On Calculating and Visualizing Rocket Trajectory Reconstitution

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Abstract

In rocket launching, it is fundamental to determine the right tracking of the vehicle in flight. Usually, real time information is received from more than one tracking system. Such information is useful while the vehicle is in flight as well as for future analysis. However, sometimes, vehicle may not be tracked by any system. Therefore, no registered data of the complete flight is available. One possible solution is to calculate the missing information to cover the "gaps" in trajectory path. This reconstitution is based on vehicle's position and velocity, in reference to any instant of the flight. This article describes an application that calculates a trajectory reconstitution in order to obtain data that is eventually missing. This trajectory path is plotted in a cartographic map projection in a browser. Resources used on this application are based on web standards.

Key-words: *trajectory reconstitution, flight safety, rocket, post-flight analysis.*

1. Introduction

The group that is responsible for predicting rocket trajectory usually has an added task of verifying how good was the flight. In order to perform flight analysis, this group needs not only the information on the predicted trajectory path, but also information on the real trajectory and all its components, such as velocities. Thus, one can compare all the results in order to conclude with reasonable precision of how good was the flight. This paper deals with cases that, for some reason, the tracking of the vehicle fails at some time during the flight and therefore there is no available information on a complete real trajectory path for it. Thus, it is important to devise an artificial means to obtain or simulate the data that are missing. In order to make this simulation, one has to develop or buy a software, that calculates the trajectory [1]. This simulation is considered as a reconstitution trajectory, and it is based on the same input data used for the calculation of the predicted trajectory and on a single information for the tracked data. Usually radars, or any other tracking system, give instantaneously the following information about the vehicle in flight for every time step: flight time, position vector and velocity vector. Then, this information, but only for one time step, will be used for the simulation. Thus, a calculation is conducting starting from this time step of the flight. This time step will become the starting point of the reconstitution. Thus, the intention of this article is to embed all the procedures to calculate a portion of a trajectory, leaving for the user to select the starting point.

With the predicted, reconstituted and, at least, a part of the real trajectories, one can now perform the necessary analysis. In order to make the comparison, as trajectories of rockets are involved, it can be of a significant advantage if visualization is considered, i.e., if the evolution of the trajectory could be seen graphically. This is in fact one way to quickly disseminate information to a wide range of users by using, for example, Internet technologies and exploring existing web standards, such as SVG (Scalable Vector Graphics). This should guarantee the application's availability and makes it easy to be deployable. However, use of graphics within Web needs special attention regarding interoperability issues so that visualization can be performed across several different platforms with different resolutions, different color sets, software, etc. There are several efforts under way to develop a set of languages that can be used within the Internet and these languages are supposed to serve as means of communication among many applications regardless of the hardware or the operating system being used. The only requirement is that the platforms that deal with such languages must have the appropriate tools installed for this purpose.

The next section explains exactly the focus of this work. Section 3 comments the Internet technologies used by this application, whereas Section 4 discusses the specification of the used application. Section 5 shows the implementation used to alleviate the problem. There is an additional problem which is to select a reconstitution starting point and this is discussed in Section 6. Finally, the last sections show potential users, conclusion and future directions.

2. Rocket trajectory reconstitution

Rocket launching spawns several processes that are essential in providing support for this complex operation. One such process is related to its trajectory. Special attention is dedicated to calculating and broadcasting a predicted trajectory, because it could indicate whether or not the vehicle could fulfill its mission. However, only a critical analysis to the flight of the vehicle can ensure the flight validation.

As the predicted trajectory was "calculated" to fulfill vehicle mission, then a simple comparison of the predicted data with real data, could show the performance of the flight. There are several parameters that can be compared, such as, velocity and flight elevation. However, as mentioned earlier, the work describe in this article explores the possibility of eventual tracking failure so that data has to be calculated and compared to verify and ensure its realistic situation.

Some of the most important information to be compared is about how high and how far the vehicle flew. Therefore, this application will deal with details concerning apogee and impact range. By analyzing the predicted, real (if any) and reconstituted data for these parameters, one can verify and even validate the flight under performance aspect. Thus, the objective of this work is to provide tools to calculate reconstituted trajectory and to analyze it comparing with its respective predicted and real trajectories.

3. Internet technologies

In order to test and validate the idea proposed in this paper, an application was created and placed in a host running Apache [2] server. All files needed, such as, predicted trajectory file, must reside in the server. Of course, the data deployed are not real because they are of restricted use. Thus, any computer, which has an access to Internet, could be a client and can have access to all the information.

