IBM Developer
SKILLS NETWORK

Winning Space Race with Data Science

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Outline

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

Executive Summary

- Summary of methodologies
  - Data collection
  - Data Wrangling
  - EDA with Data Visualization
  - EDA with SQL
  - Building an interactive map with Folium
  - Building a Dashboard with Plotly Dash
  - Predictive Analysis (Classification)
- Summary of all results
  - EDA Results
  - Interactive Analysis
  - Predictive Analysis

Introduction

- Project background and context
  - Commercial rocket launches is a very competitive market.
  - In terms of cost, China, India, Russia are tough competitors. Since 2017, SpaceX Falcon9/Falcon9 Heavt is increasingly dominating the market with better cost per kg thanks to the reusable booster concept.
  - SpaceX advertises Falcon 9 rocket launches on its website, with a cost of $62 million; other providers cost upward of $165 million each, much of the savings is because SpaceX can reuse the first stage.
- Problems you want to find answers
  - The project task is to predict if the first stage of the Space X Falcon 9 rocket will land successfully

Section 1

Methodology

Methodology

Executive Summary

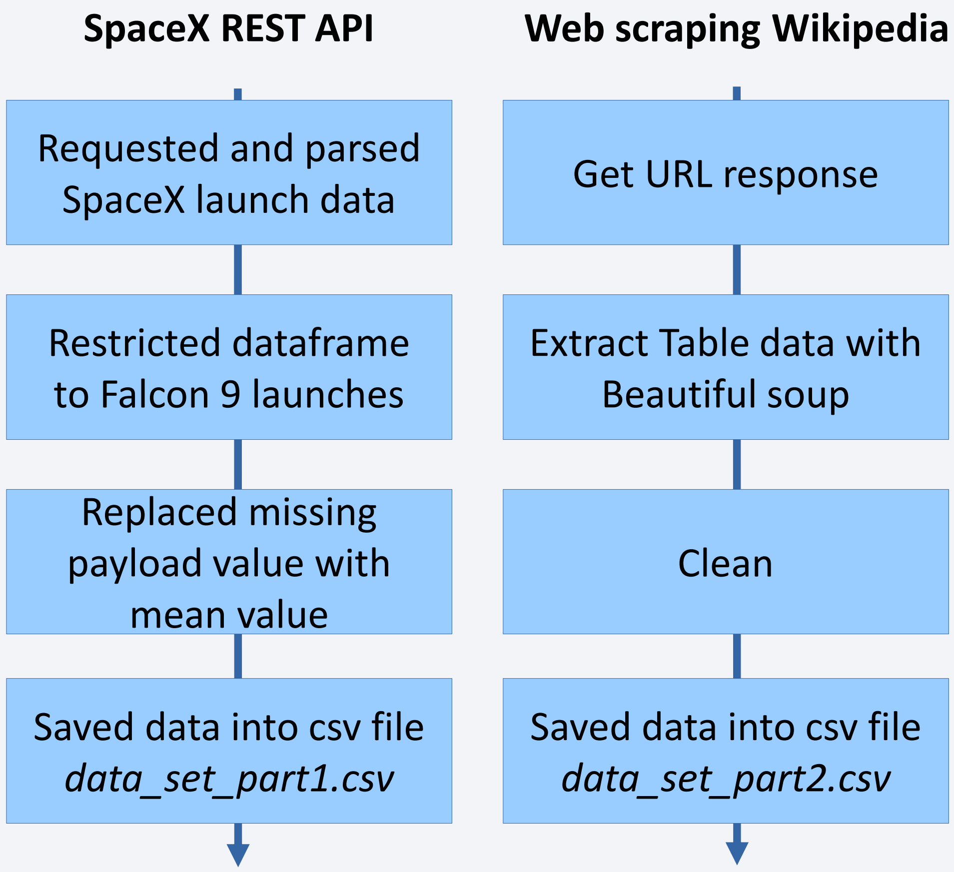
- Data collection methodology:
  - SpaceX Rest API
  - Web Scraping from Wikipedia
- Perform data wrangling
  - One Hot Encoding data fields for Machine Learning and data cleaning of null values and irrelevant columns
- Perform exploratory data analysis (EDA) using visualization and SQL
- Perform interactive visual analytics using Folium and Plotly Dash
- Perform predictive analysis using classification models
  - Linear Regression, KNN, SVM, Decision Tree models have been built and evaluated for the best classifier.

Data Collection

Data was collected by the following methods:

-open source SpaceX REST API

-webscraping Falcon9 launch data in Wikipedia



Data Collection – SpaceX API

Requested rocket launch data from SpaceX API url = https://api.spacexdata.com/v4/launches/past
Requested and parsed SpaceX data with GET request

→

Decoded response as a .json file
Turned it into Pandas dataframe

→

Used the API with functions to get info from IDs:
- **BoosterVersion**
- **Payloads**
- **LaunchSite**
- **Cores**

Stored in List

↓

Assigned list to dictionary Converted to Dataframe

↓

Selected Falcon9 data only
Replaced missing payload mass value with mean

→

Saved Dataframe into .csv file

GitHub URL of the completed SpaceX API calls:
https://github.com/nunun10/Applied-Data-Science-Capstone/blob/main/Week%201-%20Lab%201:%20Collecting%20the%20Data.ipynb

Data Collection - Scraping

Acquired historical launch data from Wikipedia page 'List of Falcon 9 and Falcon Heavy Launches'

Requested the Falcon9 Launch Wiki page from its Wikipedia URL

→ Created a beautiful soup object

→ Found all tables.
Extracted all column/variable names from the HTML table header

↓ Saved in a Dictionary
Appended Data to Keys

↓ Converted Dictionary to Dataframe

← Saved Dataframe into .csv file

GitHub URL of the completed SpaceX Web Scraping: https://github.com/nunun10/Applied-Data-Science-Capstone/blob/main/Week%201-%20Lab%202:%20First%20Stage%20Landing%20Prediction%20Web%20Scraping.ipynb

Data Wrangling

Dataframe
From SpaceX API

Identified missing values

Replaced missing "PayloadMass" value with mean value

SpaceX dataset
Further Data wrangling

Identified:
- null values for each feature
- numerical and categorical features

Calculated:
- Number of launches on each site
- number and occurrence of each orbit
- number and occurrence of missions outcome per orbit type

Created a set of 1 stage booster landing outcomes
0 True ASDS: successful landing on a drone ship
1 None None: failure to land
2 True RTLS: successful landing to a ground pad
3 False ASDS: failed landing on a drone ship
4 True Ocean: successful landing, specific region of the ocean
5 False Ocean: failed landing, specific region of the ocean
6 None ASDS: failure to land
7 False RTLS: failed landing to a ground pad

Created a Training label: 'Class'
Class = 0: booster landing failure
Class = 1: booster landing success

	FlightNumber	Date	BoosterVersion	PayloadMass	Orbit	LaunchSite	Outcome	Class
49	50	2018-05-11	Falcon 9	3750.00	GTO	KSC LC 39A	True ASDS	1
47	48	2018-04-02	Falcon 9	2760.00	ISS	CCAFS SLC 40	None None	0
50	51	2018-06-04	Falcon 9	5383.85	GTO	CCAFS SLC 40	None None	0
44	45	2018-01-31	Falcon 9	4230.00	GTO	CCAFS SLC 40	True Ocean	1
11	12	2015-01-10	Falcon 9	2395.00	ISS	CCAFS SLC 40	False ASDS	0

https://github.com/nunun10/Applied-Data-Science-Capstone/blob/main/Week%201-%20Lab%203-%20Data%20Wrangling.ipynb

EDA with Data Visualization

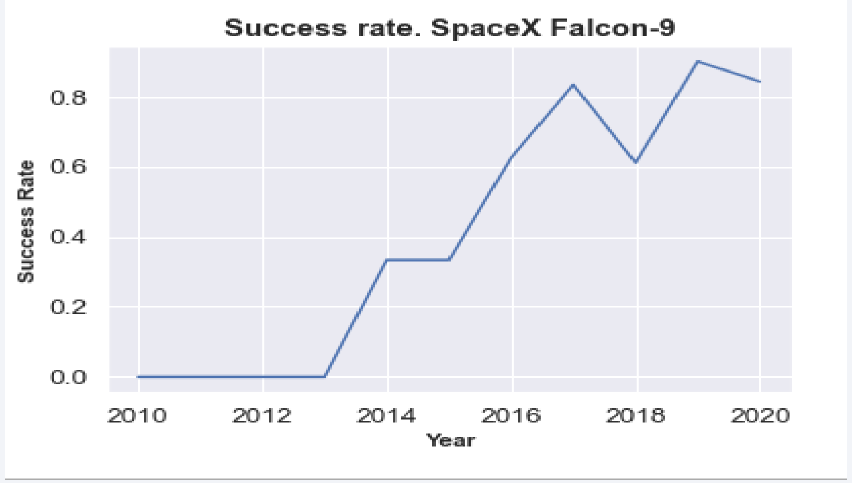
Exploring data in the Falcon 9 data frame searching for factors and relations influencing launching success rate (booster recovery).

- Payload mass
- Orbit type
- Launch site

Graphs and scatter charts with Matplotlib – Seaborn and Analysis.

Results with Scatter charts are labeled: class 0-1 (failure/success).

- Payload mass v. Flight Number
- Launch Site v. Flight number
- Launch Site v. Payload mass
- Orbit v. Flight number
- Orbit v. Payload mass
- Histogram: success rate for each orbit
- Falcon 9 & Ariane-5 launch success yearly trend.



GitHub URL of the completed notebook: https://github.com/nunun10/Applied-Data-Science-Capstone/blob/main/Week%202-%20Lab%202:%20Exploring%20and%20Preparing%20Data.ipynb

EDA with SQL

The following were created:

- MySQL local server
- Database: 'spacex_database'
- SpaceX csv file in Table “spacex_v11”
- Connection “conn” wih “spacex_database”.

