Flight Simulator Suite

User-Admin Manual
Spring 2014

Team members:

Chris Ek
Stephanie Stumpos
Michael Marinetti

Table of Contents:

1. User Manual

This User Manual is geared towards helping people use and understand the various components that make up the Flight Simulator Suite.

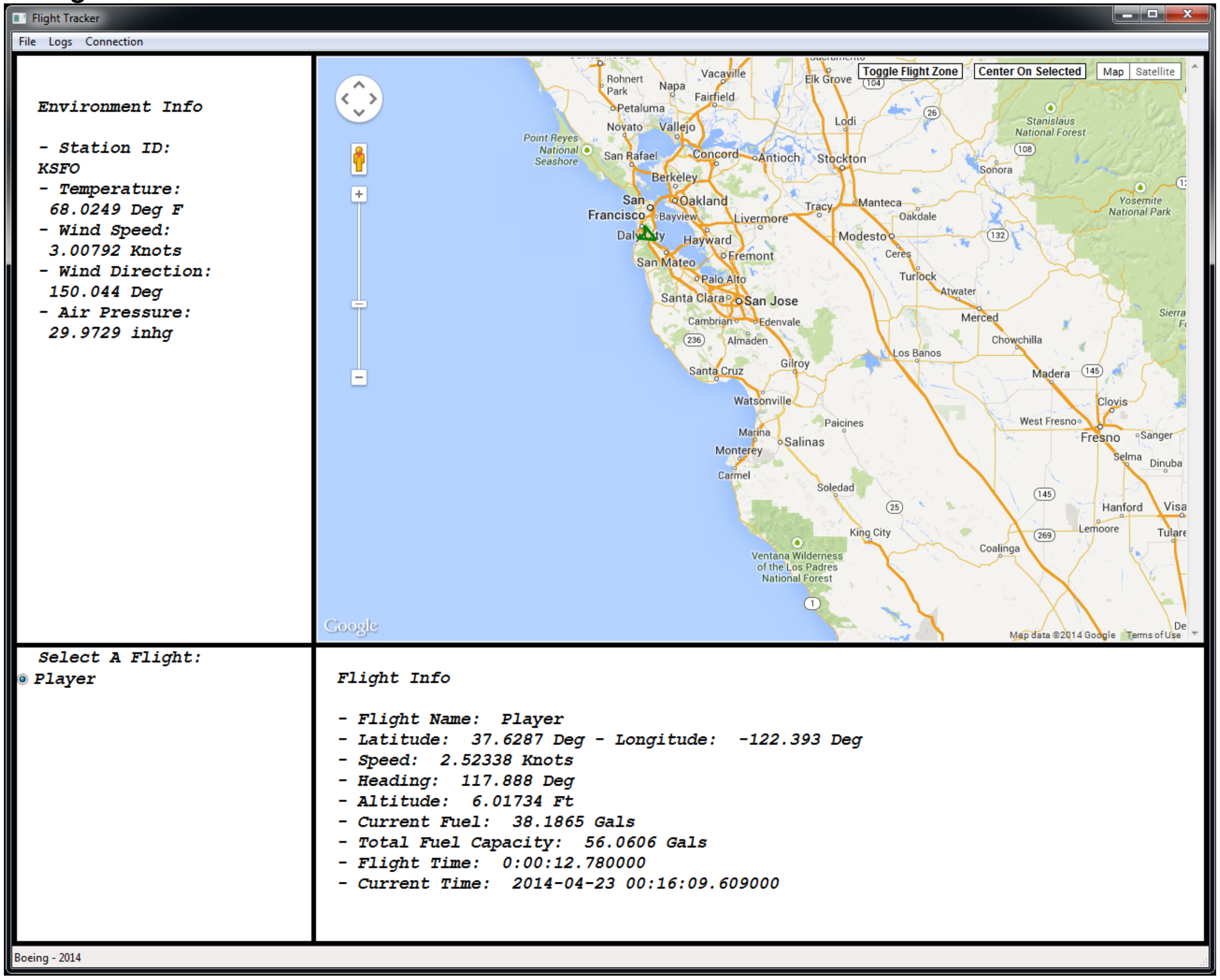
2. FlightGear

FlightGear is an open source flight simulator that is freely available on the internet. It has been developed over the years by many skilled people and has accumulated a strong following. As a result of its popularity, there are many places online to find the support necessary to run and use this program.

This is a link to FlightGear's official website: http://www.flightgear.org/. Here anyone can download the game along with any extras that they might desire such as more plane models or scenery.

Here is the link to the wiki for FlightGear: http://wiki.flightgear.org/Main_Page. The community behind this flight simulator keeps the wiki updated with useful information.

3. FlightTracker



Environment Info

- Station ID:
KSFO
- Temperature:
68.0249 Deg F
- Wind Speed:
3.00792 Knots
- Wind Direction:
150.044 Deg
- Air Pressure:
29.9729 inhg

Select A Flight:
● Player

Flight Info

- Flight Name: Player
- Latitude: 37.6287 Deg - Longitude: -122.393 Deg
- Speed: 2.52338 Knots
- Heading: 117.888 Deg
- Altitude: 6.01734 Ft
- Current Fuel: 38.1865 Gals
- Total Fuel Capacity: 56.0606 Gals
- Flight Time: 0:00:12.780000
- Current Time: 2014-04-23 00:16:09.609000

This is FlightTracker. This program helps to extend the capabilities of FlightGear through the use of open message queueing. FlightTracker displays information obtained from FlightGear.

3.1 Necessary Downloads and Setup

In order to run FlightTracker, certain steps must be taken. These steps include downloading additional software and following certain procedures to set up said software.

3.1.1 Downloads

Follow these download steps to ensure you have what is required to run FlightTracker:

*Install Python2.7 from this link:
 -https://www.python.org/downloads/

*Edit your computer's environment variables by adding the python path
 -Follow instructions at this link: http://www.pythoncentral.io/add-python-to-path-python-is-not-recognized-as-an-internal-or-external-command/

*Restart the computer

*Install ActiveMQ if you haven't already
 -Follow this link: http://activemq.apache.org/
 -install activemq 5.9.0

*Install Stompy
 -Follow this link: https://pypi.python.org/pypi/stompy
 -click the green download button
 -unzip the folder
 -from the command line navigate to the folder you just unzipped
 -make sure the file 'setup.py' is there
 -enter this into the command line: python setup.py install
  - This should install the Stomp library for python

*wxPython (for python2.7)
 -Follow this link: http://www.wxpython.org/download.php#msw
 -download the version for python2.7

3.1.2 Setup

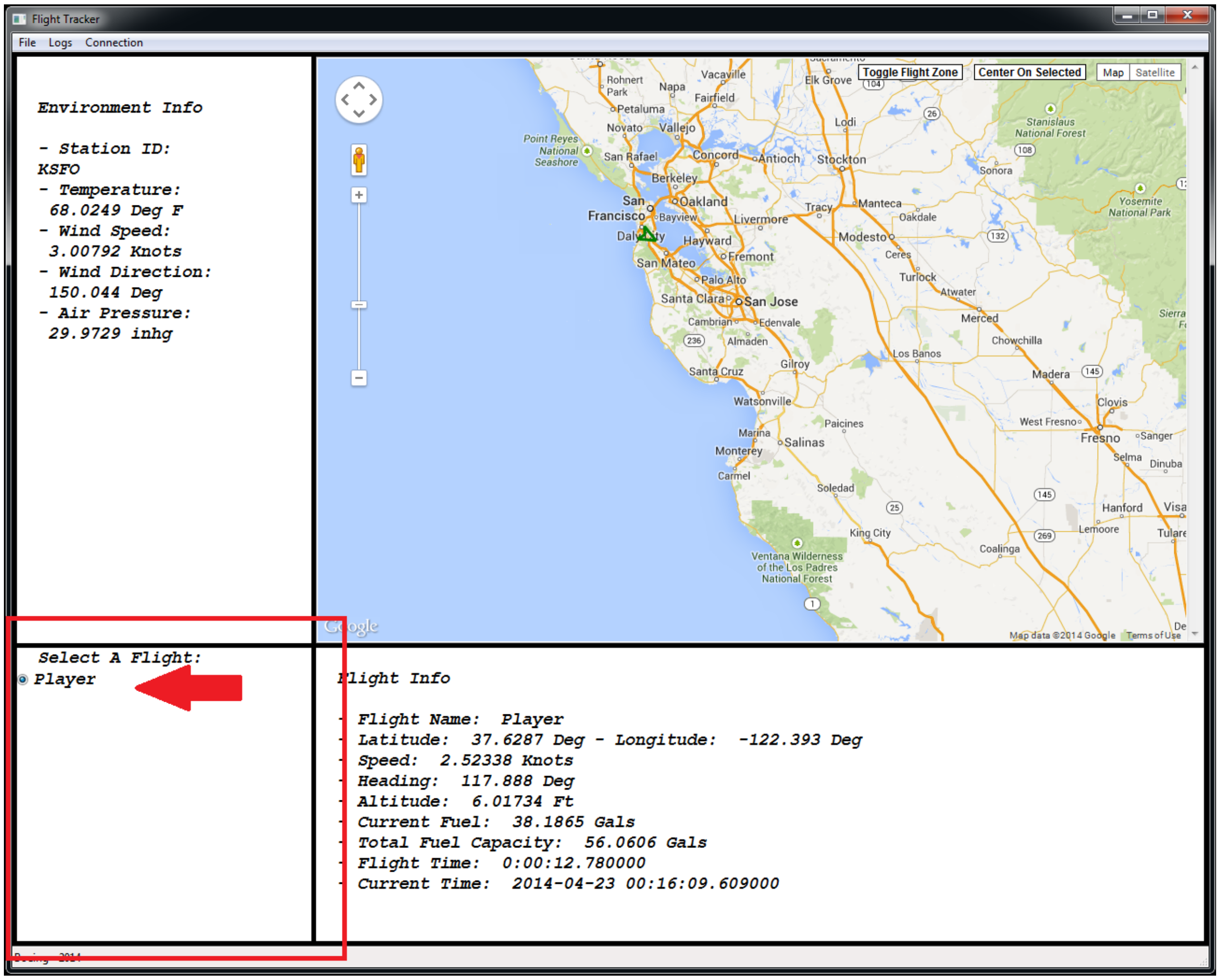
In order to run FlightTracker you must have the ActiveMQ broker running. A connection to the broker is required for FlightTracker to function. To start the broker just:

- navigate to the ActiveMQ folder that was created when you installed ActiveMQ
- entering the 'bin' folder and double click the file 'activemq'
- this should start up a command prompt window with the broker running in it

After starting the broker, you may now start FlightTracker by executing the python file: FlightTracker.py. It is recommended that an instance of FlightGear also be running concurrently so that useful information will actually be displayed by FlightTracker.

