

# An Analysis for Regional Data Availability and Out of LoS Conditions

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## Abstract

During flight test operations at Turkish Aerospace Inc., maintaining continuous telemetry data reception is critical for safety and performance evaluation. To accurately identify, categorize, and predict regions of telemetry signal loss, a dual-component real-time analysis framework was developed. This paper presents the design and implementation of two custom real-time data acquisition modules—Out of Line of Sight Conditions and Regional Data Availability—integrated directly into the IADS (Interactive Analysis and Display System) telemetry ground station environment using external software applications.

The framework partitions the airspace into two distinct operational envelopes based on altitude. For off-runway, high-altitude flights (above 3,000ft), the Out of Line of Sight Conditions module dynamically verifies the aircraft's position against geometric Line-of-Sight (LoS) limits. Utilizing current velocity and heading data, it provides test conductors with real-time predictive alerts, calculating exactly when and where the aircraft will breach LoS boundaries if current flight parameters are maintained. Conversely, for on-runway and low-altitude operations (below 3,000ft), the Regional Data Availability module performs granular telemetry coverage analysis. It calculates the percentage of successful telemetry link reception across specific runway sectors, generating observational data to drive targeted RF infrastructure and antenna placement improvements.

Post-flight, this comprehensive suite enables engineers to definitively attribute data dropouts to physical LoS limitations rather than onboard equipment or ground station anomalies. Ultimately, this real-time data acquisition approach significantly enhances situational awareness during flight tests and provides actionable metrics for continuous telemetry coverage optimization.

**Key words:** Telemetry, Line-of-sight prediction, Data acquisition, IADS, Ray casting.

## Introduction

Turkish Aerospace Inc. (TA) is the technology center for the design, development, modernization, and production activities of air platforms in Türkiye. For all indigenous and modernization programs in TA—spanning fixed-wing aircraft (TF-X, HÜRJET, HÜRKUŞ, HÜRKUŞ II), rotary-wing platforms (ATAK, ATAK-II, GÖKBAY), and unmanned aerial vehicles (ANKA, AKSUNGUR, ANKA-III, KİHA)—telemetry systems and Flight Test Management Centers are highly utilized, ensuring that all these projects are actively monitored via telemetry during their flight test phases. The study explained in this paper has been executed on a prototype of the TF-X (Turkish Fighter) Program. TF-X is Türkiye's fifth-generation indigenous national combat

aircraft, designed to meet the complex operational requirements of modern aerial warfare. The development flight tests of TF-X require uninterrupted, high-fidelity data transfer to validate its advanced avionics, flight control systems, and structural limits. The real-time analysis framework detailed in this paper was specifically developed and utilized to optimize the telemetry infrastructure during these critical development flights of the TF-X project. Furthermore, aiming to ensure telemetry connectivity in both runway and off-runway areas, this framework is actively employed to collect precise coverage data not only during flight but also for establishing and improving connectivity inside the hangar, in front of the hangar, and across the runway.

During complex flight test operations, the continuous and reliable acquisition of telemetry data plays a vital role in both ensuring flight safety and increasing test efficiency. Pre-planned flight tests are monitored in real-time in the Flight Test Management Center by the respective system engineers via telemetry. If the acquired data does not comply with the expected design criteria or test requirements, an immediate warning is given to the pilot while the aircraft is still in the air, allowing test maneuvers to be corrected or repeated. This real-time intervention capability greatly increases the effectiveness of test flights and prevents unnecessary flight hour costs. However, the degradation or complete loss of the telemetry link eliminates this situational awareness and reduces test efficiency. Instantly determining the root causes of telemetry loss during flight tests—distinguishing whether the issue stems from the onboard transmission system, ground station antennas, or physical Line-of-Sight (LoS) masking due to the Earth's curvature and topographic elevations—has historically been a highly reactive and ambiguous process. To eliminate this ambiguity, geographic information systems (GIS) are utilized. However, dynamically performing mathematical analysis of massive topographic data through software like the Interactive Analysis and Display System (IADS) during an active flight creates severe hardware and software bottlenecks. This paper presents a dual-component real-time analysis framework designed for use in flight test operations, integrated into the IADS environment via external C++ software libraries. The developed "Out of Line of Sight Conditions" module processes massive LoS polygon data to predict

telemetry dropouts seconds in advance based on the aircraft's current heading and groundspeed without blocking the main IADS loop, while the "Regional Data Availability" module provides precise coverage mapping during on-ground tests performed on the runway, hangar, and apron areas.

