The Optimal Spaceport Location in Australia

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1. Abstract

The literature review found that the main geographical and political considerations for a spaceports location to be latitude, azimuth restrictions, meteorological considerations, population density and accessibility. Australia is currently developing three, land-based spaceports in different locations across the country. Namely, the Arnhem Space Centre (NT), Bowens Orbital Spaceport (QLD) and Whalers Way Orbital Launch Complex (SA), each provide unique advantages and disadvantages. The scientific research question was posed into which of these is the most optimal spaceport location. A point based ranking system would be able to quantify the main geographical and political considerations and find the most viable spaceport location. The results demonstrated that the Southern Launch's Whalers Way Orbital Launch Complex is the most optimal spaceport location for future space exploration in Australia as it offers a low population density with close proximity to major city, Port Lincoln, for the transportation of payload and resources. A wide azimuth range and favourable weather conditions make it the most optimal spaceport location for future space exploration within Australia.

2. Literature Review

2.1. Location Considerations

In relation to the optimisation of a spaceport's location, there are many geographical factors that need to be taken into consideration. According to T. Roberts' 'Spaceports of the World' (2019), the considerations of a spaceport's location are determined geographically and politically. Geographically, "to take full advantage of the Earth's rotation for space launch, an object must be launched due eastward from a spaceport located precisely on the equator". As Australia is relatively close to the equator (latitude = 0), launches can better utilise the horizontal velocity of the earth's surface (figure 1), enabling launches closer to the equator to reduce the energy required to break away from earth's gravity.

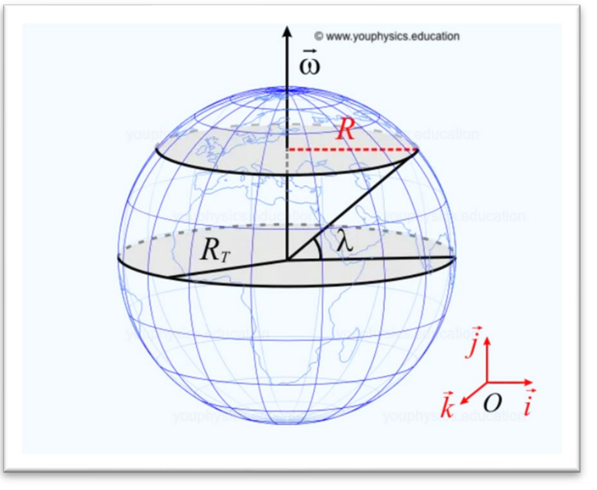

Figure 1. Relative Motion - Earth's rotation speed vs latitude. [Image]. YouPhysics. Retrieved April 16, 2023 from https://www.youphysics.education/relative-motion/relative-motion-problems/relative-motion-problem-6/

Figure 2. Roberts, T. (2019, March). Figure 3: Azimuth Limitations at Cape Canaveral and Vandenberg. [Map]. Centre for Strategic and International Studies. Retrieved April 16, 2023 from https://aerospace.csis.org/spaceports-of-the-world/

Due to the risks of debris and potentially toxic propellant that are disposed during both successful launch stages, and crashes from aborted launches, drop zones are also detrimental factors as to where rocket stages can fall back to the Earth's surface. The allowable direction and area drop zones are allowed inhabit are measured in azimuths, "the direction it travels in the horizontal plane after leaving the launch pad, measured in degrees clockwise from due north" (Roberts, 2019). Populated areas and foreign countries are azimuth limitations that can restrict a spaceport's ability to maximise the earths rotational velocity eastward. Explored by Robert (2019), "The Cape Canaveral spaceport in Florida is restricted by the populated east coast of the United States to its north and southern Florida and several Caribbean Island nations to its south" with azimuths lying between 35° and 120° (figure 2). As Australia is a continental island, the presence of water all around us is beneficial as the risk of dropping debris over populated or foreign areas is minimal. However, the impact of dropping debris and potentially harmful debris into the ocean must be considered.

According to Roberts (2019), favourable natural factors such as lack of natural disasters and clear airspace also come into consideration. NASA's 'Space Shuttle Weather Launch Commit Criteria and KSC End of Mission Weather Landing Criteria' (n.d.) states that fuelling prior to launch "will not begin if:

- The 24-hour average temperature has been below 5°C.
- The temperature has fallen below 0.5°C at any time during the previous 24 hours.

After tanking begins, the countdown shall not be continued, nor the shuttle launched if:

- The temperature exceeds 37 degrees for more than 30 consecutive minutes".

NASA (n.d.) identifies "the allowable peak wind speed observed at the 60-foot level of the fixed service structure depends on the wind direction and ranges from 19 to 34 knots". In addition, there must be no precipitation "at the launch pad or within the flight path". Lightning and clouds that contain hazardous electric fields, "Cumulus Clouds, Anvil Clouds, Debris Clouds", also impeded on launch capabilities, with NASA (n.d.) stipulating "Do not launch when lighting is observed and the cloud which produced the lightning is within 10 nautical miles of the flight path. Launch may not occur until 30 minutes has elapsed since the lightning flash, or the cloud has moved more than 10 nautical miles away".

T. Roberts' 'Spaceports of the World' (2019) states that political factors need to be considered for an optimal spaceport. Accessibility and political stability needs be maintained to ensure that the spaceport is in a safe, controlled location free from foreign intervention, "ensuring unfettered access to the launch site at all times" (Roberts, 2019). However, some spaceport locations are restricted due to the political relationships between the operating country and its neighbouring countries. "For example, to avoid its adversaries to the east, the Israeli spaceport on the Palmachim Airbase exclusively launches westward into retrograde orbits, sacrificing launch efficiency for regional political stability" (Roberts, 2019).

