CITRIS Aviation Prize Team Overview: UC Santa Cruz

Proposal title: Simulation-Based Analysis of Guidance, Navigation, and Scheduling for Advanced Air Mobility in Northern California

Team members:

- Alexander Aghili, Undergraduate, Computer Science and Mathematics
- Zoe La Clair, Undergraduate, Applied Mathematics
- Andre Aledia, Undergraduate, Computer Engineering
- Christine Perez, Undergraduate, Electrical Engineering
- Eric Vin, Graduate, Computer Science

Team advisor: Daniel Fremont, Assistant Professor, Computer Science and Engineering

Goals and System Description

- Complete Evaluation System for any AAM/UAM design
- Give useful feedback to quickly iterate on system design
- Integrate with existing research systems
- Utilize Microsoft Flight Simulator environment for simulation and data collection.

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System Evaluation: Overview

- Collect data from MSFS Simulation
- Create Evaluation Systems From Aircraft Data
  - Interchangeable Software Components
  - Use analyzed information to inform further components
- Use for routing, terminal procedures, and scheduling software.

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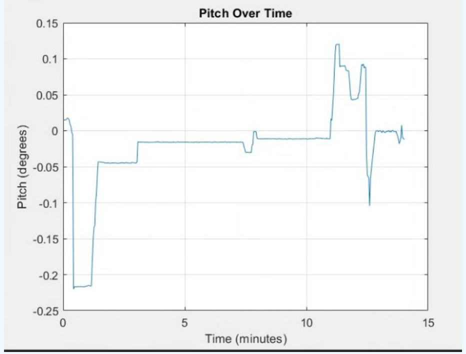
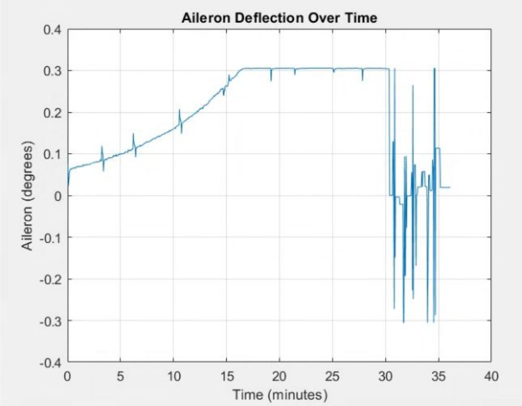
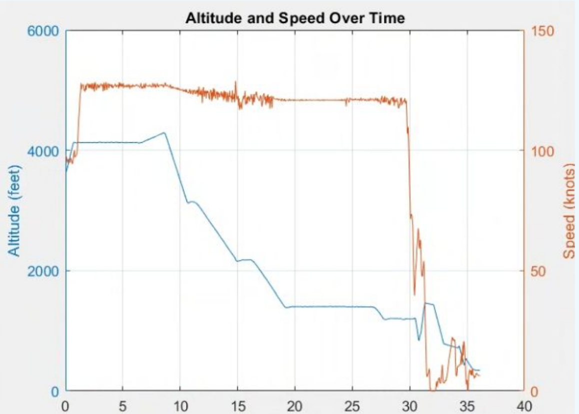
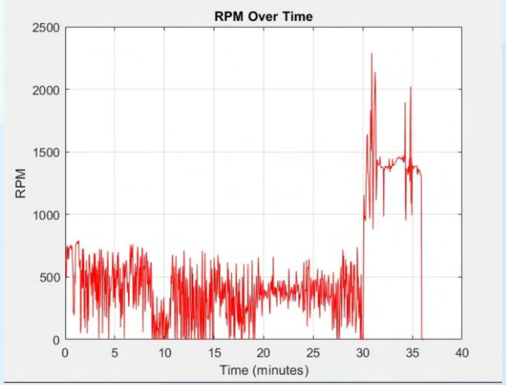
System Evaluation: Aircraft Data

- Variety of Aircraft Data
  - Aircraft Position and Altitude
  - Control Inputs
  - Aircraft Configuration



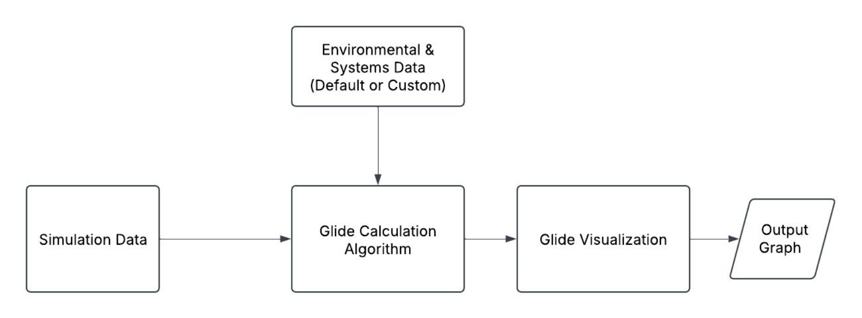


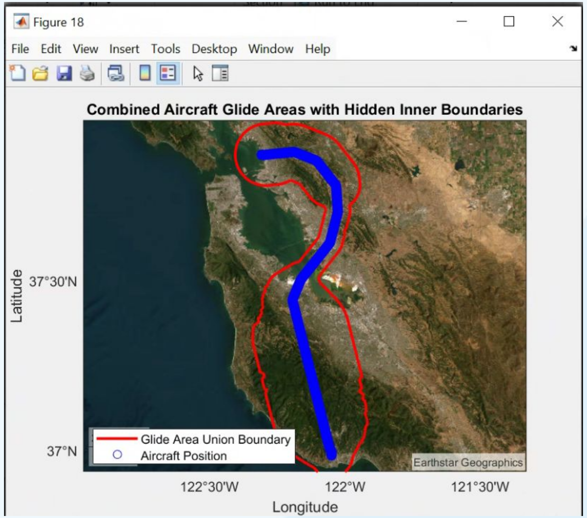




System Evaluation: Case Study - Glide

- Custom
  - Data Inputs
  - Algorithms
  - Equations
- Can be done for all components
  - Noise
  - Energy
  - Terrain
  - Obstacles
  - Traffic





Best glide angle is calculated using:

$$\sin\gamma_{bg} = -\sqrt{\frac{4C_{D_0}}{\pi e A\cos^2\phi + 4C_{D_0}}}$$

This is the angle between the flight path and the ground that provides the highest L/D ratio.

```
gamma_bg_rad = asin( -sqrt((4.*C_D0')./(pi*e*A*cos(phi)^2 + 4.*C_D0')) );
```

Convert glide angle from radians to degrees using `convang`:

```
gamma_bg = convang(gamma_bg_rad,'rad','deg');
```

Best glide drag is calculated using:

$$D_{min} = D_{bg} = \frac{1}{2}\rho(TAS_{bg}^2)S(2C_{D_0}) = -W\sin\gamma_{bg}$$

```
D_bg = -W*sin(gamma_bg_rad);
```

Best glide lift is calculated using:

$$L_{bg} = L_{max} = W\cos\gamma_{bg} = \sqrt{W^2 - D_{bg}^2}$$

```
L_bg =  W*cos(gamma_bg_rad);
```

Calculate dynamic pressure using `dpressure`:

```
qbar = dpressure([TAS_bg' zeros(size(TAS_bg,2),2)], rho);
```

Calculate drag and lift coefficients using:

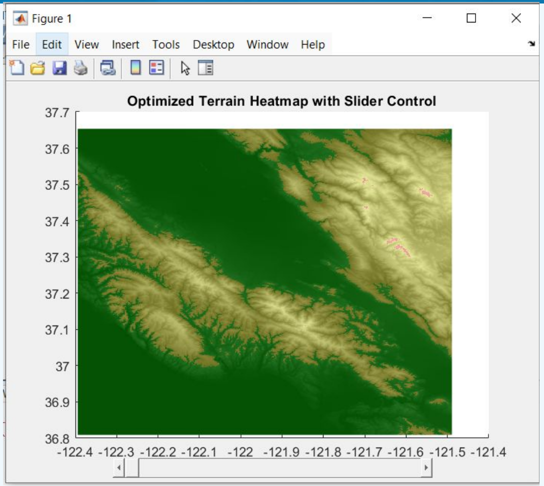
$$C_{D_{bg}} = \frac{D_{bg}}{\bar{q}S}$$

