Data Science Capstone

Will Falcon 9 First Stage Rockets Land Successfully?

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AUGUST 2021

Outline

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- Results
- Conclusion
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Executive Summary

FlightNumber	Date	BoosterVersion	PayloadMass	Orbit	LaunchSite	Outcome	Flights	GridFins	Reused	Legs
1	2010-06-04	Falcon 9	6104.959412	LEO	CCAFS SLC 40	None None	1	False	False	False
2	2012-05-22	Falcon 9	525.000000	LEO	CCAFS SLC 40	None None	1	False	False	False
3	2013-03-01	Falcon 9	677.000000	ISS	CCAFS SLC 40	None None	1	False	False	False
4	2013-09-29	Falcon 9	500.000000	PO	VAFB SLC 4E	False Ocean	1	False	False	False
5	2013-12-03	Falcon 9	3170.000000	GTO	CCAFS SLC 40	None None	1	False	False	False
6	2014-01-06	Falcon 9	3325.000000	GTO	CCAFS SLC 40	None None	1	False	False	False
7	2014-04-18	Falcon 9	2296.000000	ISS	CCAFS SLC 40	True Ocean	1	False	False	True
8	2014-07-14	Falcon 9	1316.000000	LEO	CCAFS SLC 40	True Ocean	1	False	False	True
9	2014-08-05	Falcon 9	4535.000000	GTO	CCAFS SLC 40	None None	1	False	False	False
10	2014-09-07	Falcon 9	4428.000000	GTO	CCAFS SLC 40	None None	1	False	False	False

Methodology:

- Data collected from SpaceX API
- Data web scraped from SpaceX online tables that hold historical Falcon 9 launch information
- The data was collected from the two sources above and cleaned to hold only relevant information.
- Then the data was used for exploratory data analysis, visual analysis, and machine learning predictions to better understand if Falcon 9 rockets will land successfully.

Introduction

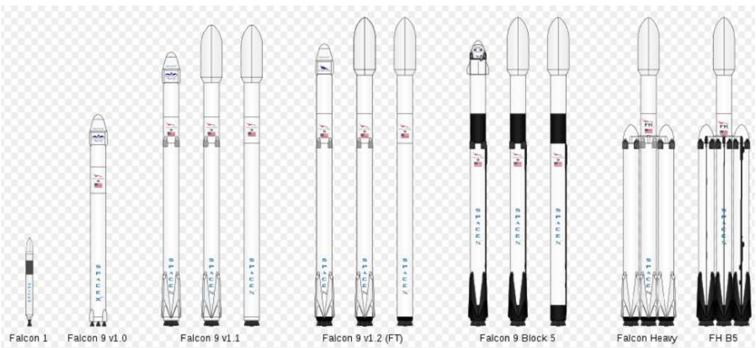
Background & context:

- SpaceX advertises Falcon 9 rocket launches at a cost of $62 million, which is much less than the ~$165 million of other providers.
- These savings largely come from the fact that SpaceX can reuse the first stage of rockets.
- Therefore, if we can predict if the first stage will land, we can also predict the cost of a rocket launch.
- This information would be useful to have if an alternate company wants to bid against SpaceX for a rocket launch.

Business Problem:

- Can we accurately predict if the first stage will land successfully?

Methodology



- Data collection methodology:
  - The data was collected via the SpaceX API and web scraped from online sources that hold historical launch success and failure data.
- Perform data wrangling
  - Once the data was acquired, it was cleansed using Python and SQL to:
    - remove irrelevant information
    - create dummy variables for categorical data
    - remove or replace missing information
- Perform exploratory data analysis (EDA) using visualization and SQL
  - Python and SQL were both used to:
    - Identify launch sites
    - Find success and failure rates of Falcon 9 first launches
    - Identify relevant factors, such as booster versions, payload mass, and Orbit type
- Perform interactive visual analytics using Folium
  - Folium mapped the location of launch sites, NASA, and successes and failures at each location.
- Perform predictive analysis using classification models
  - Logistic Regression, Support Vector Machine, Decision Tree, and K-Nearest Neighbor models were all used (to roughly the same accuracy rate) to predict success rates of the Falcon 9 launches

Data collection

SpaceX API:

- The SpaceX REST API was used to gather data regarding each launch.
- The irrelevant information was removed from the dataset to keep only the information we wanted, such as the rocket type, payload, flight number, cores, etc.

Webscraping:

- Using BeautifulSoup and Python, historical launch data was webscraped from online data sources.
- The irrelevant information was removed to keep only the information required, such as flight number, launch site, payload mass, launch outcome, etc.

Data collection – SpaceX API

Add the GitHub URL of the completed SpaceX API calls notebook as an external reference and peer-review purpose.

[Data Collection API]

```
# create dataframe from launch_dict
data = pd.DataFrame(data = launch_dict)
```

```
# show head of dataframe
data.head()
```

	FlightNumber	Date	BoosterVersion	PayloadMass	Orbit	LaunchSite	Outcome	Flights	GridFins	Reused	Legs	LandingPad	Block	ReusedCount	Serial	Longitude	Latitude
0	1	2006-03-24	Falcon 1	20.0	LEO	Kwajalein Atoll	None None	1	False	False	False	None	NaN	0	Merlin1A	167.743129	9.047721
1	2	2007-03-21	Falcon 1	NaN	LEO	Kwajalein Atoll	None None	1	False	False	False	None	NaN	0	Merlin2A	167.743129	9.047721
2	4	2008-09-28	Falcon 1	165.0	LEO	Kwajalein Atoll	None None	1	False	False	False	None	NaN	0	Merlin2C	167.743129	9.047721
3	5	2009-07-13	Falcon 1	200.0	LEO	Kwajalein Atoll	None None	1	False	False	False	None	NaN	0	Merlin3C	167.743129	9.047721
4	6	2010-06-04	Falcon 9	NaN	LEO	CCSFS SLC 40	None None	1	False	False	False	None	1.0	0	B0003	-80.577366	28.561857