### Data Preparation Process and Topographic Modeling

The preliminary preparation phase of the system is of great importance to identify the telemetry connection regions where flight tests will be executed and to ensure test maneuvers are conducted within safe LoS boundaries. The Global Mapper software is utilized in this process. During the field analysis, the exact location where the telemetry tracking antenna will be situated (latitude, longitude, altitude) and the antenna gain values to determine the maximum coverage area independent of obstacles are entered into the system. Based on this data, the Global Mapper application automatically extracts the Line-of-Sight (LoS) boundaries of the antenna. Since the radio horizon and the masking angle of topographic obstacles change as the aircraft's altitude changes, LoS boundaries are manually analyzed using the Global Mapper application for each altitude band. This analysis is conducted separately for every 1,000ft for altitudes between 3,000ft and 25,000ft, and every 5,000ft for altitudes from 25,000ft to 50,000ft, saved in .bmp format, and shown in Fig.1. Due to confidentiality requirements, it should be noted that all visuals presented in this paper are fictional and used for illustrative purposes only.



*Fig.1. An example of Line-of-Sight (LoS) analysis generated using Global Mapper for a specific altitude.*

These saved .bmp extended LoS visuals are transferred to the IADS Moving Map display

where calibration is performed (by entering the corner coordinates) and a .geo extension file

with the same name as the visual is created. During the test, the aircraft's location on the map is determined using this .bmp file and the generated .geo file, which is directly used for the visual tracking of the operators. While the visual map background is loaded into IADS, the analytical and mathematical aspect of the work is carried out in the background. While extracting LoS analyses from the Global IADS is a standard software in the aviation industry for real-time data visualization; however, it is not an engine designed for computational geometry algorithms. The main constraints faced by the system are as follows: Checking whether the aircraft's instantaneous GPS data remains within the boundaries of an approximately 20,000-vertex polygon dozens of times per second is not possible with standard IADS functions. Calculating which edge of this polygon the aircraft is flying towards based on its heading requires complex trigonometric functions. When these complex calculations are forced to run through IADS's own built-in functions or simple scripts, the system's

Mapper application, the corner points of the polygon (approximately 3,000 to 20,000 vertices) indicating the LoS boundaries are also outputted to be used in external software. These massive data sets are fed into the system as .txt files to be processed by the mathematical modules.

### Limitations of the IADS System

performance capabilities are severely exceeded, which can lead to catastrophic failures. Due to the surpassing of these systemic capacities, short or long-term operational interruptions occur in the IADS application. This situation causes the aircraft data, which is highly critical for flight safety, to be unavailable for instantaneous viewing by the Flight Test Management Center, thereby creating an unacceptable risk. To completely eliminate this safety vulnerability, the computational load has been removed from IADS and transferred to external real-time data acquisition modules (DLLs) written in C++.

### Real-Time Data Acquisition Modules

The system is divided into two different modules in accordance with the nature of the telemetry signal. The module developed for high-altitude operations loads the relevant .txt file obtained from Global Mapper into memory according to the instantaneous altitude of the aircraft. To check whether the aircraft's position is inside or outside this approximately 20,000-vertex polygon, the algorithm is executed. The calculation of the number of intersections is shown in equation (1). The external module written in C++ completes this loop in microseconds without imposing any load on IADS.

$$\text{Intersection Count} = \sum_{i=1}^n \text{Intersect}(P_{ac}, \text{Ray}, \text{Edge}_i) \quad (1)$$

The geometric basis of this ray-casting algorithm, including the aircraft's position vector and the intersection point, is visualized in Fig.2.

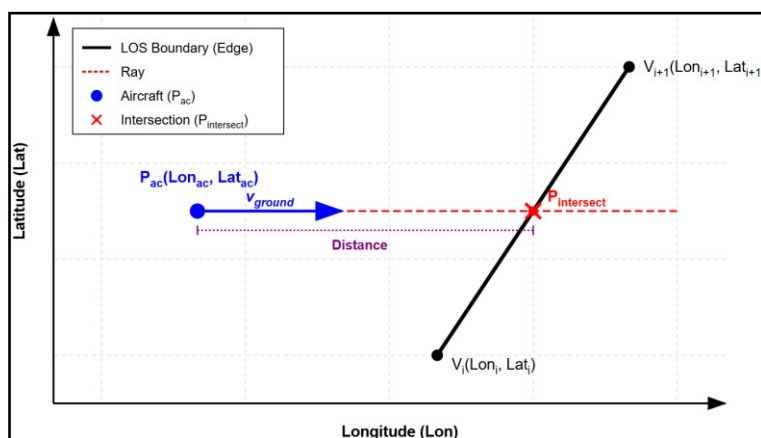


Fig.2. Mathematical representation of the Ray Casting algorithm used to dynamically predict LoS boundary breaches.

