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## METHODOLOGY FOR CALCULATING THE LAUNCH ADJUSTMENT FOR SOUNDING ROCKETS BASED ON LEWIS CONCEPTS

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**Abstract.** This article aims to implement a method of adjusting the azimuth and elevation angles of the uncontrolled rocket launcher, based on Lewis concepts, compatible with the Guarú software method and validating it through a trajectory simulator. The objective is also to obtain results that demonstrate the compensation of the wind effect on the trajectory according to the adjustment of the implemented method. The methodology consists in the implementation of a flight simulator for unguided rockets that receives the adjustment value and integrates the trajectory of the rocket to the rocket's impact point, taking into account the effect of the wind. To simulate the motion of a rocket, a mathematical model of the rocket and its subsystems is required. The presented method was obtained in MatLab language and compatible with the method used in simulations by the Centro Espacial de Alcântara (CEA) and it has compensated the effect of the wind on the trajectory of uncontrolled sounding rockets.

**Keywords:** Adjustment, Azimuth, Elevation, Simulation, Rockets.

### 1. INTRODUCTION

The calculation of the adjustment of the unguided rocket launcher refers to a wind effect compensation procedure, where this technique is applied to determine the adjustment of the launch track (azimuth and elevation angles) in relation to the prevailing wind, with the need for the real flight, where the rocket is under the influence of the wind, the next simulated step of the nominal trajectory (GARCIA, 2007). The azimuth angle is defined by two planes that pass through the vertical of the launch point, one of which is the geographical North and the other is the plane of the planned trajectory. The elevation angle is defined by the rocket axis, connected to the launcher, and the local horizontal (PALMERIO, 2016).

The Alcântara Launch Center is located on the northern coast of the state of Maranhão, in Alcântara city, with the geographical coordinates are 2 ° 19 'S latitude and 44 ° 22' W longitude and it is 40 meters high (ROBALLO, 2007). The climate in the Center has tropical characteristics, where the relief features cliffs on its coast with a height of 50

meters (GILSER, 2009). For this purpose the characteristics of the winds are captured by an anemometer tower and by atmospheric sounding balloons.

The anemometric tower is a 72 meters metallic structure and is positioned 40 meters above sea level. There are six anemometers installed in its structure at 48, 52, 58, 70, 85 and 112 meters of altitude, where information on intensity and wind direction is collected. The helium atmospheric sounding balloon has the function of collecting information on the intensity and direction of the wind up to a maximum altitude of 30,000 meters, in addition to transmitting information on temperature, humidity, pressure and position (MATA e FILHO, 2016). This data is transmitted to the data processing center at the CLA meteorological center. Then, this information is sent to the computer in the control center, to the Guar software, which sets the values of the adjusted azimuth and elevation angles, as shown in Figure 1.