3.2 ‘Select A Flight’ Panel

This panel displays all of the active flights in the instance of FlightGear. You, the main player, are listed as ‘Player’. Here you may select any flight in order to make it the currently selected flight.



Environment Info

- Station ID:
KSFO
- Temperature:
68.0249 Deg F
- Wind Speed:
3.00792 Knots
- Wind Direction:
150.044 Deg
- Air Pressure:
29.9729 inhg

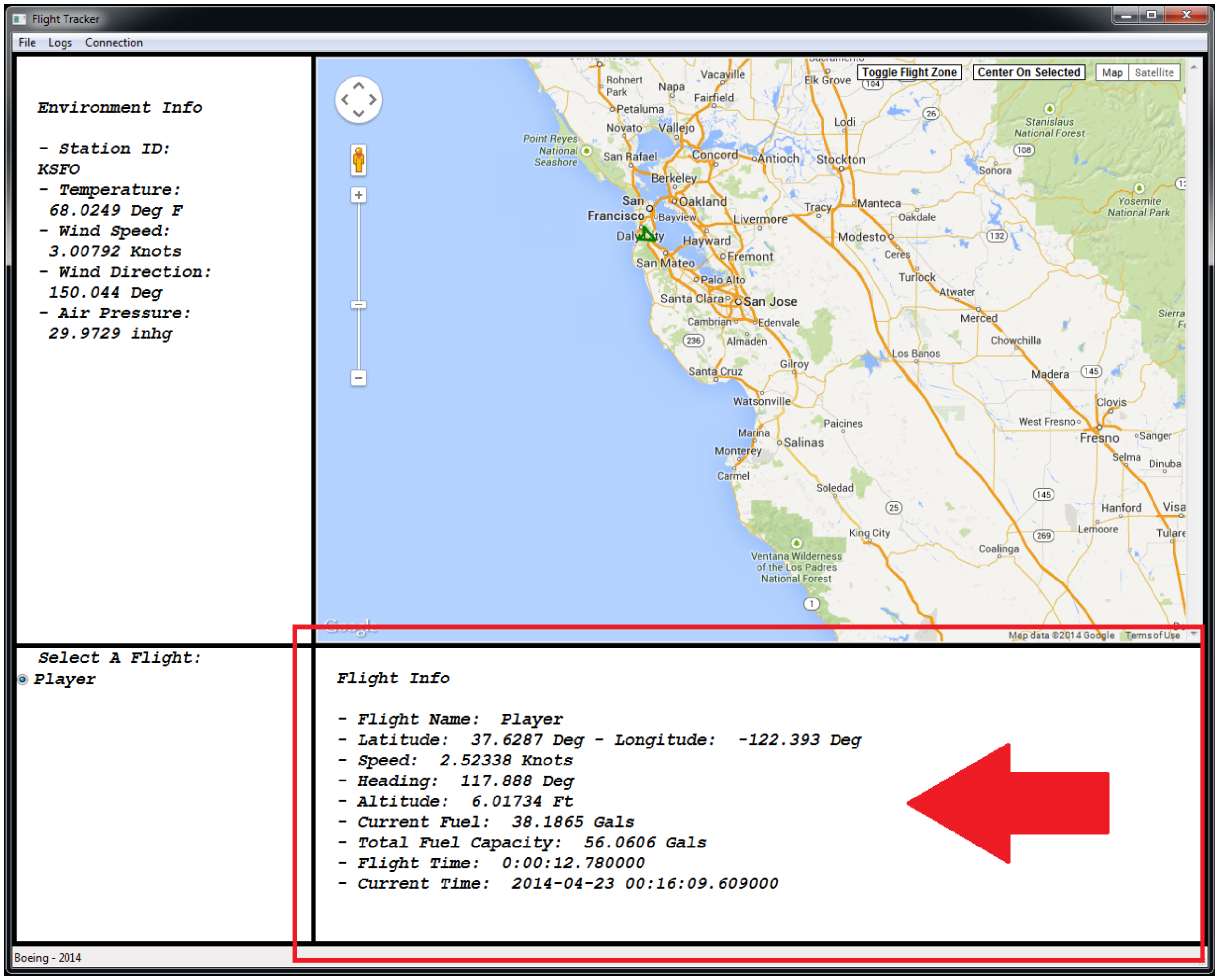
Select A Flight:
● Player

Flight Info

- Flight Name: Player
- Latitude: 37.6287 Deg - Longitude: -122.393 Deg
- Speed: 2.52338 Knots
- Heading: 117.888 Deg
- Altitude: 6.01734 Ft
- Current Fuel: 38.1865 Gals
- Total Fuel Capacity: 56.0606 Gals
- Flight Time: 0:00:12.780000
- Current Time: 2014-04-23 00:16:09.609000

3.3 'Flight Info' Panel

This panel displays all of the flight information from the currently selected flight including flight speed, orientation, and position. The currently selected flight can be changed by selecting a different flight from the 'Select A Flight' panel.



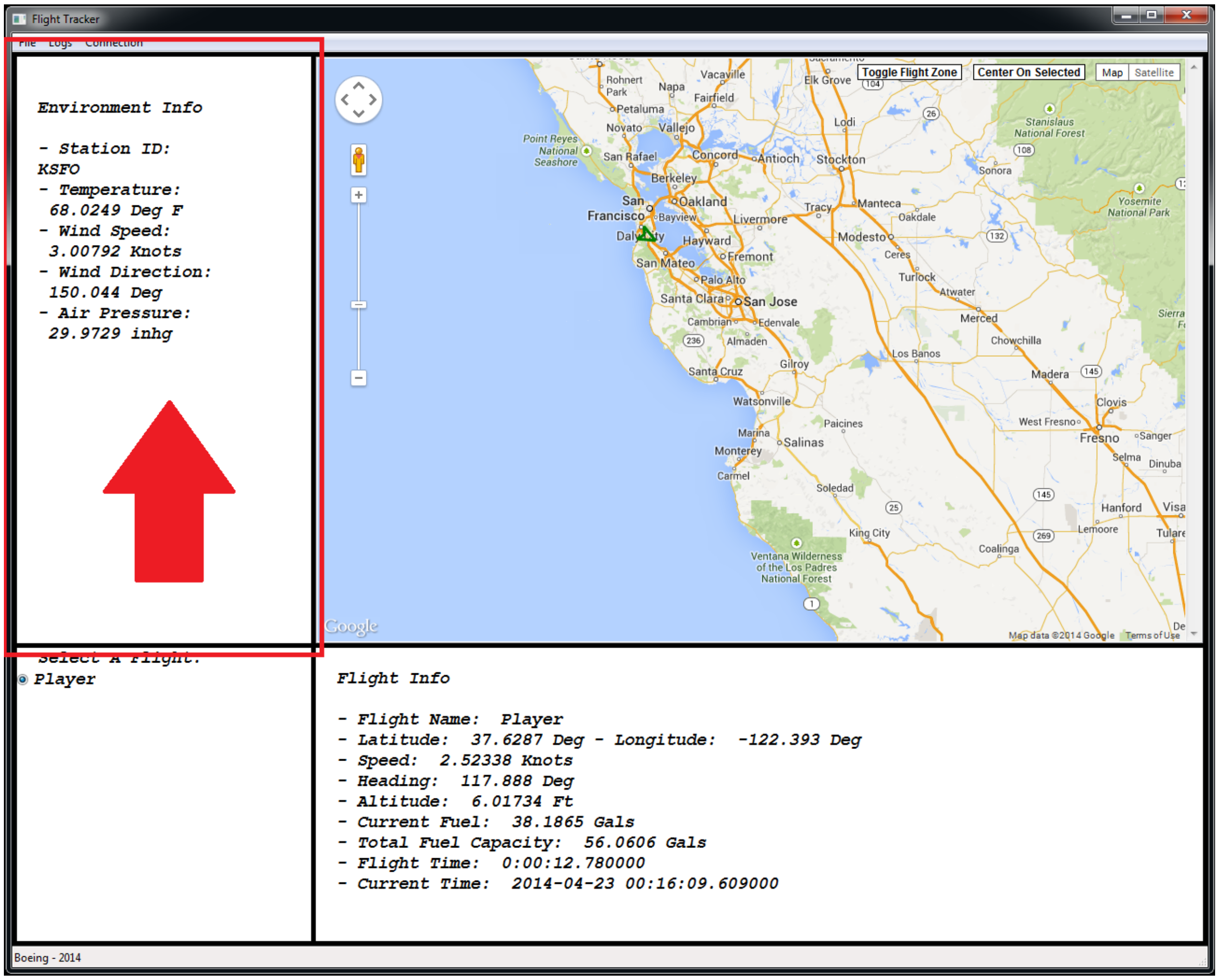
```
Environment Info

- Station ID:
KSFO
- Temperature:
 68.0249 Deg F
- Wind Speed:
 3.00792 Knots
- Wind Direction:
 150.044 Deg
- Air Pressure:
 29.9729 inhg
```

```
Select A Flight:
Player
```

```
Flight Info

- Flight Name:  Player
- Latitude:  37.6287 Deg - Longitude:  -122.393 Deg
- Speed:  2.52338 Knots
- Heading:  117.888 Deg
- Altitude:  6.01734 Ft
- Current Fuel:  38.1865 Gals
- Total Fuel Capacity:  56.0606 Gals
- Flight Time:  0:00:12.780000
- Current Time:  2014-04-23 00:16:09.609000
```

3.3 ‘Environment Info’ Panel

This panel displays weather information for the surrounding environment from your flight’s perspective. This information will change based on the position of your flight. Information that is displayed includes wind speed, temperature, and air pressure.