On the client side, some technologies are essential to be installed. Nowadays, many applications, running by web, depend on some resources installed within browsers in order to be properly visualized. This is an interactive application and the interaction is conducted through Java. Therefore, a java 1.5 plug-in [3] must be installed on the client side. It also needs a SVG Viewer 3.03 [4] in order to plot cartographic maps. Another technology needed is the JavaScript [5] language. These technologies communicate among themselves and with HTML document, enable the page to be deployed.

Figure 1 shows the scheme used for this application:

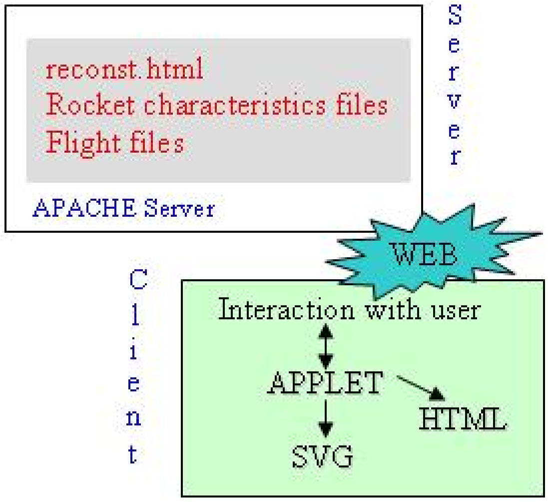

Figura 1. Scheme application

All languages and tools used for the application are available for download from the Internet and are free of charge. Some of these open web standards were developed by W3C (World Wide Web Consortium) [6], such as XML, DOM and SVG [7] and these will be briefly described below.

EXtensible Markup Language (XML), just like HTML, is a format to organize documents and data in a structured manner on the Web. It is a meta-language, i.e., it can define other languages. However, it is not a successor of HTML, which is mostly used to present a document.

Document Object model (DOM) is basically an interface, which is used by a programming language, to access HTML or XML documents. It is a standard API (Application Programming Language) to the document structure. Programs and scripts can dynamically access web documents to update their content, structure and style.

Scalable Vector Graphics (SVG) is a language that can describe two-dimensional graphics based on XML. It is not a proprietary language. The act of plotting by means of SVG can be dynamic and interactive. Originally, this technology was specified by Adobe as Precision Graphics Markup Language (PGML). There is another web standard, Vector Graphics Markup Language (VML) from Microsoft. SVG incorporated the best characteristics of both PGML and VML formats.

Some browsers already support native SVG, but in most of them, one is required to install an appropriate plug-in in order to visualize any SVG objects.

SVG Viewer is a plug-in developed by Adobe which provides tools for a browser to show any SVG elements, such as texts and images.

JavaScript is a script language which was developed by Netscape Communications in order to improve interactivity on web pages.

4. Specification

A predicted rocket trajectory is calculated from instant 0 until the end of flight. It is necessary to count on a lot of vehicle parameters, such as thrust variation, and the knowledge on vehicle's events. Thus, one can calculate a predicted trajectory.

As previously mentioned, the objective of this work is to obtain a reconstitution trajectory, which reflects into a calculation based on an instant determined by the user, up to the end of flight. Thus, all information about vehicle and its events must be accessible by the application. Within the context of this application, it needs data about the flight, such as flight time, position and velocity. These are the data tracked by one or more tracking systems. In order to visualize the trajectory, it still needs a file which must contain predicted position (latitude and longitude coordinates).

Thus, with these information a trajectory could be calculated starting from any instant and could be compared numerically and visually.

Therefore, the only task for the user is to select an instant from which the calculation will be performed. Then, of course, results are analyzed. This starting point corresponds to an instant of flight with its position (X, Y, Z) and velocities (Vx, Vy, Vz). Section 6 contains a detailed description of how one can choose a starting instant and its importance.

Once the initial point was already assigned, a process of reconstitution trajectory calculation will be started. First of all, when the calculation is being made for predicted trajectory, the initial position vector is in reference to the launch pad, as well as its initial velocity vector is in reference to the vehicle state, i.e., velocity zero. Thus, the coordinates received by the tracking system are from this referential launch pad. However, reconstitution trajectory calculation needs these data in reference to the earth's center [8]. Therefore, a change in the referential is made by the application according to some Model Earth, as shown in Figure 2.

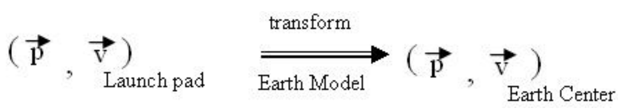

Figura 2. Change of reference

Then, a trajectory will be calculated. The results will be deployed numerically giving information about its apogee and range and graphically through drawing the path on a cartographic map.

