NZ Engineering Science Competition Judges Report 2024

The sixteenth annual "NZ Engineering Science Competition" was held from 10am to 6pm on Saturday 10th August 2024. We had 275 teams take part with entries from 83 schools across New Zealand, making it our largest event ever.

Competition Question

The 2024 question was:

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

As usual the question was motivated by a topical issue (and one that is particularly relevant to New Zealand).

Many teams noted that the current Cook Strait Ferries need to be replaced, with an aging fleet that has been plagued by a series of issues in recent years[1]. A project was underway to deliver two rail-enabled ferries, but this was cancelled by the current government (after the project had spent over 400 million dollars).[2] The country needs a reliable and viable connection between the North and South island. Ferries are one possible solution but there are other approaches which could be pursued. Building a bridge or tunnel to connect the two islands would present significant engineering challenges and be extremely expensive, so exploring creative alternatives is a worthwhile exercise, hence the motivation to investigate airships as a possible solution.

An airship is a type of lighter-than-air aircraft that can navigate through the air flying under its own power[3]. They are significantly more fuel efficient than heavier-than-air aircraft and large airships have the potential to carry very heavy loads (i.e. hundreds of tonnes). Airships are also much faster than ferries, meaning it would be possible to make more frequent trips between the islands. Many tourists use the existing ferries, and the novelty of airship travel is likely to be highly appealing to tourists. Airships would also allow for greater connection options (as travel would not be limited to following the existing ferry route, since airships can also travel over both land and sea and have much more flexibility with where they can ground). With climate change a key concern, airships could dramatically reduce carbon emissions (relative to ferries and/or traditional aircraft). Indeed, some designs are zero emission vehicles.

While airship use declined significantly over the 1930s and 40s (partly due to a series of high profile crashes, such as the Hindenberg disaster[4]) they are still in use today and a number of companies are working towards developing large scale airships for passenger and/or freight transport. This includes companies such as Aerosmana, Atlas, Flying Whales and Hybrid Air Vehicles (HAV). Modern airships tend to use helium, rather than hydrogen (although it should be noted hydrogen would be a better gas to use if safety concerns could be addressed, as hydrogen provides more lift, and helium is a finite resource that is far more expensive than hydrogen).

[1] https://www.rnz.co.nz/news/national/528514/timeline-a-recent-history-of-cook-strait-ferry-woes
[2] https://www.rnz.co.nz/news/national/504650/interislander-ferry-fleet-project-to-wind-down-after-being-denied-further-government-funding
[3] https://en.wikipedia.org/wiki/airship
[4] https://en.wikipedia.org/wiki/Hindenburg_disaster

While the use or airships to replace the Cook Strait ferries might initially sound like farfetched, recent developments suggest that we may see airship usage resume in our corner of the world in the not too distant future, with Flying Whales announcing the establishment of a base in Australia[5].

The competition question was deliberately open-ended, with no single "correct" answer, and allowed for a wide variety of approaches to answering it. Teams were expected to research and understand the topic, make appropriate assumptions and then devise a mathematical modelling approach to answering the question, and then write a clear and concise report to present their findings. All of this within just an eight-hour period!

A wide range of modelling approaches were taken, and the judges had a challenging task to decide on the finalists and competition winners.

Judging Process

Judging was done over three rounds by members of the Department of Engineering Science and Biomedical Engineering. Rounds one and two narrowed the 275 entries down to a shortlist of 10 to enter the third and final round. A small panel of expert judges, with extensive experience in teaching mathematical modelling then reached a consensus on the winning team and the two runners up teams. All judging was completed blind, with team identities only revealed after all judging was completed.

Judge's Comments

Each report should start with an abstract (sometimes referred to as a summary). While this if often written last, it is the first thing judges read. Your abstract should *briefly* outline your approach to solving the problem and very importantly it should tell the reader **what the answer you found was**. Many abstracts failed to mention the answer to the competition question.

To reach an answer that could be placed in the abstract will of course require solving the problem.

The very first step along this path was interpreting the question. Teams needed to carefully consider the wording of the question and in particular what might be meant by "airship" and "replace". "Airship" was typically interpreted sensibly using the common definition, in-line with that given by Wikipedia[6].

Teams generally interpreted "replace" along the lines of meaning that the airships could meet the current (or projected) demand for transporting passengers, vehicles and rail cars across the Cook Straight. Some teams decided to exclude rail from their modelling, due to the large mass of rail cars (a loaded rail freight car can mass upwards of 100 tonnes). This was acceptable, although it should be noted that even rail freight cars could be carried by some of the proposed airships, which include designs with a 600 tonne capacity[7]. Excluding vehicles as well is perhaps a step too far, as the key function of the Cook Strait ferries for many passengers is the ability to take a vehicle with them from one island to the other.