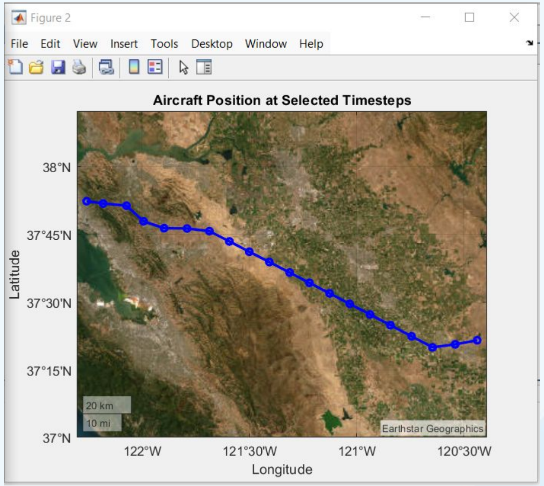
```
C_D_bg = D_bg./(qbar*S);
```

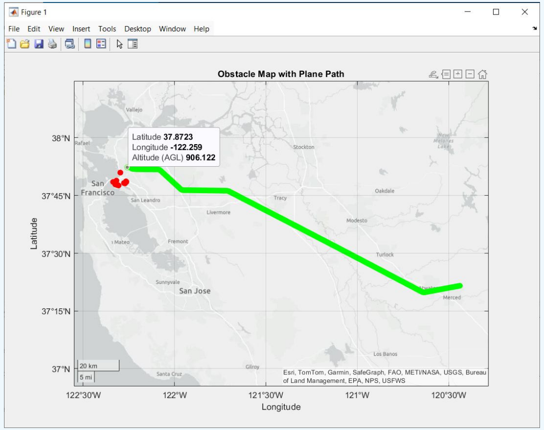
$$C_{L_{bg}} = \frac{L_{bg}}{\bar{q}S}$$

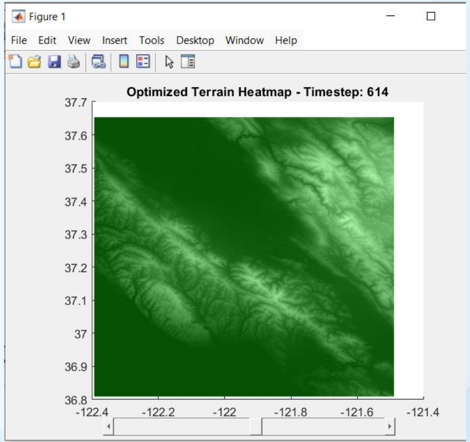
```
Weight = 2400;
WingReferenceArea = 174;
WingAspectRatio = 7.38;
ParasiteDragCoefficient = 0.037;
AircraftEfficiencyFactor = 0.72;
```

System Evaluation: Analysis









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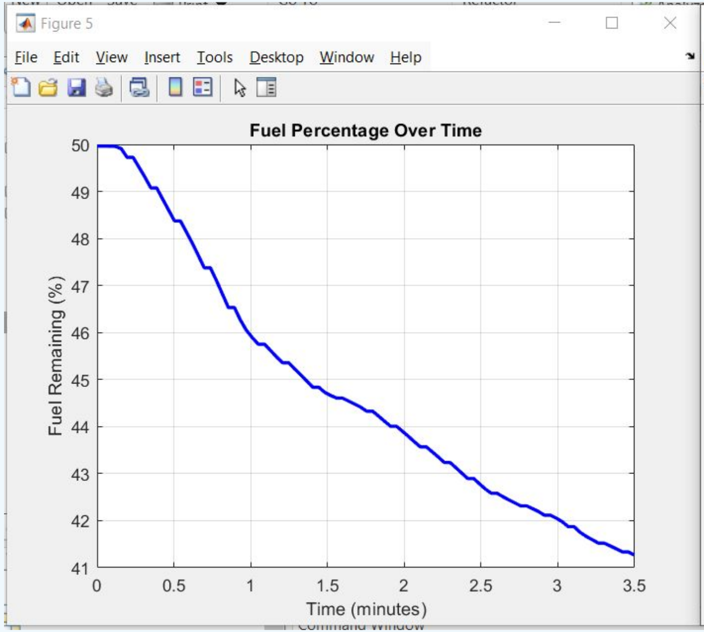
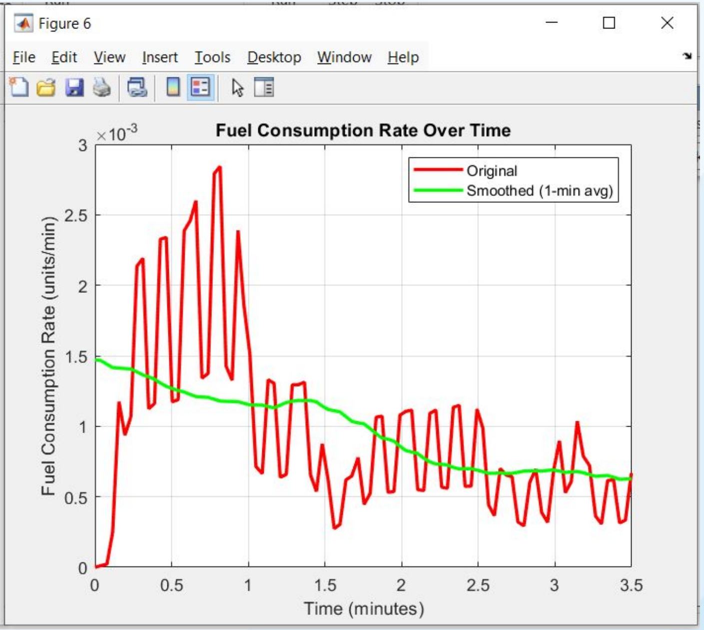
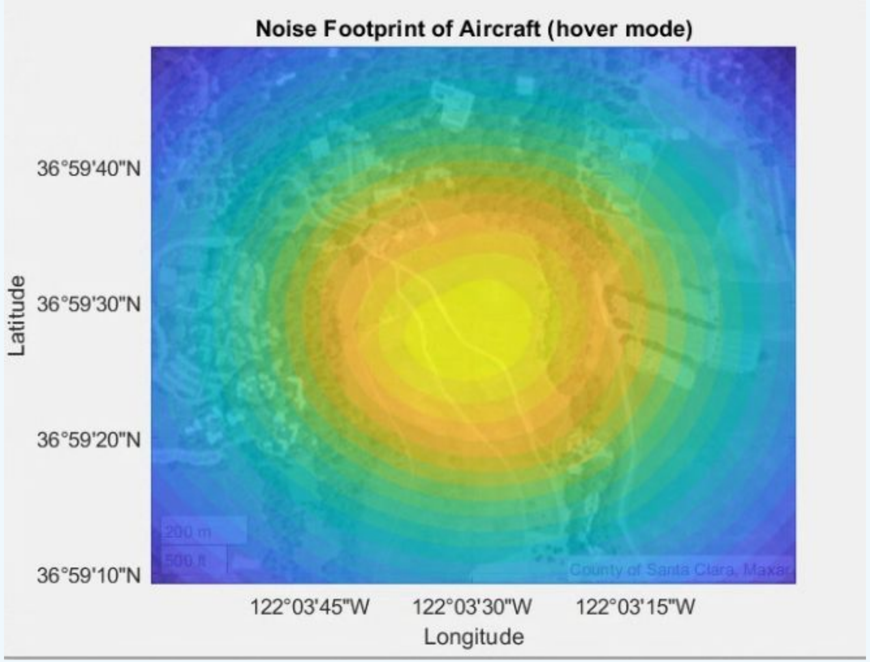
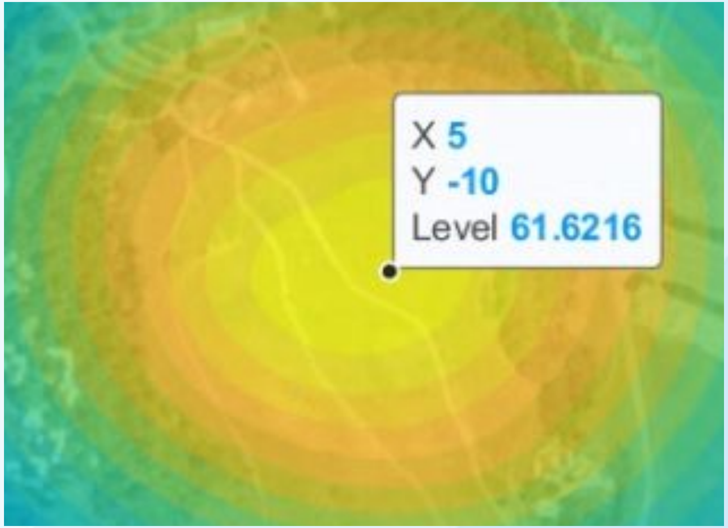
System Evaluation: Analysis



