Capabilities and Features of the FliteViz4D Visualization Tool

James A. Ritchie III; FAA ANG-C55
Andrew J. Fabian; FAA ANG-C55

April 2017

DOT/FAA/TC-TN17/21

Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

U.S. Department of Transportation
Federal Aviation Administration

William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405
NOTICE

This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or use thereof. The United States Government does not endorse products or manufacturers. Trade or manufacturer's names appear herein solely because they are considered essential to the objective of this report. This document does not constitute FAA certification policy. Consult your local FAA aircraft certification office as to its use.

This report is available at the Federal Aviation Administration William J. Hughes Technical Center’s Full-Text Technical Reports page: actlibrary.tc.faa.gov in Adobe Acrobat portable document format (PDF).
[THIS PAGE IS INTENTIONALLY LEFT BLANK]
Abstract
This technical note documents the capabilities and features of the Flexible Flight Traffic Exploration Visualization 4D (FliteViz4D) tool developed for visualizing recorded and simulated air traffic data. The need for a visualization tool is explained. Then, the capabilities of the tool are presented with screenshots from a recorded air traffic scenario. Detailed explanations of the input data required are described, followed by the different aspects of an air traffic scenario that can be visualized. The statistics and other tools that FliteViz4D provide to the user are defined and presented.
[THIS PAGE IS INTENTIONALLY LEFT BLANK]
Acknowledgements

The authors would like to thank Mike Paglione, FAA for providing support, general guidance, and valuable feedback while creating this document.

Ron Wilkinson, GDIT, provided technical support when trying to run and debug FliteViz4D.

The development of FliteViz4D would not have been possible without the support of the rest of the Modeling and Simulation Branch’s software development team: Andrew Crowell, (formerly) FAA; Nicole Nelson, (formerly) FAA; Michael Bevilacqua, (formerly) CSSI; Byron Hoy, CSSI; Andrew Tasso, FAA; and Ian Wilson, (formerly) CSSI.
Executive Summary

The Federal Aviation Administration (FAA) and supporting organizations are developing new procedures, designing robust decision support tools, and modifying current restrictions as part of the Next Generation Air Transportation System (NextGen) to improve the current National Airspace System (NAS). Such improvements will allow for an increase in traffic volume and more efficient routes for airlines and passengers. These enhancements will lead to efficiency improvements and will help the FAA meet the demand of the future, while improving the safety for all who use the airspace.

Before any new tool or procedure is introduced to the NAS, extensive research, testing, and verification of these systems is essential to determine their benefits, limitations, and requirements. To assist with this process, many analysis tools have been developed to validate and test a system. These tools include statistical analysis software and visualization software. Typically, the specific concept or group of concepts under study drive the design of the analysis and visualization software, limiting it to performing calculations on or illustrations of that explicit set of concepts. This makes it problematic to repurpose for new and emerging concepts. An increase in cost and time for concept validation is required to develop and perform a new validation process.

The Modeling and Simulation Branch (MSB) at the FAA William J. Hughes Technical Center is tasked with analyzing many of the concepts to support the mission and investment analysis decisions of the NAS acquisition management process. This requires extensive inspection of generated flight scenarios to understand how a new idea affects the NAS, and what kind of advances and risks it introduces. To meet the needs of customers, the MSB development team developed a flexible, extensible, interactive four-dimensional (4D) visualization tool for visualizing aircraft and airspaces.

The paper presents the Flexible Flight Traffic Exploration Visualization 4D (FliteViz4D) developed by the Modeling and Simulation Branch. An overview of the capabilities of the FliteViz4D tool is given. The features of the tool are explained in detail in later sections, followed by a summary of the capabilities.
# Table of Contents

1. **INTRODUCTION** .................................................................................................................. 1

2. **APPLICATION OVERVIEW** ................................................................................................. 2
   2.1 4D VISUALIZATION .............................................................................................................. 2
   2.2 3D CAMERA ....................................................................................................................... 5
   2.3 LIVE FEED DVR ................................................................................................................... 6
   2.4 COMPARING TWO AIRCRAFT ............................................................................................. 6

3. **FEATURES** ............................................................................................................................. 9
   3.1 DATA TYPES ........................................................................................................................ 9
      3.1.1 Trajectory Conflict Probe Tables ................................................................................. 9
      3.1.2 Flight Data Tables ....................................................................................................... 10
      3.1.3 FliteViz Data Format .................................................................................................. 10
      3.1.4 Performance Data Analysis Recording System (PDARS) ............................................ 11
      3.1.5 Airspace Concept Evaluation System (ACES) ............................................................. 11
   3.2 FLITEVIZ 4D VISUAL FEATURES ..................................................................................... 12
      3.2.1 Flight Features ............................................................................................................. 12
      3.2.2 Airspace Features ....................................................................................................... 16
   3.3 STATISTICS .......................................................................................................................... 19
   3.4 TOOLS ................................................................................................................................ 21

