

Winning Space Race with Data Science

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Outline

- Executive Summary
- Introduction
- Methodology
- Results
- Conclusion
- Appendix



Executive Summary

Summary of Methodologies

The research aims to identify the key factors that influence the success of SpaceX rocket first stage return. By analyzing various launch attributes, we aim to improve the understanding of what makes these landings more effective. The following methodologies were applied to achieve this goal:

- **Collect data** through SpaceX REST API and web scraping to gather comprehensive launch details.
- **Wrangle the data** to define a success/fail outcome variable for second stage recoveries.
- **Explore the data** using visualization techniques, focusing on factors such as payload, launch site, flight number, and yearly trends.
- **Analyze the dataset** with SQL to calculate key metrics: total payload, payload ranges for successful launches, and the total number of successful and failed outcomes.
- **Investigate launch site success rates** and examine their proximity to important geographical markers.
- **Visualize the most successful launch sites** and identify payload ranges associated with successful recoveries.
- **Build predictive models** using logistic regression, support vector machines (SVM), decision trees, and K-nearest neighbor (KNN) to determine the likelihood of landing success.

Exploratory Data Analysis:

- Launch success has improved over time
- KSC LC-39A has the highest success rate among landing sites
- Orbit ES-L1, GEO, HEO, and SSO have a 100% success rate

Visualization/Analytics:

- Most launch sites are near the equator, and all are close to the coast

Predictive Analytics:

- All models performed similarly on the test set. The decision tree model slightly outperformed



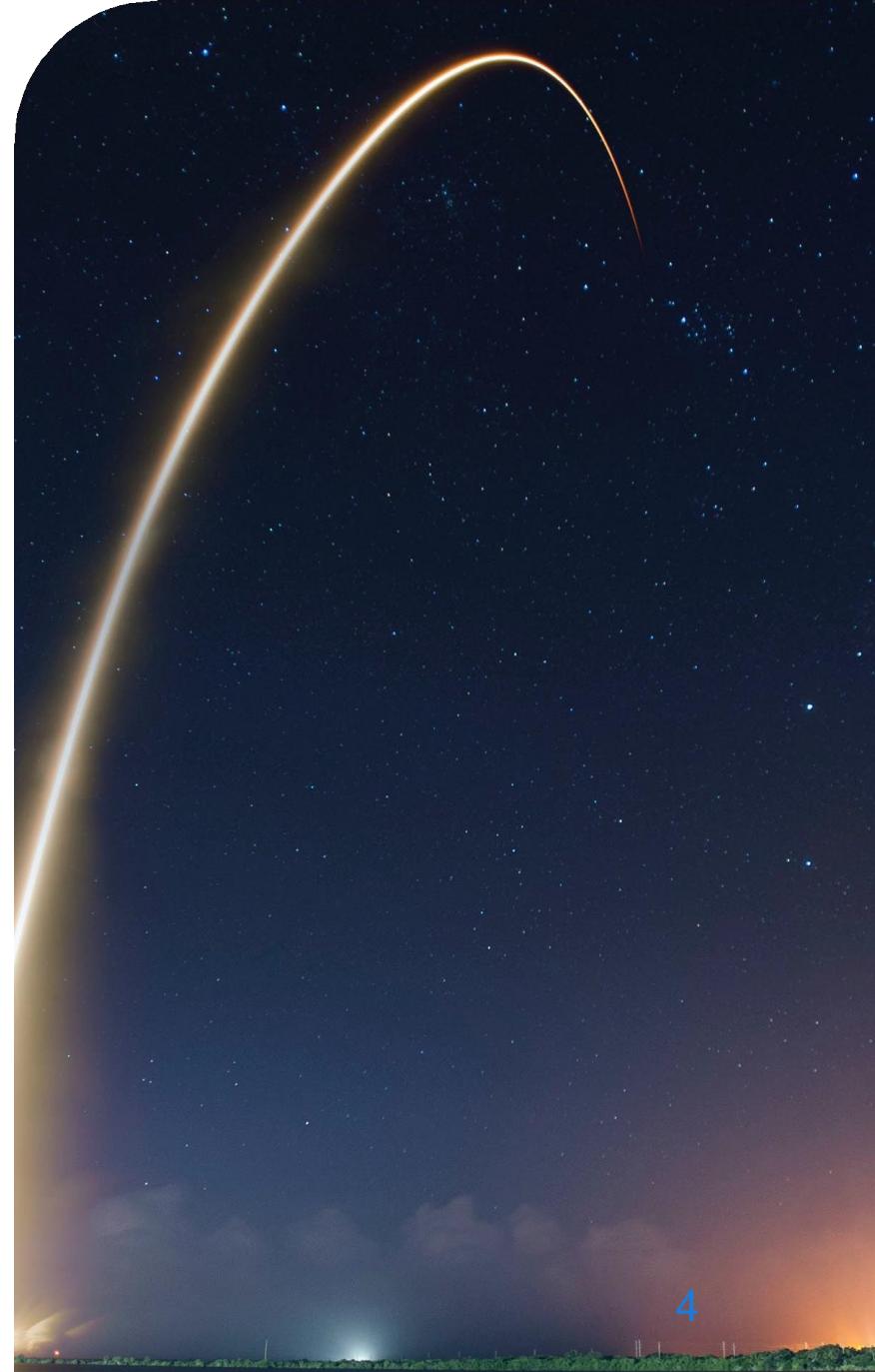
Introduction

Background

SpaceX is one of the world's most innovative aerospace companies, with a clear mission: to dramatically reduce the cost of access to space. One of the keys to achieving this has been the development of the Falcon 9 rocket's first stage recovery and reuse technology. By recovering and reusing the first stage, SpaceX not only saves millions of dollars per launch, but also drives a revolution in the space industry. SpaceX, a leader in the space industry, has achieved milestones such as sending spacecraft to the International Space Station, launching the Starlink satellite constellation and conducting manned missions. These achievements are due to the fact that its launches are much cheaper (\$62 million per launch) thanks to the reuse of the first stage, compared to other providers that reach \$165 million. This work focuses on analyzing the factors affecting first stage landing success, providing a better understanding of these operations and predicting their success with machine learning models.

Explore

- How payload mass, launch site, number of flights, and orbits affect first-stage success
- Rate of successful landings over time
- Best predictive model for successful landing (binary classification)



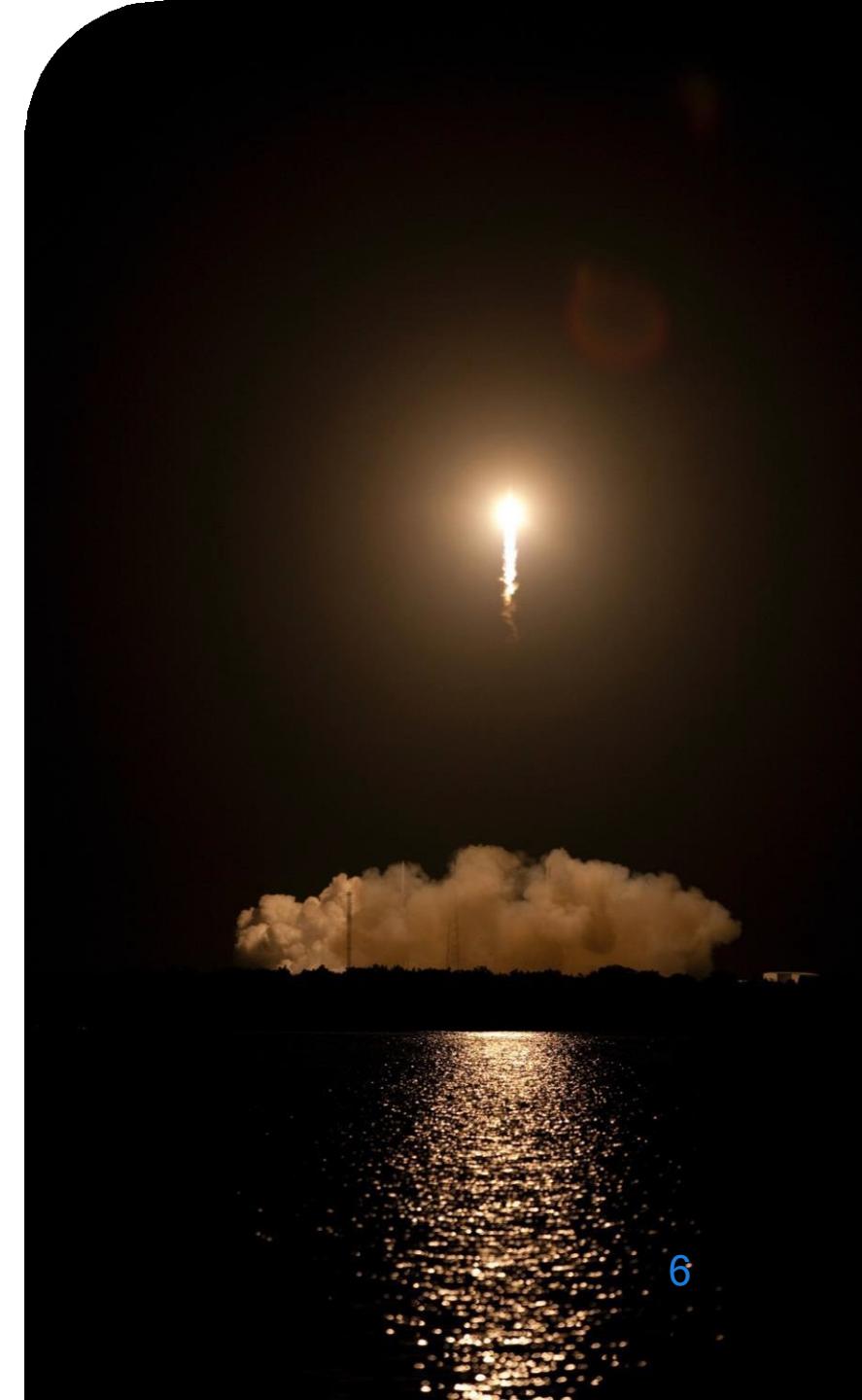
Section 1

Methodology

Methodology

Steps

- **Collect data** using the SpaceX REST API and web scraping methods.
- **Wrangle data** – filter, handle missing values, and apply one-hot encoding – to prepare for analysis and modeling.
- **Explore the data** through EDA using SQL and visualization techniques.
- **Visualize results** interactively with Folium and Plotly Dash.
- **Build classification models** to predict landing outcomes. Tune and evaluate to determine the best model and parameters.



Data Collection - SpaceX API

Steps

- **Request** rocket launch data from SpaceX API.
- **Decode** the response with `.json()` and convert it to a dataframe using `.json_normalize()`.
- **Request** detailed launch info from SpaceX API using custom functions.
- **Create** a dictionary from the data.
- **Convert** the dictionary into a dataframe.
- **Filter** the dataframe to keep only Falcon 9 launches.
- **Replace** missing values in Payload Mass with `.mean()`.
- **Export** the cleaned data to a CSV file.



Data Collection – Web Scraping

Steps

- **Request data** (Falcon 9 launch data) from Wikipedia
- **Create BeautifulSoup object** from HTML response
- **Extract column names** from HTML table header
- **Collect data** from parsing HTML tables
- **Create dictionary** from the data
- **Create dataframe** from the dictionary
- **Export data** to csv file



Data Wrangling

Steps

- **Perform EDA** and determine data labels
- **Calculate:**
 - #of launches for each site
 - #and occurrence of orbit
 - #and occurrence of mission outcome per orbit type]
- **Create binary** landing outcome column (dependent variable)
- **Export data** to csv file

Landing Outcome

- Landing was not always successful
- **True Ocean:** mission outcome had a successful landing to a specific region of the ocean

Landing Outcome

Cont.

- **False Ocean:** represented an unsuccessful landing to a specific region of ocean
- **True RTLS:** meant the mission had a successful landing on a ground pad
- **False RTLS:** represented an unsuccessful landing on a ground pad
- **True ASDS:** meant the mission outcome had a successful landing on a drone ship
- **False ASDS:** represented an unsuccessful landing on drone ship
- **Outcomes converted** into 1 for a successful landing and 0 for an unsuccessful landing



EDA with Visualization

Charts

- Flight Number vs. Payload
- Flight Number vs. Launch Site
- Payload Mass (kg) vs. Launch Site
- Payload Mass (kg) vs. Orbit type

Analysis

- **View relationship** by using **scatter plots**. The variables could be useful for machine learning if a relationship exists
- **Show comparisons** among discrete categories with **bar charts**. Bar charts show the relationships among the categories and a measured value.



EDA with SQL

Queries

Display:

- Names of unique launch sites
- 5 records where launch site begins with 'CCA'
- Total payload mass carried by boosters launched by NASA (CRS)
- Average payload mass carried by booster version F9 v1.1.