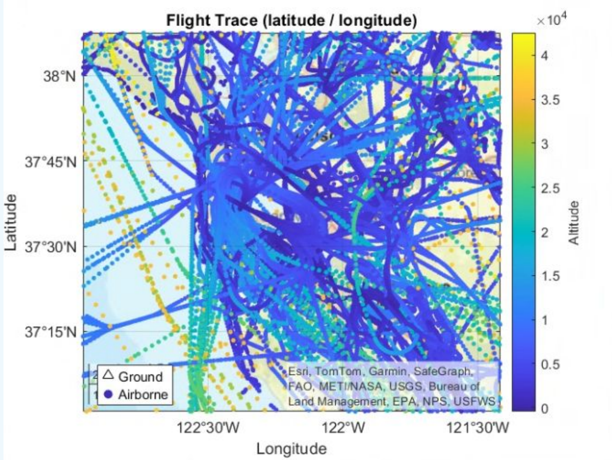


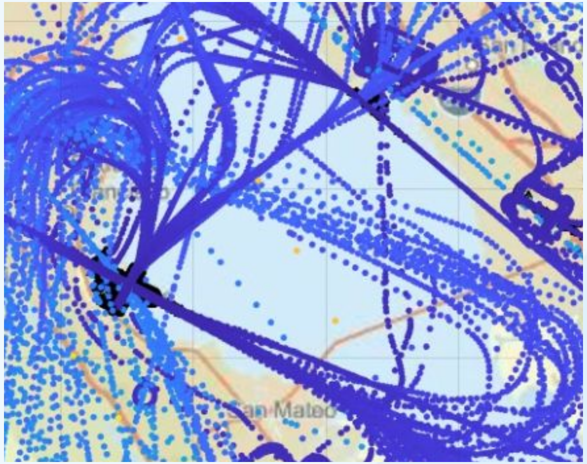
System Evaluation: Analysis

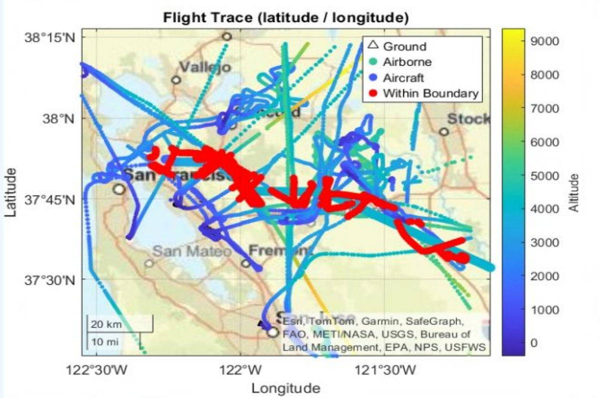


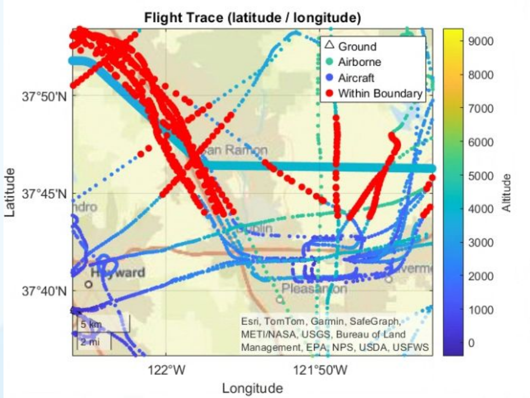


System Evaluation: Analysis









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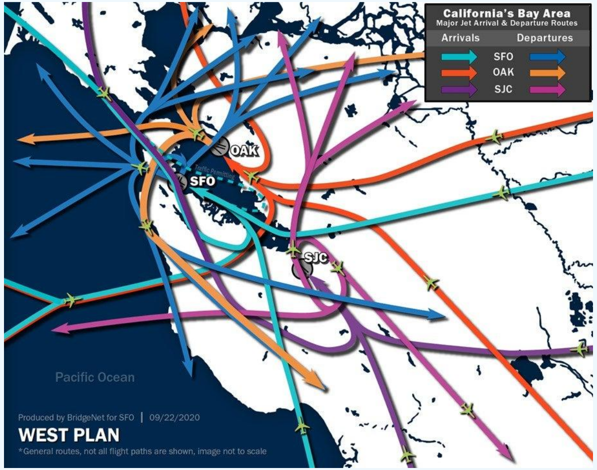
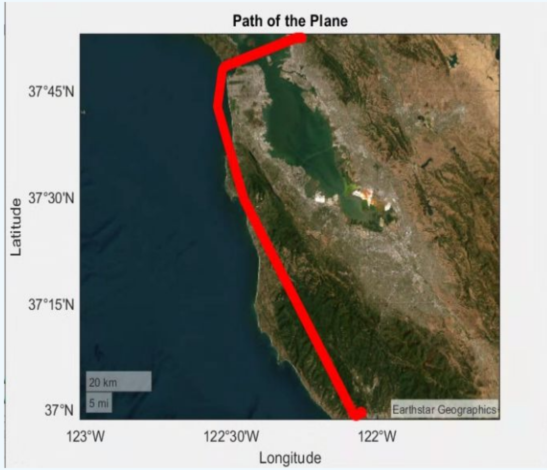
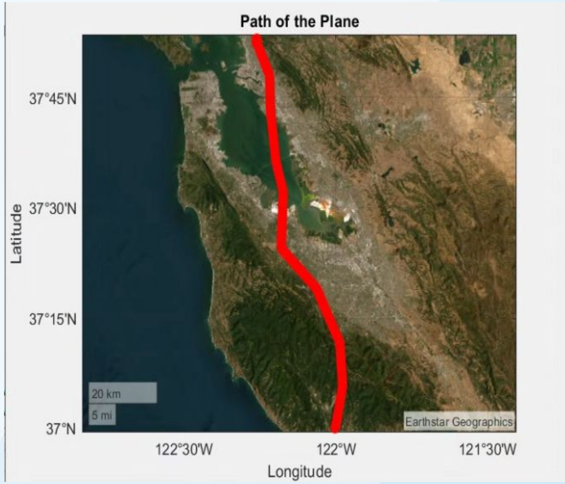
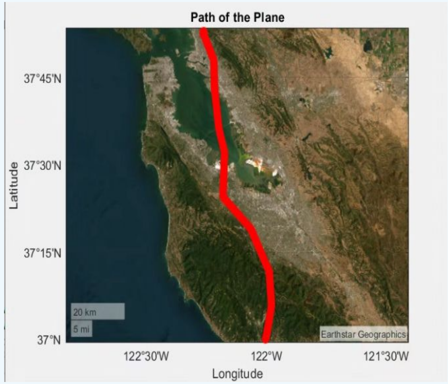
Routing

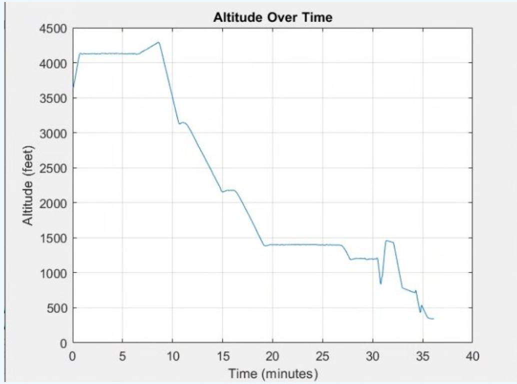

California's Bay Area
Major Jet Arrival & Departure Routes
Arrivals
Departures
SFO
OAK
SJC
Pacific Ocean
Produced by BridgeNet for SFO | 09/22/2020
WEST PLAN
*General routes, not all flight paths are shown, image not to scale

