WISE OR OTHERWISE?
THE
DREAM OR REALITY OF
COMMERCIAL WING IN GROUND EFFECT VEHICLES

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OVERVIEW

As marine vessels get faster, particularly with the new technologies such as WIG, they provide a transport solution that lies somewhere between that of conventional boat and aircraft. To get beyond the experimental phase, the development of these vessels must make a transition from technology-led to market-led, for they will have to operate within a competitive world. In particular, the cost of manufacture and operation must fit in with commercial expectations – but what are those expectations?

This paper:
- Provides an economic model to interpolate between the main cost elements of existing conventional boat and aircraft transport, so as to explore the commercial expectations which WIG vehicles must satisfy. Several vehicle and market scenarios are discussed.
- Considers obstacles to commercialisation and how these may change as both technology and market evolve.
- Questions the commercial viability of the WIG concept and discusses market entry and development strategy.
- Provides clear cost targets for designers to respond to.

ABOUT THE AUTHOR

Graham Taylor has a background in engineering and commercial management, supported by an MBA from Thames Valley University, London in 1995. He has held a variety of commercial positions within several industries, including the post of Technical Director of The Royal Institution of Naval Architects. He has maintained a close interest in the development of high speed marine vehicles for 20 years, is currently undertaking practical experimentation with a series of radio controlled ekranoplan models (Appendix A), and has published several papers on WIG.

1. INTRODUCTION TO THE COMMERCIALISATION OF WIG

WIG[1] (or WISE[2]) offers a new transport solution somewhere between boat and aircraft. Proposals for commercial WIG encompass the exotic trans-ocean passenger and freight proposals of Reeves[3], Hooker[4]and Stinton[5], through to the more modest proposals by Fischer[6] and Jörg[7]. For such ambitions to make the transition from dreams to reality they must work both technically and commercially, because successful WIG design is not just about the creation of a new type of vehicle, but also the creation of a new industry.

For WIG to become commercially successful it must obey two basic rules:

- Its price must not exceed that which the market will pay.
- Its cost must not exceed its price.

Therefore WIG cost of manufacture and operation must meet market expectations. Those expectations are highly influenced by the qualities and availability of similar transport 'competition', such as boat, aeroplane, train etc.

Knowledge of cost limitations from the outset provides clear design messages. Past approaches to exploring the fit of WIG within existing transport solutions include 'reverse transport efficiency', 'transport productivity', and the 'Karman-Gabrielle diagram'[8]. However they do not provide much insight into the factors needed for commercial success from industry start-up through to maturity.

This paper uses a crude model to explore commercial issues and attempt to answer the question of what the price of WIG should be and, therefore, present a clear target to designers. In so doing it moves WIG design from technology-led "what can we build" then "how can we sell it", to market-led "what can we sell" then "how can we build it".

1. AN ECONOMIC MODEL

An economic 'business case' model has been designed to interpolate between the main cost elements of existing conventional boat and aircraft transport, so as to explore the commercial

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[1] "Wing In Ground effect"
[2] "Wing in Surface Effect"
[3]Reeves J. M. L (1989) Enhanced Performance Low Flying Aircraft – A Future? Intersociety Advanced Marine Vehicles Conference. Arlington VA June 5-7, 1989.
[4]Hooker S. F. "Wingships: A Prospect for High Speed Ocean Transport" Jane's Surface Skimmers 1982.
[5]Stinton D. (1997) Heavy, Long-Haul Operations Using the Air-Sea Interface. RINA. Proc int. conference on Wing-In-Ground-Effect Craft (WIGs) 5-4 Dec. 1997 London.
[6]Fischer H. (1996) Some thoughts on the Use of lift-off-aids as one condition for the Economical Operation of Wingships. Proceedings of Ekranoplans & Very Fast Craft Workshop 1996. University of New South Wales pp 60-77
[7]Jörg G. W (1997) Tandem Airfoil Flareboats (TAF) RINA. Proc int. conference on Wing-In-Ground-Effect Craft (WIGs) 5-4 dec. 1997 London.
[8]Rozhdestvensky, K. V. (1995). Ekranoplans - Flying Ships of the Next Century . Proc. Institute of Marine Engineers, Sydney, Australia. Twenty-first Century Flying Ships, University of New South Wales Nov. 7-8 1995 pp 47-70

expectations which WIG vehicles must satisfy (Figure 1). The model uses the 'Total Direct Operating Costs Per Passenger' (TDOCPP) as a common denominator. The TDOCPP figures for boat and aircraft form the lower and upper limits respectively of a bandwidth within which WIG may be commercially viable. In essence they are the goal posts for designers.