It is important to mention that the results obtained through this calculation are highly reliable and many a time better than those obtained from a predicted trajectory. While the vehicle is being launched there is a probability of some perturbation due to a contact with the launch pad. Therefore, the reconstituted calculation intrinsically embeds information of the real attitude as well as the climate conditions.

A brief schema of the complete reconstitution calculation is shown in figure 3.

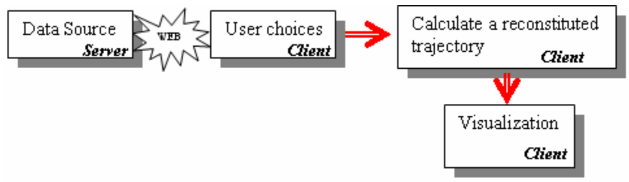

Figura 3. procedure

The next section will discuss how the specified technologies can implement this specification.

5. Implementation

Figure 4 shows the starting application on client side.

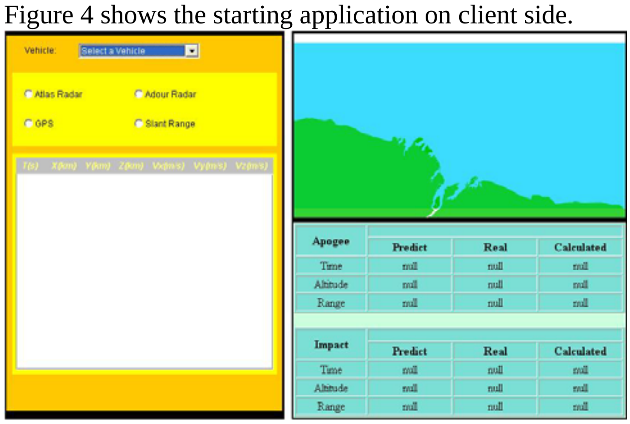

Figura 4. Starting page

The HTML page, which has the embedded applet and SVG files, has all references directed to the XML files as well as to the JavaScript files. Therefore when the page is loaded, the applet starts running and a JavaScript script, through DOM, manipulates the XML file, which contains the outlines for the most countries of the world, in order to draw a cartographic map in a SVG area. In this case a zoomed area around Alcantara Launch Center (CLA), located in north of Brazil, is performed. All the coordinates are represented in terms of geodetic latitude and longitude. Therefore, the outlines of the continents as well as the outlines of countries are based on latitude and longitude. For each country, one can easily insert a new attribute, such as population, sensitive areas, in order to analyze risk of impact.

This application is interactive and dynamic. Usually, it is used in the post flight analysis. All interactive procedures were developed in Java. A Java routine reads all parameters needed according to user's choice. All files needed about at least one flight, must be available on the server. Thus, one can choose which vehicle or which flight the user wants to analyze. Afterwards, one chooses on which system tracking the calculation will be based and finally chooses the reconstitution initial point.

As there is integration between Java – JavaScript – HTML – SVG, on each user's choice, a different Java event is started. Depending on the Java event chosen, a different JavaScript script is invoked. The Java to JavaScript communication is performed because Java applets need this communication to access the Document Object Model (DOM) or to call JavaScript functions on a HTML page. Support to JavaScript in applications written in Java is through netscape.javascript package from Netscape.

This application's interface with the inputs as well as reconstitution calculation are written in java and the results are presented in HTML and SVG. JavaScript plays an important role, because it is a bridge between Java routines, containing all trajectory calculations, with SVG and HTML, which contain all results of the visualization for analyses. JavaScript can access all SVG objects and HTML document, which means that it can control which data is for drawing in SVG and which data is for HTML table. When a user makes a choice on one tracking system, the integration of all technologies is used. Figure 5 shows the application after this choice. The left portion is based on java applet; upper right portion is entirely SVG; lower right portion is HTML.

