LAUNCHER ADJUSTMENT SYSTEM FOR SOUNDING ROCKETS

Alexandre Garcia, alexandregarcia@iae.cta.br
Instituto de Aeronáutica e Espaço. Praça Marechal Eduardo Gomes, 50 – Vila das Acácias – CEP 12228-904 – São José dos Campos – SP – Brasil.

Mauro Hugo Mathias, mathias@feg.unesp.br
Universidade Estadual Paulista. Av. Dr. Ariberto Pereira da Cunha, 333, CEP 12.516-410 – Guaratinguetá – SP – Brasil.

Francisco Carlos Parquet Bizarria, fcpb@iae.cta.br
Instituto de Aeronáutica e Espaço. Praça Marechal Eduardo Gomes, 50 – Vila das Acácias – CEP 12228-904 – São José dos Campos – SP – Brasil.

Abstract. *This paper presents a new methodology to control the launcher position for unguided sounding rockets to compensate the winds perturbations. The goal is to have an automatic system to set the azimuth and elevation angles of the rocket in the launcher using a prototype for all practice simulation. The main contributors to dispersion of the impact parts of this type of the rockets are manufacturing or assembly misalignments and the wind. Wind dispersion can be made less significant by the use of wind-compensation techniques and automations procedures to set the rocket an-gles position in the launcher. The tests with the prototype, which was built for this project, have proved that it is possible to have a very good position precision in the azimuth and elevation angles.*

Keywords*: Rocket, Launcher, Wind and Automatic.*

1. INTRODUCTION

This paper presents a new methodology to control the position of the launcher for unguided sounding rockets to compensate the winds perturbations. The goal is to have an automatic system to set the azimuth and elevation angles of the rocket in the launcher. When a stable unguided rocket encounters a horizontal wind, it tends to head into the relative wind, and its subsequent trajectory deviates from the no-wind trajectory (Griner, 1967). At launcher, the rocket velocity is relatively low and, consequently, the wind is more significant. Moreover, small angular changes in the trajectory at launcher are amplified by gravity-turning and cause substantial changes in the burnout conditions. As a result, the launch configuration and low-level wind structure are quite critical with respect to the dispersion of the rocket apogee or impact point. It is usually necessary to measure the pre-launch winds and to compute launch angle using a wind-weighting technique.

Prior to the Second World War, little was known about properties of the Earth’s atmosphere above 20 km, the limit for which balloons could carry scientific instruments. By the early 1950s (Dougherty, 2006), sounding rockets had become a valuable tool for research into the upper reaches of the atmosphere.

Nowadays the sounding rockets can be launched from many places in the world. In an accomplished research, consulting many space centers, it wasn’t possible to identify an automatic system to set the rocket adjustment in the launcher. In most of these centers, the launcher set is manually done or by a not automatic way. That adjustment is necessary to compensate the wind perturbations for unguided rockets. Sounding Rockets take their name from the nautical term *to sound* , which means to take measurements (Montenbruck, *et al*., 2001). They are basically comprised of solid fuel rocket motors and payload. The payload is the section that carries the instruments to perform the experiment and to send data back to Earth.

The Nominal flight trajectories of projectiles are usually calculated by considering nominal performance data of the rocket in a standard atmosphere (Kramer, 1973). However, this information is normally not sufficient for fairly accurate flight path adherence and for impact prediction, since any rocket is more or less susceptible to prevailing winds in the atmosphere. The wind can significantly affect the flight of rockets (Wallops Flight Facility, 1999). Unguided rockets must be wind-corrected in order to fly the planned trajectory. Pre-launch winds, which are initially taken at approximately 3 hours prior to the launch, are used to determine the azimuth and the elevation angle, which will result in the vehicle’s flight on the desired trajectory.

The figure 1 shows the Brazilian Sounding Rocket VSB-30 that was developed in partnership with the German Aerospace Center - DLR. This rocket needs to have a minimum impact dispersion area, because it is a requirement to launch in European Space Centers.

The VSB-30 is a two-stage, unguided, Brazilian rocket, which consists of a solid propellant S31 rocket motor as the first stage, a S30 motor as the second stage and a hardware assembly to accomplish scientific experiments as payload.