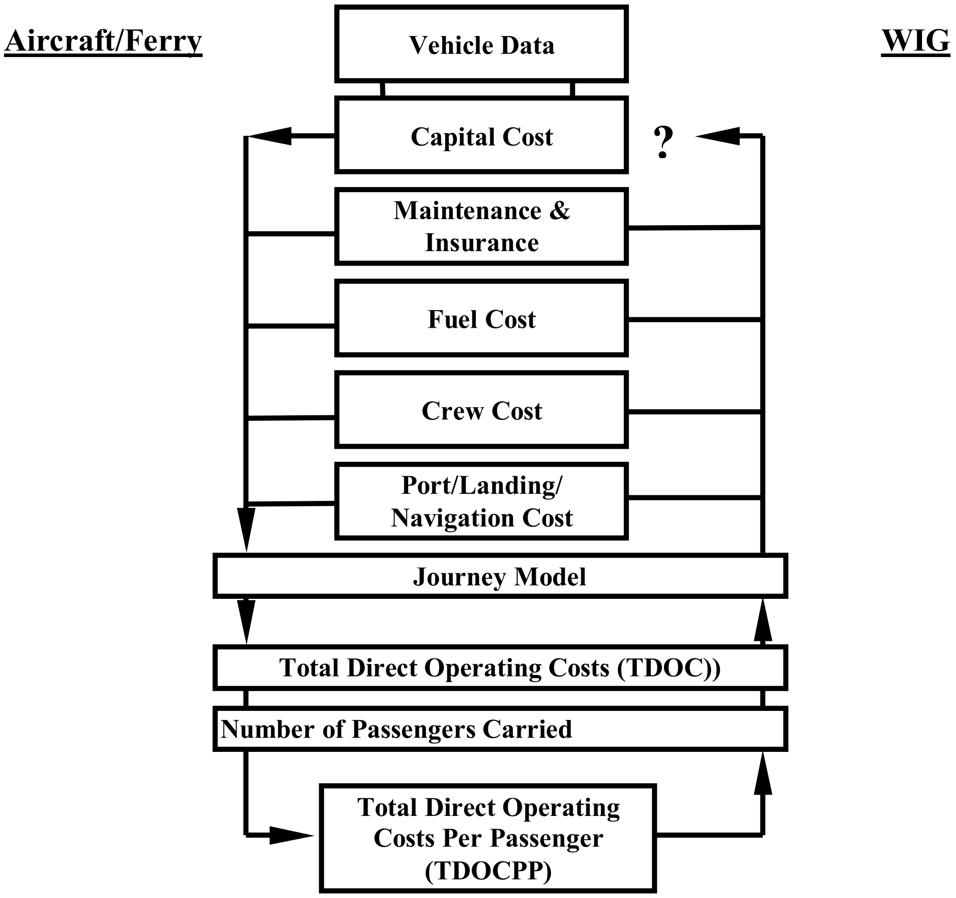

Figure 1: Analysis Framework – Main cost elements

2.1 ANALYSIS METHODOLOGY

We can make the quite reasonable assumption that the price a passenger is prepared to pay for travel on a WIG lies somewhere between the price of travel by aircraft and the price of travel by boat. By assuming that the fare price is the cost-per-passenger plus a percentage profit, and that the percentage profit is the same for aircraft and boat operation, we can remove profit from the equation and compare the vehicles in terms of cost per passenger. Therefore, to be competitive, the costs-per-passenger for a WIG must lie between that of the aircraft and the boat. The figures for aircraft and boat effectively form the limits of a 'bandwidth' of potentially competitive costs per passenger for WIG vehicles. By working backwards using the main cost element, a 'bandwidth' for the potential capital costs of WIG craft can be derived.

The model assesses WIG capital cost by examining main cost elements for a variety of transport vehicles over a hypothetical island-to-island route, working from capital and running costs of the vehicles to arrive at the total direct operating cost (TDOC). This is divided by the number of passengers carried to give the 'total direct operating cost per passenger' (TDOCPP - see Figure 1). The total direct operating cost per passenger figure derived from the competing transport vehicles is used as a guide to set target TDOCPP for WIG craft[9]. The model is then worked back by modelling estimated main cost elements for the WIG craft and using a goal-seeking sub-routine to derive capital cost figures for WIG craft that satisfy the target TDOCPP figures. As the TDOCPP forms the base line for fare pricing, comparison of craft by TDOCPP is essentially the same as comparison by fare price.

This approach is valid from two viewpoints:

1) The passenger, who may be presented with a variety of transport options for a given route and makes their choice based on their perception of the premium payable for dimensions of the service such as speed, comfort and convenience.
2) The potential operator who sees a route and may invest in one of a variety of transport solutions to service it.

2.2 MODELLED SCENARIOS

The model caters for a variety of industry conditions, spanning introduction through to maturity:

Scenario Definition

- *Open Competition:* Where the competing aircraft and passenger ferries are free to operate at common/typical hours per day for their class.

- *Constrained Competition:* There may be situations where the competing transportation is constrained to similar operating hours as WIG (e.g. insufficient demand outside daylight hours, day trips only etc.). Examples of this are the Quicksilver fast ferries, capable of a 24 hour commuter role but which, in fact, only carry high-value passengers one return trip per day to the Barrier Reef, or the Maldivian inter-island sea-plane service which only flies during daylight hours.

- *Niche Competition:* Where there is no existing competition to constrain WIG capital costs. In this model it is assumed that the WIG can be constructed for two-thirds of the capital cost of equivalent aircraft.

