# FDR data as a source for flying events visualisation and aircraft parameter estimation

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DOI: 10.13111/2066-8201.2012.4.3.3

***Abstract:*** *The hundreds of parameters that are recorded by Flight Data Recorders (FDR) during flight facilitates the investigation of incidents and also provides the opportunity to use the recorded data to predict future aircraft behaviour.*
*Current researches are oriented in the direction of data detection responsible for a typical behavior of flight, data reconstruction and flight simulation.*
*This paper presents a mathematical model for aircraft used in flight data interpretation, and an application that can give the graphical representation of any flight data parameter. Also, using a preprocessed data set, application produces a flash animation of the aircraft flight.*

***Key Words:*** *FDR data, mathematical model, flight data interpretation*

## 1. INTRODUCTION

The diversity and the number of civilian applications involving the use of aircraft study are continuously growing. Although these vehicles incorporate the newest technologies and expertise in use, it is also accompanied by an increase in accidents. Accident investigators traditionally use flight data to investigate major accidents and require highly accurate and flexible tools. With the appropriate software, the investigator can then visualize the airplane's attitude, instrument readings, power settings and other characteristics of the flight. Today, many airlines have Flight Data Analysis (FDA) programs, essentially proactive systems to exploit recorded flight data on a daily basis.

Within the effort of supporting the research and development in the field of aeronautics and flight safety, this work represents a complementary contribution to a better understanding of flight events, and allows establishing faster and with a better accuracy the causes that have led or have favored their occurrence. Also software application contributes to flight events prediction and to the avoidance of the potential risk situations. The software simulation is developed to analyze, in an objective manner, the premises of a flight incident of an aircraft and will help to identify, investigate, and correct the factors that create future accident. The proposed graphical animation enables the investigating team to visualize the moments of the flight before the event.

The animation processes are activated through an ergonomic and configurable graphical user interface with multiple information focused on functions. For a better communication between the user and applications, graphic symbols are coupled with a text and the 3D virtual scenes are sent to the screen-windows. Computer Special Keyboard Keys in order to provide navigation facilities in the virtual scene (changes of the viewpoint, of the angle of view and of the observed point). Some results can be stored in text files or video file. Data analysis in terms of systematic errors is essential, and consists for example, in matching the state data recorded at the time with the state data which were obtained at the same time *t* from the existing state at time *t-1*.

## 2. ACCIDENTAL EVENTS IN AERONAUTICS AND THE USE OF FDR

The accidents and incidents in aviation transports [1] are in general catastrophic events, very expensive for the aviation industry and for the people involved represent extremely situation with a big global impact in all the media over the world. Aviation accident in the official definition means an event associated with the operation of an aircraft in which:

(a) a person or many suffers a fatal or serious injury;

(b) the aircraft sustains damage or structural failure which adversely affects its strength, performance or flight characteristics and require a major repair or replacement;

(c) the aircraft is missing or is completely inaccessible.

This definition not include engine failure or damage, when the damage is limited to the engine, its cowling or accessories; or for damage limited to propellers, wing tips, antennas, tires, brakes, fairings, small dents or puncture holes in the aircraft skin. Accidental events are always the result of several contributing factors, in general is difficult to locate a single cause.

The causes of the aviation accidents and incidents [2] are in present separated in two: human causes and technical causes. If we look at the statistics and analyse the aviation accidents recorded during 1950 – 2004, there were 2147 serious accidents, resulting in damage or destruction of aircraft. The causes involved are:

- In 45% of cases the cause is clearly "a human error"
- In 30% of cases could not be defined the exact cause or further research is also carried out,
- In 13% of cases, the cause was due to technical defects of aircraft,
- In 5% of cases, the weather cause was decisive,
- In 4% of cases the cause was terrorist acts, sabotage, hijacking etc.
- In 3% of cases the causes was related to the activity of ground, etc.

In order to monitor and to have the possibility to analyse the flight parameters for an air-plane the installation of a Flight Data Recorder (FRD) is in many cases mandatory. FDR is a separate unit installed on an aircraft capable to record, in time, a large number of aircraft’s in flight parameters. The main purpose of an air-plane FDR system is to collect and record data from a variety of air-plane sensors onto a medium designed to survive an accident. In present this system is combined with a device capable to record conversation in the cockpit, radio communications between the cockpit crew and the ground station. The total system is currently called “black box” and the unit is mounted separately in an envelope capable to resist at impact with ground at big speed and to the heat of an intense fire. FDR are usually located in the rear part of the aircraft, typically in the tail. After an event or an accident, the recovery of the FDR is mandatory and the investigating body use the recorded parameters in order to identify the causes of the event.