Data collection – Web scraping

Add the GitHub URL of the completed web scraping notebook, as an external reference and peer-review purpose

[Data Collection Webscraping]

```python
df= pd.DataFrame({ key:pd.Series(value) for key, value in launch_dict.items() })
```

```python
df
```

	Flight No.	Launch site	Payload	Payload mass	Orbit	Customer	Launch outcome	Version Booster	Booster landing	Date	Time
0	flight_number	CCAFS	Dragon Spacecraft Qualification Unit	0	LEO	SpaceX	Success\n	F9 v1.0B0003.1	Success\n	4 June 2010	18:45
1	flight_number	CCAFS	Dragon	0	LEO	NASA (COTS)\nNRO	Success	F9 v1.0B0004.1	Success	8 December 2010	15:43
2	flight_number	CCAFS	Dragon	525 kg	LEO	NASA (COTS)	Success	F9 v1.0B0005.1	Success	22 May 2012	07:44
3	flight_number	CCAFS	SpaceX CRS-1	4,700 kg	LEO	NASA (CRS)	Success\n	F9 v1.0B0006.1	Success\n	8 October 2012	00:35
4	flight_number	CCAFS	SpaceX CRS-2	4,877 kg	LEO	NASA (CRS)	Success\n	F9 v1.0B0007.1	Success\n	1 March 2013	15:10
...	...	...	...	...	...	...	...	...	...	...	...
116	flight_number	CCSFS	Starlink	15,600 kg	LEO	SpaceX	Success\n	F9 B5B1051.10	Success\n	9 May 2021	06:42
117	flight_number	KSC	Starlink	~14,000 kg	LEO	SpaceX Capella Space and Tyvak	Success\n	F9 B5B1058.8	Success\n	15 May 2021	22:56
118	flight_number	CCSFS	Starlink	15,600 kg	LEO	SpaceX	Success\n	F9 B5B1063.2	Success\n	26 May 2021	18:59
119	flight_number	KSC	SpaceX CRS-22	3,328 kg	LEO	NASA (CRS)	Success\n	F9 B5B1067.1	Success\n	3 June 2021	17:29
120	flight_number	CCSFS	SXM-8	7,000 kg	GTO	Sirius XM	Success\n	F9 B5	Success\n	6 June 2021	04:26

121 rows × 11 columns

Data wrangling

Using Python and SQL, the data from both the API and Webscraping collections was cleaned up in similar ways:

- The data was converted into dataframes and tables for easier processing
- Irrelevant information was removed from the dataframes and tables
- Missing information was either removed or replaced by the mean of the feature
- Categorical data was converted into useable numerical values via dummy variables and one-hot encoding

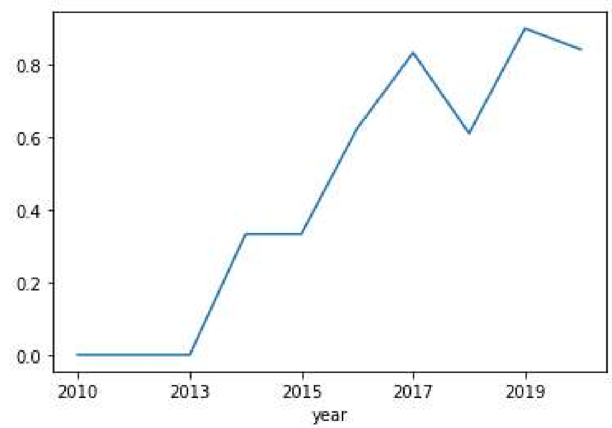
Data Wrangling

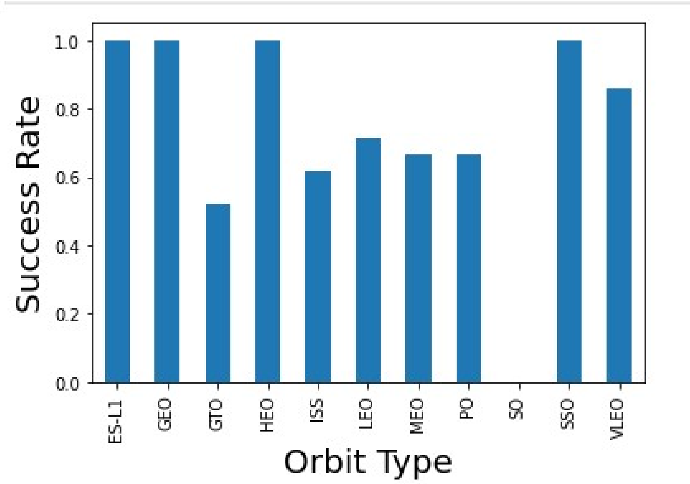
EDA with data visualization

EDA with visualization was used to:

- Explore the relationship between features, such as payload mass vs launch site
- Visualize the relationship between features, such as success rate and orbit type
- Visualize success rate over time

[EDA with Visualization]





EDA with SQL

SQL was used to identify helpful information such as:

- Launch sites
- Total & average payload mass (and related success / failure rates)
- Dates of successful landings
- The relationship between boosters and payload mass
- Total successful and failed launches