- *Formative Industry:* Where risks associated with pioneering WIG craft operations are reflected in short asset life and high interest rates on finance.

- *Established Industry:* Where, over time and experience, risk aspects have been reduced, (economic) asset life is lengthened and interest rates reduced.

[9] This paper makes the reasonable assumption that because the aircraft and ferry vehicles used in the model already exist they are commercially viable and therefore can serve as a benchmark.

Under *Open Competition* and *Constrained Competition* scenarios the WIG's are costed at both the average aircraft and average ferry TDOCPP; the target capital cost for WIG fall somewhere in between.

For *Niche Competition*, a notional 33 seater and 50 seater WIG is modelled against a 33 and 50 seater regional aircraft. This is further explored over a variety of journey distances and WIG speeds.

To explore the full range of commercial environments the model is applied under the market scenarios in the following matrix:

	Formative Industry:	*Established Industry:*
Open competition:		
Constrained competition:		
Niche competition:		

2.3 THE MODEL - NOTES AND ASSUMPTIONS[10]

2.3.1 Scenario Variables

The following elements are varied according to the market scenario: hours of operation, craft amortisation years, rate of residual value, and interest factor. See Appendix B and discussion below.

2.3.2 Comparable craft[11]

The model uses costing for:

- Saab 340 regional aircraft (33 passenger seats) capital cost $ 10,800,000
- Saab 2000 regional aircraft (50 passenger seats) capital cost $ 15,500,000
- 45m NGA fast passenger ferry (300 passenger seats) capital cost $ 13,000,000
- 38m Austal catamaran ferry (430 passenger seats) capital cost $ 4,000,000
- Wig 1 – 33 passenger seats, notional specification with power at 1/3rd that of Saab 340, with cruising speed of 150 km/h
- Wig 2 – 50 passenger seats, based on Raketa-2 specification with cruising speed of 150 km/h
- Wig 3 - 150 passenger seats, based on A.90 ekranoplan specification with cruising speed of 400 km/h

2.3.3 Route length

A length of 200 km is used as a base in the model. Effect of route length on commercial viability is explored for the 33 and 50 seat WIG under *Niche* conditions.

2.3.4 Capital costs and financing, amortisation and recovery

For the purpose of this paper a very simplistic common approach has been taken. Craft capital cost is assumed to be financed by a bank loan resulting in equal periodic payments, so

[10] More detail on the modelling and assumptions are set out in Taylor G K (1998) – see author bibliography
[11] It is argued that the price a customer is prepared to pay for transport is independent of the size of the craft. Thus the diverse craft used are all comparable at TDOCPP level as they perform the same function, and in this respect size is not important

avoiding depreciation complexities. The economic lives of the craft are co-incident with the term of the loan and differences in interest rates applied reflect perceptions of commercial risk. The model allows for port fit and ancillaries as a percentage of craft cost.

While financiers have built up a body of knowledge about aircraft depreciation, the difficulty comes when dealing with craft for which there is little track record, such as fast ferries and WIG's. With pioneering/developmental craft, not only is there a question concerning the longevity of the craft for economic purposes, but also the residual value of the craft may be affected by obsolescence as the type evolves. Under *Formative* industry conditions WIGs 1, 2 & 3 are written down in 6, 7, and 8 years respectively, whereas in the *Established* industry they are written down in 14 years. Financiers may also take into account the time horizon of the operating company and its likelihood of being around in the future to pay off the debt (credit rating), or finding another buyer for the craft. Interest rate is assumed to be affected by assessment of risk, so a further percentage is added to WIG craft.

2.3.5 Craft utilisation modelling

The number of passengers carried per annum depends on the 'usual hours of operation' according to the type of craft. This will be weather and visibility dependent although 350 days per year operation is assumed for all vehicles. The ability of a commercial WIG to fly at night or through fog is unclear. The model assumes that operating hours are restricted to good daylight visibility. Two seasons are modelled, with journeys rounded to round trips.

Hours vary according to scenarios:

- *Open Competition* – the hours of operation reflect the common/typical hours for the vehicle type.
- *Constrained Competition* – hours of operation of all vehicles are constrained to those of WIG.
- *Niche Competition* – hours as per *Constrained Competition*

2.3.6 Other elements included:

- The model makes reasonable allowance for vehicle acceleration and deceleration times when leaving and entering port, and also aircraft climb, descent and taxi time.
- Estimate of crew costs.
- Port, landing and navigation costs can be a very significant[12] element of total costs, depending on regions and facilities used. This is difficult to model and is omitted because this paper considers WIG in a region unlikely to be served by sophisticated systems. However the TDOCPP, particularly for aircraft, may be understated.
- Fuel is costed at $200 per tonne for all vehicles.
- Hull insurance is taken as 1% of capital cost for all craft, and 1.5% for WIG, reflecting uncertainty of risk. Maintenance is charged at 4% of capital cost per year except where specified by aircraft manufacturer.
- The speed/distance sensitivity study allows power and fuel consumption to increase with speed, as a percentage of the equivalent aircraft power: 150 km/h = 33.3% to 550 km/h = 90%.