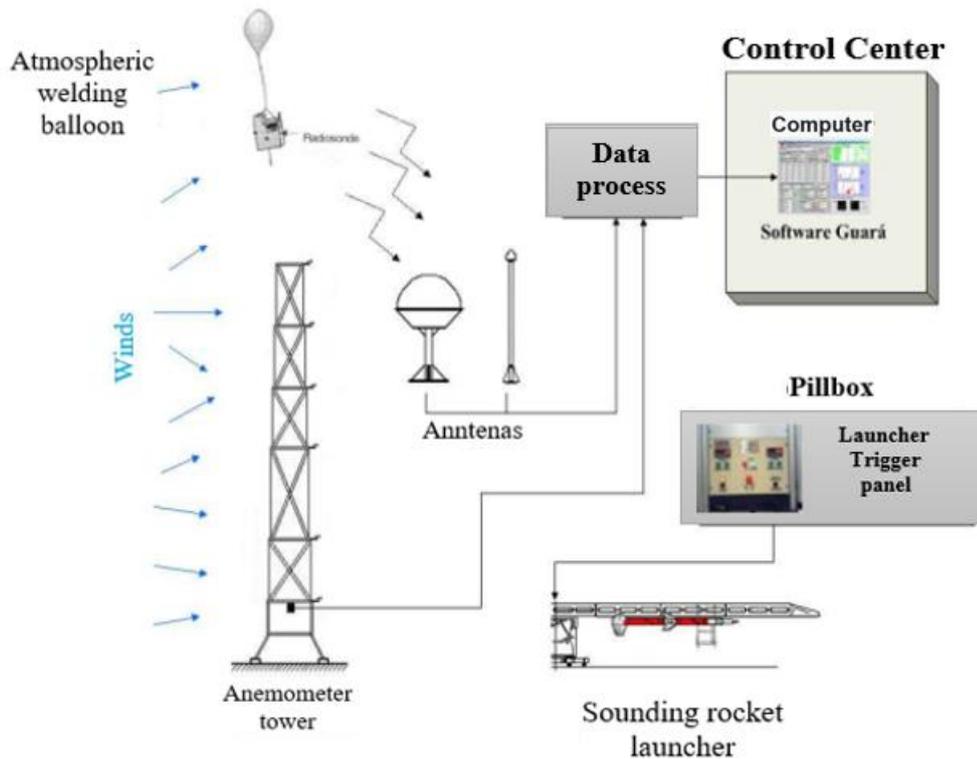


Figure 1. Scheme for obtaining the CLA wind profile

Adapted from: GARCIA (2017)

The microgravity environment is favorable for carrying out experiments in different areas of science with many technological and useful applications for humanity. This environment can be reached through the flight of a sounding rocket, for example. However, for launching rockets a high level of precision, safety and reliability is required. Uncontrolled sounding rockets are launched through the launch track and to compensate for the direct influence that the wind has on the rocket's trajectory, it is necessary to adjust the azimuth and elevation angles in order to compensate for this effect (GARCIA, 2007).

With this study, the objective is to obtain a method of adjusting the launcher of an uncontrolled sounding rocket, launched from the Alcntara Launch Center, according to the Guar method, current method used in the CLA, for Flight Safety and better accuracy of the isolation area required for launches. For checking is going to be necessary to obtain results that demonstrate a difference in the impact distance without adjusting the launching rail and using the adjusting according to the method.

## 2. METHODOLOGY

In order to compensate this effect, the Guar software presents some simplifications, as the method is based on the concept developed by Lewis (1949), which went through some adaptations until defining the program. To calculate the launcher's adjustment with the respective new azimuth and elevation values, the following procedures are performed:

weighing the wind and calculating the ballistic wind, calculating the effect of the unit wind and, finally, calculating the adjustment.

The methodology of the present work consists of initially implementing Lewis (1949) wind weighing concepts - evaluated by James and Harris (1961) - and antisymmetric compensation, addressed by Kramer (1973), implemented through MATLAB language. It aims to develop the method compatible with that used in CEA (Centro de Lançamento de Alcântara) through the software named "Guará". For that, the process step-by-step will be presented and simulations and validation will be carried out through the implementation and simulation in a trajectory simulator that uses a spheroidal earth model (more realistic simulation model) validated and real wind profiles obtained by Alcântara Space Center.

The Guará software receives wind data to proceed with the calculations to determine the adjustment. The adjustment methodology implemented in Guará is simplified, considering only the first order effect of both wind and azimuth and elevation angles on the location of the impact point.

With respect to the launch orientation, it is considered that a variation in the azimuth will result in an angular displacement of the trajectory corresponding to the variation angle, while the effect of the elevation variation is a linearization around the nominal elevation. For the calculation of the adjustment, Guará replaces the measured wind profile just before launch with a weighted average, where the weighting weights correspond to the influence that each layer of the atmosphere has on the location of the impact point. The weighted average of the wind is called ballistic wind.

Thus, the deviation that the measured wind would cause in the trajectory is estimated by multiplying the effect of the unit wind by the ballistic wind. These deviations are calculated separately for the front, side and tail components of the ballistic wind. Now, knowing the effect of the launch orientation on the trajectory, the adjustment of the launcher is carried out in order to compensate for the deviation of the wind in an antisymmetric way, that is, if the wind tends to increase the impact distance, the adjustment in the elevation must be such as to decrease this distance, while the variation in azimuth must compensate for lateral deviations in the path.

