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Tracking and impact point of survey rocket by Telemetry and Slant-Range device

NILTON R. CANTANHEDE, EWALDO EDER CARVALHO, PAULO FERNANDES DA SILVA JÚNIOR & JONAS DE JESUS BARROS

Abstract: This work presents an alternative method of getting tracking, and the impact point of the actual flight of a rocket, by telemetry data and slant-range device. The tracking and impact point data were obtained from an actual flight path by merging the angular components of a telemetry antenna (Azimuth, and Elevation) and the radial distance information provided by the slant-range device. The position components were analyzed with the telemetry antenna in automatic mode, target tracking, comparing with the tracking results performed by the radar. The result obtained by the composition of the coordinates of the telemetry/slant-range set, it was observed that the point of impact generated by this group had a distance of 237.64 (meters), in relation to the impact generated by the tracking of the radar. Indicating a significant reduction of the search area and can be used as na alternative form of use. It allows you to provide additional location information for payload recovery around the actual point of impact.

Key words: Impact point, rocket, slant-range device, telemetry, tracking.

1 - INTRODUCTION

In the current context, rocket launch centers are of fundamental importance in space activity, with regard to scientific research and technological development, with responsibilities linked to vehicle assembly, rocket launch, trajectory monitoring and payload rescue, which is a set of measuring equipment or satellite, transported by a space vehicle to accomplish a certain mission (Fugivara 2015). Since the monitoring is carried out along the trajectory until reaching the injection point in orbit or on the ground with obtaining the point of impact (PI) (Brazil 2018).

In monitoring, the trajectory systems or means of the location used to calculate the rocket's position and impact point are the radars, which provide the location of the target and which are the only source of information for flight safety (FS). For small unmanned vehicles controlled from the ground, solutions based on computerized systems have been proposed (Angonese & Rosa 2015) and developing better mathematical tools for analyzing missile control, using technologies as neural networks, object-oriented programming, Gaussian process error model (Lemos & Simões 2013, Barros 2005).

The need for continuous determination or location of this point is an essential condition for flight safety, in which the monitoring of the tracking and estimation of the vehicles PI, allows the mission control to discern whether the rocket will eventually deviate outside the permitted limits protected areas (Giles & Whitford 1980). Tracking the trajectory and the point of impact are important both for FS, as a way of ensuring the safety of inhabited areas, as well as to ensure a better accuracy of the point of impact, which will allow rescue teams if necessary, to carry out the rescue of the payload after impact.

Several means are used to get the positioning and point of impact of rockets, such as the global positioning system (GPS) and the use of radar on the ground, and telemetry (Yi-Yuan & Kuu-Young 2002, Montenbruck 2002). GPS is a proprietary system, and for military tests in countries that do not have the technology, prerogatives are required that make its use unfeasible. The ground radar is an option used in the Alcantara Launch Center - MA, but tracking an air vehicle presents several difficulties, especially in the first moments after launch, and in cases of loss of vehicle positioning, leading to the termination decision, of rocket flight. The fusion of telemetry data and inclined range device provides an alternative for rocket location.

The use of pulse code modulation (PCM) via the rocket telemetry system has a long research time (Yan et al. 2010). In the work of Babayomi et al. (2013), a wireless sensor network is designed and simulated to indicate the positioning of projectiles in the rocket explosion test zone. In Louis (2006), a low-cost test system with embedded systems for remote ignition and remote rocket abortion was developed in the event of specific circumstances.

The location where the vehicle is expected to hit the earth's surface is one of FS's main concerns, making it necessary to forecast the likely point of impact of the vehicle at each instant of flight (Schelim et al. 2017). Means that can identify the point of impact and aggregate information together with the sensors that are used by the Center in the location of impact will provide a reduction in the effective search area, providing conditions for better PI accuracy for search teams.

This work proposes the use of data from the slant-range device and the angular position of a telemetry antenna as a means of obtaining the tracking, and the point of impact of the survey rocket, in order to help payload rescue, consisting of an alternative to reduce the effective search area, combined with the impact points generated by the trajectory radar. This work uses on-board data from the survey vehicle together with angular information from a telemetry antenna, in order to have a means of locating the impact point. This work is divided into four more parts in addition to this introduction. In section 2 the methodology used in the development of the work is discussed, in section 3 the referential system of points is presented, in section 4 the results obtained are commented and section 5 deals with the considerations of the work.