The idea of using a "black box" (in reality the colour of the equipment is orange) appear in the year 1945-1950 when the Civil Aeronautics Board from USA issued a regulation about the installation of an FRD system on the civil air crafts. In 1958 the first crashprotected system of record was tested and accepted. The recorded parameters were five at that time: altitude, airspeed, heading and vertical accelerations as a function of time. In time the FDR system may consists of an analogue or a digital flight data acquisition unit and a digital recorder.

The support for data recording was different in time according with the evolution of the technology: a photo-graphical paper, a magnetic tape or a solid-state memory. The first generation of FDR recorded only five parameters including acceleration, air speed, compass heading, time and altitude.

In the present there are analogue and digital FDR. The third generation of FDR (known as SSFDR) were introduced in 1990 and uses solid-state technologies for recording data. These recorders can record up to 256 operational parameters for 25 hours [3]. In time the aeronautical authorities have had many problems in order to recuperate and locate the "black boxes" after a crash and a new solution is to communicate wireless the flight parameters on a data-link in real-time.

By regulation, newly manufactured aircraft must monitor at least twenty eight important parameters such as time, altitude, airspeed, heading, and aircraft attitude. In addition, some FDR can record the status of more than 300 other in-flight characteristics that can aid in the investigation.

The Flight Data Recorder and the Cockpit Voice Recorder are important and valuable tools in the accident investigation process. Both are reliable data sources in order to provide information that may be difficult or impossible to obtain by other means.

It is important to use the data on the recorders used in conjunction with other information gained in the investigation or in the case of determining the Probable Cause of an aircraft accident. Using computer and audio equipment, the information stored on the FDR recorders is extracted and translated into an understandable format. The investigation can uses this information as one of many tools to help the specialists to determine the causes of the accident.

Air traffic control tapes with their associated time codes are used to help in order to determine the local standard time of one or more events during the accident sequence. These times are applied to the transcript using a computer process, which provides a local time for every event on the transcript.

## 3. TYPICAL STRUCTURE OF DATA FOR RECORDED FLIGHT PARAMETERS

Today FDR systems can record hundreds of parameters (to facilitate aircraft accident investigations, in 1977 the Federal Aviation Administration [5], has increased the requirements for FDR to include a minimum of 88 parameters). The data parameters type can be binary, nominal, interval-scaled or ratio-scaled in the raw binary format. Before proceeding with the analysis of flight data, a preprocessing must be done. An essential step in data preprocessing is the engineering unit conversion where the raw binary data is mathematically processed to obtain the relevant engineering unit. Also, the data preprocessing is required to ensure validity of the data and consists in removal wrong data corrupted by measurements, data normalization and data reconstruction. To identify the flight data that correspond to atypical behavior of an aircraft is also a very difficult process.

Tipically, the flight data can be divided mainly in four categories, the motion and air data variables, the control variables, the engine variables, and the discrete variables. The minimal list of FDR parameters was recommended by FAA in 1977:

(1) Time;
(2) Pressure altitude;
(3) Indicated airspeed;
(4) Heading--primary flight crew reference (if selectable, record discrete, true or magnetic);
(5) Normal acceleration (Vertical);
(6) Pitch attitude;
(7) Roll attitude;
(8) Manual radio transmitter keying, or CVR/DFDR synchronization reference;
(9) Thrust/power of each engine--primary flight crew reference;
(10) Autopilot engagement status;
(11) Longitudinal acceleration;
(12) Pitch control input;
(13) Lateral control input;
(14) Rudder pedal input;
(15) Primary pitch control surface position;
(16) Primary lateral control surface position;
(17) Primary yaw control surface position;
(18) Lateral acceleration;
(19) Pitch trim surface position or parameters of paragraph (a) (82) of this section if currently recorded;
(20) Trailing edge flap or cockpit flap control selection (except when parameters of paragraph (a) (85) of this section apply);
(21) Leading edge flap or cockpit flap control selection (except when parameters of paragraph (a) (86) of this section apply);
(22) Each Thrust reverser position (or equivalent for propeller airplane);
(23) Ground spoiler position or speed brake selection (except when parameters of paragraph (a) (87) of this section apply);
(24) Outside or total air temperature;
(25) Automatic Flight Control System (AFCS) modes and engagement status, including autothrottle;
(26) Radio altitude (when an information source is installed);
(27) Localizer deviation, MLS Azimuth;
(28) Glideslope deviation, MLS Elevation;
(29) Marker beacon passage;
(30) Master warning;
(31) Air/ground sensor (primary airplane system reference nose or main gear);
(32) Angle of attack (when information source is installed);
(33) Hydraulic pressure low (each system);
(34) Ground speed (when an information source is installed);
(35) Ground proximity warning system;
(36) Landing gear position or landing gear cockpit control selection;
(37) Drift angle (when an information source is installed);
(38) Wind speed and direction (when an information source is installed);
(39) Latitude and longitude (when an information source is installed);
(40) Stick shaker/pusher (when an information source is installed);
(41) Windshear (when an information source is installed);
(42) Throttle/power lever position;
(43) Additional engine parameters (as designated in Appendix M of this part);