GitHub URL of the completed EDA with data visualization notebook:
https://github.com/nunun10/Applied-Data-Science-Capstone/blob/main/Week%202-%20Lab%201:%20EDA%20with%20SQL.ipynb

Build an Interactive Map with Folium

Launch success rate may depend on the location and proximity of a launch site. **Folium Interactive Map was used for visualizing and analyzing SpaceX Launch Sites.**

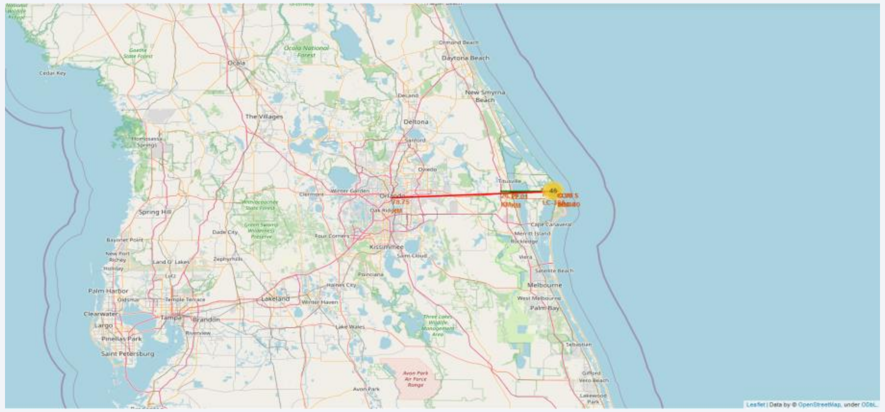
- Used Interactive mapping library called Folium
- Identified all SpaceX launch sites on a map: Florida, California
- Included longitude and latitude info.
- Identified successful/failed launches for each site on map

Calculated the distance between a launch site (CCAFS_SLC40 in Cape Canaveral, FL) and:

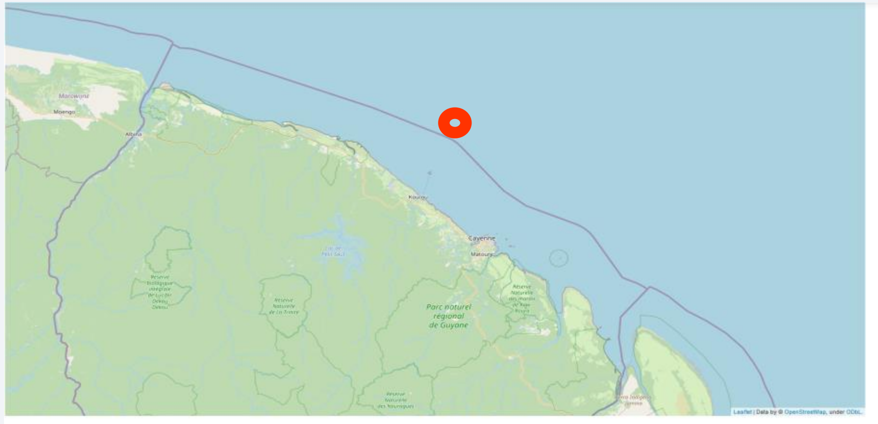
- Closest coastline
- Closest high traffic density railway: Florida East Coast Railway
- Closest high traffic density highway: Interstate I95
- Closest high density urban area: Orlando (FL)

For reference, we added the localization of European Space Agency (ESA) /ArianeEspace Ariane 5 and Soyuz launch pads in Kourou, French Guiana.

GitHub URL of the completed notebook: https://github.com/nunun10/Applied-Data-Science-Capstone/blob/main/Week%203-%20Lab%201:%20Launch%20Sites%20Locations%20Analysis%20with%20Folium.ipynb



CCAFS_SLC40 in Cape Canaveral FL
Coordinates: -80.577º, 28.563º



Ariane launch pad - Kourou in French Guiana
Coordinates: -52.792º, **5.265º (~ Equator)**

Build a Dashboard with Plotly Dash

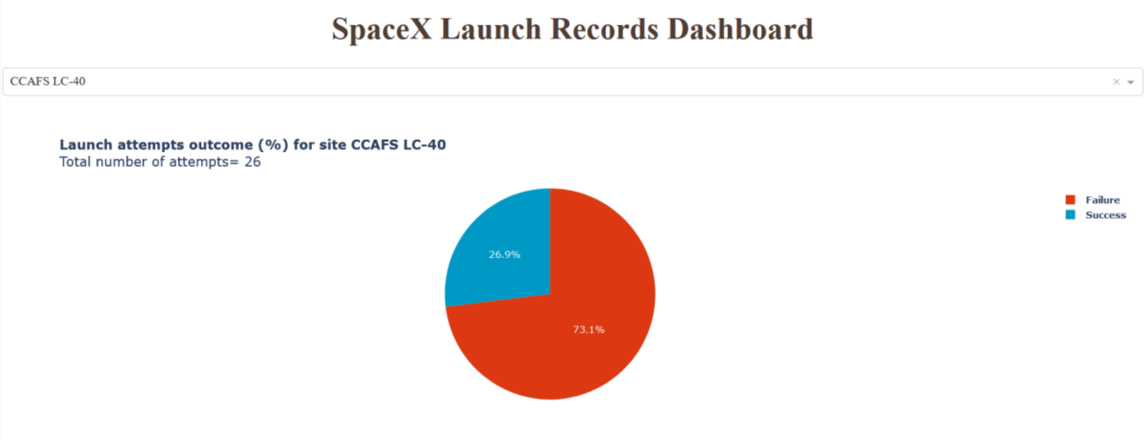
We built an interactive dashboard with Plotly including:

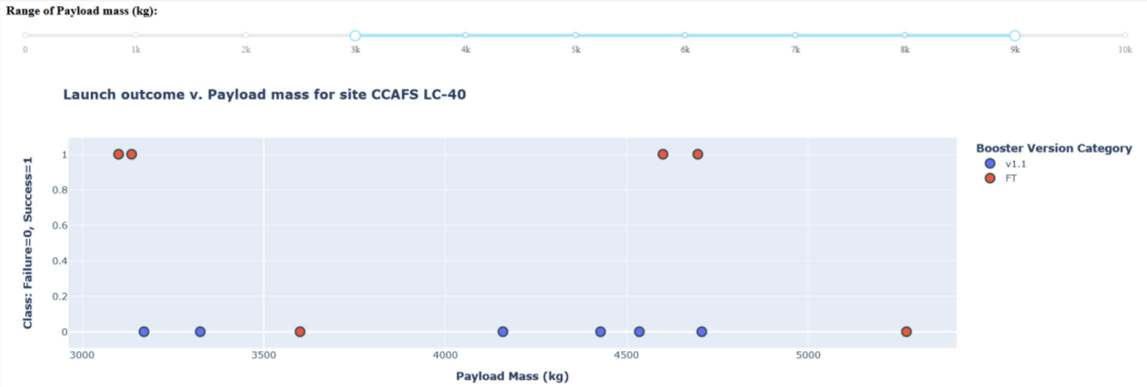
- Dropdown menu for selecting launch sites
- Pie charts displaying success rate.
- Scatter chart displaying launch site, payload mass, success/failure
- Range slider for selecting range of payload mass (kg).

for analyzing SpaceX launch records features:

- site with largest successful launches.
- site with highest launch success rate
- payload range(s) with highest launch success rate
- payload range(s) with lowest launch success rate
- F9 Booster version (v1.0, v1.1, FT, B4, B5, etc.) with highest launch success rate.

GitHub URL of the completed notebook :
https://github.com/nunun10/Applied-Data-Science-Capstone/blob/main/Week%203-%20Lab%202:%20Interactive%20Dashboard%20with%20Ploty%20Dash.py





Predictive Analysis (Classification)

Imported Falcon9 launching data from .csv to Pandas dataframe

Supervised Classification models
Launcher landing Labels
- Class 0: fail
- Class 1: success

Data normalization

Split Data: Training, Testing Sets
Shuffling option !

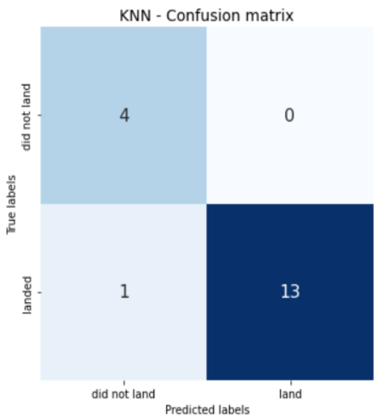
Model Training

Logistic Regression

Support Vector Machine (SVM)

Decision Tree Classifier

K Nearest Neighbors Classifier



Testing set

Predictive analysis
Accuracy
Confusion matrix

Selection of best model

GitHub URL of the completed notebook:
https://github.com/nunun10/Applied-Data-Science-Capstone/blob/main/Week%204-%20Lab%201-%20First%20Stage%20Landing%20Prediction%20ML.ipynb

Results

- The SVM, KNN, Decision Tree and Logistic Regression models are the best in terms of prediction accuracy for this dataset
- Low weighted payloads perform better than the heavier payloads.
- The success rate for SpaceX launches is directly proportional to time in years they will eventually perfect the launches.
- KSC LC 39A had the most successful launches from all the sites
- Orbit GEO, HEO, SSO, ES L1 has the best Success Rate.

