Flight Data Visualization and Post-test Flight Data Analysis System by Using Database

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Abstract — Flight test is conducted to prove performance required. Aircraft development engineers or flight test engineers use visualization tools for flight test to monitor aircraft performance in Flight Telemetry Ground Station. Thereafter, telemetry flight data are analyzed by analyzing tools after flight test. Conventional systems used for flight test record the real time flight data into certain storage medium based on file. Thus, to analyze data after flight test, complicated steps of download and import process are needed. In this paper, two kinds of systems based on database are designed and implemented for flight test. Suggested systems provide useful visualization tools that monitor performance of the aircrafts and designed to store real time telemetry data into database during the flight test. Also, proposed systems are designed to analyze flight test data easily in various search conditions and to visualize the same situations of past flight test immediately by using. Some tools of the suggested system are already in use in the field of flight test and more tools will be applied.

Index Term — Flight Data Visualization, Post-test Flight Data Analysis, Flight Telemetry Ground Station, Database, Track Display

I. INTRODUCTION

Aircraft development life cycle is divided into 3 phases: First, concept phase that the overall aircraft performance and configuration are determined, such as payload and range, aircraft size, number and locations of engines, airfoil, applications of new technologies in design and manufacturing. Second, development phase which consists of function, architecture, design and implementation. Last, production and operation phase that production and operation are managed. Due to the highly complex and integrated nature of modern aircraft systems, the regulatory authorities have highlighted concerns about the possibility of development errors causing or contributing to aircraft failure conditions. Thus, certification procedure which applies instructions of DO-178B/ED-12B and DO-254/ED-80 should be followed to prevent development errors on developed aircrafts[1, 2, 3, 4].

Flight test should be conducted by not only safe but also definite means to prove required performance of aircrafts in real world. Also, overall system performance should be monitored to confirm PFCS(Primary Flight Control System) and SFCS(Secondary Flight Control System) function correctly under normal operating conditions throughout the aircraft’s flight envelope [5, 6].

FTGS (Flight Telemetry Ground Station), a facility that receives, processes and visualizes telemetry data from remote location to monitor the aircraft performance during flight test, is used. In this facility, aircraft development engineers or flight test engineers monitor performance of the aircraft with data visualization tools such as map display, 3D aircraft model display, etc.[7-11].

After each flight test, there are a number of actions that should be taken to assure weather the objectives of the flight were met, no unexpected results were encountered, and to determine when the next flight can be conducted. Analyzing tools are required for PFD (Post Flight Debrief), which is carried out after flight test, data may be useful such as telemetry flight data sheets, graphs and video records of flight test conducted in a chronological order to ensure completeness[5].

Conventional flight test tools usually have been developed is that recording the real time telemetry data during flight test into certain storage medium on file basis. Also, real time flight data are categorized and recorded by each flight sorties. Therefore, complicated steps of download and import processes are required to search certain point of certain parameter for analysis in numerous flight test files.

In this thesis, we propose flight test tools based on database, unlike conventional systems based on files. Suggested tools are grouped together by FDVS(Flight Data Visualization System) and PFDAS(Post-test Flight Data Analysis System). FDVS is designed to enable engineers, who conducted flight test or participated in aircraft development, to monitor aircraft status during flight test in real time. Real time telemetry data received during flight test are immediately stored in database. PFDAS is designed not only to debrief and analyze flight test data easily by various conditional search but also to visualize the same situations of past flight test by using database.

II. BACKGROUND

A. Flight Data Visualization

It is very important for aircraft development engineers or flight test engineers to check unexpected failure of on-flight aircraft and to monitor status of the aircraft for decision making for test[5]. For this reason, flight data visualization tools are used, which collect data of the aircraft from remote location and display[12-15]. These tools are used in MCR (Mission Control Room) in FTGS, which controls and monitors flight test missions, which is shown as Fig. 1.
[12] research introduces 2D and 3D model visualization and interface structure of precise data display as well as concept for design and implementation of Flight Data Visualization System and also discusses how to manage big scale of geographic models and data sets effectively in real time 3D application.

[15] research suggests waypoint tracking visualization system to help pilot recognize current flight status and alarm possible collision by analyzing flight path and geographic information. This system consists of Flight Manipulation System, Visualization/UDP Engine, Visualization Panel and Waypoint Tracking. This system is designed to be adapted for aircraft development or flight training. However, there are limitations on visualizing primary control surfaces (Aileron, Rudder and Elevator) and 3D motion (Pitch, Roll and Heading).