[EDA with SQL]

```
%%sql

SELECT "Landing__Outcome", COUNT(*) AS TOTAL
FROM SPACEXTBL
WHERE (("Landing__Outcome" LIKE '%Success%') AND ("Date" > '2010-06-04') AND ("Date" < '2017-03-20'))
GROUP BY "Landing__Outcome"
ORDER BY "Landing__Outcome" DESC;
```

```
 * ibm_db_sa://fgl32023:***@dashdb-txn-sbox-yp-dal09-04.services.dal.bluemix.net:50000/BLUDB
Done.
```

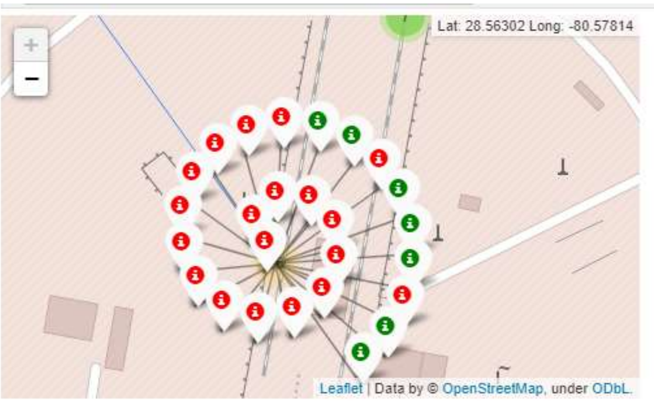
Landing_Outcome	total
Success (ground pad)	3
Success (drone ship)	5

Build an interactive map with Folium

Folium was used to:

- Locate the launch sites and NASA on a map
- Identify successful and failed launches at each launch site
- Calculate distance from each launch site to its proximities

[Interactive Visual Analytics]



Predictive analysis (Classification)

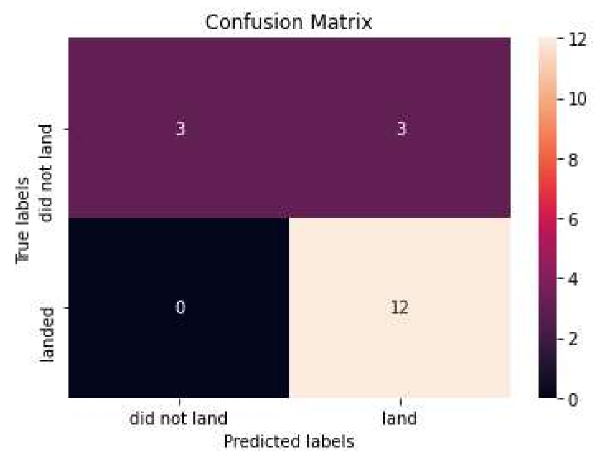
Machine Learning and Classification were used to predict the chances of success for Falcon 9 Launches.

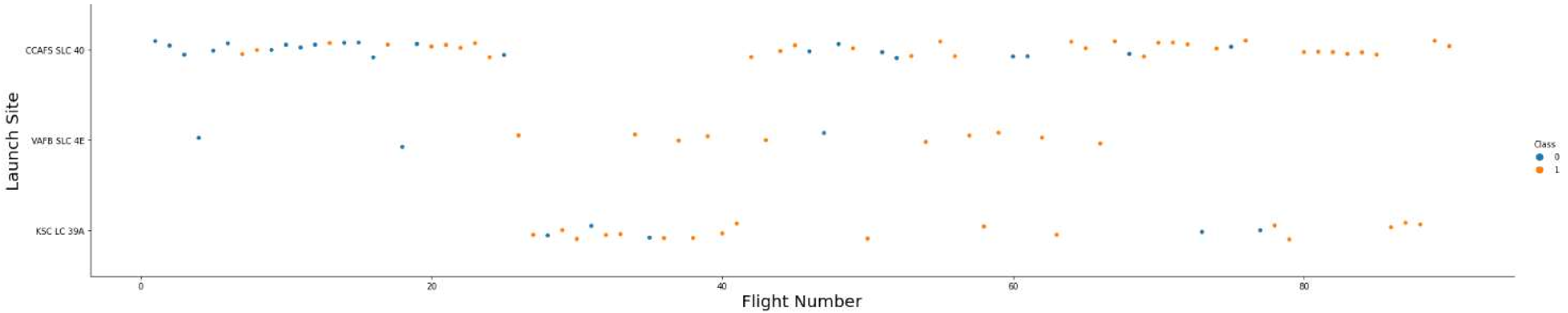
Four types of models were utilized, all with similar rates of accuracy (~84%):

- Logistic Regression
- Support Vector Machine
- Decision Tree
- K-Nearest Neighbors

These models were all pretty accurate, with their weakest points being false positives.

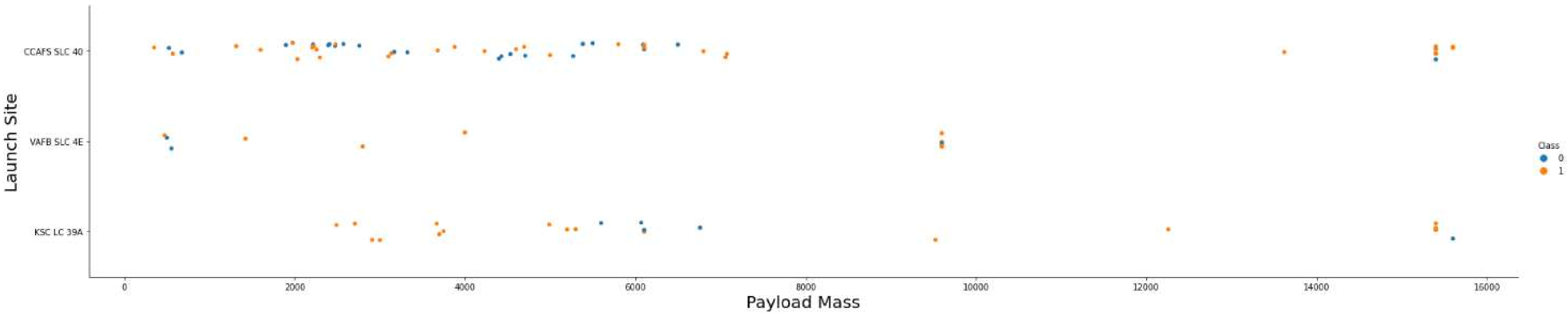
[Predictive Analysis]