List:

- Date of first successful landing on ground pad
- Names of boosters which had success landing on drone ship and have payload mass greater than 4,000 but less than 6,000
- Total number of successful and failed missions
- Names of booster versions which have carried the max payload
- Failed landing outcomes on drone ship, their booster version and launch site for the months in the year 2015
- Count of landing outcomes between 2010-06-04 and 2017-03-20 (desc)



Map with Folium

Markers Indicating Launch Sites

- Added **blue circle** at **NASA Johnson Space Center's coordinate** with a **popup label** showing its name using its latitude and longitude coordinates
- Added **red circles** at **all launch sites coordinates** with a **popup label** showing its name using its name using its latitude and longitude coordinates

Colored Markers of Launch Outcomes

- Added **colored markers** of **successful (green)** and **unsuccessful (red)** **launches** at each launch site to show which launch sites have high success rates

Distances Between a Launch Site to Proximities

- Added **colored lines** to **show distance between** launch site **CCAFS SLC-40** and its proximity to the **nearest coastline, railway, highway, and city**



Dashboard with Plotly Dash

Dropdown List with Launch Sites

- Allow user to select all launch sites or a certain launch site

Pie Chart Showing Successful Launches

- Allow user to see successful and unsuccessful launches as a percent of the total

Slider of Payload Mass Range

- Allow user to select payload mass range

Scatter Chart Showing Payload Mass vs. Success Rate by Booster Version

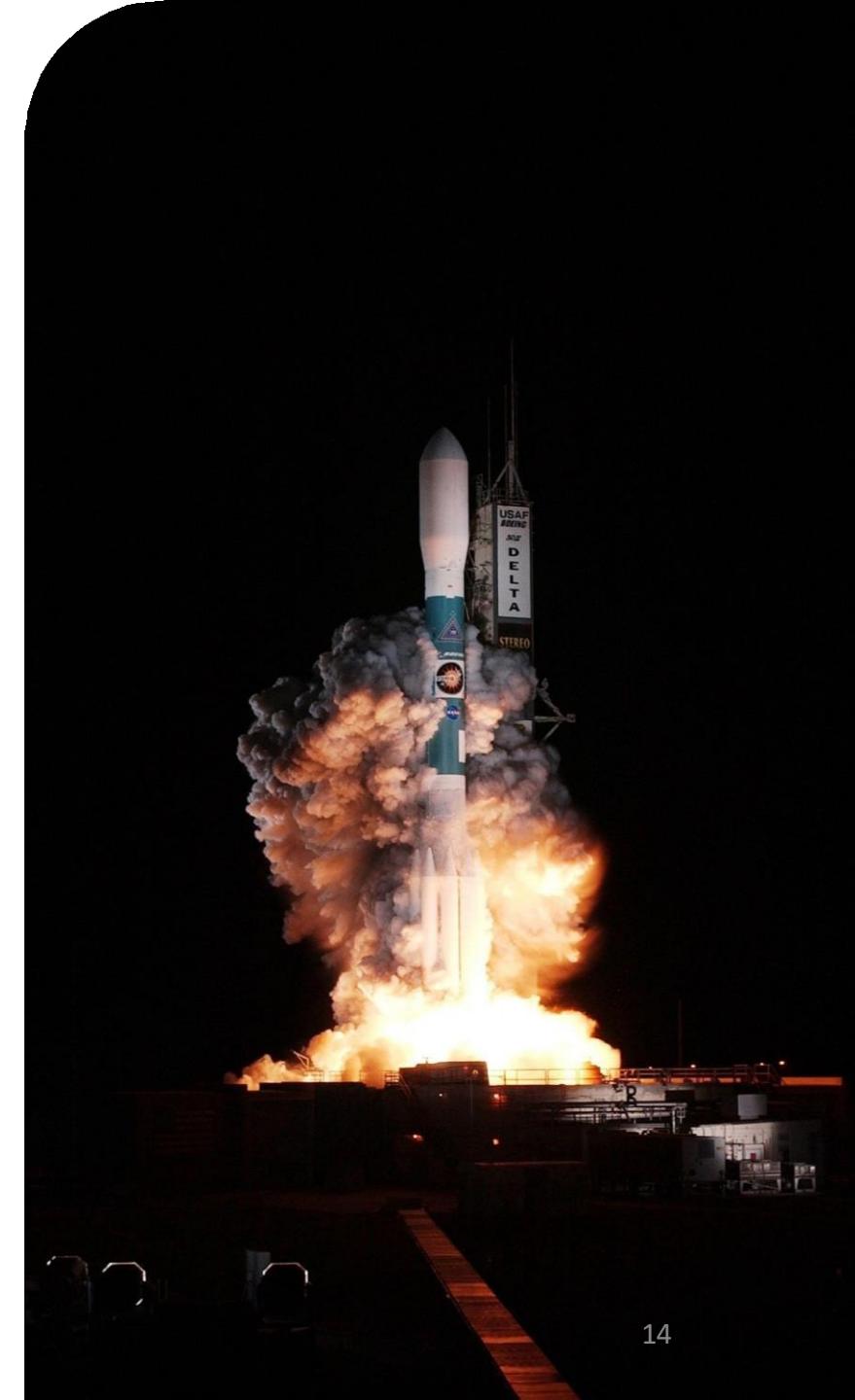
- Allow user to see the correlation between Payload and Launch Success

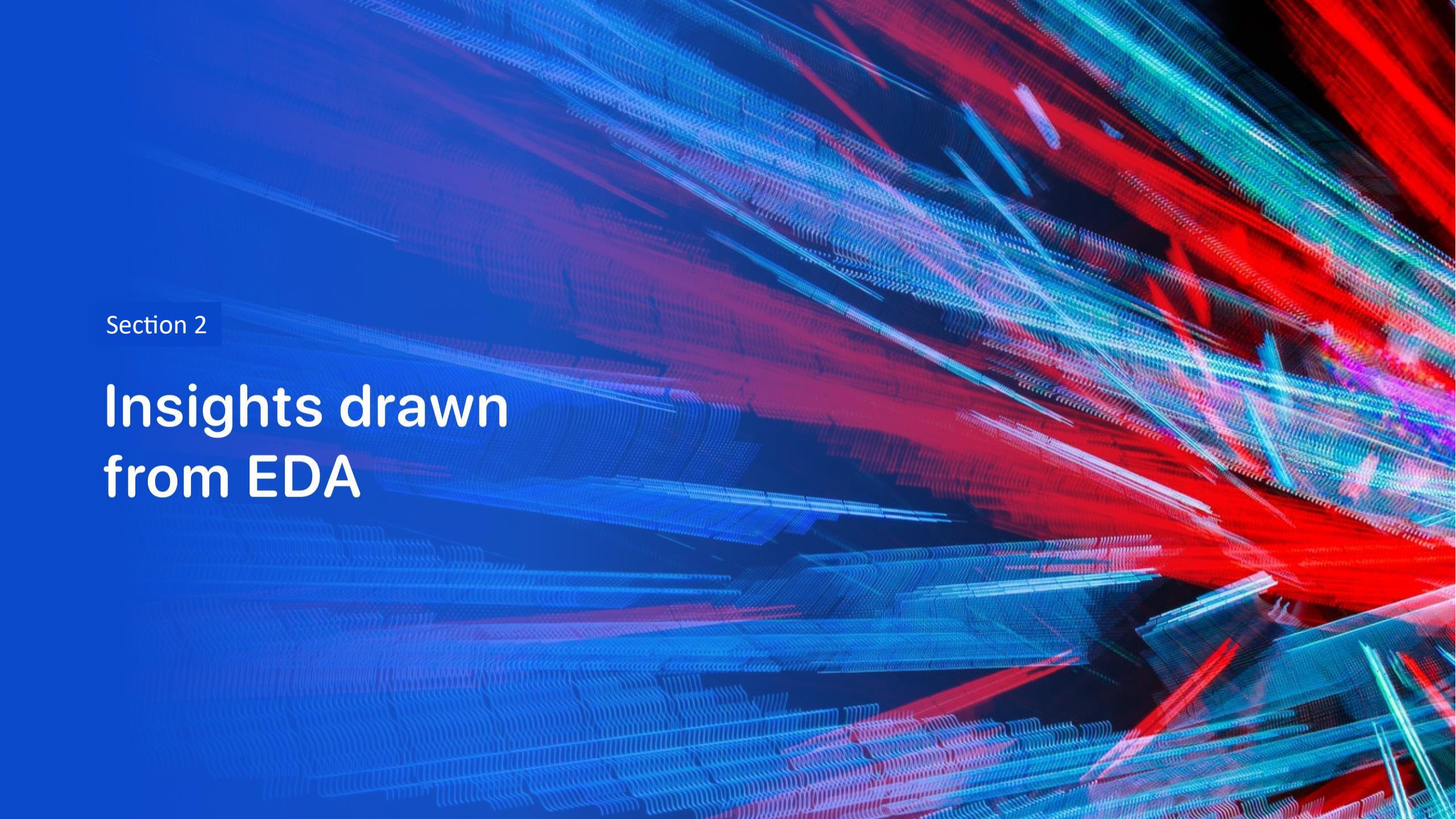


Predictive Analytics

Charts

- **Create** NumPy array from the Class column
- **Standardize** the data with StandardScaler. Fit and transform the data.
- **Split** the data using train_test_split
- **Create** a GridSearchCV object with cv=10 for parameter optimization
- **Apply** GridSearchCV on different algorithms: logistic regression (LogisticRegression()), support vector machine (SVC()), decision tree (DecisionTreeClassifier()), K-Nearest Neighbor (KNeighborsClassifier())
- **Calculate** accuracy on the test data using .score() for all models
- **Assess** the confusion matrix for all models
- **Identify** the best model using Jaccard_Score, F1_Score and Accuracy



The background of the slide features a complex, abstract pattern of glowing lines. These lines are primarily blue and red, creating a sense of depth and motion. They form a grid-like structure that curves and twists across the frame, resembling a digital or architectural space.

Section 2

Insights drawn from EDA

Results Summary

Exploratory Data Analysis

- Launch success has improved over time
- KSC LC-39A has the highest success rate among landing sites
- Orbit ES-L1, GEO, HEO and SSO have a 100% success rate

Visual Analytics

- Most launch sites are near the equator, and all are close to the coast
- Launch sites are far enough away from anything a failed launch can damage (city, highway, railway), while still close enough to bring people and material to support launch activities

Predictive Analytics

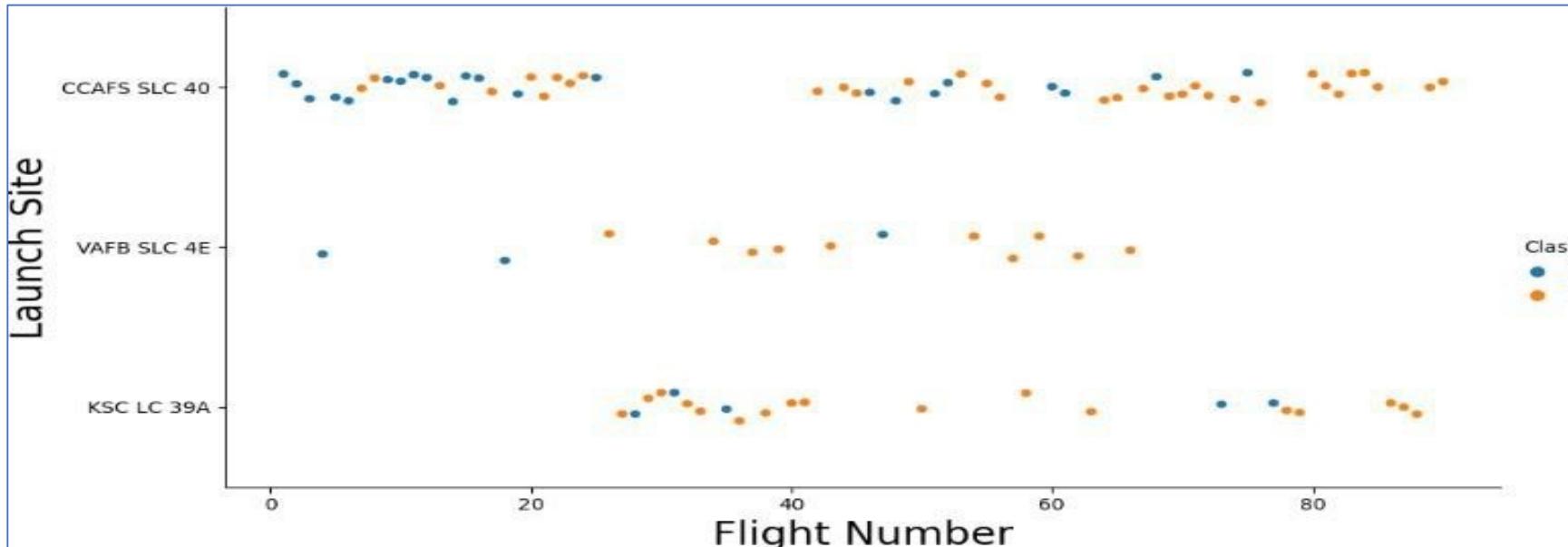
- Decision Tree model is the best predictive model for the dataset