2 - MATERIALS AND METHODS

The Alcantara Launch Center has an average of four rocket launches per year, highlighted by the launch of models VSB-30, FTB, VS-30, VS-40, and VLS-1 rockets (Brazilian Space 2021), with tracking carried out through two radars, one in the city of Raposa-MA and the other in the city of Alcantara-MA, with wireless connection via telemetry, used to send data from the rockets' internal sensors.

The distance between the actual impact point and the one indicated by the radars varies between a radius of 400 m to 1,000 m. Thus, distances shorter than those showed by the radars promote significant gains in the vehicle's recovery or its payload. Although several launches are performed at the Launch Center in Alcantara-MA, only the flight used in this work used the alternative tracking method using the slant-range device with telemetry data.

The measurements presented in this work were obtained from a real flight, carried out at the ALC, Alcantara – MA, with the launch of VSB-30 probing rocket in 2016, being the only vehicle of this type with slant-range device and telemetry launched (Pisacane 2005). The used data were available by the Trajectories and Synchronization Section, and by the Telemeasure Section for research and development purposes. In monitoring the trajectory and showing the impact point, data from the Adour radar and the telemetry antenna were used, both in the city of Alcantara – MA.

The radial distance measurements can be generated by comparing the phase of the PCM signal from the baseband of the receivers, with the PCM reference signal of the slant-range device shown Figure 1.

Figure 1. Slant Range device, used to measure the distance between the payload Telemetry Station and the Telemetry Station.

Telemetry data are sent to the ground station over an RF link similar to that used by the command system. The most common type of modulation is phase shift keyed pulse code modulation PSK-PCM (Carden et al. 2002). To obtain the point of impact, the angular positions (Azimuth and Elevation) of the Telemetry Antenna were used together with the measurement of the radial distance generated from the phase displacement, between the payload and the Telemetry Station, as a way of composing the location of the payload in space, thus ensuring an additional means of locating the point of impact on the ground. The mechanics of the operation of the IP location system by telemetry can be seen in Figure 2.

2.1 - Distance calculation

In the measurement performed by the slant-range device, radial distance is used, thus, the baseband generated by the internal reference generator is kept synchronized in phase with the signal wave derived from the incoming telemetry flow, that is, telemetry data demodulated by the receiver. The receiver system consists of a receiver, bit detector and synchronizer, and frame synchronizer (Cai et al. 2011). In Figure 3, illustrates the two instants for the distance calculation: First, before launch, in which