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[5] https://www.abc.net.au/news/2024-10-11/outback-town-launches-airship-cargo/104457420
[6] https://en.wikipedia.org/wiki/airship
[7] https://aerospaceglobalnews.com/video/aerosmenas-ufo-shaped-airship-aiming-for-2024-launch/

“Cook Strait ferries” was typically interpreted to encompass the Blueridge and Interislander ferries that together provide transport between Picton and Wellington.

To solve the problem each team needed to research the topic (which also serves to provide useful information for the introduction section). While airships are an uncommon vehicle to see in the skies, there is a wealth of information about past, present and planned airships available online. During the research phase, teams who did a good job would likely have come across some key data, e.g.

- Existing usage statistics for both passenger and freight transport on the ferries
- The typical cargo capacity of suitable airships, both in terms of volume and weight.
- The typical velocity of suitable airships
- The geographic distance between key points on the North and South island

While making assumptions is vital for reducing the complexity of the problem, many teams made assumptions with little justification or thought as to how realistic that assumption was.

Some common assumptions made were:

- Travel will be between the Wellington and Picton ferry terminals
- Weather conditions will not impact the time taken to travel from the North to the South island
- We only need to consider mass (not volume) when loading airships
- A small capacity airship is appropriate
- No allowance for loading/unloading
- Airships will only operate during daylight hours

The above assumptions certainly simplify things but are all flawed (to various degrees) and will result in an unrealistic solution.

For example, the existing ferries travel between Wellington and Picton because that is where the docks for the ferries are located. Airships don’t require the same docking facilities that ferries do (instead you would need to consider sites that have enough open land to be able to bring an airship down on). If your solution proposes hundreds of airships, many of which will be on the ground at the same time, then you need to give some thought to where they would fit.

Strong winds will certainly impact on travel times (and Wellington is renowned for being windy!)

Volume needs to be considered along with mass. Just because there is sufficient lifting capacity to carry 20 cars, doesn’t mean there is sufficient volume to fit them in the airship (remember they will also need to be manoeuvred in and out, so can’t be packed too tightly). Similarly, if you carry passengers, they would appreciate somewhere to sit and a way of getting to their seat (you can’t just pack them in like sardines!).

Using a small airship is unwise, as a fleet of hundreds of small airships is likely far less practical than using a smaller fleet of very large airships (in the same way we wouldn’t choose to replace the ferries with hundreds of small boats).

Loading and unloading airships will take a non-negligible amount of time (particularly when private vehicles are involved). Ignoring this time will result in an inaccurate answer that overestimates how many trips can be made during the day. For comparison, turnaround time for vehicle ferries is around 90 minutes to 2 hours (to provide enough time to unload and load). Airships will carry fewer people and vehicles than ferries, but it is still important to account for the time involved to land, unload, reload and take off again.

With modern technology there is no reason to limit the operation of airships to daylight hours. This isn't done with ferries or planes, and it is highly likely any airship service would run into the night, to reduce the number of airships required (just as Bluebridge run their ferry service 24/7).

While assumptions are vital, some thought should be given to the appropriateness of each assumption made. Sensible assumptions were one of the things that set many of the top teams apart from the others.

Once relevant information has been researched and appropriate assumptions have been made teams can proceed to developing a mathematical model, which is the heart of the competition.

There were many possible approaches.

At a minimum teams needed to research the existing demand (e.g. number of passengers, vehicles and rail freight per year), choose a suitable airship model to use and then calculate how many trips such an airship could make within a specified period (e.g. a day). This provides a figure for how much cargo a single airship could carry within a specified period. Dividing the demand by the cargo that can be carried by a single airship then provides a simplistic estimate of the number of airships required.

