.6 Statement of requirements

It is useful to base the profitability study on a suitable selection of WIG vehicles. A selection of suitable vehicles is made based on a set of requirements. The requirements to select the vehicles are presented below.

Three requirements are drafted to select a set of WIG vehicles:

1. The permissible wave height of the vehicles is higher than 1.0m. This ensures that the vehicle can operate on 4 or more suitable routes (see section 6.5) with a seakeeping operability rate higher than 75%. A lower permissible wave height would reduce the seakeeping operability rate drastically.
2. A set of vehicles with varying passenger capacities is sought after. The benefit of WIG vehicles with varying passenger capacities is that it can show different results in the profitability analysis. The difference in passenger capacities of the vehicles is preferably as large as possible.
3. The displacement/power ratio of the vehicles is higher than 7 kg/kW. For this value is the efficiency of the vehicles higher than that of other methods of transportation such as aircrafts and hydrofoils.

   A comparison of the displacement/power ratio of WIG vehicles and other transport methods is made by Fischer & Zagklis (2013). The comparison is shown in figure 4.6.1.

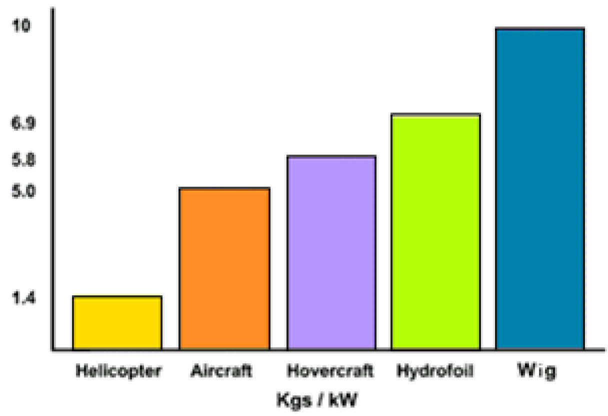


*Figure 4.6.1 Comparison of displacement/power ratios of transport methods (Fischer & Zagklis, WSH-500, 2013)*

## 4.7 Estimation method permissible wave height

The literature research revealed that there is a lack of clarity on the seaworthiness aspect of WIG vehicles. Clarity is needed on this aspect because there is no uniform measure and the permissible wave height of the vehicles can be of significant influence on the seakeeping operability rate. In this paragraph are the permissible wave heights of recently built vehicles (2004-2017) estimated by looking at the design of the vehicles, rule of thumb by Fach et al. (2004) and the permissible wave height estimation of sea planes.

There are two available approaches to estimate the permissible wave height:

1) The rule of thumb by Fach et. al (2004) gives an estimate of the permissible wave height of WIG vehicles based on their span.
2) The formula of Gudmundsson (2013) gives an estimate of the permissible wave height of seaplanes based on their weight (see 3.3.2).

The permissible wave heights of the recent built WIG vehicles are estimated based on their design. A key design feature to estimate the permissible wave height is the ability of a vehicle to perform a belly landing or not.

The permissible wave height of recently built WIG vehicles which cannot perform a belly landing is estimated by using the rule of thumb of Fach et al. (2004). This method states that the permissible wave height of WIG vehicles is approximately 5% of the span of the vehicle. The formula to estimate the permissible wave height for vehicles which do not have the ability to perform a belly landing is presented below.

$$H_{p_{no\ belly\ landing\ WIG}} = 0.05 * S \qquad (4.7.1)$$

It is likely that WIG vehicles which can perform a belly landing have a higher permissible wave height than the vehicles which cannot, because these vehicles have characteristics similar to seaplanes. One could argue, that the permissible wave height of these vehicles can be calculated by using a estimation formula intended for seaplanes. The formula to estimate the permissible wave height of seaplanes is provided by Gudmundsson (2013) and presented below. (see section 3.3.2).

$$H_{p_{seaplane}} \approx \frac{2}{3} * 1.25 * \ln(W_G * 2.20462) - 8.6414 \qquad (4.7.2)$$

Given that the estimation of the permissible wave height of seaplanes by Gudmundsson is based on weight, and the WIG vehicles are generally heavier than seaplanes, it is likely that this estimate is too high. It can be assumed that the permissible wave height of the vehicles (of which can perform a belly landing) can be estimated by taking the *average* of both the rule of thumb method by Fach et al. (2004), and the formula provided by Gudmundsson (2013). The formula to estimate the permissible wave height for vehicles which do not have the ability to perform a belly landing is presented below.

$$H_{p_{belly\ landing\ WIG}} = \frac{H_{p_{no\ belly\ landing\ WIG}} + H_{p_{seaplane}}}{2} \qquad (4.7.3)$$

The following symbols can be noted in the formula: $H_p$ = permissible wave height [m], S = span [m], $W_G$ = gross weight [kg].

## 4.8 Database of vehicle specifications

Presented in this section, is a database with WIG vehicle specifications, to enable a comparison between vehicles. Fach et al. (2004) created a database of typical WIG vehicles up until 2004. This database is extended with recent built WIG vehicles (2004-2017).

The database of general WIG vehicles is presented in table 4.8.1. Linear color scales are added to a number of specifications to indicate positive characteristics of WIG vehicles. In the first column, the names of WIG vehicles are shown. In the corresponding row, the specifications are listed. The vehicles are sorted by the year they were built. What can be deduced from the database, is how a WIG vehicle performs in comparison to other WIG vehicles.

The information below highlights notable specifications of recently built WIG vehicles.

- The WSH-500 is the vehicle with the highest permissible wave height of the recently built vehicles. It has an estimated permissible wave height of 1.4m. The Aron M80 also has a relatively high estimated permissible wave height of 1.2m.
- What can be noticed, is that the recent built WIG vehicles have varying passenger capacities in the range of 5-50 people. The WSH-500 is the vehicle with the highest passenger capacity, as it has a passenger capacity of 50 passengers.
- What is notable is that the Burevestnik-24, haenarae-X1 and WSH-500 have, in comparison to other WIG vehicles, favorable power/passenger, displacement/passenger, displacement/power ratio’s. The assumption is that these variables have among others a positive effect on the fuel efficiency.

The used sources are: Fach et al. (2004), Aron (2018), Wingship brochure (2018), (Horak, 2018), (Romanenko, 2018), (Telegraph co uk, 2010), (Ivanov, 2018). Caution must be applied with these sources. Most of the sources are not substantiated with scientific literature.

*Table 4.8.1 Database of WIG vehicle specifications (Fach et al. & own work)*

| WIG | Length [m] | Span [m] | nr of propulsion [-] | Power [kW] | Displacement [kg] | Speed [km/h] | Passengers [PAX] | Permissible wave height [m] | Power/passengers [kW/PAX] | Displacement/ passengers [kg/ PAX] | Displacement/ power [kg/ kW] | Belly landing (y/n) | Type | Year built | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KM | 98.0 | 38.0 | 10 | 71347 | 500000 | 550 | 450 | 3.5 | 159 | 1111 | 7 | Y | A | 1967 | Fach et al. (2004) |
| Orlyonok | 58.0 | 31.5 | 2 | 26479 | 140000 | 400 | 150 | 1.5 | 177 | 933 | 5 | Y | A | 1972 | |
| Volga 2 | 11.6 | 7.6 | 2 | 220 | 2700 | 120 | 8 | 0.5 | 28 | 338 | 12 | N | A | 1986 | |
| Lun | 73.8 | 44.0 | 8 | 79438 | 400000 | 550 | 250 | 2.5 | 318 | 1600 | 5 | Y | A | 1987 | |
| Airfish 3 | 9.9 | 7.5 | 1 | 55 | 760 | 135 | 2 | 0.3 | 28 | 380 | 14 | N | A | 1990 | |
| Strizh | 11.4 | 6.6 | 2 | 235 | 1630 | 200 | 2 | 0.5 | 118 | 815 | 7 | N | A | 1991 | |
| TAF VIII-5 | 19.8 | 8.5 | 1 | 1200 | 9200 | 176 | 15 | | 80 | 613 | 8 | N | A | ~1994 | |
| XTW-2 | 18.5 | 12.7 | 2 | 440 | 4000 | 150 | 12 | 0.5 | 37 | 333 | 9 | N | A | ~1995 | |
| Hydrowing | 9.9 | 7.8 | 2 | 88 | 1050 | 120 | 2 | 0.4 | 44 | 525 | 12 | N | A | ~1995 | |
| Hoverwing 2vt | 10.6 | 10.6 | 2 | 78 | 1150 | 124 | 2 | 0.5 | 39 | 575 | 15 | N | A | 1997 | |
| Aquaglide 2 | 10.5 | 5.9 | 2 | 162 | 2100 | 150 | 4 | 0.4 | 41 | 525 | 13 | N | A | ~2000 | |
| Airfish 8 | 17.2 | 15.2 | 2 | 345 | 4300 | 159 | 8 | 0.5 | 43 | 538 | 12 | N | A | 2001 | |
| Haenarae-X1 | 12.3 | 11.0 | 2 | 150 | 1500 | 120 | 5 | 0.8** | 30 | 300 | 10 | Y | A | 2007 | Own work |
| Aron M50 | 10.0 | 12.9 | 1 | 186 | 1400 | 167 | 5 | 0.8** | 37 | 280 | 8 | Y | B | 2007 | |
| Orion 12, Ivolga, EK-12, CYG-11 | 15.0 | 12.5 | 2 | 486 | 3700 | 185 | 12 | 0.6* | 41 | 308 | 8 | N | A | 2009 | |
| Bavar 2 | 8.4 | 5. 9 | 1 | - | - | 185 | 2 | - | - | - | - | Y | B | 2010 | |
| Burevestnik-24 | 19.5 | 16.0 | 2 | 772 | 7850 | 250 | 24 | 0.8* | 32 | 327 | 10 | N | B | 2016 | |
| WSH-500 | 29.0 | 27.0 | 2 | 2000 | 17100 | 185 | 50 | 1.4* | 40 | 342 | 9 | N | A | 2013 | |
| Orion 14, EK-14 | 13.1 | 12.3 | 2 | 716 | 4200 | 250 | 14 | 0.6* | 60 | 350 | 6 | N | A | 2014 | |
| Orion 20 | 19.1 | 19.8 | 3 | 1470 | 9250 | 185 | 20 | 1.0* | 74 | 463 | 6 | N | A | 2015 | |
| Xiang Zhou-1 | 12.7 | 11.0 | 1 | - | 2500 | 185 | 7 | 1.0** | - | 357 | - | Y | B | 2017 | |
| Aron M80 | 12.2 | 13.6 | 1 | 560 | 3560 | 185 | 8 | 1.2** | 70 | 388 | 6 | Y | B | 2017 | |

* = permissible wave height is estimated according formula 4.7.1

** = permissible wave height is estimated according formula 4.7.3

## 4.9 Analysis of three vehicles

Using the database, the specifications of the recent built WIG vehicles are compared. Only one WIG vehicle met all three requirements: the WSH-500. Furthermore, two WIG vehicles stand out because of favorable specifications: the Aron M80 stands out because it has a relatively high permissible wave height and the Burevestnik-24 stands out because it has relatively favorable efficiency ratios. In this section, the characteristics, strengths and weaknesses of these vehicles is further elaborated upon to give background information and to make a final selection.

### 4.9.1 WSH-500

The WSH-500 is an A type WIG vehicle produced by the company Wingship based in Singapore. Characteristics of the vehicle are the reversed delta wing and the relatively big size. The vehicle has two floaters.

Strengths of the vehicle are the relatively high estimated permissible wave height, high passenger capacity and a low power/passenger ratio. The permissible wave height is estimated to be 1.4m. It has a passenger capacity to carry 48+2 persons.

What is notable in the business plan of the WSH-500 is that the intended routes are situated in Greece and South-Korea. The seakeeping operability rate of the WSH-500 is estimated to be 71% on a similar route: Piraeus-Heraklion (see figure 4.2.2). This raises the following question: what can be a suitable route for high-speed WIG passenger ferry transport? In chapter 6 are suitable routes selected. (Fischer & Zagklis, WSH-500, 2013)

*Figure 4.9.1 The WSH-500 (Fischer & Zagklis, WSH-500, 2013)*

### 4.9.2 Aron M80

The Aron M80 is the latest WIG vehicle made by the South-Korean based company, Aron. The vehicle is characterized by the Ekranoplan wing configuration. The main source of buoyancy is the fuselage, which functions as a hull when it is in displacement mode. What is notable is that the vehicle can perform a belly landing with its hull.

The strength of this Aron M80 is its relatively high estimated permissible wave height of 1.2m. This is result of having the ability to perform a belly landing. There are multiple versions made, which can indicate that the design is optimized, and general faults or failures are reduced. It can be possible that due to the high seaworthiness, the vehicle can expand into multiple operational regions and/or markets. The weaknesses of this vehicle, are that it has a low passenger capacity of 6+2 and a relatively unfavorable power/passenger, displacement/passenger, displacement/power ratio's. The ratio's give the impression that the Aron M80 has a robust design with the price of a relatively higher weight.

Yun et al. (2012) states that some of the Aron vehicles operate as water taxis.

*Figure 4.9.2 The Aron M80 (Aron, 2017)*

### 4.9.3 Burevestnik-24

The Burevestnik-24 is a WIG vehicle made by the company sky and sea group. Seven versions of the vehicle were made in the period 2004-2016.

The vehicle is characterized by a double-wing layout and two big ducted propellers. The Burevestnik-24 has similarities to a Sesquiplane. This is a plane where one wing has not more than half the surface area of the other. The advantage of the double-wing layout of the Burevestnik is that it may reduce interference drag between the wings compared to a bi wing configuration. The advantage over WIG vehicles with wings (such as Orion 12), is that the added wings are placed higher above the water.

The Burevestnik-24 is one of the most efficient vehicles. The strength of the vehicle is that it has favorable power/passenger, displacement/passenger, displacement/power ratios. These ratios can be positive for the fuel efficiency. Furthermore, the passenger and crew capacity of 24 people might be interesting as it is relatively high. The weakness of the vehicle is likely to be its low estimated permissible wave height of 0.8m. As a result of this weakness, the operational profile could be limited.

A notable fact, is that the company behind the Burevestnik initially aimed to operate on frozen lakes in Siberia (2013). Now (2018), operational regions all over the world are indicated on their website to persuade investors. (Romanenko, 2018)

*Figure 4.9.3 The Burevestnik-24 (Romanenko, 2018)*

## 4.10 Conclusion

The goal of this chapter is to select a set of WIG vehicles to base the profitability study on. In order to do this, the following steps are performed. The influence of the seaworthiness of a vehicle on the seakeeping operability is analyzed. The permissible wave heights of recently built vehicles are estimated. A set of requirements is outlined in order to select the vehicles. A database of WIG vehicle specifications is drafted. Lastly, the vehicles are selected based on those requirements.

Yun et al. (2010) state that the seaworthiness is the main factor limiting WIG vehicle operations. In this research, the seaworthiness is defined by the permissible wave height. The seakeeping operability rate is calculated for several routes, to show the influence of the permissible wave height. This is represented in figure 4.2.2. It is clear that the permissible wave height has a big influence on the seakeeping operability rate. The higher the permissible wave height of a vehicle, the higher the seakeeping operability rate.

Three requirements are drafted to select a set of WIG vehicles:

4. The permissible wave height of the vehicles is higher than 1.0m. This ensures that the vehicle can operate on 4 or more suitable routes (see Ch. 6.5) with a seakeeping operability rate higher than 75%. A lower permissible wave height would reduce the seakeeping operability rate drastically.
5. A set of vehicles with varying passenger capacities is sought after. The benefit of WIG vehicles with varying passenger capacities is that it can show different results in the profitability analysis. The difference in passenger capacities of the vehicles is preferably as large as possible.
6. The displacement/power ratio of the vehicles is higher than 7 kg/kW. For this value is the efficiency of the vehicles higher than that of other methods of transportation such as aircrafts and hydrofoils.

The permissible wave heights of the recently built vehicles are estimated to make a correct comparison and it is estimated based on the design of the vehicles. A distinction has been made between WIG vehicles on their ability to perform a belly landing or not. The permissible wave height of vehicles which can perform a belly landing is generally higher. These vehicles have the similar design characteristics as seaplanes, which improve the permissible wave height. The permissible wave height of standard WIG vehicles, which cannot perform a belly landing, is estimated using the rule of thumb of Fach et al. This rule of thumb states that the permissible wave height equals 5% of the span of the vehicle. The permissible wave height of vehicles which can perform a belly landing (similar to seaplanes) is estimated by taking the average of the two calculations.

Fach et al. (2004) created a database of typical WIG vehicle specifications up until 2004. The database is extended with recent built WIG vehicles (2004-2017). The database with WIG vehicle specifications is presented in table 4.8.1.

The WSH-500 and Aron M80 are selected to base to profitability study on. The vehicles scored good on the first requirement. The WSH-500 has an estimated permissible wave height of 1.4m. The Aron M80 has an estimated permissible wave height of 1.2m. The vehicles also have varying passenger capacities of 8 and 50 people. The displacement/power ratio of the WSH-500 is 9 kg/kW. The displacement/power ratio of the Aron M80 is 6 kg/kW. Notable is that the ratio of the Aron M80 does not meet the requirement. It is assumed that requirement 1 is of more importance than requirement 3. Considering that the Aron M80 scores well on the first requirement, it is included in the selection.

# 5 Cost of concepts

The costs of the concepts are estimated and presented in this chapter from the perspective of an operator. There are three main costs: capital, operating and voyage. This chapter focuses on the modifiable variables that could to reduce the cost of the WIG vehicles.

## 5.1 Methodology

A good cost estimation of the concepts is essential for the profitability study. The costs of the concepts is estimated by making use of both ship and aircraft cost estimation theory, due to the knowledge that WIG vehicles are a combination of ship and aircraft. The methodology is as follows: First, the selling price of the concepts is estimated. Thereafter, each cost is described, estimated and presented.

The costs are divided into capital, operating and voyage. Capital cost arises during the purchase of the vehicle, (i.e. it is the cost needed to bring the vehicle to an operating status). Operating costs are the ongoing expenses connected with the day-to-day running of a vehicle. This includes an allowance for manning, insurance and maintenance cost. Voyage costs are variable costs associated with a voyage. The cost structure is illustrated in figure 5.1.1. A difference is made in time dependent cost and voyage cost.

*Table 5.1.1 Cost structure (own work)*

| **Capital cost** | **Operating cost** | **Voyage cost** |
|---|---|---|
| *Time dependent cost* | *Time dependent cost* | *Voyage dependent cost* |
| Financing cost | Manning cost | Fuel cost |
| | Maintenance cost | Port cost |
| | Insurance cost | Administration cost |

## 5.2 Minimum selling price

A variable which has a significant influence on the capital cost is the price for which the vehicles are acquired. This is the price at which a vehicle is sold, by the producer, to the operator. In this cost estimation, it is assumed that the price for which the vehicles can be acquired is equal to the minimum selling price of a WIG vehicle producer, when 30 vehicles are produced. In this section, the minimum selling price of each vehicle is estimated and presented from the perspective of the producer.

As there are currently no methods available to estimate the minimum selling price of WIG vehicles, chosen is to estimate the minimum selling price of the concepts by using a general aviation estimation method. This minimum selling price estimation method is made by Gudmundsson (Gudmundsson, 2013). It can be used because the systems of general aviation vehicles and WIG vehicles (such as: hull, wings, engines) are, at a certain level, comparable.

It can be assumed that the number of units produced is approximately 30. The reason behind this number is that it represents 3 routes, with a fleet of 10 WIG vehicles. It is likely that this number may need adjusting in the profitability analysis.

The variables determining the minimum selling price are shown in table 5.2.1. Striking variables take shape in the number of units produced, number of prototypes and the rate of manufacturing. It can be assumed that the number of prototypes is seven. This is the same number of prototypes as is used to design the Burevestnik-24. Of the Aron M80 and WSH-500, the number of prototypes is unknown.

The used rates for engineering, tooling and manufacturing are standard rates stated in the book of Gudmundsson (2013). Rates for engineering, tooling and manufacturing are respectively 116, 79 and 69€/h.

*Table 5.2.1 Variables influencing the minimum selling price (own work)*

| **Variable** | **Aron M80** | **WSH-500** |
|---|---|---|
| Weight structural airframe [kg] | 1534 | 7746 |
| Power [kW] | 560 | 2000 |
| Speed [km/h] | 185 | 185 |
| Material [-] | Composite | Aluminum |
| Diameter propeller [m] | 2 | 2 |
| Number of propellers [-] | 1 | 2 |
| Number of units produced [-] | 30 | 30 |
| Number of prototypes [-] | 7 | 7 |
| Rate engineering [€/h] | 116 | 116 |
| Rate tooling [€/h] | 79 | 79 |
| Rate manufacturing [€/h] | 69 | 69 |

*Table 5.2.2 Minimum selling price estimation (own work)*

| | **Aron M80** | **WSH-500** |
|---|---|---|
| Selling price [€] | 4 200 000 | 12 700 000 |

The minimum selling price is defined by the total cost to produce a number of vehicles. The total costs are split in fixed cost and variable cost. The certification cost, consisting of engineering, development flight test operations and tooling cost, are fixed. The manufacturing, quality control and material costs are variable; they are dependent on the number of units produced. A quantity discount factor is used for the separate components. This means that is assumed that discount is obtained because a high number of components is bought.

The estimated minimum selling price is shown in table 5.2.2. The formulas and symbols used to calculate the minimum selling price are listed in appendix 11.1. The estimation is referenced from the book, "*Aircraft cost analysis*", *(2013)*.

In table 5.2.3 and 5.2.4, the minimum selling price analysis of the Aron M80 and the WSH-500 is shown. This information shows that the Aron M80 and the WSH-500 are respectively €2 294 698 and €7 036 122, assuming that 100 units are produced in 5 years.