(44) Traffic alert and collision avoidance system;
(45) DME 1 and 2 distances;
(46) Nav 1 and 2 selected frequency;
(47) Selected barometric setting (when an information source is installed);
(48) Selected altitude (when an information source is installed);
(49) Selected speed (when an information source is installed);
(50) Selected mach (when an information source is installed);
(51) Selected vertical speed (when an information source is installed);
(52) Selected heading (when an information source is installed);
(53) Selected flight path (when an information source is installed);
(54) Selected decision height (when an information source is installed);
(55) EFIS display format;
(56) Multi-function/engine/alerts display format;
(57) Thrust command (when an information source is installed);
(58) Thrust target (when an information source is installed);
(59) Fuel quantity in CG trim tank (when an information source is installed);
(60) Primary Navigation System Reference;
(61) Icing (when an information source is installed);
(62) Engine warning each engine vibration (when an information source is installed);
(63) Engine warning each engine over temp (when an information source is installed);
(64) Engine warning each engine oil pressure low (when an information source is installed);
(65) Engine warning each engine over speed (when an information source is installed);
(66) Yaw trim surface position;
(67) Roll trim surface position;
(68) Brake pressure (selected system);
(69) Brake pedal application (left and right);
(70) Yaw or sideslip angle (when an information source is installed);
(71) Engine bleed valve position (when an information source is installed);
(72) De-icing or anti-icing system selection (when an information source is installed);
(73) Computed center of gravity (when an information source is installed);
(74) AC electrical bus status;
(75) DC electrical bus status;
(76) APU bleed valve position (when an information source is installed);
(77) Hydraulic pressure (each system);
(78) Loss of cabin pressure;
(79) Computer failure;
(80) Heads-up display (when an information source is installed);
(81) Para-visual display (when an information source is installed);
(82) Cockpit trim control input position--pitch;
(83) Cockpit trim control input position--roll;
(84) Cockpit trim control input position--yaw;
(85) Trailing edge flap and cockpit flap control position;
(86) Leading edge flap and cockpit flap control position;
(87) Ground spoiler position and speed brake selection; and
(88) All cockpit flight control input forces (control wheel, control column, rudder pedal).

## 4. AIRCRAFT MATHEMATICAL MODELS FOR FDR DATA PROCESSING

The method presented in the article is general and valid for any dynamical system. For the present application an adequate mathematical model is required. This model is that of a flying vehicle.

For the present paper we will utilize the formulation described in the reference [4]. It will be choose the variant based on the Euler rotation group. The trajectory equations are:

$$\left| \dot{x}_0 \quad \dot{y}_0 \quad \dot{z}_0 \right|^T = \left| A \right| \quad \left| u \quad v \quad w \right|^T$$

where: $x_0, y_0, z_0$ are coordinate in a reference frame (earth) and $u, v, w$ are the speed components along body frame,

$$A = \begin{vmatrix} \cos\Theta \cos\Psi & \sin\Phi \sin\Theta \cos\Psi - \cos\Phi \sin\Psi & \sin\Phi \sin\Psi + \cos\Phi \cos\Psi \sin\Theta \\ \cos\Theta \sin\Psi & \sin\Phi \sin\Theta \sin\Psi + \cos\Phi \cos\Psi & \cos\Phi \sin\Theta \sin\Psi - \sin\Phi \cos\Psi \\ -\sin\Theta & \sin\Theta \cos\Phi & \cos\Phi \cos\Theta \end{vmatrix}$$

where: $\Theta, \Phi, \Psi$ are the Euler position angles

The Euler position angles equations are:

$$\left| \dot{\Phi} \quad \dot{\Theta} \quad \dot{\Psi} \right|^T = \left| C \right| \quad \left| p \quad q \quad r \right|^T$$

where: $p, q, r$ are the rate of roll, pitch and yaw

$$C = \begin{vmatrix} 1 & \sin\Phi \tan\Theta & \cos\Phi \tan\Theta \\ 0 & \cos\Phi & -\sin\Phi \\ 0 & \sin\Phi \sin\Theta & \cos\Phi \sec\Theta \end{vmatrix}$$