For Weighing the Wind, first, for the application of this methodology, the wind is weighed. Weighing the wind makes it possible to calculate the influence of a wind profile on the impact point of a suborbital rocket when it returns to the surface after its flight (MATA, 2017). To calculate the weight of the wind, the atmosphere is divided into layers at different altitudes. Then, simulations of the rocket trajectory are carried out considering a constant wind profile from the ground to a certain altitude. The wind weighing function ( $f_i$ ) describes the relationship between the rocket impact displacement vector corresponding to a uniform wind to a stipulated altitude ( $I_i - I_0$ ), and impact displacement vector corresponding to a constant wind from the ground up to an altitude of 20000 meters or 30000 meters ( $I_n - I_0$ ).

The value of the weighing function, considering a constant wind profile up to an altitude  $i$ , It is given by:

$$f_i = \frac{\sqrt{I_i^2 + I_0^2 - 2 \times I_i \times I_0 \times \cos(\alpha_i - \alpha_0)}}{\sqrt{I_n^2 + I_0^2 - 2 \times I_n \times I_0 \times \cos(\alpha_n - \alpha_0)}} \quad (1)$$

Where:

$I_i$ : impact distance, considering the influence of the wind up to a certain altitude  $i$ .

$\alpha_i$ : impact azimuth, considering the influence of the wind up to a certain altitude  $i$ .

$I_0$ : impact distance without wind influence.

$\alpha_0$ : impact azimuth, without influence of the wind.

$I_n$ : impact distance, considering the influence of the wind up to 20,000 meters.

$\alpha_n$ : impact azimuth, considering the influence of the wind up to 20,000 meters.

To calculate the weight of the wind at each altitude layer ( $i$ ) we use:

$$\Delta f_i = f_i; i=1 \quad (2)$$

$$\Delta f_i = f_i - (f_{i-1}); i=2 \text{ until } n \quad (3)$$

This research proposes a study on a methodology for calculating the adjustment of the launching track of these rockets to compensate for the effect of the wind on their trajectories. For that, a trajectory simulator was also implemented, and the adjustment was determined so that the effect of the wind on the trajectory was efficiently compensated. The simulator uses the 4th and 5th order Runge-Kutta numerical method to obtain the solution of the differential equations in the simulator.

The methodology consists of implementing a flight simulator for unguided rockets that receives the adjustment value and integrates the trajectory of the rocket to the point of impact of the rocket, taking into account the effect of the wind. To simulate the movement of a rocket, a mathematical model of the rocket and its subsystems is necessary.

The simulator was implemented in MATLAB language, as it is a very versatile tool in mathematical calculations. The rocket behavior was calculated through numerical integration performed by MATLAB routines, providing results of the rocket flight data. The numerical method that was used to solve differential equations in the simulator is the 4th and 5th order Runge-Kutta method.

Figure 2 shows a Flowchart that corresponds to the integration of each flight phase, having as input data the information about the rocket and the flight path, following the sequence of events and the models used in each flight phase.