4. **SUMMARY** ............................................................................................................................ 23

5. **REFERENCES** ......................................................................................................................... 24
List of Figures

Figure 1 – Close up of 3D flight model in FliteViz4D, with the track points, trajectory box, and separation wire frame ................................................................. 2
Figure 2 – Screenshot of FliteViz4D depicting a flight at the beginning of its descent ............... 3
Figure 3 – FliteViz4D main GUI control menu ................................................................. 4
Figure 4 – Screenshot of FliteViz4D depicting a flight one hour into its decent .................... 4
Figure 5 – Two flights in a crossing conflicting trajectories ................................................. 6
Figure 6 – Two flights in head on conflicting trajectories ..................................................... 7
Figure 7 – Flight Details window showing statistics of the two shown flights in FliteViz4D ... 7
Figure 8 – Flight Details window for a single flight ......................................................... 8
Figure 9 – Example of a basic aircraft model in FliteViz4D ............................................ 12
Figure 10 – Example of detailed aircraft models in FliteViz4D ........................................ 13
Figure 11 – An aircraft in FliteViz4D with its track, label, and minimum separation box ...... 14
Figure 12 – Close up of two aircraft models with the minimum separation distance wire box .... 14
Figure 13 – Close up of a flight with its trajectory projected via wire frame ...................... 15
Figure 14 – Close up of flight with its predicted position 180 seconds into the future ......... 15
Figure 15 – The borders of the states of the United States in FliteViz4D ......................... 16
Figure 16 – Flights in the Chicago (ZAU) ARTCC ......................................................... 17
Figure 17 – Side view of 4D convective weather polygons and flight reroutes in FliteViz4D (Crowell et al., 2012) ................................................................. 18
Figure 18 - Top view of 4D convective weather polygons and flight reroutes in FliteViz4D (Crowell et al., 2012) ................................................................. 19
Figure 19 – Flight Details window in FliteViz4D showing Pairs statistics ......................... 21
Figure 20 – Flight Details window showing the statistics for only one aircraft ............... 22

List of Tables

Table 1 – The required fields of the FliteViz Data Format ............................................. 10
Table 2 – Optional Fields in the FliteViz Data Format ............................................... 11
Table 3 – Statistics that FliteViz4D can display/calculate ........................................... 20
1. Introduction

As part of the Next Generation Air Transportation System (NextGen) to improve the current National Airspace System (NAS), the Federal Aviation Administration (FAA) and supporting organizations are developing new maneuvers, decision support tools, and modifying current restrictions. These improvements will allow the FAA to increase traffic volume and improve safety in the current system.

Extensive research, testing, and verification of emerging systems are essential to determine their benefits, limitations, and requirements on the NAS. Many different types of analysis tools, ranging from visualization tools to statistical analysis tools, need to be planned and established when the need to evaluate a system arises. Numerous tools were designed around a specific idea or group of concepts, which makes them difficult to repurpose for new and emerging models. If new and emerging concepts need to be visualized, new visualization tools need to be developed, leading to an increase in time and cost for validating these concepts.

The Modeling and Simulation Branch (MSB) at the FAA William J. Hughes Technical Center is tasked with analyzing many of the concepts to support the mission and investment analysis decisions of the NAS acquisition management process. To be able to meet the needs of the customers, the MSB development team developed a flexible, extensible, interactive 4D visualization tool for visualizing aircraft and airspaces. The current iteration of the software has been released under the name of Flexible Flight Traffic Exploration Visualization 4D (FliteViz4D). This software is designed to provide a visualization and analysis platform to the aviation industry for the analysis of new concepts, post-analysis of air traffic, and presentation of air traffic and airspace information.

FliteViz4D is a four-dimensional visualization, meaning three-dimensional space evolving over time (Crowell, Fabian, & Nelson, 2012). The FliteViz4D software is designed to be used on a ranging set of scenarios for assisting analysts in understanding what is happening with a new procedure or maneuver. The tool can be used as a microscope to analyze air traffic and airspaces, and has been used in a number of studies performed (Young, Crowell, Fabian, Schwartz, & DiBuccio, 2011), (Crowell, Fabian, Young, Musialek, & Paglione, 2011a), (Crowell, Fabian, Young, Musialek, & Paglione, 2011b), (Ritchie, Fabian, Young, & Paglione, 2016).

The remainder of this document describes the major capabilities of the FliteViz4D program, and captures the features of this program in more detail. Section 2 of this document describes the major capabilities of FliteViz4D. Section 3 describes the features of the program in more detail. This is then followed by a summary of everything presented in Section 4.
2. Application Overview

The FliteViz4D software application provides the user with specialized capabilities to analyze air traffic and airspace data visually. This section describes the major capabilities that FliteViz4D offers to the user.