Flight Number vs. Launch Site

Exploratory Data Analysis

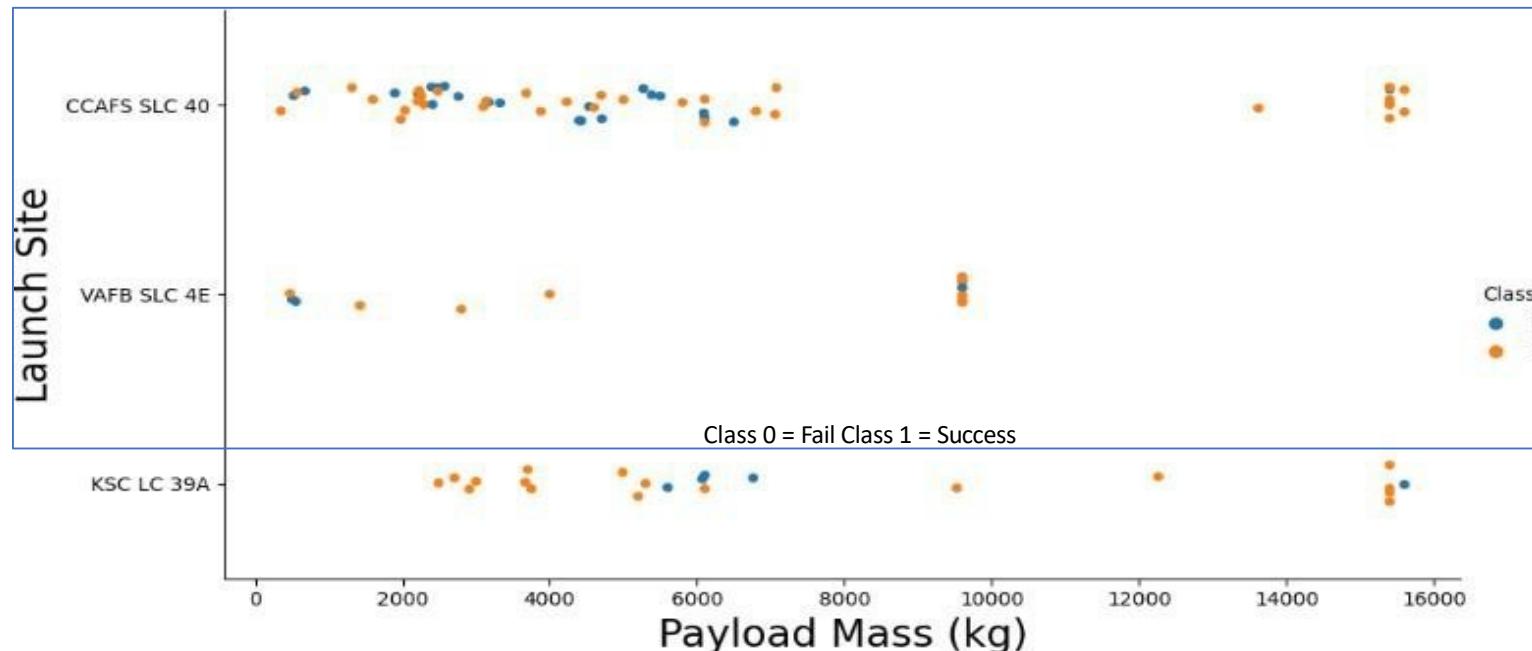
- **Earlier flights** had a **lower success rate** (**blue =fail**)
- **Later flights** had a **higher success rate** (**orange =success**)
- Around half of launches were from CCAFS SLC 40 launch site
- VAFB SLC 4E and KSC LC 39A have higher success rates
- We can infer that new launches have a higher success rate



Payload vs. Launch Site

Exploratory Data Analysis

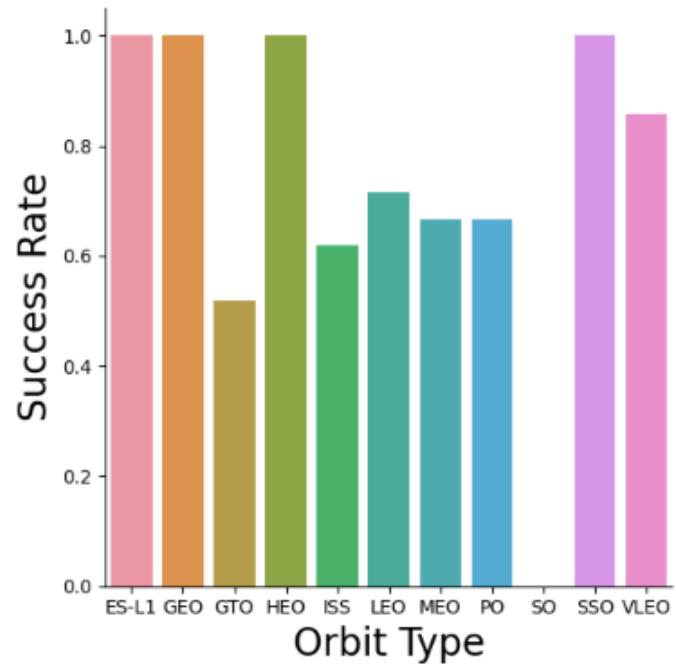
- Typically, the **higher** the **payload mass** (kg), the **higher** the **success rate**
- Most launches with a payload greater than 7,000 kg were successful
- KSC LC 39A has a 100% success rate for launches less than 5,500 kg
- VAFB SKC 4E has not launched anything greater than ~10,000 kg



Success Rate by Orbit

Exploratory Data Analysis

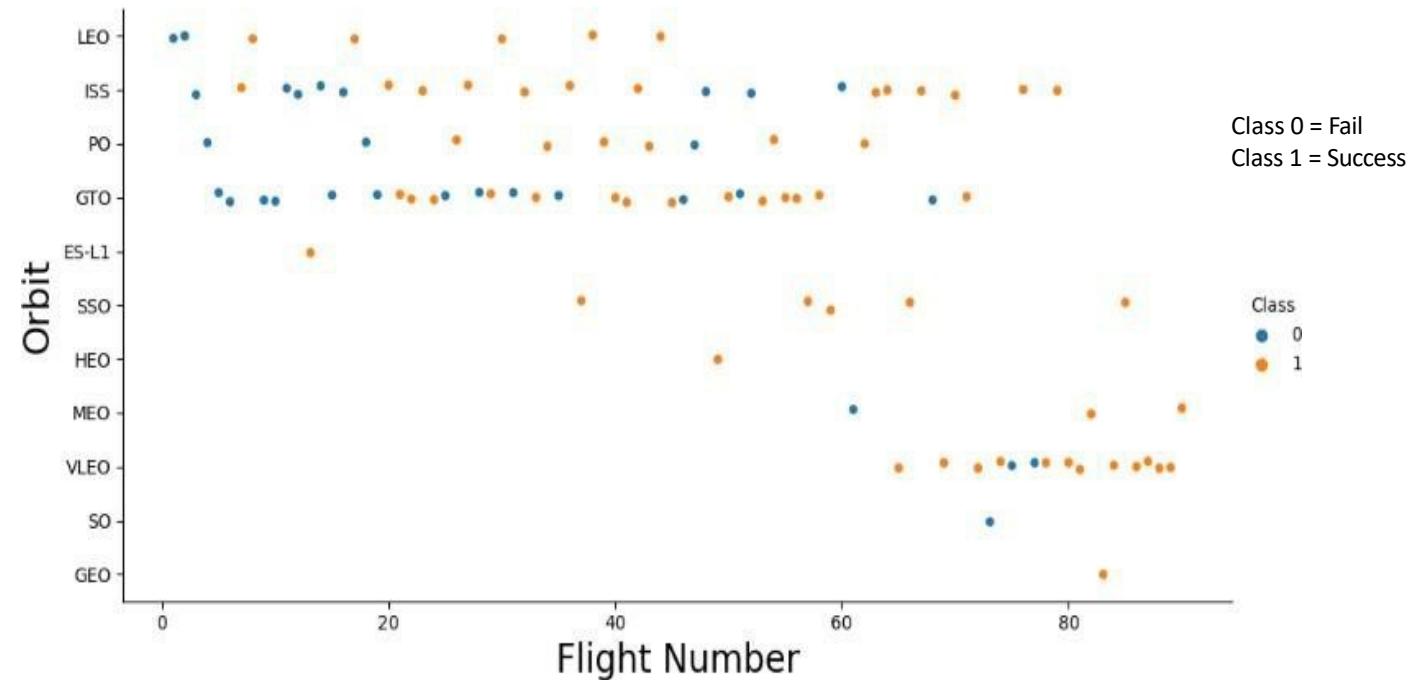
- **100% Success Rate:** ES-L1, GEO, HEO and SSO
- **50%-80% Success Rate:** GTO, ISS, LEO, MEO, PO
- **0% Success Rate:** SO



Flight Number vs. Orbit

Exploratory Data Analysis

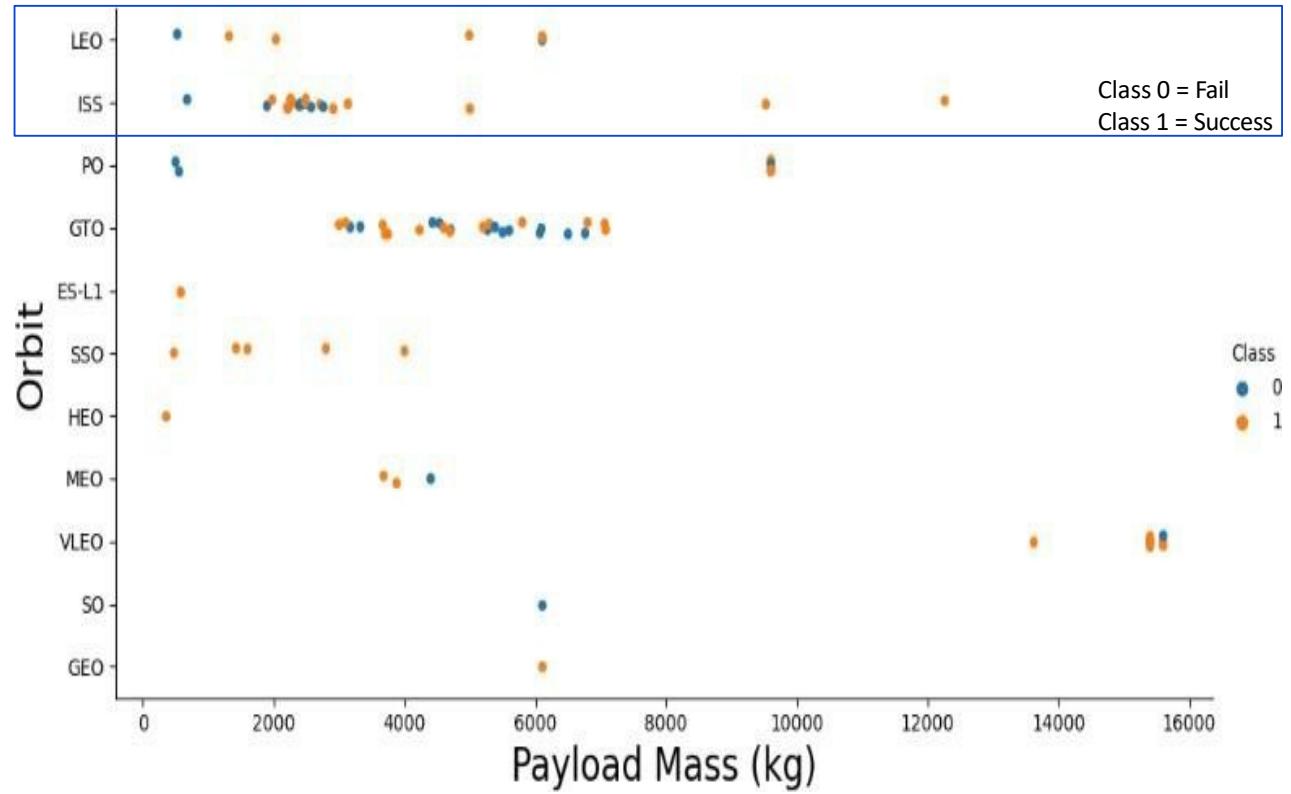
- The success rate typically increases with the number of flights for each orbit
- This relationship is highly apparent for the LEO orbit
- The GTO orbit, however, does not follow this trend