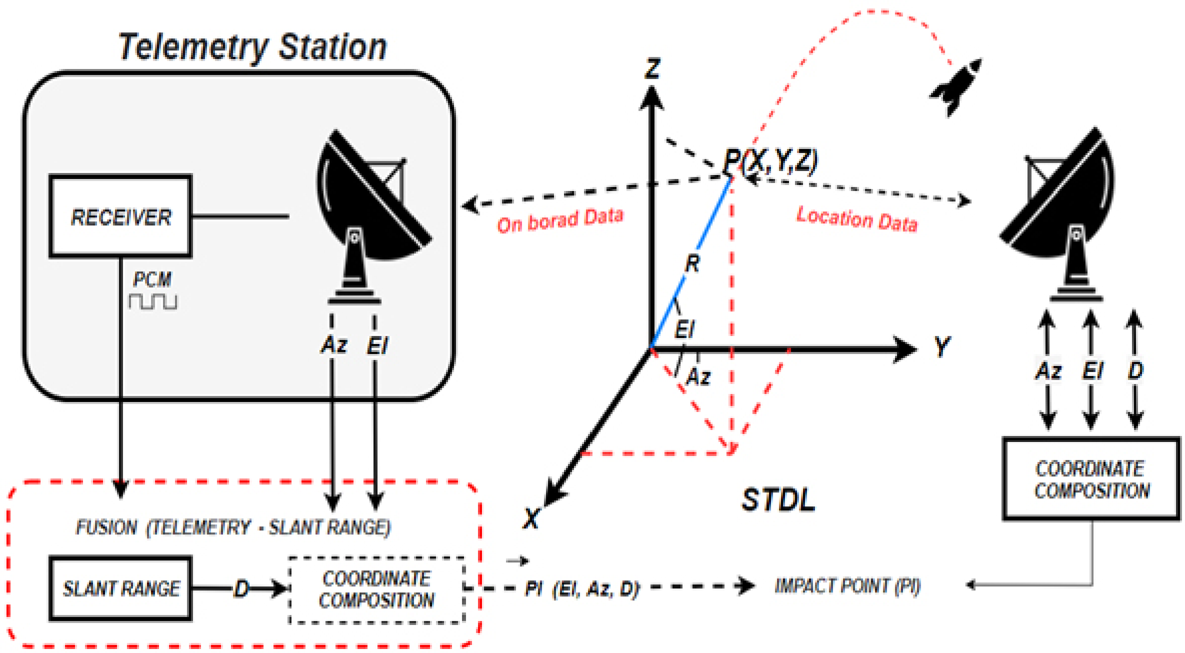

Figure 2. Illustration of obtaining the impact point.

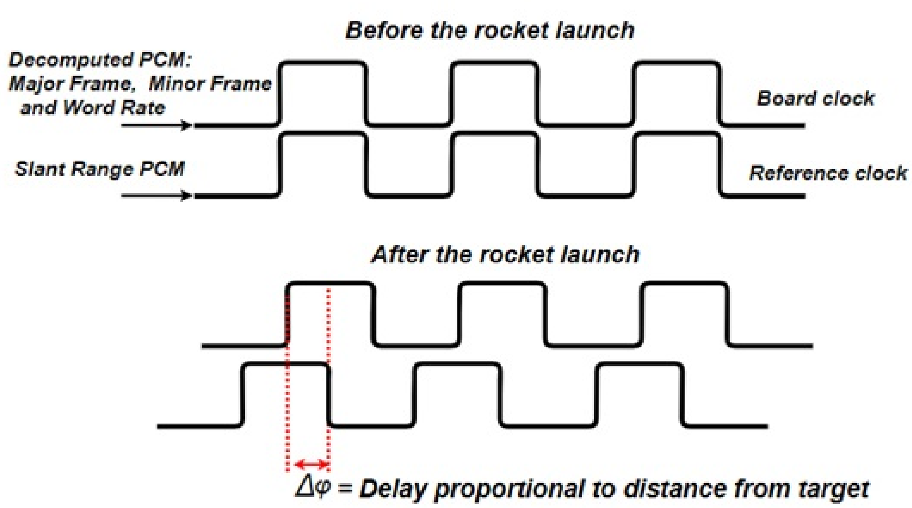

Figure 3. Demonstrates the two instants for the measurement performed by the slope range.

the demodulated PCM and the slant-range decice PCM are in phase; and second, after the launch, in which the rocket displacement begins, in this case, the phase comparator continuously measures the difference between in the signals generated $\Delta\phi$ which is subject to a propagation delay due to the radial distance. In which the phase or time difference is a direct indication of the payload position related to the telemetry antenna in tracking mode, enabling the vehicle to be located and the point of impact to be indicated.

2.2 - Positioning

The Telemetry Station located in $P_u = (X_u, Y_u, Z_u)$, were X_u, Y_u and Z_u are the user's reference coordinates (X, Y, Z). For the Slant Range system, the data that the user can measure are the azimuth and elevation angles of the Elevation (E_L) and Azimuth (A_Z), in addition to the radial distance derived from the comparison of the PCM signal retrieved by the bit synchronizer, with a ground reference. This distance is defined as (D).
The information desired by the system is the position of the rocket given by $P_S = (X_S, Y_S, Z_S)$. To obtain X_S, Y_S and Z_S we must first calculate the difference vector between the user's and the rocket's positions in the user's reference frame, this difference vector is given by:

$$dP' = \begin{pmatrix} dx' \\ dy' \\ dz' \end{pmatrix} = \begin{pmatrix} r \cdot cos\phi \cdot sin\theta \\ r \cdot sin\phi \cdot sin\theta \\ r \cdot cos\theta \end{pmatrix} \quad (1)$$

The position information (location) of the rocket is given by $P_S = (X_S, Y_S, Z_S)$. In obtaining P_S the difference vector is calculated between the user reference positions and the rocket in the user reference. Transforming the user's position in coordinates East, North, Up (ENU) and the coordinates (X, Y, Z) are converted to Earth Centered Earth Fixed (ECEF), and also, to ECEF for the WGS 84 geocentric Global Positioning System - GPS (Hofmann-Wellenhof 2021). Thus, from the latitude, longitude and height coordinates (ϕ, λ, h), one can calculate the rotation matrix from the user reference $F = (X, Y, Z)$.