2.1 4D Visualization

The primary feature of FliteViz4D is the four-dimensional (4D) visualization capabilities. An aircraft or airspace can be viewed at any angle in three physical dimensions (latitude, longitude, and altitude) and time. A three-dimensional (3D) model of a plane represents the location of the aircraft. Figure 1 illustrates the 3D flight model in FliteViz4D. The flight model is not to scale, and its size can be adjusted by the user.

Figure 1 – Close up of 3D flight model in FliteViz4D, with the track points, trajectory box, and separation wire frame

Each aircraft in FliteViz4D has a label that provides the aircraft identifier and two user defined statistics. These labels assist the user in discerning aircraft from one another, as well as give some information about where the flight is, as well as some other meta-data. The flight label illustrated in Figure 2 portrays the altitude in feet and groundspeed in knots, which is the default selection for the label.
Figure 2 – Screenshot of FliteViz4D depicting a flight at the beginning of its descent

The wire box frame shows the current prediction of the flight’s trajectory. Around the aircraft is another wire frame in the shape of a cylinder, which depicts the legal separation zone around the aircraft. If two of these cylinders intersect, then the aircraft are considered to be in conflict, which is a violation of legal separation between aircraft.

Diamonds are used to represent the previous and future actual positions of the aircraft, typically extracted from surveillance radar position reports. This is different from the wire boxes since the diamonds denote the actual location of the aircraft at that point, while the wire boxes are predictions. The diamond track has settings to turn off the whole track, the lead (future) track, or the trail (past) track. The air traffic scenario illustrated in Figure 2 and Figure 4 is from a historic air traffic recording, so the entire track is known and can be depicted accordingly.

From this example, the user can see the predicted trajectory of this aircraft as compared to the actual path of the aircraft. As the trajectory changes over time, the visualization updates the location of the predicted trajectory of the aircraft. This can show the user how accurately the trajectory predictor performs as compared to what the aircraft flew. It also shows how the trajectory predictor adjusts its estimate over time.

As shown in Figure 3, FliteViz4D incorporates time into the visualization similar to a digital video recording with play, stop, forward and backward buttons. This allows the user to fully visualize how flight trajectories and their paths change over time, making the 3D visualization a 4D animation.
The time section of the menu contains a slider that the user can drag to advance and reverse time in the scenario. The current time can be represented in seconds of the day, as in Figure 3, or as hours, minutes, and seconds. Pressing the play button, the visualization will advance in time based on the specified play rate. The play rate can be configured by the user, allowing the simulation to run anywhere from real time to a rate of 1000x. As time is updated, the objects are animated by advancing, appearing, or disappearing in the display window. Figure 4 shows an example of the visualization depicted in Figure 2 advanced through time by one hour.

The first thing to notice in Figure 4 is that the aircraft has moved along the diamond point path. The altitude of the aircraft has decreased, which is confirmed by looking at the previous track points. The instantaneous ground speed of the aircraft has fallen to 412 knots. The trajectory for the flight in Figure 4 has updated as compared to what it is in Figure 2 since the flight has descended further. This box is updated as the flight moves,
which shows the user how the algorithm changes the predicted trajectory as the flight continues along its path in time.

### 2.2 3D Camera

A 4D visualization is only as powerful as it is easy to navigate. With three dimensions being displayed on a two-dimensional screen, it is very important for the user to be able to quickly and easily navigate around the visualization to gather all the information available. If a visualization is limited to a single point of view, the user may not see everything that is occurring. This could lead to information not being seen or misinterpreted. There exist numerous 3D cameras for use in 3D visualizations, but the requirements for the camera needed for FliteViz4D are unique, and these cameras could not meet all of them.

An example of an easy to use 3D camera is the one in Google Earth\(^1\). The camera designed for Google Earth is only intended for viewing the ground via satellite imagery. This camera is very effective at doing this, but FliteViz4D requires the ability to look at objects above ground, and focus at altitudes where flights will be. The agility and precision of the camera in a visualization needs to be appropriately tuned for the scale and detail allowed by the visualization, e.g. minute detail is lost to the user if the camera is unable to zoom in close enough to see it (Crowell et al., 2012). Retaining the ease of use in a visualization with variable levels of detail and focus is complicated to accomplish. FliteViz4D may contain numerous amounts of information throughout the visualization while the user may wish to focus on a small part of it. This requirement is very similar to a three-dimensional video game where, though the visualization is very large, the user is only interested in the player’s current position within the visualization. Taking concepts from designing a 3D video game and those used within Google Earth and other similar globe visualizations, a powerful camera was developed that meets all requirements of a visualization tool such as FliteViz4D.