Payload vs. Orbit

Exploratory Data Analysis

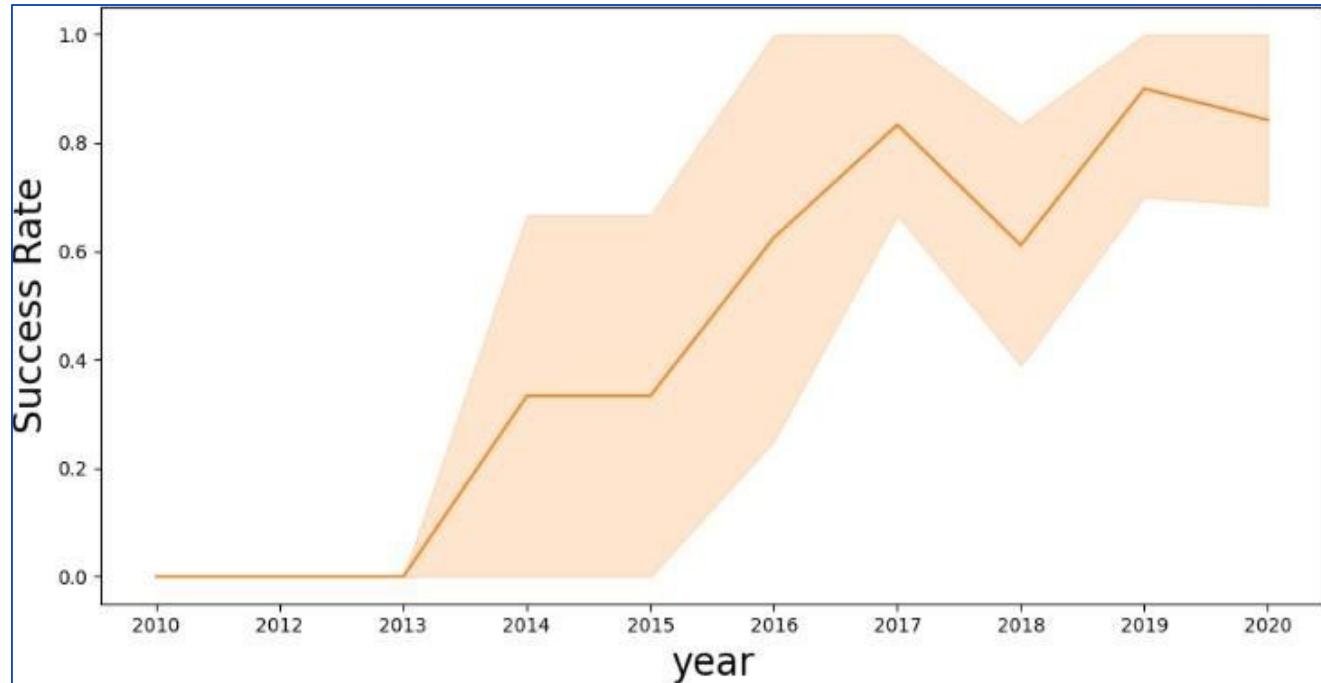
- Heavy payloads are better with LEO, ISS and PO orbits
- The GTO orbit has mixed success with heavier payloads



Launch Success over Time

Exploratory Data Analysis

- The success rate improved from 2013-2017 and 2018-2019
- The success rate decreased from 2017-2018 and from 2019-2020
- Overall, the success rate has improved since 2013



Launch Site Information

Launch Site Names Cont.

- CCAFS LC-40
- CCAFS SLC-40
- KSC LC-39A
- VAFB SLC-4E

Landing Outcome

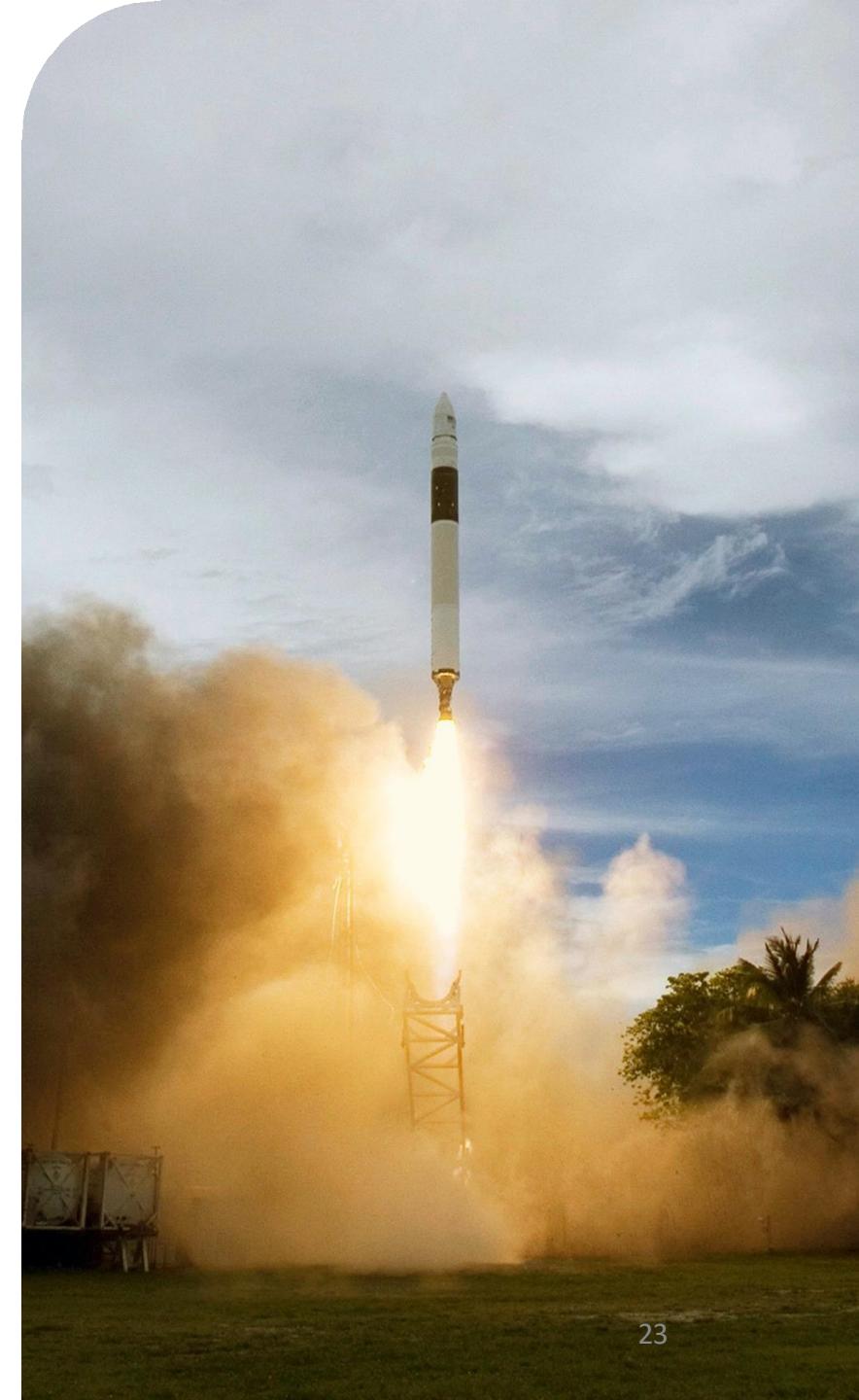
```
[30]: %sql ibm_db_sa://yyy33800:dwNkg8J3L0IBd6CP@1bbf73c5
%sql SELECT Unique(LAUNCH_SITE) FROM SPACEXTBL;
* ibm_db_sa://yyy33800:**@1bbf73c5-d84a-4bb0-85b9
sqlite:///my_data1.db
Done.

[30]: launch_site
      CCAFS LC-40
      CCAFS SLC-40
      KSC LC-39A
      VAFB SLC-4E
```

Records with Launch Site Starting with CCA

- Displaying 5 records below

DATE	time_utc	booster_version	launch_site	payload	payload_mass_kg	orbit	customer	mission_outcome	landing_outcome
2010-06-04	18:45:00	F9 v1.0 B0003	CCAFS LC-40	Dragon Spacecraft Qualification Unit	0	LEO	SpaceX	Success	Failure (parachute)
2010-12-08	15:43:00	F9 v1.0 B0004	CCAFS LC-40	Dragon demo flight C1, two CubeSats, barrel of Brouere cheese	0	LEO (ISS)	NASA (COTS) NRO	Success	Failure (parachute)
2012-05-22	07:44:00	F9 v1.0 B0005	CCAFS LC-40	Dragon demo flight C2	525	LEO (ISS)	NASA (COTS)	Success	No attempt
2012-10-08	00:35:00	F9 v1.0 B0006	CCAFS LC-40	SpaceX CRS-1	500	LEO (ISS)	NASA (CRS)	Success	No attempt
2013-03-01	15:10:00	F9 v1.0 B0007	CCAFS LC-40	SpaceX CRS-2	677	LEO (ISS)	NASA (CRS)	Success	No attempt



Payload Mass

Total Payload Mass

- **45,596 kg** (total) carried by boosters launched by NASA (CRS)

```
%sql SELECT SUM(PAYLOAD_MASS_KG_) \
    FROM SPACEXTBL \
    WHERE CUSTOMER = 'NASA (CRS)';
```

* ibm_db_sa://yyy33800:***@1bbf73c5-d84a-4f
sqlite:///my_data1.db

Done.

1

45596

Average Payload Mass

- **2,928 kg** (average) carried by booster version F9 v1.1

```
%sql SELECT AVG(PAYLOAD_MASS_KG_) \
    FROM SPACEXTBL \
    WHERE BOOSTER_VERSION = 'F9_v1.1';
```

* ibm_db_sa://yyy33800:***@1bbf73c5-d84a-4f
sqlite:///my_data1.db

Done.

1

2928

Landing & Mission Info

1st Successful Landing in Ground Pad Landing

- 12/22/2015

```
%sql SELECT MIN(DATE) \
FROM SPACEXTBL \
WHERE LANDING_OUTCOME = 'Success_(ground_pad)'

* ibm_db_sa://yyy33800:***@1bbf73c5-d84a-4bb0-85b
  sqlite:///my_data1.db
Done.

1
2015-12-22
```

Total Number of Successful and Failed Mission Outcomes

- 1 Failure in Flight
- 99 Success
- 1 Success (payload status unclear)

Booster Drone Ship

- Booster mass greater than 4,000 but less than 6,000
- JSCAT-14, JSCAT-16, SES-10, SES-11 / EchoStar 105

```
%sql SELECT PAYLOAD \
FROM SPACEXTBL \
WHERE LANDING_OUTCOME = 'Success_(drone_ship)' \
AND PAYLOAD_MASS_KG BETWEEN 4000 AND 6000;

* ibm_db_sa://yyy33800:***@1bbf73c5-d84a-4bb0-85b
  sqlite:///my_data1.db
Done.

payload
_____
JCSAT-14
JCSAT-16
SES-10
SES-11 / EchoStar 105
```



```
%sql SELECT MISSION_OUTCOME, COUNT(*) as total_number \
FROM SPACEXTBL \
GROUP_BY MISSION_OUTCOME;

* sqlite:///my_data1.db
Done.

Mission_Outcome  total_number
_____
Failure (in flight)    1
Success              98
Success              1
Success (payload status unclear) 1
```

Boosters

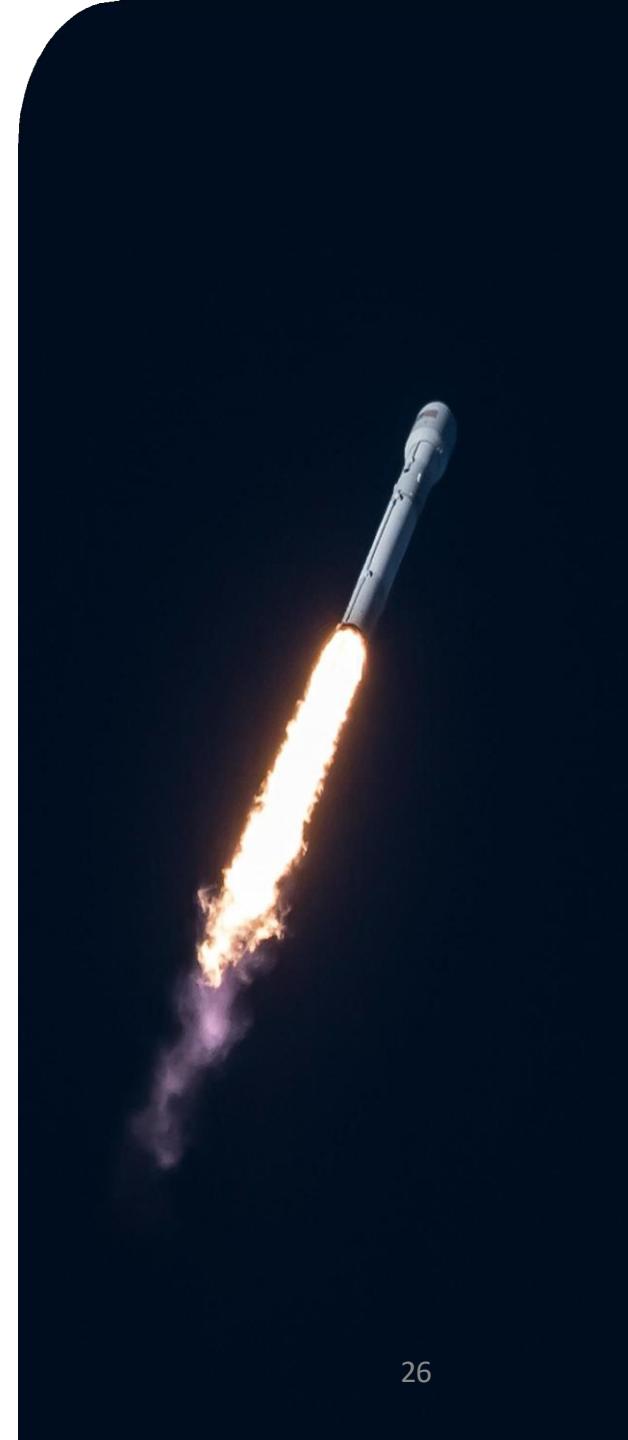
Carrying Max Payload

- F9 B5 B1048.4
- F9 B5 B1049.4
- F9 B5 B1051.3
- F9 B5 B1056.4
- F9 B5 B1048.5
- F9 B5 B1051.4
- F9 B5 B1049.5
- F9 B5 B1060.2
- F9 B5 B1058.3
- F9 B5 B1051.6
- F9 B5 B1060.3
- F9 B5 B1049.7

```
%sql SELECT BOOSTER_VERSION \
FROM SPACEXTBL \
WHERE PAYLOAD_MASS_KG = (SELECT MAX(PAYLOAD_MASS_KG) FROM SPACEXTBL);

* sqlite:///my_data1.db
Done.
```