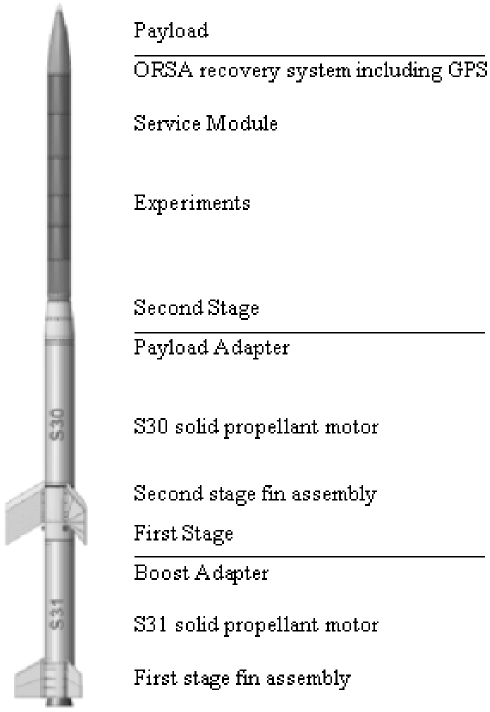

Figure 1. VSB-30 Brazilian sounding rocket

2. PROBLEM INTRODUCTION

The rocket motions during flight are governed by a number of forces and factors: motor thrust, aerodynamic forces, gravity, wind, wind shear, atmospheric friction, decrease of the rocket mass resulting from the consumption of propellants during flight, the movement of the center of gravity during that process, and forces generated by air rudders and jet vanes (Ordway *et al*., 2007).

The main contributors to dispersion of the impact parts of this type of the rockets are manufacturing or assembly misalignments and the wind (James, 1961). Wind dispersion could be made less significant by the use of wind-compensation techniques and automations procedures to set the position of the launcher. In Brazil, the calculation of the adjustment of the azimuth and elevation angles is made for dedicated software called "Guará" (Yamanaka and Gomes, 2001), which was developed for Brazilians Launcher Center. This software needs the real time information about direction and velocity of the wind. In Alcantara Launcher Center (CLA), for instance, there is an anemometric tower with 6 altitude levels: 48m, 52m, 58m, 69m, 85m, and 112m to get surface wind information. For upper altitudes, normally, soundings balloons are launched. The Guará needs the direction and velocity of each altitude level to calculate the correction adjustment for the launcher in order to compensate the wind perturbations. The figure 2 shows a mask of Guará Software on processing wind data. In CLA, the Flight Safety Officer uses the Guará software for calculating the corrections in the launcher position, with the purpose to compensate the wind influence. After that, the officer asks verbally, by phone, the Launcher Operator for performing the azimuth and elevation adjustments in the control devices, which are located in a blockhouse near the launcher.

Normally, it is necessary to anticipate that adjustments in around 7 minutes (H0-7) before the rocket liftoff. During this period of time are performed mainly the activities that are related to communication of launching information and physical adjustment of the launcher. If the direction and velocity of the wind have been changed during these activities, within safety limits, not any other correction will be done in the launcher. It will probably cause a rocket trajectory turning away from the desired one and will consequently change the impact point dispersion. When we have different values of azimuth and elevation between the last adjustment (H0-7) of the launcher and the exact moment (H0) of the liftoff, it changes the impact point and the rocket performance and mainly the dispersion area. An example of what deviations these different values cause is shown in figure 3, considering an error of two degrees in the nominal azimuth and elevation angles of the VSB-30 Unguided Sounding Rocket.