The above approach is a good starting point and can be extended in many ways. Extending this simple approach is what tended to set apart the top teams from the rest. Here is a sample of a few possible extensions:

- Modelling potential future growth in demand and adjusting the number of airships accordingly
- Using two (or more) models of airship, to deal with different types of cargo (e.g. one for passengers and vehicles and another for freight)
- Modelling the airship travel time in detail from a physics perspective (E.g. determining flight time, which accounting for wind resistance)
- Modelling the time required for a return trip, incorporating relevant factors such as refuelling/recharging, loading/unloading, take-off and landing, along with cruising
- Accounting for planned (and unplanned) maintenance
- Accounting for variation in weather conditions, which might result in cancellation of flights
- Determining optimal locations for ports (remembering we don't have to necessarily use Picton and Wellington)
- Designing an airship from first principles, incorporating the physics of buoyancy
- Modelling how passengers, vehicles and freight would be situated on-board an airship (accounting for mass and volume constraints)
- Modelling the time taken to load in detail (e.g. considering the flow of private vehicles onto an airship).

The above list is not exhaustive. Some approaches require the use of probability and statistics, while others rely on physics and calculus.

Although not necessary to be considered a top entry, a number of teams wrote computer code to support their mathematical modelling. Using numerical computation is a viable approach and can be an excellent technique when faced with equations that are too difficult to solve by hand. It is important to note that any computer code written must add value to the mathematical modelling, rather than just being included to try and impress the judges.

Once a team had found their answer to the question, they then needed to complete their report.

A well written report is essential for doing well in this competition. As already mentioned, the report should begin with a short summary/abstract that summarises the findings and includes the answer to the question (this is often written last). The report should then continue with an introduction, with information that outlines relevant background information and prior research on the topic.

Some teams wrote out separate sections for their definitions and modelling assumptions. While this is not an issue per se, the more common approach in scientific research is to write a dedicated section that describes the modelling approach, which will include the assumptions made and any relevant definitions.

The modelling section was the weakest part of most team reports. The judges found that it was difficult to easily understand or follow the modelling approach taken by many teams. It is important to define any equations or modelling techniques used, preferably with relevant references to other research. Make sure all variables in any equations are defined, so that the reader can understand what is being calculated. Be sure to include units on any results you provided (e.g. if your airship travels at a speed of 100, we need to know what units are being used). Including **labelled** diagrams can be hugely helpful to your reader. Your modelling section should be written clearly, so that it is easy to follow by an audience with a similar level of knowledge to yourself.

The next section should detail the modelling results. Relevant figures and tables can be extremely helpful for assisting readers with visualising the understanding your results. Again, **labels** on any graphs are critical. A graph that doesn't contain labelled axes is very hard for a reader to correctly interpret.

Finally, the report should present your conclusions based on the modelling results.

A key part of the modelling process is reflecting on whether the results obtained make sense, when compared with reality. A few teams did this very well and pinpointed areas where their model could be improved to better reflect reality. Other teams obtained highly implausible results from their model and didn't stop to question them! Highly implausible results can indicate errors in your calculations or a model that was based on incorrect assumptions (e.g. perhaps an important factor was not included in your model).

Answers varied hugely. Many teams obtained single digit answers (e.g. 6 airships). A significant proportion of teams came up with a two-digit answer while some teams obtained values in the hundreds or even thousands (very large values should have set alarm bells ringing!) Some teams concluded that it was impossible or unviable to replace the Cook Strait ferries (this is a perfectly valid conclusion if it was substantiated by modelling).

This year's question was challenging for teams and perhaps unsurprisingly no single team managed to nail everything the judges were looking for. We recognize it is unrealistic to expect a perfect model to be developed in the short time provided, so it is impressive that many teams made credible efforts, showing excellent modelling skills and creative thinking, communicated in an understandable manner.

How to do better

For those students who will be competing again in the future here are a few tips on how to improve your chances of winning

- Ensure you begin your report with a summary/abstract that briefly describes your approach AND the solution you obtained. Make sure your answer is *clearly* stated in your summary (with units if appropriate).
- Choose your assumptions carefully. Ask yourself "is this a realistic assumption to make?"
- Take care to use a model appropriate to the problem and be aware of your model's limitations (some very sophisticated approaches were unfortunately not applicable to the contexts to which they were applied).

- Explain your approach clearly, so that an audience with a similar level of knowledge to you can follow your modelling and also understand WHY you have used that approach (some equations seemed to appear out of thin air, with no justification of where they came from or what the variables represented).
- Be sure to show HOW you solved your model (sometimes solutions were presented with no working, we need to be able to follow how you arrived at your answer).
- Use visual tools such as graphs, images, diagrams, figures and tables, where appropriate, to effectively and efficiently present information.
- Make sure you perform a reality check on any solutions obtained. Does the answer seem plausible? Your report should include a discussion of how realistic (or not) your solution is, ideally with reference to existing data. If your model produced an unrealistic answer be sure to discuss why this might be the case.