*Table 5.2.3 Minimum selling price analysis of Aron M80 (Gudmundsson (2013) & own work)*

| | **Man-hours** | **Rate, €/h** | **Total Cost** | **Cost per unit** | |
|---|---|---|---|---|---|
| Engineering | 128319 | 116 | € 34 165 050 | € 341 650 | |
| Development support | | | € 1 238 467 | € 12 385 | |
| Flight test operations | | | € 427 009 | € 4 270 | |
| Tooling | 54238 | 79 | € 9 787 831 | € 97 878 | |
| **Certification Cost** | | | **€ 45 618 356** | | |
| Manufacturing labor | 806686 | 69 | € 126 482 356 | € 1 264 824 | |
| Quality control | | | € 24 664 059 | € 246 641 | |
| Materials/equipment | | | € 4 979 052 | € 49 791 | |
| Units produced in 5 years | | | | | **100** |
| Quantity Discount Factor | | | | | 0.7105 |
| | | | | **Without QDF** | **With QDF** |
| Fixed landing gear discount | | | | -€ 7 500 | -€ 5 329 |
| Engine | | | | € 308 936 | € 219 495 |
| Propeller | | | | € 3 428 | € 2 436 |
| Avionics | | | | € 15 000 | € 10 657 |
| **TOTAL COST TO PRODUCE** | | | | **€ 2 337 302** | **€ 2 244 698** |
| Manufacturer's liability insurance | | | | | € 50 000 |
| **MINIMUM SELLING PRICE** | | | | | **€ 2 294 698** |

*Table 5.2.4 Minimum selling price analysis of WSH-500 (Gudmundsson (2013) & own work)*

| | **Man-hours** | **Rate, €/h** | **Total Cost** | **Cost per unit** | |
|---|---|---|---|---|---|
| Engineering | 230959 | 116 | € 61 493 146 | € 614 931 | |
| Development support | | | € 5 091 269 | € 50 913 | |
| Flight test operations | | | € 2 793 913 | € 27 939 | |
| Tooling | 186893 | 79 | € 33 726 651 | € 337 267 | |
| **Certification Cost** | | | **€ 103 104 979** | | |
| Manufacturing labor | 2673703 | 69 | € 419 216 723 | € 4 192 167 | |
| Quality control | | | € 81 747 261 | € 817 473 | |
| Materials/equipment | | | € 15 194 603 | € 151 946 | |
| Units produced in 5 years | | | | | **100** |
| Quantity Discount Factor | | | | | 0.7105 |
| | | | | **Without QDF** | **With QDF** |
| Fixed landing gear discount | | | | -€ 7 500 | -€ 5 329 |
| Engine | | | | € 1 102 461 | € 783 286 |
| Propeller | | | | € 6 856 | € 4 871 |
| Avionics | | | | € 15 000 | € 10 657 |
| **TOTAL COST TO PRODUCE** | | | | **€ 7 309 453** | **€ 6 986 122** |
| Manufacturer's liability insurance | | | | | € 50 000 |
| **MINIMUM SELLING PRICE** | | | | | **€ 7 036 122** |

The minimum selling price of the Aron M80 and the WSH-500 versus the number of units produced, is plotted in figure 5.2.1. If 30 vehicles are produced, the minimum selling prices of the Aron M80 and the WSH-500 are respectively €4 200 000 and €12 700 000.

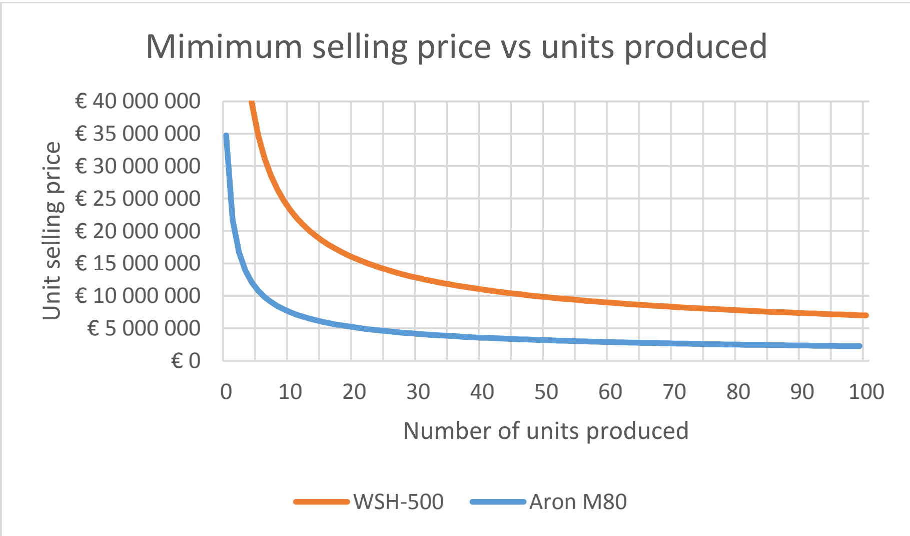


*Figure 5.2.1 Minimum selling price vs units produced Aron M80 (own work)*

In figure 5.2.2 and 5.2.3 are break-even analyses shown for several units produced ranging from 0 to 100. Different price settings are used to analyze the break-even point. The intersections of the revenue with the fixed+variable cost, mark the break-even points for each maintained price. A clear difference of the fixed cost and the variable cost is shown in the figures.

The fixed and variable costs of the Aron M80 are estimated by comparing the vehicle with a single engine composite general aviation aircraft. The fixed and variable costs of the WSH-500 are estimated by comparing the vehicle with a double engine aluminum general aviation aircraft.

The model behind the break-even analyses is as follows:

$$TR = P * N$$

$$TC = FC + VC = FC + C * N$$

Break-even:

$$TR = TC$$

$$P * N = FC + C * N$$

$$N = \frac{FC}{P - C}$$

The symbols are as follows: TR = total revenue [€], P = price [€], N = number of units produced [-], TC = total cost [€], FC = fixed cost [€], VC = variable cost [€], C = cost of manufacturing, quality control and material [€].

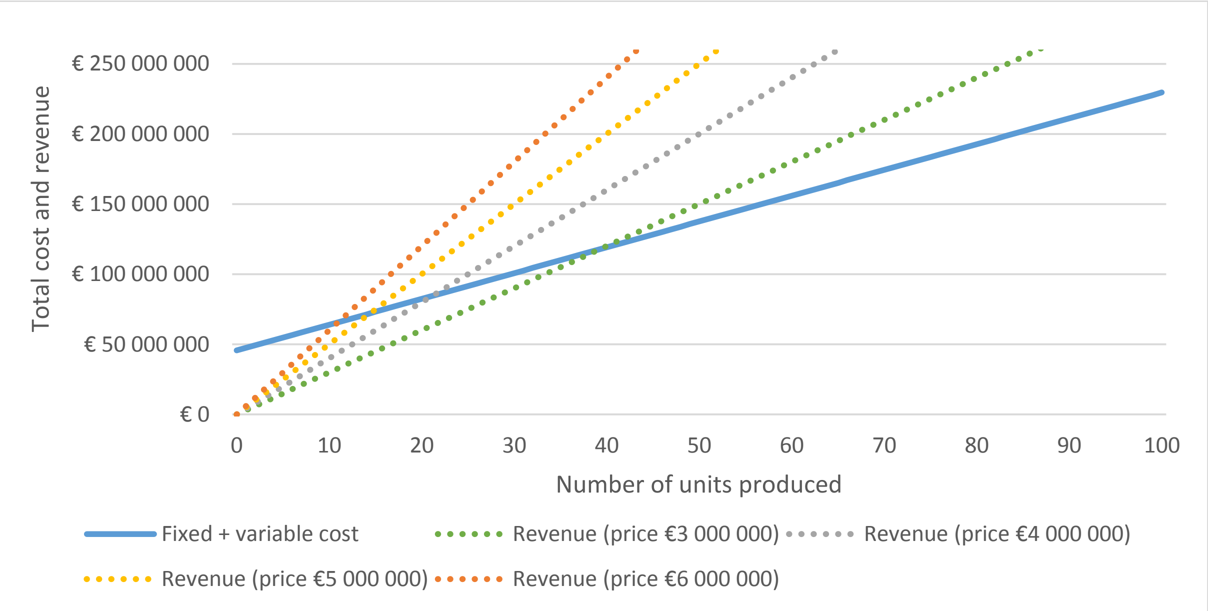


*Figure 5.2.2 Break-even analysis of Aron M80 for different price settings (own work)*

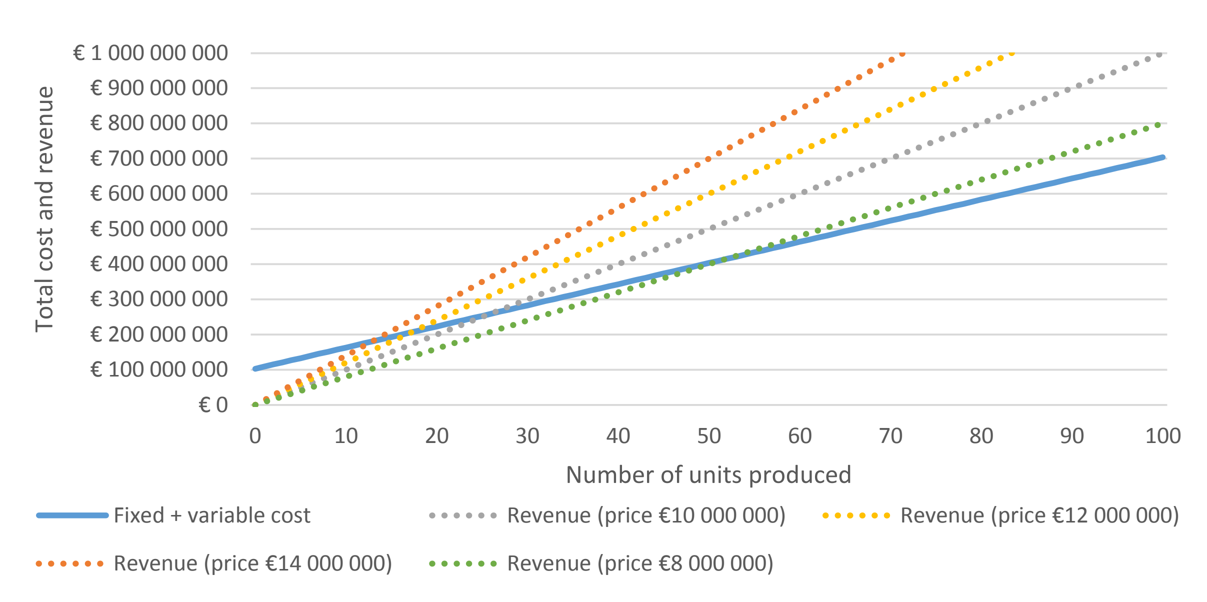


*Figure 5.2.3 Break-even analysis of WSH-500 for different price settings (own work)*

### 5.2.1 Possible options to reduce minimum selling price

The minimum selling price of the vehicles can be lowered by reducing the fixed and variable costs. It is interesting to reduce the variable cost by lowering the manufacturing rates. Or, alternatively, produce more units to lower the amount of fixed cost per unit.

Transferring the manufacturing of the concepts to a country with lower manufacturing rates can be beneficiary for the minimum selling price. The minimum selling price is for 60% dependent on the cost of manufacturing. The cost of manufacturing is directly dependent on the manufacturing rate. A 50% reduction of the manufacturing rate would induce a 30% reduction in minimum selling price.

Figure 5.2.1 shows that the minimum selling price of the concepts is reduced when more units are produced. Given the inversely proportional relationship, it is clear that a high number of units produced is preferable. This relation also indicates that for a smaller number of units produced, the Aron M80 is preferable above the WSH-500, as the slope of the Aron M80 curve is lower.

## 5.3 Capital cost

The capital costs of the vehicles are estimated and presented in this section. It consists out of the financing cost and is strongly dependent on the purchase price of the concepts.

Table 5.3.1 shows the estimation of the capital cost of the vehicles presented.

*Table 5.3.1 Capital cost estimation (own work)*

| Cost | Aron M80 | WSH-500 |
|---|---|---|
| Financing cost [€/y] | 244 000 | 739 000 |
| **Capital cost [€/y]** | **244 000** | **739 000** |

### 5.3.1 Financing cost

The financing cost is, in this research, defined as the cost of loan repayment (interest included).

The financing cost and determining variables are shown in table 5.3.2. The loan duration equals the assumed economic lifetime of the vehicle over 20 years. Assumed is that the size of the loan is, in this case, 80% of the purchase price as it is a standard equity debt ratio in the maritime industry.

Furthermore, the interest rate is assumed to be 0.33% per month as this equals a compounded interest rate of 4%. The total amount paid over 20 years is respectively €5 200 000 and €16 300 000.

*Table 5.3.2 Variables influencing financing cost (own work)*

| Variable | Aron M80 | WSH-500 |
|---|---|---|
| Loan duration [y] | 20 | 20 |
| Purchase price [€] | 4 200 000 | 12 700 000 |
| Size loan [in % of purchase price] | 80 | 80 |
| Interest rate per month [%] | 0.33 | 0.33 |
| Financing cost [€/y] | 244 000 | 739 000 |

The used formula to estimate the financing cost is as follows:

$$Financing\ cost = \frac{12 * i * Purchase\ price * 0.8}{1 - 1/(1+i)^n}$$

### 5.3.2 Possible options to reduce capital cost

The capital costs of the vehicles can be lowered by reducing the financing costs. It is interesting to reduce the purchase price or the interest rate, because these variables have a big influence. The purchase price can for example be reduced by moving the manufacturing of the vehicles to a country with lower manufacturing rates. The capital cost can also be reduced by ordering more vehicles, and thus lowering the price for which the vehicles can be acquired.

## 5.4 Operating cost

The operating costs of the Aron M80 and the WSH-500 are estimated and presented in this paragraph. They consist out of the manning, maintenance and insurance costs. This is estimated through making use of the cost estimation method of Gudmundsson (2013), and by using maritime data of Drewry shipping consultants (2014).Table 5.4.1 shows the operating costs of the vehicles presented.

*Table 5.4.1 Operating cost estimation (own work)*

| Cost | Aron M80 | WSH-500 |
|---|---|---|
| Manning cost [€/y] | 120 000 | 144 000 |
| Maintenance cost [€/y] | 45 000 | 260 000 |
| Insurance cost [€/y] | 126 000 | 381 000 |
| **Operating cost [€/y]** | **291 000** | **785 000** |

### 5.4.1 Manning cost

The manning costs of the vehicles are based on the variables: number of captains, number of stewards and according salaries. These variables are shown in table 5.4.2. The salaries are estimated by using data of Drewry shipping consultants (2014). The number of captains of the concepts are given by the fact sheets of the Aron M80 and the WSH-500 (Fischer & Zagklis, WSH-500, 2013) & (Aron, 2018). The number of stewards is based on the number of stewards available on similar sized aircrafts (the Cessna 402C and the Dornier 328-300JET). (Gudmundsson, 2013)

*Table 5.4.2 Variables influencing manning cost (own work)*

| Variable | Aron M80 | WSH-500 |
|---|---|---|
| Number of captains/engineers | 2 | 2 |
| Number of stewards | 0 | 1 |
| Monthly salary captain/engineer [€/month] | 5 000 | 5 000 |
| Monthly salary steward [€/month] | 2 000 | 2 000 |

Table 5.4.1 shows the estimation of the manning costs of the vehicles presented.

*Table 5.4.3 Manning cost estimation (own work)*

| Cost | Aron M80 | WSH-500 |
|---|---|---|
| Manning cost [€/y] | 120 000 | 144 000 |

### 5.4.2 Maintenance cost

The maintenance costs of the vehicles are estimated by using the operational cost estimation theory of Gudmundsson (2013). He states that the maintenance cost can be derived by the ratio of maintenance hours per flight hour.

The variables that determine the maintenance cost are noted in table 5.4.4. The ratio of maintenance man-hours to flight hours, is dependent on the size of the vehicle. The Aron is compared to a small general-aviation jet, and the WSH-500 is compared to a medium-sized business jet. It is assumed that no complex avionics are installed. The engine overhaul costs are defined by the number of engines, times the number of flight hours x 5. The standard rate of an airframe and power plant mechanical engineer is stated by Gudmundsson. The number of flight hours is estimated as follows:

$$4.5\ hours\ per\ day * 350\ days = 1575\ hours\ per\ year$$

*Table 5.4.4 Variables influencing maintenance cost (own work)*

| Variable | Aron M80 | WSH-500 |
|---|---|---|
| Ratio of maintenance man-hours to flight hours [-] | 0.3 | 2.0 |
| Rate for a certified airframe and power plant mechanic [€/h] | 78 | 78 |
| Number of flight hours [h/y] | 1575 | 1575 |
| Engine overhaul cost [€/y] | 6 500 | 13 000 |
| Number of engines [-] | 1 | 2 |

Table 5.4.5 shows the estimation of the maintenance costs of the vehicles presented.

*Table 5.4.5 Maintenance cost estimation (own work)*

| Cost | Aron M80 | WSH-500 |
|---|---|---|
| Maintenance cost [€/y] | 45 000 | 260 000 |

### 5.4.3 Insurance cost

The insurance costs of the vehicles are estimated by using the general aviation cost estimation theory of Gudmundsson (2013). This estimation method is used because the price and operating maneuvers of WIG vehicles are similar to those of general aviation aircrafts.

In table 5.4.6, the variables that determine the insurance cost are shown. Gudmundsson states that for general aircraft a standard ratio of 1.5 % of the insured value can be used to estimate the insurance cost per year. He argues further that the insurance cost can differ a lot and that it is strongly dependent on the flight experience. Assumed is that the insurance rate for a WIG vehicle is 3% because there currently is no WIG flight experience.

*Table 5.4.6 Variables influencing insurance cost (own work)*

| Variable | Aron M80 | WSH-500 |
|---|---|---|
| Insured value of vehicle [€] | 4 200 000 | 12 700 000 |
| Insurance ratio [%] | 3 | 3 |

Table 5.4.7 shows the estimation of the insurance cost of the concepts presented.

*Table 5.4.7 Insurance cost estimation (own work)*

| Cost | Aron M80 | WSH-500 |
|---|---|---|
| Insurance cost [€/y] | 126 000 | 381 000 |

### 5.4.4 Possible options to reduce operating cost

The operating costs of the vehicles can be reduced by reducing the manning, maintenance and/or insurance cost. It is, in particular, interesting to reduce the insurance cost. The insurance cost is dependent on the selling price and an insurance rate and both variables can be reduced. The insurance rate is likely to decrease over time when no accidents occur.

A reduction in manning or reducing maintenance cost is not recommended. This could have a negative effect on the occurrence of accidents.

## 5.5 Voyage cost

The voyage costs of the vehicles are estimated and presented in this subsection. The costs are made up of the fuel, port and administration costs. This is estimated by making use of the cost estimation method of Gudmundsson and by using maritime data of Drewry shipping consultants.

Table 5.5.1 shows an estimation of the voyage costs of the vehicles presented.

*Table 5.5.1 Voyage cost estimation (own work)*

| Cost | Aron M80 | WSH-500 |
|---|---|---|
| Fuel cost [€/y] | 98 000 | 351 000 |
| Port cost [€/y] | 53 000 | 120 000 |
| Administration cost [€/y] | 18 000 | 18 000 |
| **Voyage cost [€/y]** | **169 000** | **489 000** |

### 5.5.1 Fuel cost

The fuel costs of the vehicles are estimated by using the cost estimation theory of Gudmundsson (2013). The fuel cost is dependent on the specifications of the concepts.

Table 5.5.2 shows the variables which determine the fuel cost. The striking assumption is that cruising power is determined to be 60% of the total power. The price of fuel is taken as the price of kerosene on 15 June 15, 2018. This price is 715 $/mt. This equals 0.93 euro/kg kerosene.

*Table 5.5.2 Variables influencing fuel cost (own work)*

| Variable | Aron M80 | WSH-500 |
|---|---|---|
| Typical power during cruise [kW] | 336 | 1200 |
| Typical specific fuel consumption during cruise [kg/kW] | 0.20 | 0.20 |
| Price of fuel [€/kg] | 0.93 | 0.93 |
| Number of flight hours [h/y] | 1575 | 1575 |

Table 5.5.3 shows the estimation of the fuel costs of the vehicles presented.

*Table 5.5.3 Fuel cost estimation (own work)*

| Cost | Aron M80 | WSH-500 |
|---|---|---|
| Fuel cost [€/y] | 98 000 | 351 000 |

### 5.5.2 Port cost

The port costs of the vehicles consist out of the quay cost, port charges and the cost of storing the vehicles. The costs are estimated by using the quay costs of the port of Rotterdam as benchmark and the cost of renting a hangar of which a standard rate is given by Gudmundsson (2013).

In table 5.5.4, the variables which determine the port cost are demonstrated. The quay costs of the port of Rotterdam are 3,13 €/m/24h (Port of Rotterdam, 2018). Assumed here is that the port charges for the Aron M80 and the WSH-500, are €20 and €45 per trip. Typical hangar costs are stated in the book of Gudmundsson; a typical hangar cost for a small and medium sized jet are € 26 000 and € 61 000 per year.

*Table 5.5.4 Variables influencing port cost (own work)*

| Variable | Aron M80 | WSH-500 |
|---|---|---|
| Quay costs [€/m/24h] | 3.13 | 3.13 |
| Port charges [€/y] | 32 000 | 71 000 |
| Hangar [€/y] | 26 000 | 61 000 |

Table 5.5.5 shows the estimation of the port cost of the concepts given. The port cost consists out of the quay cost, the port charges and the cost to rent a hangar.

*Table 5.5.5 Port cost estimation (own work)*

| Cost | Aron M80 | WSH-500 |
|---|---|---|
| Port cost [€/y] | 70 000 | 158 000 |

### 5.5.3 Administration cost

The administration costs are the overhead costs. These costs are dependent on the number of employees and the fleet size.

Table 5.5.4 shows the variables which determine the administration cost. Assumed is that four employees are required. Assumed is that the salary of an employee is equal to that of a first engineer (Drewry shipping consultants, 2014).

*Table 5.5.6 Variables influencing administration cost (own work)*

| Variable | Aron M80 | WSH-500 |
|---|---|---|
| Number of employees required | 4 | 4 |
| Monthly salary employee [€/month] | 3000 | 3000 |
| Fleet size | 10 | 10 |

Table 5.5.7 shows the estimation of the administration cost of the concepts given.

*Table 5.5.7 Administration cost estimation (own work)*

| Cost | Aron M80 | WSH-500 |
|---|---|---|
| Administration cost [€/y] | 18 000 | 18 000 |

### 5.5.4 Possible options to reduce voyage cost

The voyage costs of the vehicles can be lowered by reducing fuel or port costs. A reduction in fuel cost could, for example, be achieved by developing a more fuel-efficient design. Furthermore, port costs could be reduced by making price agreements with ports.

## 5.6 Conclusion

In this chapter, the costs of the Aron M80 and WSH-500 are estimated. The costs are divided into: capital, operating and voyage cost, and each cost is addressed.

A variable of influence on the capital and operating costs is the price for which the vehicles can be acquired. This price is estimated by using a general aviation cost estimation method. The purchase price is dependent on the number of vehicles produced. The purchase prices of the Aron M80 and the WSH-500 are respectively €4 200 000 and €12 700 000 when 30 units are produced.

