Spaceport Optimization Research Project

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Over the past hundred years, space exploration has gone from looking up to the sky with a telescope, to sending humans to the moon, and now working to send humans to mars. In this time, humans have made leaps and bounds in the technology used in space exploration, which has allowed us to send rockets and spacecraft out of our atmosphere more and more. Currently there are 6 FAA licensed airports in the United States, with an additional 8 non-licensed airports. While this can sustain the current domestic demand, innovations in technology and new users will continue to drive the expansion of spaceports across the country.

Spaceports have historically been built in places that provide strategic advantages for launching and receiving spacecraft. One of the main factors in choosing a spaceport location is proximity to the equator, which allows for greater launch efficiency due to the Earth's rotation. For this reason, NASA's Kennedy Space Center in Florida, which is situated at 28 degrees north latitude, was chosen as the launch site for the Apollo moon missions. Additionally, spaceports are typically built in remote areas with limited air and sea traffic to minimize the risk to nearby population centers in the event of a launch failure. Another consideration is the availability of suitable infrastructure and facilities, such as launch pads, assembly buildings, and tracking stations. These factors have all played a role in the placement of spaceports in the United States, which include locations such as Cape Canaveral, Florida, Vandenberg Air Force Base in California, and Wallops Island in Virginia.

New technology and drivers has, and will continue to change, which factors are the most important for placing a spaceport. For example, New launch capabilities allow efficiency regardless of a spaceport's proximity to the equator. The Andoya spaceport project was established in 2018, and has placed a spaceport in northern Norway.

When looking at where in the US a new spaceport should be built, there are many factors to consider, and many ways to look at them. There are thousands of theoretical locations, and dozens of advantages and disadvantages for each. This then leads to the first question, how do we choose how to pick the best location for a new spaceport. The solution that we chose was to use an optimization model based on the Facility Location Problem(FLP).

The facility location model is a mathematical approach used to determine the optimal location for facilities such as factories, warehouses, and distribution centers. The model seeks to minimize the total cost of transportation and facility operation, while also taking into account factors such as customer demand, supply chain logistics, and local regulations. The model typically involves identifying potential facility locations, analyzing the transportation costs associated with each location, and then selecting the location that offers the lowest total cost. The facility location model has broad applications across industries, including retail, manufacturing, and logistics. By using this model, companies can make informed decisions about where to locate facilities, which can lead to cost savings, improved efficiency, and increased customer satisfaction.

In our case, not all of our inputs are exact monetary costs, but we are able to still use the underlying methods for our model. Our initial model took in a few basic constraints and inputs, and then was able to determine which counties were “the best” for these constraints. The model is built so as the research continues, additional conditions and inputs can be easily added.

For each input into the model there is a specific reason, which some users may value differently than others. A spaceport with which is designed for testing may be better suited for more remote locations, while travel based may want to be closer to highly populated areas. For this reason, each constraint can be weighted as the user would like.

The first run of our model included 3 variables, population density, weather data, and flight corridors. For all of our inputs, data was broken down by county, such that we had specific results. We were able to obtain weather data from HRRR and population data from the Census. The FAA has information on flight corridors which we were able to utilize. In this run we included three different classes A,B and C. These mission classes are placeholders for different mission types. Different missions such as vertical vs horizontal launches will require different constraints among weather, nearby population, and air traffic, which will affect which sites can be chosen for a specific mission. As the research continues, we will develop the actual constraints for these missions but for now, A, B, and C are pretend missions with made-up constraints to show that the location planning model can differentiate between them.