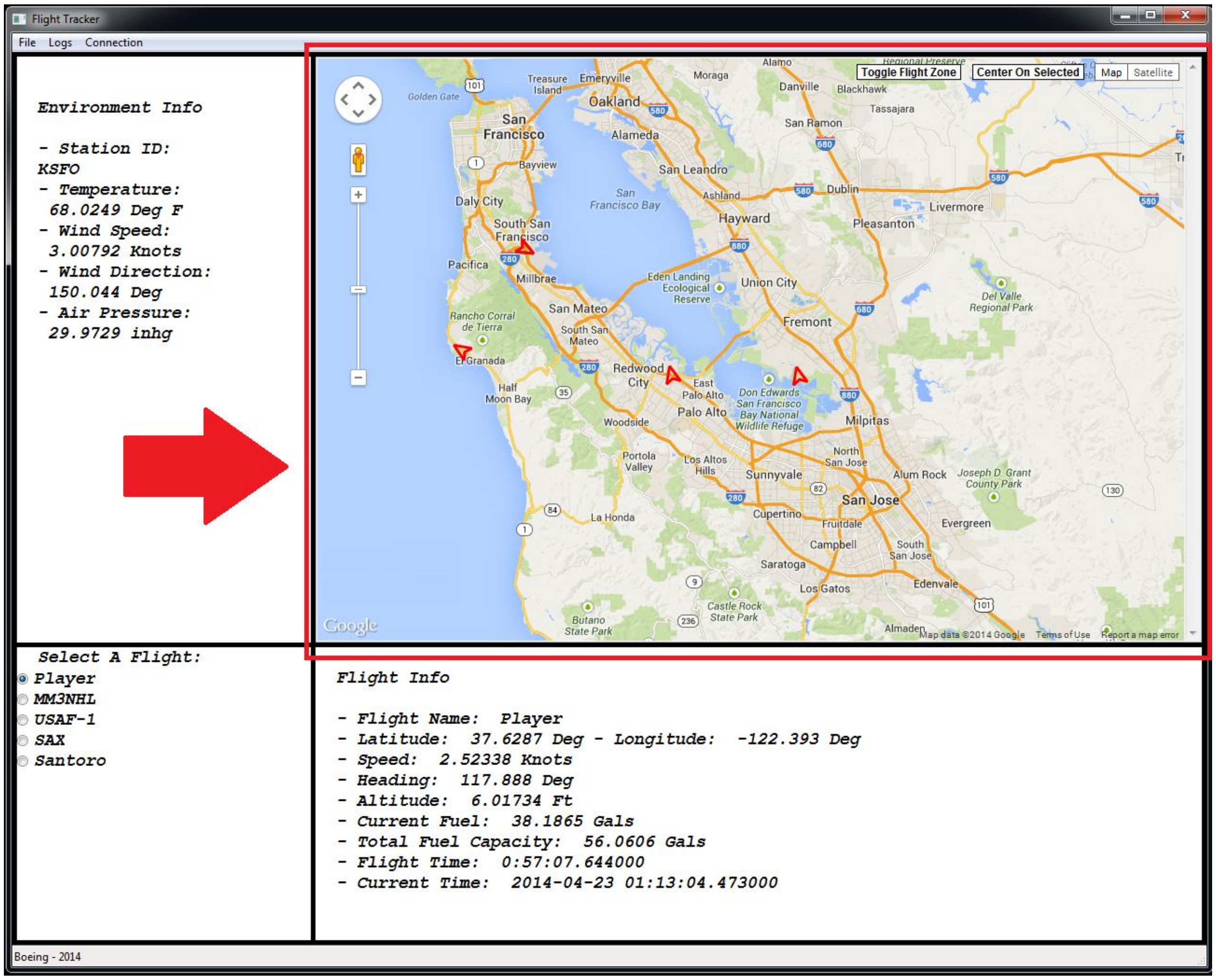
```
Environment Info

- Station ID:
KSFO
- Temperature:
 68.0249 Deg F
- Wind Speed:
 3.00792 Knots
- Wind Direction:
 150.044 Deg
- Air Pressure:
 29.9729 inhg
```

```
Select A Flight:
Player
```

```
Flight Info

- Flight Name:  Player
- Latitude:  37.6287 Deg - Longitude:  -122.393 Deg
- Speed:  2.52338 Knots
- Heading:  117.888 Deg
- Altitude:  6.01734 Ft
- Current Fuel:  38.1865 Gals
- Total Fuel Capacity:  56.0606 Gals
- Flight Time:  0:00:12.780000
- Current Time:  2014-04-23 00:16:09.609000
```

3.4 The Map Panel

This panel takes all of the flight information for all active flights in FlightGear, and uses the information to display the flights on a map. This is a Google map and can be treated as such. The capabilities of the map include the capabilities of any standard Google map. Flights will be displayed as markers on the map and will change position and orientation as their flight info is updated.



Environment Info

- Station ID: KSFO
- Temperature: 68.0249 Deg F
- Wind Speed: 3.00792 Knots
- Wind Direction: 150.044 Deg
- Air Pressure: 29.9729 inhg

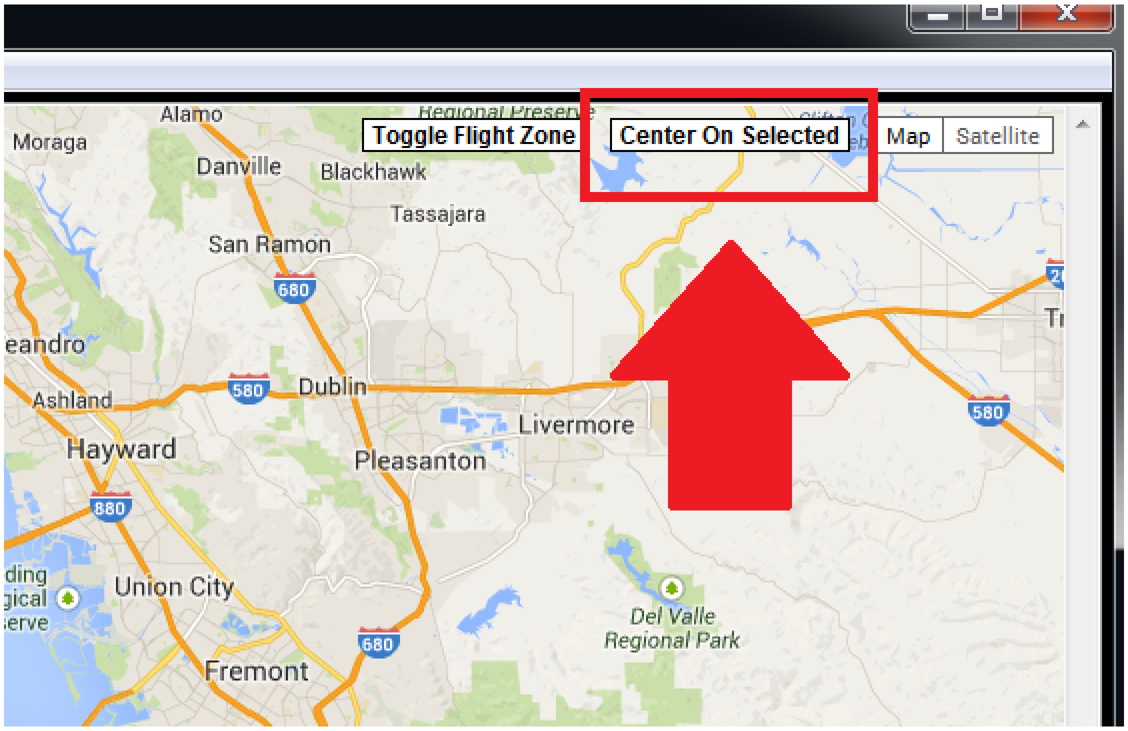
Select A Flight:
- [✓ Player]
- MM3NHL
- USAF-1
- SAX
- Santoro

Flight Info

- Flight Name: Player
- Latitude: 37.6287 Deg - Longitude: -122.393 Deg
- Speed: 2.52338 Knots
- Heading: 117.888 Deg
- Altitude: 6.01734 Ft
- Current Fuel: 38.1865 Gals
- Total Fuel Capacity: 56.0606 Gals
- Flight Time: 0:57:07.644000
- Current Time: 2014-04-23 01:13:04.473000

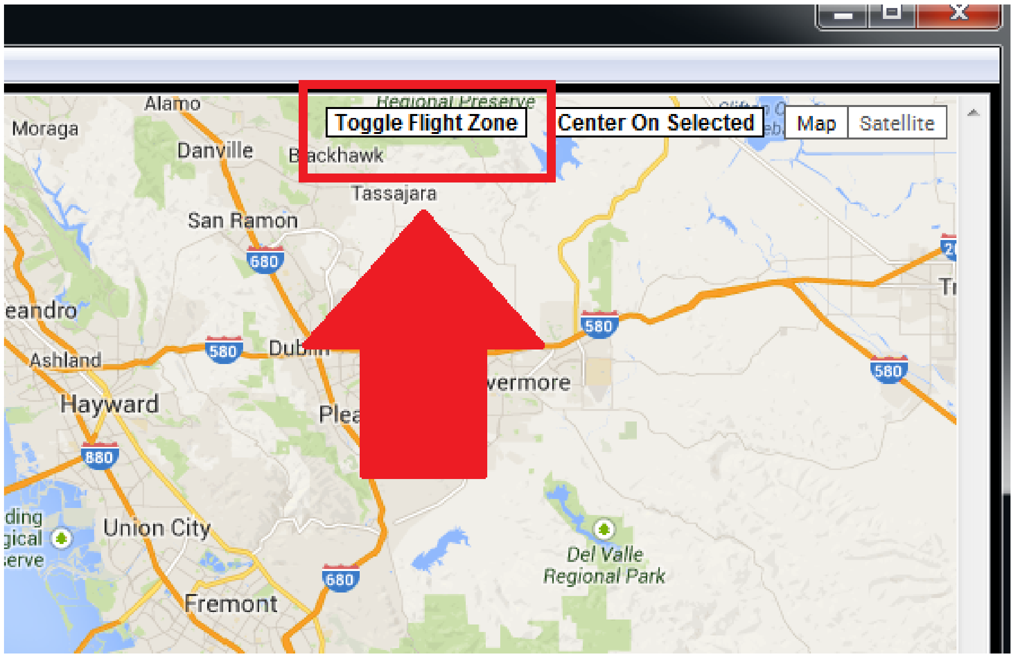
3.4.1 Center on selected

The map has an added button called ‘Center On Selected’ that centers the map on the currently selected flight.