$$F = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} -sin\lambda & sin\phi cos\lambda & cos\phi cos\lambda \\ cos\lambda & -sin\phi sin\lambda & cos\phi sin\lambda \\ 0 & cos\phi & sin\phi \end{pmatrix} \quad (2)$$

Rotating the difference vector between the user and rocket positions to the reference (X, Y, Z) gives:

$$dP = F \cdot dP' \quad (3)$$

With the sum of the difference vector with the user's position, the rocket position is obtained, indicated by:

$$P_S = P_u + dP \quad (4)$$

3 - REFERENTIAL SYSTEM

In the referencing system of the point for locating rockets, spherical coordinate, geodesic, ECEF, and local Cartesian systems are used. The Local Spherical System AER (Azimuth, Elevation, and Range) is a reference system that allows us to locate any point in space in a spherical form of a set of three values (Venturi 2015).

The Geodesic Coordinate System is used for navigation based on GPS (Global Position Systems), in which the points are close to the Earth's surface, being represented by latitude, longitude, and altitude, which represents the vertical local distance between the measured point and the reference ellipsoid (Hofmann-Wellenhof 2021, Weiss 2021).

The Earth Centered Coordinate system, Earth Fixed (ECEF) considers the rotation of the Earth around its axis of rotation, with a fixed point on the Earth's surface having a set of three (X, Y, Z) axes located in the center of the Earth, in the Z pointing towards the North pole, the X-axis intersects the Earth sphere at 0° latitude and 0° longitude and the Y-axis is orthogonal to the Z and X axes (Cai et al. 2008).

The Local Cartesian Coordinate System (ENU) (East, North, Up) represents the coordinates fixed at the specific local point, forming a plane tangent to the Earth's surface, with conversion East representing the X-axis, North representing the Y-axis and up the Z-axis, perpendicular to the X and Y (Cai et al. 2008).

3.1 - Coordinate Transformation

Conversion from the spherical coordinates (AER) radius (r), Elevation E_L, Azimuth A_Z. Where $r \in [0, \infty), \theta \in [0, \pi], \phi \in [0, 2\pi]$, can be retrieved to the Cartesian coordinate system (ENU) by:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} r \cdot cos\phi \cdot sin\theta \\ r \cdot sin\phi \cdot sin\theta \\ r \cdot cos\theta \end{bmatrix} \tag{5}$$

where A_z, E_L and D, are the coordinates in the local spherical system. They were transformed to the local cartesian system ENU at the point (X, Y, Z). From the ENU system, it is transformed to coordinates in the ECEF system performed by:

$$\begin{bmatrix} X_P \\ Y_P \\ Z_P \end{bmatrix} = \begin{bmatrix} X_{ECEF} \\ Y_{ECEF} \\ Z_{ECEF} \end{bmatrix} = \begin{bmatrix} (N_E + h)cos\phi cos\lambda_r \\ (N_E + h)cos\phi sin\lambda_r \\ \left[N_E(1 - e^2) + h\right] sin\phi \end{bmatrix} \tag{6}$$

where e is the first eccentricity, N_E is the radius of vertical curvature, λ_r is the latitude, ϕ is the latitude and h is the height (or altitude)

$$\begin{bmatrix} X_{NORTH} \\ Y_{EAST} \\ Z_{DOWN} \end{bmatrix} = \begin{bmatrix} -sin\lambda_r & cos\lambda_r & 0 \\ -sin\phi_r cos\lambda_r & -sin\phi_r sin\lambda_r & cos\phi_r \\ cos\phi_r cos\lambda_r & cos\phi_r sin\lambda_r & sin\phi_r \end{bmatrix} \cdot \begin{bmatrix} X_p - X_r \\ Y_p - Y_r \\ Z_p - Z_r \end{bmatrix} \tag{7}$$

Thus, the local spherical coordinates obtained by the tracking systems were transformed by the transformations represented in the Figure 4.

