

# The Analysis Module of ESA's Space Trajectory Analysis software

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**Abstract-** The use of simulation software has proven to be an essential element in the field of mission analysis and design, allowing the study of several concepts without risking human lives or the loss of expensive devices. The European Space Agency has created an open source software tool, called Space Trajectory Analysis, with the purpose of supporting the analysis phase of a space mission. The present work describes the development of the Analysis Module of STA, created to access and analyse the software's produced data, and therefore contribute to turn STA into a valuable working tool.

## I. INTRODUCTION

### I-1.General Background

A space mission is a complex process involving numerous experts in several areas to assure the correct functioning of all the necessary systems related to the development and launch of a spacecraft, such as power, thermal, structures, or communications. Requiring highly specialized labour and cutting edge technology, space projects are considerable expensive endeavours, with the insertion in a low Earth orbit of a pound of material costing about 2000 to 5000 dollars [1].

The difficulty of future repair or replacement of faulty devices forces the high reliability required for every spacecraft or mechanism. The impossibility to correct technical problems can lead to the loss of the vehicle and, in case of manned missions, the loss of the entire crew. It is therefore essential to maintain the tightest possible margin of error, and so avoid the risk of failure and the associated expenses. For missions with expandable hardware it is necessary to produce new devices for every launch, which represents a significant part of the costs.

Simulation software tools have become essential for mission analysts, allowing the prediction and test of different scenarios and concepts without risking human lives or expensive devices. Different perspectives and approaches to a mission can be analysed, at the same time new technology can be tested without the resources consumed in a real situation.

ESA decided to create its own software tool capable of supporting the preliminary phase of a space mission and the Space Trajectory Analysis (STA) was born as a partnership with several universities and research institutions worldwide.

The present work describes the development of the Analysis Module (AM) of STA, from an early requirements and design phase to the verification and validation process. This module was created to fulfil the need of a tool capable of analysing the data produced by STA according to the specifications of the user. The AM is considered to be a high level module due to the strong interaction it maintains with the rest of the software, accessing information from several modules

### I-2.Existing Mission Analysis Tools

There are numerous astrodynamics tools, many of them are commercialized while others have been created as open source software, mainly by universities or research institutions. This document will only focus on two of them, to illustrate both of the approaches.

#### ***General Mission Analysis Tool***

The General Mission Analysis Tool [2], GMAT, was developed as the result of a partnership between NASA, universities and research institutions, government agencies, private industry, and the open source community. As an open source astrodynamics software, it aims to improve the transfer of technology and be a test bed for the study of different concepts and applications.

GMAT is a multiplatform application, being able to run on Windows, MAC, and Linux. Its functionalities include the transformation of coordinate systems, the calculation of user-defined parameters or variables, or the ability to export data through different types of output (report, 2D plot, or 3D plot).

#### ***Satellite Tool Kit***

The Satellite Tool Kit [3], STK, was developed by Analytical Graphics, Inc. and is probably one of the most famous tools worldwide. Although being available to perform studies in different fields, only space missions will be considered, since it is the only one that can be compared with STA.

STK allows the user the development and study of numerous mission concepts as well as the design, analysis, and optimization of space systems. The list of STK's features includes the trajectory and orbit determination, the attitude modelling, the simulation of several environmental effects, or the generation of customized text reports, 2D or 3D plots.

STK has an expensive license, with modules ranging from 2000 to 30000 dollars. A basic version is however available for the general public as freeware.

### I-3.STA overview

Due to the strong interaction the AM maintains with STA, it is extremely important to understand the functioning of the program, and so fully understand the module's functionalities and development.

STA is an open source software created in 2005 as an idea of the Technical Directorate at ESA and aiming to become a tool capable of supporting the preliminary analysis phase of a space mission. Developed as the result of a partnership between ESA and different universities and research institutions worldwide, it has essentially three main purposes: providing the interaction of students and teachers in astrodynamics, space sciences, mathematics, and informatics, promoting the exchange of technical information and ideas leading to a raise of knowledge in the areas mentioned above, and providing a research facility to test, verify, and validate new ideas and techniques.

STA consists on a research and educational tool, and is mainly developed by Master and PhD students as part of their thesis work. Each student is assigned a module, consisting on a set of interconnected features responsible for a particular type of calculations and later integrated in the program.

There are two versions of the software, Hadean and Archean, and in the last trimester of 2010 the third version, Cambrian, will be formally released. The latest STA version is able to visualize space trajectories such as re-entry orbits or orbits around a central body, perform the preliminary design of a spacecraft, generate the aerodynamic coefficients for a re-entry vehicle, or perform a coverage analysis between two antennas.

STA is developed using a Nokia open source cross-platform application and UI framework called Qt [4], which allows the software to run on Windows, MAC, and Linux. The development of the AM is an essential milestone in the improvement of STA's functionalities, since it allows the analysis and exploration of the produced data, which is essential to transform STA into a valuable engineering tool.

### STA areas

Figure 1 shows the different areas of STA's main window: Scenario View, Scenario Element Box, Timeline, Controls, and Rendering area, whose explanation is included hereafter.

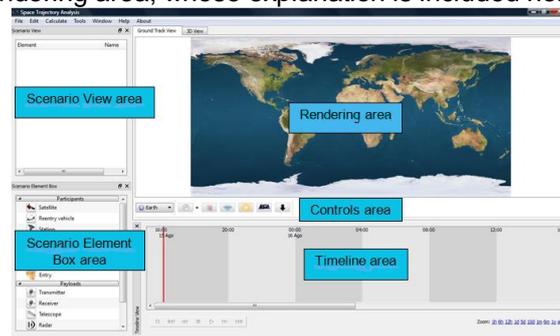


Figure 1 – Different areas in the main window of STA (Windows view).