Conclusions

- The SVM, KNN, Decision Tree and Logistic Regression models are the best in terms of prediction accuracy for this dataset
- Low weighted payloads perform better than the heavier payloads.
- The success rate for SpaceX launches is directly proportional to time in years they will eventually perfect the launches.
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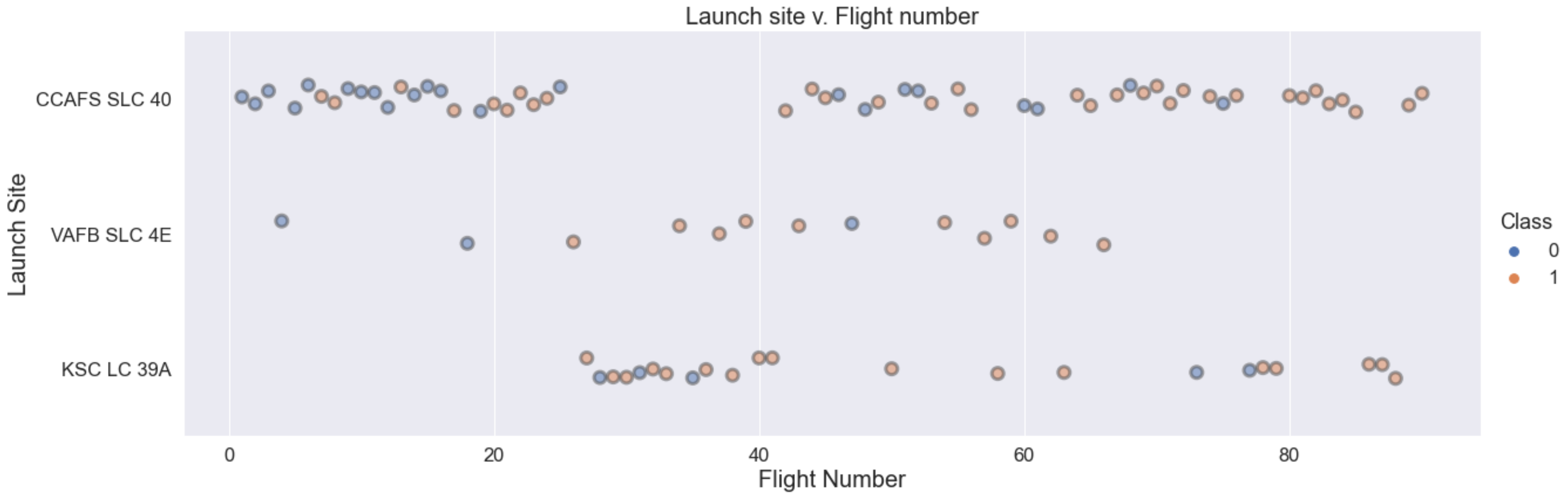
Section 2

Insights drawn from EDA

Launch Site v. Flight Number

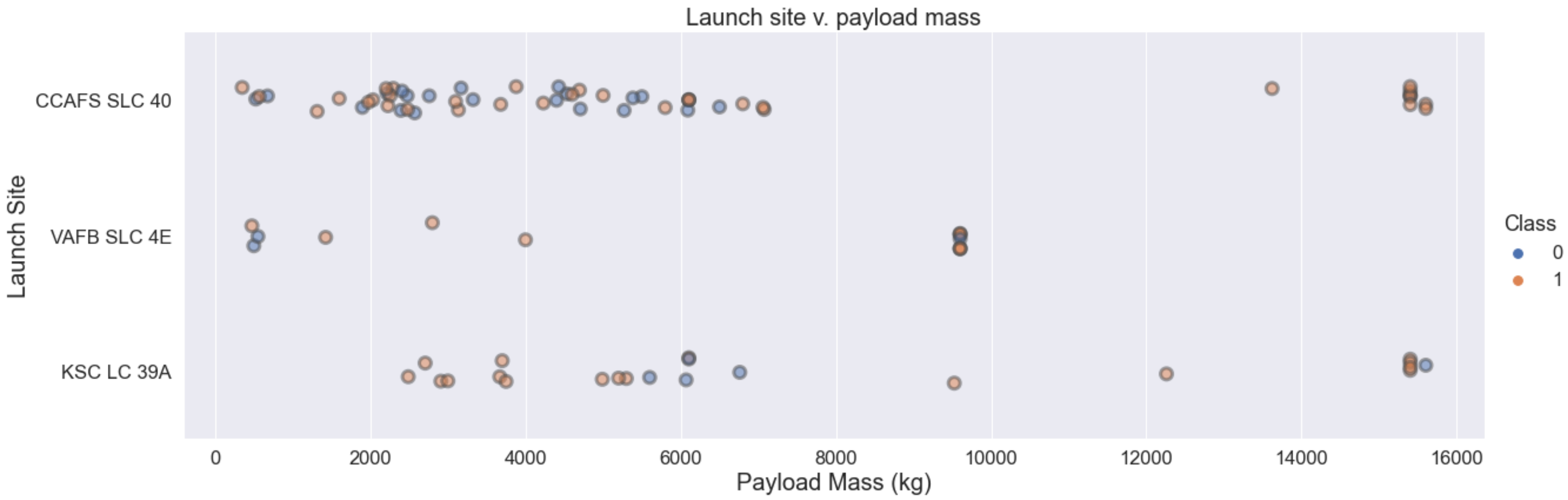


The chart displays valuable info about:

- Chronology: flight numbers
- Number of flights per launch site
- Success/Failure per launch site

- Cape Canaveral CCAFS-SLC 40 is the most used launch site.
- CCAFS-SLC 40 concentrates most of failures , particularly **in the early stage of Falcon9 project**.
- Given CCAFS-SLC 40 southern location, most “risky” GTO and GEO launches may take place there.
- Additional info needed: orbit, payload mass

Launch Site v. Payload



The chart brings additional info:

- Payload mass per launch site
- Success/Failure per payload mass

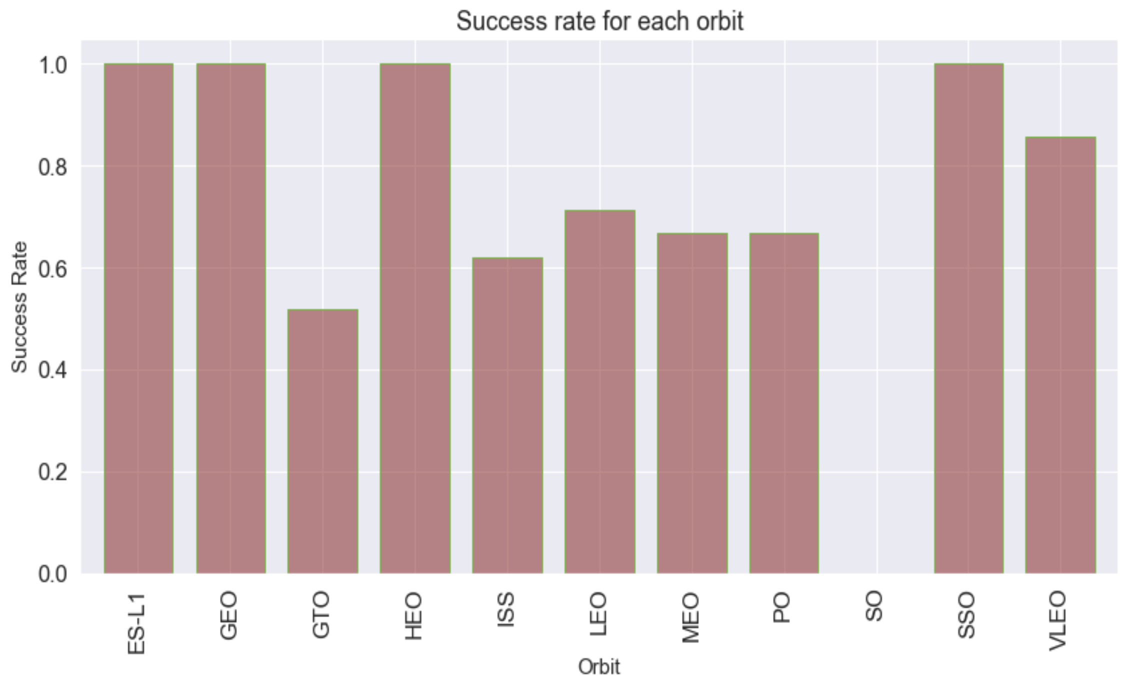
- Given Falcon9 specifications, heavy payloads > 10000 kg are sent to low/medium orbits LEO/MEO only.
- It looks like the percentage of failures is lower for heavy payload. Which would indicate that low orbits are less risky to the success of the mission (recovery of booster).
- Light payloads are not necessarily all sent to GTO/GEO.
- More information is needed for extracting some correlation: success rate v. payload/orbit

Success Rate vs. Orbit Type

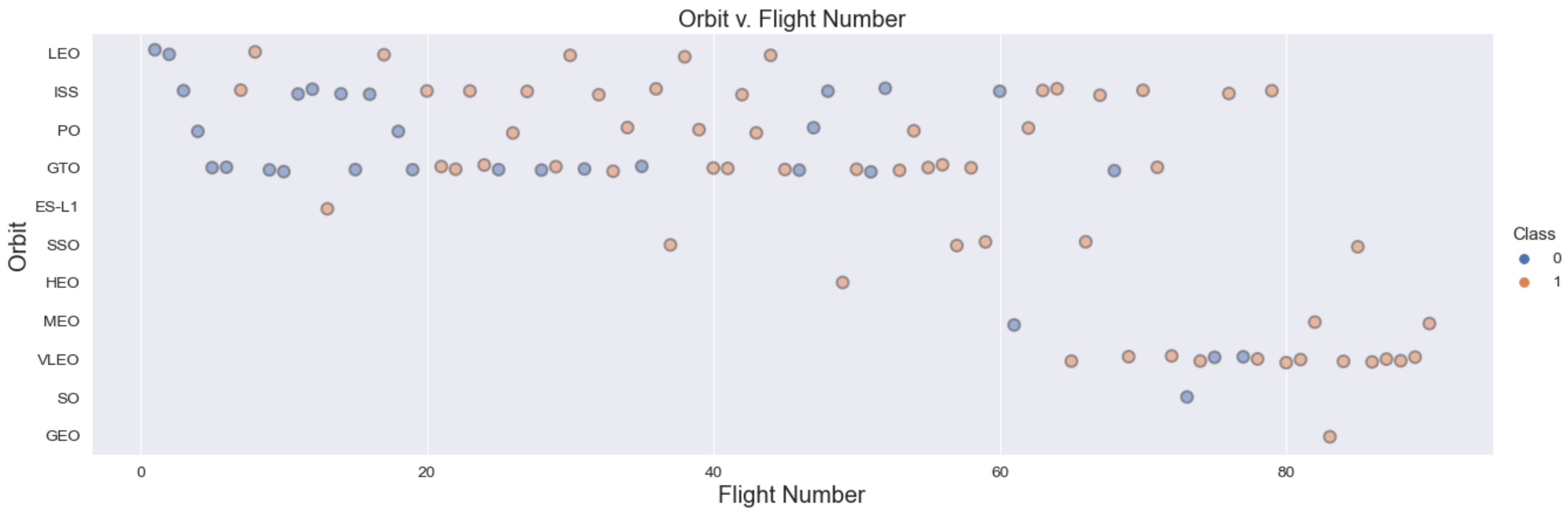
Remarks:
- GTO is a transfer orbit to GEO. Low thrust engines of the payload (satellite) complete the orbiting phase.
- We ignore results: GEO, SO, HEO, ESL-1, MEO. The number of flights is not significant.