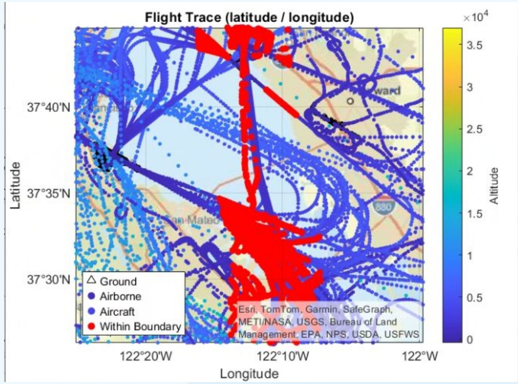

Path of the Plane
37°45'N
37°30'N
37°15'N
37°N
Latitude
123°W
122°30'W
122°W
Longitude
20 km
5 mi
Earthstar Geographics


Path of the Plane
37°45'N
37°30'N
37°15'N
37°N
Latitude
122°30'W
122°W
121°30'W
Longitude
20 km
5 mi
Earthstar Geographics

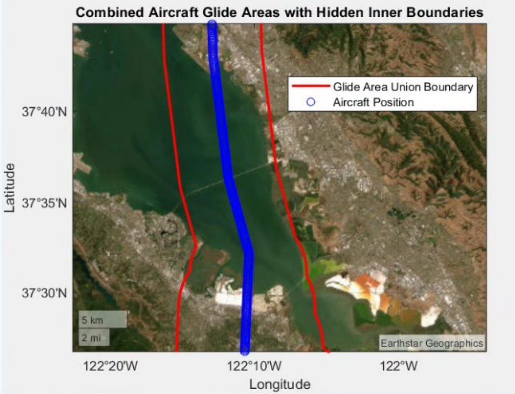
Routing

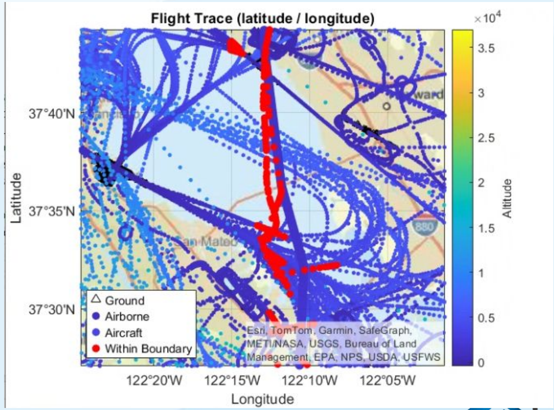

Path of the Plane
37°45'N
37°30'N
37°15'N
37°N
Latitude
20 km
5 mi
Earthstar Geographics
122°30'W
122°W
121°30'W
Longitude


Altitude Over Time
Altitude (feet)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
0
5
10
15
20
25
30
35
40
Time (minutes)

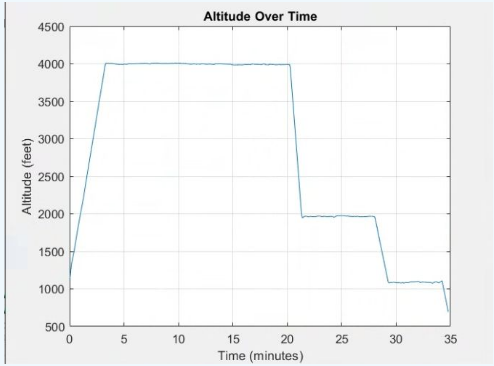

Flight Trace (latitude / longitude)
37°40'N
37°35'N
37°30'N
Latitude
Ground
Airborne
Aircraft
Within Boundary
Esri, TomTom, Garmin, SafeGraph, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, USFWS
122°20'W
122°10'W
122°W
Longitude
×10^4
3.5
3
2.5
2
1.5
1
0.5
0
Altitude

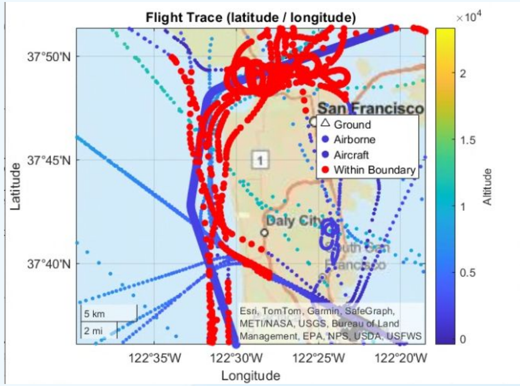

Combined Aircraft Glide Areas with Hidden Inner Boundaries
Glide Area Union Boundary
Aircraft Position
37°45'N
37°30'N
37°15'N
37°N
Latitude
20 km
10 mi
Earthstar Geographics
122°30'W
122°W
121°30'W
Longitude


Combined Aircraft Glide Areas with Hidden Inner Boundaries
Glide Area Union Boundary
Aircraft Position
37°40'N
37°35'N
37°30'N
Latitude
5 km
2 mi
Earthstar Geographics
122°20'W
122°10'W
122°W
Longitude


Flight Trace (latitude / longitude)
37°40'N
37°35'N
37°30'N
Latitude
Ground
Airborne
Aircraft
Within Boundary
Esri, TomTom, Garmin, SafeGraph, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USDA, USFWS
122°20'W
122°15'W
122°10'W
122°05'W
Longitude
×10^4
3.5
3
2.5
2
1.5
1
0.5
0
Altitude

Routing





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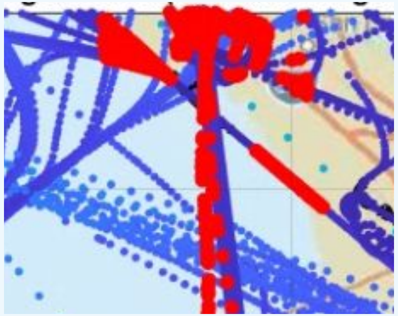
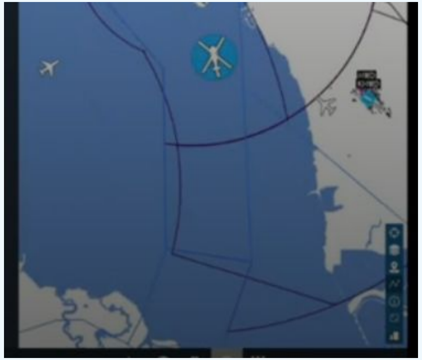
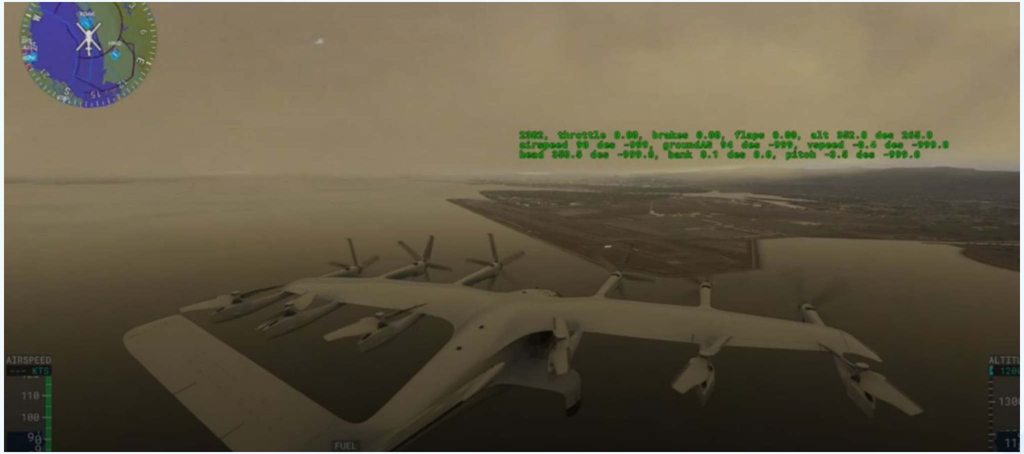
Scenic Scenarios