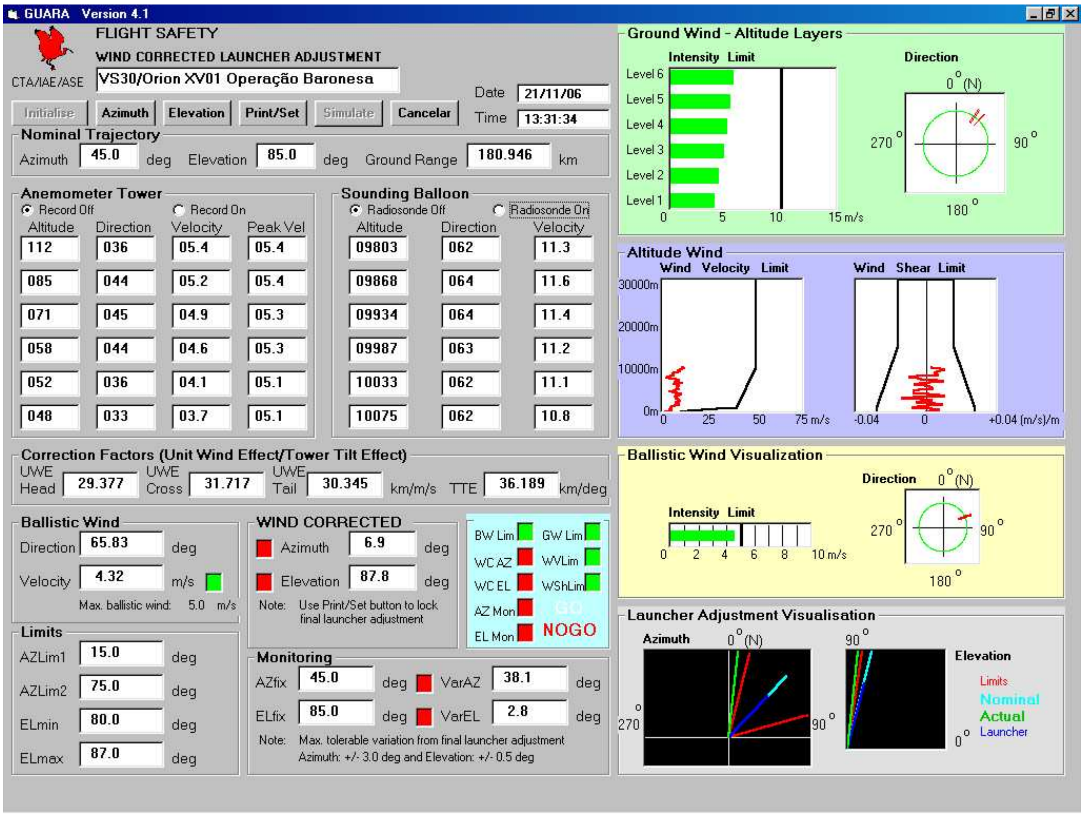

Figure 2. Guará Software

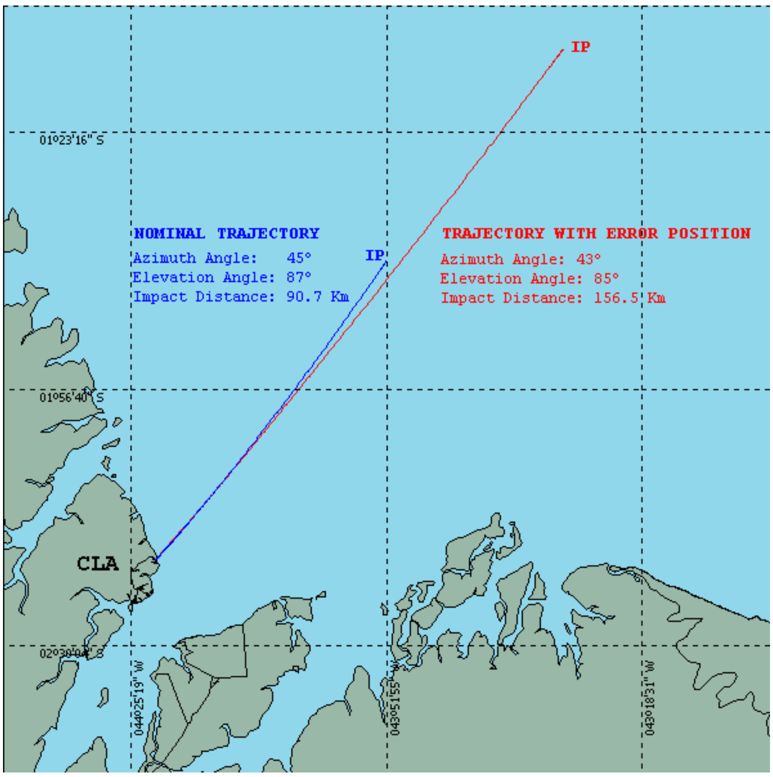

Figure 3. Trajectory Evolution

The Program Rocket Simulation - ROSI was used to have the trajectories calculations (Kramer, et al., 1976). The difference in both trajectories shows a considerable dispersion of the impact point (IP) around 66 km of distance.

3. IMPACT POINT DISPERSION

In a campaign of the unguided sounding rocket, it is necessary to have a critical analysis of the dispersion area, i.e., the Flight Safety Officer must know all rocket parameters that should disturb the trajectory, like, aerodynamics drag, thrust misalignment, thrust variation, and of course the launcher adjustment error that is the main objective of this work. All parameters cited are included to dispersion calculation.

Figure 4 shows a dispersion area calculated for the first flight of the VSB-30 in CLA, that occurred in November 2004. Table 1 shows the rocket parameters errors used for this theoretical case.

Table 1: Rocket parameters errors.

Thrust Variation	2%
Thrust Misalignment in Pitch	0.1º
Thrust Misalignment in Yaw	0.1º
Aerodynamic Drag	10%
Weight Variation	1%
Fin Misalignment	0.01º
Launcher Elevation Error	0.5º
Launcher Azimuth Error	1.0º
Head Wind	0.5 m/s
Cross Wind	0.5 m/s