An alternate perspective, M. Ilhan and F. Gündogdu's 'Analyzing Critical Criteria of Spaceport Site Selection Based on Spherical Fuzzy AHP Method' (2022) provides an insight into the construction of spaceports in an aerospace emerging country, Turkey. It stipulates that "that technical requirements, cost and economy, and infrastructure are the most important main criteria for the success of the spaceports". As a subsequent criterion, they found that factors such as "population density, operational costs, and transportation costs" are mostly related to company investments and cost-based parameters.

G. Wild's 'Optimising the Potential Location of Spaceport Australia based on Current Suborbital Space Tourism Requirements' (2015) approaches the accessibility of a spaceport as the "measure of convenience (or inconvenience)… to travel to and from the spaceport". As seen in figure 3, there are locations of low population densities, relatively close to larger population centres.

As Australia has a large area of less than 0.1 people/km^2 (Wild, 2015), there are a wide variety of locations that have a low population density (figure 3). Population density is an important consideration in terms of the risk to the public. "Historically, spaceports have ensured safety to the public through their geographical isolation. Specifically, they have traditionally been located on the coast with operations performed over the sea, or alternatively in areas of low population density" (Wild, 2015).

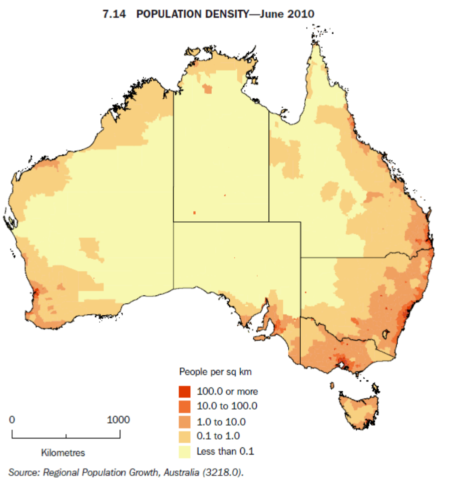

Figure 3. Regional population. (2023, April 20). [Map]. Australian Bureau of Statistics. Retrieved May 4, 2023 from https://www.abs.gov.au/statistics/people/population/regional-population/latest-release

'Can Your Airport Become a Spaceport? The Benefits of a Spaceport Development Plan' (2010) by B. Gulliver proposes an alternate way to find a location for spaceports. The idea of airports becoming 'Aero-spaceports' arose when US general aviation airports attained Federal Aviation Administration (FAA) licencing to support suborbital space launch operations. From a legal standpoint, it may be easier to establish a spaceport through an airport as the airspace is already occupied by the airport owners and it would not intrude into foreign airspace. However, the geographical and political considerations, explored by Roberts (2019) and Wild (2015), for spaceport locations should be prioritised over ease of establishment to ensure it meets the cost-based criteria for future space exploration.

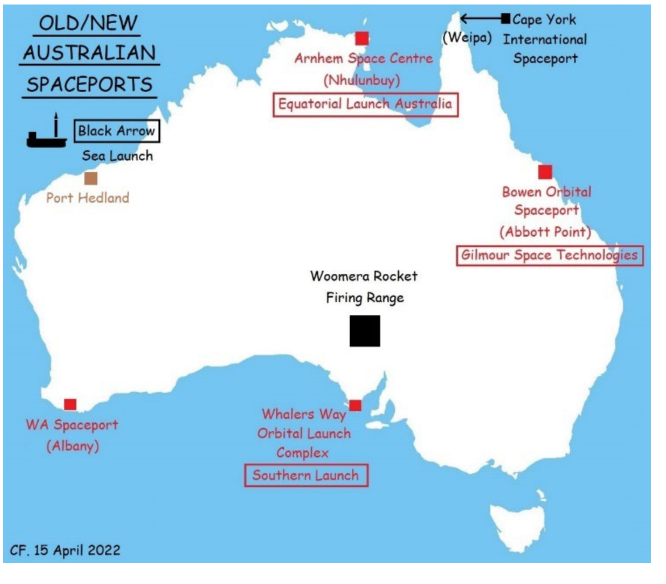

Figure 4. OLD/NEW AUSTRALIAN SPACEPORTS. (2022, April 15) [Map]. Space & Defence. Retrieved April 4, 2023 from

https://spaceanddefense.io/wp-content/uploads/2022/04/image009.jpg

2.2. Spaceports in Australia

Australia is currently developing three, land-based spaceports in different locations across the country (figure 4) each with unique properties. The most recent of which, is the Arnhem Space Centre (ASC). The ASC, supported by Equatorial launch Australia, is located in the Northern Territory, 12°S of the equator (figure 5). 'Australia's Old and New Potential Spaceports' (Space & Defence, 2022) explores the spaceports' ability to launch from its low latitude and wide azimuth, reducing the cost and energy required from the absence of manoeuvres. Its proximity to the equator takes advantage of the earths rotation's horizontal velocity. With a 0.43 people/km ^2 (East Arnhem) and minimal air traffic, the location of this spaceport is away from densely populated areas.