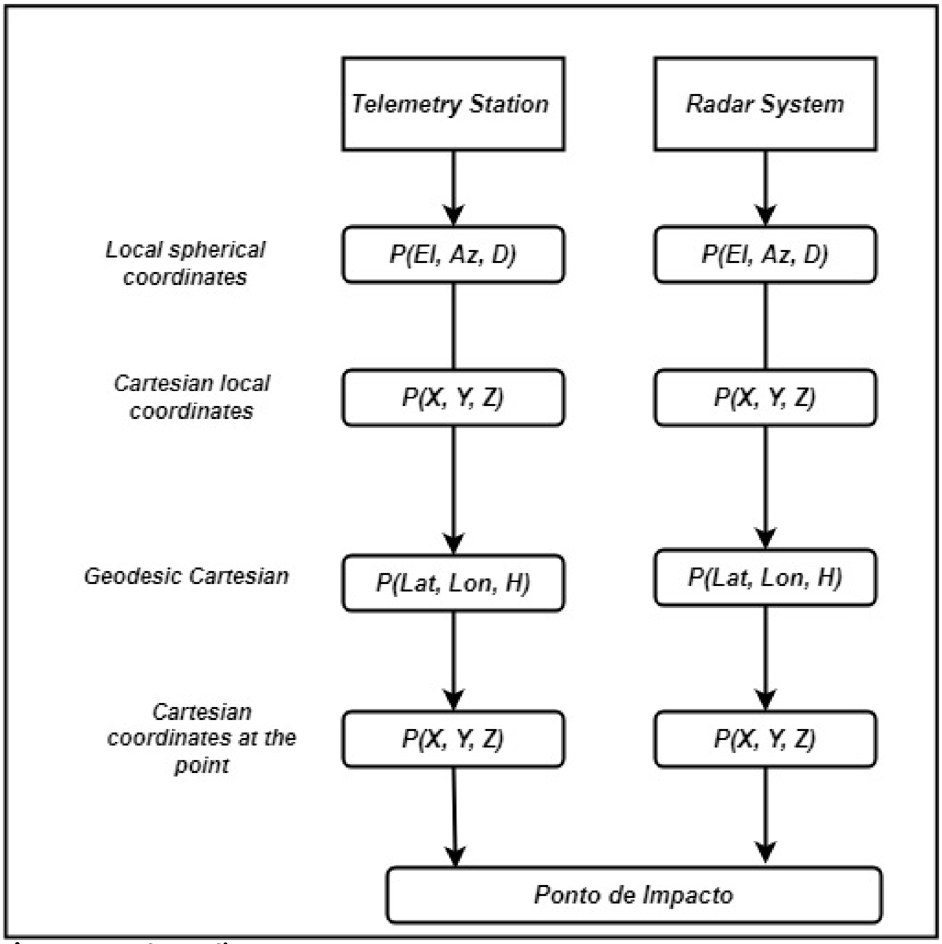

Figure 4. Used coordinate systems.

4 - IMPACT POINT INDICATION OF THE SURVEY ROCKET BY FUSION TELEMETRY-SLANT RANGE

The proposed method, of the sign of impact point and tracking of rocket, is innovative by the use of position data of slant-range device and telemetry, and can be used as alternative tracking to the localization by radar. In Figure 5, shows the evolution of the payload trajectory of the survey rocket from the time in 36 (s) to the point of impact on the X_{NORTH} axis coordinate, assessed by the radar and the set of components obtained from the antenna position and data from the telemetry. A small difference can be seen between the trajectory indicated by the radar and the telemetry/slant-range composition. The most significant results can be observed from the instant 250 (s), in which the curves are coincident until the final instant.

In Figure 6, shows the evolution of the trajectory developed by the rocket at the coordinate of the Y_{EAST} axis, in which greater variations in the loss of the rocket signal by the radar can be noted. The result of the telemetry/slant-range set showed less noise, with minimal variation, and a result of PI close to the radar.