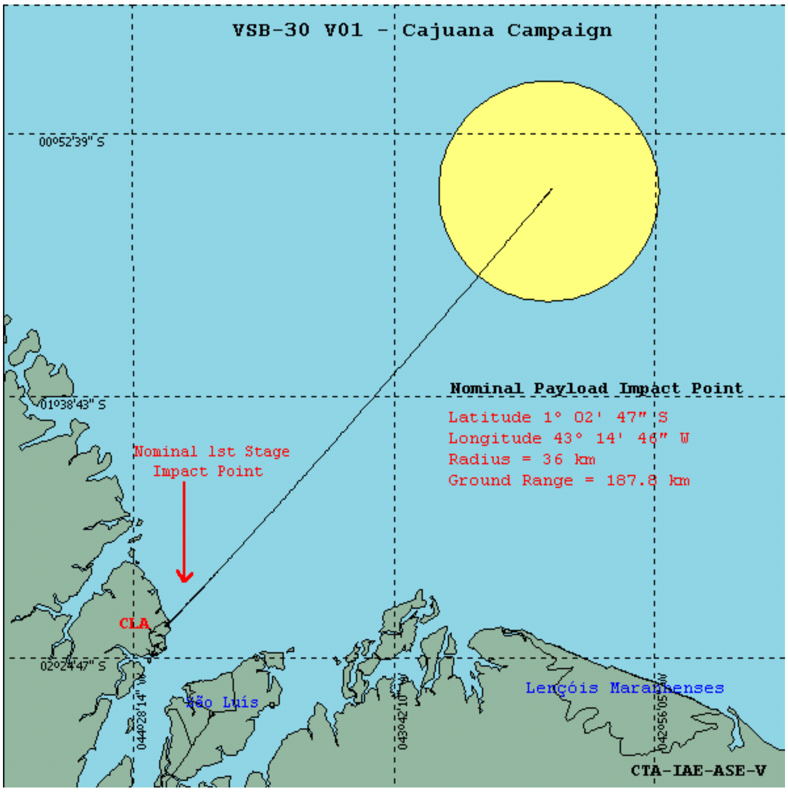

Figure 4. Trajectory Evolution

For that example the calculated impact area had a radius around 36 km. The winds influence and the azimuth and elevation error are responsible for almost a half part of impact dispersion area, for this case.

4. PROPOSAL

This work presents a proposal of systemic architecture, to make automatic actions in the positioning of launcher for unguided sounding rockets, which are based on a supervision system, a programmable logical controller, a sensor and actuators. The main idea is to build a prototype system to simulate all necessary activities for automatic launcher adjustments.

The motivation about development of this work is to have an automatic system to set the launcher position in real time, after any winds perturbation on launcher in the time of the rocket countdown, considering all the terms of the flight security in an unguided sounding rocket campaign.

If we have an automatic system to set the launcher in a time smaller than 7 minutes (H0-7), probably we will have a decrease of the launcher azimuth and elevation error. Consequently it is going to have a minor dispersion area.

Figure 5, shows the present systemic architecture used in Brazil and in the various of the Rocket Space Centers in the world to set the angles of azimuth and elevation to adjust the unguided sounding rocket to compensate the winds perturbations. We can see that all operations are very dependent on the Flight Safety Officer and the Launcher Operator. That present process cannot input any mistake by Flight Safety Officer or Launcher Operator, because if it happens it will compromise the dispersion area and the rocket performance, shown in examples of the figures 3 and 4.