Capital costs are the costs of financing the concepts. These are the costs of loan repayment and interest. A reduction in the purchase price or interest rate can cause a significant reduction in capital cost. Operating costs are the ongoing expenses connected with the day-to-day running of a vehicle. It consists out of manning, insurance and maintenance cost. It can be interesting to reduce the insurance cost of the vehicles because of their large contribution to the operating cost. Voyage costs are variable costs associated with the annual voyages. The voyage costs consist out of the fuel, port and administration cost. The fuel costs can, for example, be reduced by developing fuel efficient designs.

The capital, operating and voyage cost of the Aron M80 and the WSH-500 are estimated. The costs are shown in table 5.6.1.

*Table 5.6.1 Total cost of concepts (own work)*

| Cost | Aron M80 | WSH-500 |
|---|---|---|
| Financing cost [€/y] | 244 000 | 739 000 |
| **Capital cost [€/y]** | **244 000** | **739 000** |
| | | |
| Manning cost [€/y] | 120 000 | 144 000 |
| Maintenance cost [€/y] | 45 000 | 260 000 |
| Insurance cost [€/y] | 126 000 | 381 000 |
| **Operating cost [€/y]** | **291 000** | **785 000** |
| | | |
| Fuel cost [€/y] | 98 000 | 351 000 |
| Port cost [€/y] | 53 000 | 120 000 |
| Administration cost [€/y] | 18 000 | 18 000 |
| **Voyage cost [€/y]** | **169 000** | **466 000** |
| **TOTAL COST [€/y]** | **721 000** | **2 051 000** |

# 6 Potential demand

It is meaningful to base the profitability study on routes with a high potential demand for WIG transport. This ensures that the profitability is tested in a favorable environment. This chapter will explore the potential demand for WIG transport on a number of routes, comparing three key aspects: number of passengers, seakeeping operability and distance range. The most suitable routes for profitable WIG transport are selected and investigated. The potential demand of these routes is assessed in more detail.

## 6.1 Methodology

The methodology to make a sound comparison of the potential demand of a selection of routes is described below.

Firstly, the economic theory behind demand is assessed. This theory explains what a "demand function" is and gives two supply and demand functions focused on public transport. It paints the picture of how demand functions for transport normally look. Secondly, the most suitable routes for profitable WIG transport are selected. The routes are selected on having the combination of a high number of passengers, a high seakeeping operability and a distance ranging between 50 and 350 km. The demand of these selected routes is assessed for better understanding of the market. This is done by fitting demand curves to passenger and price data; the demand functions are derived from the curves. The trend of the demand curves of transport correspond to demand curves focused on public transportation. Finally, the potential demand for WIG transport on the selected routes is estimated by using the demand functions. These functions are mainly based on the price paid for the transport and the number of passengers. It is likely that there are more factors determining the potential demand. These other potential influential factors are described.

## 6.2 Known and unknown market space

The future market of WIG vehicle transport is likely to be divided in a 'known' and 'unknown' part of the market space. This section will provide a breakdown of what both parts represent and why the potential demand for WIG transport can be estimated by using data of the known market space.

Chan Kim & Manborgne (2004) describe the known and unknown market space with the terms "red ocean" and "blue ocean". Red oceans are all the industries in existence today – the known market space. Blue oceans, in contrast, denote all the industries not in existence today – the unknown market space, untainted by competition. In their book they argue that a company with a blue market strategy creates and captures uncontested market space, thereby making the competition irrelevant and creating value for the company, its buyers and employees. This is however only valid when the company is the first entrant and gains competitive advantage through control of resources.

WIG vehicles can operate in both red or blue oceans. They can operate in a red ocean as a substitute for other transportation methods. They can also operate in blue oceans due to their unique speed and range specifications. In a blue ocean, for example, it can fulfill a demand for faster transport, or it can fill the void for routes with no transport methods currently offered.

The potential demand for WIG transport is estimated by using data of the known market space. The other methods of transportation can 'potentially' be substituted by WIG transport. This is being done for two reasons: a) it is possible to get data of a known market, b) it is a good way to limit the extent of this research.

The limitations in the data become problematic when analyzing the demand for WIG transportation, as the market may be much larger than the data sample suggests. This potential error margin (in relation to the demand for suitable routes) is explored and estimated in paragraph 6.6.

## 6.3 Supply & demand function of public transport

When the economic theory behind public transport is addressed in literature, it often has a certain standard supply & demand function. Explored below, are two standard supply & demand functions of public transport, described to provide insight in to how the supply & demand function of WIG transport looks.

A “classic” supply & demand function of transport is presented by Rodrique (2017). He describes that many transportation systems are behaving in correspondence to the demand and supply. These systems are influenced by price variations. He argues further that a micro economic theory is applicable on the transport sector. This means for example that if the demand for a transport rises, it’s price will decrease. (Rodrique, 2017)

Shown in figure 6.3.1, is the classic supply & demand curve of transport. The demand curve represents the total quantity of consumers which are willing to be transported at a certain cost. Other influential factors, such as income, quality or reliability, are in this case kept constant. The supply curve represents the quantity of transport which the transport operators are willing to provide at a certain cost. The equilibrium point is the point where the supply and demand curve meet. The quantity and price for which consumers are willing to buy transport is in this case equal to the quantity and price for which providers are offering transport. (Rodrique, 2017)

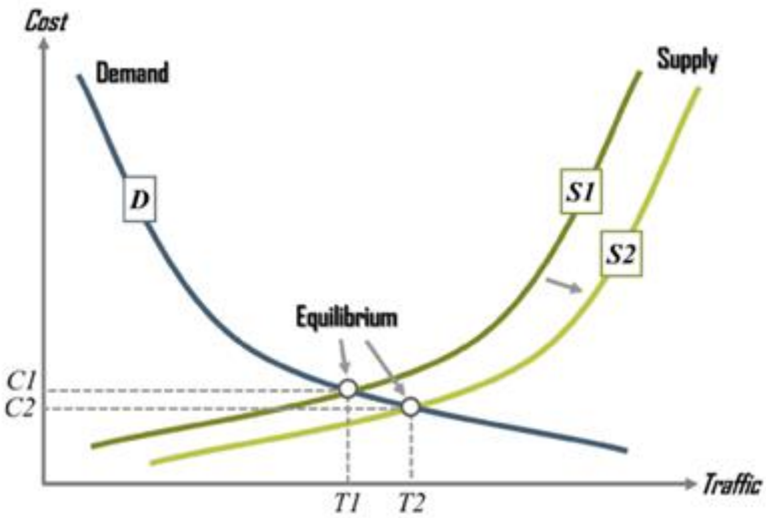


*Figure 6.3.1 Classic supply and demand curve of transport (Rodrique, 2017)*

A supply & demand curve of public transport is described by Lomas (2000). He uses the bus and tram as methods of transportation. Notable in his work, is the notion that public demand is related to, and a result of, flexible and inflexible demand. Passengers which have a flexible demand have the flexibility to choose whether or not to use the public transport. Generally, these passengers are, for example, car or bike owners. In contrast, passengers which have an inflexible demand, do not have such mobility and are obliged to choose the public transport. (Lomas, 2000)

In figure 6.3.2, is the supply and demand curve of public transport drawn by Lomas. The flexible demand is displayed as the green line and the inflexible demand as the purple line. The more expensive transport is more price elastic and the less expensive less price elastic. (Lomas, 2000)

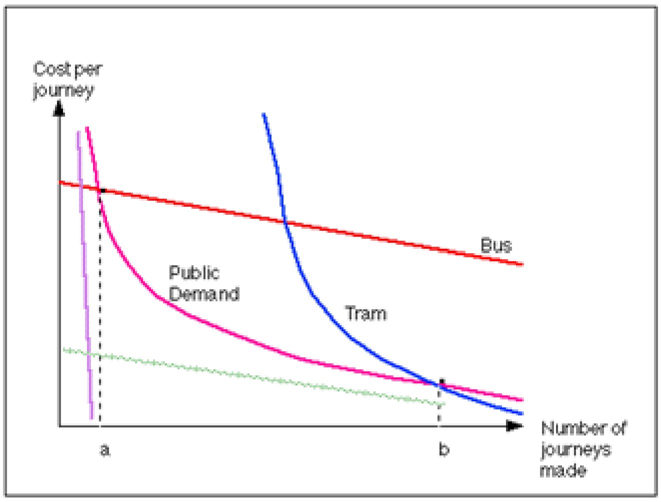


*Figure 6.3.2 Supply and demand curve of public transport (Lomas, 2000)*

It is interesting to see that the demand functions and curves of Rodrique and Lomas have similarities. Both demand curves of public transport have downward slopes. The slopes start steep and decrease as the traffic increases.

## 6.4 Selection of most suitable routes

It is logical to base the profitability study on routes with the highest potential demand for WIG transport. This section will endeavor to identify said routes. The methodology, requirements and output of the selection are presented.

The company RDC Aqualines (2018) illustrates multiple routes which can be suitable for WIG transport based on the distance and population. What is notable is that in their selection criteria the seakeeping operability rate is not taken into account.

In this section are the most suitable routes for WIG transport selected by adding criteria to the analysis of RDC Aqualines (2018). The methodology is as follows: Firstly, requirements for the routes are drafted. Thereafter, is a first selection of suitable routes made by analyzing all of the routes and their performance on the requirements. Thirdly, a set of criteria is drafted to select the best routes of the first selection. Lastly, the most suitable routes are selected by making use of the set of criteria.

A first selection of suitable routes is made based on the following requirements:

- The seakeeping operability rate is higher than 75% when the permissible wave height is 1.5m. (assuming that passengers want transport to be reliable).
- The travelling distance ranges between 50 and 350 km (significant time advantage over other ways of transport).
- There are no regulations limiting the use of high-speed vehicles.
- Transport by WIG vehicle is faster than transport by land.

The first selection of suitable routes for WIG transport is show in table 6.4.1. Differences in seakeeping operability rates and number of passengers are visible.

*Table 6.4.1 First selection: suitable routes for WIG transport (own work)*

| Route | Distance [km] | Seakeeping operability at Hs=1.5 m [%] | Passengers (2017) |
|---|---|---|---|
| Abu Dhabi - Doha | 300 | 91 | 0 (2 335 959 in 2014) |
| Abu Dhabi - Bandar Abbas | 350 | 98 | 22 782 |
| Buenos Aires - Montevideo | 210 | 100 | 2 637 710 |
| Douala – Bata | 245 | 98 | - |
| Helsinki - Tallinn | 80 | 95 | 7 679 485 |
| Istanbul – Varna | 270 | 83 | 73 992 |
| Piraeus - Heraklion | 300 | 75 | 1 094 553 |

The most suitable routes of this selection are selected by making use of the following criteria:

- The number of passengers is as high as possible. This is beneficial for two reasons: a) transporting a small (high end) part of the total number of passengers is likely to be big enough to enable profitable transport, b) there is a lot of data for this research.
- The seakeeping operability rate is as high as possible. This is of the essence as it is proven to be the limiting factor to operate WIG vehicles.
- The route has a distance between 50 to 350 km. WIG transport has, in this distance range, a time advantage over other methods of transportation.

The most suitable routes for WIG transport are: “Buenos Aires-Montevideo” and “Helsinki-Tallinn”. The statistics of these routes are shown in table 6.4.2. The routes have a seakeeping operability rate of 100% and 95% when the permissible wave height is 1.5 m. Both routes have a high number of passengers traveling with all methods of transportation of respectively 2 637 710 & 7 679 485 PAX. The routes have no limiting (speed) regulations.

*Table 6.4.2 Second selection: the most suitable routes for WIG transport (own work)*

| Route | Distance [km] | Seakeeping operability at Hs=1.5 m [%] | Passengers (2017) |
|---|---|---|---|
| Buenos Aires - Montevideo | 210 | 100 | 2 637 710 |
| Helsinki - Tallinn | 80 | 95 | 7 679 485 |

Suitable, but rejected routes, are shown in table 6.4.3. Reasons of rejection are presented in the column on the right.

*Table 6.4.3 Rejected routes for WIG transport (own work)*

| Route | Distance [km] | Seakeeping operability at Hs=1.5 m [%] | Passengers (2017) | Reason of rejection |
|---|---|---|---|---|
| Abu Dhabi - Doha | 300 | 91 | 0 (2 335 959 in 2014) | Transport is restricted due to diplomatic reasons. |
| Abu Dhabi - Bandar Abbas | 350 | 98 | 22 782 | Low number of passengers. |
| Douala – Bata | 245 | 98 | - | No data found. Assuming that there are not enough passengers. |
| Istanbul – Varna | 270 | 83 | 73 992 | Relative low number of passengers and low operability rate. |
| Piraeus - Heraklion | 300 | 75 | 1 094 553 | Relative low operability rate. |

The following sources are used in this section: (Aqualines, 2018), (Medcruise, 2018), (Athens international airport, 2018), (Bussanbud - Hormuz Ferry Service, 2013) & (Knoema, 2018).

## 6.5 Demand for transport on selected routes

The routes “Buenos Aires – Montevideo” & “Helsinki – Tallinn” are proven to be very suitable for WIG transport. It is interesting to investigate and describe the demand for transport on these routes to estimate the potential demand for WIG transport. The demand for transport, as well as the demand functions, curves and statistics of both routes are both presented and explored in this section.

### 6.5.1 Demand for transport on route: Buenos Aires – Montevideo

There are currently three ways of transportation on the route Buenos Aires – Montevideo. These are transport by: aircraft, fast ferry and ferry + bus. Statistics of each transportation method are shown in table 6.5.1. The statistics represent monetary units of 2017. The passengers traveling with a car are deducted from the statistics to make a correct comparison. This means that the passengers presented in the statistics travel without a car.

*Table 6.5.1 Statistics of transport on route: Buenos Aires – Montevideo (own work)*

| | Aircraft | Fast ferry | Ferry + bus | Total |
|---|---|---|---|---|
| Price [€] | 129 | 102 | 46 | |
| Duration [h] | 2.3 | 2.8 | 4.8 | |
| Passengers [PAX/y] | 272 816 | 446 304 | 1 918 590 | **2 637 710** |
| Revenue [€/y] | 35 193 264 | 45 523 008 | 88 255 140 | **168 971 412** |
| Price*duration/distance [€*h/km] | 1.41 | 1.36 | 1.05 | |

A description of each transportation method is given hereafter.

The aircraft takes off from the Jorge Newbery airport (AEP) in Buenos Aires. It lands on the Carrasco international airport (MVD) in Montevideo. The durations of the traveling stages are as follows: terminal 1.5 h, flight 0.8 h. The price of a ticket in 2017 is estimated because the monetary units of the year 2017 are used. Assuming that the price of a ticket in 2017 equals the average price of 4 prices in 2018 and 2019, means that the ticket price is 129 euro. The dates to estimate the average ticket price are: 16-10-18, 16-01-19, 16-04-19, 16-07-19 (Google flights consulted on 1 October 2018). The Carrasco airport statistics of 2014 stated that the annual number of passengers transported was 272 816 in 2014 (Foggia, 2014). Assumed here is that the number of passengers in 2017 is the same as in 2014, because the growth rate in the period 2008-2014 is inconsistent. The revenue of this method of transportation is calculated by multiplying the number of passengers with the ticket price.

The fast ferry (operated by Buquebus) departs from the "Tigre" ferry terminal in Buenos Aires. It arrives at the "Fluvio Maritima" terminal in Montevideo. The durations of the traveling stages are as follows: terminal 0.5 h, sailing 2.3 h. The price of a ticket in 2017 is estimated. Assuming that the price of a ticket in 2017 equals the average price of 5 prices in 2018 and 2019, means that the ticket price is 102 euro. The dates to estimate the average ticket price are: 16-10-18, 16-11-18, 16-12-18, 16-01-19, 16-02-19, (Directferries.com consulted on 1 October 2018). The port of Montevideo states that the number of passengers was 576 752 in the year 2017 (ANP, 2018). It also states that the number of cars transported was 65 224. Assuming that the average number of passengers traveling in a car is 2, gives that 22 % of the fast ferry passengers travel with a car. This means that 446 304 passengers travel without a car. The revenue of this method of transportation is calculated by multiplying the number of passengers with the ticket price.

The ferry and bus (both operated by Colonia Express) depart from the "Tigre" ferry terminal in Buenos Aires. It arrives at the "Colonia del Sacramento" ferry terminal in Colonia del Sacramento. From there a bus departs to Montevideo. The durations of the traveling stages are as follows: terminal 0.5 h, sailing 1.2 h, bus 3.1 h. The price of a ticket in 2017 is estimated. Assuming that the price of a ticket in 2017 equals the average price of 5 prices in 2018 and 2019, means that the ticket price is 46 euro. The dates to estimate the average ticket price are: 16-10-18, 16-11-18, 16-12-18, 16-01-19, 16-02-19, (Directferries.com consulted on 1 October 2018). The port of Montevideo states that the number of passengers was 2 302 628 in the year 2017 (ANP, 2018). It also states that the number of cars transported was 192 019. Assuming that the average number of passengers traveling in a car is 2, gives that 17 % of the passengers travels with a car (Helsinki – Tallinn 16%). This means that 1 918 590 passengers travel without a car. The revenue of this method of transportation is calculated by multiplying the number of passengers with the ticket price.

There is currently no WIG transportation on the route Buenos Aires – Montevideo. The duration of this transportation method would be 1.8 h. It consists of waiting time in the terminal and actual flight time. The waiting time in the terminal can be comparable to that of ferry transport, namely 0.5 h. The duration of such a flight would be 1.3 h with an average speed of 170 km/h.

It is, for this route, valid to compare transport from airport to airport and harbor to harbor with each other, because the locations of the harbors and airports are, with respect to the city centers, comparable. The duration and price of transport from the city centers to the harbors or airports are almost the same using the transportation method taxi.

Figure 6.5.1 is a map of the transportation routes between Buenos Aires and Montevideo shown. The aircraft route and the ferry routes are indicated with different colors.

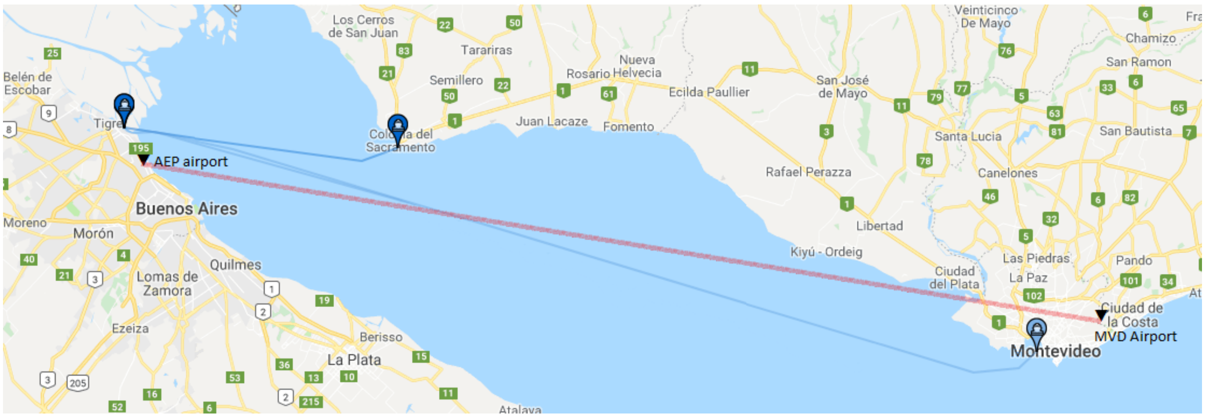


*Figure 6.5.1 Transportation routes (blue = ferry, red = aircraft) (Google maps, 2018)*

In figure 6.5.2, one can find a comparison of the duration of each transportation method. The travel stages of each transportation method are visible. What is notable in the figure is that the waiting time for aircraft transport is relatively long. By comparison, the WIG transport has the shortest duration.

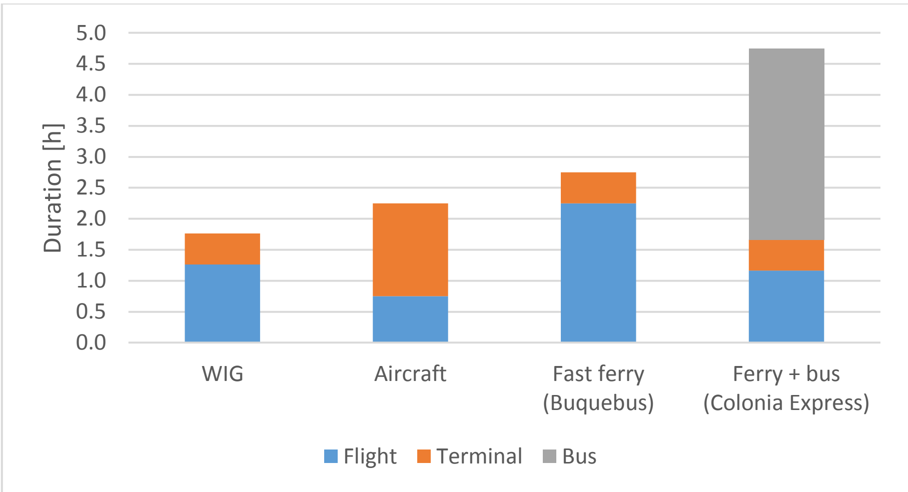


*Figure 6.5.2 Difference in duration of transport per method on route: Buenos Aires – Montevideo (own work)*

The demand function of transport on the route Buenos Aires – Montevideo is estimated by fitting a curve through passenger, ticket price and duration data. The demand function gives insight into the number of passengers of whom buy transport at a certain price. In figure 6.5.3, is demand curve of transport on this route is revealed. The dots represent the equilibrium points where the demand curve meets the supply curves. A trend line (where the slope declines when the passengers increase) is plotted in the figure. This trend line represents the demand curve. The demand function is also shown in the figure. What is notable in this figure is that the demand curve has a similar trend as the demand curves of transport described by Rodrique (2017) and Lomas (2000). What can be seen in the figure is that the transport which has more value is priced higher than the transport with less value. Furthermore, the number of passengers is low at a high price, and high at a low price. It should be noted that there are, of course, more variables determining the demand curve. This is merely a model, an estimate.

