Team 1107

The Above Islander

"How many airships would be required to replace the Cook Strait Ferries?"

Abstract

The purpose of this report was to determine the amount of airships required to successfully replace the Cook Strait ferries, in an efficient way. In this investigation, we have determined that the optimal number of airships required is 15 airships, due to the concerns for both safety, efficiency and sufficient spare airships when other airships require servicing or slight increases in demand due to seasonal patterns. The model used to determine this quantity involved calculating the minimum integer value of airships necessary to decrease the traffic intensity (amount of cargo arriving relative to the transportation volume) to less than 1. This means that over a period of 24 hours the rate of transportation exceeds the rate of arrival of cargo into the queue, therefore resulting in an efficient system. To determine the optimal amount of airships we had to first find how much cargo/passengers we had to shift per day, how much an airship could carry, and how long it would take for an airship to complete a trip. This led us to the answer of 11 airships, which was increased to 15 to ensure there was an adequate number of excess airships in times of demand that exceeded the base capacity, or for maintenance requirements.

Introduction

The Cook Strait ferries are facing operational problems, while large amounts of carbon emissions are released into the atmosphere. The ships are planned to be withdrawn and need replacement, as seen in Figure 1. Yet, they are vital for the economy and provide transportation for locals and tourists alike. This conundrum can be solved by our proposal: replacing the ferries with airships. Not only does this reduce the travel time, but also significantly lowers carbon emissions[1]. In this report, we will therefore model the transportation of cargo and passengers, and provide a projected value for an economic and reasonable number of airships to achieve this purpose.

Ship	Age	
	As at 2021	At planned service withdrawal date
Aratere	23	27
Kaitaki	26	29
Kaiarahi	23	27

[2] *Figure 1: Age of current Interislander fleet*

[1] Space, S. I. (2023, October 6). The airship's second wind: How cargo airships could revolutionise logistics. Sent Into Space. https://www.sentintospace.com/post/could-cargo-airships-revolutionise-logistics
[2] Interislander Ferries and Terminals: Detailed Business Case. (2021). In transport.govt.nz. KiwiRail.

Interpretation and Definition of Key Terms

We have defined Cook Strait ferries as simply the Interislander and Bluebridge ferries. This is what we aim to replace with our airships. We aim to model the required airships to replace every ferry in both fleets.

We have defined airship as a a lighter-than-air aircraft having propulsion and steering systems[3]. Through this definition, we have selected one particular model of airship, ATLAS-LTA's ATLANT-300 heavy cargo model airship.

We have defined replacement as to carry the same amount of cargo as the Cook Strait ferries over the same time period.

Model

1.1 General Model

The model for this context is derived from queuing theory – a branch of mathematics which explores queues and waiting lines. While there are many forms of components of queuing theory which can be used for a number of applications, (e.g. reducing wait times in lines, preventing congestion, and in this case optimising public transport), we will use a simplified model which assumes the linear input and output of cargo items within the system. While this isn't necessarily completely accurate, in the context of cargo being transported across Cook Strait, generally we can claim a constant flow of cargo is occurring, when we ensure that congestion is cleared by the end of any particular day. This is done by modelling the number of active airships required by daily metrics of cargo data. With this:

$$\rho = \frac{\lambda}{N\mu}$$

Where ρ is traffic intensity of the system; λ is the arrival rate at one of the airship ports, (in items per hour); N is the number of **active** airships; and μ is the rate of transportation, (in items per hour).

For the system to remain in a steady flow, and avoid a backlog of any particular item of cargo, the traffic intensity of the system must be less than 1. Therefore the statement,

$$\rho < 1$$

is determined. This model effectively finds the minimum number of airships (N) that would be sufficient in transporting all of the passengers each day across Cook Strait. This number of **active** airships would result in no build-up of backlog within the system.
This is an advantage as it accounts for both books and customers that arrive without a booking in advance, based on the statistics provided by NZ Interislander.