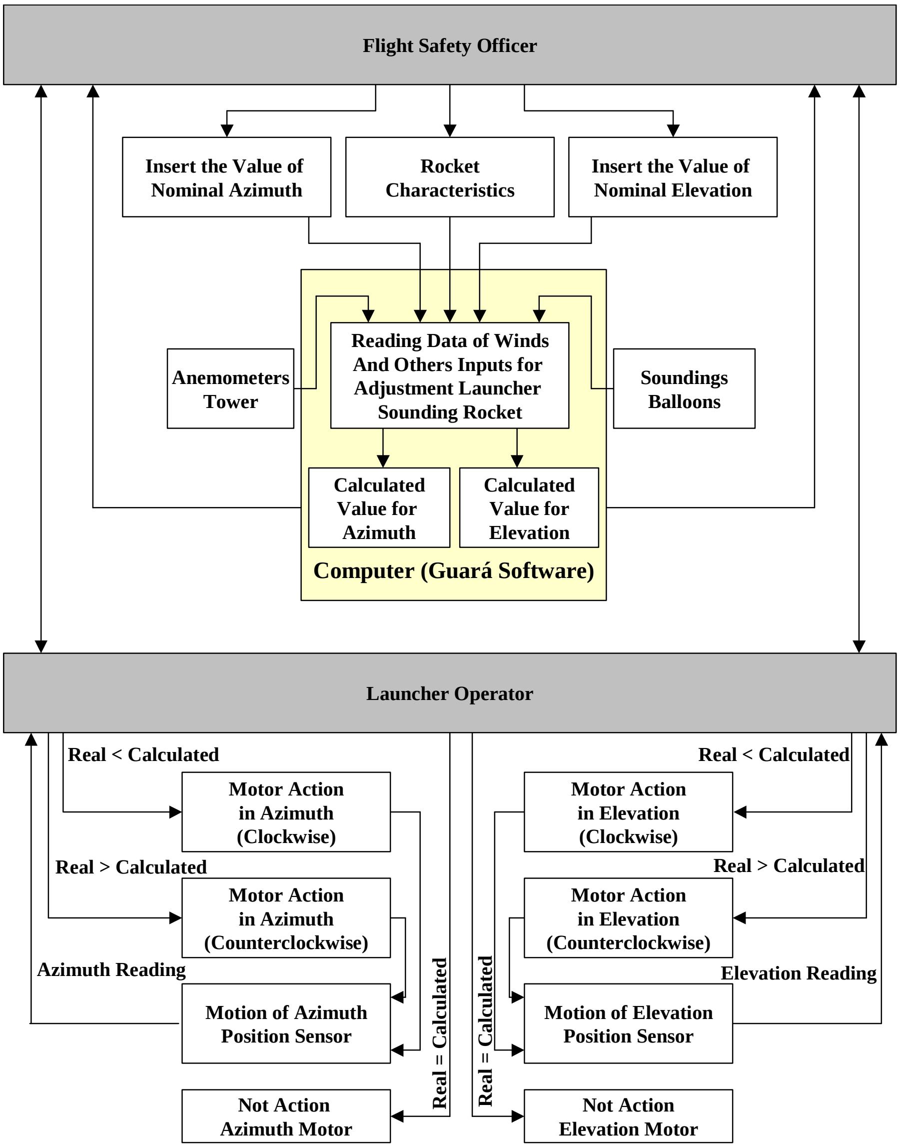

Figure 5. Present System

Figure 6, shows a proposal of systemic architecture to automate the set of the launcher. The goal proposal is: after having the winds perturbations and the calculation of launcher position, processed by Guará, the azimuth and elevation angles go to Programmable Logic Controllers - PLC by communication protocol. After that the PLC setting the actuators (motors) until the angles positions that the Guará has calculated. The information about actual azimuth and elevation angles will get by sensors (incremental encoders) to PLC, after that it will go to communication protocol and to Guará software.

The PLC is an electronic digital system used in the industry for automation and control (Plaza and Medrano, 2006). They contain multiple inputs and outputs that use transistors and other circuitry to simulate switches and relays to control equipments. Data memory is the capacity for data storage. Program memory is the capacity for control software.

The objective is to have the actual position of the launcher in the interface of Guará software in real-time. This way the Flight Safety Officer will have more precise information about launcher. With this, the Flight Safety Officer should reduce the time of the last adjustment of the launcher. Consequently, it will reduce the launcher azimuth and elevation error and the dispersion impact point area.

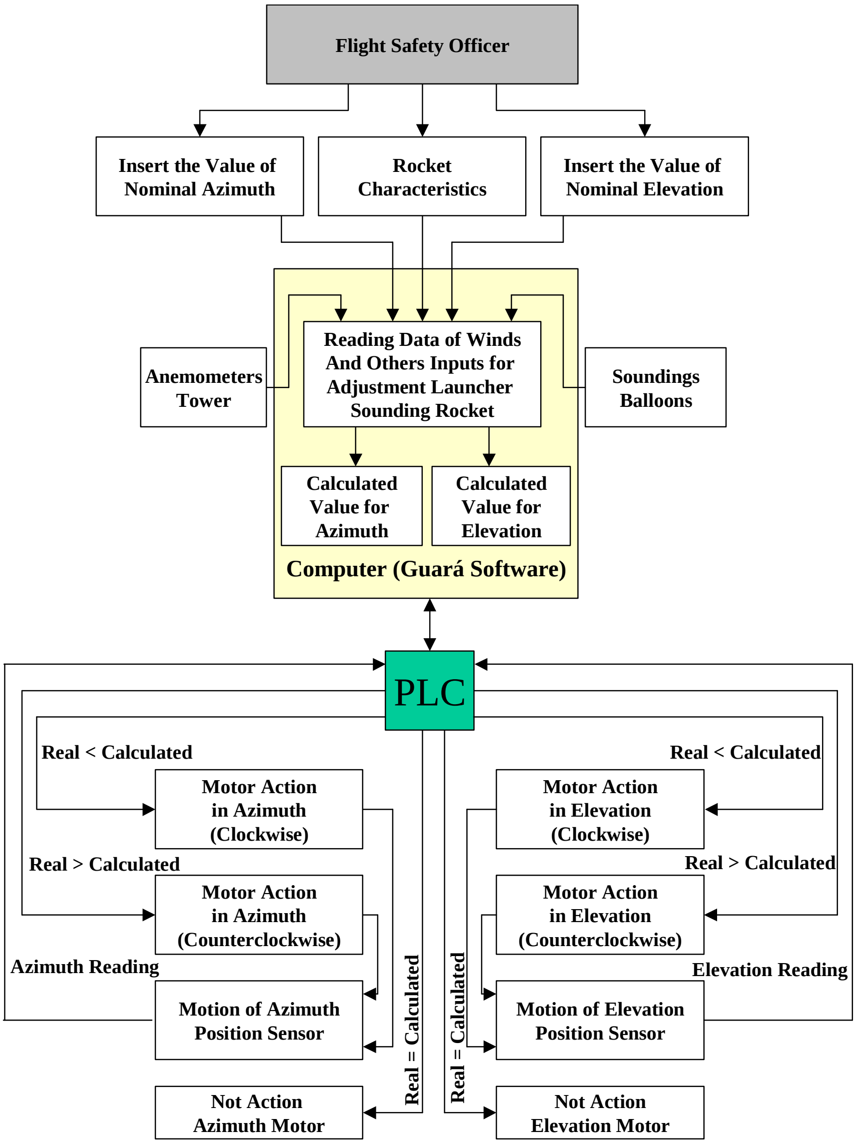

Figure 6. Proposal System

The proposal system has the follow components:

The Launcher is a plant of the system, for practical simulation, constituted by motors, position sensors (encoders), launcher rail, speed reducer, etc. The Guará Software is responsible to get all information about winds perturbations, after that, it has to process and to calculate the position correction for azimuth and elevation angle. The Communication Protocol is responsible to have a communication between Guará Software and PLC. The PLC is responsible to get the azimuth and elevation angle information, calculated by Guará, and then to action the motors to the new position. The

Motors have to motion the launcher rail. One motor will move the azimuth angle and other the elevation angle. The Speed Reducers will reduce the motor velocity to have a better precision position. The Sensors (encoders) will measure the positions of azimuth and elevation angle. It will be feedback to PLC, with the instantaneous position of the launcher rail. The winds information are measured by Anemometers Tower for low altitude level and Soundings Balloons for upper altitude level, captured by Antennas. All winds information go to Wind Data Process and then to computer with Guará software to calculate the launcher position angles to compensate the winds perturbation.

Figure 7, shows a proposal of the architecture system. The idea is to control and change the launcher settings automatically from Control Center that is localized far from the blockhouse and the rocket launcher. It has the advantage that the adjustment can be performed shortly before liftoff. It will minimize the deviation between the calculated and the actual setting.

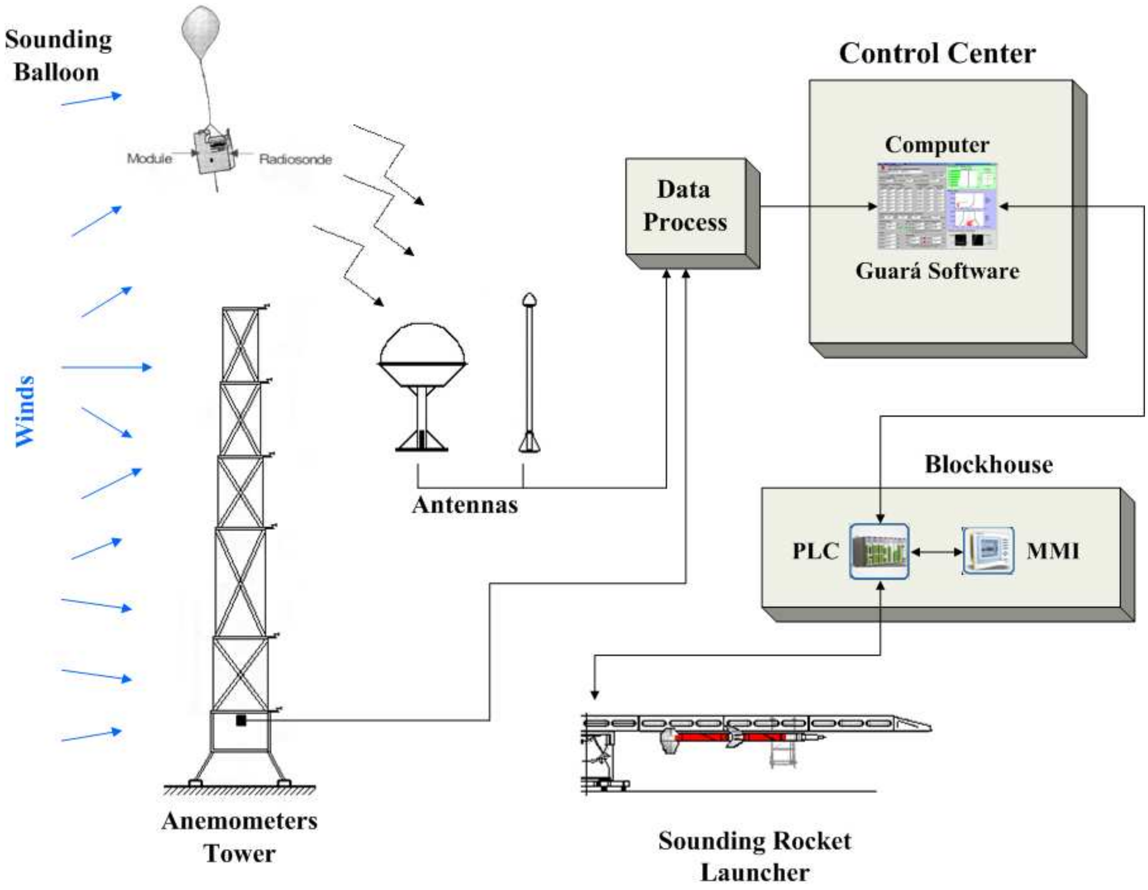

Figure 7. Systemic Architecture

The prototype built for this work, figure 8, is a miniature of a launcher used to simulate the position angles for the unguided sounding rocket in the launcher.