Results

Winners of The Pullan Prize for first place ($1000 for each team member)

- Team 1185 from **Mount Albert Grammar School**, Auckland (Year 12/13): Ryan Shen, Jacob Miller, Victor Coen, Felix McElwee

Runners Up ($500 for each team member)

- Team 1107 from **Christ's College**, Christchurch (Year 12/13): Angus Whitteker, Nicholas Sharr, Harry Vaughan, Aaron Kwak
- Team 1186 From **Hamilton Boys' High School**, Hamilton (Year 13): Rupert Leary, TJ Lee, Paul Xu, Weiyi Jiang

Highly Commended

- Team 1096 from **ACG Parnell College**, Auckland (Year 11): Eric Liu, Derek Ding, Liam O'Grady, Youfu Ma
- Team 1046 from **Macleans College**, Auckland (Year 12): Alston Yam, Bruce Zhang, Jay Zhao, Tony Yu
- Team 1014 from **Marist College**, Auckland (Year 12): Sinchana Kumar, Isabel Broderick, Catherine Don, Vanessa Gomes
- Team 1163 from **Nelson College**, Nelson (Year 13): Jamie Ben, Kael Matthew, Oliver Morton, Leon James
- Team 1196 from **New Plymouth Boys High School**, New Plymouth (Year 13 Neo Hatcher, Thomas Hope, Jeffery Armstong, Thisal Gunasinghe
- Team 1025 from **Selwyn College**, Auckland (Year 13): Ben Ward, Toby Low, Bennett Yeo, Jamie Craske
- Team 1295 from **St Dominic's Catholic College**, Auckland (Year 11/12/13): Coco Chen, Seidee Hernandez, Isabelle Nash, Maria Serges
- Team 1275 from **St Peter's School, Cambridge** (Year 13): Zach Macaskill-Smith, Katie Li, Leon Lee, Tim Qian

Participation

We had 275 teams from 83 schools participate this year.

We had many "Action shot" photos submitted during the course of the day. These photos were uploaded to our department Facebook page and can be viewed at: www.facebook.com/engsci

Avondale College and Epsom Girls Grammar tied for the most entries from an individual school, with an impressive 13 teams competing from each. See below for a complete list of schools and how many teams they entered.

ACG Parnell College	9	New Plymouth Boys High School	3
ACG Sunderland	5	New Plymouth Girls' High School	6
Aquinas College	2	Newlands College	5
Ashburton Christian School	1	Northcote College	2
Auckland Grammar School	4	Onslow College	2
Avondale College	13	Orewa College	2
Awatapu College	2	Otago Boys High School	1
Baradene College	3	Pakuranga College	5
Buller High School	1	Palmerston North Boys' High School	5
Burnside High	7	Palmerston North Girls' High School	1
Catholic Cathedral College	2	Pinehurst School	4
Central Hawke's Bay College	1	Rangi Ruru Girls School	3
Central Southland College	1	Rangitoto College	11
Christ's College	2	Rolleston College	1
Diocesan School for Girls	2	Rosehill College	1
Epsom Girls Grammar School	13	Rosmini College	5
Fiordland College	1	Saint Kentigern College	4
Fraser High School	1	Sancta Maria College	6
Glendowie College	4	Scots College	1
Green Bay High School	1	Selwyn College	2
Hamilton Boys' High School	2	St Cuthbert's College	5
Hillcrest High School	1	St Dominic's Catholic College	2
Hobsonville Point Secondary School	4	St John's College, Hillcrest	1
Howick College	2	St Patrick's College, Kilbirnie	1
Hurunui College	1	St Patrick's College, Silverstream	1
James Hargest College	1	St Paul's Collegiate (Hamilton)	1
John Paul II High School	1	St Peter's College Epsom	1
Kelston Boys High School	1	St Peter's School Cambridge	1
King's College	6	Takapuna grammar school	7
Kristin School	9	Tauranga Boys' College	3
Liston College	3	Titirangi Rudolf Steiner School	2
Long Bay College	4	Trinity Catholic College	2
Lynfield College	6	Waimea College	2
Macleans College	12	Waitakere College	2
Marist College	3	Wellington High School	5
Massey High School	5	Western Springs College	1
Michael Park School	1	Westlake Boys High School	4
Mount Albert Grammar School	5	Whakatane High School	2
Mount Maunganui College	2	Whanganui High School	6
Mount Roskill Grammar	3	Whangaparaoa College	5
Nelson College	2	Whangārei Boys' High School	1
		Whangarei Girls' High School	1