There is a commercial system used for data visualization in FTGS. This system consists of 3 parts; Mathematical Display Application, 3D Display Application and Map Display Application to display telemetry data in various forms. Since this system provides Display Editor, which is able to produce complicated images easily, it can be adapted for many types of airplane. However, it doesn't follow DO-178B/C (Software Considerations in Airborne Systems and Equipment Certification). And this system provides the function of 3D Display by allocating Pitch, Roll, Heading and Altitude for 3D attributes. However, there are limitations in representing precise motions of aircraft such as Aileron, Rudder, Elevation, Landing Gear, etc. Map Display Application of this system provides display of overlaid parameter data in GIS (Geographical Information System) data. This application can display the position and track of airplane on existing GIS data (Roads, Rivers and Political boundaries), as well as zoom-in and zoom-out are available. It also provides tool (lines, test and polygons) so that users can draw additional features on the map. However, there is deterioration in map reality that GIS data are implemented, applied in this application, when compared with real satellite map images. Moreover, it is impossible to display position of aircraft in one map when testing 2 or more aircrafts. In addition, heading of the aircraft can not be expressed.

B. Post-test Flight Data Analysis

Flight test engineers need to analyze stored telemetry data after flight test to confirm abnormal events or defects of facilities and define causes.

There are cases that FDR (Flight Data Recorder) and Pro-spector are used to support those needs [16, 17]. In those cases, commercial web browser application is provided which imports flight test data into centralized data storage device and export file to use in analysis system. This application stores telemetry data during real time flight test into server in certain file format or Chapter 10 format suggested by IRIG 106 [18], which is digital recording standard. To utilize these stored files for analysis after flight test in visualized form, file importing process is required. Application users access through the web browser, then retrieve required data with web page interface. The retrieved data can be displayed in graphs, also can be saved in CVS or Matlab form of files through exporting process. The source files used in this application are stored by sortie. This mechanism is the cause of increasing costs of data manipulation and search for analysis after flight tests.

[16] reads data from FDR, lists up and schematizes the data. Thereafter, it shows 3 dimensional aircraft model which displays cockpit instrument panel and aircraft control surfaces deflection by using animation function. It also provides aircraft track display by using map images obtained from GIS tool and Google Earth.

C. Requirements

Usually in conventional systems, data for analysis after flights test are stored in certain storage media. To search or to re-visualize the data on abnormal event, complicated steps are required. This requirement is the cause of cost increase for analysis, when flights test files are accumulated and increased. To overcome this limitation, it is necessary to utilize database which effectively stores real time telemetry data during flight test, is also able to search data in various conditions immediately, ensures safety of data management and is able to support various applications.

Moreover, improvements are needed as follows on the flight test tools usually used nowadays;
- 3D model display tool should be designed to monitor the aircraft status more precisely by visualizing not on-
ly primary control surfaces (Aileron, Rudder and Elevator) but also 3D motion (Pitch, Roll and Heading) and status of engine ignition or landing gears.

- Instrument Display tool should be implemented by qualified code generators with DO-178B/C[23].
- Create own converting formulae to display the exact position of aircraft on Google satellite images under particular flight test environment that internet can not be connected.
- Track Display tool should be enable to display up to 4 aircrafts simultaneously.

III. SYSTEM DESIGN AND IMPLEMENTATION

The development scope of the suggested system is the dotted part of Fig. 2. It is designed with FDVS, which receives the telemetry data of real time status of the aircraft and monitors flight test process and PFDAS, which stores data into database and helps analyzing data after flight test.

In Fig.3, FDVS is designed to visualize flight test process by providing 3D Display, Instrument Display and Track Display tools. PFDAS consists of Data Searching Module, Data Recording Module and Data Representation Module. These Modules enable to retrieve data for analysis and to output the retrieved data values in graphs or CSV form of file by using database. They are also designed to revvisualize past flight test by being interconnected with FDVS.

A. Flight Data Visualization System

1) 3D Model Display

As shown in Fig. 4, 3D Model Display tool displays altitude of aircraft (Pitch, Roll and Yaw) in 3D coordinate system by using 3D aircraft model. It also displays primary control surfaces (Aileron, Rudder and Elevator) and landing gear, engine ignition status to confirm altitude change of aircraft.
Furthermore, it displays data of Pitch, Roll, Heading, VOR(VHF Omni Range), Altitude, IAS(Indicated Airspeed), VS(Vertical Speed) and RPM(Revolution Per Minute) on instrument images. 3D Model Display tool is implemented by Unity 3D which is usually used for 3D visualization system[21, 22].