The main feature of the camera that sets it apart from many others is the focal point (Crowell et al., 2012). The focal point in a visualization is the current point the user is focusing on. 3D cameras, like in games and Google Earth, only have either fixed focal points, or focal points with very limited mobility. FliteViz4D required a focal point that can be moved along all three axes, which allows the user to focus on any point in space.

The camera in FliteViz4D was designed to be able to view the focal point from any angle or distance. Rotating the camera around the focal point, as well as zooming in and out of the point is accomplished via easy to use mouse controls. As the user zooms in closer to the focal point, movements become more precise allowing the camera to be just as easy to navigate from one end of a runway to the other, as it is to navigate from one end of the country to the other (Crowell et al., 2012). The camera could also be locked onto an object, where it will follow it until the user manually detaches it, or the object disappears from the visualization.

\(^1\) [https://www.google.com/earth/](https://www.google.com/earth/)
2.3 Live Feed DVR

A Digital Video Recorder (DVR) is a device that captures a live video and records it so that it can be viewed later, with rewind, fast forward, and pausing features. FliteViz4D uses this capability to record the visualization so that it can be viewed in a video later on. The feed can also be sent through a network socket, allowing a third party to view the visualization live.

The DVR system provides additional controls to the user that can jump to the current live feed or give time control to the user, allowing them to move the time to any point in the past. When the live feed time is selected, the time will update whenever a new message is received that contains a time stamp. Some of these messages may be track reports and others may be only time updates. The user may select which types of messages are allowed to control the time (Crowell et al., 2012).

2.4 Comparing Two Aircraft

In the previous example, one aircraft and its actual and predicted trajectories were visualized. Another common user need is to compare two flights and examine how close their trajectories were separated over time. Two examples of this are shown in Figure 5 and Figure 6. Figure 5 shows a pair of aircraft in a crossing conflicting trajectory pattern, while Figure 6 shows a pair of aircraft in a head on conflicting trajectory pattern.

![Figure 5 – Two flights in a crossing conflicting trajectories](image)
Figure 6 – Two flights in head on conflicting trajectories

The red and blue circles with a box around them ahead of the aircraft show the predicted position of the aircraft in the future, based on flight plan information and current location and speed of the flight. How far out in the future this prediction is, known as the look-ahead time, is adjustable by the user. Figure 6 shows the predicted location of the flights five minutes into the future.

Comparing statistics between two aircraft is made easy using the Flight Details feature of FliteViz4D. The flight details window is a centralized location for flight statistics of a single or pair of aircraft. Figure 7 displays two flights and the Flight Details window illustrates a set of user configurable separation statistics between them.

Figure 7 – Flight Details window showing statistics of the two shown flights in FliteViz4D
Using the Flight Details window, statistics for each aircraft is shown, including the pairwise statistics between the two aircraft. This tool helps with visualizing conflicts between aircraft, giving the user numerical confirmation of what they are visualizing. The user can easily switch between pairs, making it simple to look up statistics for a set of flights. This feature can be used for single flight as well by clicking on the Flights tab. Figure 8 displays this feature in action.

![Flight Details window for a single flight](image)

**Figure 8 – Flight Details window for a single flight**

With all of the capabilities, FliteViz4D operates analogous to a biologist’s microscope in supporting the examination of the operating details of an air traffic flight scenario, whether it is artificially generated or from recorded air traffic data. This allows the user to gain a better understanding of what is occurring during a procedure or throughout the entire NAS during a specific time. These visualizations also help with explaining how new maneuvers or procedures can affect the NAS in both positive and negative viewpoints.
3. Features
FliteViz4D has many features built into the program to assist the user in visualizing and performing analysis on flight scenarios. These features can be broken up into four major areas: the different types of input data to FliteViz4D, the features of the visualization, the statistical analysis features, and other tools FliteViz4D offers the user. This section describes these features in more detail.

3.1 Data Types
FliteViz4D can load data from different formats. The formats that FliteViz4D can currently input include:

- Trajectory Conflict Probe Tables (TCP)
- Flight Data Tables (FD)
- FliteViz Data Format
- Performance Data Analysis and Reporting System (PDARS)
- Airspace Concept Evaluation System (ACES)

Each data type has different elements that describe a flight and its path, as well as other information as discussed in the following sections. Some formats have more information than others do, which can lead to some features of FlightViz4D not working since there are pieces of data missing. The following subsections detail the different data types.

3.1.1 Trajectory Conflict Probe Tables
The Trajectory Conflict Probe (TCP) tables are a flight dataset that is internal to the Modeling and Simulation Branch. This dataset is an Air Route Traffic Control Center (ARTCC)-centric set of flight data that can represent recorded or simulated air traffic data. Database tables are used to store this data, and FliteViz4D will connect to the database directly to load it.