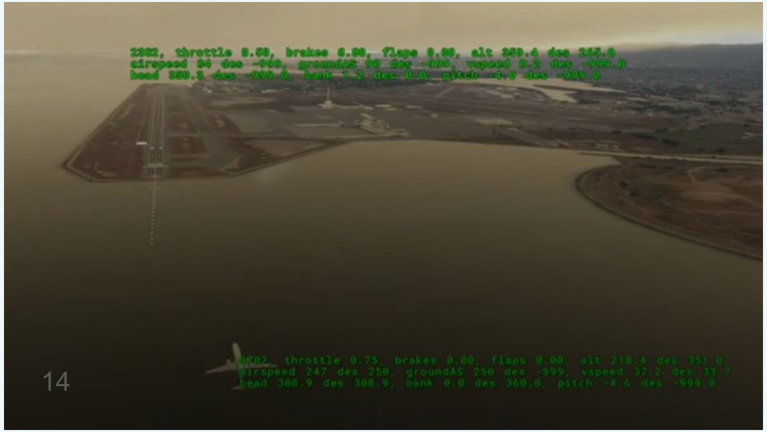




```
model scenic.simulators.msfs.model
import math

ego = new EgoAircraft at waypoint("VPMID", Range(800, 1400))

TYDYE = new Waypoint with waypoint_id "TYDYE", with alt 3000
TRUKN = new Waypoint with waypoint_id "TRUKN", with alt 5000, with speed 250

trukn2 = [TYDYE, TRUKN]

WUVON = new Waypoint with waypoint_id "WUVON", with alt 4100
MITOE = new Waypoint with waypoint_id "MITOE", with alt 2000, with speed 180
GO_AROUND = new Waypoint with lat 37.687960, with lon -122.192458, with alt 400
THREE_ZERO = new Waypoint with lat 37.702506, with lon -122.215325, with alt Range(800, 1400)

oak_30_arr = [WUVON, MITOE, GO_AROUND, THREE_ZERO]

a = new Plane737Max8Passengers at waypoint("FRNNY", 4100), with speed 210, with trajectory oak_30_arr
b = new Plane737Max8Passengers at spatial_position_to_euclidian(37.608353, -122.379887, 0), with trajectory trukn2, with ground 1
```

Scenic Scenarios





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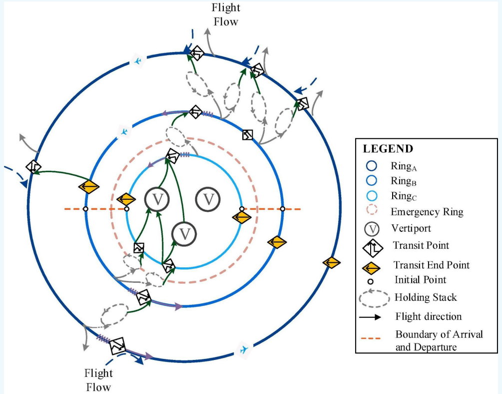
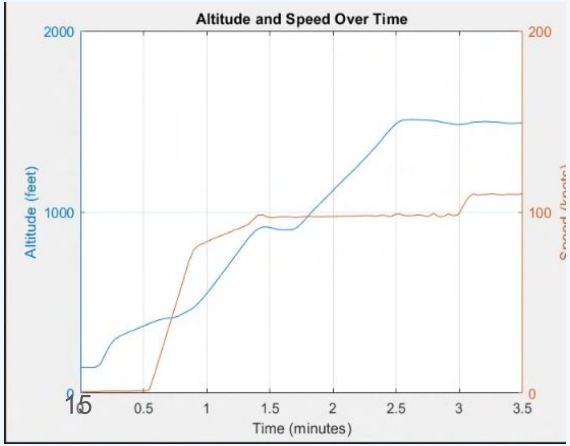
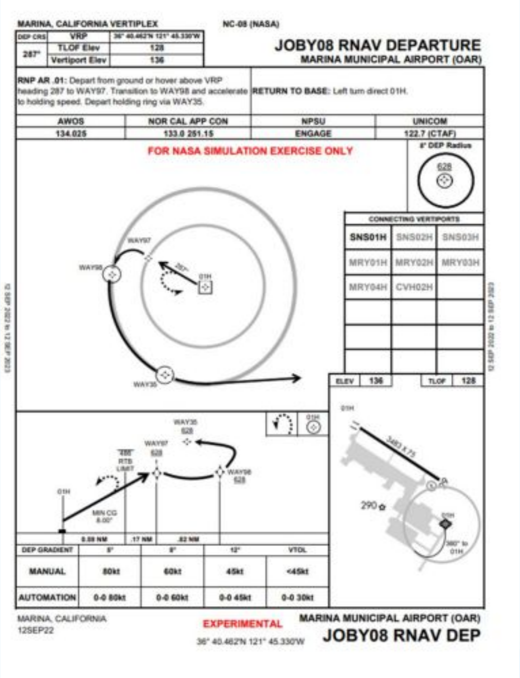
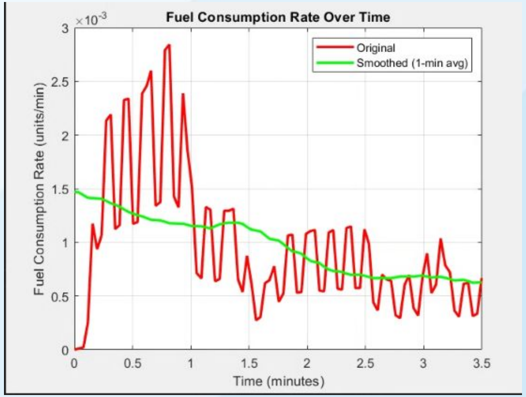
Terminal Procedures

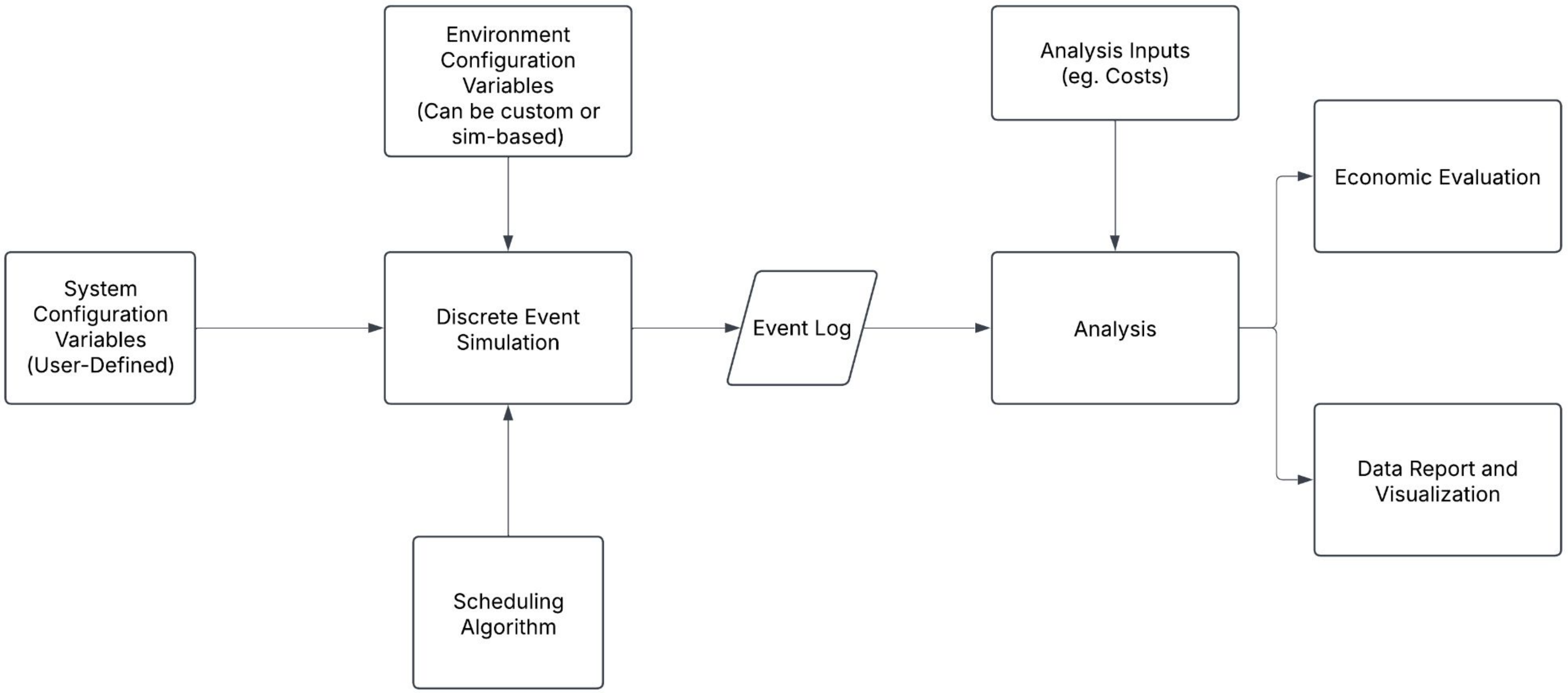








Scheduling System



Scheduling System

Vertiport Dataset Schema

Field Name	Data Type	Description
id_string	String	Unique 3-letter code identifying the vertiport
id_num	Integer	Unique numeric ID for the vertiport
capacity	Integer	Number of aircraft the vertiport can accommodate