The launcher prototype design is constituted by the computer integrated with Guará software, PLC and all necessary components to simulate the motions (motors) and the reading (encoders) positions of azimuth and elevation angles.

In Guará software was implemented a new module, to set the launcher. In this module we have three options:

- Manual: to set the launcher with any value. That option is applied when the rocket is being assembled in the launcher or when the Flight Safety Officer needs to set a safety position. This option can be set by Flight Safety Officer localized at Control Center by Guará or by Launcher Operator localized at blockhouse by MMI.
- Semi-Automatic: to set the launcher with the values calculated by Guará.
- Automatic: to set the launcher with the values calculated by Guará updating the values of adjustment to each in around 20 seconds automatically.

In figure 8 is showed the system prototype, built to simulation all necessary activities to adjust the position of the rocket in the launcher.

The next step is to implement all conception of this work in the Brazilian Launchers Centers. At every simulation performed with the prototype have been obtained satisfactory results. The control system (PLC) and the module integrated with software Guará brought to this project good expectation.

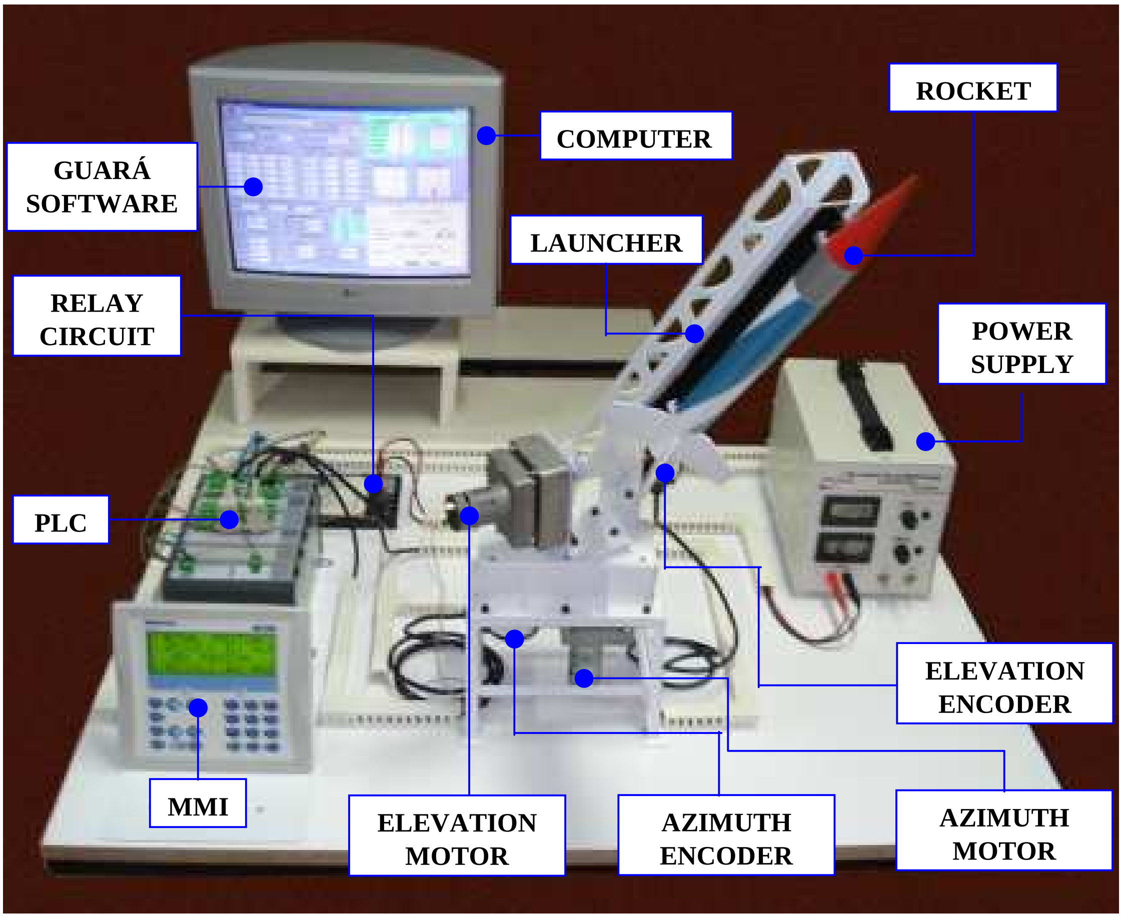

Figure 8. Launcher System Prototype

5. RESULTS

The velocities of the azimuth and elevation motors are respectively 0.5 and 0.15 rps. Both motors have the maximum and minimum velocities that were found in Brazilians Launchers and others Centers in the world. The tests using the prototype system have showed good results. In figure 9 are showed a graph with information about azimuth and elevation angles corrections, calculated by Guará every 20 seconds until H0, for a simulation of unguided rocket campaign. In that graph are showed too, the evolutions adjust for azimuth and elevation angles control by the automatic system prototype. The proposal system can adjustment the azimuth and elevation angles in automatic way, until 20 seconds before liftoff. This process can reduce the adjustment error caused by the winds perturbation.