	Location	Mission type
1	Wolf County, KY	A, B
2	East Caroll Parish, LA	C
3	McCreary County, KY	A, B
4	Jefferson County, MS	C
5	McDowell County, WV	A, B

Figure 1: Results of Initial FLP Model Run

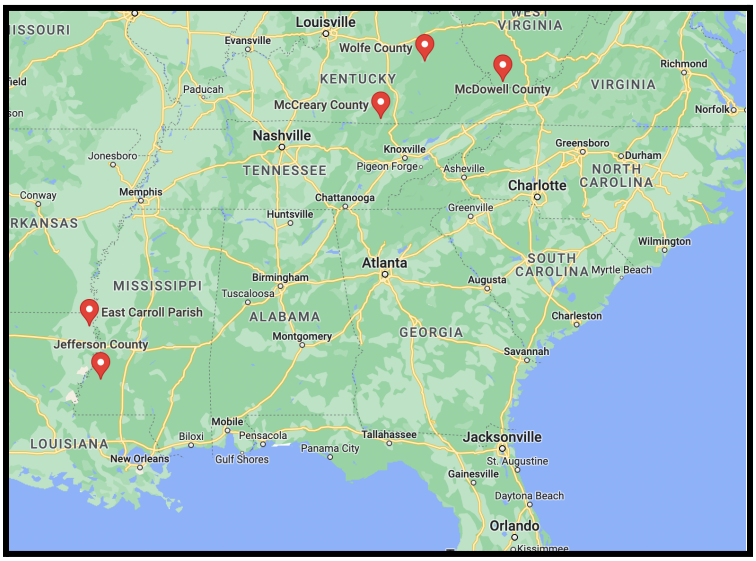

Figure 2: Locations of Counties from Initial FLP Model Run

In figure 1 we see the five best counties that the FLP model decided on, as well as which mission types are acceptable at those locations. Looking at figure 2 we can see the exact locations of these. Although they met our initial conditions, there are likely other locations that will work better once the model is fully expanded.

In order to improve upon our first run, there were three areas in which we wanted to focus. The first is historic launch paths, the second is improved flight analysis, and the third is including proximity to coastline. By looking at previous launch trajectories, we will be able to determine the size of the area in which our parameters should be enforced, as well as the direction of that area. This then causes us to expand our model to look at the counties a spacecraft is launched over, as opposed to just the county that it was launched in.