Schema for Aircraft Distribution Starting State

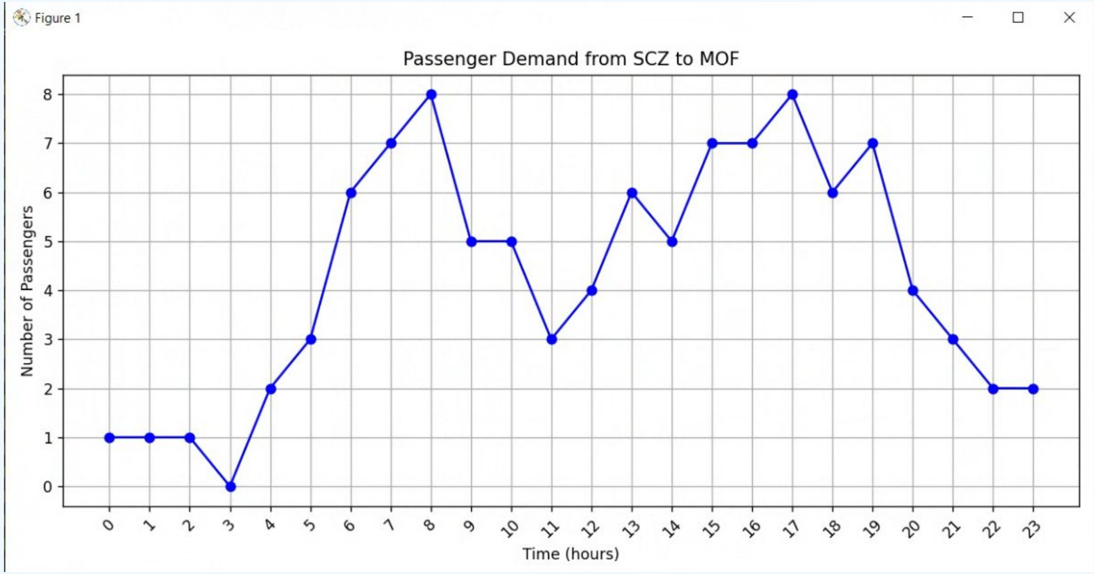
Field Name	Data Type	Description
Vertiport	String	Unique 3-letter code identifying the vertiport
# of aircraft in vertiport	Integer	Number of aircraft assigned to the vertiport
aircraft_id	Integer	Unique identifier for each aircraft
aircraft_capacity	Integer	Capacity of each aircraft

loc	dep_times
SCZ	00:00,01:10,02:20,03:30,04:40,05:50,07:00,08:10,09:20,10:30,11:40,12:50,14:00,15:10,16:20,17:30,18:40,19:50,21:00,22:10
MOF	00:10,01:20,02:30,03:40,04:50,06:00,07:10,08:20,09:30,10:40,11:50,13:00,14:10,15:20,16:30,17:40,18:50,20:00,21:10,22:20
BER	00:15,01:30,02:45,04:00,05:15,06:30,07:45,09:00,10:15,11:30,12:45,14:00,15:15,16:30,17:45,19:00,20:15,21:30,22:45,23:59
MER	00:05,01:25,02:45,04:05,05:25,06:45,08:05,09:25,10:45,12:05,13:25,14:45,16:05,17:25,18:45,20:05,21:25,22:45,23:30,23:59
DAV	00:30,01:45,03:00,04:15,05:30,06:45,08:00,09:15,10:30,11:45,13:00,14:15,15:30,16:45,18:00,19:15,20:30,21:45,23:00,23:59

```
5
SCZ,1,4
MOF,2,4
BER,3,4
MER,4,4
DAV,5,4
```

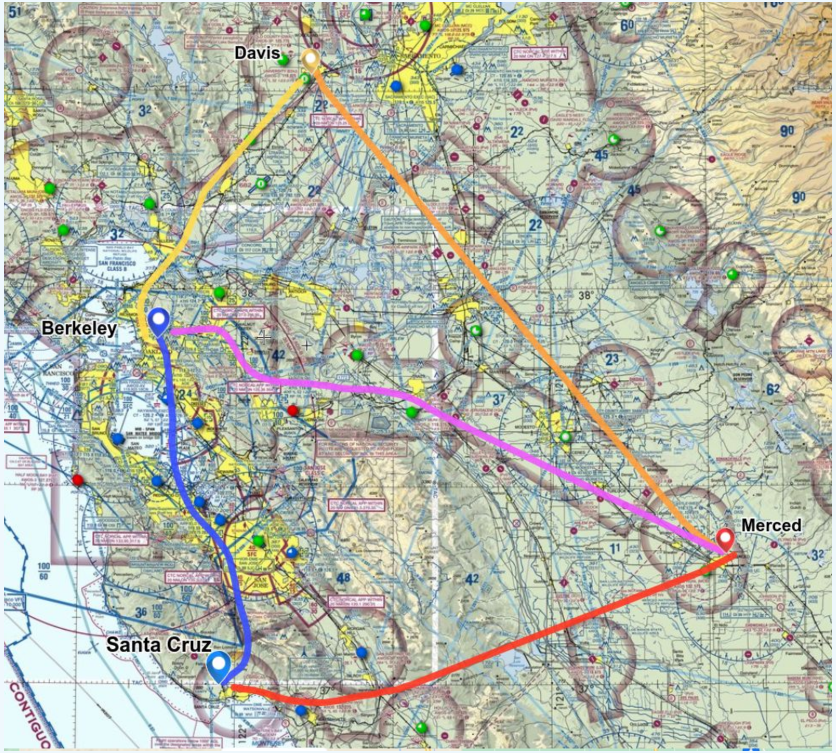
```
15
SCZ,2
1,4
2,4
MOF,4
3,4
4,4
5,4
6,4
BER,1
7,4
MER,3
8,4
9,4
10,4
DAV,5
11,4
12,4
13,4
14,4
15,4
```

Scheduling System



src	dest	hourlyPassengers
SCZ	MOF	[1,1,1,0,2,3,6,7,8,5,5,3,4,6,5,7,7,8,6,7,4,3,2,2]
SCZ	BER	[0,1,2,1,0,3,5,9,8,8,7,5,6,5,4,6,9,7,5,4,5,4,1,1]
SCZ	MER	[1,0,1,1,3,5,6,9,7,6,7,6,3,3,4,5,9,7,8,4,5,2,0,1]
SCZ	DAV	[0,0,0,2,1,3,5,7,9,5,6,4,6,4,7,8,8,9,5,6,5,3,1,0]
MOF	SCZ	[1,0,2,1,3,5,6,7,9,5,4,3,3,5,4,8,8,7,7,4,5,3,2,0]
MOF	BER	[0,0,1,2,1,3,5,8,8,8,7,3,3,3,4,7,8,9,6,5,3,1,0,0]
MOF	MER	[1,0,2,1,0,3,7,9,9,6,5,4,6,3,5,5,7,9,8,5,3,1,1,0]
MOF	DAV	[0,1,0,0,2,4,6,8,8,5,4,6,3,5,6,5,9,8,7,6,4,2,0,1]
BER	SCZ	[1,1,2,0,1,3,6,7,7,6,4,3,5,4,6,5,8,9,7,6,4,1,2,1]
BER	MOF	[0,1,2,2,3,3,5,9,7,6,5,6,3,3,7,5,7,9,8,7,3,4,2,1]
BER	MER	[0,0,2,0,1,3,6,9,7,6,7,6,4,3,4,8,8,7,7,5,4,2,2,0]
BER	DAV	[1,1,1,2,2,3,7,8,8,5,7,4,4,6,4,6,7,8,6,7,5,4,2,1]
MER	SCZ	[0,1,2,1,3,4,7,9,8,7,5,3,3,4,6,8,7,8,5,4,5,4,1,0]
MER	MOF	[1,1,2,2,1,5,6,8,9,7,6,4,5,5,4,7,9,9,5,6,4,1,0,2]
MER	BER	[1,0,2,0,1,3,7,8,9,6,5,3,4,5,5,5,7,8,6,7,3,1,2,2]
MER	DAV	[0,1,2,1,0,4,5,9,9,8,6,6,5,3,4,5,8,7,5,4,3,2,1,1]
DAV	SCZ	[0,0,2,1,3,5,7,8,9,6,7,6,3,5,4,5,9,8,6,7,3,1,0,0]
DAV	MOF	[1,1,2,1,2,5,7,8,9,5,6,4,3,6,5,8,8,7,5,5,3,1,2,1]
DAV	BER	[1,0,2,1,0,3,5,7,9,8,7,3,4,5,6,8,9,7,5,6,4,3,2,1]
DAV	MER	[0,1,1,1,2,3,6,9,8,7,5,4,5,6,6,7,9,8,5,6,4,2,1,0]