[3] Airship. (2024). In Merriam-Webster Dictionary. https://www.merriam-webster.com/dictionary/airship

1.2 Required Transportation Quantity

The two Cook Strait Ferry services, Interislander and Bluebridge, transport a significant amount of cargo every year, coming in the following four types; passengers, cars, trucks and rail wagons (containers). Our model will show the number of active airships required to replace both of these services. The total quantity of cargo transported by type can be summarised in the following table:[4][5][6][7]

Cargo Type	Yearly Transport Quantity	Average Transport Quantity Per Day
Passengers	1,332,692	3,651.21
Cars	555,326	1521.44
Trucks	46,643	127.79
Rail Wagons (Containers)	52,000	142.47

When calculating the total transport quantity of cars and trucks, due to limited data, we had to assume that the ratio between Interislander cars and trucks is the same for Bluebridge cars and trucks. (Interislander and Bluebridge are the two Cook Strait ferry companies.)

1.3 Arrangement of Cargo/Passengers

The type of airship we are using is the ATLANT-300 heavy cargo model. We have decided this airship is best suited to the requirements of lifting heavy loads, being purpose built for cargo, being fully automated with no flight crew and being able to withstand strong winds even when landing and taking off (up to 45 kt crosswinds)[8]

To maximise the space available with the specifications of the airship cargo bay[9], a potential model of the cargo bay layout has been created. This consideration is based on a design of just cars and passengers being in this specification of the airship we have adapted for this specific use. We have created a separate design for the transportation of rail wagons and trucks. We grouped together these two things as it was likely people who wanted to take their car across the Cook Strait ferries also are likely to want to go on the same airship themselves which is how it currently works. Then we put the rest of the more industrial cargo in a separate airship category.

First we found the ratio of passengers:cars and trucks:rail wagons

- 3651.29/1521.44 = 2.4:1 (2.4 passengers for every 1 car)

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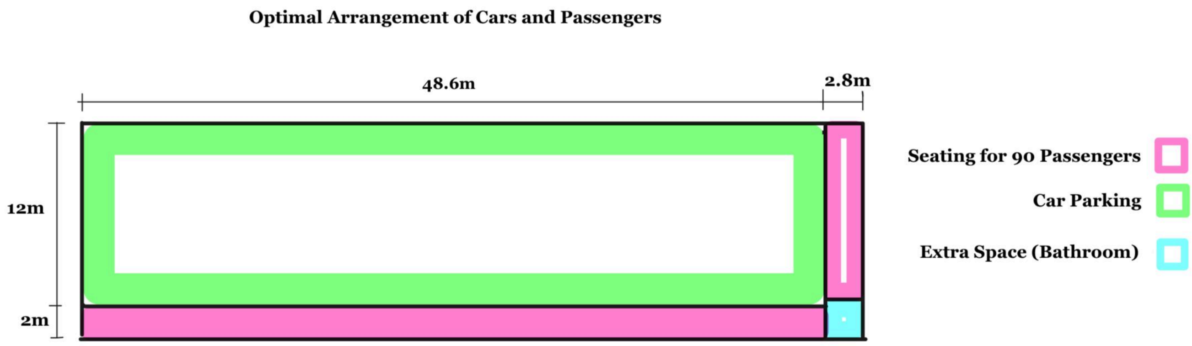
4 (*The History of the Interislander Ferry - Interislander - Cook Strait Ferries*, n.d.-b)
5 StraitNZ Bluebridge Freight Information. (n.d.). https://www.bluebridge.co.nz/freight/
6 Interislander Ferries and Terminals: Detailed Business Case. (2021). In transport.govt.nz. KiwiRail.
7 Fox, A. (2024, March 30). Bluebridge ferries: the quiet Cook Strait achiever. NZ Herald. https://www.nzherald.co.nz/business/bluebridge-ferries-the-quiet-cook-strait-achiever/EDOHGM62WFF3XARFYNQW36QRCA/
8 ATLANT Cargo Airship | Atlas LTA Advanced Technology. (2021, February 21). Atlas LTA Advanced Technology.
9 ATLANT Cargo Airship | Atlas LTA Advanced Technology. (2021, February 21). Atlas LTA Advanced Technology.