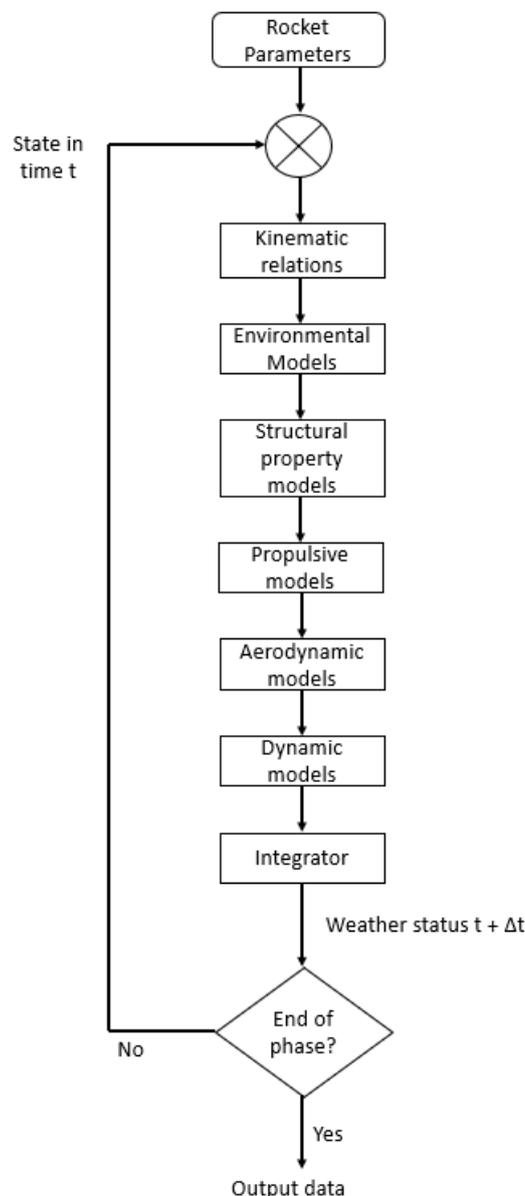


Figure 2. Flowchart of the Rockets Simulator.  
Available from: Author, 2018

The simulator was implemented in a generic way, being able to be used for different uncontrolled rockets, with different phases of flight. The flight phases are defined in the rocket input file. Each phase has its specific data such as: duration of flight time, mass data, propulsive and aerodynamic. Generally, the end of one phase and the beginning of another is associated with some change in the trajectory or physical characteristics of the rocket, such as leaving the rocket from the rail, igniting an engine, separating a stage, starting the yo-yo, etc., as shown in Figure 3.

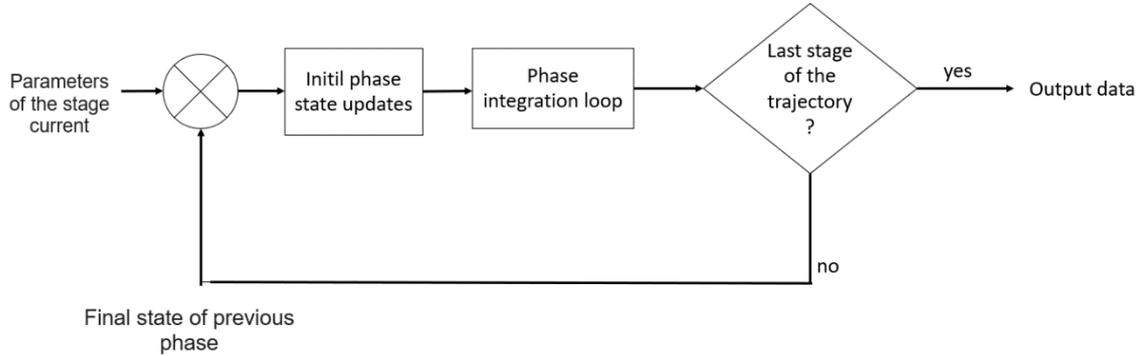


Figure 3. Flowchart of integration of the trajectory

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### 3. RESULTS

In order to illustrate the effect of the Guar adjustment, the simulations for a correct adjustment and another not are presented in this section.

Table 1 shows the simulation performed with 25 different winds, with their respective azimuth and elevation values used for each wind. It shows also the obtained ballistic wind value and the distance between the impact points when not corrected by the implemented method and values of the distances when the adjustment was made through the implemented method.