GTO sees the lowest success rate as suggested in previous slide.
SSO (polar low orbit) **the highest one.**

Success rate may strongly depend on both:
- payload mass
- orbit.



Flight Number v. Orbit Type



The chart brings additional info:

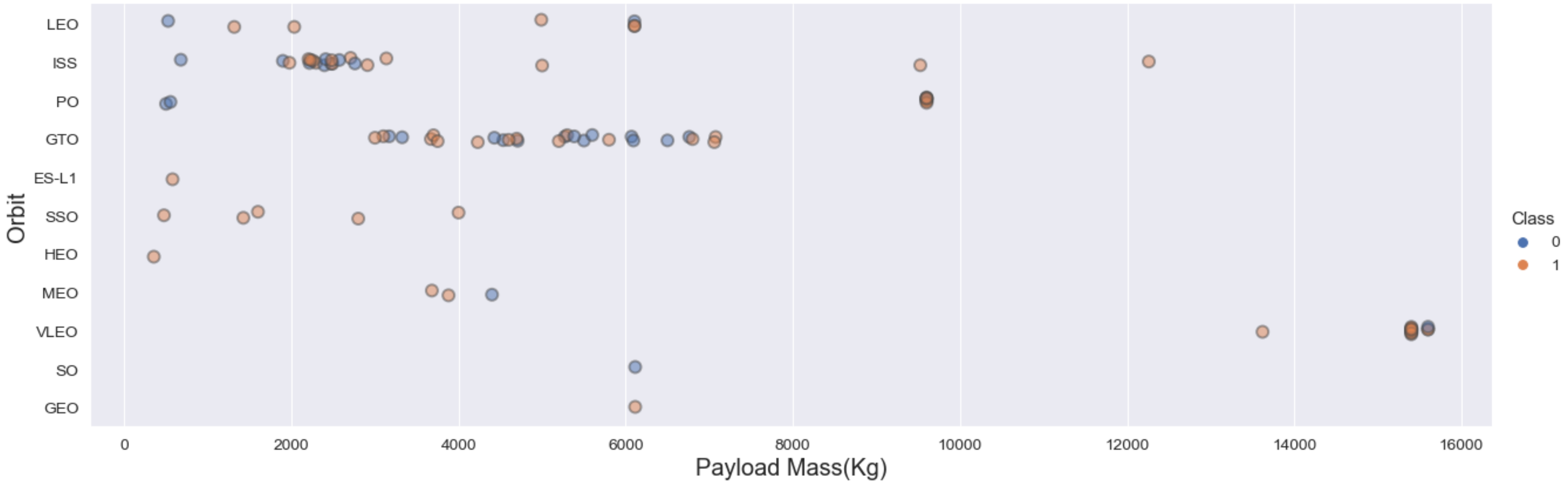
- Number of flights per Orbit.
- Success rate per orbit

- The number of flights for: GEO, SO, HEO, ESL-1, MEO is not significant for concluding about success rate.
- PO, SSO, ISS, VLEO are low orbits
- GTO is a transfer orbit to GEO.

It looks like GTO are higher risk missions, low orbits are lower risk.

We confirm with the following histogram.

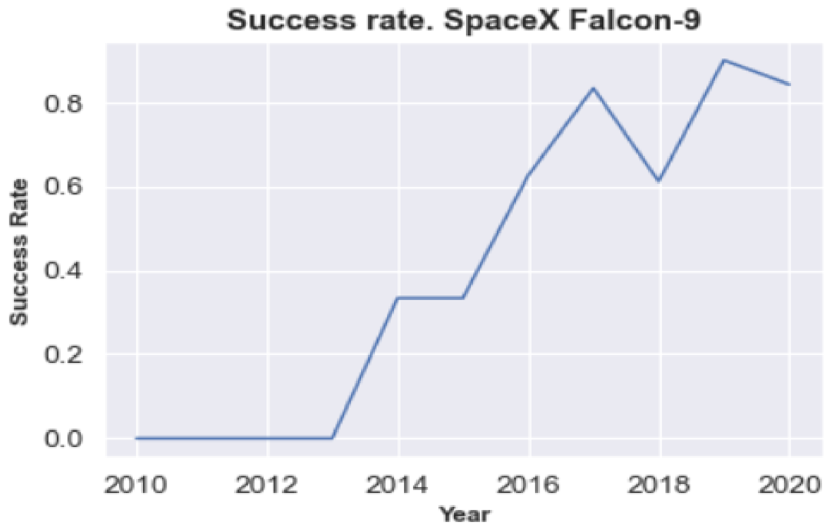
Orbit Type v. Payload



The chart brings final info about “Orbit v. Payload”. It describes the distribution “success rate v. (payload, orbit)”
Main trends:

- Maximum success rate with: low orbit except (ISS) and low payload mass
- ISS: based on “Orbit Type v. Flight Number” 5/8 failures occurred in the early stage of Falcon 9 project. When Falcon 9 reliability was low.
- Between 2000 and 7500 kg, success rate seems to be evenly distributed for GTO.
- Independently of payload mass, GTO is a risky “orbit” affecting missions success rate. Falcon 9 reliability improves over time, but there are still recent failed booster recovery after GTO launches.

Launch Success Yearly Trend



Falcon 9 reliability significantly improves over time .

Success rate, **here defined after successful booster recovery for Falcon9,** depends on:

- Payload mass
- Orbit
- + other factors we investigate next

- Independently of payload mass, orbits, **Ariane 5 has a close to 100% success rate** for 82 flights since 2003.
- Falcon9 average booster recovery success rate si 66%.
- Success rate currently sufficient for SpaceX financial viability.

All Launch Site Names

Before starting launch sites analysis, we list the names of all launch sites and some launch records (from SQL queries).

```
df_unique_launchsites=pd.read_sql_query("Select distinct Launch_Site  from spacex_v11 ",conn)
print(df_unique_launchsites)
```

```
    Launch_Site
0   CCAFS LC-40
1   VAFB SLC-4E
2    KSC LC-39A
3  CCAFS SLC-40
```

There are 4 distinct launch sites

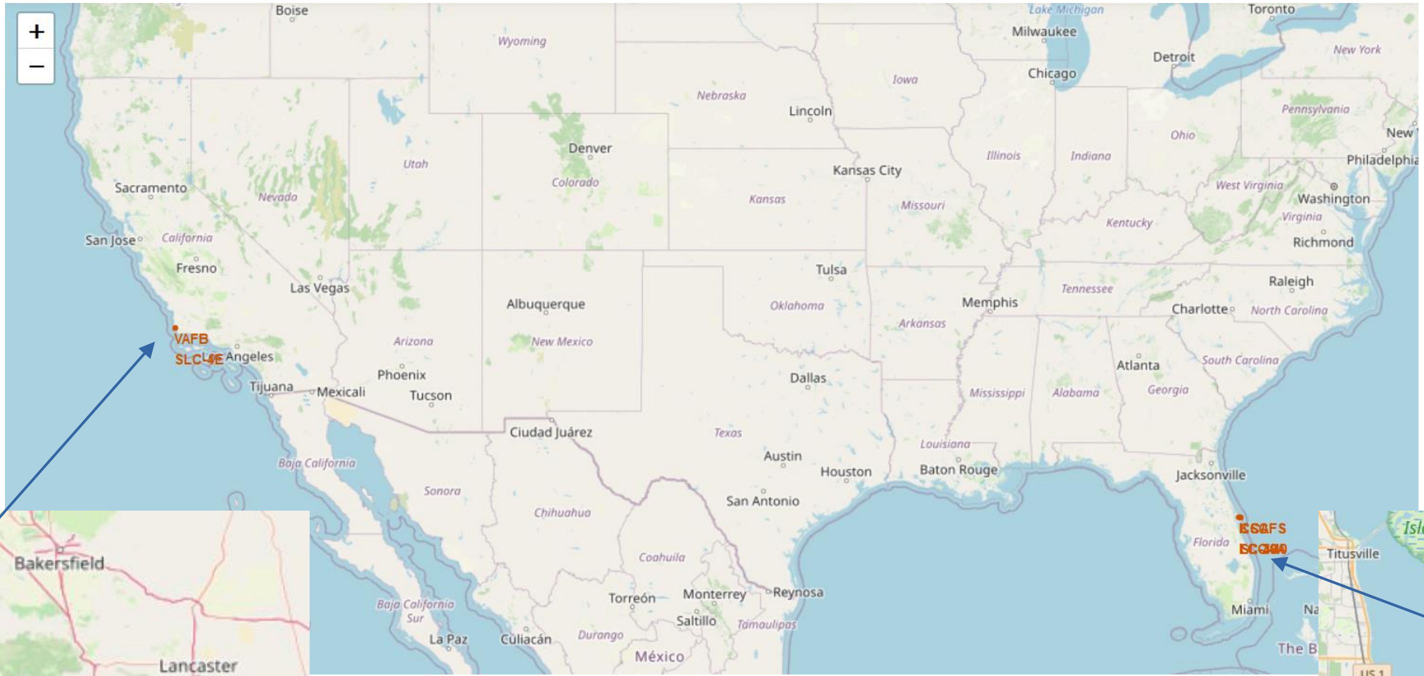
Launch Site Names Begin with 'CCA'