- 142.47/127.79 = 1.115:1 (1.115 rail wagons for every truck)

In our layout we tried to get as close as possible to this figure, while taking into account other concerns such as passenger experience and the law of the minimum which means that the rate of transportation is not dictated by total capacity but by the most limiting factor, either weight or volume. For passengers/cars this meant we took 45 cars and 90 passengers as the limit was due to volume rather than weight. For rail wagons and trucks each weighing 28,200kg[10] and trucks 35,000kg[11] respectively. The capacity of the cargo was limited by the weight rather than the volume. This meant that to get as close as possible to the ratio we took 2 trucks and 3 rail wagons on each airship trip.



This was the design we came up with for putting cars and passengers together within the cargo bay dimensions. Each car park was a standard 5.4m long and 2.4m wide[12] and then the right hand seating was 7 rows of 4 seats and the bottom seating was 31 rows of 2 seats. Giving a total of 90 seats. We used seating dimensions of 1.56m (including leg room) x 0.45m. We then checked that this met weight specifications. With 90 passengers + 90 seats (assumed 15kg) coming in at 9000 kg and 45 cars (with a weight of 1,947kg) being 87,615 kg. For a total of 96,615kg, under the prescribed limit of 165,000kg[13].

For the design of the 2 trucks and 3 rail wagons this was simple as two trucks would fit in a row with a maximum length of 19m[14] and a width of 2.55m[15] and the rail wagons with dimensions of 5.89 x 2.35 x 2.36 m[16] meant that they could easily fit into this space as weight was the limiting factor as 2 trucks

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[10] Blue Water Shipping. (n.d.). 20 foot dry container | Specifications and dimensions. https://www.bws.net/toolbox/container-specifications/20-foot-dry

[11] Bhatt, S. (2024, May 27). How much does a semi truck weigh? A comprehensive guide. Grimmsautomovation. https://www.grimmsautomovation.com/blog/how-much-does-a-semi-truck-weigh-a-comprehensive-guide/

[12] On-site car park requirements - Building and resource consents - Wellington City Council. (n.d.). Wellington City Council. https://wellington.govt.nz/property-rates-and-building/building-and-resource-consents/resource-consents/before-you-apply-for-a-resource-consent/on-site-car-park-requirements

[13] ATLANT Cargo Airship | Atlas LTA Advanced Technology. (2021, February 21). Atlas LTA Advanced Technology.

[14] NZ Transport Agency. (n.d.). Semi-trailers | NZ Transport Agency Waka Kotahi. https://www.nzta.govt.nz/vehicles/vehicle-types/vehicle-classes-and-standards/vehicle-dimensions-and-mass/heavy-trailers-and-vehicle-combinations/semi-trailers/

[15] NZ Transport Agency. (n.d.-a). Heavy trailers and vehicle combinations | NZ Transport Agency Waka Kotahi. https://www.nzta.govt.nz/vehicles/vehicle-types/vehicle-classes-and-standards/vehicle-dimensions-and-mass/heavy-trailers-and-vehicle-combinations/

[16] Container and wagon types. (n.d.). KiwiRail Freight. https://www.kiwirailfreight.co.nz/rail-freight/container-and-wagon-types/

(35,000kg each) came to 70,000kg and 3 rail wagons (28,200kg each) 84,600 came to a total of 154,600 also under the prescribed limit of 165,000kg.

We also factored in that fuel would be required to be added so for our travel time of 70 mins (see below) this would require 1,514kg of fuel as explained below and with this weight added in we still had some allowance between our load and the maximum airship capacity

This meant in total for each car/passenger airship 45 cars and 90 passengers could be carried and for the truck/rail wagon airship 2 trucks and 3 rail wagons could be carried safely and this was what we found to be the most efficient way.

1.4 Time Taken for Trips

To calculate μ, the rate of transportation (items/hour), we need to determine the maximum number of trips that can be conducted in a 24 hour period.
The time taken for the total trip is subdivided into five sections:

1. Loading Time — The time taken for both cargo, passengers and fuel to be fully added to the airship.
2. Takeoff Time — The time taken for the airship to reach the cruising altitude for the flight.
3. Flight Time — The time taken for the airship at cruising speed to travel until the beginning of landing
4. Landing Time — The time taken for the airship to return to ground level from the cruising altitude
5. Unloading Time — The time taken for both the cargo and passengers to debark the airship

Each of these times must be calculated with the maximum theoretical time in mind, so that any delays due to weather conditions or boarding time do not cause a backlog in the scheduling of flights.