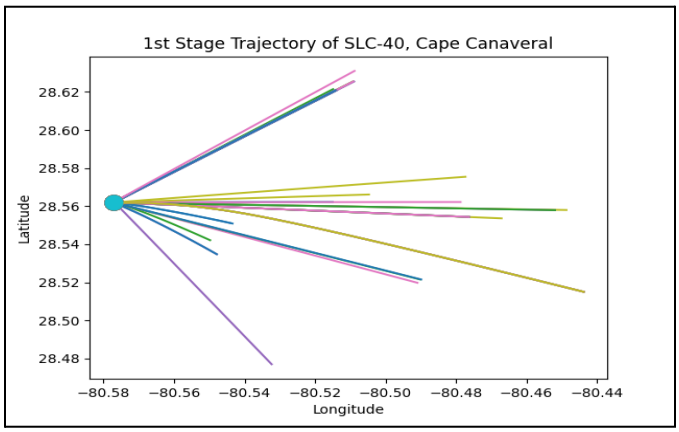

Figure 3: Historical Launches out of Cape Canaveral

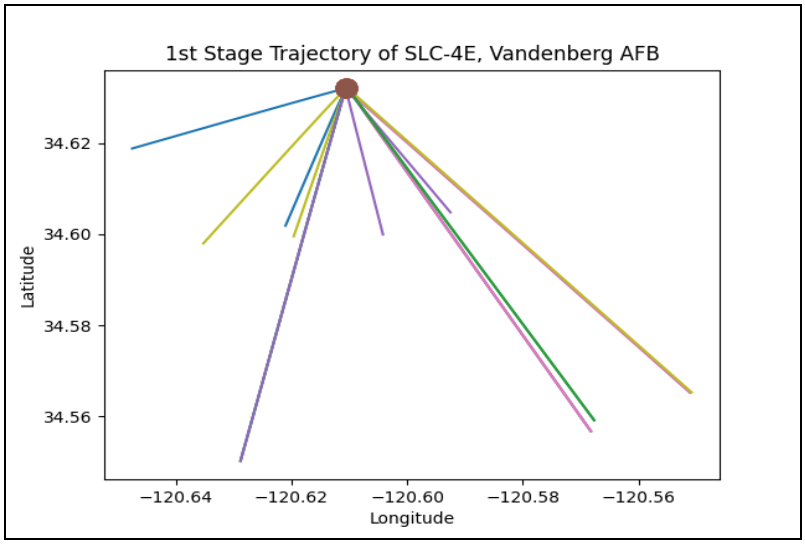

Figure 4: Historical Launches out of Vandenberg Air Force Base

Looking at figures 3 and 4 we can see the historical launch patterns out of Cape Canaveral and Vandenberg Air Force Base. There are clear patterns primarily focused east, as well as some south/southwest. This makes sense as they both launch above the ocean(in case of failure), as well as with the rotation of the earth which assists in launch efficiency. Going forward, we intend to reduce the bias of only 2 launch sites by looking at other locations. Then we can examine the amount of airspace used to incorporate into our FLP Model.

Although flight corridors show the common pathways of commercial airlines, they do not show the frequency in which they are used. Knowing frequency of flights over a given area would allow us to calculate the cost of a delay/reroute on airlines for when the airspace above the spaceport is closed. There are multiple sources for flight tracking online, but the initial support for this project came from OpenSky Network. OpenSky Network is a global non-profit organization that provides a platform for sharing real-time

air traffic data. Its mission is to improve the safety, efficiency, and capacity of the air transportation system through the use of advanced technologies. OpenSky operates a network of ground-based receivers that capture Automatic Dependent Surveillance-Broadcast (ADS-B) signals transmitted by aircraft. ADS-B is a technology that allows aircraft to broadcast their location, speed, altitude, and other information to ground-based receivers and other aircraft. They have an extensive network, and remote database that is easy to access. Figure 5 shows an example of OpenSky's coverage of the United States.