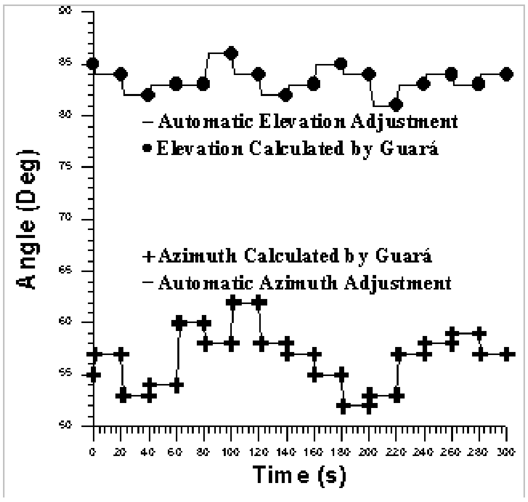

Figure 9. Azimuth and elevation angles adjustments

6. COMMENTS AND CONCLUSIONS

This paper shows a practical idea of an automatic system to set azimuth and elevation angles for launcher adjustment, to compensate winds perturbations for unguided sounding rockets.

The tests using the prototype could prove that it is possible to have a very good position precision in the azimuth and elevation angles, much better than the actual systems used in many Launcher Centers in the world.

The flight safety goal is to protect the public, range participants, and property from the risk created by conducting potentially hazardous operations to prevent mishaps that would result in embarrassment to the responsible of the rocket, the Launcher Center and the Government. Although these risks can never be completely eliminated, the flight should be carefully planned to minimize the risks involved while enhancing the probability for attaining the mission objectives (Ward, 1993). The purpose is to develop advanced technologies to detect, for instance, natural resources, to improve meteorological forecast and communications and to accomplish scientific experiments to the civilian society.

The rehearsals performed with the prototype showed that it is possible to improve the present systems used in the rockets space centers in the world. With this it's possible to say that the procedures at present used for set angles positions in the launcher for unguided suborbital rockets will provide one new alternative of control. This may improve the terms of flight safety in the Launcher Centers and mainly to have a better precision of the last adjustment before rocket liftoff, reducing the rocket impact dispersion.

7. ACKNOWLEDGEMENTS

The authors would like to acknowledge the Brazilian Space Agency - AEB (action number 6704) for financial support of this work.

8. REFERENCES

Dougherty, Kerrie. Upper atmospheric research at Woomera: The Australian-built sounding rockets**.** Acta Astronautica, Volume 59, Issues 1-5, July-September 2006, Pages 54-67

Griner, Gary M. Effect of Rocket Thrust-Time Curve on Wind Dispersion. Journal of Spacecraft, Vol. 4, Nº 11, November 1967, 1533p.

James, Robert L. A Three-Dimensional Trajectory Simulation Using Six Degrees of Freedom with Arbitary Wind. Technical Note D-641. National Aeronautics and Space Administration. Langley Research Center. Washington - USA. 1961. 28p.

Kramer, H. J.; Craubner, A.; Ziegltrum, W., ROSI Rocket Simulation, DFVLR TN 12/76, 1976.

Kramer, H.J. Wind Weighting Analysis for Unguided Rockets. Techisches Memorandum Nr. 119. DLR, 1973.

Montenbruck, Oliver at all. GPS Tracking of Sounding Rockets – A European Perspective. 1st ESA Workshop on Satellite Navigation User Equipment Technologies NAVITEC 2001, ESTEC Noordwijk, 10-12 Dec. 2001

Ordway, Frederick I. III at all. A memoir: From peenemünde to USA: A classic case of technology transfer. Acta Astronautica, Volume 60, Issue 1, January 2007, Pages 24-47.

PLAZA, Inmaculada; MEDRANO, Carlos. Exceptions in a Programmable Logic Controller implementation based on ADA. Computers in Industry, In Press, Corrected Proof, Available online 27 October 2006.

Wallops Flight Facility (WFF), Range Safety Program, Section 2.0, 1999.

Ward, Philip R., Range Safety Manual for Goddard Space Flight Center/Wallops Flight Facility. June 1993.

Yamanaka, S.S.C.; Gomes, R.M., Launch Pad Setting Calculation – GUARÁ. Technical Report 024/ASE-V/01. Aeronautic Institute of Space – Brazil. May 2001.