Figure 5. Arnhem Space Centre. (2019, October 11). [Map]. Developing East Arnhem. Retrieved June 8, 2023 from https://www.developingeastarnhem.com.au/blog/project/arnhem-space-centre

There is also the Bowen Orbital Spaceport (Abbot Point, Queensland) built by aerospace company Gilmour Space Technologies. C. Kwan's 'Queensland approves new small rocket launch site at Abbot Point' (2021) attests to the new range of capabilities the location brings such as "orbits, inclinations, and altitudes" that are required for Low Earth Orbits (LEO). The spaceports easterly facing position and proximity to the equator (latitude = 20°S) give it a desirable horizontal velocity. However, the spaceports azimuth is restricted by the popular tourist destination, the Whitsundays. 'Proposed Abbot Point Spaceport Initial Risk Observations' (2020) by S. Wallis, reinforces that "Population risks are very high – 11km to 11,000 people in Bowen will be very significant when a Risk Hazard Analysis is done - likely to result in denial of Launch Permits or limited launches per year", in addition to "Danger zones (being) likely to require civilian evacuation prior to launch" (figure 6).

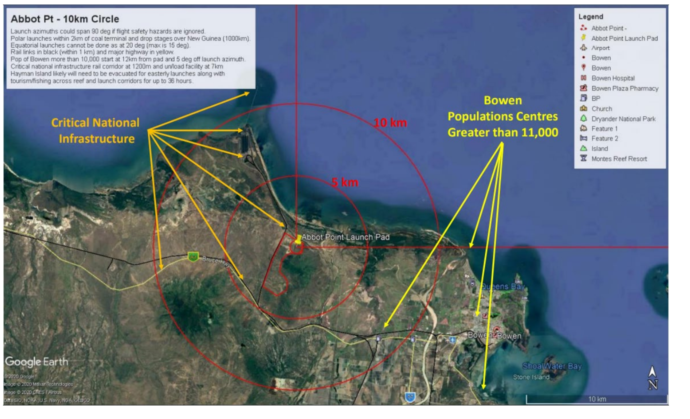

Figure 7. Wallis, S. (2020, September 18). Abbot Pt - 10km Circle. [Map]. Atlantean International Pty Ltd. Retrieved June 8, 2023 Proposed Abbot Point Spaceport Initial Risk Observations [Paper Presentation]

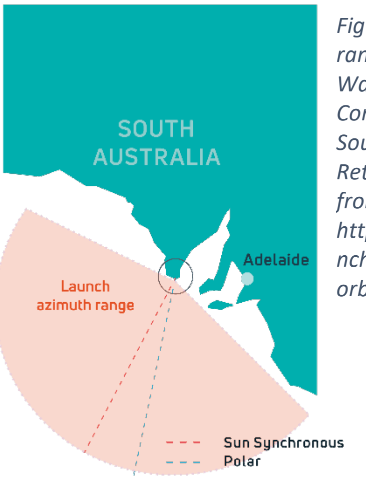

Figure 6. Launch azimuth range from the Whalers Way Orbital Launch Complex. (n.d.). [Map]. Southern Launch. Retrieved June 8, 2023 from https://www.southernlaunch.space/whalers-way-orbital-launch-complex

Finally, there is the Southern Launch's Whalers Way Orbital Launch Complex (WWOLC) in Sleaford, South Australia (35°S). This spaceport is advantageous as it has largest azimuths and drop zone of the 3 spaceports. According to the 'Australian Census Data' (2016), Sleaford, has a population density of 0.17 people/km^2, enabling the WWOLC to launch into high inclination orbits with minimal risk of debris falling into populated areas. Additionally, South Australian Space Industry Centre chief executive R. Price states that "good weather conditions and low air traffic across the Great Australian Bight made Whalers Way a perfect spot for launches" (2022).

G. Wild's 'Optimising the Potential Location of Spaceport Australia based on Current Suborbital Space Tourism Requirements' has identified several markets for future exploration from these spaceports, namely:

1. "Commercial human spaceflight (space tourism).
2. Point-to-point (high-speed passenger) transportation.
3. Basic and applied research.
4. Aerospace technology test and demonstration.
5. Remote sensing.
6. Education.
7. Media and public relations."

With the emerging industry of aerospace within Australia, these developing spaceports will be analysed for their qualitative and quantitative data to determine the most optimal location for a spaceport in Australia.

3. Scientific Research Question

As the aerospace industry continues to emerge, is there an optimal spaceport location in Australia that could be used for future space exploration?

4. Scientific Hypothesis

Based on the geographical and political considerations outlined in section 2.1.:Latitude, Azimuth limitations, Meteorological considerations, Population density, and Accessibility, the Arnhem Space Centre will be the most optimal spaceport location for future space exploration as the industry continues to emerge.

5. Methodology

The research question and hypothesis are to be tested by secondary research, pertaining of the literature pertaining the existing spaceport locations and their location factors in Australia and around the world. Three locations: the Arnhem Space centre, the Bowen Orbital Spaceport, and Whalers Way Orbital Spaceport, were chosen as samples for the research and calculations, for a wide variety of data. Based on the literature outlined in section 2, a point-based system that ranks the spaceport most effective for each criteria will rank these locations based on geographical and political factors (i.e. highest rotational velocity - 3 points through to lowest rotational velocity - 1 point).

5.1. Latitude (rotational assist)

Quantitative data will be calculated to analyse the rotational assist of existing spaceports in Australia. Using $c = 2\pi r \cdot cos\theta$, the circumference for each location was found where, r = the radius of the earth (6371000m), and θ = the latitude (in radians) of the spaceports, respectively. The rotational assist (m/s) will be determined by dividing the respective circumferences of the spaceports with the time it takes for the earth to complete a full revolution (86000s).