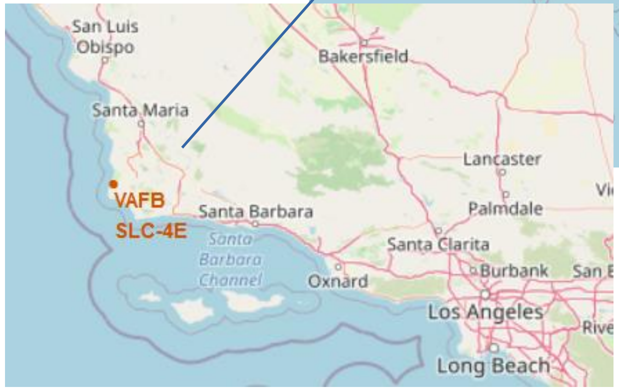
5 records where launch sites begin with `CCA`

```
df_launchsites_CCA5=pd.read_sql_query("Select * from spacex_v11 where Launch_Site Like 'CCA%' Limit 5",conn)
df_launchsites_CCA5
```

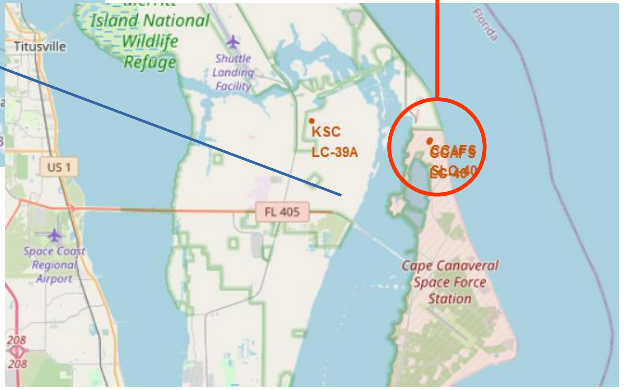
	id	Date	Time (UTC)	Booster_Version	Launch_Site	Payload	PAYLOAD_MASS__KG_	Orbit	Customer	Mission_Outcome	Landing_Outcome
0	1	2010-04-06	0 days 18:45:00	F9 v1.0 B0003	CCAFS LC-40	Dragon Spacecraft Qualification Unit	0	LEO	SpaceX	Success	Failure (parachute)
1	2	2010-08-12	0 days 15:43:00	F9 v1.0 B0004	CCAFS LC-40	Dragon demo flight C1, two CubeSats, barrel of...	0	LEO (ISS)	NASA (COTS) NRO	Success	Failure (parachute)
2	3	2012-05-22	0 days 07:44:00	F9 v1.0 B0005	CCAFS LC-40	Dragon demo flight C2	525	LEO (ISS)	NASA (COTS)	Success	No attempt
3	4	2012-10-08	0 days 00:35:00	F9 v1.0 B0006	CCAFS LC-40	SpaceX CRS-1	500	LEO (ISS)	NASA (CRS)	Success	No attempt
4	5	2013-03-01	0 days 15:10:00	F9 v1.0 B0007	CCAFS LC-40	SpaceX CRS-2	677	LEO (ISS)	NASA (CRS)	Success	No attempt

SpaceX: All launch sites





- VAFB SLC-4E: Vandenberg Space Launch Complex 4 (CA)
- KSC-LC29A: Kennedy Space Center - Merritt Island (FL)
- CCAFS-LC40: Cape Canaveral Launch Complex 40 (FL)
- CCAF-SLC40: Cape Canaveral Space Launch Complex 40(FL)



Total Payload Mass

Calculate the total payload carried by boosters from NASA (2 methods)

```
#  For validation purposes... sum in df_NASA_CRS  'PAYLOAD_MASS__KG_'   column
df_NASA_CRS=pd.read_sql_query("Select * from spacex_v11  where Customer='NASA (CRS)'",conn)
print(df_NASA_CRS.head(2))
print('----')
print('Total payload mass, customer= NASA (CRS):', df_NASA_CRS['PAYLOAD_MASS__KG_'].sum(),' kg')
```

```
   id        Date      Time (UTC) Booster_Version  Launch_Site       Payload  \
0   4  2012-10-08 0 days 00:35:00  F9 v1.0  B0006  CCAFS LC-40  SpaceX CRS-1
1   5  2013-03-01 0 days 15:10:00  F9 v1.0  B0007  CCAFS LC-40  SpaceX CRS-2

   PAYLOAD_MASS__KG_      Orbit    Customer Mission_Outcome Landing_Outcome
0                500  LEO (ISS)  NASA (CRS)         Success      No attempt
1                677  LEO (ISS)  NASA (CRS)         Success      No attempt
----
Total payload mass, customer= NASA (CRS): 45596  kg
```

```
#  Based on SQL only...
sql_nasa_crs_mass= """ Select sum(PAYLOAD_MASS__KG_) as 'Total payload mass (kg) NASA CRS'
                    from spacex_v11
                    where Customer='NASA (CRS)' """
payload_NASA_CRS=pd.read_sql_query(sql_nasa_crs_mass,conn)
print(payload_NASA_CRS)
```

```
   Total payload mass (kg) NASA CRS
0                           45596.0
```

Average Payload Mass by F9 v1.1

Calculate the average payload mass carried by booster version F9 v1.1

```
payload_F9v11=pd.read_sql_query("Select avg(PAYLOAD_MASS__KG_) as 'avg mass (kg)' from spacex_v11 where Booster_Version='F9 v1.1'",conn)
print(payload_F9v11)
```

```
   avg mass (kg)
0         2928.4
```

First Successful Ground Landing Date

Find the dates of the first successful landing outcome on ground pad

```
min_Date_success_landing=pd.read_sql_query("select min(Date) from spacex_v11 where Landing_Outcome = 'Success (ground pad)'",conn)
print(min_Date_success_landing)
```

```
    min(Date)
0  2015-12-22
```

Successful Drone Ship Landing with Payload between 4000 and 6000

%sql select BOOSTER_VERSION from SPACEXTBL where landing_outcome='Success (drone ship)' and PAYLOAD_MASS__KG_ BETWEEN 4000 and 6000;

List the names of the boosters which have success in drone ship and have payload mass greater than 4000 but less than 6000

```
%sql select BOOSTER_VERSION from SPACEXTBL where landing_outcome='Success (drone ship)' and PAYLOAD_MASS__KG_
```

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

Booster_Version
F9 FT B1022
F9 FT B1026
F9 FT B1021.2
F9 FT B1031.2

Total Number of Successful and Failure Mission Outcomes

List the total number of successful and failure mission outcomes

```
%sql select count(MISSION_OUTCOME) as missionoutcomes from SPACEXTBL GROUP BY MISSION_OUTCOME;
```

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

missionoutcomes
1
98
1
1

Boosters Carried Maximum Payload

List the names of the boosters which have carried the maximum payload mass

```
#  sql query
qboost= """Select distinct Booster_Version, max(PAYLOAD_MASS__KG_) as max_payload_mass
from spacex_v11
group by Booster_Version
order by max_payload_mass  desc"""
```

```
boost_max_load= pd.read_sql_query(qboost,conn)
boost_max_load.head(5)
```

	Booster_Version	max_payload_mass
0	F9 B5 B1049.4	15600
1	F9 B5 B1060.2	15600
2	F9 B5 B1048.4	15600
3	F9 B5 B1048.5	15600
4	F9 B5 B1056.4	15600

2015 Launch Records

List the failed landing_outcomes in drone ship, their booster versions, and launch site names for in year 2015

```
#  sql query
q_failed_landing= """ Select Date, Booster_Version, Launch_Site, Landing_Outcome
                    from spacex_v11
                    where Landing_Outcome = 'Failure (drone ship)'
                    and Date like '%2015%'    """
```

```
fail_drone= pd.read_sql_query(q_failed_landing,conn)
fail_drone.head(5)
```

	Date	Booster_Version	Launch_Site	Landing_Outcome
0	2015-01-10	F9 v1.1 B1012	CCAFS LC-40	Failure (drone ship)
1	2015-04-14	F9 v1.1 B1015	CCAFS LC-40	Failure (drone ship)

Rank Landing Outcomes Between 2010-06-04 and 2017-03-20

Rank the count of landing outcomes (such as Failure (drone ship) or Success (ground pad)) between the date 2010-06-04 and 2017-03-20, in descending order

```
#  sql query
q_count_landing= """ Select Landing_Outcome, count(*) as count_landings
                    from spacex_v11
                    where Date between '2010-06-04' and '2017-03-20'
                    group by Landing_Outcome
                    order by count_landings desc  """
```