These tables include validated and smoothed track point data, trajectory data, route data, and clearance data. The track point data contains validated and time interpolated track point information. At a minimum, FliteViz4D requires the position of the flight in oblique stereographic \((x, y, z)\) points as defined by the adaptation, time for each point, and the aircraft identifier. Additional values include groundspeed in knots, heading of the aircraft from true north in degrees, smoothed values of the position, adherence age, and airspace name.

If the user would like to visualize trajectories, the trajectory tables must be loaded. These tables include the trajectory build time, time of the trajectory point, stereographic position of the aircraft at that time, and the groundspeed of the aircraft. In addition, depending on the plugins used, other tables including weather information, clearance information, route information, and airspaces are loaded into the program for statistical information and other illustrations within the visualization.
3.1.2 Flight Data Tables

Another dataset internal to the Modeling and Simulation Branch is comprised of the Flight Data (FD) tables. This dataset is stored in database tables, like TCP, to which FliteViz4D has direct access. The Flight Data tables contain information regarding flight position, flight plan information, hold clearances, beacon code messages, and interim altitude clearances. The data in these tables are not limited to an ARTCC, like the TCP tables, allowing FlightViz4D to visualize more aircraft with longer trajectory paths. Information contained in these tables is not cleaned or pre-processed, keeping the information in a raw state.

Some drawbacks to these tables are the lack of trajectory information within the dataset, as well as some other statistical information that is contained in the TCP tables. FlightViz4D will not display some statistical and visual elements if these tables are used due to the lack of information provided.

3.1.3 FliteViz Data Format

The FliteViz data format is the simplest of the datasets, being a single comma separated values (CSV) file in ASCII plaintext. This file has five required fields and 14 optional fields. Each row of the CSV file represents an aircraft’s surveillance position track report, with a resolution of a second. Table 1 describes the required fields for the FliteViz data format.

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACID</td>
<td>String</td>
<td>The aircraft identifier</td>
</tr>
<tr>
<td>TIME</td>
<td>Integer</td>
<td>The time of the point</td>
</tr>
<tr>
<td>ALTITUDE</td>
<td>Integer</td>
<td>The altitude of the aircraft in feet at the point</td>
</tr>
<tr>
<td>LAT/Y</td>
<td>Decimal</td>
<td>Latitude coordinate in decimal degrees OR Y coordinate in nautical miles of the point</td>
</tr>
<tr>
<td>LON/X</td>
<td>Decimal</td>
<td>Longitude coordinate in decimal degrees OR X coordinate in nautical miles of the point</td>
</tr>
</tbody>
</table>

The user can use either x- and y-coordinates from one of FliteViz4D’s supported Earth projections or the latitude and longitude to represent the track positions in the FliteViz data format. FliteViz4D expects the units to be in nautical miles for the x- and y-coordinates or decimal degrees for the latitude and longitude. Mixing these can lead to visualization errors as well as calculation errors for distances in other features. The format does not allow for a mixed coordinate system representation within a single CSV file.

If only using the required parameters, some features of FliteViz4D may not work since the data is missing. To overcome this, optional fields can be added to allow for functionality that is more complete. These optional fields are shown in Table 2.
Table 2 – Optional Fields in the FliteViz Data Format

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC_EQUIP</td>
<td>String</td>
<td>Aircraft Equipage Code</td>
</tr>
<tr>
<td>AC_TYPE</td>
<td>String</td>
<td>ICAO Aircraft Type Identifier</td>
</tr>
<tr>
<td>ORIGIN</td>
<td>String</td>
<td>Origin airport</td>
</tr>
<tr>
<td>DEST</td>
<td>String</td>
<td>Destination airport</td>
</tr>
<tr>
<td>FLIGHT_TYPE</td>
<td>String</td>
<td>Flight type for the ARTCC (Over Flight [OVR], Departure [DEP], Arrival [ARR], Internal [INR])</td>
</tr>
<tr>
<td>ADHER_AGE</td>
<td>Integer</td>
<td>Adherence age² in seconds</td>
</tr>
<tr>
<td>BANK_ANGLE</td>
<td>Decimal</td>
<td>Angle in degrees the flight is banking at (negative number is banking left)</td>
</tr>
<tr>
<td>COMPOUND_ID</td>
<td>String</td>
<td>ID of the airspace compound the flight is in at this point</td>
</tr>
<tr>
<td>GROUND_SPEED</td>
<td>Decimal</td>
<td>Ground speed of the flight in knots at this point</td>
</tr>
<tr>
<td>HEADING</td>
<td>Decimal</td>
<td>Heading of the aircraft in degrees from North. Determined by FliteViz4D if not included</td>
</tr>
<tr>
<td>IN_APDIA</td>
<td>Integer</td>
<td>The APDIA³ the flight is in (if any)</td>
</tr>
<tr>
<td>LAT_OUT</td>
<td>Boolean</td>
<td>Whether the flight is out of lateral adherence</td>
</tr>
<tr>
<td>VERT_OUT</td>
<td>Boolean</td>
<td>Whether the flight is out of vertical adherence</td>
</tr>
<tr>
<td>ROCD</td>
<td>Decimal</td>
<td>Rate of climb/descent in ft/min. Negative number indicates descent</td>
</tr>
</tbody>
</table>

The FliteViz data format is purposely a simple comma delimited format with basic data types and supports the operation of FliteViz4D. However, it is a basic format so only supports a subset of the FliteViz4D features.