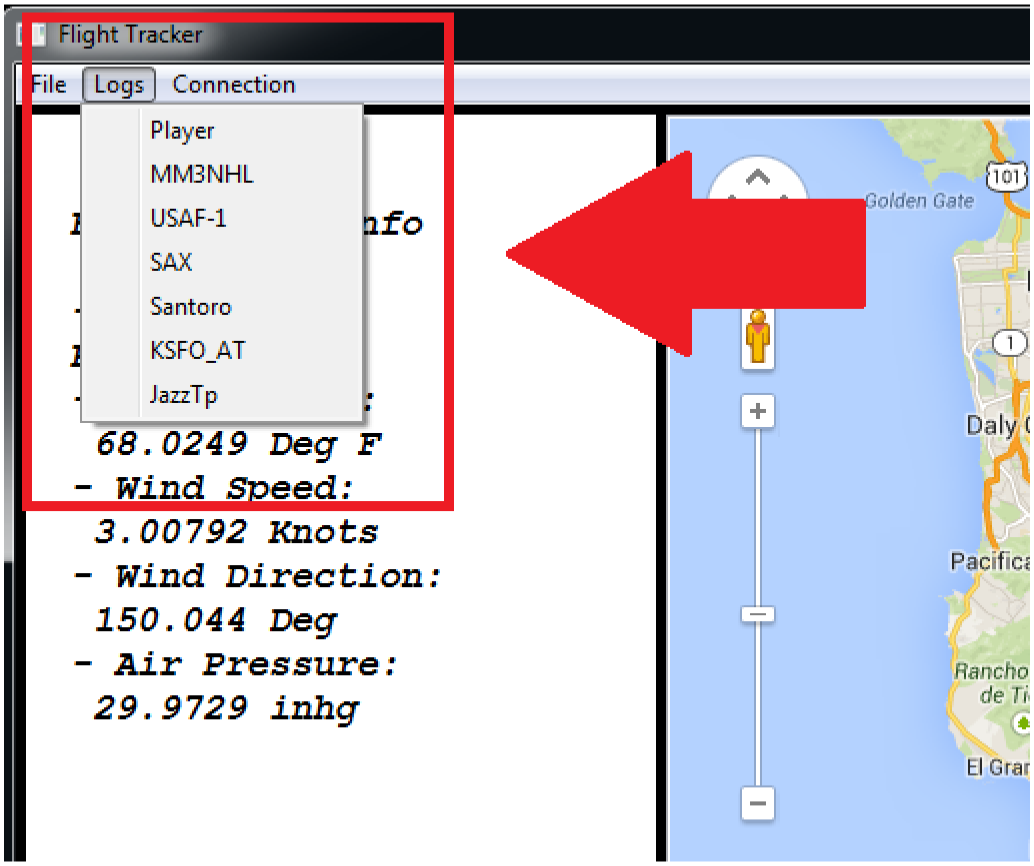
3.4.2 Toggle Flight Zone

The map also has a button that toggles a circle in which whose radius the FlightGear server will send flight information for other flights. The radius of the flight zone is 100 nautical miles. Any flight who enters the flight zone will be displayed and tracked by FlightTracker.



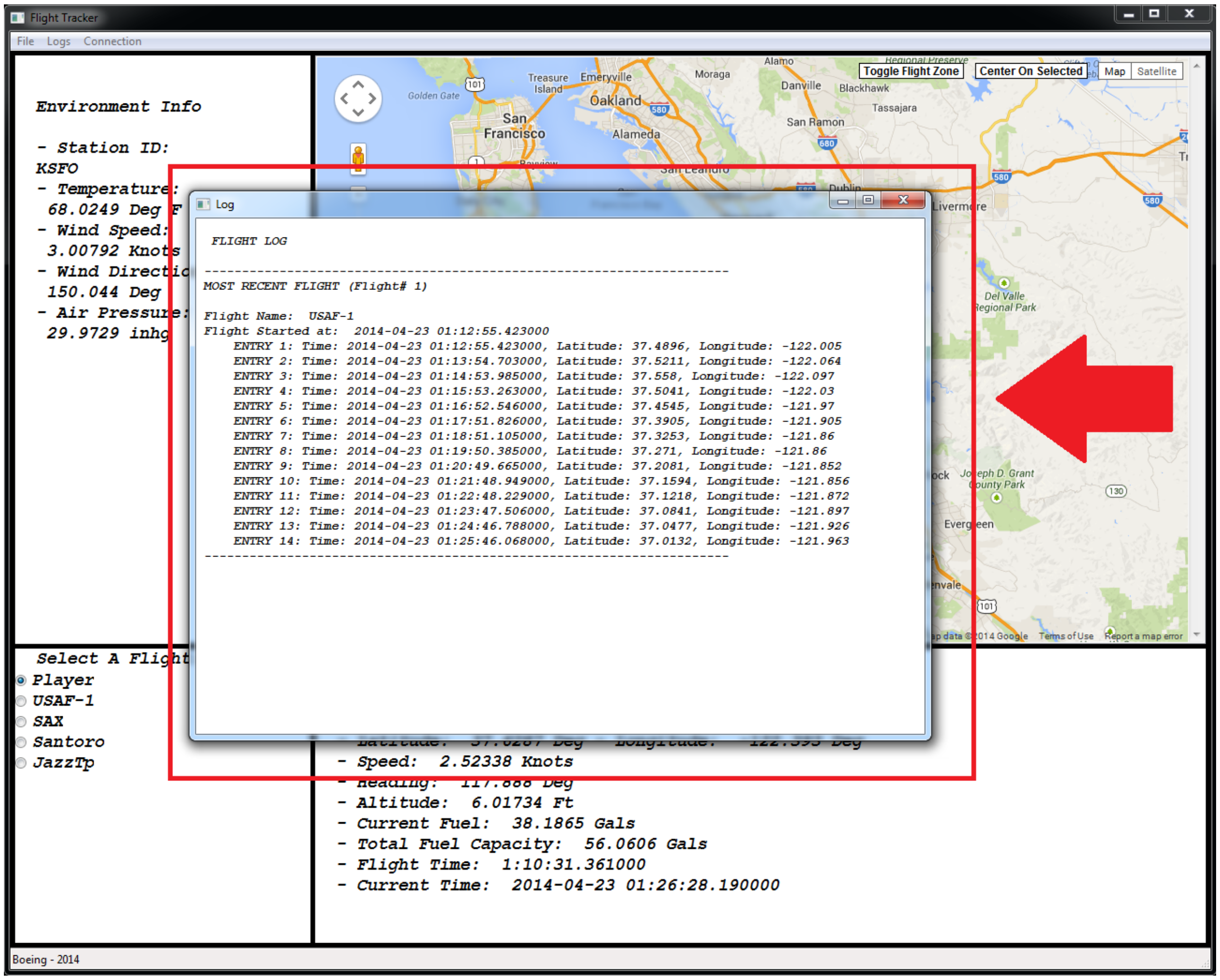
3.5 Logs

Any flight who has entered the flight zone mentioned earlier will be tracked by FlightTracker regardless of whether or not that flight is still in the flight zone or not. All multiplayer flight information is stored in logs that are kept by FlightTracker. These logs display all of the selected flight's past flights with starting and ending times as well as periodic time stamps that also include flight position. The available logs can be found in the drop down log menu option.



```
68.0249 Deg F
- Wind Speed:
 3.00792 Knots
- Wind Direction:
 150.044 Deg
- Air Pressure:
 29.9729 inhg
```

The logs that are displayed will look like this:



```
Environment Info

- Station ID:
KSFO
- Temperature:
 68.0249 Deg F
- Wind Speed:
 3.00792 Knots
- Wind Directic
 150.044 Deg
- Air Pressure:
 29.9729 inhg
```

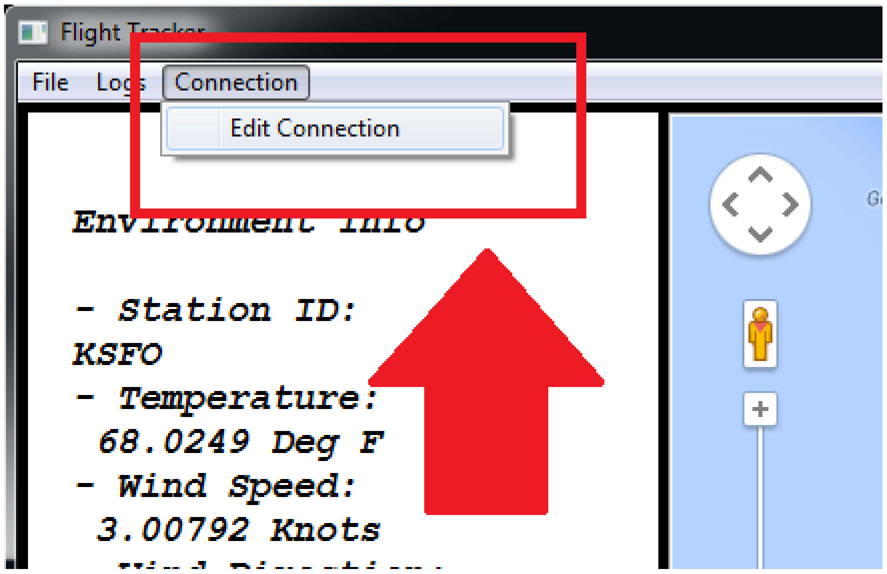
```
Select A Flight
Player
USAF-1
SAX
Santoro
JazzTp
```

```
 FLIGHT LOG

---------------------------------------------------------------------
MOST RECENT FLIGHT (Flight# 1)

Flight Name:  USAF-1
Flight Started at:  2014-04-23 01:12:55.423000
    ENTRY 1: Time: 2014-04-23 01:12:55.423000, Latitude: 37.4896, Longitude: -122.005
    ENTRY 2: Time: 2014-04-23 01:13:54.703000, Latitude: 37.5211, Longitude: -122.064
    ENTRY 3: Time: 2014-04-23 01:14:53.985000, Latitude: 37.558, Longitude: -122.097
    ENTRY 4: Time: 2014-04-23 01:15:53.263000, Latitude: 37.5041, Longitude: -122.03
    ENTRY 5: Time: 2014-04-23 01:16:52.546000, Latitude: 37.4545, Longitude: -121.97
    ENTRY 6: Time: 2014-04-23 01:17:51.826000, Latitude: 37.3905, Longitude: -121.905
    ENTRY 7: Time: 2014-04-23 01:18:51.105000, Latitude: 37.3253, Longitude: -121.86
    ENTRY 8: Time: 2014-04-23 01:19:50.385000, Latitude: 37.271, Longitude: -121.86
    ENTRY 9: Time: 2014-04-23 01:20:49.665000, Latitude: 37.2081, Longitude: -121.852
    ENTRY 10: Time: 2014-04-23 01:21:48.949000, Latitude: 37.1594, Longitude: -121.856
    ENTRY 11: Time: 2014-04-23 01:22:48.229000, Latitude: 37.1218, Longitude: -121.872
    ENTRY 12: Time: 2014-04-23 01:23:47.506000, Latitude: 37.0841, Longitude: -121.897
    ENTRY 13: Time: 2014-04-23 01:24:46.788000, Latitude: 37.0477, Longitude: -121.926
    ENTRY 14: Time: 2014-04-23 01:25:46.068000, Latitude: 37.0132, Longitude: -121.963
---------------------------------------------------------------------
```

```
- Speed:  2.52338 Knots
- Heading:  117.888 Deg
- Altitude:  6.01734 Ft
- Current Fuel:  38.1865 Gals
- Total Fuel Capacity:  56.0606 Gals
- Flight Time:  1:10:31.361000
- Current Time:  2014-04-23 01:26:28.190000
```