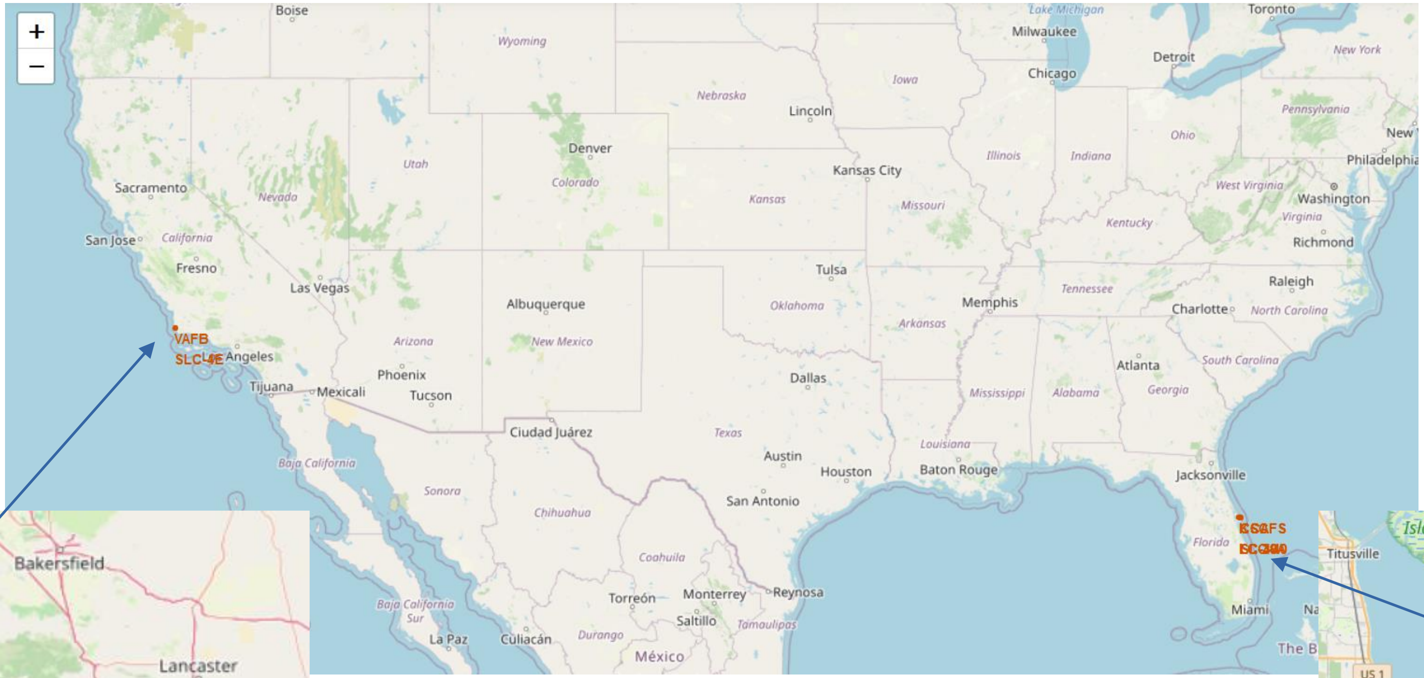
```
count_landing= pd.read_sql_query(q_count_landing,conn)
count_landing.head(10)
```

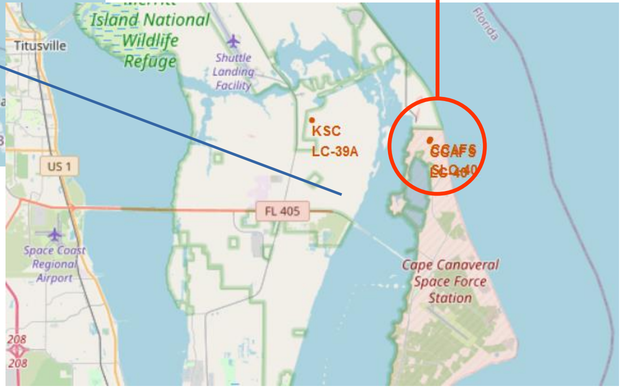
	Landing_Outcome	count_landings
0	No attempt	10
1	Failure (drone ship)	5
2	Success (drone ship)	5
3	Controlled (ocean)	3
4	Success (ground pad)	3
5	Uncontrolled (ocean)	2
6	Failure (parachute)	1
7	Precluded (drone ship)	1

Section 3

Launch Sites Proximities Analysis

SpaceX: All launch sites





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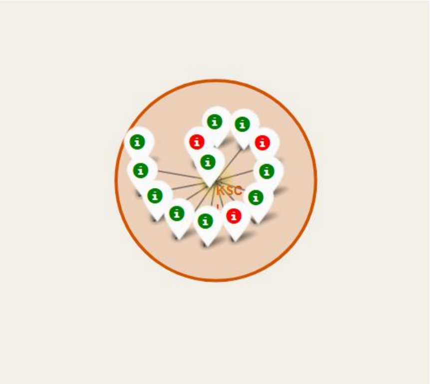
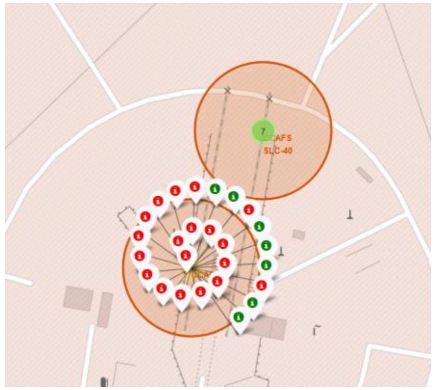
- **CCAF-SLC40: Cape Canaveral Space Launch Complex 40(FL)**

Falcon 9 Success/Failed launches for each site

Vandenberg Space Launch Complex 4 (CA)
VAFB SLC-4E



Kennedy Space Center (FL)
KSC LC 39A



Cape Canaveral (FL)
CCAFS-LC40

Cape Canaveral (FL)
CCAFS-SLC40

Launch Site	class	
CCAFS LC-40	0	19
	1	7
CCAFS SLC-40	0	4
	1	3
KSC LC-39A	0	3
	1	10
VAFB SLC-4E	0	6
	1	4

Table: Synthesis of launches outcomes
Class 0= failure
Class 1= success

ESA Unique Launch site – Kourou, French Guiana.

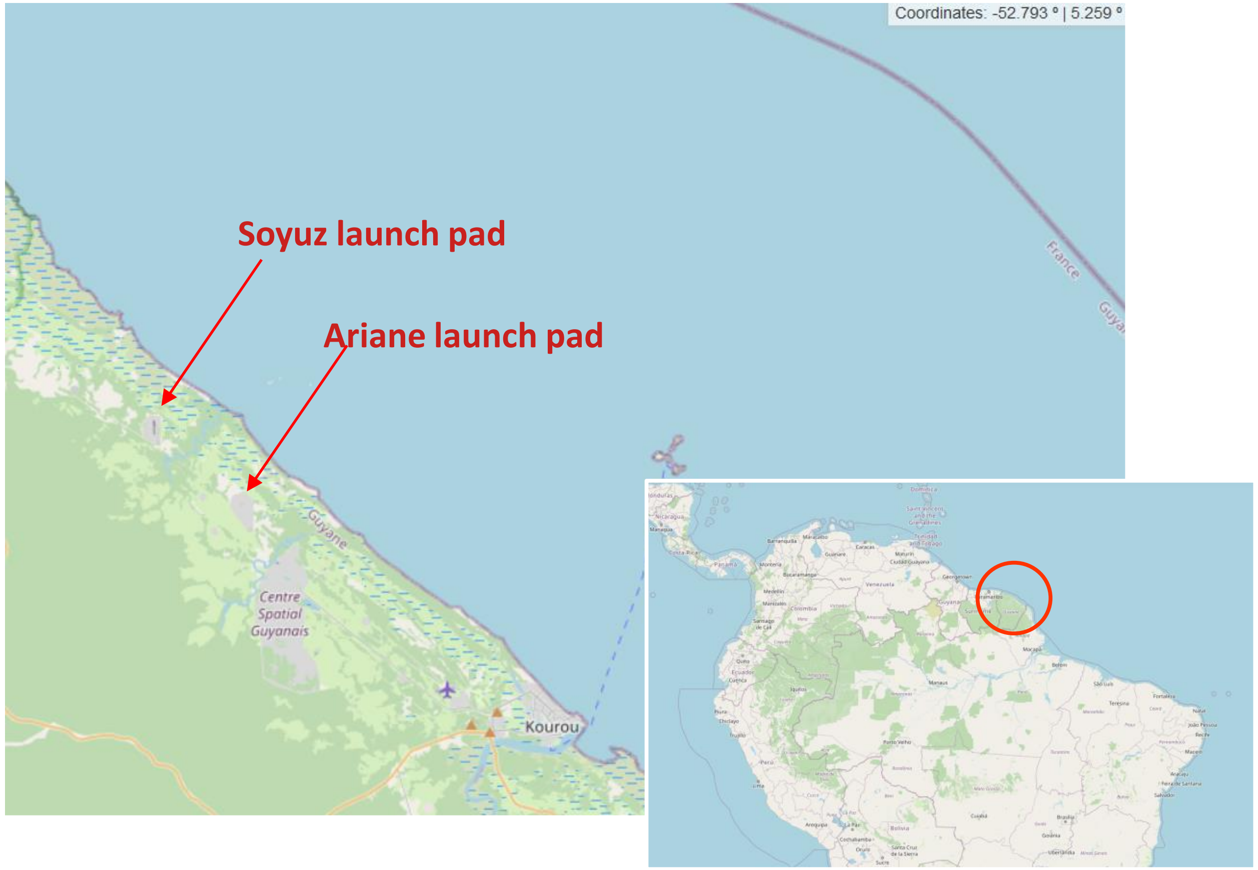
European Space Agency (ESA)/ArianeEspace launch sites in Kourou, French Guiana (France).