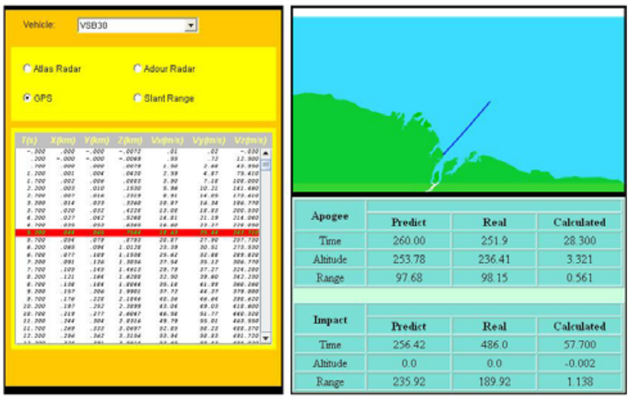

Figura 5. Visualization of the application

As soon as an initial point is chosen, the process of reconstitution trajectory calculation begins, starting from that chosen instant to the end of the flight. Software which calculates trajectory is also written in Java and it was adopted from one already written in C++ [9].

Figure 6 presents the graphical application results ready to be analyzed. It also shows a zoomed area around final tracked trajectory and starting reconstitution trajectory. This is one of the SVG resources and it is performed by the user right-clicking the mouse.

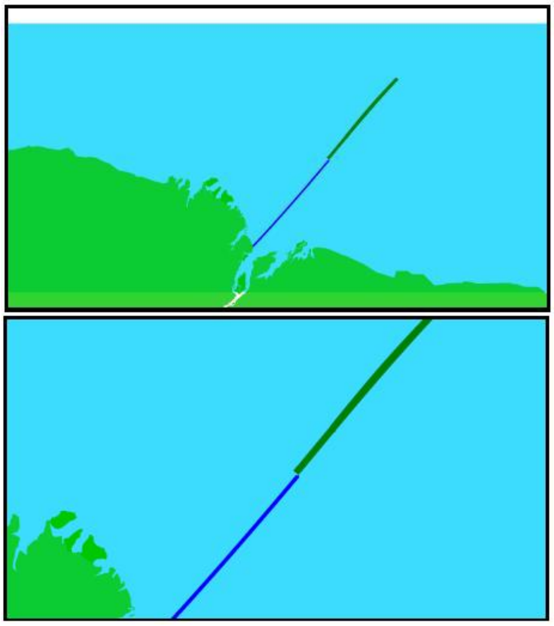

Figura 6. Graphical application result

6. Choosing starting point for reconstitution

Usually, tracking system could be from several sources: radars, Slant Range System and GPS. Then, when available, all of them could be considered as a data source for the calculation, since the registered data was in the specified format, as follows:

- Time step (s)
- Position vector → X, Y, Z (km)
- Velocity vector → Vx, Vy, Vz (m/s)

However, each system has its own characteristics; therefore even when tracking the same flight, different values could be obtained by each system. One of the tracking system could have a high precision; another one could be highly efficient closer to the target. Thus, at the same time step, the data could be different, when comparing with different sources, thus, the results could be satisfactory from the point of view of one system and not so good from another. Considering that some problem could happen with some tracking system, the difference, mentioned previously, could be considered predictable.

This application always considers input data coming from the same tracking system in order to make the calculation and analysis. Therefore, it is better to choose the tracking system which has higher reliability for this particular flight. Usually, when the tracking system is active in real time, there is a local computer that manages the received data and send them to the data centralizer, or a central computer. This host has responsibility on: (a) managing information that comes from several tracking system; (b) defining which data set is more reliable and (c) deploying or sending these data to computers which are in other departments, such as flight safety.

Then, once the best tracked data is chosen, one can calculate any trajectory that can be as close as possible to the real one. Thus, one could choose any time step of the flight to become the starting point of reconstitution calculation and the results will be satisfactory.

However, a study [10] showed that a random selection of the starting point can cause different results. Then, a unique time step does not always represent an exact real position and velocity of the vehicle. The reason, perhaps, is that the tracked data has a little dispersion of the vehicle's position, as shown in Figure 7.

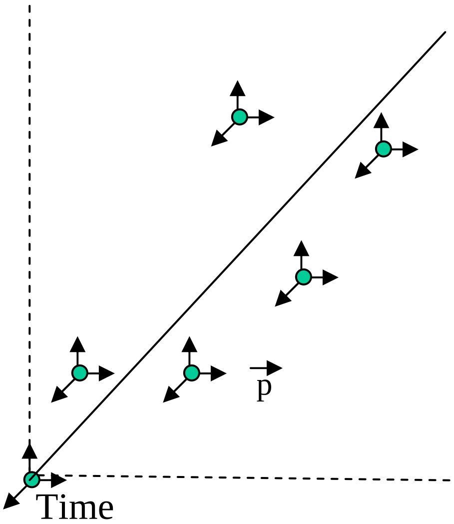

Figura 7. Position dispersion

Another source for errors could be the data treatment, in which calculations are conducted in order to obtain the velocity vector based on position vector.