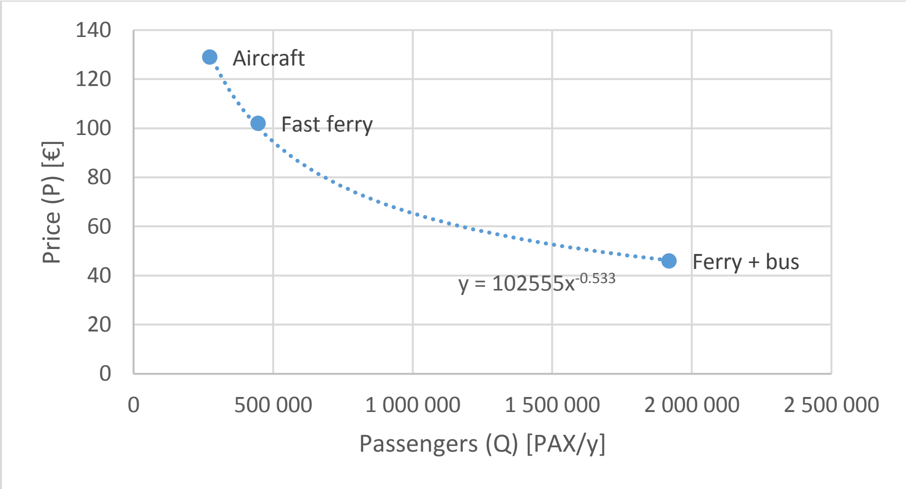


*Figure 6.5.3 Demand curve of transport on route: Buenos Aires – Montevideo (own work)*

Figure 6.5.4 demonstrates the demand multiplied by the duration and divided over the distance. Multiplying the demand by the duration gives insight into how the duration of a method of transportation affects the demand. Dividing the demand over the distance of the route enables the demand/distance ratio to be compared with the demand/distance ratio of other routes. What is striking in this figure is that the difference between the price*duration/distance values of the three points is within 40%. The figure suggests that the willingness of a passenger to choose a certain transport is defined by a fairly constant combination of price and duration. The figure illustrates that there is a high demand for ferry + bus transport. This method of transportation has a favorable price*duration/distance value. It also illustrates that there is a low demand for aircraft transport. This method of transportation has a less favorable price*duration/distance value.

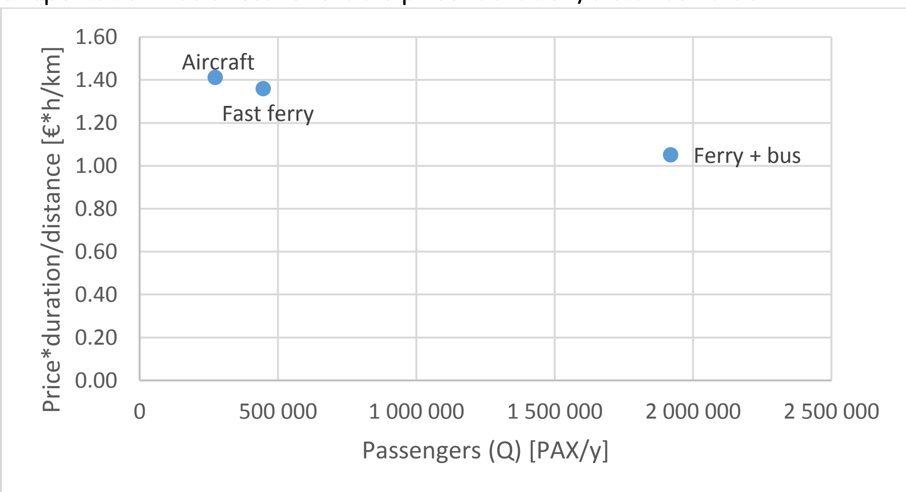


*Figure 6.5.4 Demand made independent of duration and distance of route- Buenos Aires – Montevideo (own work)*

### 6.5.2 Demand for transport on route: Helsinki - Tallinn

There are currently two ways of transportation on the route Helsinki – Tallinn. These are transport by aircraft and ferry. Statistics of each transportation method are shown in table 6.5.2. The statistics represent monetary units of 2017. The passengers traveling with a car are deducted from the statistics to make a correct comparison. This means that the passengers presented in the statistics travel without a car.

*Table 6.5.2 Statistics of transport on route: Helsinki – Tallinn (own work)*

| | Aircraft | Ferry | Total |
|---|---|---|---|
| Price [€] | 113.0 | 28.2 | |
| Duration [h] | 2.8 | 3.0 | |
| Passengers [PAX/y] | 262 285 | 7 417 000 | 7 679 485 |
| Revenue [€/y] | 29 638 160 | 219 923 968 | 249 562 128 |
| Price*duration/ distance [€*h/km] | 3.67 | 0.96 | |

A description of each transportation method is given below.

Aircraft transport between the two cities is available. The durations of the traveling stages are as follows: terminal 1.5 h, flight 0.5 h, taxi Helsinki 0.6 h, taxi Tallinn 0.2 h. The number of passengers using this method of transportation is, however, relatively low. The number of passengers transported in 2012 was 226 249 (City of Helsinki, 2012). With an annual growth rate of 3.0%, this would represent 262 285 passengers in 2017. Assuming that the price of a ticket in 2017 equals the average price of 4 prices in 2018 and 2019, means that the ticket price from Helsinki to Tallinn is 113 euro. The dates to estimate the average non-stop ticket price are: 16-10-18, 16-01-19, 16-04-19, 16-07-19 (Google flights consulted on 1 October 2018).

There are currently three ferry operators active on the route "Helsinki – Tallinn". These are: Tallink Silja, Viking and Ëckero. The price and duration of the transport organized by the ferry operators differentiates by approximately 20%. The method of transportation of these ferries is classified as ferry. The average statistics representing this method of transportation are presented in table 6.5.3. The price of an average ferry ticket in 2017, as shown on the chart, is an estimation. Assuming that the price of a ticket in 2017 equals the average price of 3*5 prices in 2018 and 2019, means that the ticket price is 28.2 euro. The dates to estimate the average ticket price are: 16-10-18, 16-11-18, 16-12-18, 16-01-19, 16-02-19, (Directferries.com consulted on 1 October 2018). The number of passengers is received from the port of Tallinn (Port of Tallinn, 2017). The number of passengers traveling by car (16%) is deducted from the number of passengers (Tapaninen, 2012).

*Table 6.5.3 Statistics of ferry transport on the route: Helsinki – Tallinn (own work)*

| | Ferry Tallink Silja | Ferry Viking | Ferry Ëckero | Total | Average |
|---|---|---|---|---|---|
| Price [€] | 31.5 | 27.5 | 25.5 | | 28.2 |
| Duration [h] | 2.5 | 3.0 | 2.8 | | 2.8 |
| Passengers [PAX/y] | 4 546 026 | 1 754 606 | 1 116 568 | 7 417 200 | |
| Revenue [€/y] | 143 199 813 | 48 251 677 | 28 472 477 | 219 923 968 | |
| Price*duration/ distance [€*h] | 0.98 | 1.03 | 0.88 | | 0.96 |

Currently, there is no WIG transportation on the route Helsinki - Tallinn. The duration of this transportation method would be 1.2 h. It consists of waiting time in the terminal, actual flight time and time in taxis. The waiting time in the terminal can be comparable to that of ferry transport, namely 0.5 h. The duration of such a flight would be 0.5 h with an average speed of 170 km/h. The duration in the two taxis would be 0.2 h.

Figure 6.5.5 denotes a comparison of the duration of each transportation method just mentioned. The differences in the duration of the transportation methods are clearly visible.

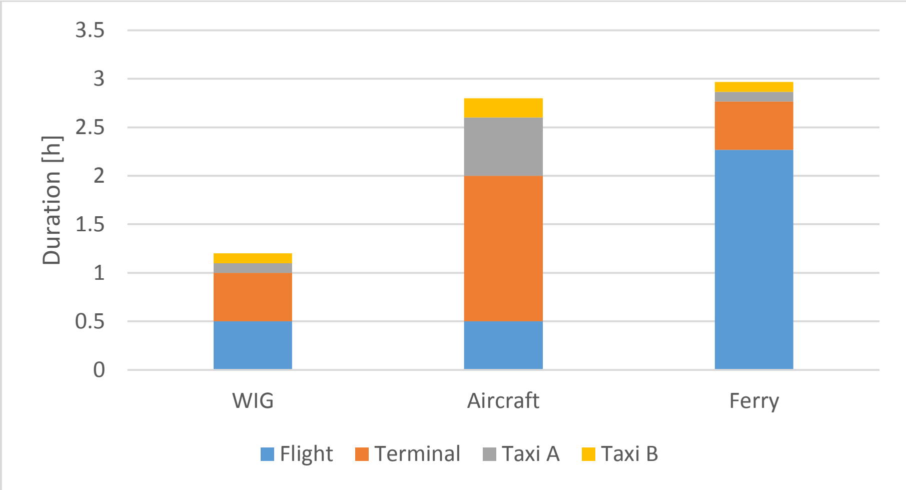


*Figure 6.5.5 Difference in duration of transport per method on route: Helsinki – Tallinn (own work)*

What is notable in table 6.5.3, is that the price*duration/distance value of the ferry transport on this route (0.96 euro*h/km) is almost the same as the price*duration/distance value of the ferry and bus transport on the Buenos Aires – Montevideo route (1.05 euro*h/km). This means that the price and duration per kilometer of transport by ferry in Buenos Aires is similar to that of transport by ferry in Helsinki. The same comparison is visible in other ratios.

For example, the price/duration ratio of the ferry transport on the routes Helsinki – Tallinn (10.07 euro/h) is comparable to the price/duration ratio of Buenos Aires – Montevideo (9.58 euro/h). The price/distance ratio of the ferry transport on the routes Helsinki – Tallinn (0.35 euro/km) is slightly comparable to the price/distance ratio of Buenos Aires – Montevideo (0.21 euro/km).

The demand function of transport, on the route Helsinki – Tallinn, is estimated by fitting a curve through passenger, ticket price and duration data. Figure 6.5.6 shows the demand curve of transport on said route. The dots represent the equilibrium points where the demand curve meets the supply curves. A trend line where the slope declines and the passengers relatively increase, is plotted in the figure—similar to Rodrique (2017) & Lomas (2000). This line represents the demand curve. The demand function is also shown in the figure.

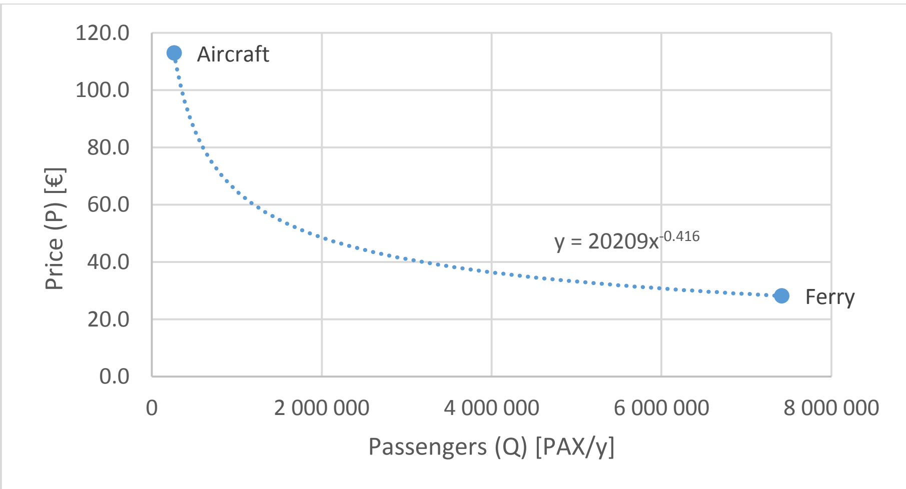


*Figure 6.5.6 Demand curve of transport on route: Helsinki – Tallinn (own work)*

What is noticeable in figure 6.5.6, is the relatively big price difference between aircraft transport and ferry transport. The figure suggests that the price is an important variable influencing the demand. A high price corresponds with a low demand, a low price with a high demand.

The above figure also shows that the number of passengers using aircraft transport is relatively low. There are two main reasons for this trend: a) aircraft transport is relatively expensive, b) the duration of aircraft transport is comparable to that of ferry transport.

It is not useful to plot the demand of transport dependent on the duration and distance on this route. The high price and long duration of aircraft transport mean that the price*duration/distance value is extremely high (3.67 euro*h/km). This value should be near the aircraft price*duration/distance value on the Buenos Aires- Montevideo route (1.41 euro*h/km) as it is the same method of transportation. Plotting a trend line through the obtained data would make no sense. Instead, more data of different transportation methods would be desired in order to make this plot.

## 6.6 Potential demand of most suitable routes

The potential demand for WIG transport on the most suitable routes is estimated now the demand for transport on these routes is known. In this paragraph is the potential demand for WIG transport on the most suitable routes described.

The potential demand functions of WIG transport on the selected routes are in theory described by the demand functions of transport on these routes:

$$\text{Buenos Aires – Montevideo: } P = \frac{102555}{Q^{0.533}}$$

$$\text{Helsinki – Tallinn: } P = \frac{20209}{Q^{0.416}}$$

From what has been evaluated so far, it is clear that the demand for transport is highly influenced by price and duration, alongside a few other potential influential variables. Some key positive and negative factors which affect the potential demand for WIG transport are listed, then explained, below:

- It is likely that potential influential variables such as comfort, sustainability, safety, feeling of safety, reliability, etc. are playing a role. Passengers can choose these 'unknown' variables above the variables price and duration.
- The demand functions will shift and change when a new transportation method is added to the market.
- New demand can be created as result of a blue ocean strategy.
- The price of transportation methods can be adjusted.
- The duration of transportation methods can be adjusted.

The role of potential influential variables such as comfort, sustainability, safety, feeling of safety, reliability, etc. on the potential demand for WIG vehicles is hard to estimate. A wild guess at the impact of these variables on the potential demand, ranges from -100% to +10%. These variables can contribute to success or, just as easily, be the destruction of it. This is illustrated by using two fictitious examples: a) a (deadly) crash has a decimating effect on the feeling of safety (potential demand -100%), b) energy efficient WIG vehicles have a positive impact on the variable sustainability (potential demand +10%). One could imagine that in particular the effect of the low fuel consumption on the sustainability could be a decisive factor in the current social debate. In future research, it would be useful to estimate the effect of other potential influential variables on the potential demand for WIG vehicles, in more detail.

The concept of introducing a new transportation method causes a disruption in the demand curve. Thus, the potential demand for WIG transport is altered. Illustrated in two examples (subparagraphs 6.6.1 & 6.6.2), is the change in the demand curve of transport when the WIG method is added on the Buenos Aires – Montevideo route.

The first example shows that the demand curve of transport hardly changes when a new transportation method is added (it is placed in line with the demand curve and has a market share of 9%). The second example shows that the demand curve of transport becomes totally different when a new transportation method is added (it is placed not in line with the demand curve and has a market share of 76%). It is logical that discrepancies appear when the new transportation method functions as substitute for other methods of transportation and is priced competitively. These discrepancies increase in size when the new transportation method replaces multiple forms of transport and the price remains competitive.

The high-speed transport market on the route Helsinki – Tallinn is an unknown market, a blue ocean. This is ideal for high-speed WIG transport as it can create new demand for transport. A blue ocean strategy can be used to access the new, unknown demand. This influences the potential demand for WIG transport, which is not considered in the demand function. It exposes a certain error margin. An informed guess of the error margin (as a result of a blue ocean strategy on the route Helsinki – Tallinn) ranges between +0% to +20% of the potential demand; this is assuming that a shorter journey duration would increase the number of commuting passengers.. The effect of a blue ocean strategy on the demand for transport on the route Buenos Aires - Montevideo is lower than that on the Helsinki – Tallinn route. Mainly because the reduction in travel duration is lower. This said, there still is an error margin, because there is a reduction in duration. An educated guess of this error margin ranges between 0% to +10%.

Another factor influencing the potential demand for WIG transport is the price of other comparable transportation methods. In this research, these prices are assumed to be constant. Chapter 7 will elaborate on the risk involved with other methods of transportation lowering their prices.

The duration of other methods of transportation is another factor that influences the potential demand for WIG transport. For the purpose of this research, these durations are assumed to be constant. Chapter 7 will elaborate on the risk involved in other methods of transport lowering the duration of the journey time.

### 6.6.1 Example 1: demand including high priced WIG transport

This example demonstrates the WIG transport added to the methods of transportation on the route Buenos Aires - Montevideo. The effect on the demand for transport with and without WIG transport is illustrated. The price of WIG transport is set, relatively high, at 160 euro. Prices of the other methods of transportation and the total number of passengers correspond with the monetary year 2017. The passenger distribution is chosen in such a way that the trend of the demand curve of transport with WIG transport is parallel to the demand curve of transport without WIG transport.

*Table 6.6.1 Statistics of transport incl. WIG on route: Buenos Aires – Montevideo (own work)*

| | **Aircraft** | **Fast ferry** | **Ferry + bus** | **WIG** | **Total** |
|---|---|---|---|---|---|
| Price [€] | 129 | 102 | 46 | 160 | |
| Duration [h] | 2.3 | 2.8 | 4.8 | 1.8 | |
| Passengers [PAX/y] | 245 534 | 379 358 | 1 765 103 | 247 714 | **2 637 710** |
| Revenue [€/y] | 31 673 938 | 38 694 557 | 81 194 729 | 39 634 304 | **191 197 527** |
| Price*duration/distance [€*h/km] | 1.41 | 1.36 | 1.05 | 1.37 | |

The statistics of transport (including WIG transport) are shown in table 6.6.1. The price of WIG transport is set at 160 euro. The duration of this form of transport is estimated to be 1.8 h. The number of passengers transported by this type of vehicle is 247 714 PAX/y. This is 9 % of the total number of passengers. The revenue of WIG transport is almost 40 million euro. The price*duration/distance value is 1.37 euro*h/km. This value is comparable to the values of aircraft and fast ferry transport; this means that the product over value ratios are comparable.

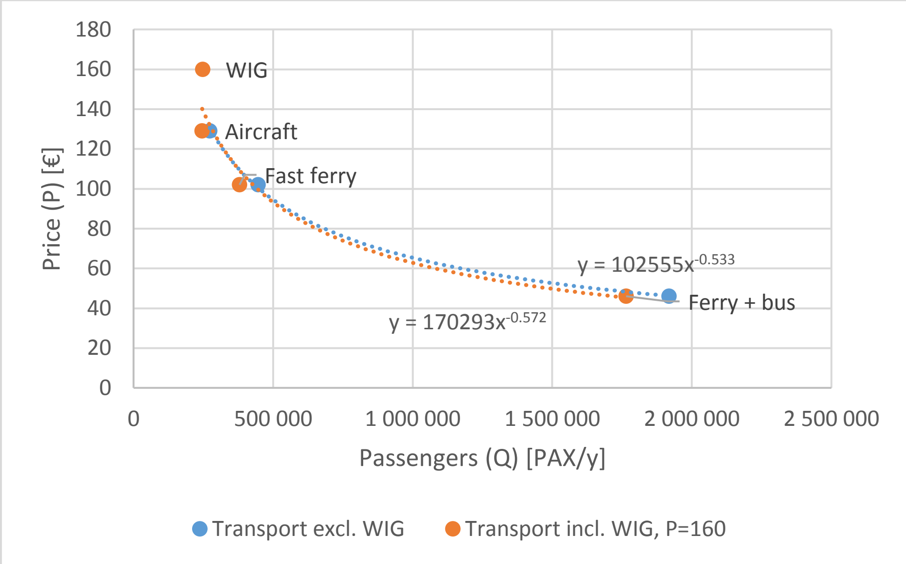


*Figure 6.6.1 Demand curves of transport on route: Buenos Aires – Montevideo (own work)*

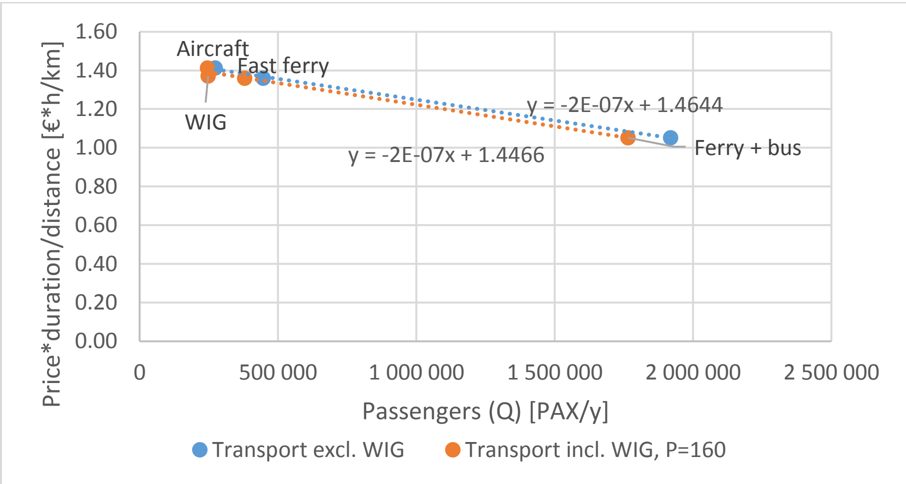


*Figure 6.6.2 Adjusted demand curves of transport on route: Buenos Aires – Montevideo (own work)*

Figure 6.6.1 & 6.6.2 demonstrates the demand curves. What is notable is that the demand curves with and without WIG transport, do not significantly differ from one another. There is a mimicry in the shape of the curve. Noteworthy also, is that the WIG transport is situated in line with the trend of the curves.

It is interesting to calculate the number of WIG vehicles needed to transport the number of passengers, as it gives an insight in the scale. The 250 000 passengers per year can be transported with 30 Aron M80's or 4 WSH-500's. The used values in this calculation are: fullness ratio of 70%, 350 working days, 5 trips/day and a seakeeping operability rate of 100%. The revenue would respectively be 1 300 000 and 10 000 000 euro per vehicle per year.

### 6.6.2 Example 2: demand including low priced WIG transport

This example shows WIG transportation added to a list of available transportation methods on the route, Buenos Aires - Montevideo. The effect on the demand for transport with and without WIG transport is illustrated.

The price of WIG transport is set, relatively low, at 40 euro. Prices of the other methods of transportation and the total number of passengers correspond with the monetary year 2017. The passenger distribution is chosen in such a way that the trend of the demand curve of transport with WIG transport is parallel to the demand curve of transport without WIG transport.

The statistics of transport (including WIG transport) are shown in table 6.6.2. The price of WIG transport is set at 40 euro. The duration of WIG transport is estimated to be 1.8 h. The number of passengers transported by WIG vehicle is 2 007 570 PAX/y. This is 76 % of the total number of passengers. The annual revenue of this form of transport is 80 million euro. The price*duration/distance value is 0.34 euro*h/km. This value is significantly lower than the values of aircraft and ferry + bus transport. This means that the product over value ratios are not comparable.