3D Model Display tool has 4 layers as shown in Fig. 5. Communication Layer receives real time data by using TCP socket from real-time data transmission module and Data Layer interprets data in pre-designated order and records in buffer. 3D Driver Layer displays 3D background and aircraft model on screen, executes the program written in script to display altitude of aircraft model, primary control surfaces, landing gear and operation of engine ignition.

2) Instrument Display

Instrument Display tool is implemented by using SCADE Display and SCADE Suite which have qualified code generators with DO-178B/C[19, 20]. It displays aircraft data and its environment such as air speed, altitude, Pitch, Roll, Heading and Ground speed, and it is designed to look same as instrument display in cockpit of aircraft. Instrument Display tool consists of 3 Layers; Data Receive Layer which receives real time data, Display Layer which displays flight data on instrument model and I/O Management Layer which manages input and output between telemetry data and instrument model.

Display Layer displays telemetry data on the screen by using instrument model. Fig.6 shows integrated development environment to design instrument model with SCADE Display.

3) Track Display

Track display tool is designed to display position, nose direction, mission track, place name and flight area of up to 4 aircrafts on map image of Google Earth by using aircraft shaped icons. Aircraft data is received from data process equipment of telemetry ground station. These data should be converted into the position data of the plane coordinate system to display the GPS data and the TACAN(Tactical Air Navigation) data, which is implemented in polar coordinate system on Google satellite image of plane coordinate system. These steps are required because flight test is conducted at facility environment that internet is not connected. To map GPS data into pixel data, altitude data and latitude data at the left bottom and the right top, length and width information of the map that are shown of the Fig. 8 map image are used.

Fig. 4. Coordinate system applied to the aircraft.

![Fig. 4](image)

Fig. 6. Design of instrument model with the SCADE Display.

![Fig. 6](image)

Fig. 7 shows tool to connect I/Os between SCADE Suite model and SCADE Display model in Fig. 6.

![Fig. 7](image)

Fig. 7. Data combination with the SCADE Suite.

![Fig. 7](image)
Function (1) concludes X axis pixel value by receiving Lon\(\theta\) which is longitude data of aircraft, Function (2) concludes Y axis pixel value by receiving Lat\(\phi\) which is latitude data of aircraft. Width, height, a, b, c and d indicate the coordinate value of Fig. 8.

\[
x = \left(\frac{\text{width}}{c - a}\right) \times (\text{Lon}\theta - a) \tag{1}
\]

\[
y = \left(\frac{\text{height}}{d - b}\right) \times (d - \text{Lat}\phi) \tag{2}
\]

TACAN provides VOR and distance from antenna. Position of aircraft is defined from VOR and DME by assuming the position of the antenna as origin. Fig. 9 indicates position of aircraft by using real time data of VOR, DME and ALT on longitude, latitude and altitude axis.

\[
\text{P} = \text{LonA} + D \times \cos(\theta - 90) \times 0.020503 \tag{3}
\]

\[
\text{Q} = \text{LatA} + D \times \sin(\theta + 90) \times 0.0165884 \tag{4}
\]

Current position and direction of aircraft are displayed in real time on the map in aircraft icon. Coordinate system space provided by Win32 API (world, page and device) is used to display the icon. Aircraft icon is rotated by using real time data of aircraft direction in world coordinate system space. Then the center of the rotated icon is moved to the origin, when rotated icon is marked on page coordinate space. Thereafter, a page with aircraft icon is drawn on monitor screen, the GPS longitude and latitude coordinates are marked on the map in pixel coordinates.

**B. Post-test Flight Data Analysis System**

In conventional system, flight test data are recorded in certain form of files of storage medium and managed by each flight sortie. Thus, as number of flight sortie increases, time for data search for analysis increases accordingly. This thesis suggests database based integration and management of data, instead of file based flight data managed by flight sortie. This system enables to store all received real time data in database and to manage, so that they can be easily used in several application programs.

Suggested PFDAS consists of data Recording, Data Searching and Data Representation module. Fig. 10 shows block diagram of this system.