As an example, Figure 8 plots the resultant Z axis coordinate by Time. Although, in that time step, the vehicle is always going up with no acceleration, the velocity in this axis had a variation that does not correspond to the reality.

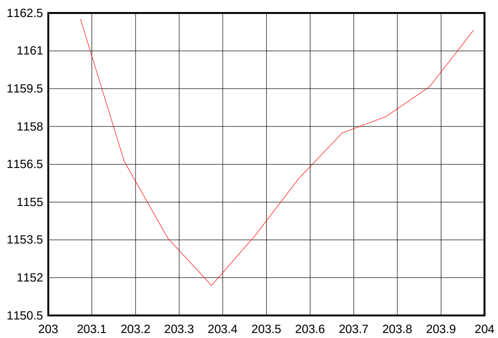

Figura 8. Vz x T

One more source for possible errors is during the calculation to obtain velocity components and the referential transformation. This has to be done based on the position of the launch pad with reference to the Earth's Centre. Therefore, choosing only one data set could not be the best implementation.

This problem can be partly solved. Instead of considering the position and velocity from only one time step, one could calculate the average based on a flight history upto a specified time step [11]. For example, as the data from radar are available in a 10 Hz frequency, i.e., 10 data set per second, it could be adopted for this calculation, an average of the last 10 values. Thus, the input values to the reconstitution trajectory, i.e., the current position and velocity, in fact, will be an average data set. If there is an error in the specified data, this error will be diluted by the others that are of good quality.

In spite of the latter case is better, this application considers only one data set for calculation, which is chosen by the user. One can calculate trajectory based on several choices (of the starting point) from the user, and then choose the best one.

7. End user

One of the major uses for the tool described in this paper is for those that are responsible to analyze the flight, making post-flight reports. It can also be useful for the team that is responsible to determine the best trajectory path for a given rocket based on its restrictions.

8. Conclusion and future directions

In Aerospace system there is a need to improve the method one can analyze the results. Specially, in applications involving rockets, one must work in order to obtain the results faster, highly reliable and to have access to all the relevant information about the event. Moreover, the way one deploys these data could be essential. In other words, rocket trajectory is a task that should make a full use of the potential of visualization facilities.

Within the context of the paper and in order to produce an application with no cost, all the technologies used must fulfill that requirement. In particular, SVG technology, deals with graphics over the web as required.

It's true that it is essential one should have the tracked data for the whole flight in order to perform its analysis and consequently report its validity. However, this study shows that even without a complete path for the vehicle, one can obtain it through calculation, delivering satisfactory results. Even without a vehicle impact point, which is very important, one can also calculate it.

In the next version, when a user chooses a data set, before reconstitution calculation, a search will be performed in order to obtain the 10 data sets around that chosen one. Based on this data set, an average calculation of all components will be performed, generating a new data set, which will be the effective starting point.

As SVG has a lot of resources, a new graphical visualization, with more relevant information, will be proposed. Impact dispersion area as well as resources for a sensitive mouse, will be implemented. Such tools will be useful because when an impact dispersion is drawn, one can determine exactly if an impact of a reconstitution trajectory will occur in a safety area. Concerning mouse resources, one can determine the latitude and longitude coordinates about the position pointed by the mouse.

Thus, one could analyze the results, not only with other trajectories (predicted and real), but also with impact area, line safety and so on.

9. References

[1] Kramer, H.J & Craubner, A. & Ziegltrum, W; ROSI – Rocket Simulation, DFVLR TN 12/76, 1976.

[2] The Apache Software Foundation. Available at http://www.apache.org/ . April 2005.

[3] Sun Developer Network. Available at http://java.sun.com/j2se/1.5.0/download.jsp . April 2005.

[4] Adobe, SVG Zone. Available at http://www.adobe.com/svg/viewer/install/main.html . April 2005.

[5] JavaScript Central. Available at http://devedge-temp.mozilla.org/central/javascript. April 2005.

[6] World Wide Web Consortium (W3C). Available at http://www.w3.org . April 2005.

[7] Scalable Vector Graphics (SVG). Available at http://www.w3.org/Graphics/SVG . April 2005.

[8] Carvalhaes, Eudy – Rampa2SI – 2002.

[9] Louis, J. E., Validação do programa fROSI, ASE-RT-007-2004.

[10] Louis, J. E., Vijaykumar, N. L., Determinação do instante inicial para o cálculo da trajetória extrapolada. WORCAP, 2004.

[11] Carvalhaes, Eudy – Suavização – 2002