1.4.1 Loading Time

The fuel required to travel the total distance is 1,514 kg, calculated by a theoretical maximum flying time of 70 minutes with 10% contingency, given a fuel consumption of 1,180 kg/h[17].
With a standard rate of fuelling of 2000 gallons per minute[18], this fuel requirement can be achieved in less than a minute of fueling.

The majority of loading time for both cargo and passenger airships are the shuffling of cars, passengers and other cargo onto the loading bay. With the layouts used above, on the passenger airship, only 45 cars and 90 passengers need to be loaded, which can be achieved comfortably within a 45 minute period.
Similarly, on the cargo airship, only 2 trucks and 3 railway wagons (containers) need to be loaded, which can comfortably be achieved in a 30 minute period.
Thus, the loading times for cargo airships and passenger airships are 30 and 45 minutes respectively.

1.4.2 Takeoff Time

The time taken to reach the cruising altitude of 1.2km can be modelled as:

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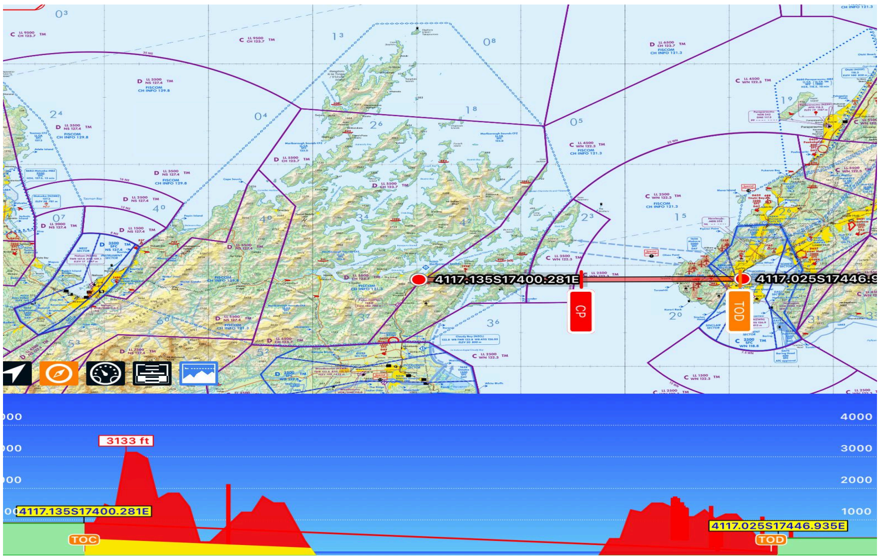
[17]Lobner, P. (2022). Atlas LTA Advanced Technology, Ltd.
https://lynceans.org/wp-content/uploads/2021/04/Atlas-LTA-Advanced-Technology-airships-converted.pdf
[18]Ayson, E. D., Dhanani, R. R., & Parker, G. A. (1970). The 747 Fuel System.
https://www.fire.tc.faa.gov/pdf/fsr-0178.pdf

$$U - W = m \times \frac{2d}{t^2}$$

Where U is the thrust force, W is weight force, m is mass, d is distance and t is time taken. A cruising altitude of 1.2 km was chosen as it is able to comfortably clear the highest altitude point across the flight path.



The takeoff can be assumed to be entirely vertical, and the model of airship used has a total thrust force of 3.295 million Newtons, calculated by 32 6,000 kgf lift propulsion systems and 8 18,000 kgf ejector lift systems.