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[12] typically 20% for aircraft in Europe

3 FINDINGS

The results for the assessment of WIG capital costs for a journey of 200 km according to the various market conditions are summarised in Figure 2.

Summary: Capital Cost Results - For 200 km journey

	Formative Industry				Established Industry			
	At Aircraft TDOCPP		At Ferry TDOCPP		At Aircraft TDOCPP		At Ferry TDOCPP	
	TDOCPP	Cap Cost	TDOCPP	Cap Cost	TDOCPP	Cap Cost	TDOCPP	Cap Cost
Open Competition								
WIG 1	$33.01	$2,250,242	$11.09	-$313,147	$33.01	$3,633,443	$11.09	-$505,636
WIG 2	$33.01	$4,293,486	$11.09	$6,116	$33.01	$6,280,277	$11.09	$8,946
WIG 3	$33.01	$32,646,688	$11.09	$7,550,054	$33.01	$44,053,170	$11.09	$10,187,981
Constrained Competition								
WIG 1	$44.62	$3,608,411	$15.70	$225,187	$44.62	$5,826,465	$15.70	$363,608
WIG 2	$44.62	$6,565,078	$15.70	$906,502	$44.62	$9,603,038	$15.70	$1,325,981
WIG 3	$44.62	$45,943,721	$15.70	$12,820,571	$44.62	$61,996,077	$15.70	$17,299,972

Niche Competition		Formative Market		Established Market	
		TDOCPP	Cap Cost	TDOCPP	Cap Cost
WIG1: % cap cost to equivalent aircraft	66.7%	$75.33	$7,200,000	$51.90	$7,200,000
WIG2: % cap cost to equivalent aircraft	66.7%	$63.89	$10,333,333	$47.18	$10,333,333

Figure 2

The capital costs, at ferry and aircraft TDOCPP represent the goal posts between which there is a bandwidth for commercially viable WIG craft. These are considered against the capital costs of the conventional vehicles: 33 seat aircraft $10.8m, 50 seat aircraft $15.5m, 300 seat 50knt ferry $13m, 430 seat 30knt ferry $4m. Figure 3, charting the results, shows the bandwidth between the target capital costs of WIG when priced against aircraft and ferry TDOCPP. This bandwidth gives some freedom for the WIG designer and marketeer.

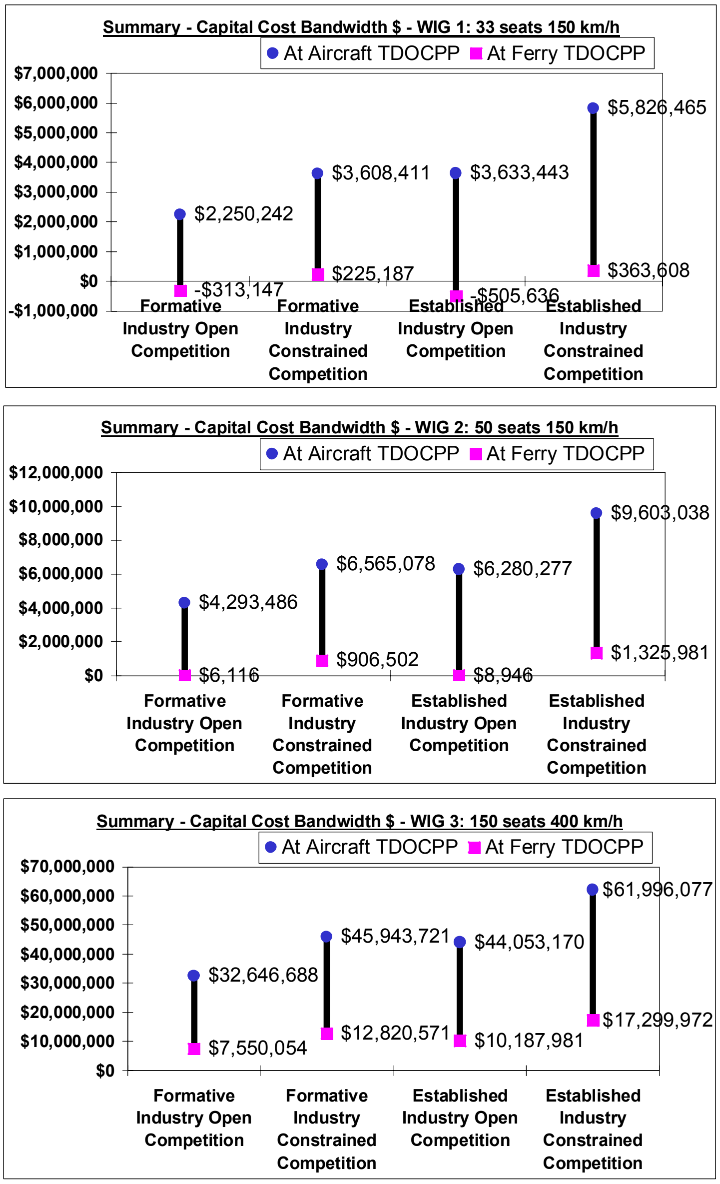

Figure 3: Capital Cost Bandwidths - Chart of Figure 2

3.1 DISCUSSION: OPEN & CONSTRAINED COMPETITION/FORMATIVE & ESTABLISHED INDUSTRY

3.1.1 Open Competition.

Open Competition is the most difficult business environment because the competing vehicles have the freedom to operate outside the daylight hours assumed for WIG. Craft costs are lowest under *Formative Industry* conditions because of the burden of interest rates and quick write-down that the TDOCPP carries.