5.2. Azimuth limitations:

Drop zones will be determined by their azimuth range in degrees. Although there is no specific distance an azimuth can be from populated areas, an equal measurement of 0.5km from the shore will be taken as the minimum distance from populated areas to ensure safety from debris and pollutant. From a map, three range measurements will be taken, with the average azimuth ranges of each sample locations being recorded and ranked, to determine which location has the largest drop zone range.

5.3. Meteorology considerations

Factors such as mean wind speeds, mean number of days of precipitation, and mean temperature range of a spaceport's location, in recent years, will be recorded and measured against one another to determine which location has the most favourable conditions (listed in section 2). Measurements taken from the Bureau of Meteorology.

5.4. Population density

Population density of spaceport locations will be measured and ranked to determine which spaceport location poses the least risk on the surrounding population.

5.5. Accessibility and Political Stability

Accessibility will be determined by the proximity of major population centres, for transportation convenience, and distance from neighbouring countries and airspace, for political security. The results will be measured and ranked to determine which location is the most accessible.

5.6. Risk Assessment

Using both qualitative and quantitative data method of research to classify the geographical and political considerations, the optimal location for a spaceport can be tested. To minimise the potential risk of bias, a wide range of literature has been researched to improve accuracy of the geographical and political spaceport locations, as the information can be substantiated in more than one reliable source. The literature used to design the experiment was written by qualified, peer reviewed authors, with data and statistics gathered from firsthand investigations by reputable sites.

6. Results

6.1. Latitude (rotational assist)

Location	Latitude (Degrees)	Latitude (RAD)	Circumference (m)	Rotational Assist (m/s)
Equator	0	0	40030173.59	463.31
Arnhem Space Centre	12	0.20943951	39155418.26	453.19
Bowen Orbital Spaceport	20	0.34906585	37616058.73	435.37
Whalers Way Orbital	35	0.61086524	32790798.53	379.52

*Table **Error! No text of specified style in document.**.1. Rotational Assist Results by Location*

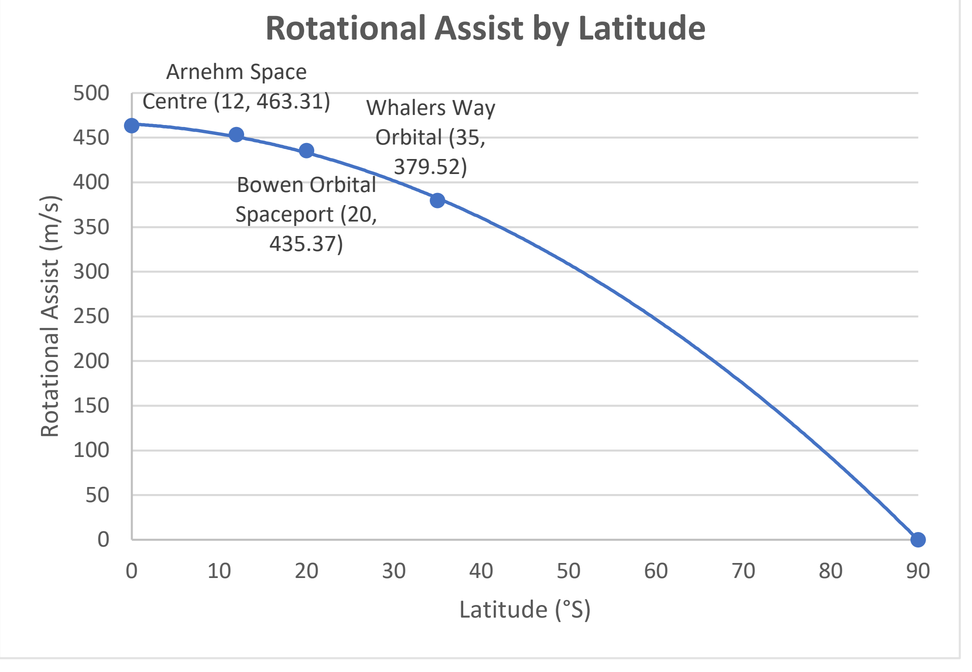

Figure 8. Rotational Assist by Latitude

6.2. Azimuth limitations

Spaceport Location	Azimuth Range (degrees from North)	
	From	To
Arnhem Space Centre	72	143
Bowen Orbital Spaceport	25	92
Whalers Way Orbital	135	296

*Table **Error! No text of specified style in document.**.2. Azimuth Range by Spaceport*