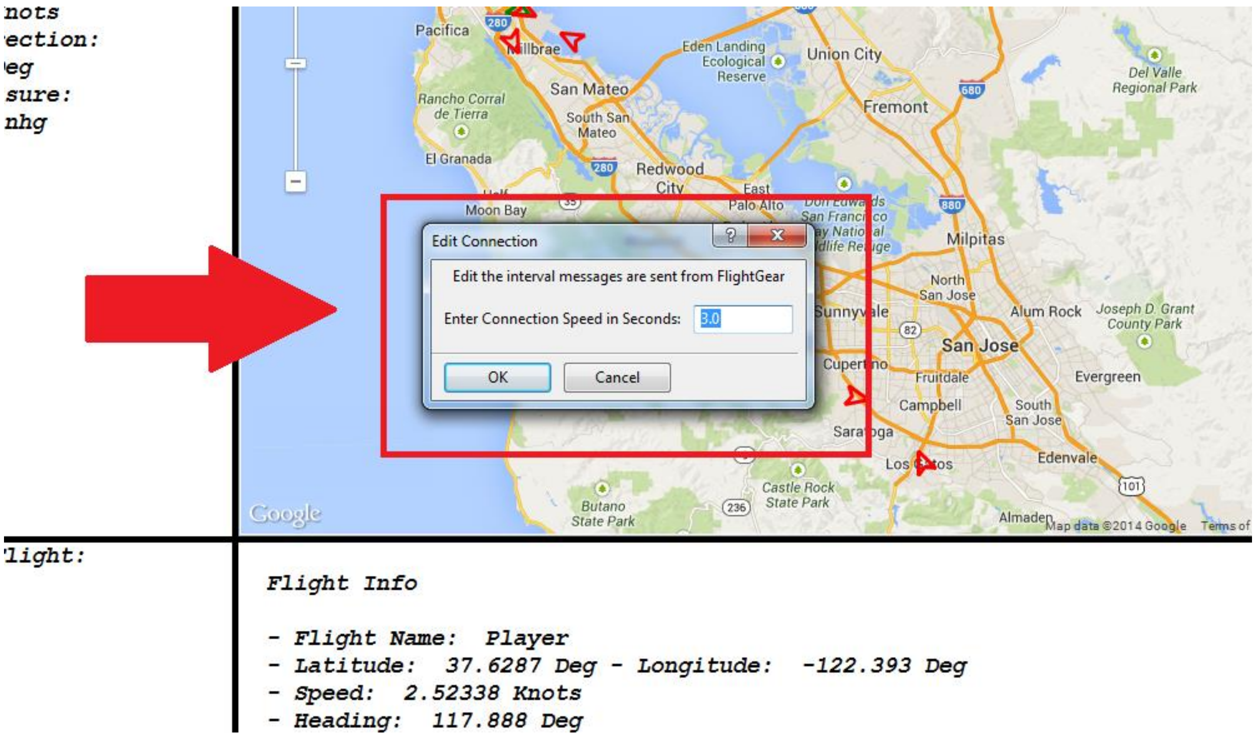
3.6 Connection Speed

The rate at which FlightGear sends messages to the ActiveMQ broker and subsequently are received by FlightTracker can be modified. Using a menu option, a dialog window will be displayed which allows you to enter any time interval at which you wish to receive messages from FlightGear.



Environment Info

- Station ID: KSFO
- Temperature: 68.0249 Deg F
- Wind Speed: 3.00792 Knots



Edit the interval messages are sent from FlightGear

Enter Connection Speed in Seconds: 3.0

Flight Info

- Flight Name: Player
- Latitude: 37.6287 Deg - Longitude: -122.393 Deg
- Speed: 2.52338 Knots
- Heading: 117.888 Deg

4. Admin Manual

This section of the administrator manual is designed to assist with implementing ActiveMQ into a program and understanding the implementation of the components of FlightTracker and CFD.

5. ActiveMQ

5.1 Broker

Programs using ActiveMQ require the broker to be running. The broker can be downloaded off the ActiveMQ website. To change the port numbers that the broker uses, navigate to the file at "../conf/activemq.xml".

```
<transportConnectors>
<!-- DOS protection, limit concurrent connections to 1000 and frame size to 100MB -->
<transportConnector name="openwire"
uri="tcp://0.0.0.0:61616?maximumConnections=1000&wireFormat.maxFrameSize=104857600"/>
<transportConnector name="amqp"
uri="amqp://0.0.0.0:5672?maximumConnections=1000&wireFormat.maxFrameSize=104857600"/
>
<transportConnector name="stomp"
uri="stomp://0.0.0.0:61613?maximumConnections=1000&wireFormat.maxFrameSize=10485760
0"/>
<transportConnector name="mqtt"
uri="mqtt://0.0.0.0:1883?maximumConnections=1000&wireFormat.maxFrameSize=104857600"/>
<transportConnector name="ws"
uri="ws://0.0.0.0:61614?maximumConnections=1000&wireFormat.maxFrameSize=104857600"/>
</transportConnectors>
```

FlightGear in the Flight Simulator Suite uses the "openwire" transport connector and the Flight Tracker GUI uses the "stomp" transport connector.

5.2 ActiveMQ Producer

Before starting either the ActiveMQ producer or consumer, the library must be initialized. This is done (C++) by doing:

```
activemq::library::ActiveMQCPP::initializeLibrary();
```

and then the corresponding shutdown statement:

```
activemq::library::ActiveMQCPP::shutdownLibrary();
```

First a connection factory must be made. This is done with the statement:

```
auto_ptr<ActiveMQConnectionFactory> connectionFactory(
                        new ActiveMQConnectionFactory(brokerURI));
```

The "brokerURI" argument in this statement is the location of the broker. This string would have the format "`failover://(tcp://localhost:61616)`". After the connection factory is made, a connection must be made.

```
m_connection = connectionFactory->createConnection();
m_connection->start();
```

The connection is then used to create a session.

```
session = connection->createSession(ACKNOWLEDGE_MODE);
```

Now, the destination object must be created. Either a topic or queue can be created.

```
destination = session->createTopic(destURI);
destination = session->createQueue(destURI);
```

A topic is used for the publish and subscribe method. This means that when a producer pushes a message to a topic, all connected consumers will get a copy of the message. A queue is used for the load balancer method. This means that when a producer pushes a message to a queue, only one connected consumer will receive that message. The “destURI” argument is the name of the topic or queue the producer is pushing to.
Finally, the producer object can be created.

```
producer = session->createProducer(destination);
producer->setDeliveryMode(DeliveryMode::NON_PERSISTENT);
```

Sending a message is simply done by calling the send method on the producer object.

5.3 ActiveMQ Consumer

Creating an ActiveMQ consumer is done the same way as the producer. The only difference is that a onMessage function is needed for when the consumer receives a message.

```
consumer->setMessageListener(this);
```

This sets the current class as the message listener. Once the “onMessage” function is overridden, the created function will then be called when the consumer receives a message.

6. FlightTracker

It is possible to implement the different functionalities of FlightTracker using the following guidelines.

6.1 Connection to ActiveMQ Broker

The FlightTracker program is connected to FlightGear through its use of ActiveMQ’s broker. This connection allows the program to swap messages with FlightGear in order to display the information and also to modify FlightGear. The connection to the broker is made through the use of the library: Stompy. Within FlightTracker’s Python source code lies some key implementations of this library.

```
conn2.set_listener('', MyListener(conn2,frame))
conn2.start()
conn2.connect(login=user,passcode=password)
```

```
conn2.subscribe(destination="TEST.FOO", id=1, ack='auto')
```

These lines of code allows the python program to start-up a connection to the broker and also to subscribe to a certain queue on the broker where it will receive its messages from.

A connection can also be made to send messages to the broker:

```
conn = stomp.Connection(host_and_ports = [(host, port)])
conn.start()
conn.connect(login=user,passcode=password)

conn.send(body = dlg.text.GetValue(),destination='MESSAGE_INTERVAL')
```

6.2 Utilization of Wx.Python

FlightTracker is made using WX.Python. Wx.Python is a Python extension for the popular Wx.Widgets library written in C++.

Here is an example of Wx.Python being used to initialize the main frame for FlightTracker:

```
        super(FlightTracker, self).__init__(parent, size=(1024,700), style = 
wx.DEFAULT_FRAME_STYLE)
        self.currentDisplayFlight = "Player"

        self.menubar = wx.MenuBar()
        self.fileMenu = wx.Menu()
        self.optionsMenu = wx.Menu()
        self.connectionMenu = wx.Menu()

        self.fileMenu.Append(EXIT, 'Exit', 'Exit')
        self.connectionMenu.Append(CONNECTION,'Edit Connection','Edit 
Connection')

        self.menubar.Append(self.fileMenu,'File')
        self.menubar.Append(self.optionsMenu,'Logs')
        self.menubar.Append(self.connectionMenu,'Connection')
```

Wx.Python allows for very fast prototyping and functionality development and is easy to learn and use making future development much simpler.

For further information, here is the website for Wx.Python: http://www.wxpython.org/. And here is the helpful wiki for Wx.Python: http://wiki.wxpython.org/.

6.3 HTML and Javascript in Python

One key feature of FlightTracker is its ability to utilize Google Maps in python. This feature is made possible by functionality provided by Wx.Python.