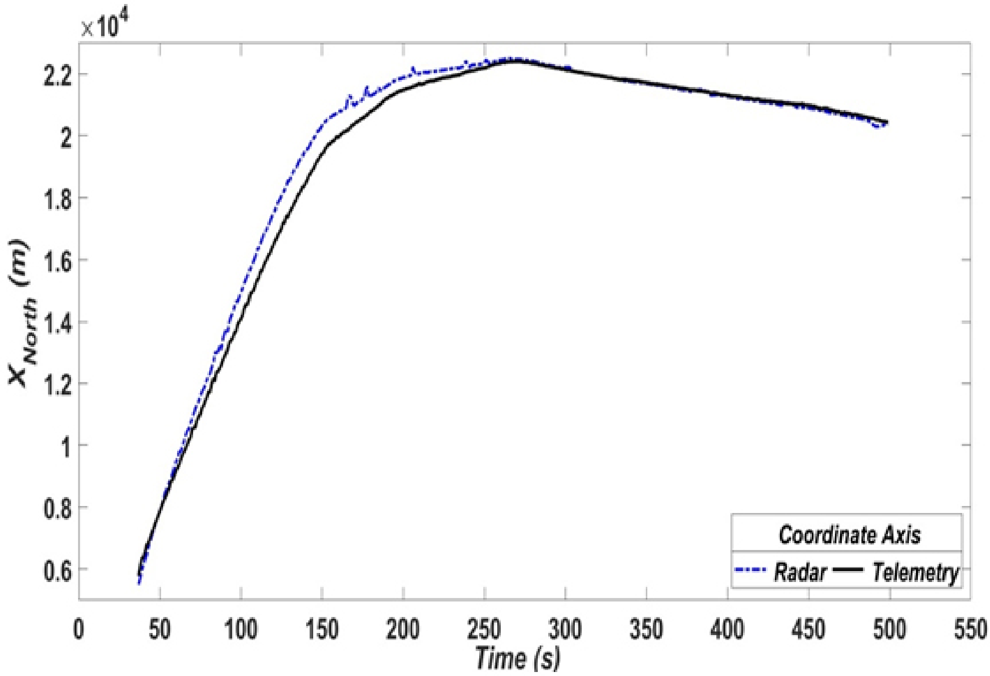

Figure 5. Comparison of tracking performed by radar in relation to Telemetry - Slant range set of the survey rocket, x-axis with respect to the rocket's position.

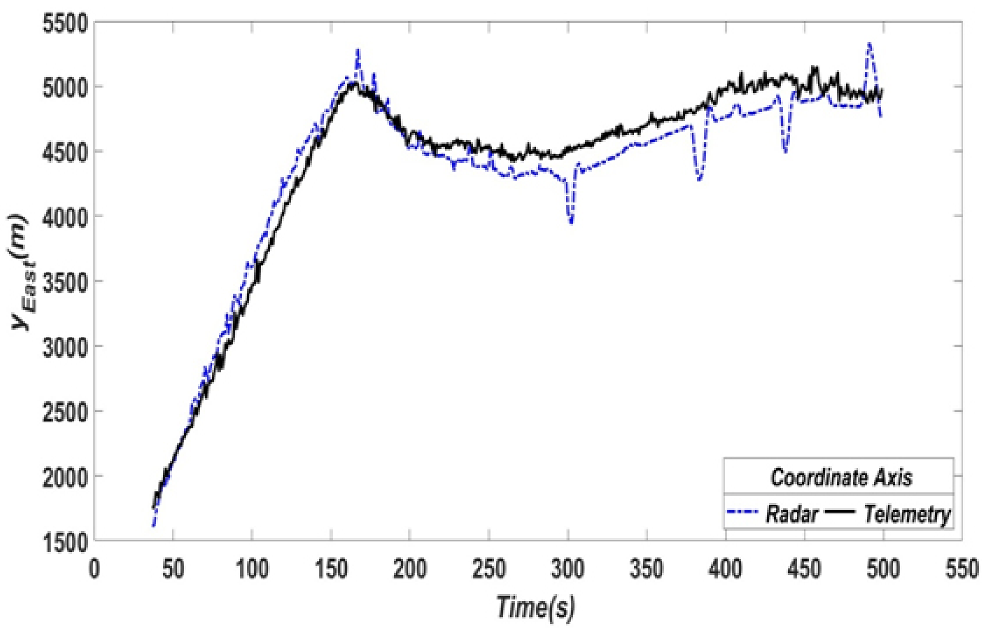

Figure 6. Comparison of radar tracking compared to Telemetry - Slant Range of the survey rocket, on the Cartesian Y-axis with respect to the rocket's position.

In Figure 7, the rocket trajectory can be observed in the coordinate of the Z_{DOWN} axis. The best result is identified between the moments of 100s to 150s. Note that telemetry showed results with less variation and impact point close to that obtained by the radar.