Once it is confirmed that the aircraft is within the LoS boundaries, the current heading is defined as a vector. The module calculates the intersection point between the aircraft's directional vector and the boundaries of the polygon. The remaining distance to this geographical intersection point is obtained using equation (2)

$$\text{Distance} = \sqrt{(\text{Lat}_{\text{intersect}} - \text{Lat}_{\text{ac}})^2 + (\text{Lon}_{\text{intersect}} - \text{Lon}_{\text{ac}})^2} \quad (2)$$

Using this calculated distance and the aircraft's groundspeed, the exact time remaining until the telemetry link drops is calculated with equation (3).

$$T_{\text{breach}} = \frac{\text{Distance}}{v_{\text{ground}}} \quad (3)$$

The results clearly show the test conductor the remaining distance and time before the aircraft exits the telemetry boundaries, as shown in Fig.3.

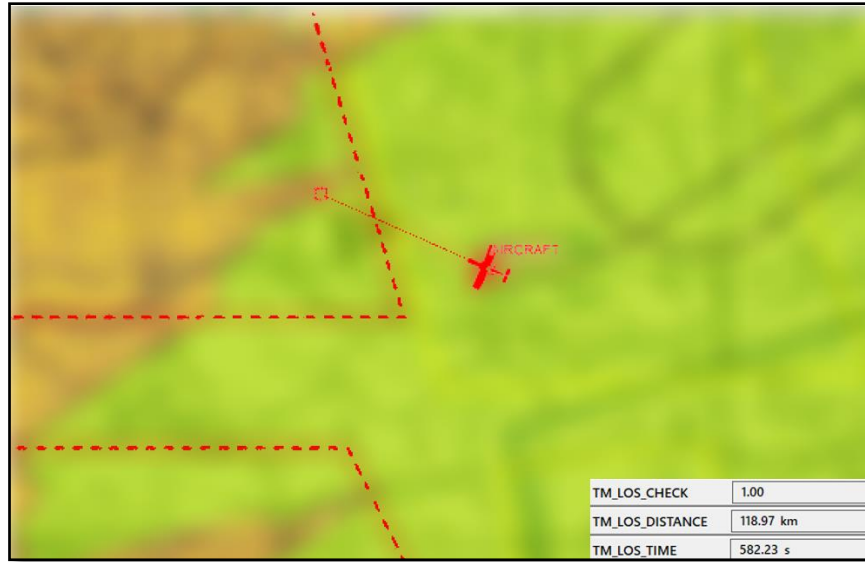


Fig.3. Real-time display of *TM\_LOS\_CHECK*, *TM\_LOS\_DISTANCE*, and *TM\_LOS\_TIME* parameters on the IADS Moving Map screen.

As shown in the IADS screen presented in Fig.3, three fundamental telemetry parameters calculated by the algorithm are utilized to provide real-time situational awareness to the operator. The functions and system states of these parameters are detailed in Table 1 as a look-up table. Specifically, the *TM\_LOS\_CHECK* parameter serves as a fundamental control flag indicating the operational mode of the system based on the flight's altitude status and boundary breaches.

Table 1 Telemetry status parameters displayed on the IADS screen (Look-up Table)

| Parameter Name         | Value / Unit  | Description                                                                                                                                                        |
|------------------------|---------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>TM_LOS_CHECK</b>    | 0             | <b>Out of LoS:</b> The aircraft has breached the calculated line-of-sight boundaries.                                                                              |
|                        | 1             | <b>Inside LoS:</b> The aircraft is within a safe line-of-sight at high altitude (> 3,000ft).                                                                       |
|                        | 2             | <b>Below 3,000ft:</b> The aircraft is at low-altitude or ground operations (Sectoral analysis is active).                                                          |
| <b>TM_LOS_DISTANCE</b> | Distance (km) | The estimated geographical distance remaining to the point where the aircraft will intersect the LoS boundary, provided that the current heading remains constant. |
| <b>TM_LOS_TIME</b>     | Time (s)      | The time remaining until the telemetry link drops (boundary breach), provided that the current groundspeed and heading remain constant.                            |