Here we can see an html page that is used to display the Google Map, being placed into a sizer in the Map Panel of FlightTracker:

```
                        #set html page to be the one created from the javascript
                        self.parent.html_view = wx.html2.WebView.New(self)
                        dir_name = os.getcwd()+"/test.htm"
                        self.parent.html_view.LoadURL(dir_name)
                        GPSSizer.Add(self.parent.html_view,1,wx.EXPAND)
                        self.SetSizer(GPSSizer)
```

This HTML page is updated periodically in FlightTracker and is displayed in the Map panel. Within the HTML code, JavaScript is also embedded. The JavaScript is used to implement the Google Maps JavaScript API. The HTML and Javascript are both managed through the class ‘PyMap.py’ which contains all of the code encapsulated within a string. Here is an example:

```
            self.html = """
                        <!DOCTYPE html>
<html>
  <head>
    <title>Accessing arguments in UI events</title>
    <meta name="viewport" content="initial-scale=1.0, user-scalable=no">
    <meta charset="utf-8">
    <style>
      html, body, #map-canvas {
        height: 100%%;
        margin: 0px;
        padding: 0px
      }
    </style>
    %s
  </head>
  <body>
    <div id="map-canvas"></div>
  </body>
</html>
                        """ % self.GoogleMapPy()
```

The method GoogleMapPy() referenced above contains all of the JavaScript used to implement the Google Maps API. Here is some example JavaScript code where a new marker is added to the map:

```
//add flight marker
                        function addMarker(lat, lon,name) {
                                    var location = new google.maps.LatLng(lat,lon);
                                    symbol = {
                                                path:
google.maps.SymbolPath.FORWARD_CLOSED_ARROW,
                                                scale: 4,
                                                strokeWeight: 3,
                strokeColor: 'red',
                rotation: 0
        };
        var marker = new google.maps.Marker({
                position: location,
                map: map,
                icon: symbol,
                title: name,
                optimized: false,
                pastLat: lat,
                pastLon: lon,
                animation: google.maps.Animation.DROP,
                selected: false
        });
        markers.push(marker);
}
```

The JavaScript methods that control the map can be called from the Python code. Here is an example where a marker on the map is updated:

```
#update the GPS map

scriptString = """updateMarker(%s,%s,"%s",%s,"%s")""" %
(str(lat),str(lon),str(name),str(heading),selected)

self.MainPanel.html_view.RunScript(scriptString)
```

The JavaScript method call is placed into a string and sent to a Python function which sends the command to the map.

7. Computational Fluid Dynamics

We have attempted to build a program that models the motion of the air. The program design is composed of two subprograms tasked with the responsibilities of computing the flow-field variables and displaying a graphical representation of the simulation. The Solver subprogram is the computational engine; the Visualizer subprogram maintains a scene graph and uses the results of the Solver to define the vertex shaders and primitive types. This document is concerned with the Solver program. We will begin with an overview of the process, followed by a brief analysis and derivation of the equations. Finally we will document the organization of the code.

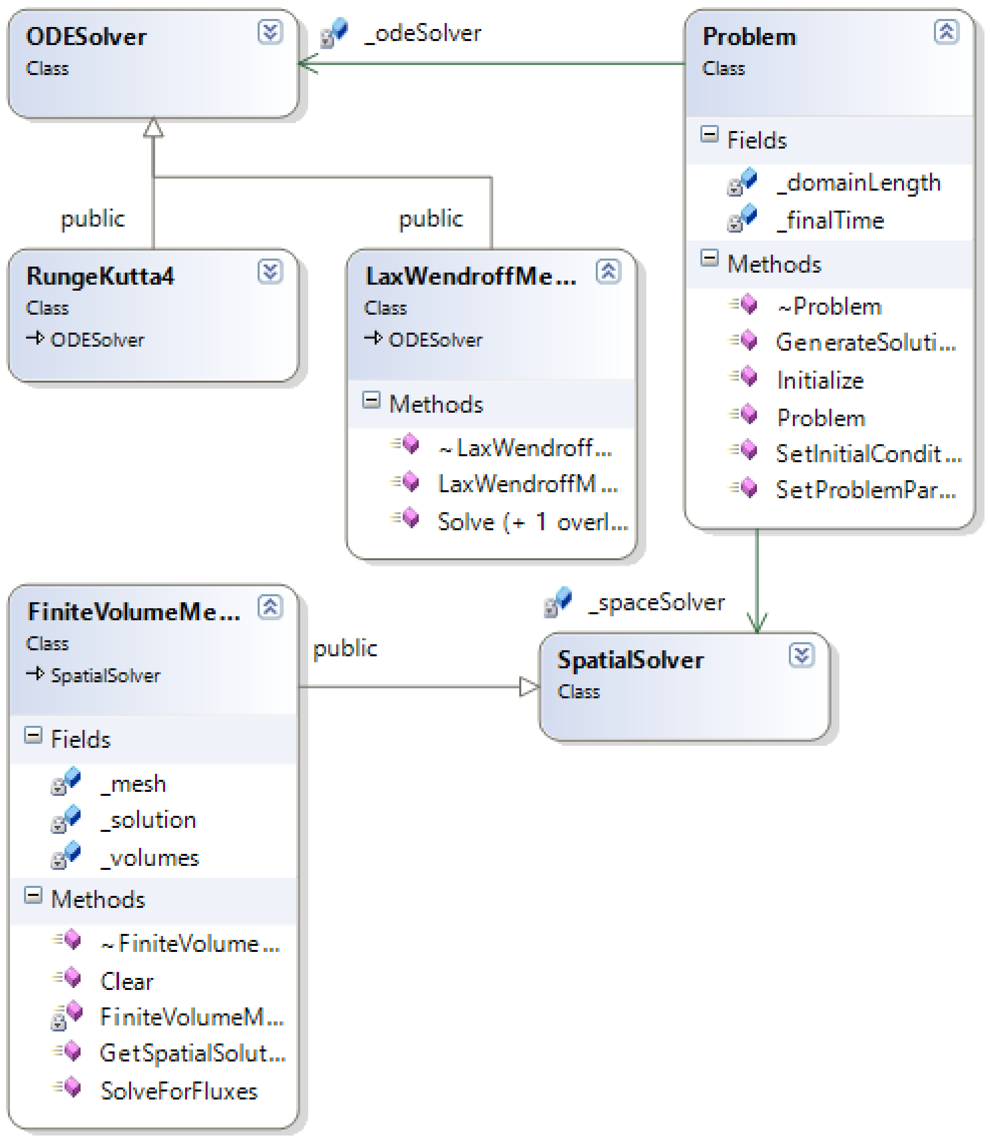
7.1 Overview

There are two primary steps of the Solver process:

1. **Discretization** of the partial differential equations and auxiliary equations (i.e. the initial conditions and boundary conditions) into a system of algebraic equations
2. **Implementation of numerical solvers** to compute the solution of the system of algebraic equations.

Before converting the partial differential equations into an algebraic form in the discretization step, we must first decide on a discretization method. There are a variety of methods we may use to accomplish this task; in this work we focus on the finite volume method. The finite volume method is a discretization of the integral form of the conservative equation. The computational domain is subdivided into a number of control volumes. The governing equation is then discretized into an algebraic expression representative of the conservation of the flow field variables for each control volume. Polynomial interpolation and numerical integration are used to obtain an algebraic expression for the quantities that express spatial change. In order to ensure that the flow-field variables are conserved, we average the flux calculations of neighboring volumes to obtain the flux across any face bounding two control volumes. Discretization in time is achieved via an implicit finite difference method.

The Solver program was organized in such a way to maximize flexibility. Any task that can be implemented with a variety of different strategies is exported to a class. Eventually, the goal is to create a fully templated program, where the management classes are templates with method or model parameters. Currently the program leverages inheritance to accomplish the use of different methods. Incorporating templates into the design will allow us to use different objects to accomplish the same task. Inheritance should be used only for objects of the same type with additional or specialized functionality. For example, we mentioned that the discretization step can be accomplished by a variety of methods. Currently, the program is arranged such that a discretization method is a derived class of an abstract class called ‘SpatialSolver’. (Admittedly, that title is not entirely accurate and should be changed to a more appropriate descriptive title such as ‘DiscretizationMethod’.) A portion of the program is illustrated below in the form of a class diagram. A more detailed diagram is included at the end of the document.



7.2 Analysis and Derivation of Governing Equations

In this section we analyze the equations that model the motion of the air. We begin the analysis with the Reynolds Averaged Navier Stokes (RANS) equation, which is a variation of the Navier Stokes equation obtained by replacing the velocity with an averaged velocity plus instantaneous velocity component. The RANS equations can be expressed as the following equation

$$\frac{\partial \boldsymbol{U}}{\partial t} + \nabla \cdot \boldsymbol{F_I} + \nabla \cdot \boldsymbol{F_V} = Q$$

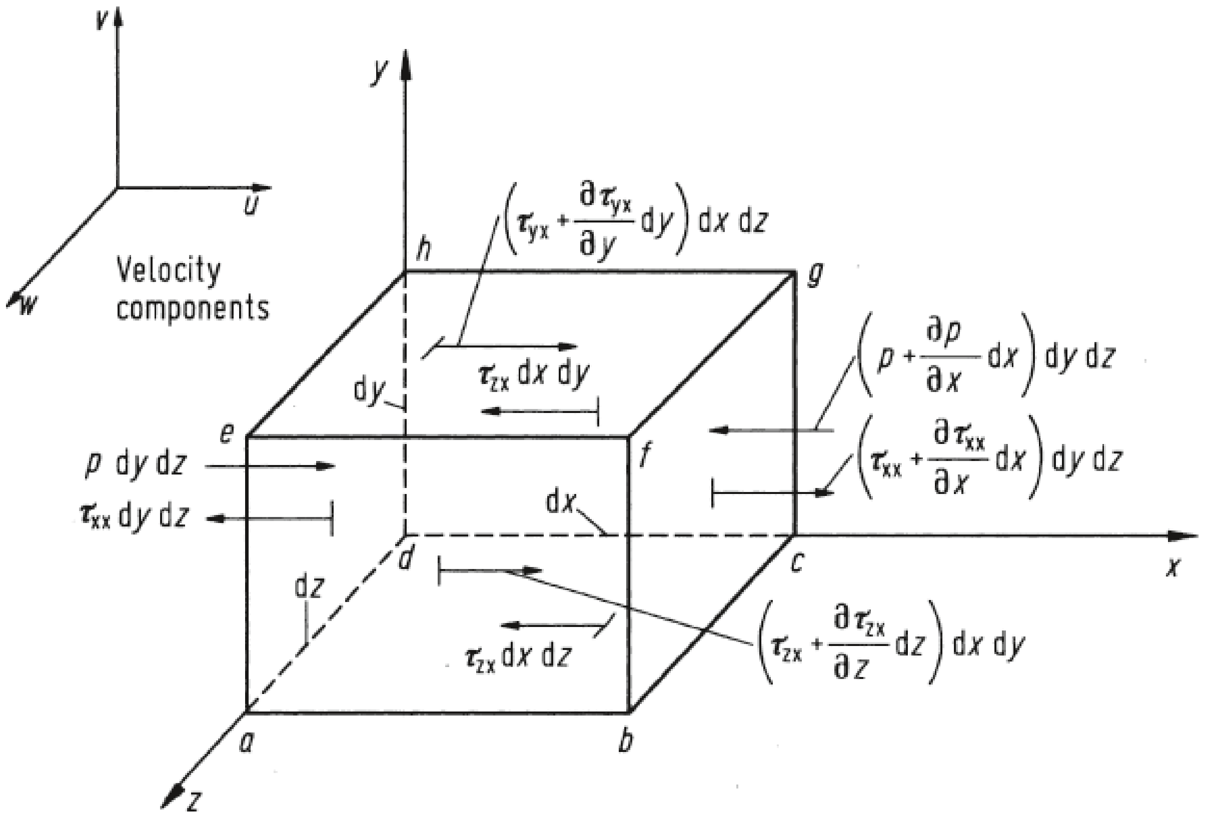
[1]