Kourou launch sites: Ariane, Soyuz

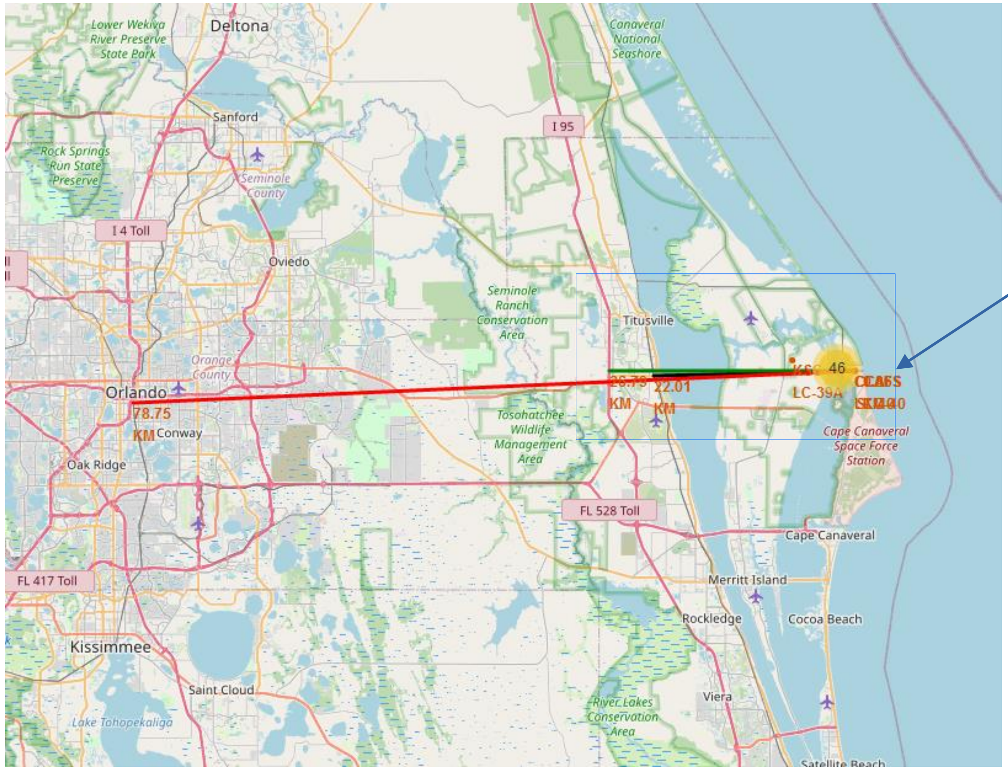
- are very close to the Equator: it’s a strong advantage for GTO/GEO flights
- are in a remote area far from any high density inhabited area and high traffic infrastructures
- Are close to the coast

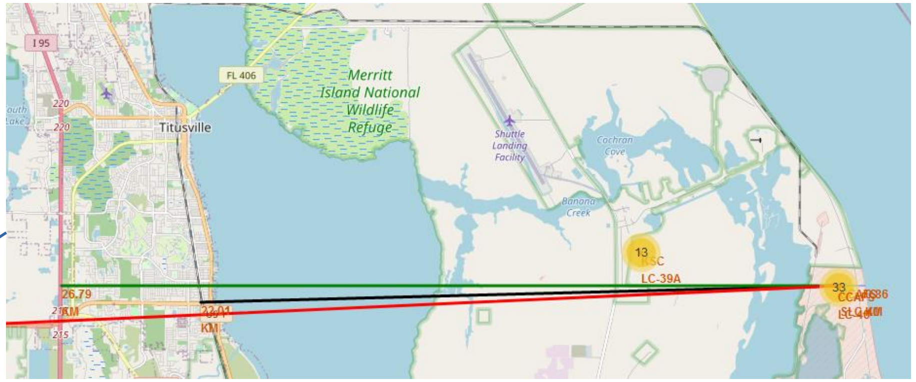
Strong Advantage over SpaceX, in terms of safety and GTO/GEO flights and energy required at lift-off.

SpaceX could compete and reduce energy at lift-off for GTO-GEO flights by introducing a concept like “Sea Launch”.



Distances between the launch site to its proximities





Distance from CCAFS_SLC40 to:

- **Closest coast: ~900 m**
- **Florida East Coast Railway: 22.0 km**
- **Highway I 95: 26.8 km**
- **Orlando: 78.75 km**

Launch sites are close to coasts. For safety issues if launcher is lost in the early stage of the flight.

Rockets are launched:

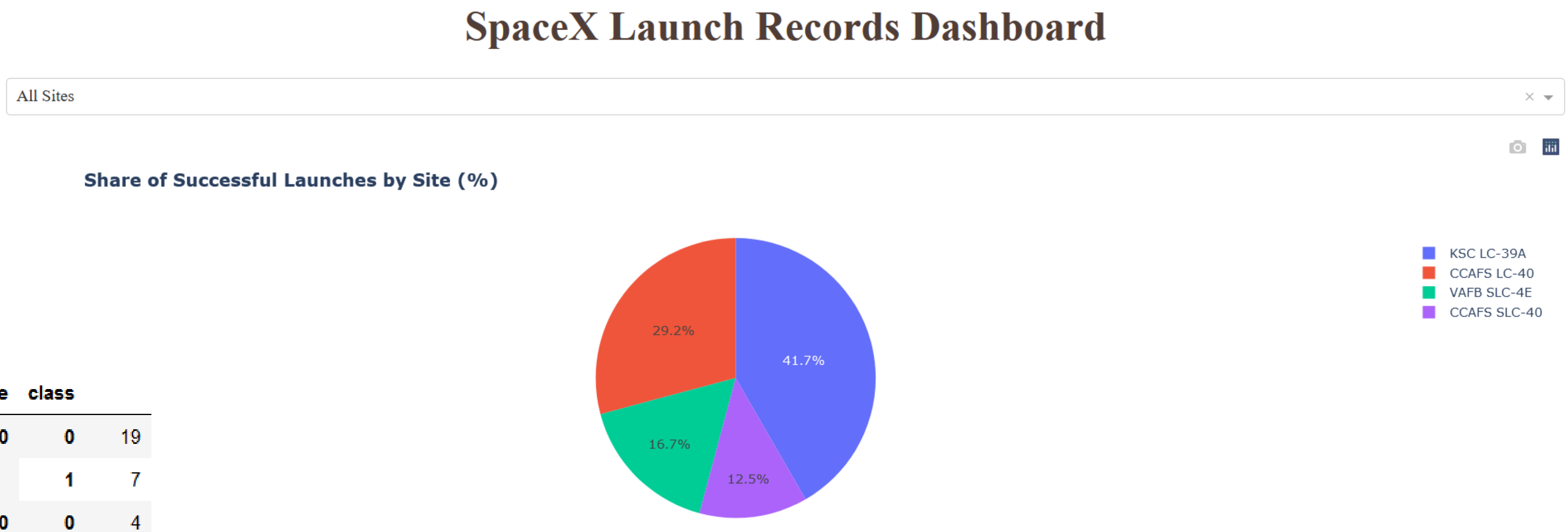
- From West to East over the ocean in Florida.
- North or South bound over the ocean in California. (Polar orbits only)

Launch sites are relatively far from populated areas for protecting population from serious incidents at lift off: explosion on the launch pad.

Section 4

Build a Dashboard with Plotly Dash

SpaceX Falcon 9: Launch success count for all sites



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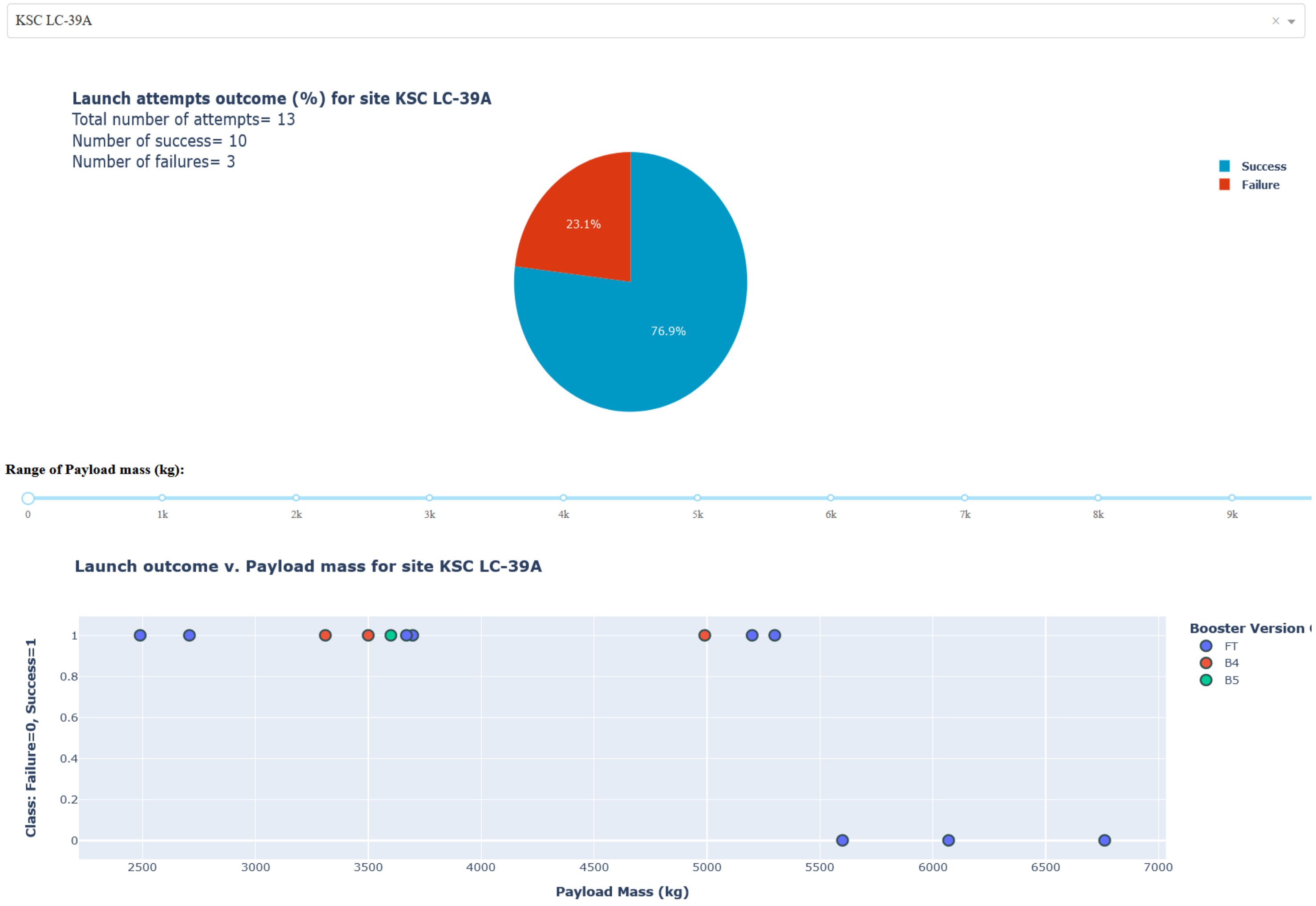
The dahsboard allows an interactive visualization and analysis of Falcon successful launches.
It completes scattered charts.
Here for all sites, we can identify the launch site with highest success rate.
Kennedy Space Center in Florida.