With the weight force of a full capacity airship (165 tonnes) equal to 1.617 million Newtons, the resultant calculation is the following:

$$U - W = m \times \frac{2d}{t^2}$$

$$3295000 - 1617000 = 165000 \times \frac{2 \times 1200}{t^2}$$

$$1678000 = \frac{396000000}{t^2}$$

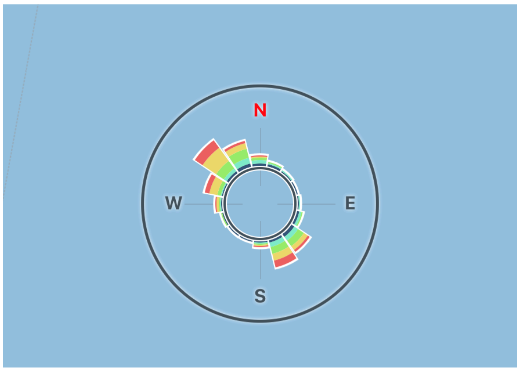
$$t = \sqrt{\frac{396000000}{1678000}}$$

= 15.362 seconds

This means, at maximum thrust, the airship could reach the cruising altitude in just 15.362 seconds. However, this is likely unsafe at a full capacity and with passengers due to such enormous forces, so a more reasonable time for taking off is 5 minutes.
Thus, the time allowed for taking off in the model is 5 minutes.

1.4.3 Flight Time

The total distance to travel is 65km. At a cruising speed of 120km/h, this distance can be covered in 32.5 minutes. However, despite wind conditions never being unsafe to fly in, they can impede on the speed of travel in extreme conditions.
The wind rose for the Cook Strait Region is included below:



The worst case scenario for conditions are 35kt NW winds, which while infrequent, do occur during some of the days, and thus need to be accounted for so that backlog is not produced. Using a vector diagram, the total impeding force is
$35sin(\pi/2)$ = 25kt. An impedance of 25kt results in a decreased speed by 46 km/h, which constitutes a total time of 53 minutes.

1.4.4 Landing Time

Continuing to use these worst case times, a more safe approach to the industry standard descent speed of 2.54 m/s[19], the total landing time is 8 minutes.

With the combined times of 13 minutes of takeoff and landing, and the worst case cruising time of 53 minutes, a total time of 66 minutes is required to travel between the islands. Increasing this to 70 minutes provides additional contingency.

1.4.5 Unloading Time

Unloading of cargo should take the same amount of time as loading, equal to 30 minutes for cargo airships and 45 for passenger airships.

Thus, adding all of these together, we produce the final values for t used in the model:
- $45 + 70 + 45 = 160$ minutes **(Passenger)**
- $30 + 70 + 30 = 130$ minutes **(Cargo)**

1.5 Arrival Rate Calculation

Based on current transport data, there are 152.13 (2 d.p.) people arriving per hour and 63.39 (2 d.p.) cars per hour arriving at each stop (Picton and Wellington) on average. Therefore there are 2.40 (2 d.p.) people per car crossing the Cook Strait.
We are working under the assumption that the arrival rate of passengers and cargo is consistent throughout the day.

[19] Hot air Balloon awareness. (2024, March 2). SKYbrary Aviation Safety. https://skybrary.aero/articles/hot-air-balloon-awareness#:~:text=The%20manufacturer's%20stated%20limit%20for,be%20given%20a%20wide%20berth.

This is the arrival rate calculation.

$$\lambda_p = \lambda_{cars} + \lambda_{passengers}$$
$$\lambda_p = 63.39 + 152.13$$
$$\lambda_p = 215.52$$

Where λ_p is the arrival rate of items for passenger/car airships, per hour.
A similar calculation can be made for the cargo airship.

$$\lambda_c = \lambda_{truck} + \lambda_{freight}$$
$$\lambda_c = 5.32 + 5.94$$
$$\lambda_c = 11.26$$

1.6 Rate of Transportation Calculation

The rate of transportation of the airships (μ) is calculated by:

$$\mu = \frac{Capacity\ of\ airship}{duration\ of\ trip}$$
$$\mu = \frac{C}{t}$$

Therefore based on the proposed interior design of the cargo bay for passenger airships, we assume that each airship fills the designated slots for cars, as there is uncertainty accounted for in the passenger seats available, (extra seats are available for passenger count exceeding predictions).
The duration of the trip, as calculated above, is the upper limit of a trip. This allows for the worst case scenario and is 160 minutes → t = 2.67 hours. Based on our flow model of the cargo bay in a passenger airship, the potential for traffic intensity to exceed 1 is highly likely to be due to an increase in the rate of passenger flow. Hence the rate of transportation should account for the worst case scenario, a backlog of passengers.