*Table 6.6.2 Statistics of transport on route: Buenos Aires – Montevideo (own work)*

| | Aircraft | Ferry + bus | WIG | Total |
|---|---|---|---|---|
| Price [€] | 129 | 46 | 40 | |
| Duration [h] | 2.3 | 4.8 | 1.8 | |
| Passengers [PAX/y] | 54 563 | 575 577 | 2 007 570 | **2 637 710** |
| Revenue [€/y] | 7 038 653 | 26 476 542 | 80 302 792 | **113 817 987** |
| Price*duration/distance [€*h/km] | 1.41 | 1.05 | 0.34 | |

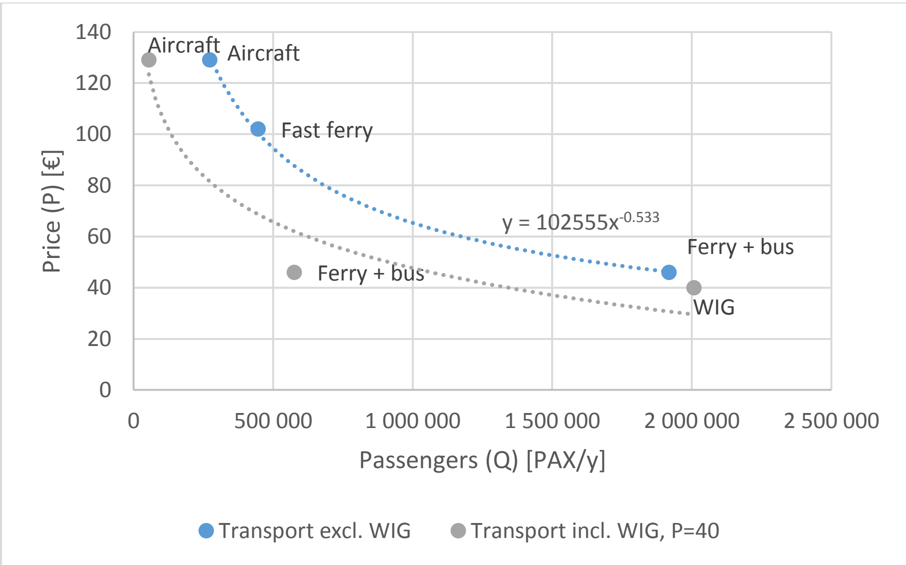


*Figure 6.6.3 Demand curves of transport on route: Buenos Aires – Montevideo (own work)*

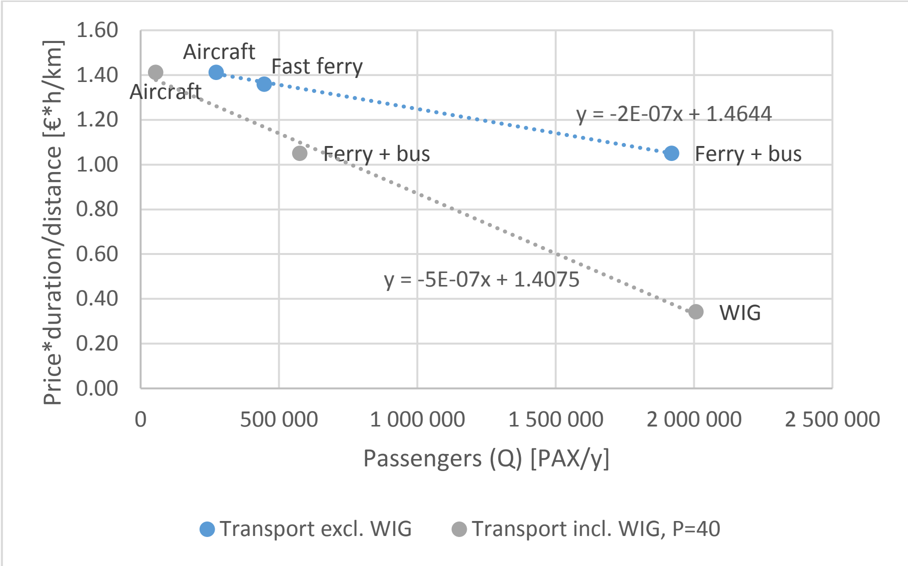


*Figure 6.6.4 Adjusted demand curves of transport on route: Buenos Aires – Montevideo (own work)*

The demand curves are shown In the figures 6.6.3 & 6.6.4. What is notable is that the demand curves with and without WIG transport differ from one another. The demand curve with WIG transport shifted down but kept the same slope. The adjusted demand curve shifted down and the slope of the curve decreased. It is striking that the transportation method fast ferry vanishes when WIG transport is added to the demand curves. What can be assumed, from this example, is that the fast ferry is outcompeted due to the pressure on the price. It means that the number of passengers willing to travel by fast ferry is not sufficient to cover the costs of fast ferry transport. The result of this assumption is that fast ferry transport is not available anymore and all of the passengers (with and without cars) have to choose other transportation methods.

The number of WIG vehicles needed to transport the number of passengers, is calculated to give insight in the scale. The 2 000 000 passengers can be transported with 273 Aron M80's or 34 WSH-500's. The used values for this calculation are: fullness ratio of 70%, 350 working days, 5 trips/day and a seakeeping operability rate of 100%. The revenue would respectively be 300 000 and 2 350 000 euro per vehicle per year.

## 6.7 Conclusion

The goal of this section is to compare, select and define routes with the highest potential demand for WIG transport.  A profitability study can be conducted based on the analysed routes. The routes are compared on the following aspects: number of passengers, seakeeping operability and distance range. The most suitable routes for profitable WIG transport are selected and investigated. The potential demand for these routes is assessed in more detail below.

The requirements to select the most suitable routes are as follows:

- The number of passengers is as high as possible. This is beneficial for two reasons: a) It positively influences the chance that the number of passengers, willing to travel by WIG transport, is high enough to enable profitable transport, b) there is a data of competitors available which is beneficial for this research.
- The seakeeping operability rate is as high as possible. This is proven to be the limiting factor to operate WIG vehicles.
- The route has a distance ranging between 50 to 350 km. In this range there is a time advantage for WIG transport over other methods of transportation.

The most suitable routes for WIG transport are: “Buenos Aires – Montevideo” and “Helsinki – Tallinn”. On the Buenos Aires – Montevideo route, annually there are 2 600 000 passengers transported. A WIG vehicle with a permissible wave height of 1.5 m has, on this route, a seakeeping operability rate of 100%. The distance between the two cities is 210 km. On the Helsinki – Tallinn route there are 7 700 000 passengers transported annually. A WIG vehicle with a permissible wave height of 1.5 m has, on this route, a seakeeping operability rate of 95%. The distance between the two cities is 80 km.

The available methods of transportation on the route Buenos Aires - Montevideo (2017) are: ferry + bus, fast ferry and aircraft. Methods of transportation on the route Helsinki - Tallinn are: ferry and aircraft. Potential WIG transport is, on both routes, faster than the other methods of transportation.

Passenger and price data of the available methods of transportation is used to estimate the demand functions of transport of both routes. This data enables insight in the market. The demand functions are derived from the curves, which are fitted to passenger and price data. Notable is that the trend of the demand curves of transport correspond, as expected, to demand curves focused on public transportation.

The potential demand functions of WIG transport on the selected routes are, in theory, described by the demand functions of transport on these routes:

Buenos Aires – Montevideo: $\mathrm{P} = \frac{102555}{\mathrm{Q}^{0.533}}$

Helsinki – Tallinn: $\mathrm{P} = \frac{20209}{\mathrm{Q}^{0.416}}$

It is clear that the demand for transport is dependent on the price and duration of the transport besides other potential influential variables such as comfort, sustainability, safety, feeling of safety, reliability, etc. It is likely that each of these variables influence the demand for transport. It is a limitation of the demand functions that the potential influential variables are not taken into account. An informed guess of the error margin, as a result of these variables on the potential demand, ranges from -100% to +10%. This is illustrated by using two fictitious examples: a) a (deadly) crash has a decimating effect on the feeling of safety (potential demand -100%), b) energy efficient WIG vehicles have a positive impact on the variable sustainability (potential demand +10%). In future research, it would be useful to estimate the effect of other potential influential variables on the potential demand for WIG vehicles, in more detail.

The demand functions of transport are influenced when a new transportation method is added. The effect of the influence varies per iteration. When the new transportation method is placed in line with the trend and has a relatively small market share, then the influence is rather small. Discrepancies appear when the new transportation method is priced competitively and functions as substitute for other methods of transportation.

A factor influencing the potential demand for WIG transport is that new demand can be created as result of a blue ocean strategy. It is estimated that the error margin, as result of not taking this into account in the demand functions, ranges between +0% and +20%. This is assuming that the shorter duration of WIG transport would increase the number of commuting passengers, as it lowers the threshold to go.

# 7 Profitability analysis

Now that the potential demand for WIG transport is evaluated, the profitability of this form of transport can be estimated. This chapter answers part of the main question of this research: can WIG vehicles, operating as high-speed passenger ferries, be profitable? It does this in two parts. Part one will look at how an operating company can enter the WIG transport market. Part two will examine the profitability of WIG transport, using the following estimations: a free cash flow prognosis, the internal rate of return, the weighted average cost of capital and the net present value.

## 7.1 Methodology

To perform a well-founded profitability analysis, a good method is essential. The methodology of the profitability analysis is described below.

The analysis is conducted from the perspective of a fictive operating company, so that the findings may accurately project the profitability of operating WIG vehicles. Goals, objectives and strategy of the operating company are will be examined in a way that clarifies the motives behind the profitability analysis. A market investigation provides background information that is essential to determine the strategy necessary to enter the WIG transport market. The strategy to enter the WIG transport market is developed and used to create a financial proposal. The profitability of WIG transport is estimated by calculating the: free cash flow prognosis, internal rate of return and net present value. The results of the calculations are presented and described below. A sensitivity study is presented thereafter to analyze the sensitivity of the variables in the results.

## 7.2 Company mission, goals & objectives

As previously mentioned, the profitability analysis is conducted from the perspective of a fictive operating company. To better understand the choices and the motives behind the profitability study, it is important to know what the mission, goals and objectives of the operating company are. This section provides a breakdown of said missions, goals and objectives.

The mission of the operating company is to provide WIG transport, because it believes that there is a market for fast transport, between the speed and distance range of ship, and aircraft-transport. Furthermore, the company believes that WIG transport has the potential to become a sustainable method of transportation in the high-speed segment, because of its high energy efficiency and high lift capacity.

The goal of the operating company is to provide the fastest transport on certain routes. The long-term goal is to provide sustainable, high-speed transport on the same routes. Key objectives to achieve these goals are: a) become a major player in the WIG transport business in 5 years, b) first commercial flight in 4 years, c) first $CO_2$ neutral flight in 10 years.

## 7.3 State of the markets

The routes: Buenos Aires – Montevideo & Helsinki – Tallinn are proven to be most suitable for WIG transport. The state of the current and future transport markets on these routes is examined and described in this section. This information is useful when selecting the best strategy to enter the market. The following aspects are discussed: size of market, growth rate, life cycle, customer segmentation, role of technology and respond of competition.

### 7.3.1 Size of markets

The size of the markets is expressed in total annual revenue. The annual revenue of all transport on both routes is estimated in chapter 6. The annual revenue of the transport market on the route Buenos Aires – Montevideo is 170 million euro (2017). The annual revenue of the transport market on the route Helsinki – Tallinn is 250 million euro (2017).

### 7.3.2 Growth rate

Both markets appear to have a steady growth rate of on average 3-4% over the past 10 years. The transport market on the route Helsinki – Tallinn shows a steady growth rate, were the growth rate of the transport market on the route Buenos Aires – Montevideo fluctuates more. In the future are similar growth rates expected. (Port of Tallinn, 2018) & (ANP, 2018)

### 7.3.3 Stage of development

Both markets have a mature stage of development. Most development takes place in the optimization of transportation methods. The ferries are operative on both routes for over a long period of time. Both markets have seen the upcoming of aircraft transport. What is notable is the introduction of the fastest ferry in the world in 2013, the wave piercing catamaran HSC Fransisco, on the route Buenos Aires – Montevideo. This fast ferry functioned partly as substitute for (fast) aircraft transport on this route and caused a decline in the number of passengers transported by aircraft in the years after the introduction.

### 7.3.4 Passenger segmentation

The customers in the transport market are the passengers. It is the passengers' *reason for travel* which allows a segmentation of customers. The passenger segmentation of both routes is described hereafter.

The passenger segmentation of passengers traveling to Finland is illustrated in figure 7.3.1. Main reasons to travel to visit Finland are 'holiday 35%', 'shopping 23%', 'visiting friends 16%', 'business 14%', 'transit 9%' and 'other reasons 3%'. This gives an indication of the passenger segmentation on the route Helsinki – Tallinn, as more than half of the total 8.3 million passengers to Finland over this route. (Visit Finland, 2018)

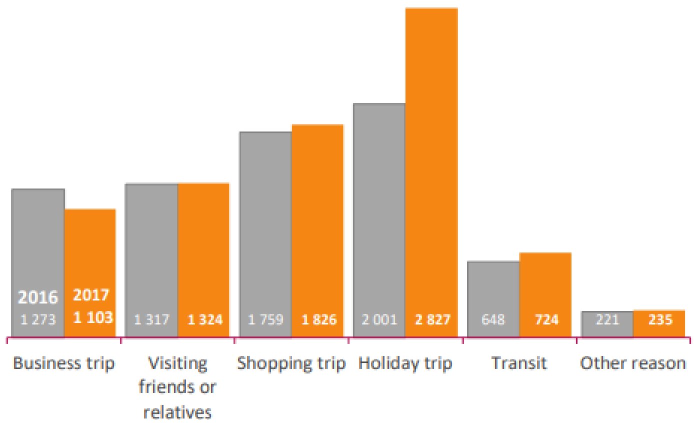


*Figure 7.3.1 Segmentation of reasons to travel to Finland, x1000 trip (Visit Finland, 2018)*

Research by Tapaninen (2012), shows why people travel by air on the route Helsinki – Tallinn. The segmentation of the reasons for travel by air shown on the route Helsinki – Tallinn is illustrated in figure 7.3.2. What is notable in the figure is that most passengers chose to travel by aircraft simply because it takes less time than by sea.

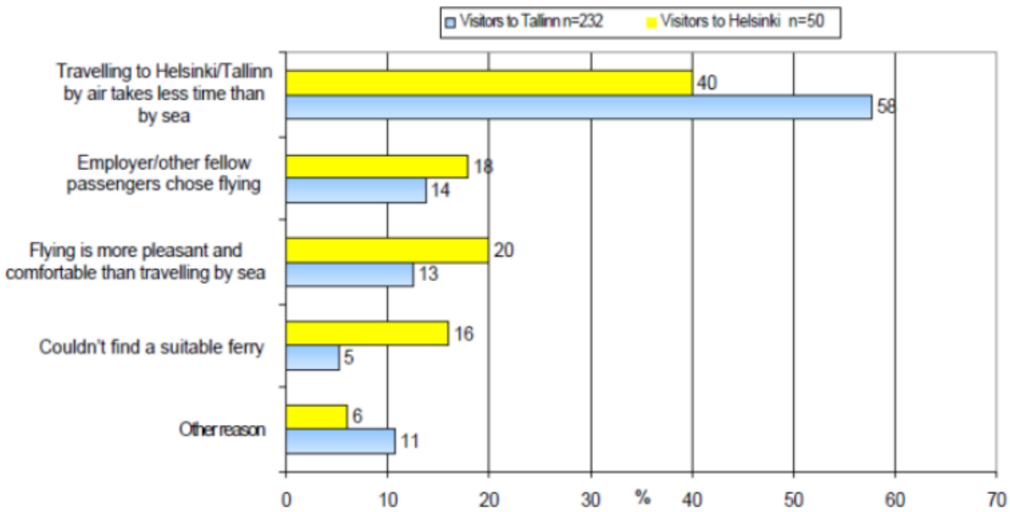

*Figure 7.3.2 Segmentation of reasons to travel by aircraft on route Helsinki-Tallinn (Tapaninen, 2012)*

The passenger segmentation on the route Buenos Aires – Montevideo shows similar behavior as the segmentation on the Helsinki – Tallinn route. Main reasons to travel for Argentine travelers are: 'leisure 50 %', 'business trip 29%', 'visiting friends 17%' & 'other 2%'. (ETC, 2011)

### 7.3.5 Role of technology

Technology plays a role in the market in the way that new, technical optimized vehicles are added to the market when old vehicles are discontinued. There is a certain delay between the invention of an optimization and its subsequent appearance in the market, because ferries and airplanes often have a lifespan of about 25 years.

### 7.3.6 Response from competition

It is logical that competitors see WIG transport as a threat when it is introduced in the transport market in which they operate. Competitors can lower their price and try to outcompete WIG transport. Another option is that they can start providing WIG transport themselves. Both options could, however, be relatively costly. The competition may lose revenue or eat market share dependable on their costs. Another option for the competitor is to prevent, or delay, WIG transport from entering the market by for example filing lawsuits.

### 7.3.7 Fuel efficiency transportation methods

It is interesting to know the fuel efficiencies of the transportation methods to know it's influence on the price. In this section are the fuel efficiencies per seat of the transportation methods estimated and presented.

The fuel efficiency of WIG transport is estimated by using the same method as the fuel cost calculation. The fuel efficiency of aircraft transport is estimated by taking the average efficiency of the aircrafts operative on the selected routes (ATR-72 & Embraer ERJ 190), (ATR, 2011) & (SUKHOI, 2013). The fuel efficiency of a ferry with a capacity to carry 2500 passengers is estimated by Cottrell (2011). Similar sized passenger ferries are used on the Helsinki – Tallinn route.

In figure 7.3.3 is the fuel efficiency per seat of a number of transportation methods shown. What is notable in the figure is that the fuel efficiency per seat of WIG transport with the WSH-500 is on average 30% lower than aircraft transport. What can be seen in the figure is that the Aron M80 has a unfavorable fuel efficiency.

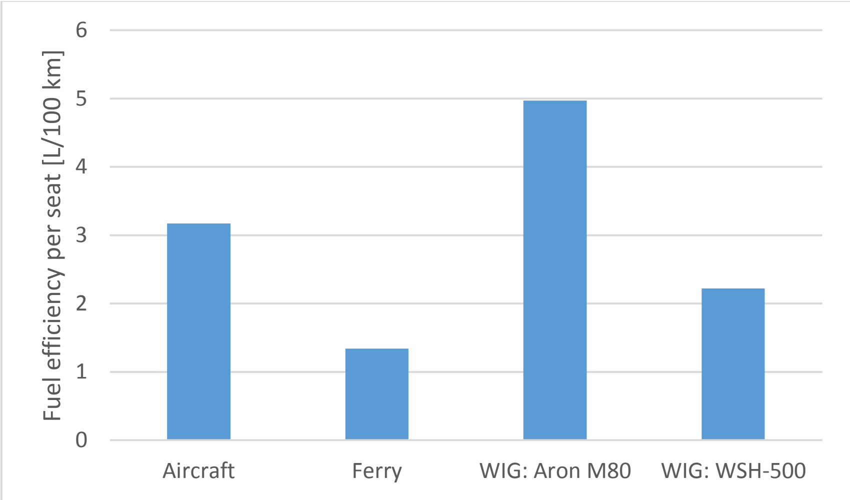


*Figure 7.3.3 Fuel efficiency of transport methods*

## 7.4 Market investigation

The transport markets are investigated because it is uncertain whether there is good business sense to enter (one of) the markets. This investigation provides background information for the profitability study. This section will investigate the transport markets. The following aspects are discussed: competition, price setting, barriers to exit and risks.

### 7.4.1 Competition

There is competition on both routes. Competing operating companies on the route Buenos Aires – Montevideo are: Colonia Express, Buquebus & Aerolineas Argentinas. Competing operating companies on the route Helsinki - Tallinn are: Tallink Silja, Viking, Ëckero and Nordic regional airlines i.a.

The market share of each competing operating company is illustrated in figure 7.4.1. The monetary units of 2017 are used in the figure. What is notable in the figure, is that in both markets the ferry operating companies have the largest market share.

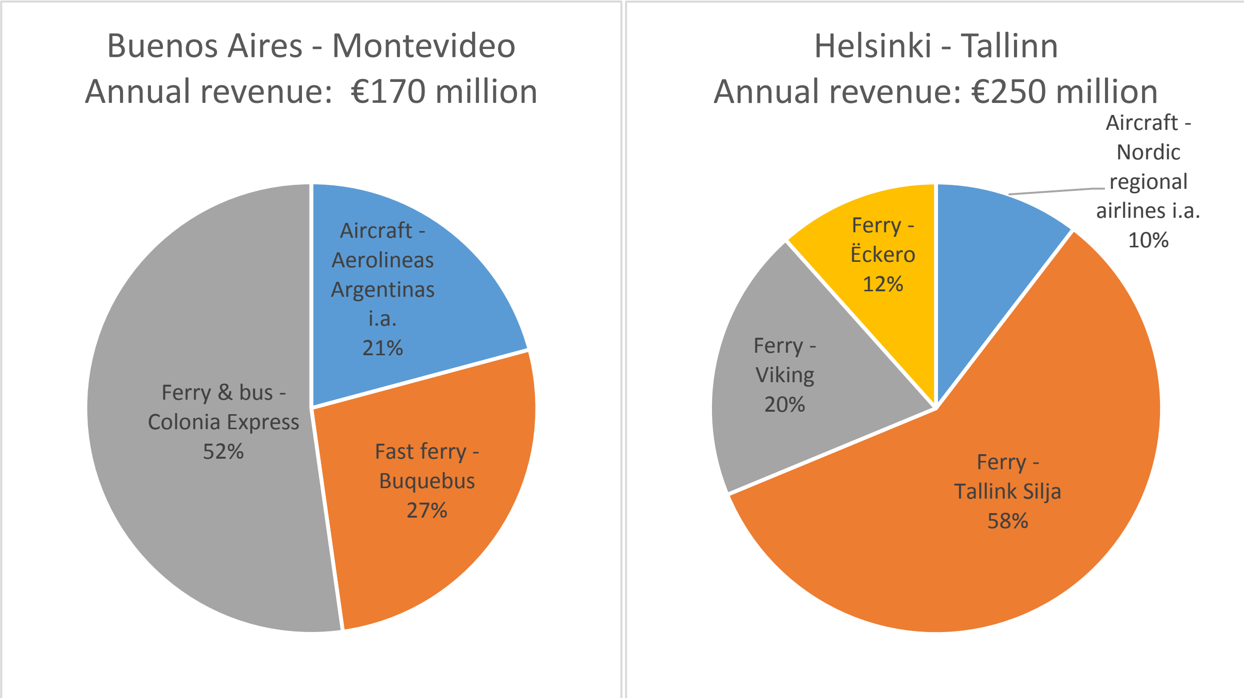


*Figure 7.4.1 Market share of transport methods (own work)*

### 7.4.2 Price setting

It is useful to estimate how the operating company should price WIG transport to optimize its profitability. The price is estimated by using a value-based pricing strategy (as explained below). It is also useful to estimate the cost-based price to determine good business sense. In this section, both strategies are addressed after which the results are presented.