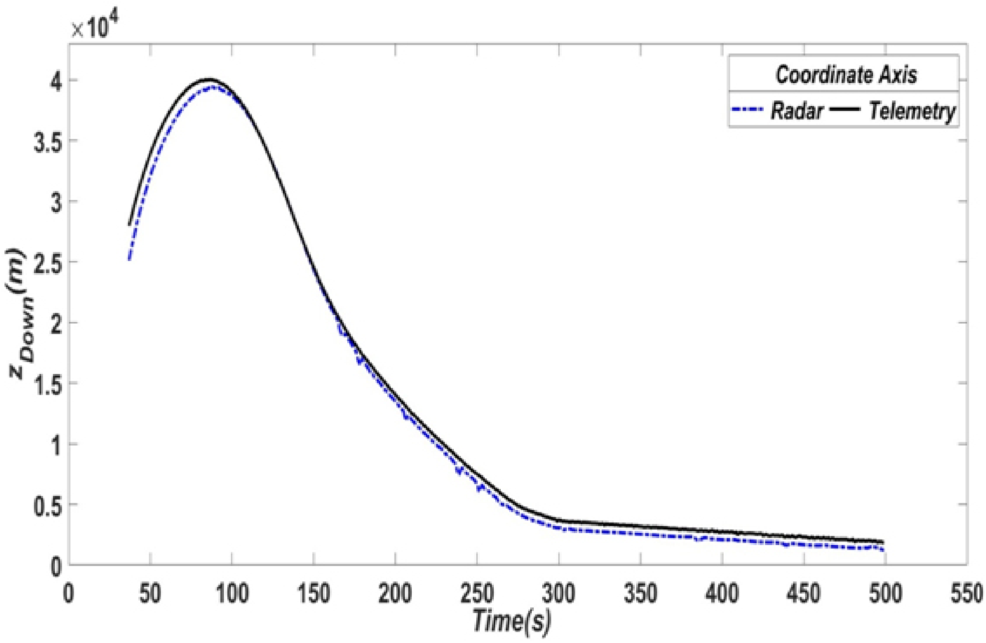

Figure 7. Comparison of radar tracking compared to Telemetry - Slant Range of the survey rocket, on the Cartesian Z-axis with respect to the rocket's position.

Figure 8. The results obtained from the composition (azimuth, elevation and distance).

The final points of impact in geodesic coordinates indicated of the survey rocket by the radar located at the point, and by the telemetry/slant-range set positioned at the point, PI_R, and by the telemetry/slant-range set positioned at the point, PI_{TLM} obtained from telemetry data, with the indications of radio of 1σ (of approximately 1000 m) to 3σ (3,300 m), where the best results are considered at a distance of less than 1σ, it can be seen Figure 8.

From the results obtained, the curves indicate that the point of impact generated by the radar at 500 (seconds) of tracking was latitude -2.273° and longitude -44.185°. For the Telemetry/slant-range set at the same time, the impact point results were -2.2709° latitude and 4.185° longitude, both impact points are within the 1σ region.

In Figure 9, shows the location point obtained at 500 seconds of tracking performed by the Adour radar, indicated by the PI_R, impact point, in relation to the location obtained by the components of the Telemetry/Slant-Range set represented by the PI_{TLM} impact point, with difference maximum between the results of 237.64 meters, with region less than 1σ, and search effective area less than radar system.