where $\boldsymbol{F_I}$ and $\boldsymbol{F_V}$ are the inviscous and viscous flux matrices, respectively. They are defined

$$\boldsymbol{F_I} = [\boldsymbol{f_{I1}} \quad \boldsymbol{f_{I2}} \quad \boldsymbol{f_{I3}}]$$
$$\boldsymbol{F_V} = [\boldsymbol{f_{V1}} \quad \boldsymbol{f_{V2}} \quad \boldsymbol{f_{V3}}]$$

$$\boldsymbol{f}_{\boldsymbol{I}_i} = \begin{pmatrix} \rho w_i \\ \bar{p}\delta_{1i} + \bar{\rho} w_i w_{\mathbf{1}} \\ \bar{p}\delta_{2i} + \bar{\rho} w_i w_{\mathbf{2}} \\ \bar{p}\delta_{3i} + \bar{\rho} w_i w_{\mathbf{3}} \\ (\bar{\rho}\tilde{E} + \bar{p}) w_i \end{pmatrix}, \boldsymbol{f}_{\boldsymbol{V}_i} = \begin{pmatrix} 0 \\ \tau_{i1} \\ \tau_{i2} \\ \tau_{i3} \\ q_i + w_i\tau_{ij} + \left(\mu + \frac{\mu_t}{\sigma_k}\right) \end{pmatrix},$$

where δ_{ji} is the Kronecker delta function, and w_i is the velocity component of the i^{th} dimension, where *i* = 1 indicates the *x*-axis, *i* =2 indicates the *y*-axis, and *i* = 3 indicates the *z*-axis. τ_{ij} denotes a viscous stress in the *j* direction exerted on a plane perpendicular to the *i*-axis. An illustration of the physical meaning of these variables is depicted in the figure below.



v
u
w
Velocity components
y
$\left(\tau_{yx} + \frac{\partial \tau_{yx}}{\partial y} dy\right) dx\, dz$
h
g
$\left(p + \frac{\partial p}{\partial x} dx\right) dy\, dz$
$\tau_{zx}\, dx\, dy$
dy
e
f
$\left(\tau_{xx} + \frac{\partial \tau_{xx}}{\partial x} dx\right) dy\, dz$
$p\, dy\, dz$
$\tau_{xx}\, dy\, dz$
dx
d
c
x
dz
$\left(\tau_{zx} + \frac{\partial \tau_{zx}}{\partial z} dz\right) dx\, dy$
$\tau_{zx}\, dx\, dz$
a
b
z

U is the solution vector of conservative variables, defined

$$\boldsymbol{U} = \begin{pmatrix} \bar{\rho} \\ \bar{\rho} w_1 \\ \bar{\rho} w_2 \\ \bar{\rho} w_3 \\ \bar{\rho}\tilde{E} \end{pmatrix}$$

A bar over the variable is used to indicate that the time average. The time average of a function is defined

$\bar{q}(\boldsymbol{x}, t) = \frac{1}{|T|}\int_{t0}^{t0+T} q(\boldsymbol{x}, t)\, dt$

First we integrate [1] over the volume of the fluid container, the domain of the problem, to obtain an equation in integral form.

$$\oiiint \frac{\partial \boldsymbol{U}}{\partial t}\, dV + \oiiint \nabla \cdot \boldsymbol{F_I}\, dV + \oiiint \nabla \cdot \boldsymbol{F_V}\, dV = \oiiint \boldsymbol{Q}\, dV$$

[2]
Now we use the divergence theorem, which states

$$\oiiint \nabla \cdot \boldsymbol{F}\, dV = \oiint (\boldsymbol{F} \cdot \boldsymbol{n}) dS$$

To rewrite [2]

$$\oiiint \frac{\partial \boldsymbol{U}}{\partial t}\, dV + \oiint (\boldsymbol{F_I} \cdot \boldsymbol{n}) dS + \oiint (\boldsymbol{F_V} \cdot \boldsymbol{n}) dS = \oiiint \boldsymbol{Q}\, dV$$

[3]
The average of a function is

$$\bar{\boldsymbol{U}} = \frac{1}{|V|} \oiiint \boldsymbol{U}\, dV$$

We further simplify [3] by replacing the volume integrals with the average to obtain

$$|V| \frac{\partial \bar{\boldsymbol{U}}}{\partial t} + \oiint (\boldsymbol{F_I} \cdot \boldsymbol{n}) dS + \oiint (\boldsymbol{F_V} \cdot \boldsymbol{n}) dS = |V|\, \bar{\boldsymbol{Q}}$$

7.3 Class List

Problem

The problem class is the highest level management class of the Solver program that provides the environment for the computation process. Upon completion, the interface between the user and the program will communicate with Solver by setting the methods and parameters of the Problem. The Problem class is responsible for integrating the time stepping with the spatial discretization. It is also responsible for loading initial conditions and boundary conditions that define a simulation instance. The mesh generation type and duration of the simulation is also defined in this class.

ODESolver

The ODESolver is the abstract class of which all numerical methods that solve systems of ODEs are derived from. Currently the classic fourth order Runge Kutta is implemented. However, since fourth order accuracy is too computationally expensive in a three dimensional implementation of the finite volume method, a second order method must be implemented. Currently Lax-Wendroff is also derived from ODESolver, **but this is an error.** The Lax-Wendroff method is a numerical method used for the discretization of hyperbolic partial differential equations. It is not a method used for solving ordinary differential equations.

FiniteVolumeMethod

The FiniteVolumeMethod (FVM) class is responsible for managing all system calls related to the spatial discretization. It does not perform any of the actual processing. Instead, it manages the objects responsible for performing each step of process. There are three objects that the FVM class manages: Mesh, Face, and Volume. It calls on these classes to generate the grid, construct the volumes, and compute the fluxes. For each step in time, the FVM method computes the flux matrices for each volume cell by iterating through the list of Volume references and updating them.

Mesh

The Mesh class generates the grid that covers the domain of the problem. It defines the faces in terms of these grid points and volume cells, or 'control volumes' in terms of enclosing faces. The purpose of maintaining a separate object for the completion of this task is to allow for the use of different meshing algorithms.

Face

A Face object manages the computations that correspond to the passage of fluid across a face in the mesh. In this context, the computations are calls to the flux function. Flux is a function of the conservative variable solution vector.

Volume

The Volume object manages the calls required to solve the governing equations for a single control volume. The functions of this class handle the computations of polynomial interpolation and numerical integration that are signature steps of the finite volume method. Since we are solving for a multidimensional quantity of multivariate functions, polynomial interpolation is too expensive. Instead we use a single data point, the value at the centroid of the volume, to approximate the integral using the midpoint rule. Currently, we confine ourselves to cube shaped volumes; we will always have six square faces bounding a volume.

$$\oiint \boldsymbol{F} \cdot \boldsymbol{n} \ dS = \sum_{k \ in \ Faces} \int_{j-0.5}^{j+0.5} \int_{i-0.5}^{i+0.5} \boldsymbol{F} \cdot \boldsymbol{n_k} \ dw_i dw_j \ \approx \sum_{k \ in \ Faces} \boldsymbol{F} \cdot \boldsymbol{n_k} S_k$$

<u>**BACK MATTER**</u>

<u>**Vocabulary**</u>

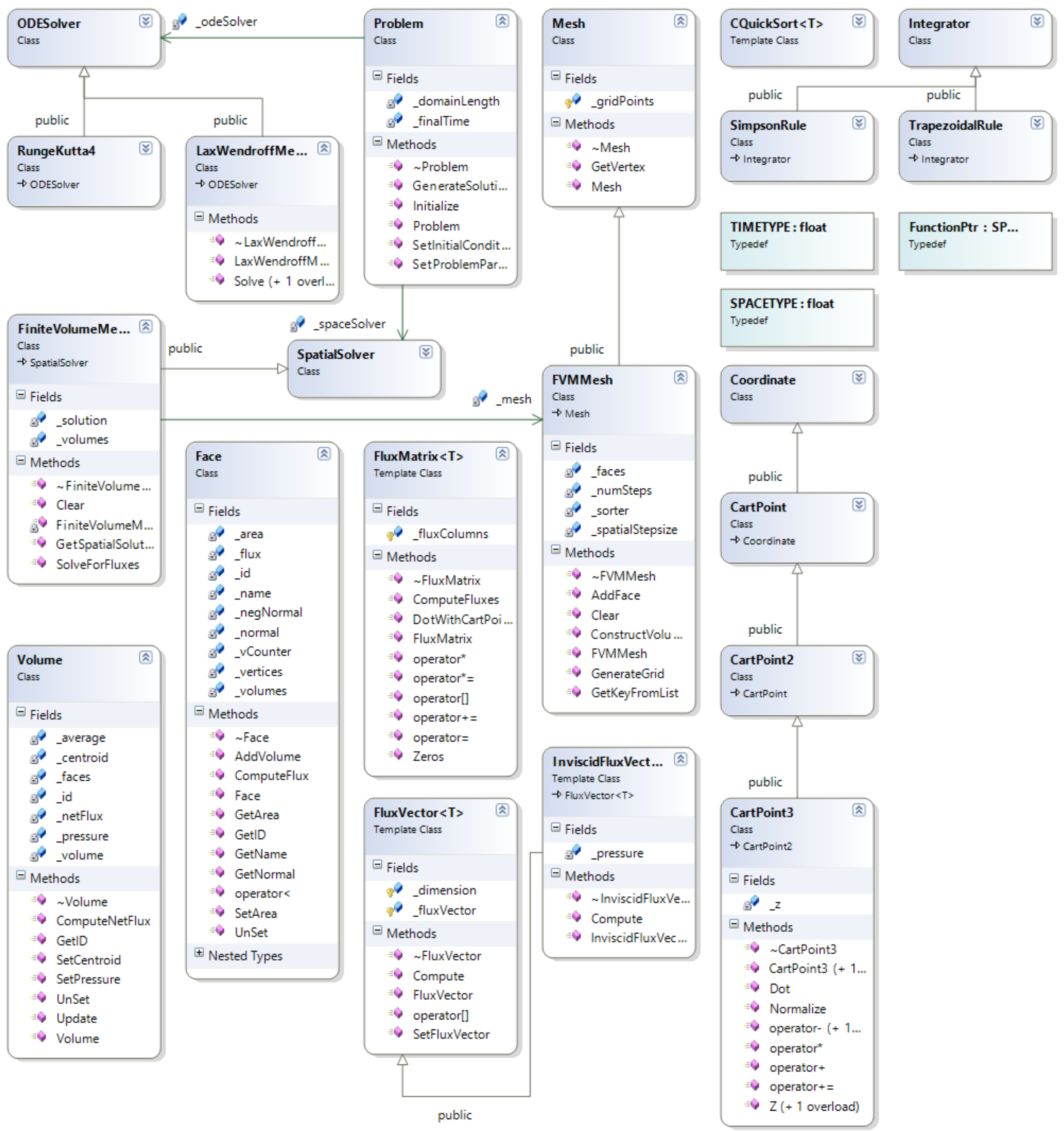
Cell. A cell is a subset of the grid points of a mesh. The intersection of all cells is empty, and the union of all cells covers the entire domain.