### 3.1.4 Performance Data Analysis Recording System (PDARS)

Performance Data Analysis Recording System (PDARS) is a system that continuously collects flight plan and radar track data from the ARTCCs, Terminal Radar Approach Control (TRACON) facilities, and from Air Traffic Control Tower (ATCT) facilities. The data collected from this system is available to FliteViz4D through the PDARS feature. The data from PDARS is the track and flight plan information.

### 3.1.5 Airspace Concept Evaluation System (ACES)

Airspace Concept Evaluation System (ACES) is a fast-time air traffic simulation platform developed by the National Aeronautics and Space Administration (NASA) Ames Research Center. The Modeling and Simulation Branch uses this software to create simulated air traffic recordings to be used for different analysis projects. To ensure that the data being output by the ACES program is correct, the capability to ingest the ACES file format was added to FliteViz4D. The data is stored in MySQL databases, to which

² The amount of time the aircraft adhered to its clearance/route. See (Nelson & Paglione, Determination of Lateral and Vertical Adherence to Route, 2013) for more information on Adherence.
³ Automated Problem Detection Inhibited Area – an airspace surrounding a terminal area within which automated problem detection (APD) is inhibited within that airspace
FliteViz4D has direct access. The ACES data contains conflict data, resolution data, flight data, and other detailed aircraft data.

3.2 FliteViz4D Visual Features

The visualization components of FliteViz4D are components of layers. These layers build the graphics for visualizing the flights, their tracks, and many other visuals for analysis work. The functionality of these layers can be described through display features, or what data components are actually visualized to the screen. In addition, FliteViz4D can calculate or take in different metrics and statistics. The data can then be tabulated alongside the visualization, displaying a mathematical representation of what the user is seeing. Lastly, different tools exist within the software to manipulate the visualization. The union of these features represents the FliteViz4D visual features.

This section explains the different layers, statistics, and tools that comprise the functional features within FliteViz4D. The following subsections discuss flight layer features, airspace layer features, statistics and metrics, and the other tools that FliteViz4D provides.

3.2.1 Flight Features

FlightViz4D allows the user to modify the actual representation of the aircraft and associated flight being animated. Either a basic aircraft model or a detailed aircraft model may be employed to represent a flight. The basic aircraft model is in the shape of a generic commercial aircraft, and there is a wide choice of colors available to distinguish the aircraft from each other. FliteViz4D chooses the default color randomly upon the start of the simulation, but the user can modify the color in the options menu using the color pallet provided. Figure 9 shows the basic aircraft model in FliteViz4D in the color red.

![Figure 9 – Example of a basic aircraft model in FliteViz4D](image)
The detailed aircraft model represents the aircraft as a detailed 3D model depending on the aircraft type. If the detailed 3D model exists in the FliteViz4D, it can be mapped to the same type actually flown, providing a higher fidelity animation. FliteViz4D will generate colors to help distinguish between them in the visualization and allow the user to modify or display the model with a specific livery if desired. Figure 10 illustrates an example of what the detailed flight models look like in FliteViz4D.

![Figure 10 – Example of detailed aircraft models in FliteViz4D](image)

The size of the aircraft model can be exaggerated to allow the user to find the aircraft easier. The amount of exaggeration is completely adjustable by the user, with the default having the aircraft model approximately five nautical miles wide, typically used for en route animations. For ground automations, the size can be reduced to approximate scale.

FlightViz4D represents the actual path or track the aircraft flew using 3D diamonds. These diamonds are shown in front and behind the aircraft in Figure 11. The track can be configured to show only the track points behind the flight, known as the trail, or only show the track points ahead of the aircraft, known as the lead. The entire track can be turned off as well.
Each aircraft has a label which shows the aircraft identifier (ACID) and other flight parameters. The user can choose up to two other parameters of the flight to show in the label. For example, Figure 11 shows the aircraft’s altitude and ground speed values. The available parameters that the label can show are described in Section 3.3. Each parameter has its own data requirements, and the user has to ensure that FliteViz4D has the required inputs to display the desired parameter correctly.