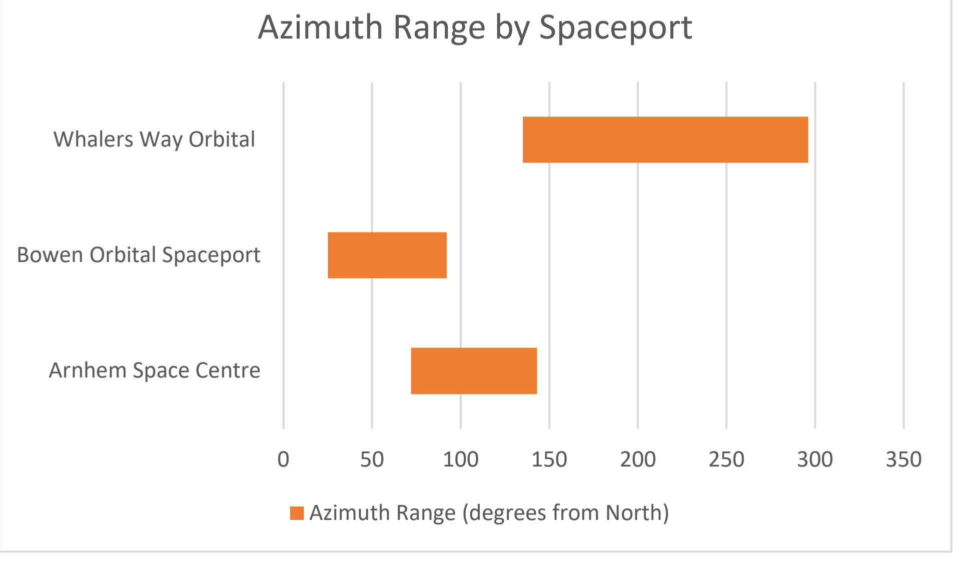

Figure 9. Azimuth Range by Spaceport

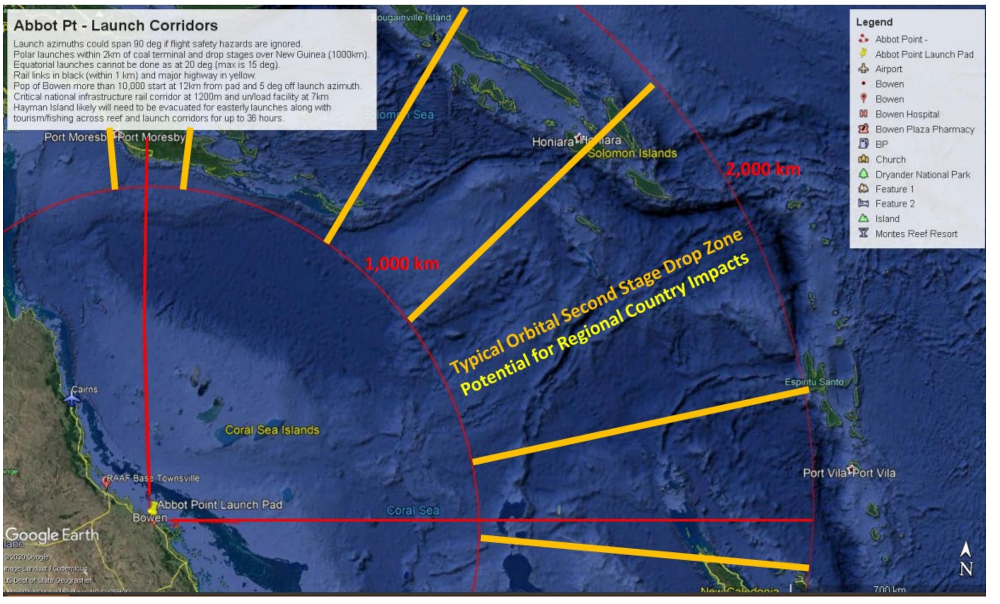

Figure 10. Wallis, S. (2020, September 18). Abbot Pt - Launch Corridors. [Map]. Atlantean International Pty Ltd. Retrieved June 8, 2023 Proposed Abbot Point Spaceport Initial Risk Observations [Paper Presentation]