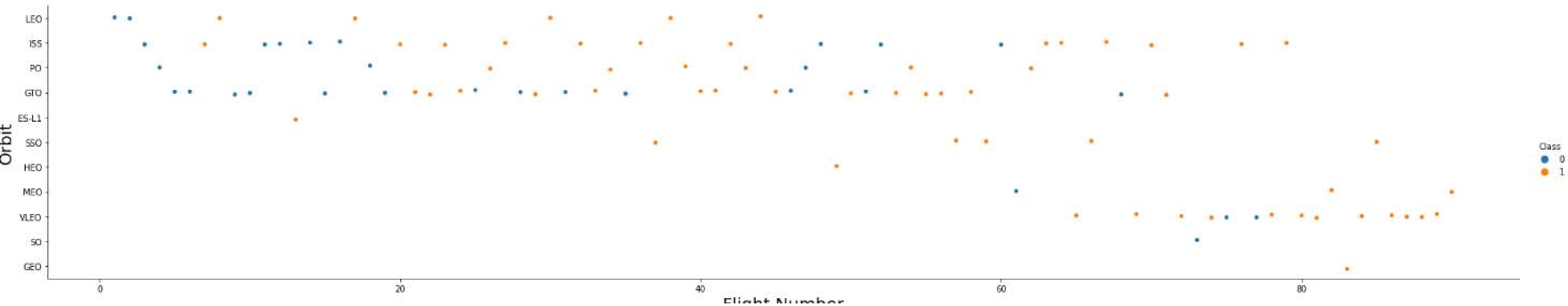
Flight Number vs. Launch Site

The higher the flight number, the more successful landing there are in every launch site.



Payload vs. Launch Site

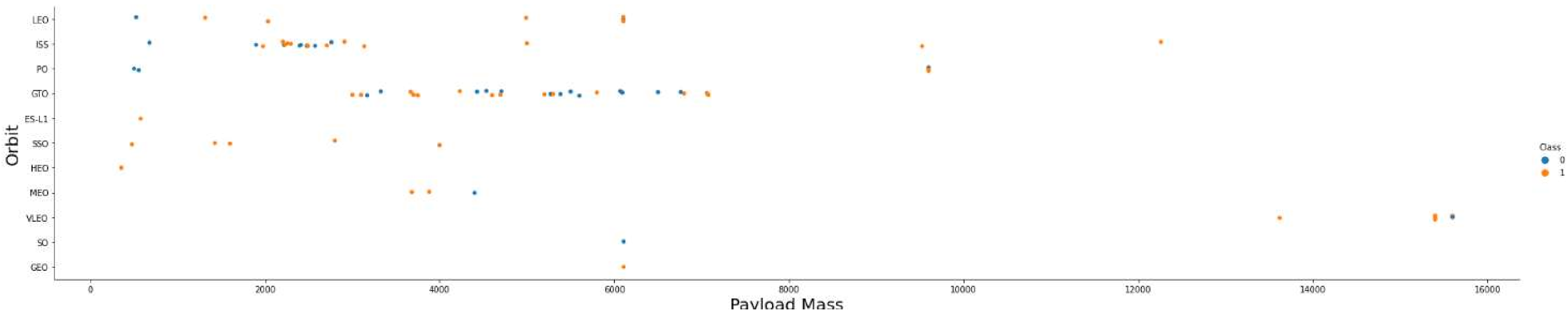
The CCAFS SLC-40 site has the most failures.



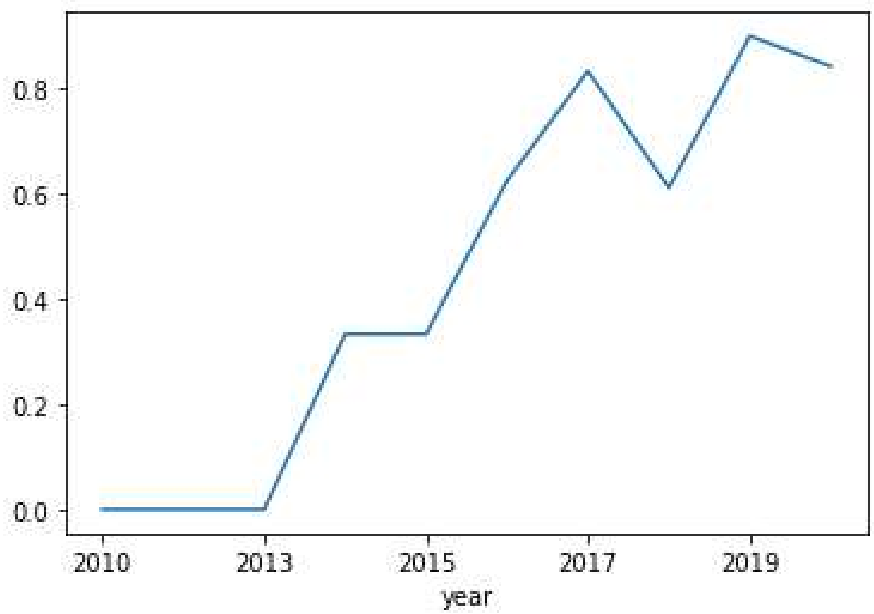
Flight Number vs. Orbit type

The higher the flight number, the more successes there tend to be.