The forces equations are:

$$m\,\dot{u} = F_x + m\,(r.v - q.w)$$

$$m\,\dot{v} = F_y + m\,(p.w - r.u)$$

$$m\,\dot{w} = F_z + m\,(q.u - p.v)$$

where: $m$ is the mass of aircraft and $F_x, F_y, F_z$ are the components of forces along the body axes ( $x, y, z$ )

The moment equations are:

$$J_x\,\dot{p} = L + (J_z - J_y)\,q.r$$

$$J_y\,\dot{q} = M + (J_x - J_z)\,r.p$$

$$J_z\,\dot{r} = N + (J_y - J_x)\,p.q$$

where: $J_x, J_y, J_z$ are the inertia moments around the body axes and $L, M, N$ are the moments components around the body axes.

From these equations it will be chosen the set adequate to the task to be solved.

That is for the trajectory analyses we will chose the trajectory equations and the Euler position angles equations.

The comparison between the measured data and the calculated data (based on the calculation of the trajectory with estimated coefficients) will conduct to the determination of the real coefficients.

In this paper only the graphic review of the trajectory is analyzed. In a future paper the real coefficients will be calculated. Also, in a future paper, the determination of the flying vehicle will be conducted.

## 5. WINDOWS APPLICATION FOR DATA PLOTTING AND FOR FLIGHT ANIMATION

The software application, developed by the authors has the intention to analyze, in an objective manner, the premises of a flight incident of an aircraft and will helps us to identify, investigate, and correct the factors that create future accident [5].

The application runs on the Windows XP Operating System and use the converted FDR data into useful information (engineering units). It has two components: “Graphical Data Manipulation” and “Animate”.

The animation processes are activated through an ergonomic and configurable graphical user interface with multiple informations focused on functions. For a better communication between the user and application, graphic symbols are coupled with text. 3D virtual scenes are sent to screen -windows.

Computer Special Keyboard Keys provides navigation facilities in the virtual scene (changes of the viewpoint, of the angle of view and of the observed point), [6], [7], [8], [9].

Some results may be stored in text files or video file. Although the interest is focused on the final phase of flight as multiple flight data as possible will be considered from the flight segment in order to find the systematic errors (if necessary data from previous flights will be also used).

Data analysis in terms of systematic errors is essential and consists for example in matching the state data recorded at time t with the state data which were obtained at the same time *t* from the existing state at time *t-1*.

The “Graphical Data Manipulation” component shows the graphic evolution in time of some parameters (roll, pitch, yaw, altitude, longitudinal acceleration, lateral acceleration, normal acceleration, true airspeed, engine RPM, engine Torque, etc.). The second application’s component has the goal to make the 3D animation look as realistic as possible the aircraft flight.

The application offers advantages in investigations because transforms the huge amount of data recorded in images (better perceived), create a sequence of events placed in perspective of time that can be repeated and is less expensive, offers additional analysis capabilities.

Also, it can be used in the specific train of navigation staff and crew.

The first component of the application (Fig.1) allows to the user the ability to choose any of the flight parameters to plot it in a chosen time interval.