The performance of the real-time prediction module during actual flight tests (FLT-X, FLT-Y, and FLT-Z) and its correlation with valid telemetry data percentages are summarized in Table 2. To conduct this analysis accurately, the "Inside LoS" and "Outside LoS" durations are calculated using the precise

position information retrieved from the onboard data recorder as the absolute ground truth. In contrast, the "Valid Telemetry Data" represents the actual percentage of data successfully received by the ground station via the telemetry link. Thanks to this study, which enables the comparison of these two distinct datasets, the nature of data dropouts has been definitively categorized. As observed in the results, a significant portion of the data loss experienced in the valid telemetry data perfectly aligns with the "Outside LoS" periods. Since this specific loss is caused by unavoidable physical and topographical masking, it represents an expected dropout where no ground station infrastructure improvement can be applied. However, any discrepancy between the expected "Inside LoS" percentage and the actual "Valid Telemetry Data" indicates an unexpected data loss while the aircraft was theoretically within a clear line of sight. This remaining gap highlights actual system anomalies—such as antenna tracking delays, multipath fading, or onboard transmitter degradation. Consequently, for this remaining percentage, the relevant systems are rigorously checked and necessary hardware or RF improvements are implemented, ensuring that engineering resources are focused on real faults rather than inevitable topographical constraints.

Table 2 Valid telemetry data percentages and LoS durations during flight tests

| Test No | All Test Duration (min) | Out of LoS Duration (min) | Inside LoS Rate (%) | Valid Telemetry Data Rate (%) |
|---------|-------------------------|---------------------------|---------------------|-------------------------------|
| FLT-X   | 125                     | 6                         | 95.20%              | 94.91%                        |
| FLT-Y   | 48                      | 0                         | 100%                | 99.63%                        |
| FLT-Z   | 91                      | 2                         | 97.80%              | 96.54%                        |

On the runway, taxiways, and aprons, telemetry link quality is completely independent of natural topographical elevations. Instead, campus buildings, ground station antenna angle limits, and multipath fading come into play. Unlike the in-flight LoS analysis, the ground area is divided into discrete parsed sectors, as demonstrated in Fig.4.

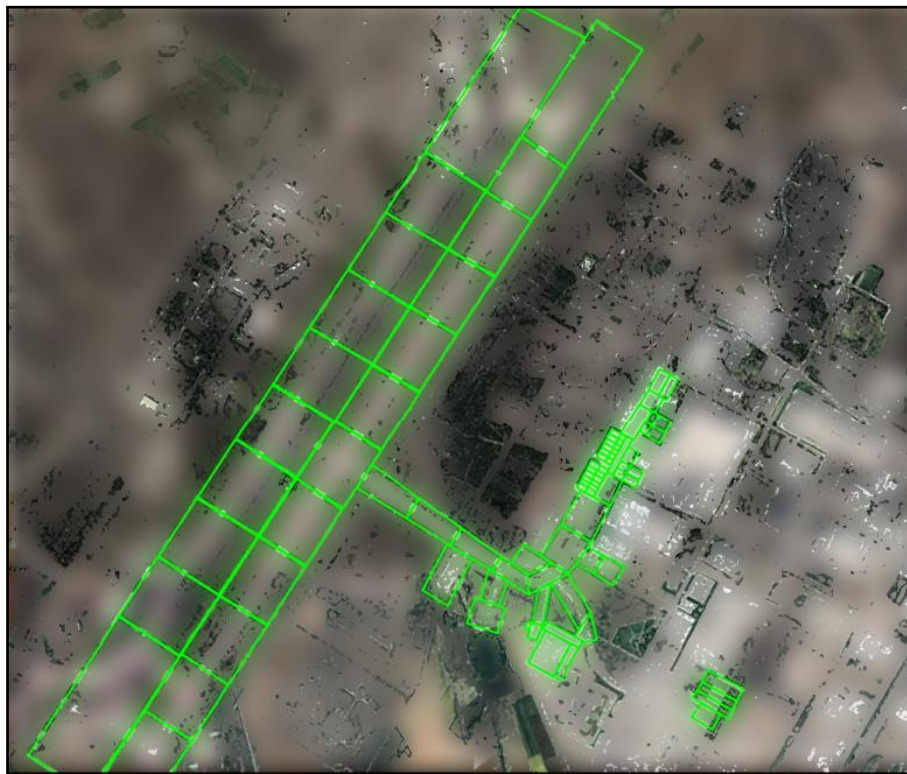


Fig.4. Parsed sectors on the runway and taxiways for ground-level telemetry coverage analysis.

The runway is divided into separate sections for the areas where the aircraft will be located, and the boundaries of these areas are determined

by DGPS measurements [1]. During the test, the aircraft's presence on the runway is detected based on its altitude data (< 3,000ft).