A value-based pricing strategy is based on the value of a product. The price is primary based on the value which customers appoint to the product. The value in a transportation product comes primarily from its duration. Because the duration of WIG transport is shorter than the duration of other methods of transportation, it is logical to set the price at a higher level and thereby target the top niche of customers. Furthermore, starting small often seems like a good idea with a new or unproven product. The top niche of customers are passengers which prefer a short duration and travel by aircraft or fast ferry. It must be noted that other secondary values, which of course also play a role, are now neglected.

A cost-based pricing strategy is based on the cost of a product. The price is determined by adding a profit element to the cost of making the product. The cost-based price is estimated using a net present value calculation as described in section 7.9. The price is determined for which the net present value equals 0 euro. In this case acts an internal rate of return (IRR) of 10% as profit margin.

In figure 7.4.2, is an illustration shown of the value- and cost-based price of WIG transport on the route Buenos Aires – Montevideo. The demand for transport is also presented in the figure and a description of the prices is given below.

The value-based price for WIG transport is chosen in such a way that the top niche of customers is targeted. The price follows the curve and is set 20% higher than it, because WIG transport has a shorter duration, and thus more value than other methods of transportation. The value-based price is extrapolated and has a limit of 180 euro to prevent unrealistic representations in the 0 – 200 000 passengers range. The price is limited because unrealistically high prices can occur because of the character of the demand curve.

The cost-based prices of two WIG vehicles are presented in the figure. These are the WSH-500 (48 passengers) and the Aron M80 (6 passengers). What is notable in the figure is that the cost-based prices of the vehicles differ significantly.

What is striking in the figure, is the difference between the value-based price and the cost-based price. A large difference, where the value-based price is higher than the cost-based price, indicates good business sense. The difference between the value-based price and cost-based price of WIG transport with the WSH-500 is positive in a large range, from 100 000 passengers. The difference between the value-based price and cost-based price of WIG transport with the Aron M80, is positive in a relatively small range, from 150 000 - 350 000 passengers. This indicates that the business sense to provide WIG transport with the WSH-500 model is better than transport with the Aron M80 model.

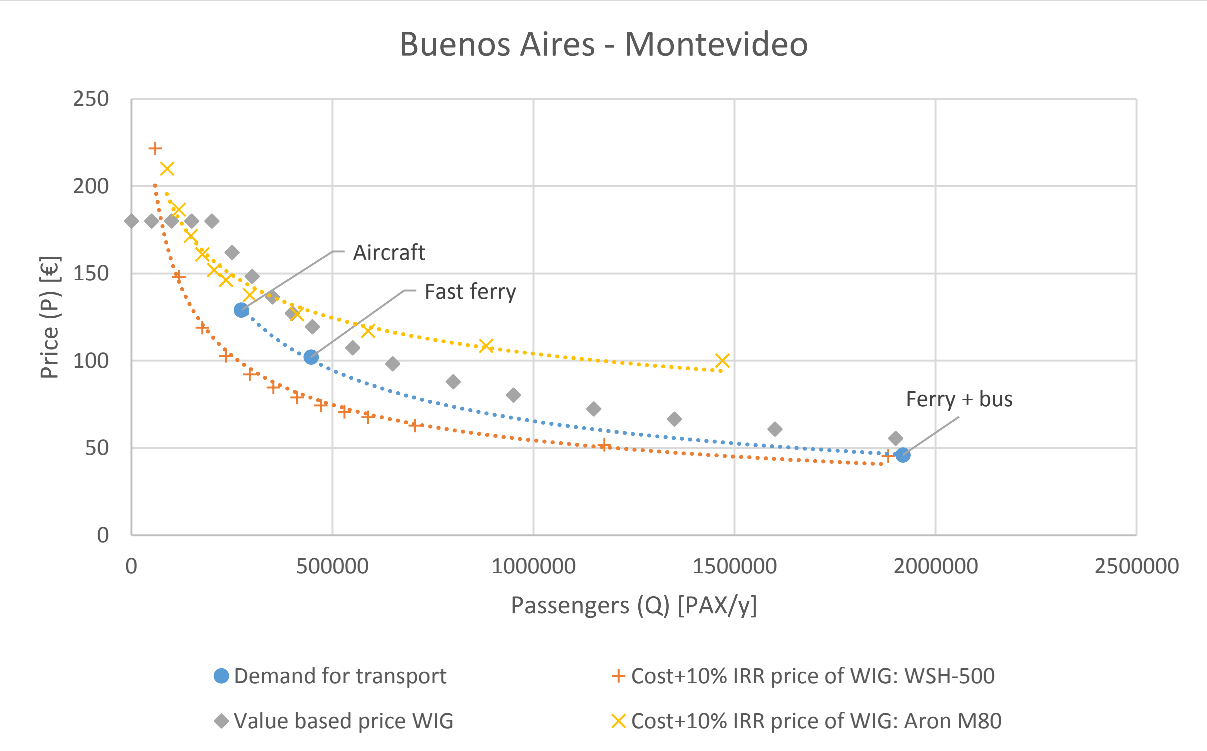


*Figure 7.4.2 Value- and cost-based pricing of WIG transport on the route Buenos Aires – Montevideo (2017) (own work)*

Figure 7.4.3 shows the value and the cost-based price of WIG transport on the route Helsinki - Tallinn. The demand for transport is also presented in the figure. A description of the prices is given below.

The value-based price for WIG transport is chosen in such a way that the top niche of customers is targeted. The price follows the curve and is set 20% higher than the curve because WIG transport has a shorter duration, and thus more value than other methods of transportation. The value-based price is extrapolated and has a limit of 150 euro to prevent unrealistic representations in the 0 – 450 000 passengers range. The price is limited because unrealistically high prices can occur because of the character of the demand curve. The cost-based prices of two WIG vehicles are presented in the figure. These are the WSH-500 (48 passengers) and the Aron M80 (6 passengers). What is notable in the figure is that the cost-based prices of the vehicles differ significantly.

What is striking in the figure is the difference between the value-based price and the cost-based price. A large difference, where the value-based price is higher than the cost-based price, indicates good business sense. The difference between the value-based price and cost-based price of WIG transport with the WSH-500 is positive in a large range, from 100 000 passengers. The difference between the value-based price and cost-based price of WIG transport with the Aron M80 is positive in a relatively small range, from 150 000 - 350 000 passengers.

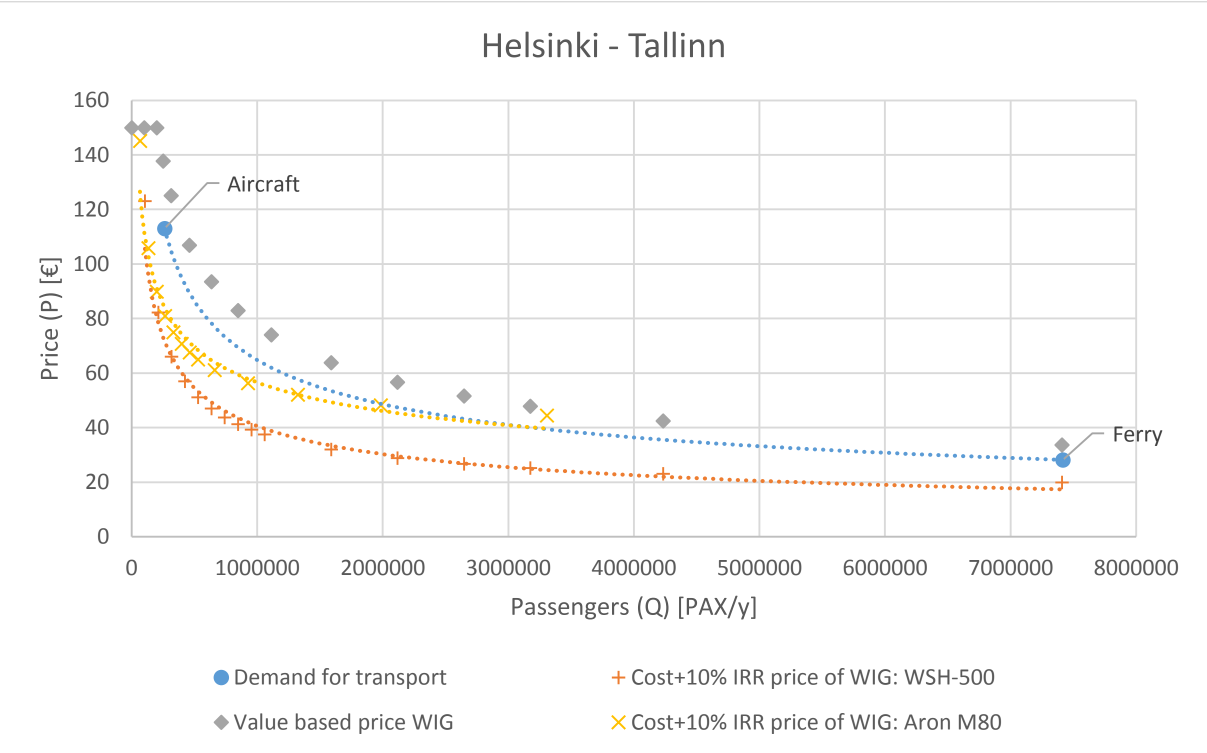


*Figure 7.4.3 Value- and cost-based pricing of WIG transport on the route Helsinki – Tallinn (2017) (own work)*

To summarize, it is recommended to maintain a relatively high, value-based, price for WIG transport. This means that a small part of the market is targeted: the top niche of customers. These customers are willing to pay a relatively high price for WIG transport because of its short duration. It is also ideal to target the relatively small top niche market because of two reasons: a) it means that investments of a small fleet can be overseen, b) the production capacity of the producer is likely to be sufficient. It is useful to influence the price setting when the demand becomes higher or lower. For example, raise the price when the demand is high, lower the price when the demand is low. In future research, it can be useful to initially target the top niche customers and to enlarge the group of customers after the market entrance by creating more transport capacity. This could increase the profitability.

### 7.4.3 Barriers to exit

The main barrier to exit is likely to be the loss in value of the highly specialized WIG vehicles and its development. Another barrier to exit may be closure costs. These costs occur when a contract, in which a financial clause has been incorporated, is not fulfilled. It can, for example, be the result of not fulfilling contracts with WIG suppliers or operators.

### 7.4.4 Risk assessment

The risks involved in entering the WIG transport market are identified and evaluated in this paragraph. The risk assessment is performed from the perspective of the operating company. First, a hazard and operability study (HAZOP) is performed and presented. Thereafter is a risk register given to act as a repository for all the identified risks.

In table 7.4.1 is the hazard and operability study of entering the WIG transport market shown.

*Table 7.4.1 Hazard and operability study of entering WIG transport market (own work)*

| | GUIDE WORD | DEVIATION | CAUSE | CONSEQUENCE | PROBABILITY | IMPACT |
|---|---|---|---|---|---|---|
| 1.1 | More | More competition | Competition lowers price or introduces new method of transportation | Less revenue | Low | Minor |
| 1.2 | | More regulations | Crash, strategy of competitors, government | More certifying cost | Medium | Moderate |
| 1.3 | | More delay at start | WIG vehicle production encounters problems | Less revenue | Medium | Minor |
| 2.1 | Less | Less funds | Vehicles more expensive, bad financing proposal | Instable company | Medium | Major |
| 2.2 | | Less demand | Crash, bad image, doubt | Less revenue | Low | Moderate |
| 2.3 | | Less supply | Malfunctions, technical problems | Less revenue | Low | Major |
| 3.1 | Low | Low operability | Specifications to positive | Lowers public opinion, less demand, less revenue | Medium | Moderate |
| 3.2 | | Low reliability | Technical problems with WIG vehicles | Lowers public opinion, less demand, less revenue | Low | Moderate |
| 3.3 | | Low comfort | Weather estimate to positive, expectation to positive | Lowers public opinion, less demand, less revenue | Medium | Moderate |
| 4.1 | None | No certifying | Crash, cost to high, bad design | No revenue, bankruptcy | Low | Severe |
| 4.2 | | No comfort | Weather estimate to positive, expectation to positive | No demand, no revenue, bankruptcy | Low | Severe |

In table 7.4.2, a risk matrix is shown. The matrix helps to quantify risks by combining the variables 'probability' and 'impact'.

*Table 7.4.2 Risk matrix (own work)*

| PROBABILITY | IMPACT: Insignificant | Minor | Moderate | Major | Severe |
|---|---|---|---|---|---|
| **Very high** | Medium | Medium | High | Extreme | Extreme |
| **High** | Low | Medium | High | High | Extreme |
| **Medium** | Low | Medium | Medium | High | High |
| **Low** | Low | Low | Medium | Medium | Medium |
| **Very Low** | Low | Low | Low | Low | Medium |

A risk matrix is presented in table 7.4.3. The risks are listed and quantified. Strategies and actions to cope with the risks are presented. What is notable in the table, is that a lack of funding is the highest risk. It is also notable that most of the risks are quantified as medium risk.

*Table 7.4.3 Risk register (own work)*

| | DESCRIPTION | PROBABILITY | IMPACT | RISK | STRATEGY | ACTION |
|---|---|---|---|---|---|---|
| 1.1 | Competition increases | Low | Minor | Low | Accept | Perform detailed market research to get to know the margins of the market. |
| 1.2 | Regulations increase | Medium | Moderate | Medium | Accept/ mitigate | Invest in legal department. |
| 1.3 | Vehicles are delayed | Medium | Minor | Medium | Transfer | Make contract based on time of delivery |
| 2.1 | Lack of funds | Medium | Major | High | Avoid/ mitigate | Make a clear financial plan, acquire financial expertise. |
| 2.2 | Demand is to low | Low | Moderate | Medium | Accept/ mitigate | Invest in marketing department. |
| 2.3 | Supply is to low | Low | Major | Medium | Mitigate | Test vehicles, go/no-go. Conduct sea trials on the intended route in cooperation with the vehicle producer. |
| 3.1 | Operability is lower as expected | Medium | Moderate | Medium | Mitigate | Test operability during sea trials on intended route. Create alliance with ferry operator to ensure transport regardless of operability. |
| 3.2 | Reliability is lower as expected | Low | Moderate | Medium | Mitigate | Test reliability during sea trials on intended route. Create alliance with ferry operator to ensure transport regardless of reliability. |
| 3.3 | Comfort is lower as expected | Medium | Moderate | Medium | Mitigate | Test comfort, go/no-go. Conduct sea trials on the intended route in cooperation with the vehicle producer. |
| 4.1 | Certifying of vehicles fails | Low | Severe | Medium | Transfer/ mitigate | Make contract based on correct certified vehicles. Assist where necessary. |
| 4.2 | Lack of comfort | Low | Severe | Medium | Mitigate | Test comfort, go/no-go. Conduct sea trials on the intended route in cooperation with the vehicle producer. |

## 7.5 Process to enter market

The process to enter the WIG transport market is based on a stage-gate system. Research revealed that implementing this system results in better decisions, more focus, fewer failures and faster development (Cooper, 1990). In this section, two aspects will be addressed: the stage-gate system and the process to enter the WIG transport market.

A stage gate system can be used to give shape to an innovation process. It is described as: "a conceptual and operational system for moving a new product from idea to launch." The process consists of stages and gates; in the stages there are activities performed. Between the stages there are gates; at each gate is the input evaluated using criteria and that yields an output (decision). Four decisions are possible: go, kill, hold & recycle. (Cooper, 1990)

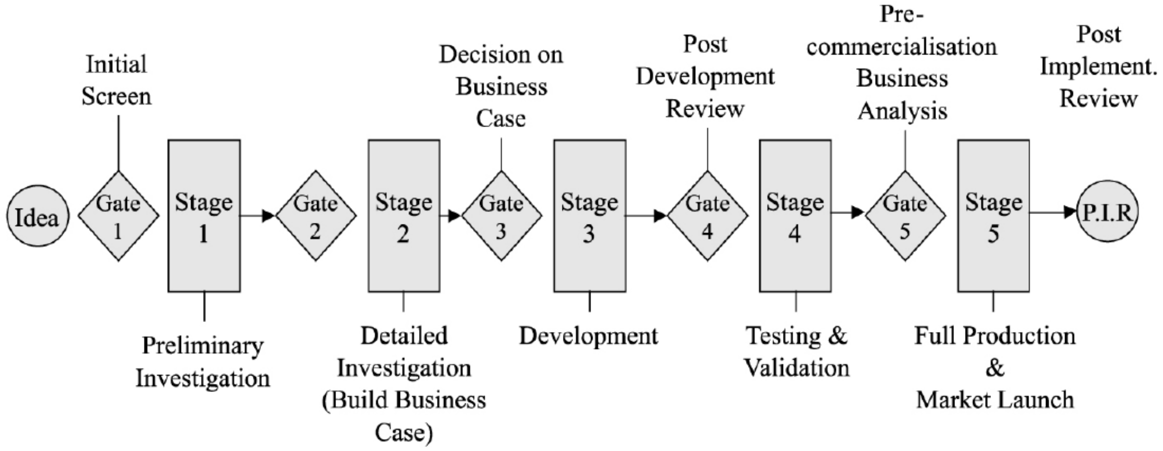


*Figure 7.5.1 Stage-gate system (Cooper, 1990)*

Figure 7.5.1 shows an illustration of the stage-gate system. The five stages of the innovation process are visible. It is reasonable to say that this research could function as stage 2 of the stage-gate system because it is in fact a detailed investigation. This gives clarity on which stages have to be fulfilled before entering the market. These are the stages: three, four and five.

The main activities of stages three, four and five are described below. The activities and criteria of each stage and gate are also presented in table 7.5.1.

In stage three, the product will be developed. It is of importance to validate the supply of certified WIG vehicles and to develop test, marketing, and operating plans. It is also useful to investigate the stage of development of the certification process of the vehicles as the certification cost and duration have a big influence on the price of the WIG vehicles, the startup cost and the duration. In similar fashion, it is important to acquire a sponsor to finance the startup cost.

In stage four, the product is tested and validated. It is useful to conduct sea trials on the intended route. This ensures that there are no unexpected technical limitations which can have a negative impact. The marketing & operational plans need to be tested in this stage to substantiate the business/financial review.

The implementation of the plans to launch the product and to operate it, takes place in the fifth stage. In this stage the vehicles are ordered and the operation plans and the marketing plans implemented. An optional activity in this stage is to acquire an alliance with an existing player to ensure transport regardless of influential variables such as the weather.

*Table 7.5.1 Activities and gate criteria  to enter WIG market (Cooper, 1990 & own work)*

| STAGE | ACTIVITIES | GATE CRITERIA (GO/KILL/HOLD/RECYCLE) |
|---|---|---|
| 3: Development | • Acquire sponsor<br>• Validate supply of certified vehicles<br>• Validate expected customers<br>• Validate subsidies<br>• Development of test plan<br>• Development of marketing plan<br>• Development of operational plan<br>• Create route analysis<br>• Create cost analysis<br>• Monitor market and customer feedback | • Sponsor acquired<br>• Supply of certified WIG vehicles is validated<br>• Local operating approval<br>• Quality check on activities<br>• Cost/financial analysis<br>• Action plan for next stage |
| 4: Testing & Validation | • Conduct sea trials on intended route in cooperation with supplier of WIG vehicles<br>• Validate operability, comfort and reliability<br>• Validate supply of certified WIG vehicles<br>• Create pre-commercialization business analysis<br>• Customer tests<br>• Test marketing<br>• Total business/financial review | • Overall detailed financial/business check points<br>• Operability, comfort, reliability of WIG vehicle is proven to be sufficient on intended route<br>• Vehicles have certification<br>• Pre-commercialization business analysis is positive<br>• Action plan for next stage |
| 5: Market Launch | • Order WIG vehicles<br>• Optional: Acquire alliance with existing player<br>• Implement operations plan<br>• Implement market launch plan | • Financing is secured<br>• WIG vehicles are ordered.<br>• License to operate WIG vehicles is acquired |

## 7.6 Strategy to enter market

If decided to enter the market, a good strategy is of the essence to become a player. The strategy to enter the WIG transport market is described in this paragraph. The effectiveness of the strategy is analyzed by performing a SWOT analysis. Moreover, the corresponding strengths, opportunities, threats and weaknesses are filled in a confrontation matrix to find the actions which should be taken to execute the strategy.

The mission of the operating company is to provide WIG transport, because it believes that there is a market for fast transport, between the speed and distance range of ship and aircraft-transport.

The operating company will first develop the product of WIG transport, then test it and eventually implement plans to launch it. It does this according to the stage-gate process (7.5). During this process are the following main aspects investigated: supply of vehicles, certification of vehicles, financing and technical limitations. When this process is completed, the product is launched.

The strategy to market WIG transport is to use a 'top niche' strategy. The way that this strategy works, is that the top niche of customers is targeted by WIG transport, using its proven shortest-duration capability as a unique selling point. The company will sell WIG transport at a high price, as a luxurious method of transport which has the shortest duration of transport time vs other methods. This means that it will target a small portion of the market, with a small fleet of WIG vehicles and relatively low investments (€ 50 – 100 million). The operating company can also gain competitive advantage due to the relatively high fuel efficiency per seat of the WSH-500 (2.22L / 100 km).

A weakness of this strategy is that the investments involved to startup the company and to acquire the vehicles are high. External investors will need to be attracted with a high internal rate of return. The investments during the startup period are initially risky, but also relatively low. Showstoppers such as: supply of vehicles, certification and technical limitations will be investigated at an early stage at relatively low cost. The risk of failure is thereby reduced. The investments involved to acquire the vehicles will be limited by starting with a relatively small fleet.

It is an opportunity to create a joint venture with the WIG-supplier. The certification process can be made faster and made insightful. Another joint venture or alliance can be created with an existing player in the market. This is useful to ensure transport, regardless of influential variables. The fact that there are two markets suitable for WIG transport can be used to ensure a fast market introduction. The operating company can engage in one, or both, transport markets.

The failure to acquire funding or certified WIG vehicles, can be a threat. The failure of acquiring funding must be avoided by providing the investors with a solid plan and a high internal rate of return. Failing to acquire certified WIG could be avoided by creating a joint venture with a supplier or starting one's own production of vehicles.

Another strategy could be to use a 'subsidized niche' strategy when the product is considered as societally important. This can for example be a good strategy to enter the market with a sustainable powered WIG vehicle. In further research, it can be useful to further investigate suitable strategies or to combine them.

To analyze the effectiveness of the 'top niche' strategy, a SWOT analysis is performed. Moreover, the corresponding strengths, opportunities, threats and weaknesses are filled in a confrontation matrix to find the actions which should be taken to execute the strategy. The SWOT analysis and confrontation matrix can respectively be seen in table 7.6.1 and 7.6.2.