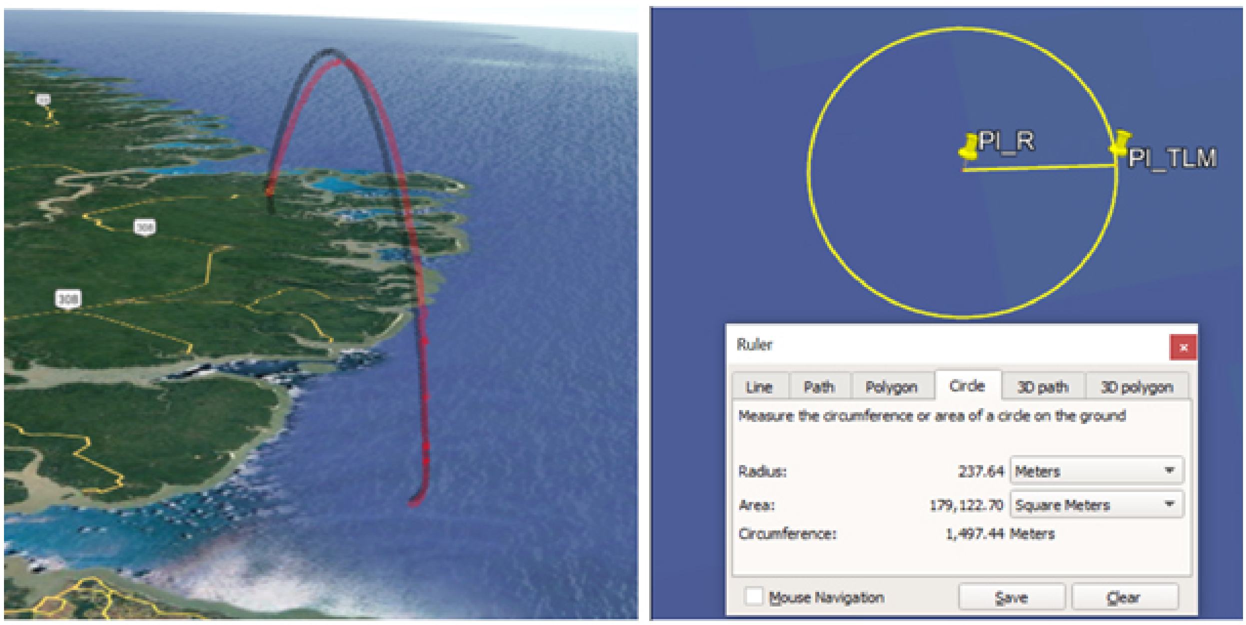

Figure 9. Comparison of points of impacts generated by the radar in relation to the Telemetry-Slant Range set.

In Table I, can see that the distance can be considered small and a significant result, for alternative location purposes, in the recovery of useful poop by rescuers at sea. The importance of obtaining more than one point of impact location seeks to facilitate and guide rescue teams to be more punctual in locating the point of the fall.

Table I. Comparison between systems radar and Telemetry Antenna Fusion/ Slant Range.

	Impact area	Radar system	Radar System and Telemetry/ Slant Range
Search Effective Area	3.156.444 m^2	3.156.444 m^2	179.317,33 m^2

5 - CONCLUSIONS

In this work, the use of the Slant Range equipment was presented via on-board telemetry data together with angular information (Azimuth and Elevation) from the Telemetry antenna, to obtain the rocket impact point, indicated as an alternative way to reduce the effective area of search for the impact points obtained by the radars. The work used the real data of a flight carried out in the launch base of Alcantara, using data sent by the payload of the VSB-30 sounding rocket. The results evaluated by the performance of the coordinates obtained by the Telemetry-Slant Range set were compared with the tracking measured by the radar. The disappointment error observed from the impact point of the radar and the fusion of the components obtained by the Slant Range equipment and the Telemetry antenna was 237.64 meters, which enabled a reduction in the impact search region for an area of 1σ, less than 1,000 m. For rocket flight safety, the point of impact is crucial, as it can prevent inhabited regions from being hit, by the observed results, the use of the set via telemetry data can be used as an additional resource in target monitoring and still be used as an auxiliary way to indicate the point of impact, increasing safety levels for this type of vehicle and reducing the search field for rescue.

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NILTON R. CANTANHEDE[1]
https://orcid.org/0000-0002-8405-242X

EWALDO EDER CARVALHO[2]
https://orcid.org/0000-0002-8894-5353

PAULO FERNANDES DA SILVA JÚNIOR[2]
https://orcid.org/0000-0001-6088-6446

JONAS DE JESUS BARROS[1]
https://orcid.org/0000-0002-2149-0307

[1]Força Aérea Brasileira, Centro de Lançamento de Alcântara, Avenida dos Libaneses, s/n, Tirirical, 65000000 São Luís, MA, Brazil
[2]Universidade Estadual do Maranhão, Centro de Ciências Exatas e Naturais, Campus Paulo, VI s/n, 65000000 São Luís, MA, Brazil

Correspondence to: **Nilton R. Catanhede**

E-mail: eng.niltoncantanhede@gmail.com

Author contributions

Nilton Rodrigues Cantanhede: main author and creator of the article. Ewaldo Eder Carvalho Santana: planning and main guidance, for the purpose of writing the article. Paulo Fernandes da Silva Júnior: main reviewer of the final text of the article. Jonas de Jesus Barros: main reviewer of article trajectory data.