Booster_Version
F9 B5 B1048.4
F9 B5 B1049.4
F9 B5 B1051.3
F9 B5 B1056.4
F9 B5 B1048.5
F9 B5 B1051.4
F9 B5 B1049.5
F9 B5 B1060.2
F9 B5 B1058.3
F9 B5 B1051.6
F9 B5 B1060.3
F9 B5 B1049.7



Failed Landings on Drone Ship

In 2015

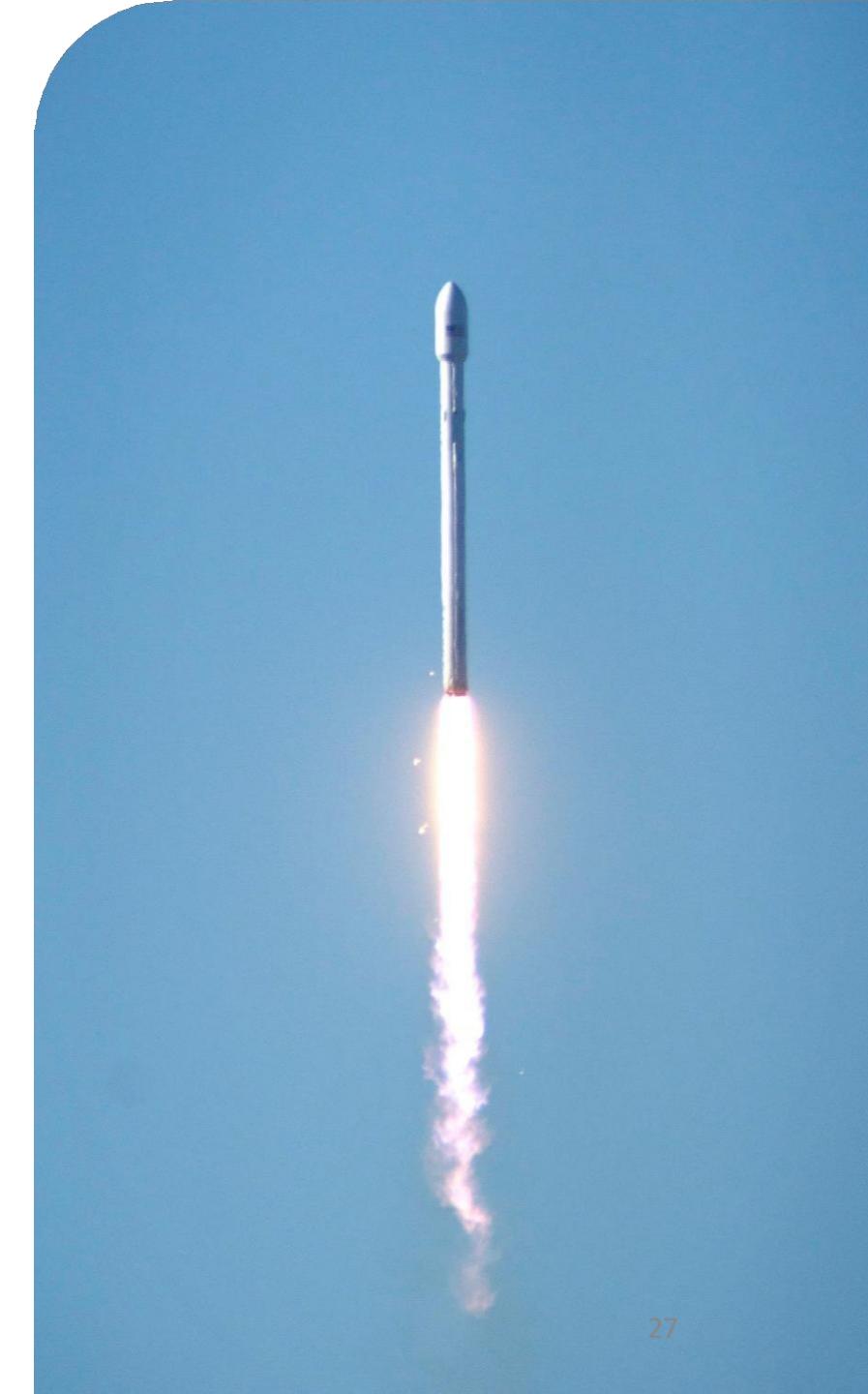
- Showing month, date, booster version, launch site and landing outcome

```
%sql SELECT substr(Date,4,2) as month, DATE, BOOSTER_VERSION, LAUNCH_SITE, [Landing _Outcome] \
FROM SPACEXTBL \
where [Landing _Outcome] = 'Failure (drone ship)' and substr(Date,7,4)='2015';
```

```
* sqlite:///my_data1.db
```

```
Done.
```

month	Date	Booster_Version	Launch_Site	Landing_Outcome
01	10-01-2015	F9 v1.1 B1012	CCAFS LC-40	Failure (drone ship)
04	14-04-2015	F9 v1.1 B1015	CCAFS LC-40	Failure (drone ship)



Count of Successful Landings

Ranked Descending

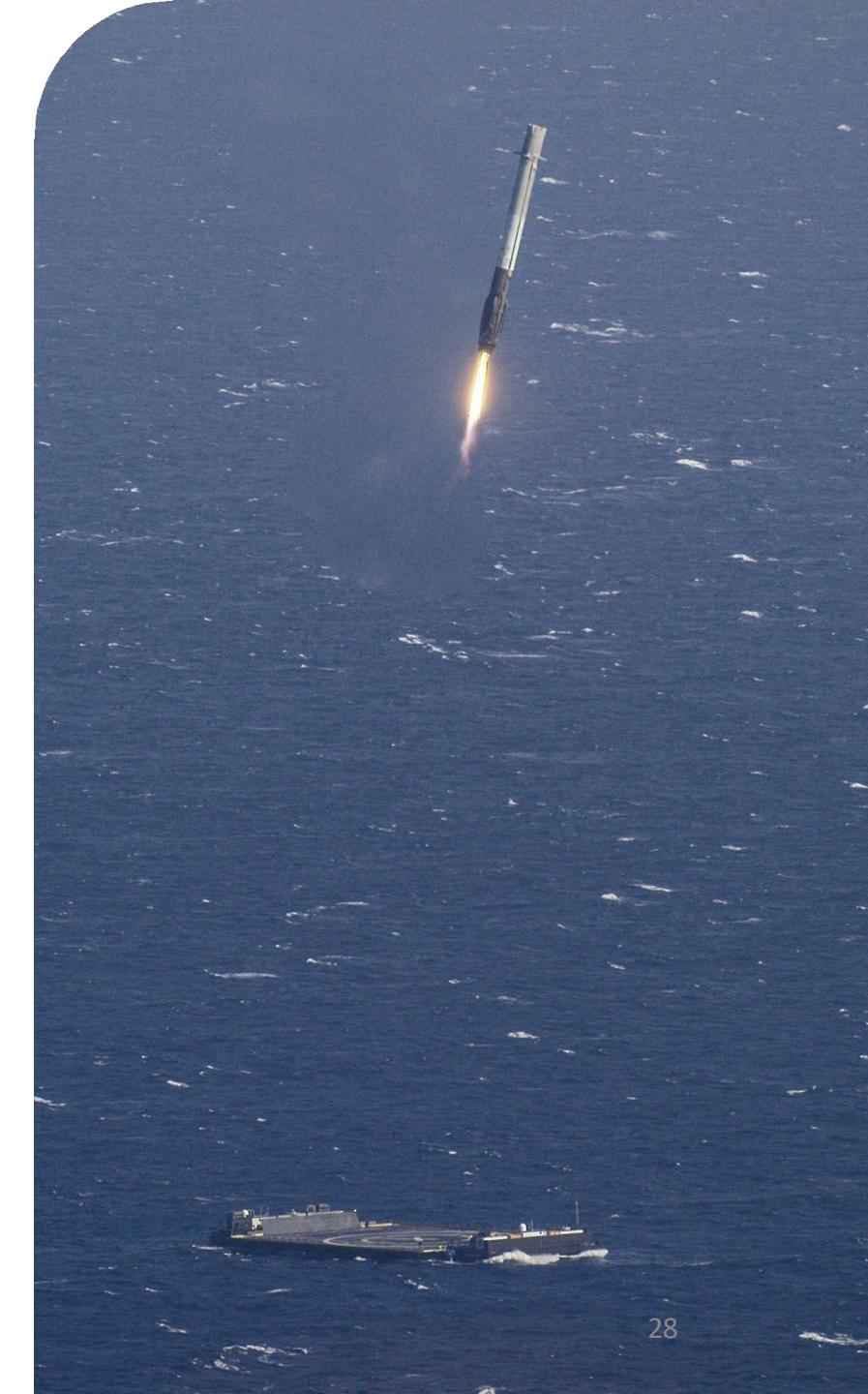
- Count of landing outcomes between 2010-06-04 and 2017-03-20 in descending order

```
%sql SELECT [Landing _Outcome], count(*) as count_outcomes \
FROM SPACEXTBL \
WHERE DATE between '04-06-2010' and '20-03-2017' group by [Landing _Outcome] order by count_outcomes DESC;
```

```
* sqlite:///my_data1.db
```

```
Done.
```

Landing _Outcome	count_outcomes
Success	20
No attempt	10
Success (drone ship)	8
Success (ground pad)	6
Failure (drone ship)	4
Failure	3
Controlled (ocean)	3
Failure (parachute)	2
No attempt	1



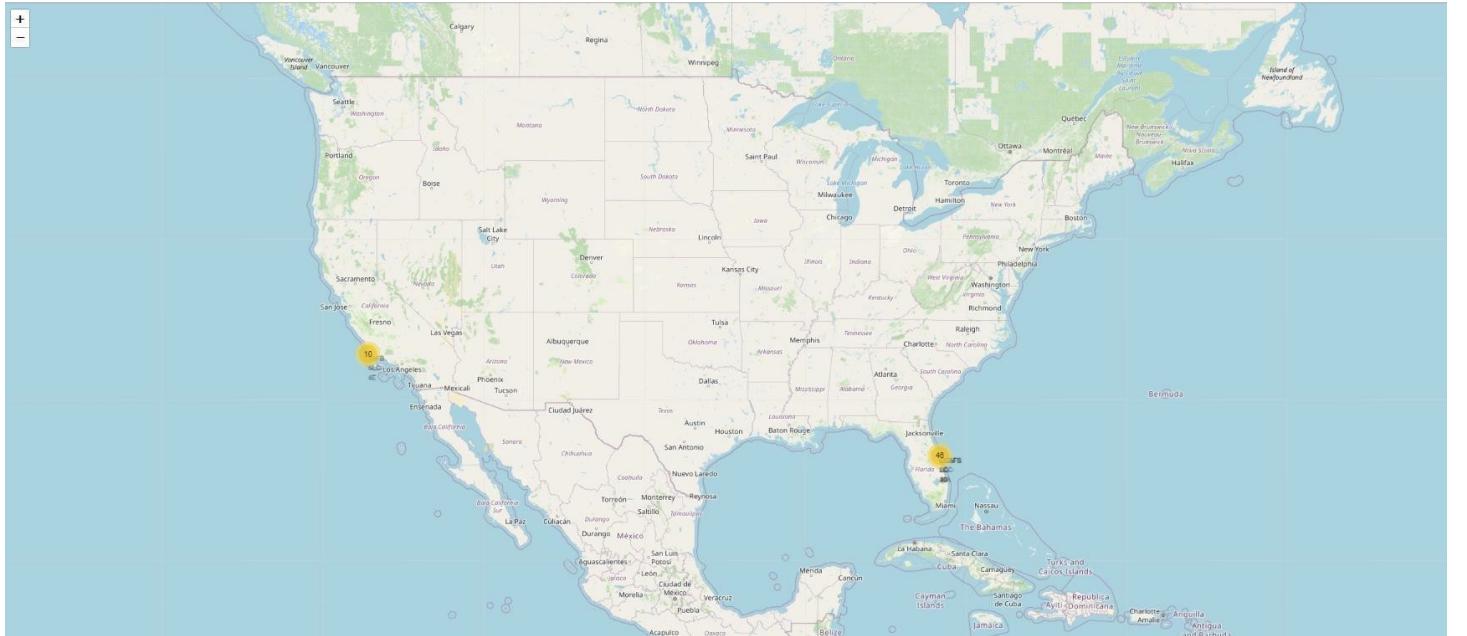
Launch Site Analysis



Launch Sites

With Markers

- **Near Equator:** the closer the launch site to the equator, the **easier** it is to **launch** to equatorial orbit, and the more help you get from Earth's rotation for a prograde orbit. Rockets launched from sites near the equator get an **additional natural boost** - due to the rotational speed of earth - that **helps** **save the cost** of putting in extra fuel and boosters.