The lower the orbit, the more successes there tends to be.



Payload vs. Orbit type



Launch success yearly trend

Launches have historically become more and more successful over time.

All launch site names

The four unique launch sites were found using SQL as below:

Task 1: Display the names of the unique launch sites in the space mission

```
%%sql

SELECT DISTINCT("Launch_Site")
FROM SPACEXTBL;
```

```
 * ibm_db_sa://fgl32023:***@dashdb-txn-sbox-yp-dal09-04.services.dal.bluemix.n
Done.
```

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

Launch site names begin with `CCA`

Task 2: Display 5 records where launch sites begin with string 'CCA'

```
%%sql

SELECT *
FROM SPACEXTBL
WHERE "Launch_Site" LIKE 'CCA%'
LIMIT 5;
```

```
 * ibm_db_sa://fgl32023:***@dashdb-txn-sbox-yp-dal09-04.services.dal.bluemix.net:50000/BLUDB
Done.
```

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

Total payload mass

Total payload mass carried by NASA-launched boosters can be found below:

Task 3: Display the total payload mass carried by boosters launched by NASA (CRS)

```
%%sql

SELECT SUM(payload_mass__kg_) AS TOTAL_NASA_mass
FROM SPACEXTBL
WHERE "Customer" LIKE '%CRS%';
```

```
 * ibm_db_sa://fgl32023:***@dashdb-txn-sbox-yp-dal09-04.services.dal.bluemix.net:50000/BLUDB
Done.
```

total_nasa_mass
48213

Average payload mass by F9 v1.1

Average payload mass can be found below:

Task 4: Display average payload mass carried by booster version F9 v1.1

```
%%sql

SELECT AVG(payload_mass__kg_) AS AVG_MASS
FROM SPACEXTBL
WHERE "Booster_Version" LIKE 'F9 v1.1%';
```

```
 * ibm_db_sa://fgl32023:***@dashdb-txn-sbox-yp-dal09-04.services.dal.bluemix.net:50000/BLUDB
Done.
```

avg_mass
2534.666666

First successful ground landing date

The date of the first successful ground landing can be found below:

Task 5: List the date when the first successful landing outcome in ground pad was achieved

```
%%sql

SELECT MIN("Date")
FROM SPACEXTBL
WHERE "Landing__Outcome" LIKE '%ground pad%';
```

```
 * ibm_db_sa://fgl32023:***@dashdb-txn-sbox-yp-dal09-04.services.dal.bluemix.net:50000/BLUDB
Done.
```

1
2015-12-22

Successful drone ship landing with payload between 4000 and 6000

Succesful drone ship landings between 4000 and 6000 can be found below:

Task 6: 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", "Landing__Outcome", payload_mass__kg_
FROM SPACEXTBL
WHERE (("Landing__Outcome" ='Success (drone ship)') AND (payload_mass__kg_ > 4000 AND payload_mass__kg_ < 6000));
```

```
 * ibm_db_sa://fgl32023:***@dashdb-txn-sbox-yp-dal09-04.services.dal.bluemix.net:50000/BLUDB
Done.
```

Booster_Version	Landing__Outcome	payload_mass__kg_
F9 FT B1022	Success (drone ship)	4696
F9 FT B1026	Success (drone ship)	4600
F9 FT B1021.2	Success (drone ship)	5300
F9 FT B1031.2	Success (drone ship)	5200

Total number of successful and failure mission outcomes

Total successful and failed missions can be found below:

Task 7: List the total number of successful and failure mission outcomes

```
%%sql

SELECT COUNT(*),
SUM("Landing__Outcome" LIKE '%Success%') AS SUCCESSES,
SUM("Landing__Outcome" LIKE '%Failure%') AS FAILURES
FROM SPACEXTBL;
```

```
 * ibm_db_sa://fgl32023:***@dashdb-txn-sbox-yp-dal09-04.services.dal.bluemix.r
Done.
```

1	successes	failures
101	61	10

Boosters carried maximum payload

Boosters that carried max payload mass can be found below:

Task 8: List the names of the booster_versions which have carried the maximum payload mass. U

```
%%sql

SELECT "Booster_Version", payload_mass__kg_
FROM SPACEXTBL
WHERE payload_mass__kg_ = (SELECT MAX(payload_mass__kg_) FROM SPACEXTBL);
```

```
 * ibm_db_sa://fgl32023:***@dashdb-txn-sbox-yp-dal09-04.services.dal.bluemix.net:50000/BLUDB
Done.
```

Booster_Version	payload_mass__kg_
F9 B5 B1048.4	15600
F9 B5 B1049.4	15600
F9 B5 B1051.3	15600
F9 B5 B1056.4	15600
F9 B5 B1048.5	15600
F9 B5 B1051.4	15600
F9 B5 B1049.5	15600
F9 B5 B1060.2	15600
F9 B5 B1058.3	15600
F9 B5 B1051.6	15600
F9 B5 B1060.3	15600
F9 B5 B1049.7	15600

2015 launch records

2015 Launch records can be found below:

Task 9: List the records which will display the month names, failure landing in drone ship outcomes, booster versions, and launch_sites for the months in 2015

```
%%sql

SELECT MONTHNAME("Date") AS Month, "Booster_Version", "Launch_Site", "Landing__Outcome"
FROM SPACEXTBL
WHERE (("Landing__Outcome" LIKE '%Failure%') AND YEAR("Date")=2015);
```