Scheduling System




```
src,dest,transportTime
SCZ,MOF,13
SCZ,BER,32
SCZ,MER,48
SCZ,DAV,72
MOF,SCZ,15
MOF,BER,14
MOF,MER,36
MOF,DAV,42
BER,SCZ,35
BER,MOF,18
BER,MER,45
BER,DAV,26
MER,SCZ,43
MER,MOF,38
MER,BER,50
MER,DAV,67
DAV,SCZ,67
DAV,MOF,45
DAV,BER,25
DAV,MER,49
```

Scheduling System

```
time,event_type,join_id,data
0,aircraftinit,1,SCZ
0,aircraftinit,2,SCZ
0,aircraftinit,3,MOF
0,aircraftinit,4,MOF
0,aircraftinit,5,MOF
0,aircraftinit,6,MOF
0,aircraftinit,7,MOF
0,aircraftinit,8,MOF
0,aircraftinit,9,MOF
0,aircraftinit,10,MOF
0,aircraftinit,11,MOF
0,aircraftinit,12,MOF
0,aircraftinit,14,BER
0,aircraftinit,15,MER
0,aircraftinit,16,MER
0,aircraftinit,17,MER
14.624794191741007,passengerbook,210,SCZ MER
19.129954663541,passengerbook,1122,BER DAV
26.66459639578306,passengerbook,814,BER SCZ
28.931026635916442,passengerbook,1749,DAV MOF
29.624794191741007,aircraftdeparture,1,1 SCZ MER 49.0 90.0 1
29.624794191741007,passengerdeparture,210,SCZ MER 49.0
34.129954663541,aircraftdeparture,2,14 BER DAV 80.0 90.0 1
34.129954663541,passengerdeparture,1122,BER DAV 80.0
38.75085966295568,passengerbook,1445,MER BER
47.33249331751791,passengerbook,1,SCZ MOF
49.76690505927268,passengerbook,1336,MER MOF
53.75085966295568,aircraftdeparture,3,15 MER BER 33.0 90.0 1
53.75085966295568,passengerdeparture,1445,MER BER 33.0
57.406561709031934,passengerbook,614,MOF MER
57.43850227995671,passengerbook,1854,DAV BER
57.696528931634965,passengerbook,417,MOF SCZ
60.58871428172766,passengerbook,1123,BER DAV
62.33249331751791,aircraftdeparture,4,2 SCZ MOF 20.0 90.0 1
62.33249331751791,passengerdeparture,1,SCZ MOF 20.0
64.76690505927269,aircraftdeparture,5,16 MER MOF 89.0 90.0 1
```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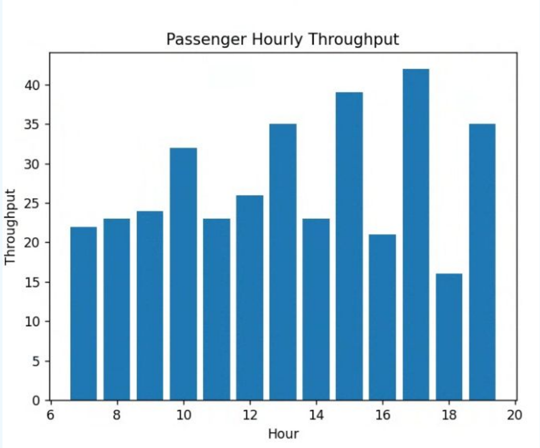
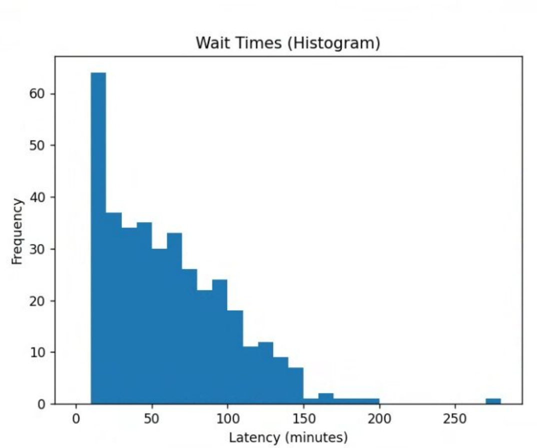
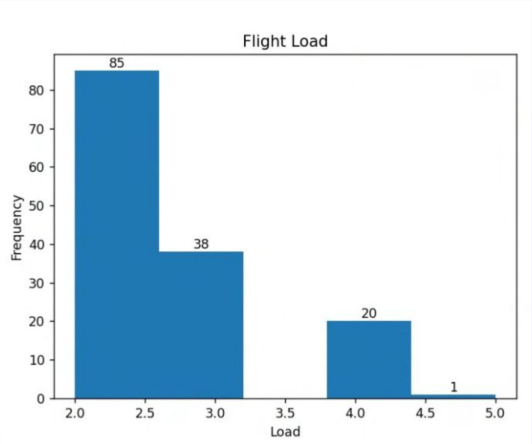
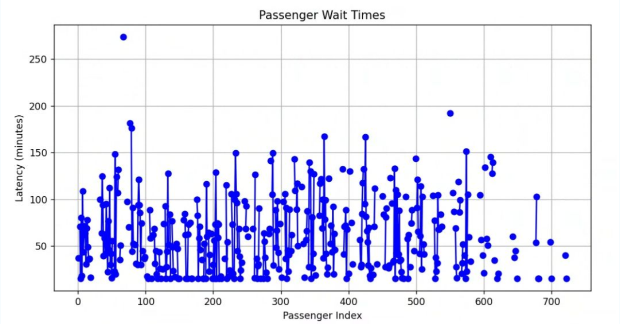
Scheduling System










```
Mean Flight Capacity: 2.5625
Std Flight Capacity: 0.7520227353241685
```