Launch Outcomes

At Each Launch Site

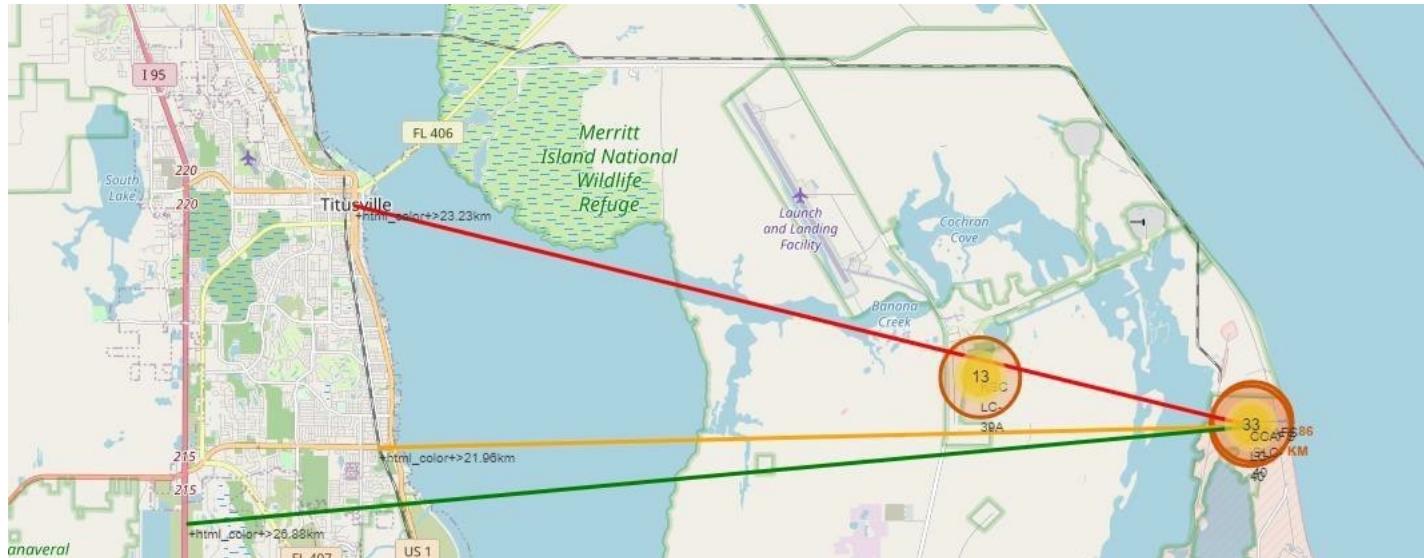
- **Outcomes:**
- **Green** markers for successful launches
- **Red** markers for unsuccessful launches
- Launch site **CCAFS SLC-40** has a **3/7 success rate (42.9%)**



Distance to Proximities

CCAFS SLC-40

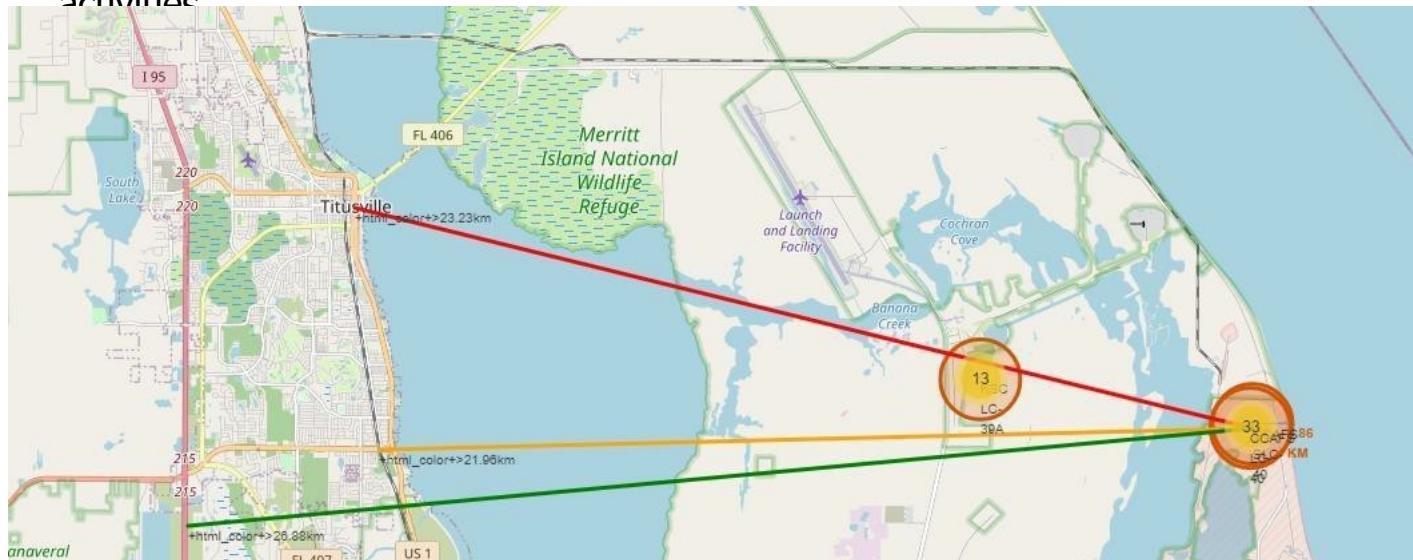
- **.86 km** from nearest coastline
- **21.96 km** from nearest railway
- **23.23 km** from nearest city
- **26.88 km** from nearest highway



Distance to Proximities

CCAFS SLC-40

- **Coasts:** help ensure that spent stages dropped along the launch path or failed launches don't fall on people or property.
- **Safety / Security:** needs to be an exclusion zone around the launch site to keep unauthorized people away and keep people safe.
- **Transportation/Infrastructure and Cities:** need to be away from anything a failed launch can damage, but still close enough to roads/rails/docks to be able to bring people and material to or from it in support of launch activities.



The background of the slide is a photograph taken from space at night. It shows the curvature of the Earth against the dark void of space. City lights are visible as numerous small white and yellow dots, primarily concentrated in the lower right quadrant where the United States appears. In the upper right, the green glow of the aurora borealis is visible in the atmosphere.

Section 3

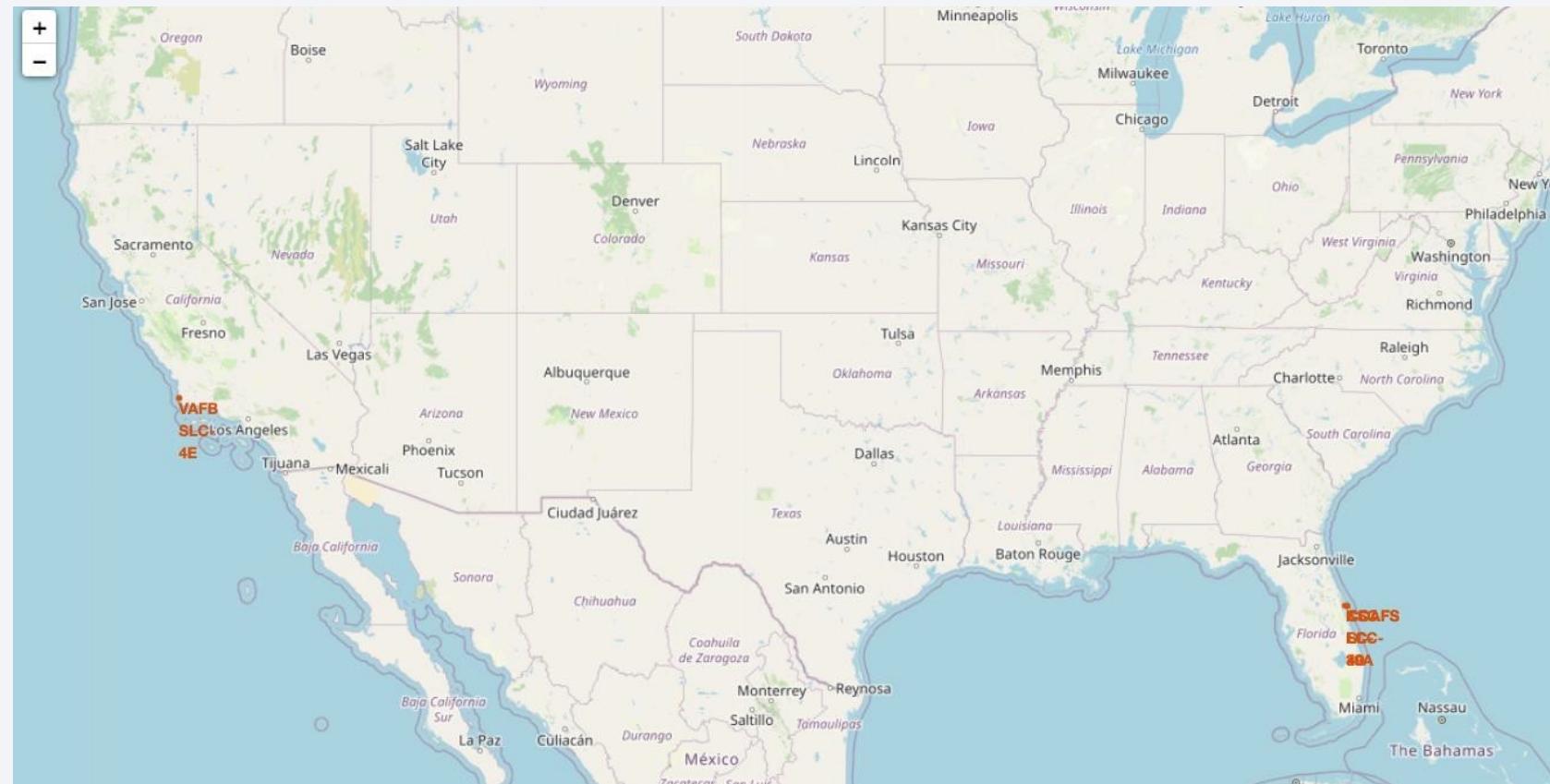
Launch Sites Proximities Analysis

All launch sites on a map

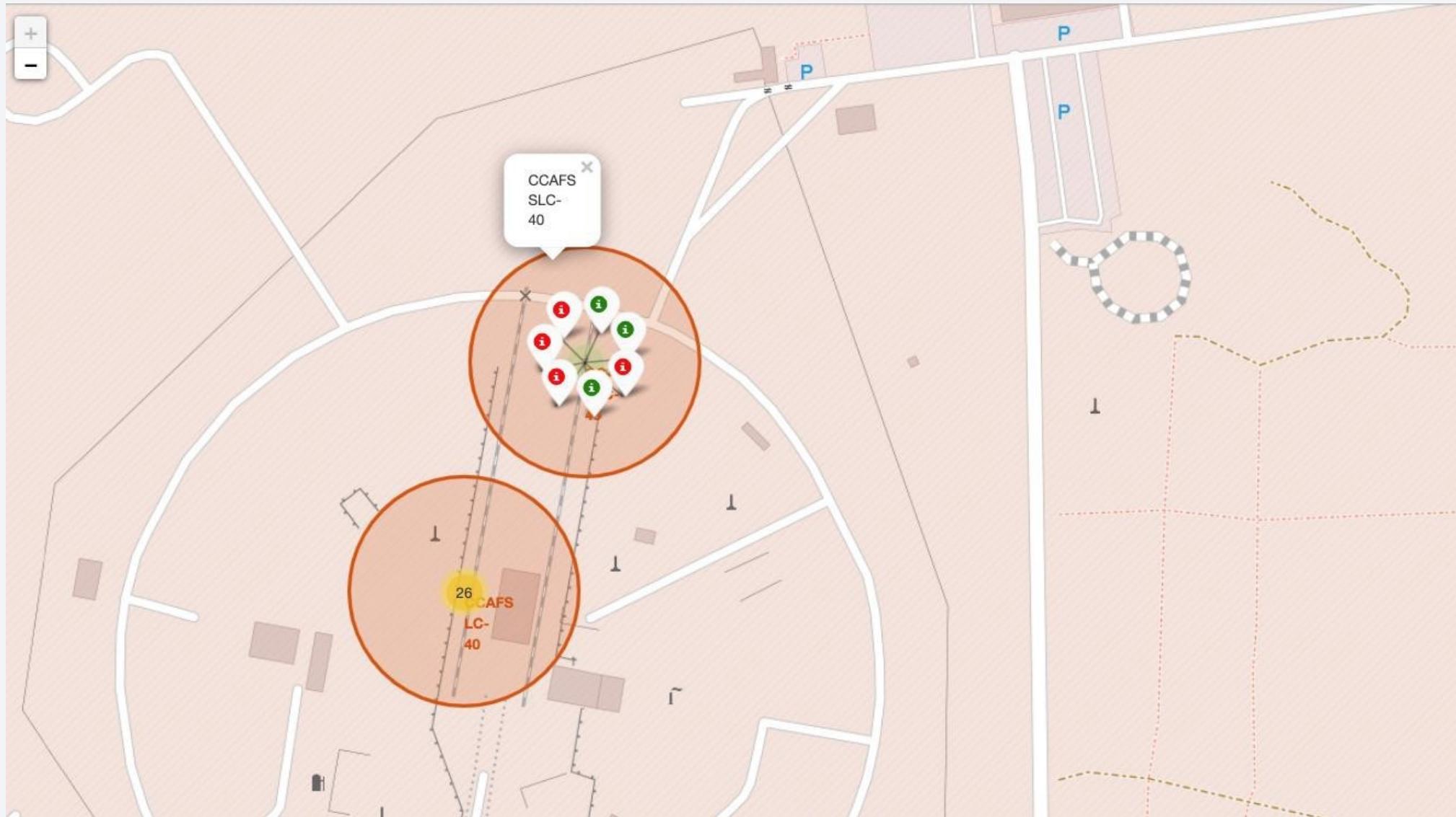
Observations:

Launch sites are in proximity to the equator and the coast. This makes sense as it takes less fuel to get into space from the equator due to the physics of Earth's rotation.

The launch sites in close proximity to the coast are also logical for safety reasons



Success/Failed launches for each site

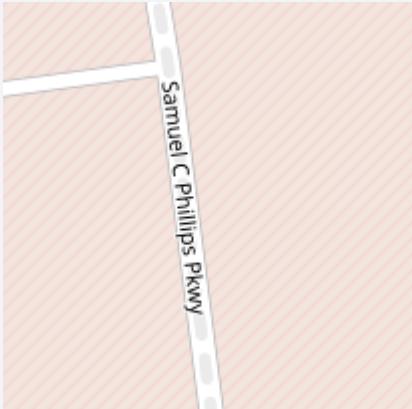


Distances between a launch site to its proximities

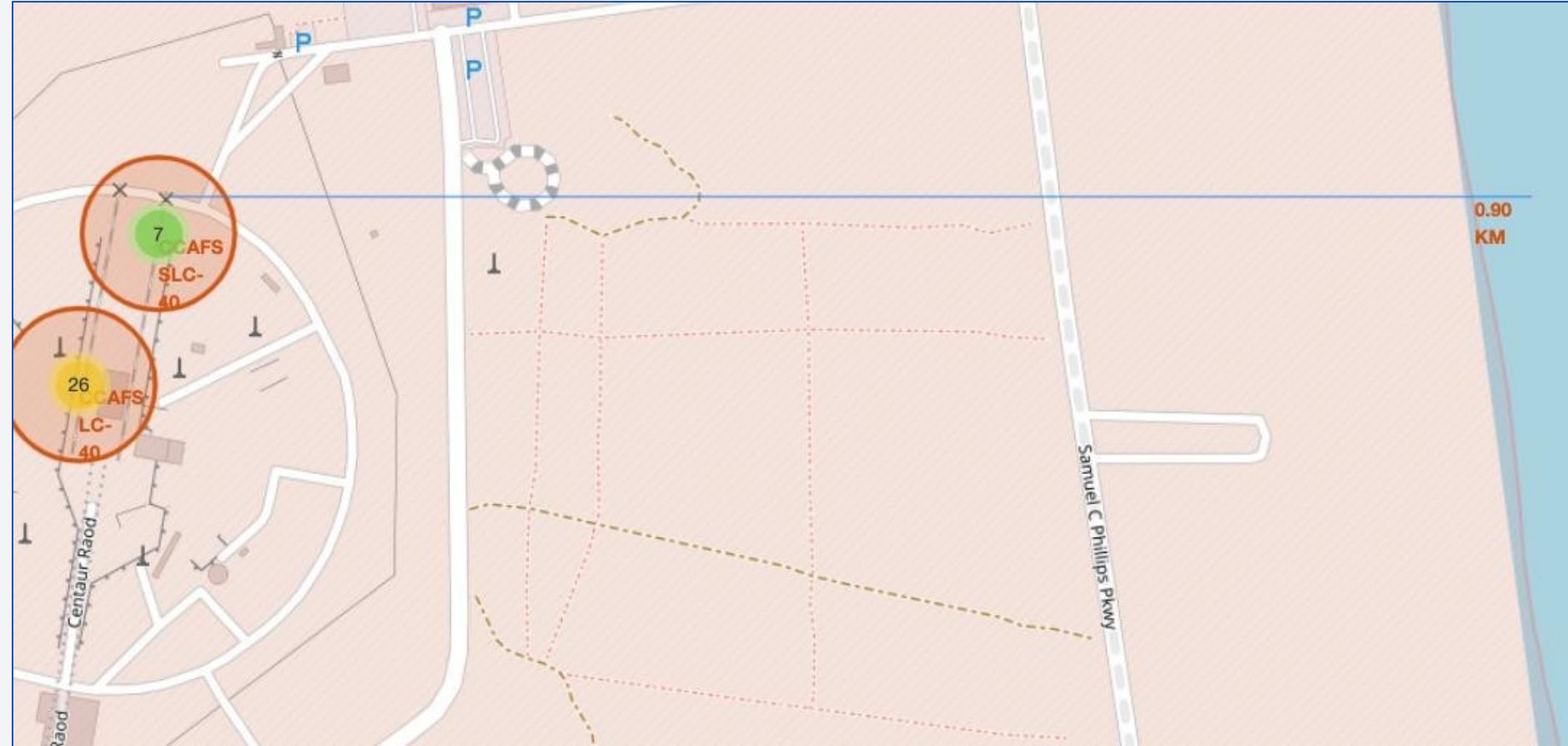
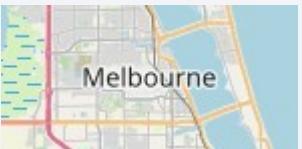
A Railway map symbol



A Highway map symbol



A City map symbol



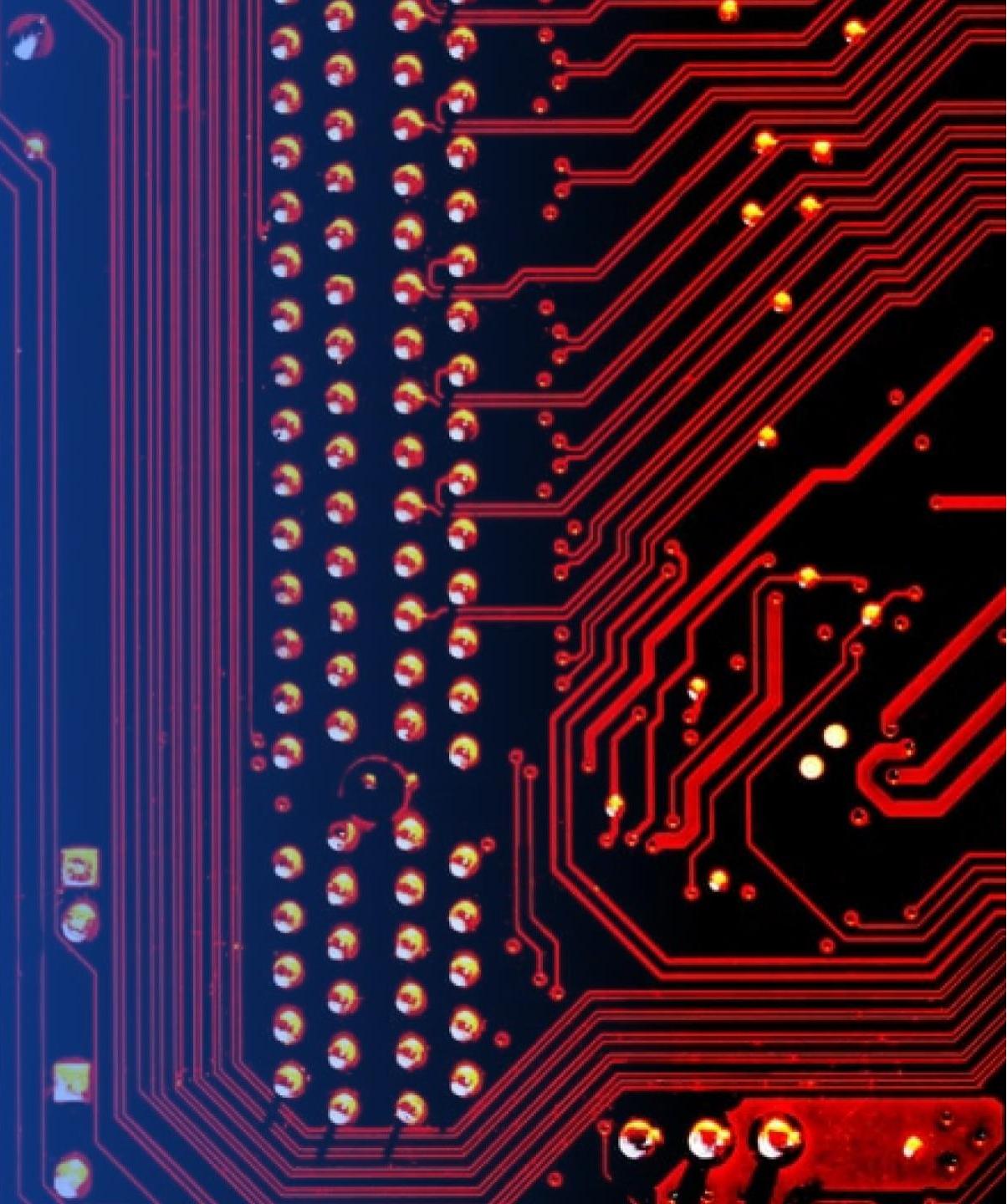
Distances between a launch site to its proximities

My Findings

- As mentioned before, launch sites are in close proximity to equator to minimize fuel consumption by using Earth's $\sim 30\text{km/sec}$ eastward spin to help spaceships get into orbit.
- Launch sites are in close proximity to coastline so they can fly over the ocean during launch, for at least two safety reasons-- (1) crew has option to abort launch and attempt water landing (2) minimize people and property at risk from falling debris.
- Launch sites are in close proximity to highways, which allows for easily transport required people and property.
- Launch sites are in close proximity to railways, which allows transport for heavy cargo.
- Launch sites are not in close proximity to cities, which minimizes danger to population dense areas.