```
 * ibm_db_sa://fgl32023:***@dashdb-txn-sbox-yp-dal09-04.services.dal.bluemix.net:50000/BLUDB
Done.
```

MONTH	Booster_Version	Launch_Site	Landing__Outcome
January	F9 v1.1 B1012	CCAFS LC-40	Failure (drone ship)
April	F9 v1.1 B1015	CCAFS LC-40	Failure (drone ship)

Rank success count between 2010-06-04 and 2017-03-20

The success ranking can be found below:

Task 10: Rank the count of successful landing_outcomes between date 2010-06-04 and 2017-03-20 in descending order

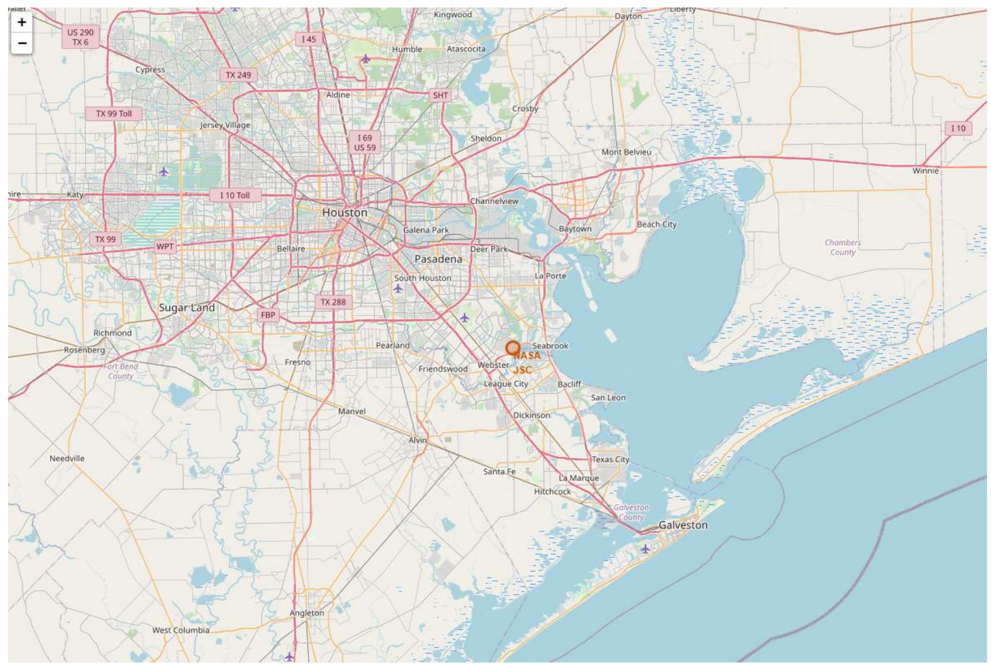
```
%%sql

SELECT "Landing__Outcome", COUNT(*) AS TOTAL
FROM SPACEXTBL
WHERE (("Landing__Outcome" LIKE '%Success%') AND ("Date" > '2010-06-04') AND ("Date" < '2017-03-20'))
GROUP BY "Landing__Outcome"
ORDER BY "Landing__Outcome" DESC;
```