*Table 7.6.1 SWOT analysis of entering the WIG market (own work)*

| **STRENGTHS [S]** | **OPPORTUNITY [O]** |
|---|---|
| 1. The competitive advantages of WIG transport are high-speed (185 km/h) and relatively high fuel efficiency per seat (2.22L / 100 km).<br>2. Top niche customers are targeted by using unique selling point: shortest duration of transport, in addition to the luxurious before and after transport.<br>3. There are two markets proven to be suitable. The operating company can engage in both.<br>4. New demand is created. | 1. Create joint venture with WIG-supplier to fasten the certification process and to keep influence.<br>2. Fast market introduction.<br>3. Create monopoly due to first mover advantage.<br>4. Create alliance with an existing player to ensure transport regardless of influential variables. |
| **WEAKNESS [W]** | **THREAT [T]** |
| 1. The investments involved to startup the company and to acquire the vehicles are high.<br>2. Lack of supply of certified WIG vehicles.<br>3. The duration and cost to startup the company are uncertain.<br>4. There is a lack of expertise. | 1. Failure of acquiring funding.<br>2. Failure of acquiring certified WIG vehicles.<br>3. Operability, reliability or comfort of the vehicles are insufficient.<br>4. Increased competition results in less revenue. |

*Table 7.6.2 Confrontation matrix (own work)*

| | **O1** | **O2** | **O3** | **O4** | **T1** | **T2** | **T3** | **T4** |
|---|---|---|---|---|---|---|---|---|
| **S1** | + | ++ | ++ | + | | | | + |
| **S2** | | ++ | + | + | | | -- | |
| **S3** | | ++ | ++ | + | | | + | ++ |
| **S4** | + | + | ++ | + | | +/- | | ++ |
| **W1** | +/- | + | +/- | +/- | -- | - | | - |
| **W2** | ++ | - | +/- | + | - | -- | | |
| **W3** | ++ | - | +/- | + | -- | | | - |
| **W4** | +/- | - | - | + | - | - | | |

| STRATEGY |
|---|
| Grow |
| Improve |
| Defend |
| Abandon |

## 7.7 Financing proposal

The operating company needs to be financed. Explored in this section, is a financing proposal of the operating company, presented according to the strategy to enter the market.

The cost to startup the company is financed by an external investor and increases exponentially over time. Assumed is that the duration of the startup phase will be 3 years and the startup costs are equal to 10% of the cost of acquiring the vehicles. If—during the startup phase—it is decided that the company will enter the market, a small fleet of WIG vehicles will be ordered in year 3 so that operations may begin in year 4. The cost to acquire the WIG vehicles is determined by the minimum selling price as calculated in section 5.2 (see figure 5.2.1). The vehicles are financed by investors at 40% and by a bank loan at 60%. The duration of the loan is 20 years and the interest rate 8%.

## 7.8 Free cash flow prognosis

A free cash flow prognosis is developed to give insight into the overall cash flow over time. This section shows examples of the free cash flow prognoses presented in four cases. The cases variate on the aspects: route and vehicle.

The free cash flow prognoses are based on the routes: Buenos Aires – Montevideo & Helsinki – Tallinn. The WIG vehicles on which the free cash flow prognosis are based, are: 4x WSH-500 and 15x Aron M80.

The free cash flow prognosis is performed from year 1 until year 23, because there are three startup years and the economic life span of the vehicles is assumed to be 20 years. After these 20 years, the vehicles are sold for 15% of the purchase value.

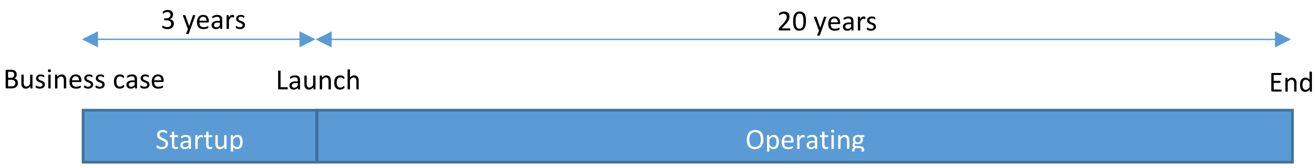


*Figure 7.8.1 Timeline (own work)*

There is a specific increase of 2% per year added to the cost of fuel (part of voyage cost) as is expected that the fuel price will rise. The increase is directly charged to the customer and has therefore no significant effect. This means that the competitive position of WIG transport will improve over time as it has a relatively good fuel efficiency. Assumed is that there is no inflation to limit the extent of this research.

In appendix 11.2, is an example of a cash flow prognosis presented.

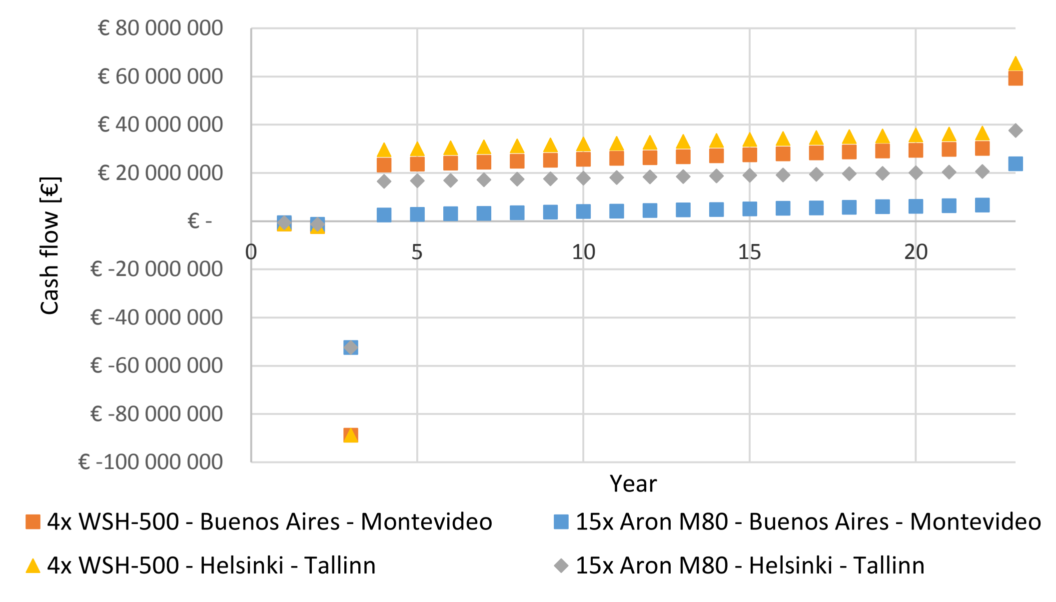


*Figure 7.8.2 Free cash flow prognoses IRR=10% (own work)*

There are four free cash flow prognoses shown in figure 7.8.2. The prognoses show similar behavior. There is a negative cash flow in the years 1-3, as result of the cost to startup the company. The financing of the vehicles in year 3 add up to the negative cash flow and subsequently cause a fall. Revenues, as result of WIG transport, cause a positive cash flow from year 4 until year 23. A gradual increase in the free cash flow is visible because less interest is paid per year over the decreasing loan. In year 23, there is a peak in the free cash flow visible; this is the effect of selling the WIG vehicles at the end of their life, for the residual value. This equals 15% of the cost of acquiring the vehicles.

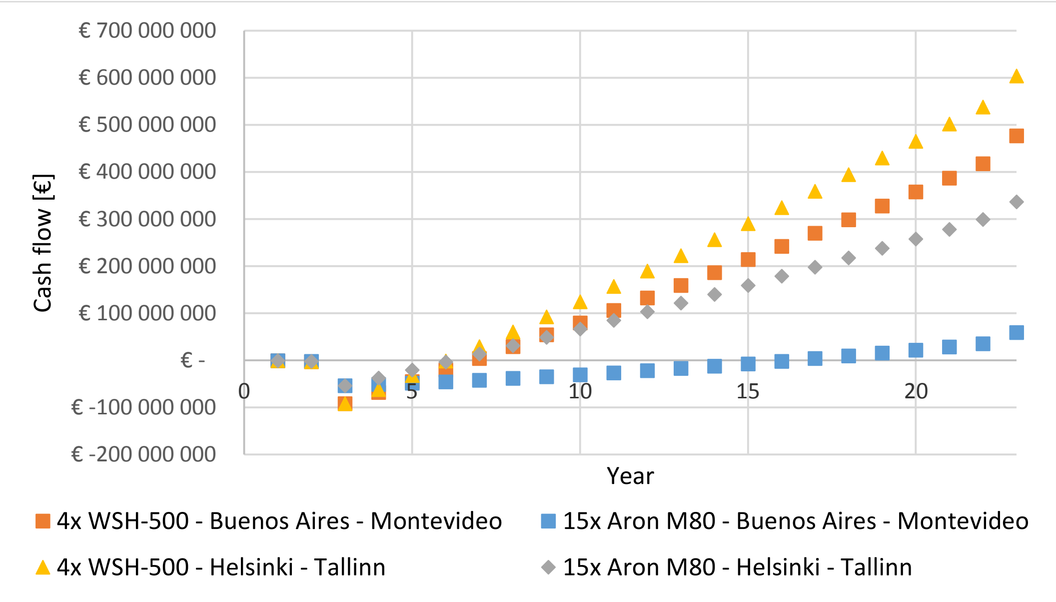


*Figure 7.8.3 Accumulated cash flow prognoses IRR=10% (own work)*

Figure 7.8.3 shows four cases of accumulated cash flow prognoses. The cases show similar behavior. The cost to startup the company (year 1-3) and the cost to finance the vehicles (year 3) cause a negative cash flow. The revenues of operating the vehicles add up to the accumulated cash flow (year 4-23). What is notable in the breakdown is that the accumulated cash flow becomes positive; this means that the investment is earned back. The year in which the accumulated cash flow is positive indicates the payback period.

## 7.9 Net present value

The potential profit of WIG transport is estimated by using a net present value (NPV) calculation. This calculation is performed on the routes Buenos Aires – Montevideo & Helsinki – Tallinn in combination with the WSH-500 and the Aron M80. The methodology and results will be presented in this section.

The formula to calculate the NPV is as follows:

$$NPV = \sum_{n=0}^{n} \frac{FCF}{(1+r)^n}$$

In this formula represents 'n' the years (1-23), 'r' the discount rate (assumed to be 10%) and 'FCF' the free cash flow.

Figure 7.9.1 shows the net present value for a number of cases which have a positive net present value. Each dot represents one case. The color of the dots illustrates a combination of vehicle and route. The cases are chosen by varying the number of WIG vehicles.

What is notable in the figure is that the total investments needed to achieve a positive NPV, start at about 50 million euro. It is also notable that the Helsinki – Tallinn route has a higher NPV per total investment. The WSH-500 in combination with the Helsinki – Tallinn results in the highest NPV.

What is striking in the figure are the peaks in the NPV over the total investment. The peaks are optimizations mainly defined by the value based price of WIG transport and the minimum selling price for which the vehicles are purchased. The value based price of WIG transport decreases as the annual number of passengers transported increases (figure 7.4.2 & 7.4.3). The minimum selling price for which the vehicles can be purchased decreases as the number of vehicles increases (figure 5.2.1).

What can clearly be seen in the figure is that the NPV of providing WIG transport with the WSH-500 on the Helsinki – Tallinn route keeps increasing over the total investment. This is the result of a large, constant difference between the cost based price and the value based price.

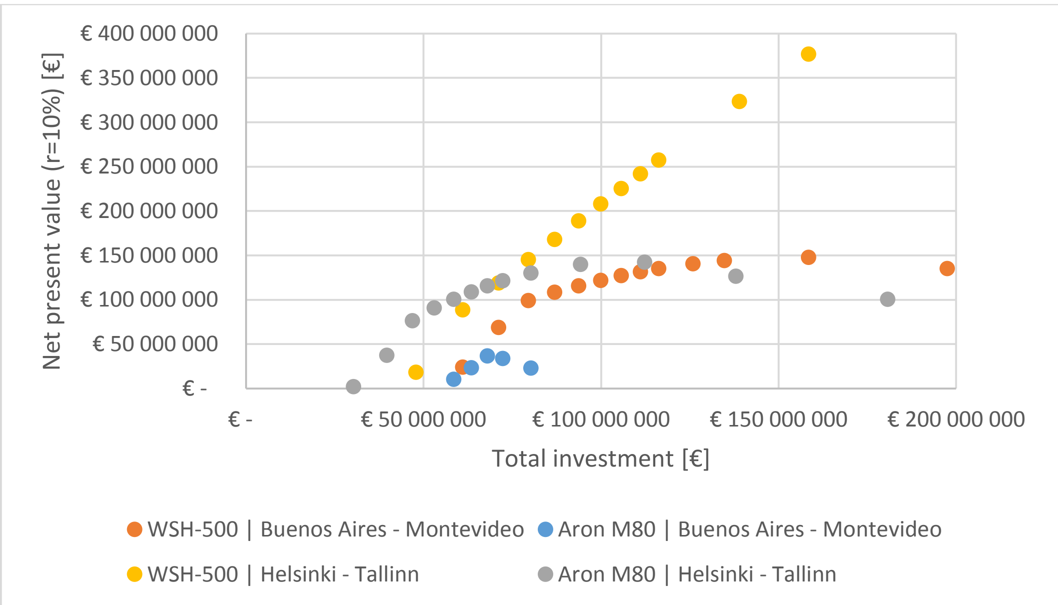


*Figure 7.9.1 Net present value vs total investment (own work)*

## 7.10 Internal rate of return

The profitability of the investments in the company, is estimated by calculating the internal rate of return (IRR). This section will look at the internal rate of return in a number of cases. Each case varies on the following aspects: type of vehicle, number of vehicles and route.

The internal rate of return is calculated by using the following formula:

$$0 = NPV = \sum_{n=0}^{n} \frac{FCF}{(1 + IRR)^n}$$

The cash flows are based on the value-based price as estimated in paragraph 7.4.

Figure 7.10.1 shows the internal rate of return for a number of cases. Each dot represents one case. The color of the dots illustrates a combination of vehicle and route. The figure reveals that the investments needed to achieve a positive internal rate of return are significant. What is notable in the figure is the increase of the internal rate of return, dependent on the total investment. What is also striking in the figure, is the dominance of the Helsinki – Tallinn route. The investments in WIG transport on the Helsinki – Tallinn route have, on average, a higher internal rate of return. This is most likely the result of a relatively high value-based price on this route, as it is dependent on the demand function for transport, which is relatively high. The WSH-500 has, on average, a higher internal rate of return than the Aron M80. What is also notable is that the internal rate of return of the WSH-500 drops, after the peak, more gradually than the Aron M80. This means that investing in the WSH-500 has better business sense, when looking beyond the initial investment.

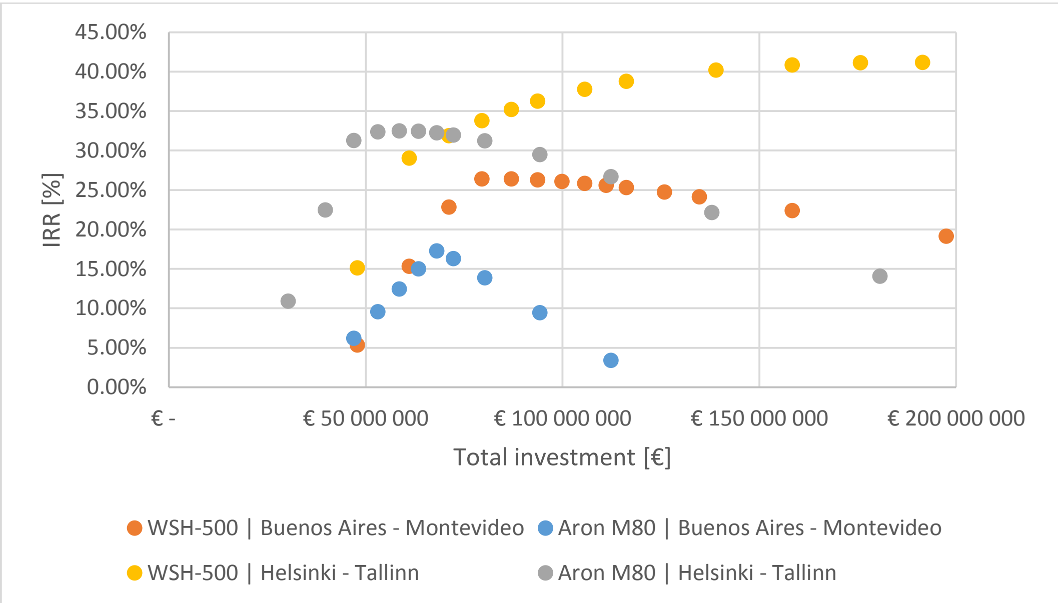


*Figure 7.10.1 Internal rate of return (IRR) vs total investment (own work)*

What is striking in the figure are the peaks of the IRR over the total investment. The cause of the peaks in the IRR is similar to the cause of the peaks in the IRR (figure 7.9.1). The peaks are optimizations between the value based price of WIG transport and the minimum selling price for which the vehicles are purchased.

Four favorable cases are presented hereafter. Demonstrated in table 7.10.1, are the main variables which determine the net present value (NPV) and the internal rate of return (IRR). The total investment to startup the company and to acquire 4 WSH-500 vehicles is 79 million euro. The total investment to startup the company and to acquire 15 Aron M80 vehicles is 47 million euro.

What can be clearly seen in this table is that the Helsinki – Tallinn route has both a higher IRR, and a higher NPV. The main reason for this difference is the variation in the number of passengers. The number of passengers, together with the price for transport define the revenue. The revenue has a big influence on the NPV and IRR.

*Table 7.10.1 Net present value and internal rate of return of four favorable cases (own work)*

| **Case** | **A** | **B** | **C** | **D** |
|---|---|---|---|---|
| Vehicles | 4 WSH-500 | 15 Aron M80 | 4 WSH-500 | 15 Aron M80 |
| Route | Helsinki - Tallinn | Helsinki - Tallinn | Buenos Aires - Montevideo | Buenos Aires - Montevideo |
| Trips per day | 9 | 9 | 5 | 5 |
| Seakeeping operability rate [%] | 94.0 % | 90.7 % | 100.0 % | 100.0 % |
| Fullness rate [%] | 70.0 % | 70.0 % | 70.0 % | 70.0 % |
| Passengers [PAX/y] | 398 000 | 180 000 | 235 000 | 88 000 |
| Passenger share [%] | 5.2 % | 2.3 % | 9.7 % | 3.4 % |
| Value based price [€] | 111 | 150 | 169 | 180 |
| Cost based price [€] | 57 | 90 | 103 | 210 |
| Total investment [€] | 79 000 000 | 47 000 000 | 79 000 000 | 47 000 000 |
| Net present value [€] | 145 000 000 | 76 000 000 | 99 000 000 | -13 000 000 |
| Internal rate of return [%] | 33.8 % | 31.3 % | 26.4 % | 6.2 % |

## 7.11 Sensitivity analysis

Please note that some variables that are used in the calculations are estimated. This results in an uncertainty in output of the calculations. This section will study the sensitivity of these values, with the results presented and described. The sensitivity of the following variables is studied: number of passengers, vehicle expenditures, interest rate, operating cost, startup cost and voyage cost.

The net present value is calculated as described in paragraph 7.9. A discount rate of 10% is used in the calculations. The input of the variables presented above is deviated.

Figures 7.11.1 and 7.11.2 show the sensitivity analyses of WIG transport on the route 'Helsinki – Tallinn'. The first analysis is based on the WIG vehicle: WSH-500. The second analysis is based on the WIG vehicle: Aron M80. The net present value is calculated for a variating input, which is illustrated in the figure by using different colors. Both analyses show a similar result.

What is notable in the figures is the big influence of the variables: number of passengers and vehicle expenditures. The number of passengers influences the revenue and NPV. A decrease of the number of passengers transported of over 40-60% will result in a negative NPV. The vehicle expenditures represent the price for which the WIG vehicles are purchased. What can be seen is that an increase of about 80% of the vehicle expenditures will still result in a positive NPV. What is striking in the figure is that the following variables are less sensitive: interest rate, operating cost, startup cost and voyage cost.

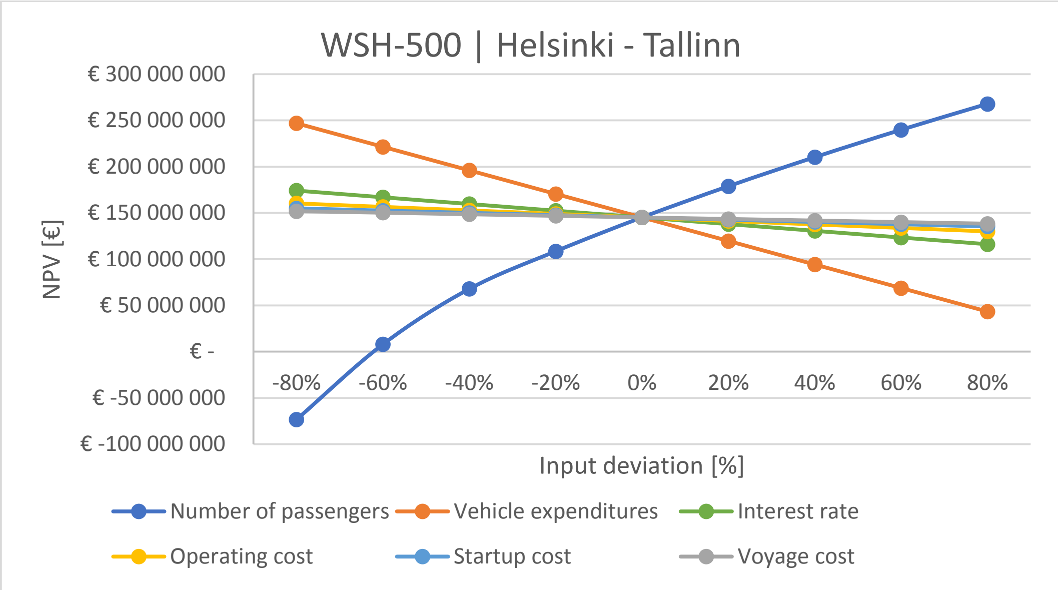


*Figure 7.11.1 Sensitivity analysis of WIG transport with the WSH-500 on the Helsinki – Tallinn route (own work)*

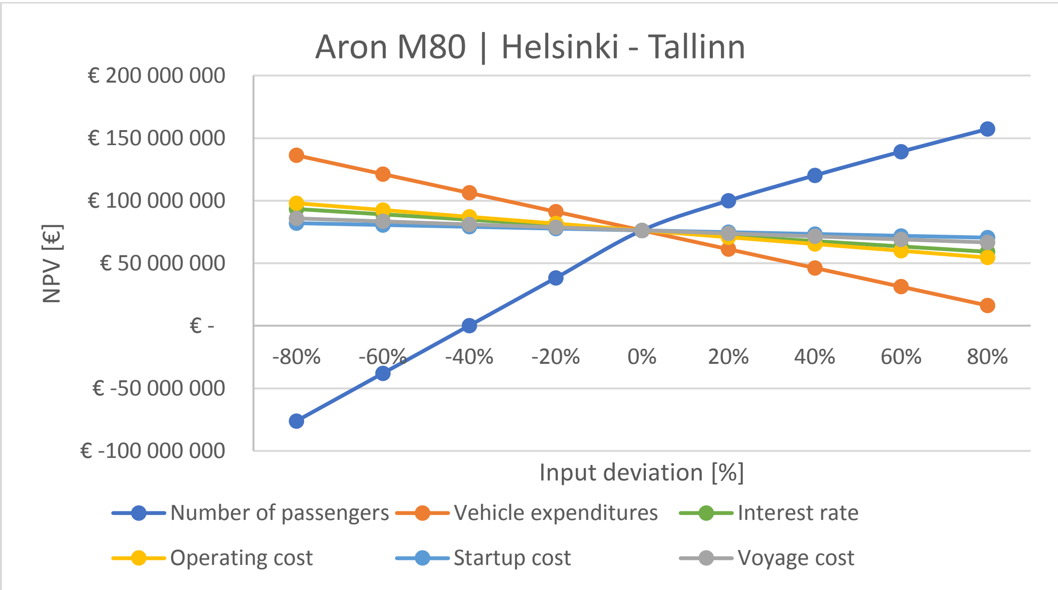


*Figure 7.11.2 Sensitivity analysis of WIG transport with the Aron M80 on the Helsinki – Tallinn route (own work)*

## 7.12 Conclusion

The goal of this chapter is to estimate whether WIG vehicles, operating as high-speed passenger ferries, can be profitable. In order to achieve this estimation, this chapter broke down the steps needed to enter the WIG transport market, from the perspective of an operating company. With this information, the profitability of two WIG vehicles, on two routes, was estimated and presented.