Around the aircraft is a wireframe in the shape of a hockey puck. This wire box depicts the minimum separation distance around the aircraft. If this wire box intersects another wire box of another aircraft, the two aircraft have lost legal separation between each other. Figure 12 shows an example of this box around two aircraft.
This box is useful in studying conflict properties in generated air traffic data. The box can be set to change color when it intersects another box to inform the user that an intersection has occurred. It allows the user to examine in detail the geometries of the flight or pair of flights during the maneuvers that make up their flight.

If FliteViz4D is given trajectory information, a wire box frame representing the predicted trajectory of the aircraft can be shown if it is enabled. The trajectory box is updated as the visualization proceeds through time. Figure 13 illustrates how the trajectory is represented in FlightViz4D.

![Figure 13 – Close up of a flight with its trajectory projected via wire frame](image)

With the trajectory information, FliteViz4D can show where the aircraft is predicted to be in the future. Using the look-ahead time slider bar on the control window, FliteViz4D can display the predicted position of the flight in the future. The user configures the amount of time in the future. A circle with a box around it indicates the predicted position of the aircraft, as shown in Figure 14.

![Figure 14 – Close up of flight with its predicted position 180 seconds into the future](image)
The user in the FliteViz4D control window sets how far ahead the predicted position box will be. This feature is useful in determining if the predicted trajectory of the aircraft leads to a conflict with another aircraft or with weather. This can help explain the interaction between the changing trajectory predictions and how an aircraft’s actual flight path materializes over time.

### 3.2.2 Airspace Features

The visualization in FliteViz4D allows the user to visualize more than just flights. The visualization can show state boundaries, allowing the user to visualize the context of the flight on earth. The type of projection of FliteViz4D’s map can be changed to one of the major projections when the user sets up the program. Figure 15 shows the map of the continental United States in FliteViz4D using the default settings.

![Figure 15 – The borders of the states of the United States in FliteViz4D](image)

Airspaces can be visualized in FliteViz4D as 3D polygons. Air Route Traffic Control Centers (ARTCC), Special Use Airspaces (SUAs), and sectors can be modelled and viewed in the visualization. Having these airspaces rendered in three dimensions allows the user to see what altitudes a section of airspace is, and what flights are in them. The three dimensional view can show different occurrences, like flights flying under or over an airspace. An example of how an airspace is rendered in FliteViz4D is shown in Figure 16. This figure displays flights flying within the Chicago ARTCC (ZAU), using a wire frame to show the horizontal and vertical boundaries of the ARTCC.
Weather has a dramatic impact on flight operations within the NAS. To help visualize why and how flights have rerouted, FliteViz4D can display weather polygons to show the weather that flights are trying to avoid. These weather polygons are a format defined by the Modeling and Simulation branch, with different colors indicating the intensity of the weather activity in the area (Young et al., 2011). Figure 17 displays a side view of the weather and flights over the Washington D.C. (ZDC) ARTCC.
FlightViz4D is able to render the polygons in three dimensions by partitioning them by altitude layers and severity. Switching to a top view, as shown in Figure 18, allows the user to see how flights are avoiding the weather in a large area.
FliteViz4D also implements visualizations for the locations of airports and fixes. These are simply represented by a two dimensional symbols on the ground. All of these options require additional data to be loaded into FliteViz4D. FliteViz4D gives the user a multitude of objects, paths, and statistics to visualize, making it a very feature rich visualization tool.

3.3 Statistics

Another important feature is the statistics module that calculates predetermined metrics and illustrates them for the user. These statistics help to explain what is going on in the visualization, and can assist in validating the animations that FliteViz4D generates. Table 3 shows the different parameters that FliteViz4D can currently calculate if configured accordingly.
Table 3 – Statistics that FliteViz4D can display/calculate