```
 * ibm_db_sa://fgl32023:***@dashdb-txn-sbox-yp-dal09-04.services.dal.bluemix.net:50000/BLUDB
Done.
```

Landing_Outcome	total
Success (ground pad)	3
Success (drone ship)	5

NASA Map

Here is the location of NASA in Houston, TX:

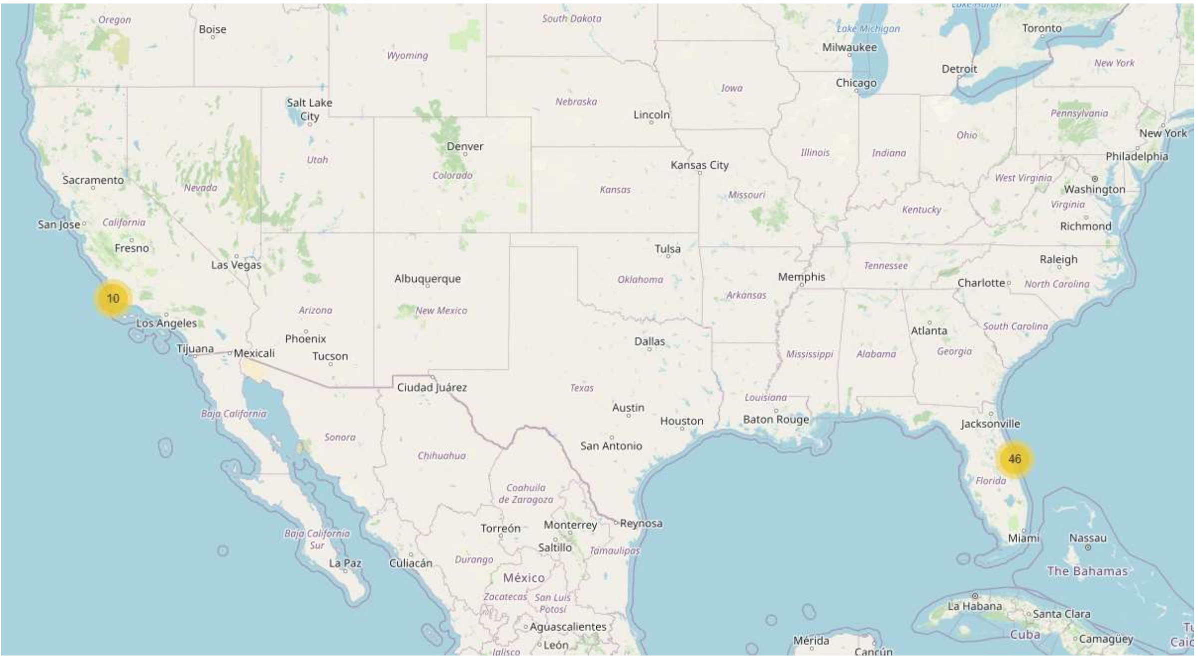


SpaceX Launch Sites

This map displays the location of SpaceX launch sites in blue.

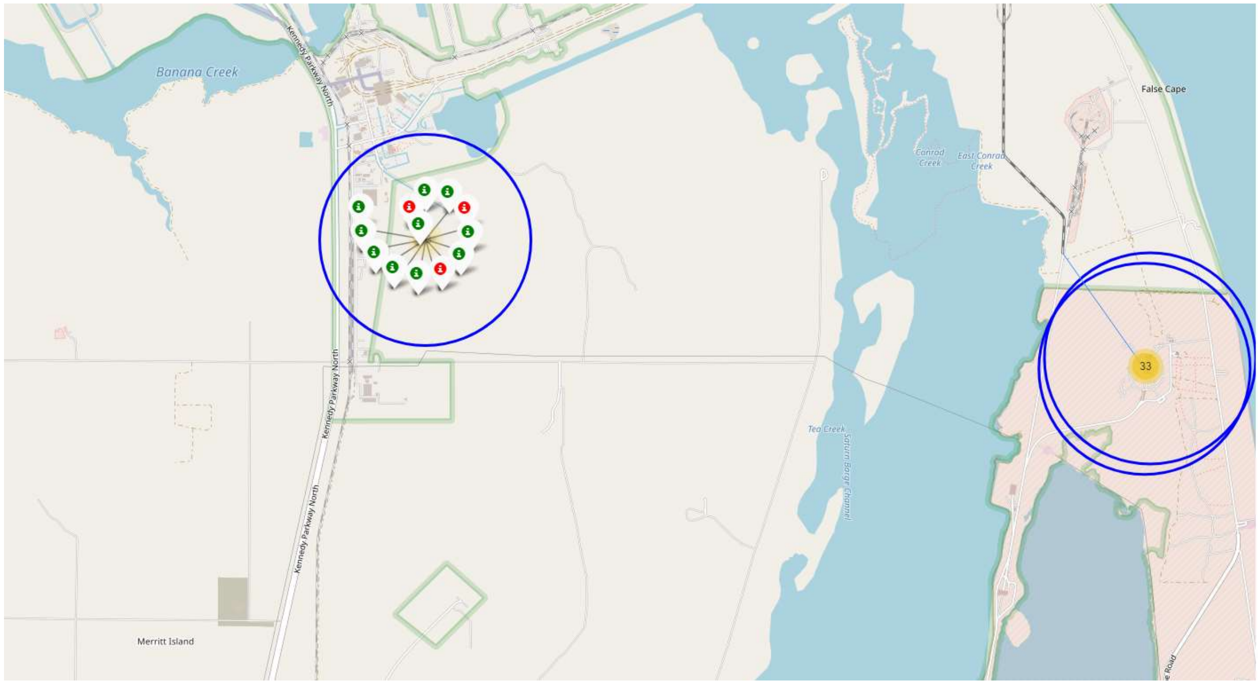
Launch History

This map displays the number of launches at each launch site.



Launch Site Successes and Failures

This map displays the success or failure of each launch at each launch site:



<Dashboard screenshot 3>

Replace <Dashboard screenshot 3> title with an appropriate title

Show screenshots of Payload vs. Launch Outcome scatter plot for all sites, with different payload selected in the range slider

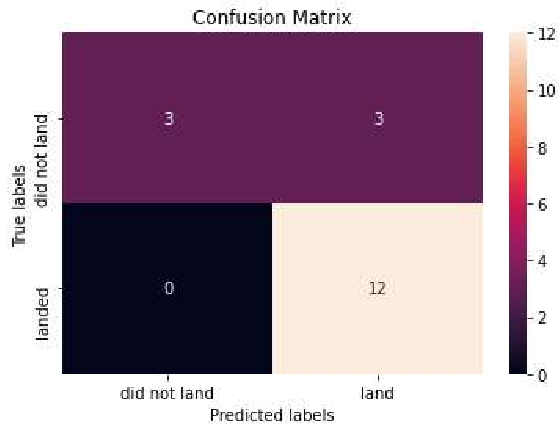
Explain the important elements and findings on the screenshot

ALGORITHM	JACCARD TRAIN ACCURACY SCORE (.accuracy_score())	JACCARD TEST ACCURACY SCORE (.accuracy_score)	TEST ACCURACY R-SQUARED SCORE (.score())	GRIDSEARCHCH Score (.BEST_SCORE)
Logistic Regression	.875	.8334	.8334	.8464
Support Vector Machine	.889	.8334	.8334	.8484
Decision Tree	.8611	.8333	.8333	.8768
K-Nearest Neighbors	.8611	.8334	.8334	.848

Classification Accuracy

All four models had roughly the same level of accuracy, so any would be a good model to use for prediction purposes.