The process to enter the WIG transport market is based on a stage-gate process. This process consists of stages and gates. After each stage there is a gate that yields an output to continue or not. The stages to enter the market are as follows:

- Stage 1: Development. The product of WIG transport is developed in this stage. This means that provisional financing and a supplier of WIG vehicles is required. Furthermore, the operating, marketing, and test plans are developed.
- Stage 2: Testing & validation. The product needs further testing and validation. It is ensured that there are no technical limitations. A pre-commercialization business analysis needs to be created. It is of importance that the vehicles are certified to transport passengers.
- Stage 3: Market launch. The vehicles are ordered. The operations and marketing plans are implemented.

There are big challenges for the operating company in the process to enter the market. The investment during the startup phase is risky because showstoppers could arise such as: lack of supply of WIG vehicles, lack of certification or technical limitations. This may affect the startup cost and/or duration. It should be noted that the cost to seek this out may be a small fraction of the benefits.

The strategy to market WIG transport, is to target the top niche of customers, using its proven shortest-duration capability as a unique selling point. The company will sell WIG transport at a high price, as a luxurious method of transport which has the shortest duration of transport time vs other available methods. This means that only a small portion of the market will be targeted, using only a minor fleet of WIG vehicles. Consequently, the investments — in the range of €50 - 100 million — can be overseen.

WIG vehicles operating as high-speed passenger ferries can be profitable. The profitability of two WIG vehicles, on two routes, is estimated based on the net present value (NPV) and the internal rate of return (IRR) and is calculated over a duration of 23 years. The NPV is estimated by using a discount rate of 10%. The IRR is estimated without using a discount rate. The price for which WIG transport is provided is determined by using a value-based pricing strategy. Furthermore, the price for which the WIG vehicles are acquired is dependent on the number of vehicles acquired.

The NPV of investments made in a WIG transport company can be positive for the investigated routes and vehicles. It varies per route, vehicle and total investment. The NPV is estimated for a number of cases, of which four favorable cases are highlighted in table 7.12.1.

*Table 7.12.1 NPV and IRR of four favorable cases (own work)*

| **Case** | **A** | **B** | **C** | **D** |
|---|---|---|---|---|
| Vehicles | 4 WSH-500 | 15 Aron M80 | 4 WSH-500 | 15 Aron M80 |
| Route | Helsinki - Tallinn | Helsinki - Tallinn | Buenos Aires - Montevideo | Buenos Aires - Montevideo |
| Seakeeping operability rate [%] | 94.0 % | 90.7 % | 100.0 % | 100.0 % |
| Passengers [PAX/y] | 398 000 | 180 000 | 235 000 | 88 000 |
| Market share [%] | 5.2 % | 2.3 % | 9.7 % | 3.4 % |
| Total investment [€] | 79 000 000 | 47 000 000 | 79 000 000 | 47 000 000 |
| Net present value [€] | 145 000 000 | 76 000 000 | 99 000 000 | -13 000 000 |
| Internal rate of return [%] | 33.8 % | 31.3 % | 26.4 % | 6.2 % |

What can be seen in the results of the NPV calculation is that the NPV of operating with the WSH-500 is relatively higher than operating with the Aron M80. Operating with WSH-500 vehicles requires, on the other hand, more investments than operating with Aron M80 vehicles to achieve a positive NPV (€47 vs 30 million). What is striking in the results is the significant difference of the NPV between the routes. The 'Helsinki – Tallinn' route has, in most cases, a higher NPV than the 'Buenos Aires – Montevideo' route. It is likely that this is caused by a combination of a relatively higher value-based price and a higher number of trips per day (9 vs 5).

The internal rates of return of investments made in a WIG transport company can be positive. The IRR varies per route, vehicle and total investment. The internal rate of return can, in number of cases, even be in the 30-42% range, which is very good. Operating with the WSH-500, appears to be very favorable on both routes, when the number of vehicles is 4 or higher. It has, in this case, an IRR higher than 25%. A similar result can be achieved by operating 15 Aron M80 vehicles on the Helsinki – Tallinn route. A lower result, but still a good one, can be achieved by operating 35 Aron M80 vehicles on the Buenos Aires – Montevideo route, it has in this case an IRR of 17%.

A sensitivity analysis on the NPV of cases A and B shows that the NPV remains positive for a large input deviation. It remains positive when the input of the following variables is deviated by 80%: vehicle expenditures, interest rate, operating cost, startup cost and voyage cost. A reduction in the number of passengers transported of over 40-60% will result in a negative NPV.

# 8 Conclusions

The goal of this research is to investigate and present the feasibility and profitability of WIG vehicles operating as high-speed passenger ferries. It is of importance to know this before putting money and time in to further research. The variables and circumstances which improve the potential commercial future of WIG transport are shown.

WIG vehicles are designed to fly a few meters above water by making use of the ground-effect. The unique selling point of WIG vehicles is that they operate in the speed (185 km/h) and distance range (50-350 km) between ships and aircraft.

WIG vehicles operating as high-speed passenger ferries are technologically feasible. The technology has a readiness level of 8 out of 9. Multiple model tests are performed and full-size prototypes are built. The vehicles, admittedly, have one main technical limitation: the seaworthiness. The seaworthiness of a vehicle is dependent on its weight and design. The motions during landing and takeoff can become too high in rough weather conditions.

A comparison of WIG vehicles results in the selection of two vehicles which are used in the profitability study: the WSH-500 and the Aron M80. The vehicles are compared on the following aspects: seaworthiness, passenger capacity and efficiency. The seaworthiness of the vehicles is compared by estimating the permissible wave height. The vehicles have a permissible wave height of 1.4m and 1.2m. The vehicles have the capacity to carry 48 and 6 passengers. The fuel efficiency per seat is 2.2 and 5.0 L / 100 km.

A cost analysis of the WIG vehicles makes the cost transparent. The costs of the 'WSH-500' and 'Aron M80'are as follows (in €/y): capital cost: 740 k and 240 k, operating cost: 790 k and 290 k, voyage cost: 490 k and 170 k, total: 2 000 k and 700 k. The analysis shows that the price for which the vehicles are acquired is an influential variable. This price decreases as the number of acquired vehicles increases, because it can, for a large part, be allotted to the development and certification of the vehicles. The cost analysis assumes that there are 30 vehicles built. In the profitability analysis, it is assumed that the  of vehicles produced equals the number of vehicles acquired.

A criteria-based selection shows the most suitable routes for profitable WIG transport: 'Buenos Aires – Montevideo' and 'Helsinki – Tallinn'. The routes scored good on the following selection criteria: high number of passengers transported, high seakeeping operability rate and suitable distance for WIG. The number of passengers transported on the routes is 2 600 000 and 7 700 000. This can be positive for the profitability of WIG transport on this route. The seakeeping operability rates of the routes are between 91% and 100% (in combination with the selected vehicles). This reduces the impact of the limiting seaworthiness. The distances of the routes are 210 and 80 km. On these distances, WIG vehicles provide transport with the shortest duration. The duration of WIG transport can be 22% and 57% shorter than the duration of transport of other methods. This reduction is influenced by the location of airports.

The demand functions of transport on the selected routes are presented below. The functions have been drawn up using passenger and price data of the year 2017, of other transportation methods on the routes such as: ferry, fast ferry and aircraft. The potential demand for WIG transport on the selected routes can, in theory, be approximated by the demand functions. These functions will be influenced when WIG transport is added to the market. Yet, the influence is likely to be rather small when the market share of WIG transport is small. On the other hand, it should be noted that discrepancies are likely to appear when WIG transport is priced competitively and functions as substitute for other methods of transportation.

Buenos Aires – Montevideo: $\mathrm{P} = \frac{102555}{\mathrm{Q}^{0.533}}$

Helsinki – Tallinn: $\mathrm{P} = \frac{20209}{\mathrm{Q}^{0.416}}$

A suitable strategy to market WIG transport is to target the top niche of customers by using the short duration of transport as unique selling point. This has multiple advantages: a) a high price can be asked, b) the number of WIG vehicles needed and corresponding investments can be overseen, c) the market share of WIG transport is relatively small.

WIG vehicles operating as high-speed passenger ferries can be profitable. Both, the net present value (NPV) and internal rate of return (IRR) of investments made in a WIG transport company can be positive. The NPV and IRR vary per route, vehicle and total investment. The results of the NPV calculation show that the NPV of operating with the WSH-500 is relatively higher than operating with the Aron M80. Operating with WSH-500 vehicles requires, on the other hand, more investments than operating with Aron M80 vehicles to achieve a positive NPV (€47 vs 30 million). What is striking in the results is the significant difference of the NPV between the routes. The 'Helsinki – Tallinn' route has, in most cases, a higher NPV than the 'Buenos Aires – Montevideo' route.

In conclusion, WIG vehicles operating as high-speed passenger ferries can be feasible and profitable. The technology behind WIG vehicles has a technological readiness level of 8 out of 9. There are multiple, full-scale prototypes made and tested. Suitable vessels and routes have been selected to deal with the primary limitation that comes with WIG vehicles; they have low seaworthiness capabilities. The seakeeping operability rates of the selected vehicles and routes range between 91% and 100%. The net present value (NPV) and internal rate of return (IRR) of investments made in a WIG transport company can be positive when suitable routes and vehicles are selected. Estimated is that the investments needed to create a profitable market entrance for WIG vehicles operating as high-speed passenger ferries start from approximately €50 million. The investments made in a WIG transport company can be very profitable because it is estimated is that internal rates of return of up to 42% can be achieved,

# 9 Recommendations

To improve the feasibility and profitability of WIG transport, the following recommendations deserve attention:

1. Improve permissible wave height of WIG vehicles
   *The permissible wave height of WIG vehicle has a significant impact on the seakeeping operability rate. The higher the permissible wave height of a vehicle, the higher the seakeeping operability rate, the higher the number of routes on which the vehicle can operate. Recommended is to improve the designs of WIG vehicles on the aspect seaworthiness by using other technologies. It could for example be useful to combine automated control systems with controllable pitch hydrofoils or hydro ski gear to reduce motions. It can be a cost efficient method to design such ideas with computer models. Furthermore, the permissible wave height of WIG vehicles could for example be improved by using a hydraulic suspension.*

2. Test comfort of WIG transport
   *There is a lack of clarity regarding the comfort of WIG transport. It is recommended to test the level of comfort and to determine values of allowable motions per level of comfort. Tests on existing vehicles can for example be performed by using motion sensors.*

3. Develop sustainable powered WIG vehicles
   *There could be a huge demand for a sustainable high-speed method of transport. The high payload capability of WIG vehicles can be useful to provide in this demand. WIG vehicles have high payload capabilities in comparison to other high-speed vehicles such as: aircrafts and hydrofoils. Research shows that the payload capabilities of for example sustainable aircraft transport is often critical. Recommended is to investigate the feasibility and profitability of sustainable powered WIG vehicles operating as high-speed passenger ferries.*

4. Improve estimate of certification costs and duration
   *In this research the certification costs and duration are estimated by using general aviation theory. In future research, it can be useful to improve the estimate of certification costs and duration because it has a large influence on the price for which WIG vehicles can be acquired.*

5. Further develop business and marketing plans
   *In this study, WIG vehicles were acquired in year 3 and operated for 20 years. It is likely that the profitability can be increased by acquiring more WIG vehicles over time and to target a broader range of customers. Furthermore, risks can be reduced by spreading the acquiring of WIG vehicles over time. It is recommended to further develop the business and marketing plans.*

6. Create innovation process based on stage-gate system
   *The process to bring WIG transport from idea to market implementation can be difficult. Recommended is to make use of a stage gate system (Cooper, 1990). This system can be used to give shape to an innovation processes.*

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# 11 Appendixes

## 11.1 Certifying cost

The total cost to certify an aircraft is the cost of engineering, development support, flight test and tooling (assuming production tooling is used to produce at least some of the prototypes). This is estimated by using the following formula:

$$C_{CERT} = C_{ENG} + C_{DEV} + C_{FT} + C_{TOOL}$$

Cost of engineering, development support, flight test operations, tooling, manufacturing, quality control and the materials are estimated by using the following formula's:

$$C_{ENG} = 2.0969 * H_{ENG} * R_{ENG} * CPI_{2012}$$

$$C_{DEV} = 0.06458 * W_{airframe}^{0.873} * V_H^{1.89} * N_P^{0.346} * CPI_{2012} * F_{CERT} * F_{CF} * F_{PRESS}$$

$$C_{FT} = 0.009646 * W_{airframe}^{1.16} * V_H^{1.3718} * N_P^{1.281} * CPI_{2012} * F_{CERT}$$

$$C_{TOOL} = 2.0969 * H_{TOOL} * R_{TOOL} * CPI_{2012}$$

$$C_{MFG} = 2.0969 * H_{MFG} * R_{MFG} * CPI_{2012}$$

$$C_{QC} = 0.13 * C_{MFG} * F_{CERT} * F_{COMP}$$

$$C_{MAT} = 24.896 * W_{airframe}^{0.689} * V_H^{0.624} * N^{0.792} * CPI_{2012} * F_{CERT} * F_{CF} * F_{PRESS}$$

Hours of engineering, tooling and manufacturing are estimated by using the following formula's:

$$H_{ENG} = 0.0396 * W_{airframe}^{0.791} * V_H^{1.526} * N^{0.183} * F_{CERT} * F_{CF} * F_{COMP} * F_{PRESS}$$

$$H_{Tool} = 1.0032 * W_{airframe}^{0.764} * V_H^{0.899} * Q_m^{0.066} * F_{TAPER} * F_{CF} * F_{COMP} * F_{PRESS}$$

$$H_{MFG} = 9.6613 * W_{airframe}^{0.74} * V_H^{0.543} * N^{0.524} * F_{CERT} * F_{CF} * F_{COMP}$$

| Symbol | Description | number | unit |
|---|---|---|---|
| F_exp | Experience effectiveness | 0.95 | - |
| CPI_2012 | Consumer price index | 1.09 | - |
| W_airframe | Weight of the structural skeleton (50 % of displacement, 65% of empty) | 1534.00 | kg |
| W_airframe | Weight of the structural skeleton (50 % of displacement, 65% of empty) | 3381.89 | lbf |
| V_H | Maximum level airspeed in knots | 100.00 | knots |
| F_CERT | Certification factor | 1.00 | - |
| F_CF | Complex flap system (no=1) | 1.00 | - |
| F_comp | Use of composites factor (2 for complete composite frame) | 2.00 | - |
| F_taper | Factor tapered wing chord | 1.00 | - |
| F_Press | Unpressurized aircraft | 1.00 | - |
| R_eng | Rate engineering man hours | 116.49 | euro |
| R_tool | Rate tooling man hours | 78.95 | euro |
| R_MFG | Rate Manufacturing man hours | 68.60 | euro |
| P_SHP | Power | 751.00 | hp |

| Symbol | Description |
|---|---|
| N | Number of planned vehicles to be produced over a 5 year period |
| N_p | Number of prototypes |
| QDF | Quantity discount factor |
| Q_M | Estimated production rate of wig/month |
| H_ENG | Engineering man hours |
| H_Tool | Tooling man hours |
| H_MFG | Labor Man hours |
| N_engineers | Number of engineers needed to develop vehicle over a 3 year period |
| C_ENG | Total cost of engineering the aircraft |
| C_DEV | Total cost of development support |
| C_FT | Total cost of flight test operations |
| C_Tool | Total costs of tooling |
| C_MFG | Total cost of manufacturing |
| C_QC | Total cost of quality control |
| C_MAT | Total cost of materials |

## 11.2 Cash flow example: WSH-500 – Buenos Aires - Montevideo

| year | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Revenues | € - | € - | € - | € 39 682 526 | € 39 682 526 | € 39 682 526 | € 39 682 526 | € 39 682 526 | € 39 682 526 | € 39 682 526 | € 39 682 526 |
| Less: Operating cost | € - | € - | € - | € 3 140 000 | € 3 140 000 | € 3 140 000 | € 3 140 000 | € 3 140 000 | € 3 140 000 | € 3 140 000 | € 3 140 000 |
| Voyage cost | € - | € - | € - | € 1 864 000 | € 1 864 000 | € 1 864 000 | € 1 864 000 | € 1 864 000 | € 1 864 000 | € 1 864 000 | € 1 864 000 |
| Startup cost | € 1 059 889 | € 2 119 778 | € 12 718 669 | € - | € - | € - | € - | € - | € - | € - | € - |
| Total | € -1 059 889 | € -2 119 778 | € -12 718 669 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 |
| Less: Capital expenditures | € - | € - | € 63 593 345 | € - | € - | € - | € - | € - | € - | € - | € - |
| Total | € -1 059 889 | € -2 119 778 | € -76 312 014 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 |
| Less: Interest | € - | € - | € 7 631 201 | € 7 249 641 | € 6 868 081 | € 6 486 521 | € 6 104 961 | € 5 723 401 | € 5 341 841 | € 4 960 281 | € 4 578 721 |
| Total | € -1 059 889 | € -2 119 778 | € -83 943 215 | € 27 428 885 | € 27 810 445 | € 28 192 005 | € 28 573 565 | € 28 955 125 | € 29 336 685 | € 29 718 245 | € 30 099 805 |
| Less: Repayment | € - | € - | € 4 769 501 | € 4 769 501 | € 4 769 501 | € 4 769 501 | € 4 769 501 | € 4 769 501 | € 4 769 501 | € 4 769 501 | € 4 769 501 |
| Total cash flow | € -1 059 889 | € -2 119 778 | € -88 712 716 | € 22 659 384 | € 23 040 944 | € 23 422 504 | € 23 804 064 | € 24 185 624 | € 24 567 184 | € 24 948 744 | € 25 330 305 |

| year | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Revenues | € 39 682 526 | € 39 682 526 | € 39 682 526 | € 39 682 526 | € 39 682 526 | € 39 682 526 | € 39 682 526 | € 39 682 526 | € 39 682 526 | € 39 682 526 | € 39 682 526 | € 39 682 526 |
| Less: Operating cost | € 3 140 000 | € 3 140 000 | € 3 140 000 | € 3 140 000 | € 3 140 000 | € 3 140 000 | € 3 140 000 | € 3 140 000 | € 3 140 000 | € 3 140 000 | € 3 140 000 | € 3 140 000 |
| Voyage cost | € 1 864 000 | € 1 864 000 | € 1 864 000 | € 1 864 000 | € 1 864 000 | € 1 864 000 | € 1 864 000 | € 1 864 000 | € 1 864 000 | € 1 864 000 | € 1 864 000 | € 1 864 000 |
| Startup cost | € - | | | | | | | | | | | |
| Total | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 |
| Less: Capital expenditures | € - | € - | € - | € - | € - | € - | € - | € - | € - | € - | € - | € -23 847 504 |
| Total | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 34 678 526 | € 58 526 031 |
| Less: Interest | € 4 197 161 | € 3 815 601 | € 3 434 041 | € 3 052 481 | € 2 670 920 | € 2 289 360 | € 1 907 800 | € 1 526 240 | € 1 144 680 | € 763 120 | € 381 560 | € - |
| Total | € 30 481 365 | € 30 862 926 | € 31 244 486 | € 31 626 046 | € 32 007 606 | € 32 389 166 | € 32 770 726 | € 33 152 286 | € 33 533 846 | € 33 915 406 | € 34 296 966 | € 58 526 031 |
| Less: Repayment | € 4 769 501 | € 4 769 501 | € 4 769 501 | € 4 769 501 | € 4 769 501 | € 4 769 501 | € 4 769 501 | € 4 769 501 | € 4 769 501 | € 4 769 501 | € 4 769 501 | € - |
| Total cash flow | € 25 711 865 | € 26 093 425 | € 26 474 985 | € 26 856 545 | € 27 238 105 | € 27 619 665 | € 28 001 225 | € 28 382 785 | € 28 764 345 | € 29 145 905 | € 29 527 465 | € 58 526 031 |

| | |
|---|---|
| Capital vehicles [€] | 158 983 362 |
| Startup cost [€] | 15 898 336 |
| Total loan [€] | 95 390 017 |
| Total investments [€] | 79 491 681 |
| Loan repayment [€] | 4 769 501 |
| Interest [%] | 8% |
| Residual value [%] | 15% |
| Annual passengers total [PAX] | 235200 |
| Value based price [€] | 169 |
| Discount rate [%] | 10% |
| **NPV [€]** | **99 256 002** |

| | WSH-500 | 4x WSH-500 |
|---|---|---|
| Purchase price [€] | 39 745 841 | 158 983 362 |
| Interest in yr 4 [€] | 1 812 410 | 7 249 641 |
| Operating cost [€] | 785 000 | 3 140 000 |
| Voyage cost [€] | 466 000 | 1 864 000 |