Face. A face is a two dimensional bounding surface of a volume.

Mesh. A mesh is a set of vertices, edges, and faces.

Volume. A volume is polyhedral contained within the domain of the problem. Volumes of a domain may overlap. The defining characteristic of a volume is that it is the space for which the solution vector of conservative variables is solved.

<u>**Class Diagram: Solver**</u>



<u>Class Diagram: Visualizer</u>

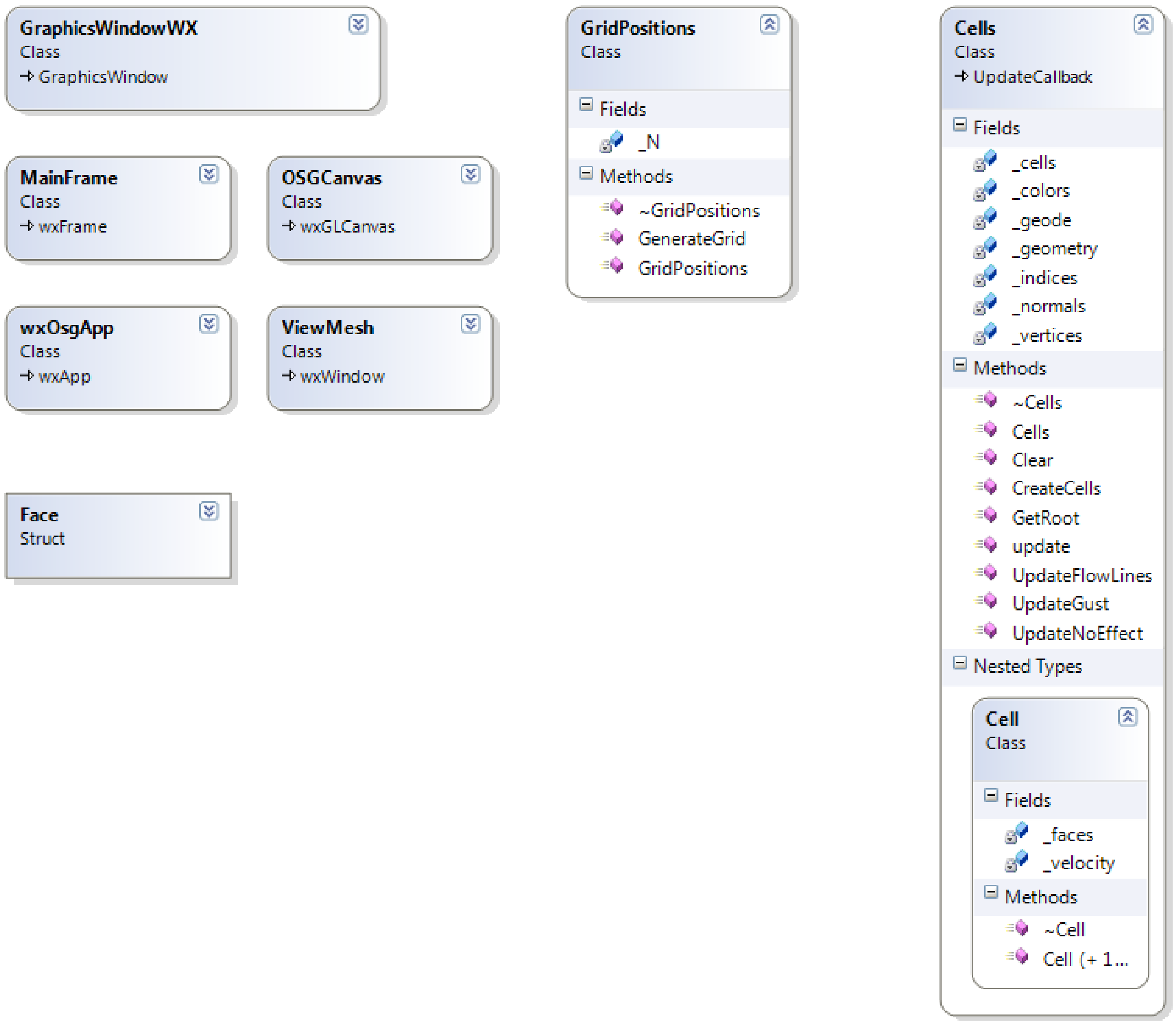
Cells – The cells class creates a mesh Geode. A Geode in Open Scene Graph is the (leaf) node of a scene graph that contains the geometrical data.

Face – The struct that holds vertex information of one face of a mesh polyhedra

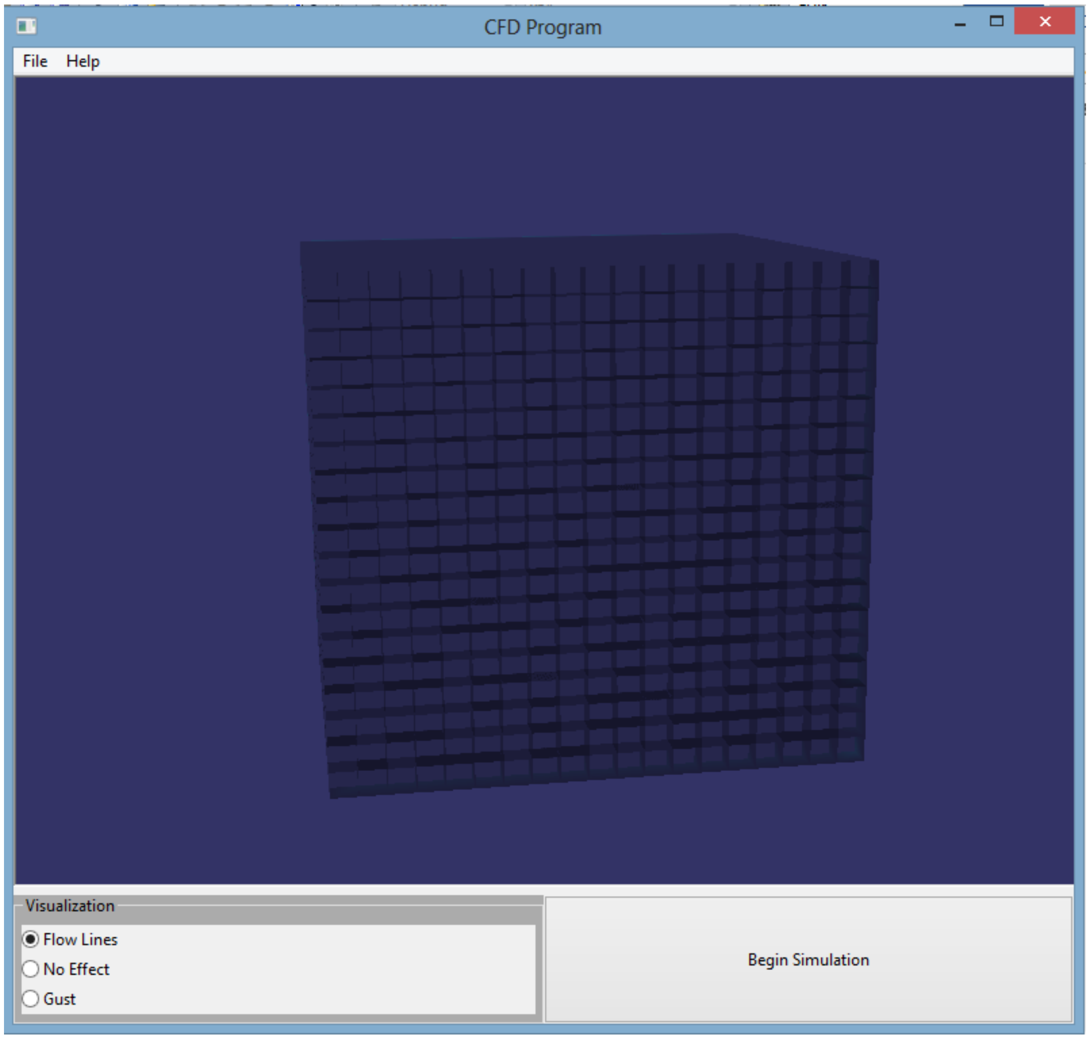
GraphicsWindow – This class is an osgViewer that is embedded in a wxWidgets. It is responsible for handling the graphics context (i.e. where to draw) of the scene graph.

MainFrame - The frame classes contain views and the widgets the user interacts with to communicate with the application. Currently this is only relevant to menus in the toolbar,

as the event handlers for the user interaction with the osg models are defined in OsgCanvas
OsgApp – This is the main enry point of the application from which the main frame is launched.
OsgCanvas – This class defines all event handlers used to interact with the model objects in the main view.
ViewMesh - The View classes contain the interface definitions to different child windows and dialog boxes. View classes are associated with a frame class. ViewMesh in particular hosts the osgViewer. It is responsible for setting the scene data.



A sample screenshot:


CFD Program
File
Help
Visualization
Flow Lines
No Effect
Gust
Begin Simulation