Table 1. Results obtained distances for different winds

WIND	CORRECTED AZIMUT (degrees)	CORRECTED ELEVATION (degrees)	DIFFERENCE BETWEEN CORRECTED AZIMUT AND NOMINAL AZIMUT (degrees)	DIFFERENCE BETWEEN CORRECTED RISE AND NOMINAL RISE (degrees)	BALLISTIC WIND VALUE (m/s)	DISTANCE BETWEEN THE NOMINAL AND PERTUBATED IMPACT POINT WITHOUT THE ADJUSTMENT (Km)	DISTANCE BETWEEN NOMINAL AND CORRECTED IMPACT POINT BY USING THE ADJUSTMENT METHOD (Km)
1	51.70°	89.35°	13.30°	5.35°	8.806	153.009	2.953
2	75.92°	87.90°	10.92°	3.9°	6.490	121.313	5.833
3	63.71°	86.80°	1.29°	2.8°	4.588	88.846	4.420
4	77.60°	87.07°	12.60°	3.07°	5.232	99.421	4.340
5	23.53°	85.35°	41.47°	1.35°	6.188	123.702	4.748
6	(-3.25°	87.95°	68.25	3.95°	9.054	166.748	11.149
7	72.64°	88.55°	7.64°	4.55°	7.493°	136.190	9.007
8	61.68°	87.99°	3.32°	3.99°	6.555	122.508	6.754
9	52.45°	89.02°	12.55°	5.02°	8.271	163.221	31.041
10	7.98°	88.18°	57.02°	4.18°	8.526	157.210	10.253
11	76.04°	87.44°	11.04°	3.44°	5.760	106.422	1.824
12	46.98°	87.30°	18.02°	3.30°	5.760	109.077	5.991
13	32.30°	84.70°	32.70°	0.70°	4.976	104.709	6.990
14	23.91°	85.27°	41.09	1.27°	6.133	125.863	9.049
15	10.57°	83.89°	54.73°	0.11°	8.453	170.566	12.290

16	10.57°	83.89°	54.73°	0.11°	8.453	170.394	12.356
17	36.73°	83.57°	28.27°	0.43°	4.597	101.246	5.908
18	21.39°	84.55°	44.61°	0.55°	6.561	135.982	9.763
19	29.56°	85.05°	35.44°	1.05°	5.374	110.254	9.409
20	31.57°	85.21°	33.43°	1.21°	5.138	113.546	10.388
21	33.59°	84.60°	31.41	0.60°	4.792	100.968	7.976
22	42.16°	85.58°	22.84	1.58°	4.073	84.655	5.495
23	56.76°	87.30°	8.24°	3.30°	5.491	104.947	6.717
24	31.71	85.45°	33.29°	1.45°	5.194	108.025	8.224
25	21.90°	85.39°	43.10°	1.39°	6.396	129.728	12.881

The table above shows the great difference in the distance between the impact points when the method is not used and when it was used to make the adjustment, showing a much smaller distance when the simulation was performed with the adjustment of the method in all results, as can be realized in the last column.

Figures 4 and 5 show the correct adjustment of the launcher for the wind of the 21st of October, where the effect of the wind was compensated with the adjusted angles of azimuth at 76.04 ° and elevation at 87.44 °.