Subsequently, the aircraft's status of being within these predetermined areas is determined. By examining the status of the telemetry connection within the area it is located, the valid data percentage for all regions is extracted. As location data, the position data returning the last healthy location in case of a telemetry link drop is used; in this way, the approximate valid data percentage measurement of the regions can be made with high accuracy with minor deviations. As presented in Table 3, the valid data percentages are extracted and evaluated for each designated sector. Sectors yielding a valid data rate below the 90% threshold—such as the interior of HANGAR-1 (54.00%) and RUNWAY\_2\_2/4 (72.00%)—are explicitly identified. In these regions, improvement works were carried out to increase the valid data percentage. These obtained data provide critical field data for telemetry infrastructure improvement works in those specific campus regions.

Table 3. Valid data for parsed sectors on the runways and hangar

| LOCATION        | VALID DATA (%) |
|-----------------|----------------|
| HANGAR-1        | 93,00%         |
| HANGAR-1 INSIDE | 54,00%         |
| RUNWAY_1_1/5    | 97,00%         |
| RUNWAY_1_2/5    | 96,00%         |
| RUNWAY_1_3/5    | 98,00%         |
| RUNWAY_1_4/5    | 99,00%         |
| RUNWAY_1_5/5    | 98,00%         |
| RUNWAY_2_1/4    | 96,00%         |
| RUNWAY_2_2/4    | 72,00%         |
| RUNWAY_2_3/4    | 95,00%         |
| RUNWAY_2_4/4    | 98,00%         |

### Operational Implementation and System Impacts

By transferring the computational load to external C++ based software, the short and long-term interruptions caused by exceeding system performance capabilities in IADS were completely prevented, guaranteeing the uninterrupted flow of flight safety data. Knowing in advance when the system link will drop enabled the pilot to correct the route before data loss occurred, thereby reducing flight costs associated with aborted test points. By preventing the evaluation of data losses that occurred while the aircraft was outside the LoS boundaries, unnecessary maintenance activities were avoided.

### Conclusion

In modern flight test operations, the real-time tracking of telemetry data is not merely an observation activity; it is the center of the interactive decision-making mechanism between the pilot and system engineers. The real-time evaluation of data quality and the instantaneous correction of maneuvers in the air are the keys to test efficiency. This study has taken telemetry tracking to a proactive dimension by overcoming the computational limitations of standard data visualization systems (IADS) with an advanced software architecture. The rigorous LoS analyses, generated using the Global Mapper application, provide a visual map background for test engineers while being converted into mathematical polygons and integrated into the module. The short and long-term operational interruptions, which occur in the IADS application due to exceeding system performance capabilities and risk flight safety by preventing the tracking of critical data, have been completely eliminated thanks to this external C++ based structure. The system flawlessly calculates the remaining distance and time to the telemetry boundary using the aircraft's groundspeed and heading data, warning of a potential telemetry loss seconds before it happens. The module developed for on-ground tests performed on the runway, on the other hand, operates completely independent of natural elevations, creating a valuable field data library that sheds light on RF infrastructure improvements by calculating telemetry success percentages across the parsed runway sectors. Ultimately, this real-time framework, which eliminates operational ambiguities, has maximized the safety of flight tests, strictly distinguished system anomalies from physical obstacle constraints (LoS), and directly contributed to the completion of flight tests with high efficiency within the planned budget and timeline.

### Future Works

Future work will focus on extending the developed framework to support multiple antenna configurations through adaptive LOS handling. In the current implementation, the LOS boundaries are generated for a single tracking antenna with a fixed gain value and a fixed geographical location. As a first improvement, separate LOS analyses will be pre-computed for antennas with different gain characteristics, since the maximum coverage range varies directly with antenna gain. During flight test operations, the system will automatically detect which antenna is active

and update the LOS boundaries displayed on the IADS Moving Map accordingly, without requiring any manual intervention from the test conductor.

The second direction addresses scenarios in which multiple tracking antennas are deployed at different geographical positions. In this case, each antenna will have its own dedicated LOS polygon set, generated with respect to its specific location coordinates and elevation. When the active antenna changes during a test—for example, as a result of a handover between ground stations—the system will automatically load the LOS map corresponding to the active antenna's position and render it on the display. This ensures that the visualized coverage area always reflects the true line-of-sight envelope of the antenna currently tracking the aircraft, regardless of which antenna is selected. Together, these two extensions will transform the framework from a single-antenna, fixed-site tool into a flexible coverage management system capable of handling heterogeneous antenna inventories and distributed ground station deployments.

## References

- [1] Understanding GPS/GNSS: Principles and Applications, Elliot D. Kaplan and Christopher J. Hegarty