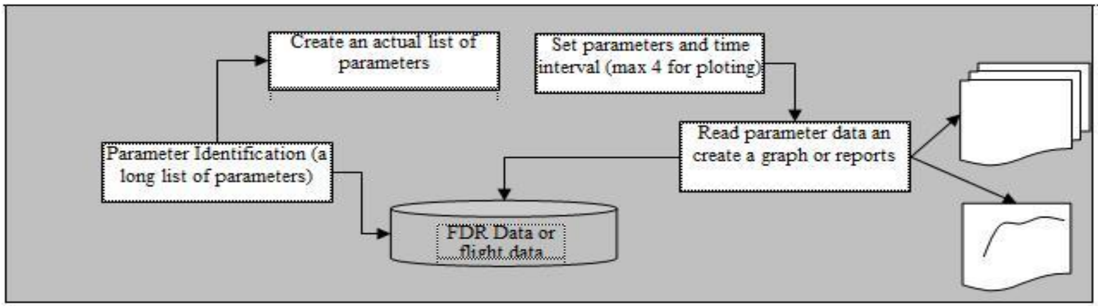
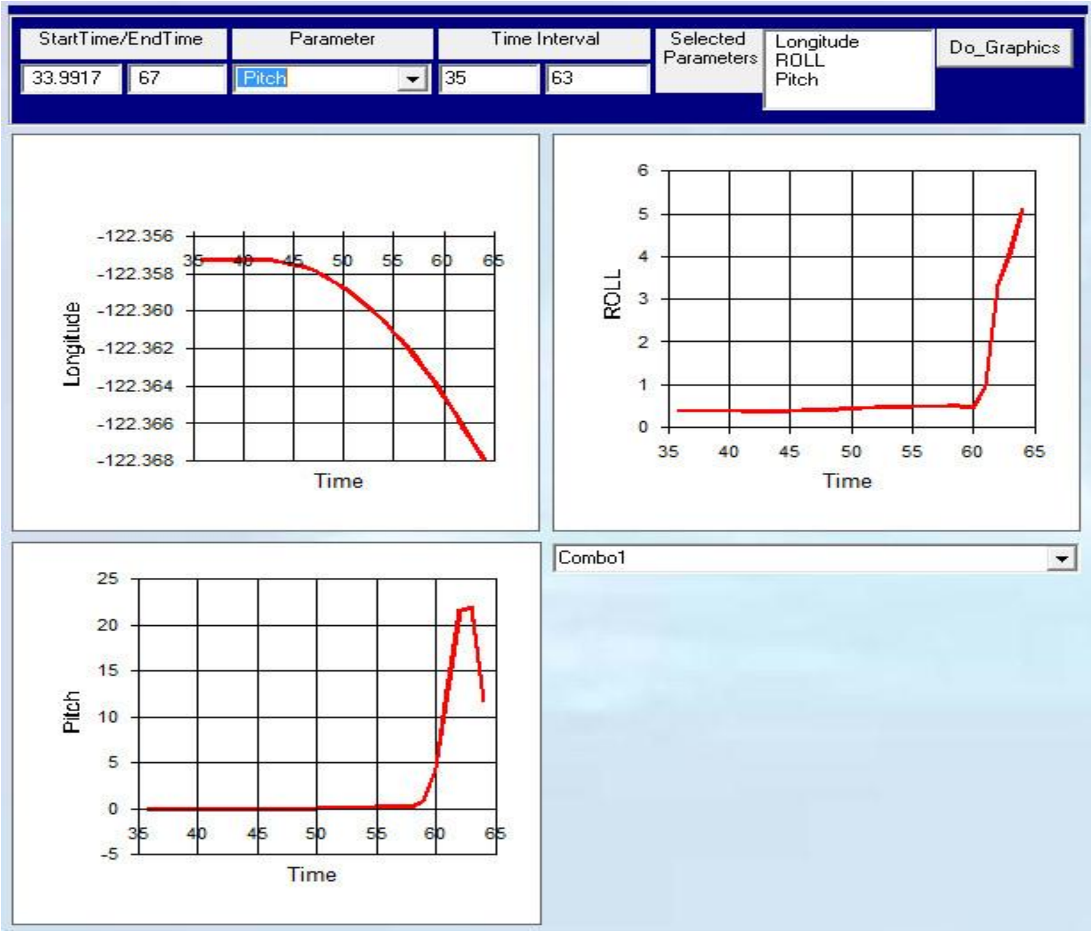



Fig.1

This component of the application is controlled through the below graphical interface and the plot results will appear in the same window:




or

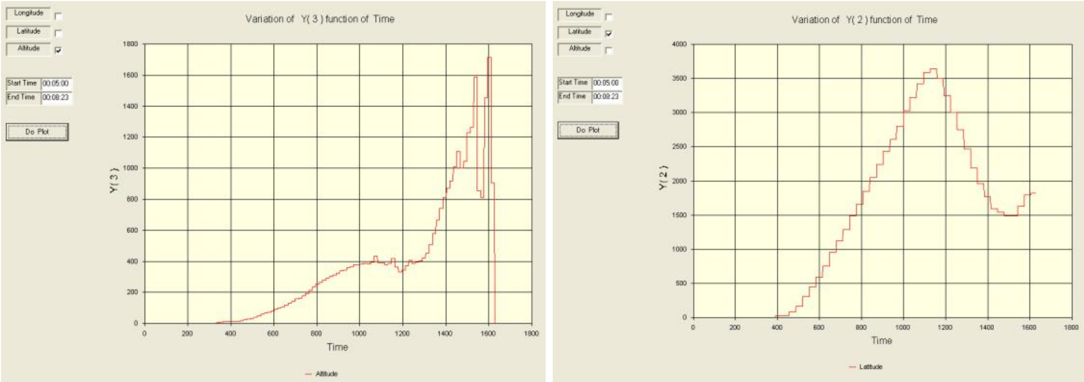



Fig.2

The second component is intended for flight animation of an aircraft in a 3D virtual environment using Flight data. In order to ensure portability and communication of information by three-dimensional graphics, the application uses the OpenGL library components, which, conventionally operates with a virtual camera that "shoots" a virtual space.