Figure 11. Arnhem Space Centre's launch direction

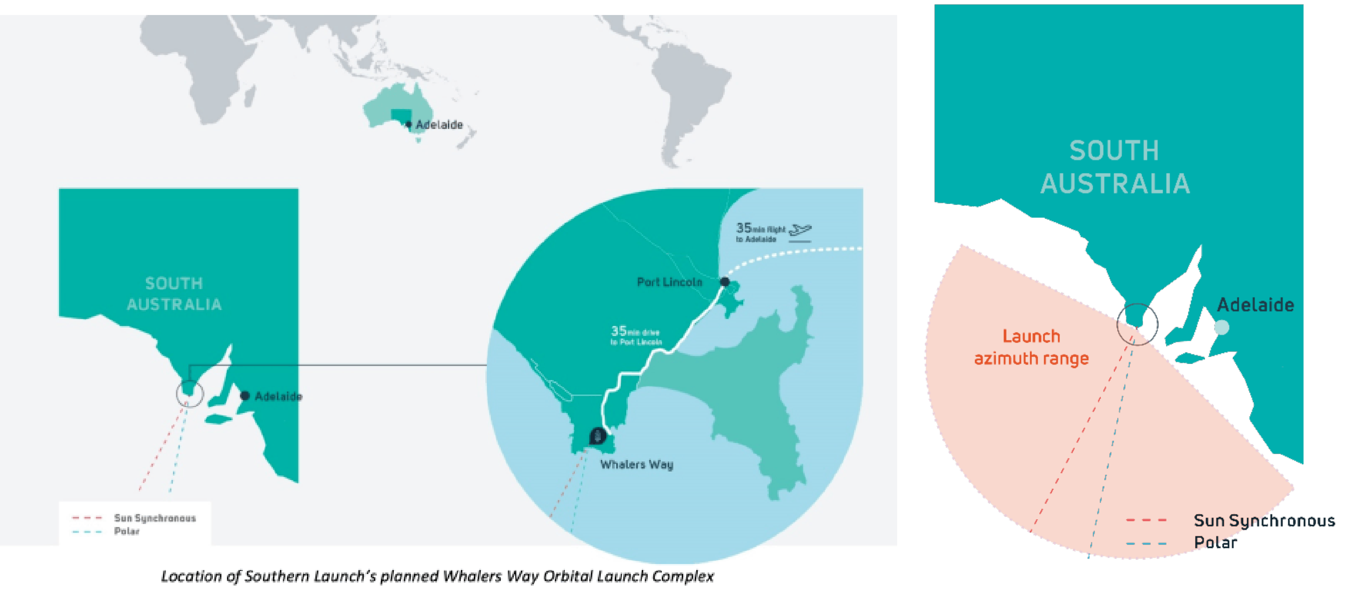

Figure 12. Location of Whalers Way Orbital Launch Complex and its azimuth range (n.d.). [Map]. Southern Launch. Retrieved June 8, 2023 from https://www.southernlaunch.space/whalers-way-orbital-launch-complex

6.3. Meteorology considerations

Spaceport Location	Mean number of days rain > 1mm by month (2022)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Arnhem Space Centre (East Arnhem)	17.3	14.8	11.7	4.3	0.9	0	0.3	0.2	0.6	2.7	7.5	14.3
Bowen Orbital Spaceport (Abbot Point)	12.1	13.9	14.9	14	12.1	8.4	6.3	5.1	3.1	4.8	5.7	8.3
Whalers Way Orbital (Sleaford)	1.8	1.8	2.3	4.6	7.5	9.1	10.3	9.8	7.2	5.5	3.3	2.7

*Table **Error! No text of specified style in document.**.3. Spaceport location and Mean number of days rain > 1mm by month (2022)*

Spaceport Location	Mean number of days rain > 1mm Annually (2003 - 2023)
Arnhem Space Centre (East Arnhem)	74.6
Bowen Orbital Spaceport (Abbot Point)	108.4
Whalers Way Orbital (Sleaford)	65.9

*Table **Error! No text of specified style in document.**.4. Spaceport Location and Mean number of days rain > 1mm Annually (2003 - 2023)*

Spaceport Location	Monthly Mean Temperature (2020-2023) (°C)		Mean Temperature Range (°C)
	Min.	Max.	
Arnhem Space Centre (East Arnhem)	15.7	35.7	20
Bowen Orbital Spaceport (Abbot Point)	17.6	30.4	12.8
Whalers Way Orbital (Sleaford)	8.1	25.4	17.3

*Table **Error! No text of specified style in document.**.5. Spaceport Location by Monthly Mean Temperature and Range (2020-2023) (°C)*

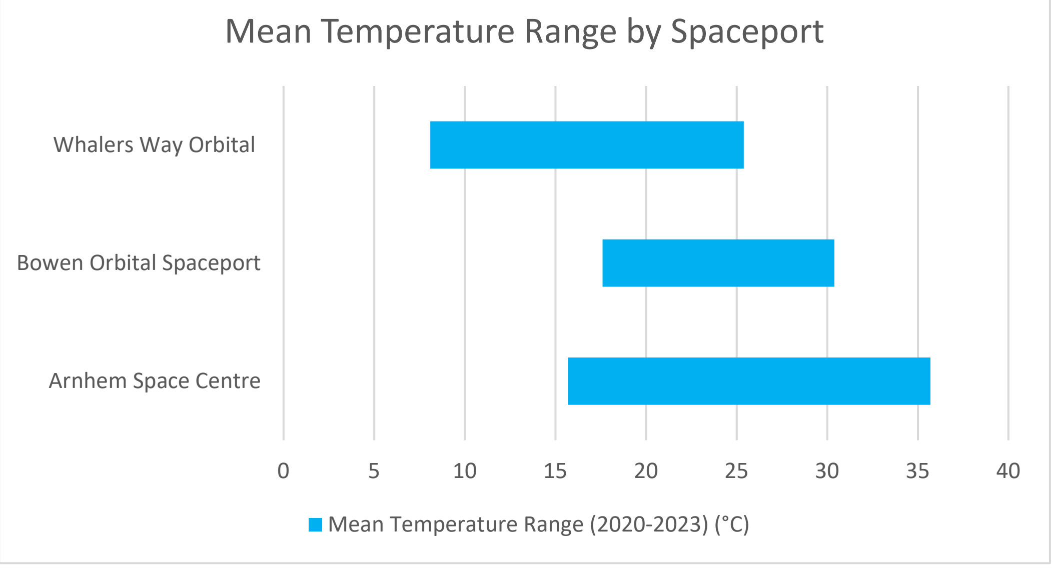

Figure 13. Mean Temperature Range by Spaceport

Spaceport Location	Mean wind speed by month (2022) (km/h)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Arnhem Space Centre (East Arnhem)	19	18.8	18	22	25.3	27	26.7	24.4	20.8	18.4	15.5	16.2
Bowen Orbital Spaceport (Abbot Point)	17.3	16.9	17.7	17.7	16.8	16.3	16	16	16.2	17.4	17.5	17.3
Whalers Way Orbital (Sleaford)	23.3	23	21.5	20.3	21.5	24.2	25.2	25.1	24.3	23.8	23.3	23.1

*Table **Error! No text of specified style in document.**.6. Spaceport Location and Mean wind speed by month (2022) (km/h)*

Spaceport Location	Mean wind speed annually 2022 (km/h)
Arnhem Space Centre (East Arnhem)	21.0
Bowen Orbital Spaceport (Abbot Point)	16.9
Whalers Way Orbital (Sleaford)	23.2

*Table **Error! No text of specified style in document.**.7. Spaceport Location and Mean wind speed annually 2022 (km/h)*

6.4. Population Density

Spaceport	Population Density at Spaceport (people/km^2)	Population Density in Azimuth (people/km^2)
Arnhem Space Centre	0.43	1.13
Bowen Orbital Spaceport	n.a.	4.14
Whalers Way Orbital	0.17	n.a.