$$\mu_{Truck} = \frac{C_{Truck}}{t_{Cargo}}$$
$$\mu_{Truck} = \frac{2}{2.167}$$
$$\mu_{Truck} = 0.92$$

$$\mu_{Passenger} = \frac{C_{Passenger}}{t_p}$$
$$\mu_{Passenger} = \frac{90}{2.67}$$
$$\mu_{Passenger} = 33.71$$

1.7 Final Model

$$N_{Total} = N_{Cargo} + N_{Passenger}$$

$$N_{Cargo} > \frac{\lambda_{Truck} \cdot t_{Cargo}}{C_{Truck}}, \text{ where } N \in \mathbb{N}$$

$$N_{Cargo} > \frac{5.325 \cdot 2.167}{2}$$

$$N_{Cargo} > 5.77 \text{ (2 d.p.)}$$

Where: N_{Cargo} is lowest possible natural number of cargo airships required for the system to have a manageable traffic intensity; λ_{Truck} is arrival rate of trucks to a given airship port; t_{Cargo} is the duration of a cargo airship's trip – including loading and unloading periods; and C_{Truck} is the number of trucks that can be transported on an airship, based on our proposed floor plan. Therefore,

$$N_{Cargo} = 6$$

and,

$$N_{Passenger} > \frac{\lambda_{Passenger} \cdot t_{P}}{C_{P}}, \text{ where } N \in \mathbb{N}$$

$$N_{Passenger} > \frac{152.13 \cdot 2.67}{90}$$

$$N_{Passenger} > 4.51 \text{ (2 d.p.)}$$

Where: $N_{Passenger}$ is lowest possible natural number of passenger airships required for the system to have a manageable traffic intensity; λ_{p} is arrival rate of passengers to a given airship port; t_{p} is the duration of a passenger airship's trip – including loading and unloading periods; and C_{p} is the number of passengers that can be transported on an airship, based on our proposed floor plan. Therefore,

$$N_{Passenger} = 5$$

Therefore,

$$N_{Total} = N_{Cargo} + N_{Passenger}$$

$$N_{Total} = 6 + 5 = 11$$

Conclusion

In conclusion, a system of using different airships for cargo (trucks and rail wagons) and passengers (cars and passengers) has allowed for an efficient process in transporting items across the Cook Strait. Using 11 airships, the traffic intensity of the system is less than 1, and thus it can be ensured that this is the most efficient way to transport all of the volume that is carried by all existing ferries across Cook Strait. Additionally, using this system has ensured a decreased amount of fuel consumed relative to the quantity transported, improving the wellbeing outcomes and environmental sustainability of the method at use. However, due to the deterioration of equipment over time, it is expected that the airships will require servicing as they are running 24/7. Thus, the addition of one cargo and one passenger airship to each island for a total of 4 additional airships will give sufficient spare airships to cover the servicing of any airships that require maintenance due to deterioration.

In this report, using a model to determine the minimum number of airships required to cause the traffic intensity to be smaller than 0, has meant that there is spare capacity due to the requirement for N to be an integer. This allows for the meeting of demand during seasonal periods of greater velocity of circulation of passengers and cargo. By factoring in significant amounts of contingency in timing, speed, fuel consumption and weight has ensured a safe system which has the measures in place to increase the quantity of transportation when necessary. As a consequence, the employment of 15 airships ensures an efficient process and spare ships in case of maintenance, in addition to sustainability and cost efficiency in fuel consumption, labour and infrastructure.

Evaluation

A few considerations into the improvement of the model could include the variation in transport velocity in each island; as it is likely a greater quantity of items and population would be based in the North Island. Additionally it doesn't account for seasonal cycles and instead only the average value is used. This means during periods of the year the system becomes less filled, while in others there may be portions of backlog, but these cancel out over the entire period of the year.

Furthermore, this model ignores the fact that the vast majority of the transportation would occur during the day, meaning some backlog could occur during this time. However, this additional demand would be cleared through during the night, so similar to the yearly cycle, the day-night cycle cancels out to the average over the course of the day.

However, the introduction of spare airships to the system means backlog does not occur, and the large contingency in timing ensures any delays due to fluctuations in wind, loading time etc. do not cause significant flow-on delays to subsequent transports.