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjusted Max Ratio</td>
<td>The maximum ratio of distance by min separation distance</td>
</tr>
<tr>
<td>Adherence$^4$ Age</td>
<td>Amount of time the flight has adhered to its assigned route</td>
</tr>
<tr>
<td>Aircraft Type</td>
<td>Type of aircraft (e.g. B738 for a Boeing 738)</td>
</tr>
<tr>
<td>Actual Position</td>
<td>Current latitude, longitude, and altitude of the aircraft</td>
</tr>
<tr>
<td>Along Track Error</td>
<td>Positional error along the track</td>
</tr>
<tr>
<td>Altitude</td>
<td>The current altitude of the aircraft</td>
</tr>
<tr>
<td>Bank Angle</td>
<td>Angle at which the aircraft is inclined about its longitudinal axis with respect to the horizontal.</td>
</tr>
<tr>
<td>Clearance</td>
<td>The cleared altitude of the aircraft</td>
</tr>
<tr>
<td>Cross Track Error</td>
<td>Positional error abeam of the track</td>
</tr>
<tr>
<td>Destination</td>
<td>The destination airport of the aircraft</td>
</tr>
<tr>
<td>Encounter Angle</td>
<td>Angle between two aircrafts’ headings</td>
</tr>
<tr>
<td>Future Position</td>
<td>The position of the aircraft at the set look ahead time</td>
</tr>
<tr>
<td>Ground Speed</td>
<td>The ground speed of the aircraft</td>
</tr>
<tr>
<td>Heading</td>
<td>The heading of the aircraft</td>
</tr>
<tr>
<td>Horizontal Closure Rate</td>
<td>Rate at which two aircraft are getting closer laterally</td>
</tr>
<tr>
<td>Horizontal Error</td>
<td>Total horizontal positional error</td>
</tr>
<tr>
<td>Horizontal Separation</td>
<td>Distance between two aircraft laterally</td>
</tr>
<tr>
<td>In APDIA$^5$</td>
<td>Whether the aircraft is in an APDIA</td>
</tr>
<tr>
<td>Lateral Conformance</td>
<td>Whether the aircraft is laterally in conformance to the trajectory</td>
</tr>
<tr>
<td>Longitudinal Conformance</td>
<td>Whether the aircraft is longitudinally in conformance to the trajectory</td>
</tr>
<tr>
<td>Max Ratio</td>
<td>A loss of separation metric detailed in [wherever]</td>
</tr>
<tr>
<td>Origin</td>
<td>The origin airport of the aircraft</td>
</tr>
<tr>
<td>Predicted Position</td>
<td>The position predicted by the trajectory engine at the set look ahead time</td>
</tr>
<tr>
<td>Trajectory Age</td>
<td>The difference between the current time and the build time of the trajectory</td>
</tr>
<tr>
<td>Trajectory Horizontal Separation</td>
<td>The horizontal distance between the actual and predicted positions of the aircraft</td>
</tr>
<tr>
<td>Trajectory Vertical Separation</td>
<td>The vertical distance between the actual and predicted positions of the aircraft</td>
</tr>
<tr>
<td>Vertical Closure Rate</td>
<td>Rate at which two aircraft are getting closer vertically</td>
</tr>
<tr>
<td>Vertical Conformance</td>
<td>Whether the aircraft is vertically in adherence to the trajectory</td>
</tr>
<tr>
<td>Vertical Error</td>
<td>Total vertical positional error</td>
</tr>
<tr>
<td>Vertical Separation</td>
<td>Distance between two aircraft vertically</td>
</tr>
<tr>
<td>Wake</td>
<td>Turbulence the aircraft generates</td>
</tr>
</tbody>
</table>

$^4$ See (Nelson & Paglione, 2013) for more information on adherence

$^5$ APDIA - Automated Problem Detection Inhibited Area
Since FliteViz4D can display flights with just the track information, additional inputs are required for generation of some of these metrics.

### 3.4 Tools

A number of tools are implemented in FliteViz4D to give the user more information about aircraft, utilizing the statistics mentioned in Section 3.3, or help the user adjust the visualization to allow for a better view of what they are looking for. Tools like Flight Filter and Move Label allow the user to reduce the number of flights and move the flight labels around to get a better view of what they want to see.

The Flight Details panel is a one-stop source of many statistics for a flight or multiple flights. When doing pair-wise analysis on aircraft, the Pairs tab in the Flight Details window gives the user a great deal of information about the two aircraft. As shown in Figure 19, the statistics for each individual aircraft is calculated, as well as the statistics between the pair. Section 3.3 describes all of the statistics that can be displayed in FliteViz4D’s Flight Details window.

![Figure 19 – Flight Details window in FliteViz4D showing Pairs statistics](image)

In the Flight Details window under the Pairs tab, the user can add new pairs to or remove existing pairs from the list of paired flights. The individual statistics for each aircraft is shown in the bottom left-hand corner, while the paired statistics is shown in the bottom right hand corner.

If only a single flight’s statistics are needed, then the Flight tab can be used in Flight details. This tab shows the statistics for the individual aircraft similar to the way it is
shown in the Pairs tab, but with only one flight. The user can switch between flights, and can set the camera to follow the selected flight. Figure 20 displays the Flight Details window being used to view the statistics of the selected aircraft.

Figure 20 – Flight Details window showing the statistics for only one aircraft
4. Summary
Flexible Flight Traffic Exploration Visualization 4D (FliteViz4D) is a flight visualization tool that was developed for analyzing recorded and simulated air traffic. It is a microscope for examining different aspects of air traffic for a variety of studies. FlightViz4D provides detailed statistical information on the location of flights and distances between flight pairs. Its 3D camera allows the user views from any angle to explore complex spatial relations in datasets. Live DVR can be used to record the visualization for presentations, allowing for great visual examples to complex explanations. With the power to visualize weather data, flight trajectories, flight paths, and airspaces, the visualizations can be used in almost any study being performed.
5. References