1) **Database**

Modules on database are designed based on relational database model, as a part of PFDAS platform. Database takes the most important role in this suggested system. All the telemetry data during flight test are immediately stored in database, and the database has two uses. First, it is used for many kinds of
analysis after flight test. It is also used for revisionalization of flight test conducted in the past through 3D Model Display, Instrument Display and Track Display tools of FDVS. Database is designed to depart real time data and historical data subjectively. It categorizes real time data which is mostly write operations and historical data which mostly perform read operations, so that it can ensure recording speed and searching speed by index. Database table consists of approximately 200 attributes to record telemetry flight data, it receive 50 times of data per second. Fig. 11 shows some parameters that compose the table.

```
<table>
<thead>
<tr>
<th>field name</th>
<th>test name</th>
<th>date</th>
<th>accel</th>
<th>aileron_l</th>
<th>aileron_r</th>
<th>alt</th>
<th>lat</th>
<th>lon</th>
<th>...</th>
<th>pitch</th>
<th>roll</th>
<th>yaw</th>
</tr>
</thead>
<tbody>
<tr>
<td>type</td>
<td>VARCHAR20</td>
<td>DATE</td>
<td>float</td>
<td>float</td>
<td>float</td>
<td>int</td>
<td>float</td>
<td>float</td>
<td>...</td>
<td>float</td>
<td>float</td>
<td>float</td>
</tr>
</tbody>
</table>
```

Fig. 11. Table structure.

2) Data Recording

Data Recording Module is interconnected with real time data process equipment. The received real time data are stored in database. Communication Layer consists of Connection Management and TCP socket communication, is linked with real-time data transmission equipment through network. Process Layer interprets data framed and transmitted via socket and sends it to Data Buffer. Data Layer accesses database and stores data from Data Buffer.

3) Data Representation

Data Representation Module is used when revisionalization of past flight test is needed. Data Representation Module replays historical data stored in database, interconnects with FDVS and revisionalizes past flight test. Data Layer accesses and retrieves data with conditions that are users input from User Interaction Layer. Data Process Layer converts data retrieved from database into socket data transmission form which can be used in FDVS, and transmits by using socket.

4) Data Searching

If unexpected failures of aircraft or events of flight test mission are found during flight test, flight test engineers would perform data analysis after flight test. Data Searching Module is designed for those analytic works to be easily performed interactively based on web, provides menu driven search functions. Searched data are to be displayed in tables and graphs, converted into files for saving. User Interaction Layer consists of ‘Data Chart Display’, ‘Export CSV File’ and ‘Select Service Menu’, follows user’s command and displays retrieved data.

Menu driven searching functions are ‘Parameters Search’, ‘Comparative Search’, ‘Conditional Search’ and ‘File Export’. ‘Parameters Search’ function shows all parameter data collected in certain flight test in table form. ‘Comparative Search’ function is used when parameter comparison analysis is required in timely manner in certain flight test. Number of compared parameters is from 2 up to 4. ‘Conditional Search’ function is for every flight test stored in database, and can be used to analyze weather certain selected parameter value is in certain range. ‘File Export’ function is designed for users to convert flight test data into certain form of file so that users are able to apply general analytic tools.
IV. ACHIEVEMENTS

A. Database

In Fig. 12 and Fig. 13, the data processing procedure after flight test for data analysis of suggested system and conventional system are compared. Fig. 12 shows procedure of conventional systems.

Several steps are needed as follows to use telemetry flight data after flight test. First, PCM data from RF Receiver in Chapter 10 format record into cartridge memory of Data Recorder. To use the data, cartridge memory should be removed from Data Recorder and inserted to Read/Write Device, which is connected with I/O PC and download to I/O PC as file format. Thereafter, upload the files to Disk Array of Web Server and store in Disk Array. Data Processor also records telemetry data in real time. To use the data recorded in Data Processor, it should be downloaded to storage of Control Server, then again uploaded to Disk Array of Web Server. Finally, the flight data stored in Disk Array should be imported for usage of analysis work.

On the contrary, suggested system needs the following procedure, as shown in Fig. 13, for storing real time data storage, analysis and revisualization.

Flight data are directly stored in the database server connected with Data Processor during flight test. The stored data can be immediately used at any time for analysis without any other processes. Suggested system enables real time data process for analysis not only during flight test but after flight test. Furthermore, Engineers who are participated in development can share data and use in several applications for various analytic works. Moreover, it enables integrated management, policy for security maintenance and to ensure physical and logical data independence.

Suggested system can also provides redisplay of situations in past flights test. Hereat, FDVS is used. In other words, past flight test can be immediately revisualized by using 3D Model Display, Instrument Display and Track Display tools of suggested FDVS with database.