*Table **Error! No text of specified style in document.**.8. Spaceports and their population density in surrounding areas*

6.5. Accessibility and Political Stability

Spaceport	Nearest Major City	Distance from Major City (km)
Arnhem Space Centre	Darwin	500
Bowen Orbital Spaceport	Townsville	25
Whalers Way Orbital	Port Lincoln	17

*Table **Error! No text of specified style in document.**.9. Spaceports and the distance from their nearest major city*

Spaceport	Nearest Neighbouring Country in direction of launch	Distance from Neighbouring Airspace (km)
Arnhem Space Centre	Papua New Guinea	584
Bowen Orbital Spaceport	New Caledonia	1670
Whalers Way Orbital	Antarctica	3557

*Table **Error! No text of specified style in document.**.10. Spaceports and their distance from neighbouring country's airspace*

Spaceport	Latitude	Azimuth	Meteorological			Population Density	Accessibility	
			Wind	Precipitation	Temperature		Major City	Foreign countries
ASC	3	2	2	2	1	1	1	1
BOS	2	1	3	1	3	2	2	2
WWO	1	3	1	3	2	3	3	3

*Table **Error! No text of specified style in document.**.11. Point ranking system by geological and political factors.*

Spaceport	Total Points
Whalers Way Orbital	19
Bowen Orbital Spaceport	16
Arnhem Space Centre	13

*Table **Error! No text of specified style in document.**.12. Total ranking points*

7. Discussion

To determine the most optimal spaceport location within Australia, the most important geographical and political considerations have been recorded and analysed. The latitudes of the three spaceport locations: Arnhem Space Centre (ASC) at 12°S, Bowens Orbital Spaceport (BOS) at 20°S, and Whalers Way Orbital (WWO) at 35°S, was used to calculate their corresponding distances from the Earths centre axis. Figure 8 shows that, by moving further from the equator, velocity assist due to earth's rotation decreases, therefore the cost of launching a rocket/satellite, with theoretically increase. Assuming an Eastward launch, using the equator as a baseline for maximum rotational velocity assist (463.3 m/s), the ASC (453.2 m/s) can theoretically utilise 97.8% of the earth's horizontal velocity. The BOS (435.4 m/s) is the next effective use of the earth's horizontal velocity, with 94.0%. The WWO can utilise the Earth's horizontal velocity the least, with velocity 379.5 m/s, 82.0% of the maximum rotational velocity. However, due to its South-West orientation, launches are actually go against the Earths horizontal velocity.

As for the azimuth and drop zones, the WWO had the largest range of 161° (296° – 135°) facing South-West (figure 9). It faces near to no azimuth limitations as its broad range faces completely open ocean (figure 12). The second largest azimuth range belongs to the ASC with 71° (143° - 72°) (figure 9). Although the second largest range, the ASC's azimuth resides over parts of Far North Coast Queensland and Papua New Guinea (figure 11.), meaning the drop zones are restricted to specific bodies of water. The smallest azimuth range, 67° (92° - 25°) (figure 9), belongs to the BOS. The limitations of this azimuth's range are the surrounding Islands and reef (figure 10), that are "likely to require regional country approval to drop stages on their territory (land and/or sea)… and significant stakeholder consultations and consider loss of income to Great Barrier Reef (assuming more than a few launches per year)" (Wallis, 2020).

The meteorology considerations are split into 3 subcategories: mean wind speeds, mean number of days of precipitation, and mean temperature range. The area with the lowest mean wind speed annually (table 7) is the BOS's 16.9 km/h. Converted to knots, 9.1kn, BOS has the lowest value below the dangerous wind threshold "19 – 34 knots"(NASA, n.d.), thus, making it the safest in terms of mean wind speed. The ASC, mean annual wind speed (table 7) 21.0 km/h, is second lowest. Equating to 11.3kn, it is safely below the dangerous wind speed for launch. With 23.2 km/h (table 7), the WWO has the highest mean annual wind speed. This value equates to an average 12.5kn, which is still a safe wind speed to launch at, but 37% higher than the BOS's 9.1kn.

The mean number of days precipitated annually for the ASC, BOS, and WWO, respectively are 74.6, 108.4, and 65.9 days (table 4). Meeting the precipitation requirements of "no precipitation at the launch pad or within the flight path" (NASA, n.d.) 82.0% of the time, was the WWO. The ASC met the precipitation requirements 79.6% of the time, with the BOS only meeting the requirements at 70.3% of the time.