SpaceX Falcon9 Launch site with highest launch success ratio

KSC LC-39A
Kennedy Space Center in Florida.
13 flights, 10 successful missions.

- Heavy payload are “high risk”
- Success does not seem to depend upon boosters versions with low mass payload <5500kg.
- B5 and FT are the most reused launchers. Data is not sufficient, but may indicates that they are as reliable as 1 time launchers.



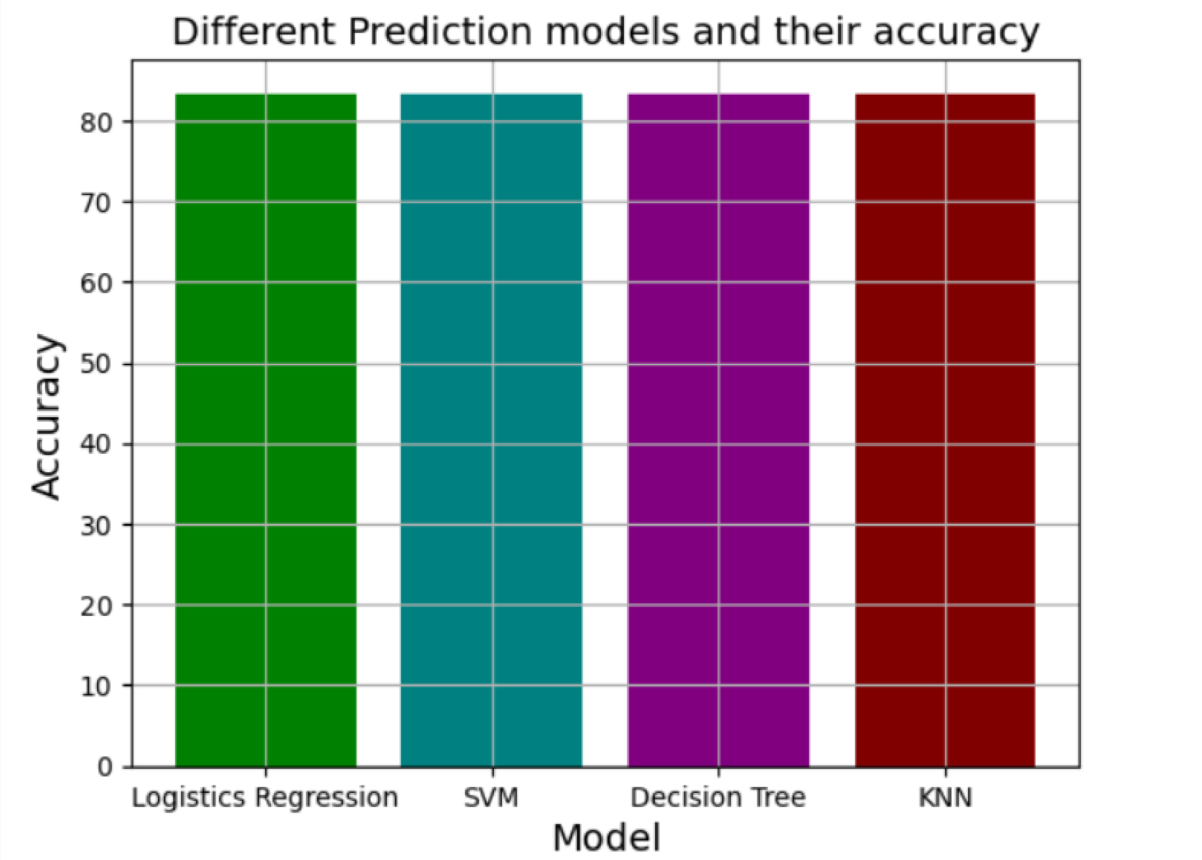
Launch outcome v. Payload mass (all sites)

- V1.0 and v1.1 are early launchers with low reliability.
  Landing legs, were pioneered on the Falcon 9 v1.1 version, but that version never landed intact.
  They were phased out in 2015.
- FT: “Full Thrust” is the next generation and has the highest success rate for payload mass under 6 tons. Including with “drone landing” (see details in next slide).
- Many FT flights are done with reused launchers. And show good reliability.
- Heavy payload are “high risk”.

Section 5

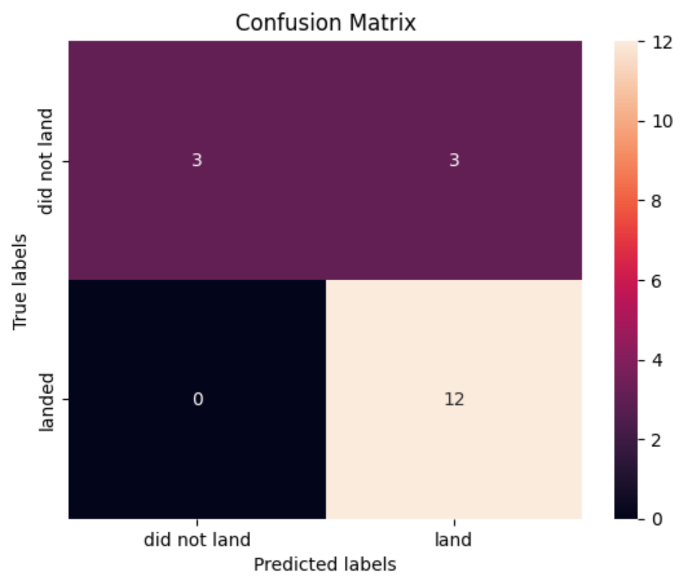
Predictive Analysis (Classification)

Classification Accuracy

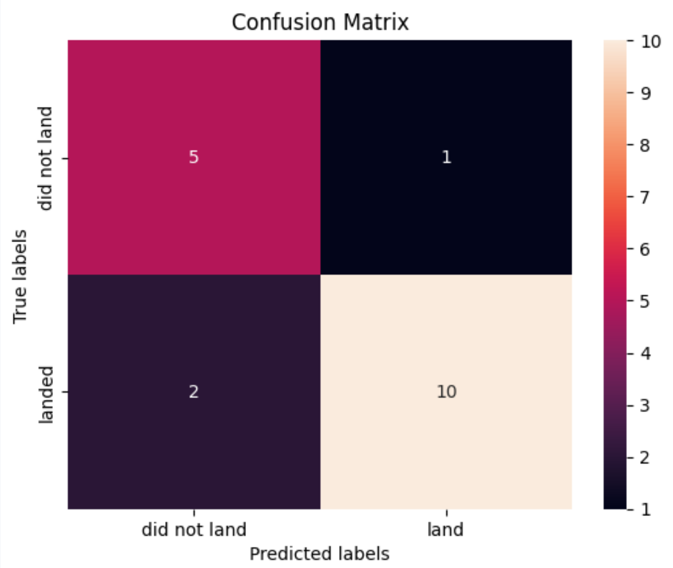


All the models performed equally well with accuracy of 83.33333%

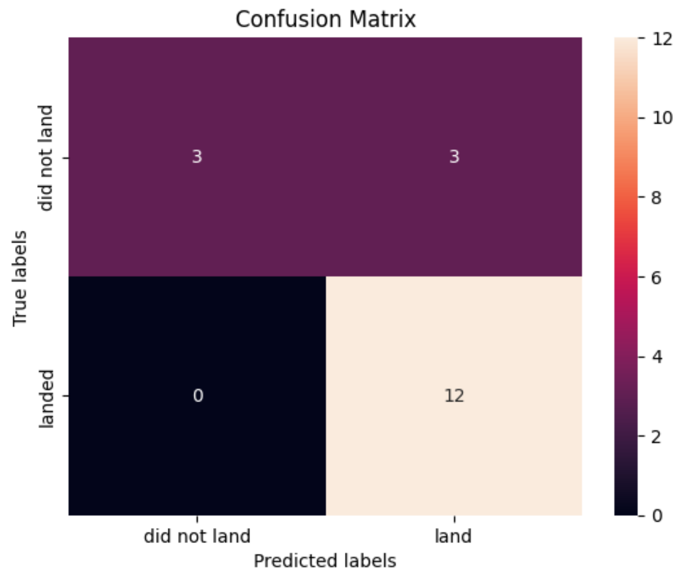
Confusion Matrix



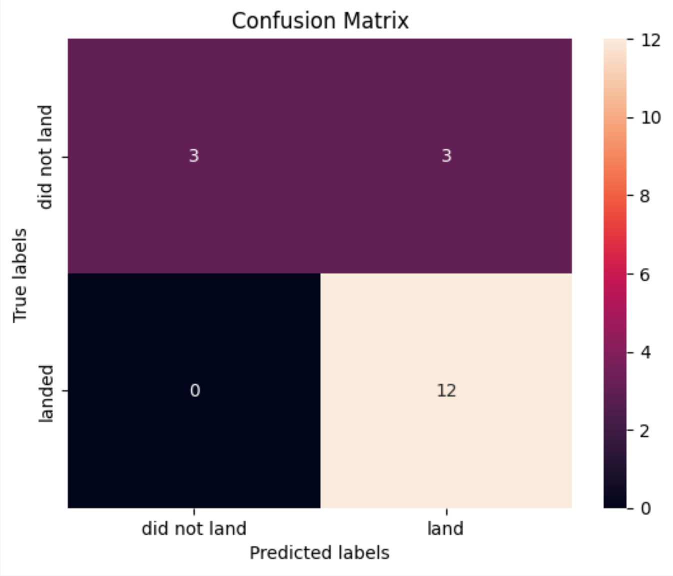
KNN



Decision Tree



SVM



Logistic regression

Conclusions

- The SVM, KNN, Decision Tree and Logistic Regression models are the best in terms of prediction accuracy for this dataset
- Low weighted payloads perform better than the heavier payloads.
- The success rate for SpaceX launches is directly proportional to time in years they will eventually perfect the launches.
- KSC LC 39A had the most successful launches from all the sites
- Orbit GEO, HEO, SSO, ES L1 has the best Success Rate.

Thank you!