B. Flight Data Visualization System

Fig. 14 shows screenshot of 3D Model Display implemented.

The altitude of the aircraft is displayed in the center of the screen by receiving data of Pitch, Roll and Heading. By using mouse, 3D model can be rotated in various angles, zoom in and out are also available. Implemented 3D model can display the motion of primary control surfaces by data of receiving data of Aileron, Rudder and Elevator. It also displays the status of engine ignition and motion of landing gear when taking off and landing. Image of dedicated camera for landing gear is displayed in the left bottom of Fig. 14 for zoom-in of landing gear motion. The right bottom of Fig. 14 shows the part which displays instrument information simplified PFD of aircraft. Instrument information displayed here are HDG, Pitch, Roll, Altitude, IAS, Engine Torque, VOR, Vertical Speed Rate, etc.

Fig. 15 shows screenshot of instrument display for PFD of aircraft cockpit, which is implemented by using SCADE Display and SCADE Suite.

GPS position data have errors, since geographical coordi-
nate system have converted into plane coordinate system. To correct these errors, functions are implemented that take the latitude and longitude data as parameters and output correction value. Function (5) corrects longitude errors and function (6) corrects latitude errors.

\[ R = 0.2 \times (\text{longitude} - 126.5) \times (38.81521 - \text{latitude}) + 20 \times (\text{longitude} - 124.4143) + 2 \]  
(5)

\[ S = (-2) \times (38.82521 - \text{latitude}) \times |\text{longitude} - 127.5| + (-17) \times (\text{latitude} - 36)^2 + 166 \]  
(6)

Pixel values from the calibrating functions are shown in Fig. 16 and Fig. 17.

Since corrected pixel values are implemented in 2-dimensional map, it is possible to display more precise position of aircraft. Fig. 18 shows track display performed by receiving telemetry data of aircraft (Latitude, longitude, Heading, Altitude, VOR and DME). Up to 4 aircraft icons are displayed at the locations that synchronized with position data.

4 boxes on the left top in Fig. 18 display information of on-flight aircrafts, such as position, altitude, speed, etc. Up to 4 aircrafts are visualized on one screen at the same time when multi flight test, it helps decision making since it enables engineers to expect aircraft direction by implemented direction of aircraft nose.

C. Post-test Flight Data Analysis System

Suggested system provides various search functions based on web. Fig. 19 shows main web page of PFDAS.
Menu provides ‘Parameters Search’, ‘Comparative Search’, ‘Conditional Search’, ‘File Export’, etc. In ‘Parameters Search’ function, when search conditions are entered on the search screen, flight test name in that date can be selected on search list. Flight test data list requested is shown in Fig. 20.

‘Comparative search’ function is designed to show data in graphs so that data are to be compared and analyzed as follows Fig. 21, when flight test name and up to 4 parameters to be compared are selected. In the screenshot, the vertical axis indicates unit of parameter values, the horizontal axis indicates time unit. Engineers are able to precisely confirm the data value by graph zoom-in and zoom-out.

‘Conditional Search’ function provides data analysis function for every flight test. This menu shows trends of selected values, when users select parameters to be analyzed among every flight test data. In Fig. 22, vertical axis indicates value of search range, horizontal axis indicates time unit.

‘File Export’ function performs converting data that retrieved by entering certain flight test name into file. Fig. 23 shows output of converted Excel file from flight test data.

V. CONCLUSION

Flight Data Visualization System and Post-test Flight Data Analysis System by using database are suggested in this thesis. In conventional systems, complicated steps of data process are required to search, analyze and revvisalize the points of
abnormal events. In this suggested system, it is possible to store received flight test data into database in real time so that data analysis can be immediately conducted without complicated data process procedure, and searching in various conditions is also available. 3D Model Display tool of Flight Data Visualization System for real time data monitoring is designed to implement not only the altitude of the flight but also motion of primary control surfaces. Stable Instrument Display tool is implemented by using SCADE Suite and SCADE Display that provide safety-critical programming environment. After several times of test in field, we could verify the fact that Track Display tool displays the exact position of aircraft on Google satellite images up to 4 aircraft.

Post-test Flight Data Analysis System for data analysis after flight test enables various conditional searching by using database. And it is designed to output the retrieved data in graphs or various formats of files. Also, database and Flight Data Visualization System are linked so that past flight test can be easily visualized.

Some tools of the suggested system have already been used in FTGS. The rest of the tools will also provide improved flight test environment to engineers after several steps of tests and qualification procedures.

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