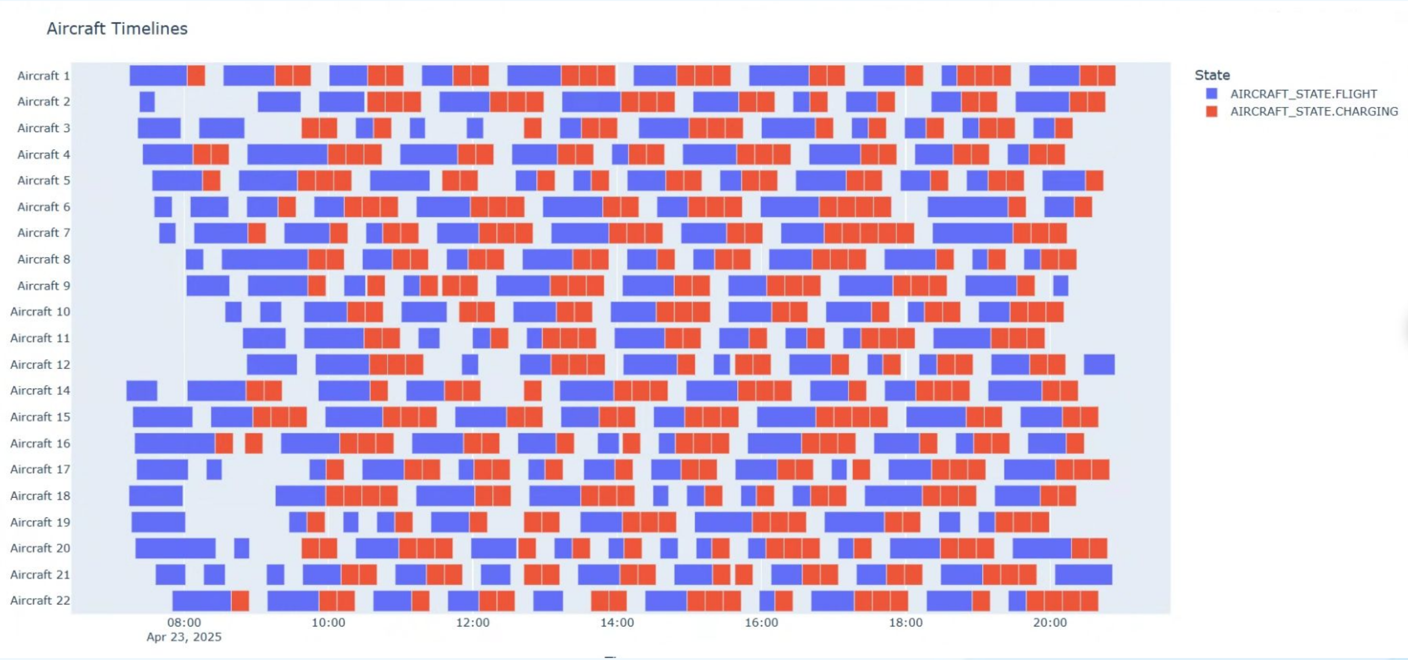
```
Number of Stranded Passengers: 21
Percentage of Stranded Passengers: 5.49738219895288%
Number of Standard Passengers (Waiting for longer than 3 hours): 0
```

```
Average Latency: 59.48958136516817, Total Number of Passengers: 382
Average Throughput: 19.0 passengers/hour
Passenger Book Rate: 21.22222222222222 passengers/hour
```



```
--- Fleet-Wide Average Proportions ---
{'STATIONARY': 0.3104848852381858, 'FLIGHT': 0.4268964207668418, 'CHARGING': 0.2626186939949724 5}
```

Scheduling System



Scheduling System

```
item,cost,unit,useful_life
joby_vehicle,2200000,plane,10
archer_vehicle,5000000,plane,10
joby_charger,100000,charger,5
archer_charger,200000,charger,5
training_simulator,500000,simulator,5
hangar,1000000,hangar,20
ground_vehicle,50000,vehicle,10
it_infrastructure,200000,infrastructure,5
r_and_d,1000000,year,1
```

```
item,cost,unit
energy_cost,0.35,kwh
pilot_salary,100000,person_year
pilot_training,20000,year
flight_operations_salary,75000,person_year
ground_operations_salary,60000,person_year
landing_fees,200,flight
maintenance,100000,aircraft_year
insurance,20000,aircraft_year
general_and_adminstrative,300000,year
sales_and_marketing,400000,year
legal_and_compliance,100000,year
software_and_systems,500000,year
spare_parts,50000,year
taxes,0.11,dollar
```

Scheduling System

```
src,dest,ticket_price
SCZ,MOF,20
SCZ,BER,37
SCZ,MER,49
SCZ,DAV,72
MOF,SCZ,17
MOF,BER,14
MOF,MER,44
MOF,DAV,19
BER,SCZ,29
BER,MOF,48
BER,MER,70
BER,DAV,80
MER,SCZ,52
MER,MOF,89
MER,BER,33
MER,DAV,67
DAV,SCZ,61
DAV,MOF,16
DAV,BER,25
DAV,MER,49
```

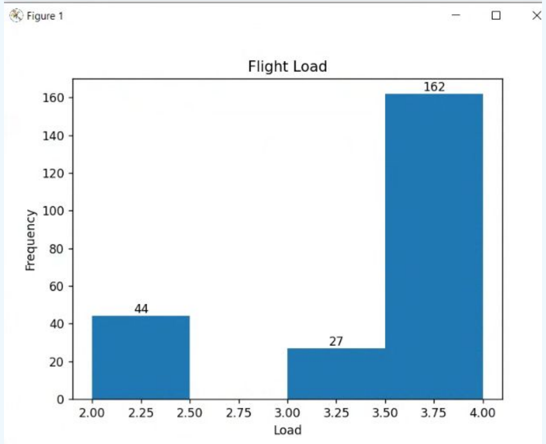
```
Data folder location: ../data/financial/
Total Flights: 233
Total Passengers: 817
Cost per Flight: $213.76
Cost per Passenger: $60.96
Revenue per Flight: $136.25
Revenue per Passenger: $38.86
Annual Revenue: $11,587,290.00
Annual Operating Costs (before Depreciation): $30,198,934.50
Annual Depreciation: $1,975,000.00
EBIT: $-20,586,644.50
Taxes Paid: $0.00
Net Income: $-20,586,644.50
```

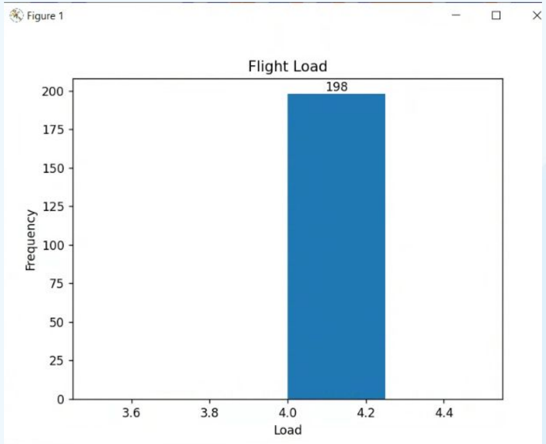
Scheduling System

```
src,dest,ticket_price
SCZ,MOF,67
SCZ,BER,123
SCZ,MER,163
SCZ,DAV,240
MOF,SCZ,57
MOF,BER,47
MOF,MER,147
MOF,DAV,63
BER,SCZ,97
BER,MOF,160
BER,MER,233
BER,DAV,267
MER,SCZ,173
MER,MOF,297
MER,BER,110
MER,DAV,223
DAV,SCZ,203
DAV,MOF,53
DAV,BER,83
DAV,MER,163
```

```
Data folder location: ../data/financial/
Total Flights: 233
Total Passengers: 817
Cost per Flight: $213.76
Cost per Passenger: $60.96
Revenue per Flight: $454.40
Revenue per Passenger: $129.59
Annual Revenue: $38,644,740.00
Annual Operating Costs (before Depreciation): $30,198,934.50
Annual Depreciation: $1,975,000.00
EBIT: $6,470,805.50
Taxes Paid: $711,788.60
Net Income: $5,759,016.89
```

Scheduling System






```
Data folder location: ../data/financial/
Total Flights: 233
Total Passengers: 817
Cost per Flight: $213.76
Cost per Passenger: $60.96
Revenue per Flight: $136.25
Revenue per Passenger: $38.86
Annual Revenue: $11,587,290.00
Annual Operating Costs (before Depreciation): $30,198,934.50
Annual Depreciation: $1,975,000.00
EBIT: $-20,586,644.50
Taxes Paid: $0.00
Net Income: $-20,586,644.50
```

```
Total Flights: 201
Total Passengers: 804
Cost per Flight: $215.31
Cost per Passenger: $53.83
Revenue per Flight: $155.26
Revenue per Passenger: $38.82
Annual Revenue: $11,390,920.00
Annual Operating Costs (before Depreciation): $27,816,050.25
Annual Depreciation: $1,975,000.00
EBIT: $-18,400,130.25
Taxes Paid: $0.00
Net Income: $-18,400,130.25
```

Conclusion

Key Points

- Use High-Fidelity Simulation to capture essential aircraft data to inform analysis systems
- Make analysis components interchangeable for differing models and equations
- Use analysis programs to evaluate proposed routes, terminal procedures, and scheduling systems
- Use Scenic for particular scenarios requiring thorough investigation for safety and efficiency

Thank You