The mean temperature range pertains to a spaceports ability to fuel, prior and post launch. "Fuelling prior to launch will not begin if the 24-hour average temperature has been below 5°C and the temperature has fallen below 0.5°C at any time during the previous 24 hours. After tanking begins, the countdown shall not be continued, nor the shuttle launched if the temperature exceeds 37 degrees for more than 30 consecutive minutes" (NASA, n.d.). Shown in figure 13, the BOS had the smallest mean temperature range at 12.8°C. The mean minimum and maximum temperature, 17.6°C - 30.4°C, both satisfy the temperature requirements outline by NASA (n.d.) with the smallest range. With a mean temperature range of 17.3°C, the WWO has a mean minimum and maximum temperature of 8.1°C and 25.4°C. Although within not breaking the temperature requirements, the mean minimum temperature is 3.1°C of the unallowable temperature requirement (5°C). As it is a mean, it is possible that some days will fail to meet this requirement. The ASC has the largest range of mean temperatures: 20°C. The mean minimum and maximum temperatures range greatly from 15.7°C – 35.7°C. 1.3°C lower than the unallowable mean temperature for launch (37°C), it is possible that the ASC will fail to meet temperature requirements on some days.

Relating to the azimuth limitations, the population density of a spaceports surrounding areas and launch path are essential to safe drop zones. With no population density at its site (table 8), the BOS poses the least threat to the population in the immediate area. However, the spaceport is located westward of city Bowen (figure 7), which has a population density of 4.14 people/km^2; the highest surrounding population density (table 8). The WWO, of 0.17 people/km^2, has the smallest population density in the immediate area. In addition, there is no population density in its azimuth path as launches are "projected over the Great Australian Bight" (Price, 2022). With a population density of 0.43 people/km^2, the ASC is the most densely populated area among the three spaceports. Comparatively, its launch path and azimuth zone passes over Far North Queensland, 1.13 people/km^2, and Papua New Guinea, 23.0 people/km^2. This makes it hazardous to the public as drop zones have a smaller area to successfully occur.

Finally, the accessibility and political stability of a spaceport's location provides "convenience (or inconvenience)… to travel to and from the spaceport" (Wild, 2015) as well as security from foreign intervention, "ensuring unfettered access to the launch site at all times" (Roberts, 2019). The spaceport with the closest major city is the WWO, with Port Lincoln 17km away (table 9). The proximity of this city enables resources and payload to be transported to the spaceport with ease. Not much further, Townsville is located 25km from the BOS (table 9) and provides the same benefits due to its proximity. However, Darwin is the closest major city to the ASC. Separated by 500km, the transportation of resources and payload from one location to another is not as timely and accessible as the other spaceport locations.

As the closest continent, Antarctica, is 3557km away, the WWO is least likely to be impacted by foreign intervention. With New Caledonia 1670km away, the BOS is "likely to require regional country approval to drop stages on their territory (land and/or sea) – likely difficult to achieve" (Wallis, 2020). Similarly, the ASC is the closest spaceport to a foreign country, with Papua New Guinea only 584km away. Such proximity to a neighbouring state, could be negative should Australia's relationship with them is poorly maintained.

Considering those 5 factors, table 11, uses a ranking point system that determines the most optimal spaceport location for future space exploration, based on the geographical and political considerations. Based on the total point score (table 12), the most optimal spaceport location is the Southern Launch's Whalers Way Orbital Launch Complex, Sleaford, SA. The spaceport offers a low population density (0.17 people/km^2) and is in close proximity to major city, Port Lincoln (17km), for the transportation of payload and resources. Its wide azimuth range (161°) is beneficial to launches as it provides large drop zones free from foreign intervention. The weather conditions meet all of NASA's Space Shuttle Weather Launch Commit Criteria and KSC End of Mission Weather Landing Criteria' (n.d.) meteorological requirements. However, the disadvantage found at the WWO is its inability to utilise the Earth's rotational velocity due to its South-West facing launches.

As stated in Wild's 'Optimising the Potential Location of Spaceport Australia based on Current Suborbital Space Tourism Requirements' (2015), areas for potential research can include "Commercial human spaceflight (space tourism), point-to-point (high-speed passenger) transportation, basic and applied research, aerospace technology test and demonstration, remote sensing, education and Media and public relations." With the emerging industry of aerospace within Australia, the WWO, as the most optimal spaceport location within Australia, makes it viable for the research into further space exploration. This could include, based on the criteria outlined in section 5, can a more optimal location in Australia be located? The disadvantage of the WWO, could further be investigated to determine a way that it can utilise the Earths rotational velocity, reducing the costs and energy required to launch. There could also be research done into the implications of drop zones in the ocean and in space, to investigate the effects of debris in each respective environment.

8. Conclusion

In conclusion, the most optimal location for a Spaceport for future space exploration within Australia, can be determined based on geographical and political considerations. The scientific research question posed for this report was "As the aerospace industry continues to emerge, is there an optimal spaceport location in Australia that could be used for future space exploration?". To answer this, the five most important geographical and political considerations:

- Latitude,
- Azimuth limitations,
- Meteorological considerations,
- Population density,
- and Accessibility,

were used to device a secondary investigation that aims to gather in data of these geographical and political considerations. From the literature in section 2, a comprehensive analysis formed by a qualitative and quantitative data method of research, was used to classify the geographical and political considerations of three spaceports: the Arnhem Space Centre, Bowens Orbital Spaceport, and Whalers Way Orbital Launch Complex. From the results and point ranking system (table 12), each spaceport location is viable for future space exploration. However, when taking into account the 5 geographical and political considerations, a subjective optimum spaceport can be determined. Specifically, the Southern Launch's Whalers Way Orbital Launch Complex offers a low population density with close proximity to major city, Port Lincoln, for the transportation of payload and resources. A wide azimuth range and favourable weather conditions make it the most optimal spaceport location for future space exploration within Australia.

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