OpenGL, as "state machine" software, provides functions to bind the values of the variables that define the current position of the observer, the conventions of representation of the objects in the scene, location of objects, lighting characteristics, material properties, etc. Through geometric transformations, any point of the 3D virtual space is transformed into 2D point and represented on the computer screen under the scheme:

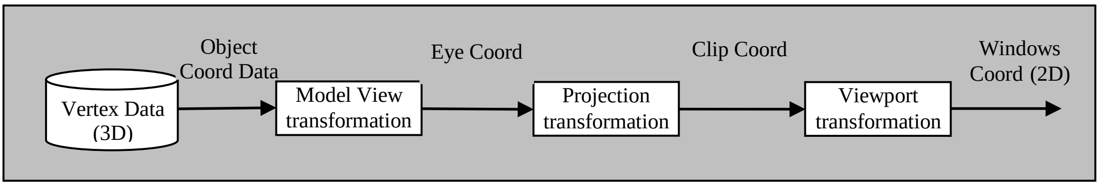



Fig.3

In addition, two special functions and GL_TEXTURE and GL_COLOR are used to "texture mapping" and for "colour" space conversion and colour component swapping.

For a realistic representation a subset of the recorded parameters are to drive the animation, tracing of the evolution projections in planes xy, xz, yz synchronized with time sequences arbitrarily chosen.

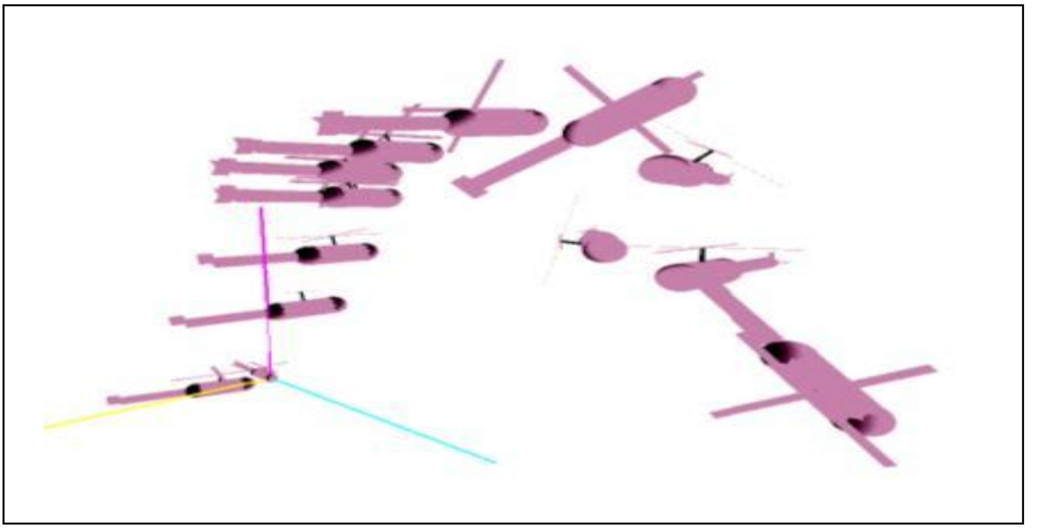


Fig.4

Features pursued in the application building: scalability, programmability and robustness. These will allow adding new modules and functionalities, ease of operation with additions and changes and will ensure that changing a module does not lead to other unanticipated effects.

## 6. CONCLUSION

The modern airplane must be provided with an operational FDR with a minimum 88 recorded parameters as a decision of FAA dated from 1977. That important data quantity must be processed, analysed and presented in a form accessible for personal without aeronautical education (lawyers and prosecutors). The paper proposes a software dedicated to the graphic interpretation of the flight data regarding the trajectory of the evolution and the attitude of the aerial vehicle.
In a future paper the analysis will be continued with the software necessary to identify, from the FDR data, the vehicle characteristics.

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