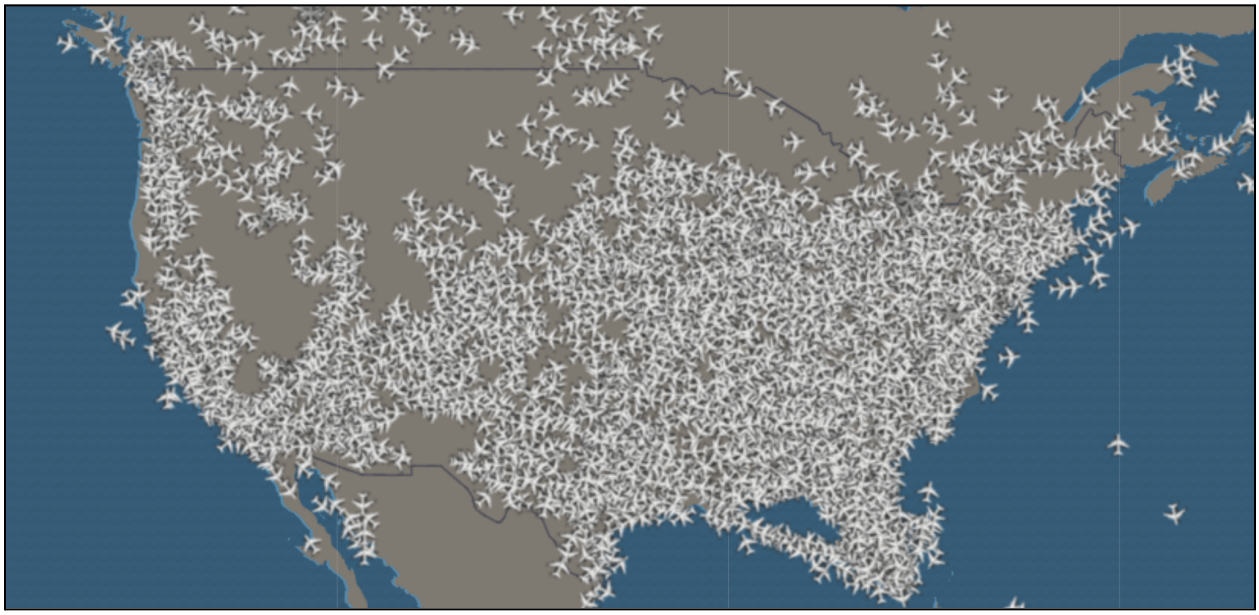

Figure 5: Example of OpenSky Data

In order to use the data given by opensky, it needed to be filtered and analyzed. To do this we first removed data that is outside of a rectangular border around the outside of the US. From there we separated flight points that were above land and those above the ocean. Although we don't want to count the flight points that are above the ocean in

given counties, they are still important if a launch is happening in a direction above the ocean. After this, we used a minimum distance formula to place each flight data point, and then counted the number of flights in each county. Although the idea behind this is relatively simple, it was very important that this process was extremely efficient as the data being processed had over 800,000 rows. In figures 6 and 7 we can see the results of the flight analysis, which can then be incorporated into our model going forward

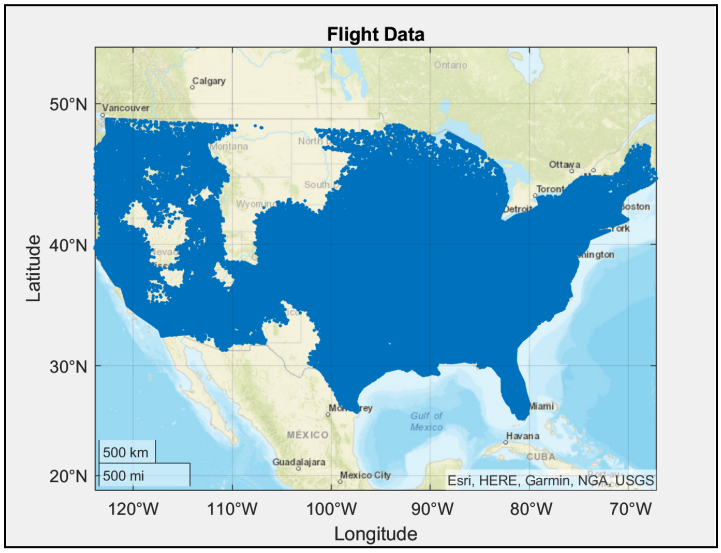

Figure 6: Map of Analysed Flight Points

County Name	Flown Over X Times	Lattitude Centroid	Longitude Centroid
'Hancock County'	132	41.00193838	-83.66653541
'Stafford County'	357	38.42071902	-77.45740039
'Webster County'	72	40.17643321	-98.49994738
'Dimmit County'	32	28.422536	-99.75672613
'Cedar County'	163	41.77232666	-91.13242305
'Deuel County'	33	44.76005795	-96.66797414
'Howard County'	72	43.35676734	-92.3171989
'Palm Beach Count	1373	26.64756457	-80.43651105
'St. Lawrence Coun	76	44.49640214	-75.06895227
'Clark County'	64	44.85825389	-97.7294963
'Dundy County'	186	40.17623524	-101.6879614
'Alamosa County'	248	37.57289314	-105.7882882
'Citrus County'	735	28.84756969	-82.52010673
'Williamsburg Cour	247	33.61992549	-79.72771203
'Walworth County'	186	42.66848698	-88.54190407
'Union County'	94	39.62554585	-84.92514203
'Kandiyohi County'	62	45.15238235	-95.00474246
'Washington Count	86	44.9694591	-67.60905949
'Hoke County'	181	35.01752901	-79.23729072
'Waseca County'	78	44.02212365	-93.58728322

Figure 7: County Level Results of Flight Analysis

Future work on this research expands into a few areas. The first includes preprocessing of counties to improve efficiency as well as further examine historic launch patterns. Additionally we want to examine the potential environmental and societal effects for placing a spaceport in a given location, as well as how to address disadvantages of the quantitative model. After this project is completed, there are a variety of potential users between the FAA, NASA, Airlines, or other space companies.