Under *Established* conditions the craft capital cost are able to rise because the burden of interest rates and quick write-down is relaxed. It seems ironic that in the early years competitive pressure keeps the capital cost down yet once industry has gained experience to build craft cheaper, the financial elements allow it to rise.

3.1.2 Constrained Competition

When competing vehicle operating hours are constrained to those of WIG the cost of WIG can be higher. Design of real WIG vehicles to the costs under *Constrained Competition* conditions appear much more achievable than under *Open Competition* scenarios.

3.1.3 The WIG Vehicles.

The low, and negative, figures derived for target capital cost of WIGs 1 & 2, when priced against ferry operations show that it is not possible for WIG to match ferry costs or fare prices. In *Open* and C*onstrained* competitive environments it will be necessary to pitch the WIG transport solution closer to that of aircraft. The bandwidth available for 150 seat WIG 3 is more viable, when one considers that the list price for the equivalent seating short haul Boeing 737 700 airliner is $43 – 51m. WIG 3 is able to support a high capital cost by virtue of its high speed (400 km/hrs) and capacity which allows its costs to be spread across more passengers. Appendix C illustrates the main cost elements for the modelled vehicles. It shows that fuel costs are a relatively small element of total operating costs and explodes the myth that fuel/power efficiency is key to WIG's competitive advantage over aircraft, since savings on the fuel element will have little effect on the overall costs.

3.2 Niche Competition

Open and *Constrained* analysis used a 'free market' approach[13], working backwards to derive a target capital cost of WIG craft in a competitive situation. The *Niche Competition* approach assumes that competition from other forms of transport is not an issue, and so does not drive the capital cost of the craft.

For the 33 and 50 seater WIG craft the capital cost is pre-set to a figure thought to be realistically achievable[14], at two-thirds that of the equivalent aircraft, and the TDOCPP is calculated according to *Formative* and *Established* market conditions. The vehicle costs and TDOCPP for 200 km journey, at a speed of 150 km/h are again set out in Figure 2. This shows the TDOCPP figures under *Niche* conditions to be considerably higher than those of *Open* and *Constrained* competition, reflecting the higher craft capital cost and indicating that the fare price would have to be double that for a notional aircraft[15] and five times that of a conventional ferry. Clearly the market will have to be researched to establish if there is sufficient demand for such a premium service. Figure 2 also shows that the TDOCPP (and hence necessary fare price) drops considerably between the *Formative* and *Established* industry conditions.

3.3 Exploring the Speed and Distance Envelope

The 33 and 50 seater WIG models have been explored further under *Niche/Formative* and *Niche/Established* conditions, by varying the craft speed (150 – 550 km/h) and journey distance (50 – 500 km). This gives a view of the WIGs competitiveness relative to aircraft.

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[13] or 'market led' approach

[14] a 'cost plus' approach

[15] note it is more expensive to travel 1 km by London Bus than by Concorde

Under *Formative* conditions (Appendix D) the 150 km/h 33 seater WIG has a TDOCPP which is only less than the SAAB 340 for journeys less than 60 km (approx.)[16]. However, if craft speed is increased to 250 km/h the WIG becomes price competitive for journeys up to 170 km, because its speed allows extra trips to be achieved in the operating day, and so carry more passengers to offset its capital cost. Under *Established*[17] conditions the 33 seater 150 km/h WIG was found to return a TDOCPP less than the aircraft for journeys up to about 190 km. Similar results were found for the 50 seater WIG (Appendix E). At 150 km/h in *Established* conditions its TDOCPP is cheaper than the equivalent aeroplane on trips up to 160 km. Under *Formative* conditions however, it was found to be only competitive up to 60 km. Two messages are clear: higher speed enables more trips and a lower total cost per passenger, and that WIGs competitiveness is limited to short range operation in the early years because of the high burden of interest rates and cost write-down.

3.4 Notes

1. Only the price of new aircraft were used in the model. Second-hand aircraft are available at large discount and, since capital cost is key this will have a dramatic impact to weaken the commercial competitiveness of WIG. Against this, the exclusion of aircraft navigation and landing costs may have painted aircraft economics in a better light than may be the case in many geographic/route locations.
2. The target costs calculated through the above methods are the *costs to the operator*, or the *price of the craft*. This is not the *manufacturing cost of the craft*. Clearly, to be commercially viable the manufacturing cost of the craft will be substantially lower than the price for which it is sold. One could expect a mark-up of 50% to give a gross margin of 30%.