```
# plot confusion matrix
yhat = knn_cv.predict(X_test)
plot_confusion_matrix(Y_test,yhat)
```




```
print("LR jaccard train score: ", metrics.accuracy_score(Y_train,knn_cv.predict(X_train) ))
print("LR jaccard test score: ", metrics.accuracy_score(Y_test, yhat))
print("LR R-squared score: ", knn_cv.score(X_test, Y_test))
print("LR gridsearch score", knn_cv.best_score_)
```

```
LR jaccard train score:  0.8611111111111112
LR jaccard test score:  0.8333333333333334
LR R-squared score:  0.8333333333333334
LR gridsearch score 0.8482142857142858
```

Confusion Matrix

All four models performed roughly the same and had the same confusion matrix. False negatives were the biggest problem with each model.

CONCLUSION

Conclusion:

- The models we used are reliable for predicting future successful launches based off historical data.
- The EDA indicates that certain parameters help make launches more successful, such as:
  - launch site VAFB SLC 4E having a higher success rate than the other launch sites
  - launches with higher flight numbers generally being more successful)
  - launches with ES-L1 orbit type are much more successful than those with GTO orbit types
  - SpaceX is learning from past mistakes, as indicated by the fact that the rate of successful launches has increased over time on average.

APPENDIX

```
print("LR jaccard train score: ", metrics.accuracy_score(Y_train,knn_cv.predict(X_train) )) #
print("LR jaccard test score: ", metrics.accuracy_score(Y_test, yhat))
print("LR R-squared score: ", knn_cv.score(X_test, Y_test))
print("LR gridsearch score", knn_cv.best_score_)
```

```
LR jaccard train score:  0.8611111111111112
LR jaccard test score:  0.8333333333333334
LR R-squared score:  0.8333333333333334
LR gridsearch score 0.8482142857142858
```

[hide] Flight No.	Date and time (UTC)	Version, Booster[b]	Launch site	Payload[c]	Payload mass	Orbit	Customer	Launch outcome	Booster landing
78	7 January 2020, 02:19:21[492]	F9 B5 ♺ B1049.4	CCAFS, SLC-40	Starlink 2 v1.0 (60 satellites)	15,600 kg (34,400 lb)[5]	LEO	SpaceX	Success	Success (drone ship)
	Third large batch and second operational flight of Starlink constellation. One of the 60 satellites included a test coating to make the satellite less reflective, and thus less likely to interfere with ground-based astronomical observations.[493]								
79	19 January 2020, 15:30[494]	F9 B5 ♺ B1046.4	KSC, LC-39A	Crew Dragon in-flight abort test[495] (Dragon C205.1)	12,050 kg (26,570 lb)	Sub-orbital[496]	NASA (CTS)[497]	Success	No attempt
	An atmospheric test of the Dragon 2 abort system after Max Q. The capsule fired its SuperDraco engines, reached an apogee of 40 km (25 mi), deployed parachutes after reentry, and splashed down in the ocean 31 km (19 mi) downrange from the launch site. The test was previously slated to be accomplished with the Crew Dragon Demo-1 capsule;[498] but that test article exploded during a ground test of SuperDraco engines on 20 April 2019.[419] The abort test used the capsule originally intended for the first crewed flight.[499] As expected, the booster was destroyed by aerodynamic forces after the capsule aborted.[500] First flight of a Falcon 9 with only one functional stage — the second stage had a mass simulator in place of its engine.								
80	29 January 2020, 14:07[501]	F9 B5 ♺ B1051.3	CCAFS, SLC-40	Starlink 3 v1.0 (60 satellites)	15,600 kg (34,400 lb)[5]	LEO	SpaceX	Success	Success (drone ship)
	Third operational and fourth large batch of Starlink satellites, deployed in a circular 290 km (180 mi) orbit. One of the fairing halves was caught, while the other was fished out of the ocean.[502]								
81	17 February 2020, 15:05[503]	F9 B5 ♺ B1056.4	CCAFS, SLC-40	Starlink 4 v1.0 (60 satellites)	15,600 kg (34,400 lb)[5]	LEO	SpaceX	Success	Failure (drone ship)
	Fourth operational and fifth large batch of Starlink satellites. Used a new flight profile which deployed into a 212 km × 386 km (132 mi × 240 mi) elliptical orbit instead of launching into a circular orbit and firing the second stage engine twice. The first stage booster failed to land on the drone ship[504] due to incorrect wind data.[505] This was the first time a flight proven booster failed to land.								
82	7 March 2020, 04:50[506]	F9 B5 ♺ B1059.2	CCAFS, SLC-40	SpaceX CRS-20 (Dragon C112.3 ♺)	1,977 kg (4,359 lb)[507]	LEO (ISS)	NASA (CRS)	Success	Success (ground pad)
	Last launch of phase 1 of the CRS contract. Carries *Bartolomeo*, an ESA platform for hosting external payloads onto ISS.[508] Originally scheduled to launch on 2 March 2020, the launch date was pushed back due to a second stage engine failure. SpaceX decided to swap out the second stage instead of replacing the faulty part.[509] It was SpaceX's 50th successful landing of a first stage booster, the third flight of the Dragon C112 and the last launch of the cargo Dragon spacecraft.								
83	18 March 2020, 12:16[510]	F9 B5 ♺ B1048.5	KSC, LC-39A	Starlink 5 v1.0 (60 satellites)	15,600 kg (34,400 lb)[5]	LEO	SpaceX	Success	Failure (drone ship)
	Fifth operational launch of Starlink satellites. It was the first time a first stage booster flew for a fifth time and the second time the fairings were reused (Starlink flight in May 2019).[511] Towards the end of the first stage burn, the booster suffered premature shut down of an engine, the first of a Merlin 1D variant and first since the CRS-1 mission in October 2012. However, the payload still reached the targeted orbit.[512] This was the second Starlink launch booster landing failure in a row, later revealed to be caused by residual cleaning fluid trapped inside a sensor.[513]								
84	22 April 2020, 19:30[514]	F9 B5 ♺ B1051.4	KSC, LC-39A	Starlink 6 v1.0 (60 satellites)	15,600 kg (34,400 lb)[5]	LEO	SpaceX	Success	Success (drone ship)