Section 4

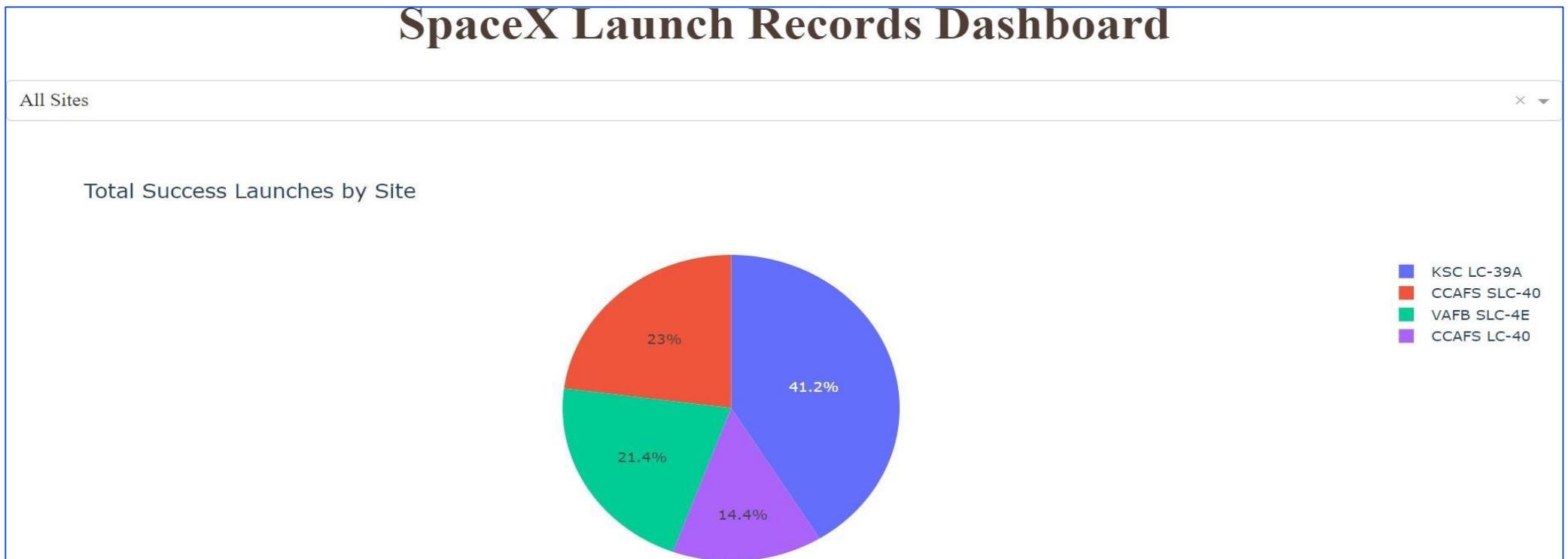
Build a Dashboard with Plotly Dash



Launch Success by Site

Success as Percent of Total

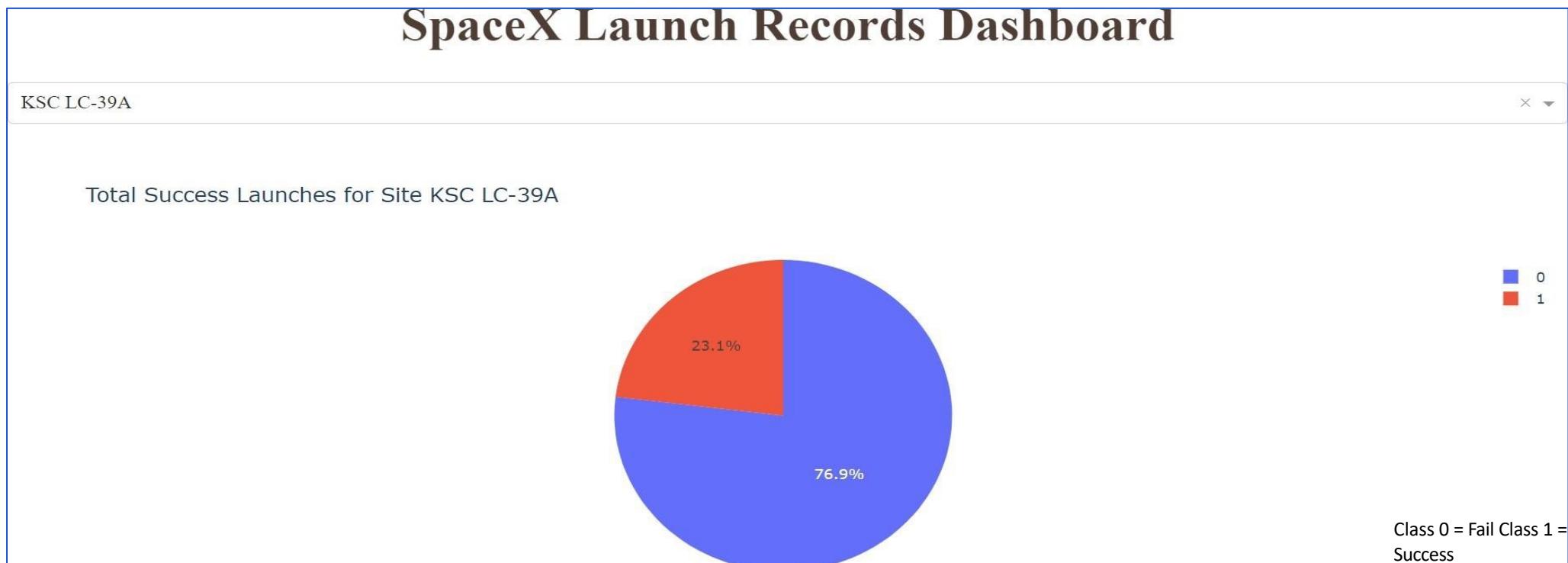
- **KSC LC-39A** has the **most successful launches** amongst launch sites (41.2%)



Launch Success (KSC LC-29A)

Success as Percent of Total

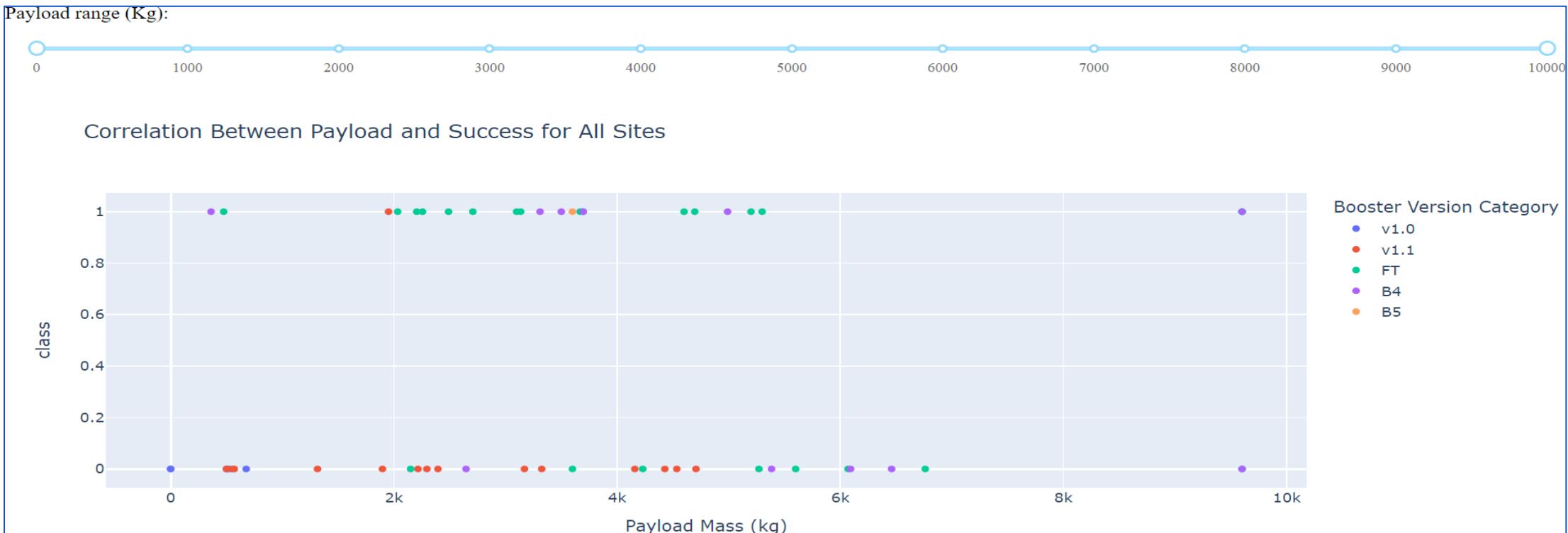
- **KSC LC-39A** has the **highest success rate** amongst launch sites (**76.9%**)
- 10 successful launches and 3 failed launches



Payload Mass and Success

By Booster Version

- **Payloads between 2,000 kg and 5,000 kg have the highest success rate**
- 1 indicating successful outcome and 0 indicating an unsuccessful outcome



The background of the slide features a dynamic, abstract design. It consists of several thick, curved lines that transition from a bright yellow at the top right to a deep blue at the bottom left. These lines create a sense of motion and depth, resembling a tunnel or a stylized landscape under a dramatic sky.

Section 5

Predictive Analysis (Classification)

Classification

Accuracy

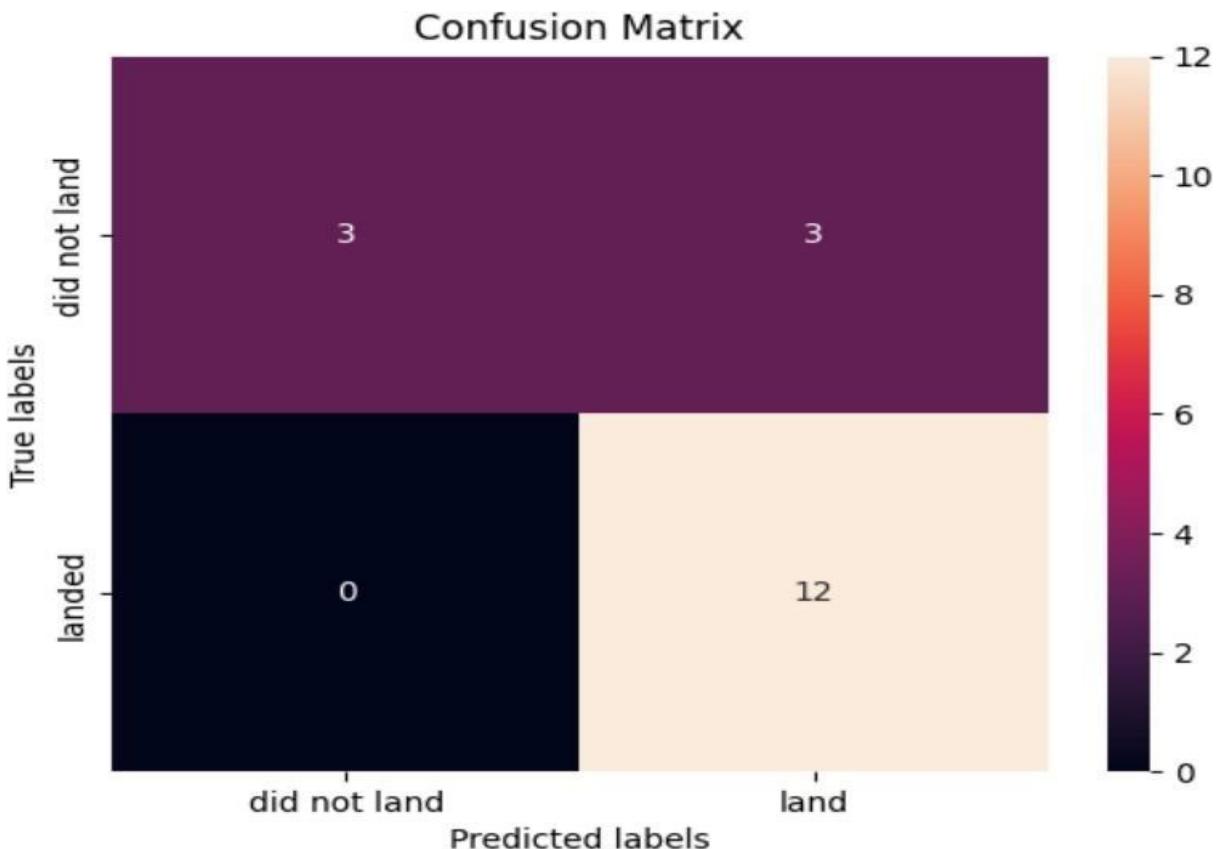
- All the **models** performed at about the same level and had the **same scores** and **accuracy**. This is likely due to the **small dataset**. The **Decision Tree model slightly outperformed** the rest when looking at `.best_score_`
- `.best_score_` is the average of all cv folds for a single combination of the parameters

	LogReg	SVM	Tree	KNN
Jaccard_Score	0.800000	0.800000	0.800000	0.800000
F1_Score	0.888889	0.888889	0.888889	0.888889
Accuracy	0.833333	0.833333	0.833333	0.833333

Confusion Matrices

Performance Summary

- A confusion matrix summarizes the performance of a classification algorithm
- All the confusion matrices were identical
- The fact that there are false positives (Type 1 error) is not good
- Confusion Matrix Outputs:
 - 12 True positive
 - 3 True negative
 - **3 False positive**
 - 0 False Negative
- **Precision** = $TP / (TP + FP)$
 - $12 / 15 = .80$
- **Recall** = $TP / (TP + FN)$
 - $12 / 12 = 1$
- **F1 Score** = $2 * (\text{Precision} * \text{Recall}) / (\text{Precision} + \text{Recall})$
 - $2 * (.8 * 1) / (.8 + 1) = .89$
- **Accuracy** = $(TP + TN) / (TP + TN + FP + FN) = .833$



Conclusion

Research

- **Model Performance:** The models performed similarly on the test set with the decision tree model slightly outperforming
- **Equator:** Most of the launch sites are near the equator for an additional natural boost - due to the rotational speed of earth - which helps save the cost of putting in extra fuel and boosters
- **Coast:** All the launch sites are close to the coast
- **Launch Success:** Increases over time
- **KSC LC-39A:** Has the highest success rate among launch sites. Has a 100% success rate for launches less than 5,500 kg
- **Orbits:** ES-L1, GEO, HEO, and SSO have a 100% success rate
- **Payload Mass:** Across all launch sites, the higher the payload mass (kg), the higher the success rate



Conclusion

Things to Consider

- **Dataset:** A larger dataset will help build on the predictive analytics results to help understand if the findings can be generalizable to a larger data set
- **Feature Analysis / PCA:** Additional feature analysis or principal component analysis should be conducted to see if it can help improve accuracy
- **XGBoost:** Is a powerful model which was not utilized in this study. It would be interesting to see if it outperforms the other classification models



Thank you!