4 DISCUSSION: WISE OR OTHERWISE - FROM DREAM TO REALITY

This paper has provided ballpark guidance on the potential costs and operating limitations of WIG craft for a reasonable business case to be made. It is also clear that factors combine to limit the commercial opportunity of WIG:

- low hours of operation
- short journey distance
- risk, obsolescence/development, economic lifetime
- competitive environment
- tight capital cost limit (depending on speed)

The main benefits from the ground-effect tend to be mutually exclusive: 1) a substantial reduction in propulsive power or fuel requirement, or 2) a substantial increase in load for the same power, compared to other vehicles. In this paper fuel economy has been found to be a second order issue compared to that of capital cost. This suggests that WIG designers focus on (2) - increasing load for the same cost, rather than (1), and so maximise the revenue earning capacity against which the capital costs can be set. Another response is to focus on high operating speed, which again enables the capital cost to be set against more trips and more passengers.

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[16] The number of trips achievable in a day is rounded to return journeys, which accounts for the steps in the charted results

[17] not illustrated

The analysis has shown market attractiveness (by virtue of its ability to support large TDOCPP) in order:

1. Niche
2. Constrained Competition
3. Open Competition

Industry start-up conditions (i.e. *Formative Industry*) are not as favourable as those when the industry has become more established. WIG is a victim of its own 'newness' and until WIG craft have gained a track record of some 10 years service, the financial factors surrounding the capital costs conspire against it.

On the basis of the analysis the WIG industry appears best begun by developing a craft for niche applications, such as to the Great Barrier Reef, where there is little comparable competition and a high fare price is more easily supported. Far from being a disadvantage, the short distance over which WIG is viable defines a niche which is poorly served by other solutions. It still lies beyond the reach of many high-speed ferries, while 'short haul' aircraft have ranges of 1500 km and their speed advantage is eroded by climb, descent and airport time[18]. Indeed, the only form of transport offering a similar utility is the TGV/bullet train, which requires high capital and infrastructure spend, and has little relevance in the marine environment.

This suggests that designers look to areas in the world where the special qualities of WIG can be used to maxim advantage. For example the Malay Archipelago in East Asia is particularly attractive because WIGs' absence of water contact makes it less susceptible to the strong currents funnelled between the islands by the Pacific and Indian Oceans[19].

Once a footing in niche markets has been established and a body of knowledge has been built about the development of WIG, it will be better placed to expand into *Constrained* and *Open* competition market areas.

Wise or otherwise - dream to reality

The basics of WIG technology have existed for several decades. Whether WIG now makes the transition from technology dream to business reality depends on commercial wisdom. Developers must respond to the commercial dimensions of the design specification, in particular to the tight cost limitations. The wise will match vehicle design strategy with a sensible business strategy that marries craft, market and industry evolution. Otherwise there lies the danger of presenting an over-ambitious project to an inappropriate market in an ill-prepared industry.

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[18] The aircraft offering the greatest utility against WIG were identified as the Bombardier Q8 series 100 – 400 offering 37 – 78 passenger seats, with grass-strip runway capability. Prices $11.5m - $18m

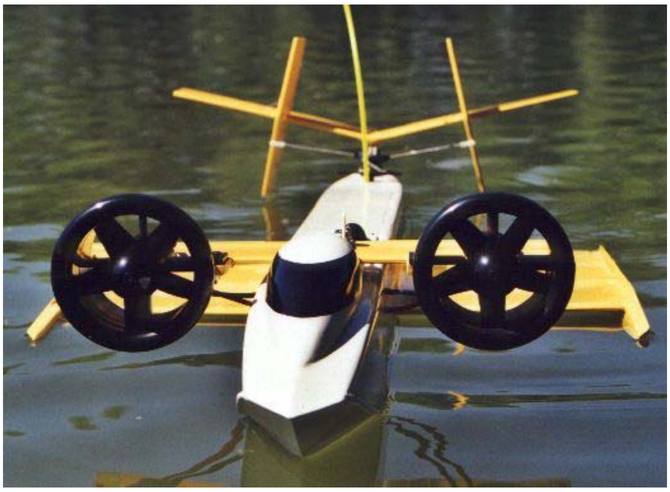
[19] Markets identified in order of attractiveness: East Asia, Caribbean, Europe. See Taylor GK (1997) Market Focused Design

APPENDICES

APPENDIX A.
The author is currently conducting practical experiments in ground effect using radio-controlled models.