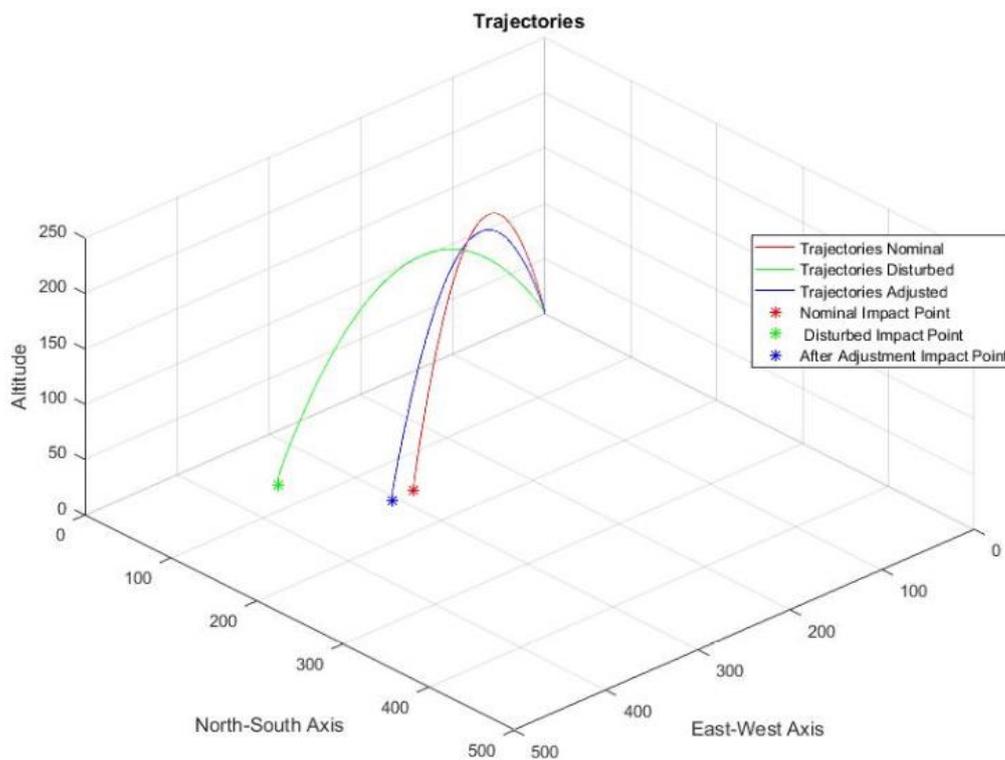


Figure 4. Comparison of 3D Trajectories  
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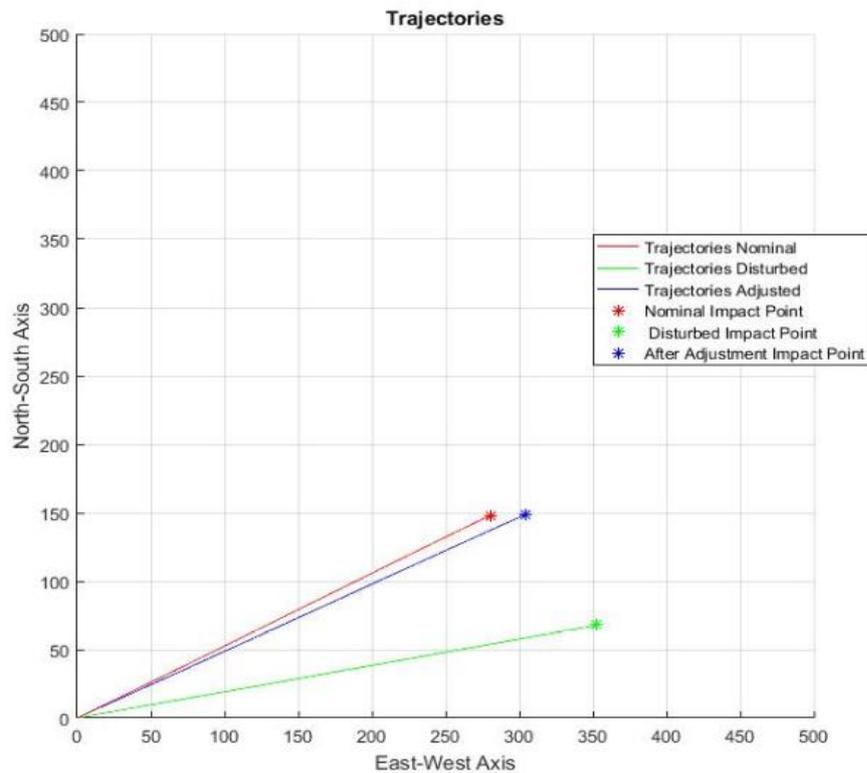


Figure 5. Comparison of Trajectories in top view

Available from: Author, 2018

#### 4. CONCLUSION

Determining how to adjust the launch angles of uncontrolled sounding rockets is essential to the success of launch missions. With this work, it was found that the divergence in the trajectory caused by the effect of the wind is reduced by the method based on the concepts of Lewis (1949), thus being capable for flight safety and for possible payload recoveries, since this research used a realistic trajectory simulator with real wind profiles.

The Guar software, which is used in the Flight Safety Sector, is responsible for obtaining, from wind profile data, a new launcher adjustment to compensate for the wind effect. This software presents a simplified method that, although efficient, does not always meet the requirements of CEA. In view of this situation, it is essential to use a flight simulator and adjust the launcher provided by a method capable of reducing the impact distance even under the effect of the wind on the trajectory.

The method presented based on Lewis concepts compensated for the effect of the wind on the trajectory of uncontrolled sounding rockets

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