Experimental WIG model based on Russian ekranoplan configuration (exhibited at Dec 1997 RINA Wing in Ground Effect Conference, London)

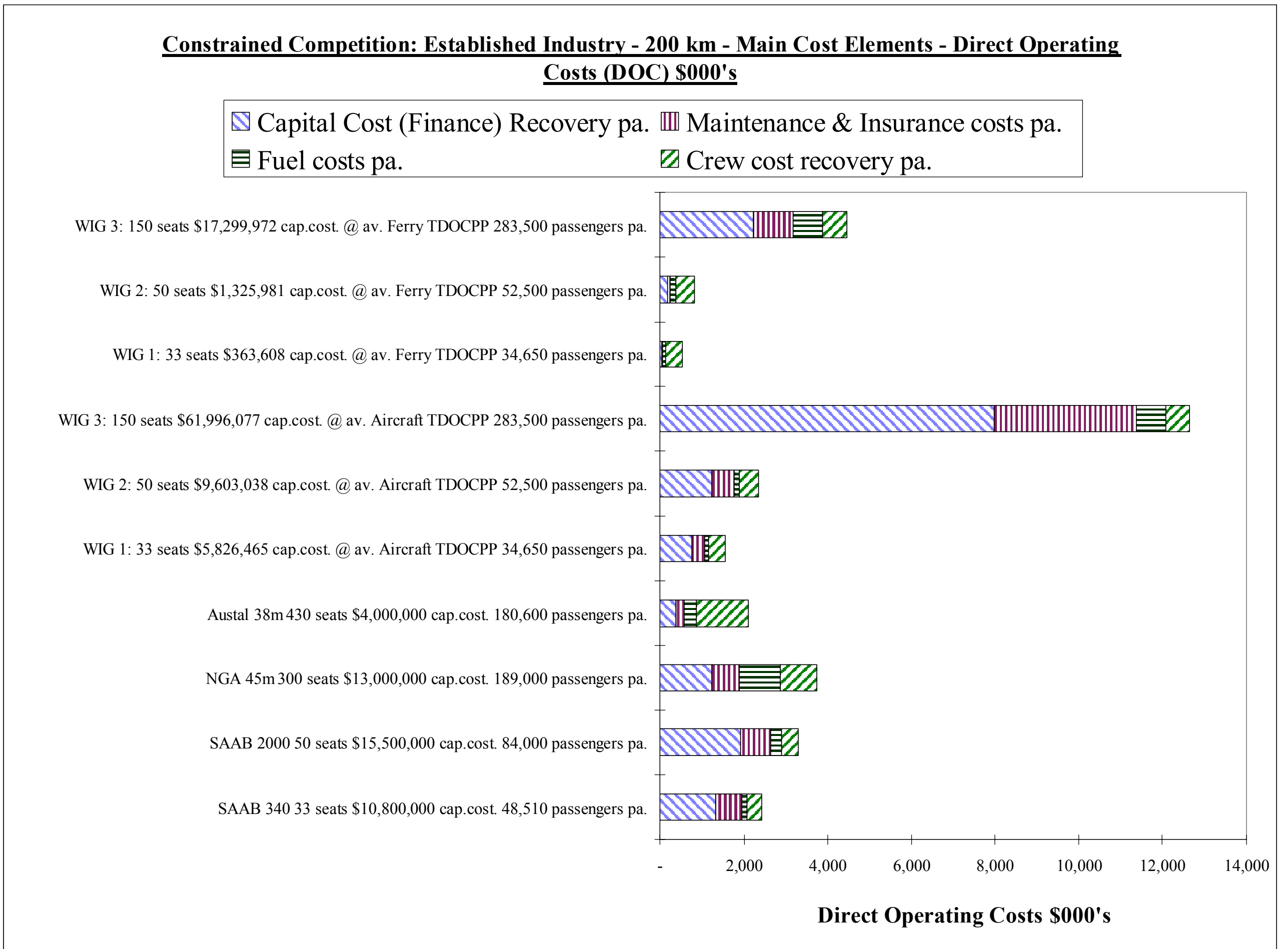
Recent ekranoplan model



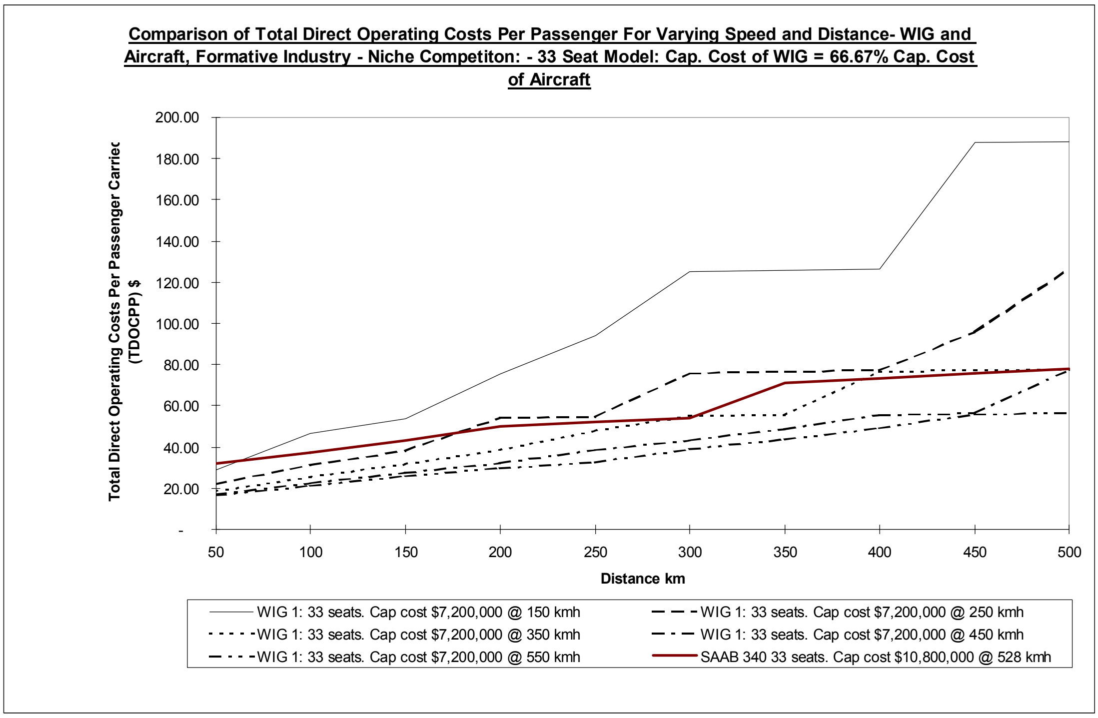
APPENDIX B. Scenario Variables:

Scenarios	SAAB 340	SAAB 2000	NGA 45m	Austal 38m	WIG 1: 33 seats	WIG 2: 50 seats	WIG 3: 150 seats
Hours of Operation							
Open Competition:							
Usual hours of operation/day (base)	12	12	12	12	8	8	8
Constrained Competition:							
Usual hours of operation/day (base)	8	8	8	8	8	8	8
Formative Industry							
Amortisation years (per)	14	14	20	20	6	7	8
Rate of residual value	15%	15%	10%	10%	0%	0%	0%
Interest factor. (rate)	5%	5%	5%	5%	7%	7%	7%
Established Industry							
Amortisation years (nper)	14	14	20	20	14	14	14
Rate of residual value	15%	15%	10%	10%	10%	10%	10%
Interest factor. (rate)	5%	5%	5%	5%	6%	6%	6%

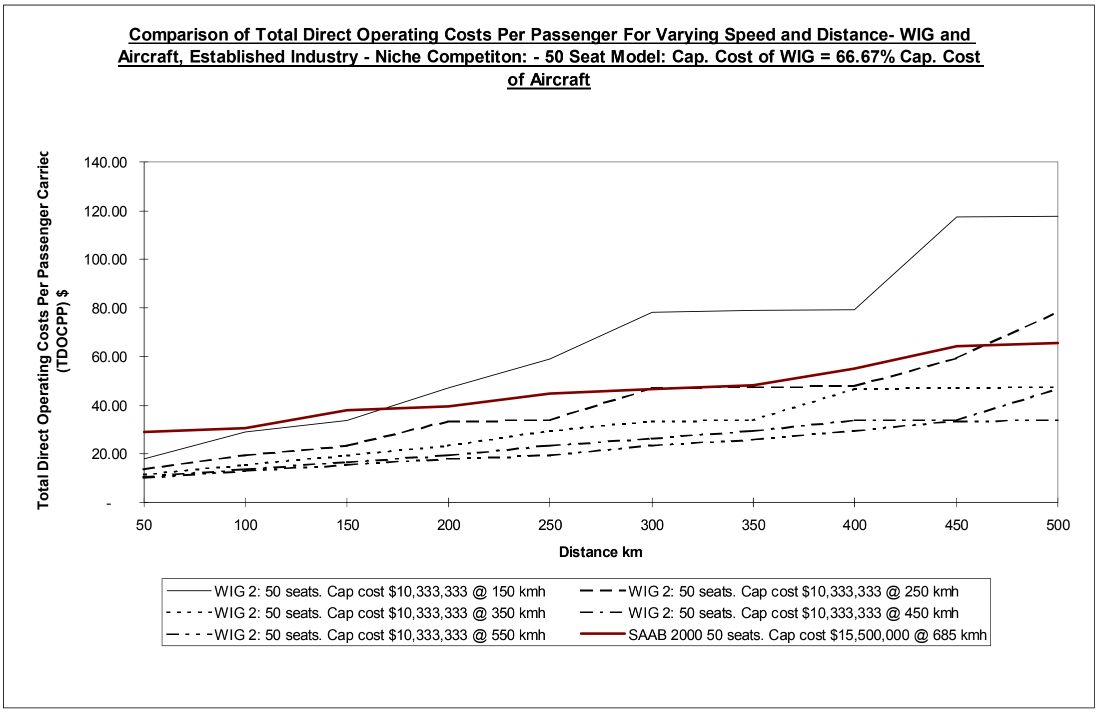
APPENDIX C. Illustration of main cost elements for selected craft



APPENDIX D. Comparison of TDOCPP for 33 seater WIG against equivalent aircraft, varying speed and journey distance.



APPENDIX E. Comparison of TDOCPP for 50 seater WIG against equivalent aircraft, varying speed and journey distance.



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