- The Scenario View is the area where the user can drag and drop the different elements to build the mission with all the required specifications.
- The Scenario element box contains a list of all the objects that can be included in a space scenario and added to the scenario view area.
- The Timeline displays the interval of time during which the mission is simulated in STA, allowing the user to play the movement of a spacecraft back and forward.
- The Controls consist on a series of buttons that control certain visualization features of 2D and 3D rendering areas.
- The Rendering area is the area in STA's main window that displays the trajectories of the elements in the scenario view, in a 2D or 3D perspective.

## **STA concepts**

STA implements three concepts whose understanding is essential to understand the functioning of the AM: Space Scenario, Participant, and Mission Arc.

A Space Scenario is defined by STA as a “set of elements that play a role in the analysis of a trajectory path in a given Universe”, as stated in the STA’s user manual [5] consisting on a group of elements that represent a certain mission. When the user initiates an STA simulation for the first time, it is necessary to insert a new scenario or open an already existing one, creating the mission to be analysed.

The implementation of the Space Scenario concept in STA is achieved using XML (Extensible Markup Language), which is a metalanguage that allows the creation of customized markup languages [6]. The different data contained in the tree of a Space Scenario (Scenario View) is saved in XML files and validated by an XML Schema which is responsible for specifying a formal data arrangement, verifying the structure and the contents of the document.

A Participant is considered to be an active element in a Space Scenario, such as a satellite, a re-entry vehicle, a ground station, or a point (a specific location on a given planet). A Participant can be classified as a Ground Object or a Space Object, depending on its location: ground stations and points are considered to be Ground Objects, and satellites and re-entry vehicles are classified as Space Objects.

A Ground Object is characterized by a ground position (latitude, longitude, and altitude) and a central body (planet in which it is located), in addition, it can have optional payload features (transmitter, receiver, telescope, and radar) and some environmental properties can be specified. A Space Object has several technical and physical properties, such as the budget specifications or the structural parameters, for instance. Additionally, it has one or more trajectory plans and, like the Ground Object, it can have the same optional payload features.

Finally, a Mission Arc is a trajectory plan that can be assigned to a Space Object, and can be one of three types: Loitering, TLE, or Entry. The Loitering arc consists on an orbit around a certain central body and a TLE (Two Line Element) is a set of orbital elements displayed in a specific order and capable of defining a space trajectory, as explained in detail in [7]. (Loitering and TLE can only be assigned to satellites.) The Entry arc is assigned to re-entry vehicles only, and consists on the initial state for the beginning of propagation.

### ***I-4. The Purpose of the AM***

The development of the AM was considered a priority in the improvement of STA. Without an analysis tool, capable of managing and studying the produced data, STA was unable to compete with other astrodynamics tools, and would be useful for visualization purposes only.

The main purpose of the AM is therefore to provide analysis tools that will allow the user to explore the data of a certain space mission, defined in a Space Scenario, according to his/her needs. The AM should be able to analyse:

- the relations between several parameters of a given Participant, calculating, for instance, the different components of the state vector for a given satellite,
- the relations between several Participants, displaying, for instance, the distance between a satellite and a ground station,
- and, finally, the relations between the same parameters from several Participants, calculating, for instance, the Keplerian orbital elements for two satellites.

To meet these requirements, the AM must recognize the different elements of the Space Scenario, access to their properties and establish the necessary relations between them. Since it is the AM’s responsibility to access and analyse the data produced by the entire software, it is considered to be a high level module, unlike modules capable of performing their calculations with minimum interaction with STA.

Many requirements have been defined in the Task Description Form document [8], which every STA developer receives when a module is assigned. However, that corresponds to the full functionalities the module must contain and, for the Cambrian version of STA and first version of the AM, only the priority features will be implemented.

## **II.AM’S REQUIRED FUNCTIONALITIES**

The priority of the AM in the Cambrian version of STA is to create the necessary tools to allow the user to explore and study the data in order to support the analysis phase of a space mission [9]. The module should analyse one or more participants and the interaction between them, according to the

user's needs. Once these tools are implemented and the AM is fully integrated in the software, a future expansion of the module's functionalities will require little additional effort.

The module should implement four types of calculations: the transformation of reference frames, the conversion of units (length, velocity, and angle units), the conversion of time, and the calculation of different parameters, whether collected from other STA modules, or exclusively obtained at the AM. Each of these functionalities will be explained below.

### ***Parameters***

When obtaining results from a simulation, it is often necessary to compare the output with other sources or previous similar studies. The existing data is, however, often available in other formats, and a useful feature to be included in the AM is to calculate and convert data between different sets of orbital elements (Keplerian, Delaunay, Equinoctial, and Spherical elements), and obtain the different components of the Cartesian state vector (position and velocity components) of a given Space Object. Additionally, the module should calculate longitude, latitude, altitude, and radial distance of a given Space Object from the Space Scenario. The knowledge of these parameters is very important for telecommunication purposes and their implementation was considered essential to an efficient interaction with the Coverage Module [9].

Finally, the AM should be able to determine the intervals of time during which two antennas, located on both a ground station and a satellite, can communicate within each other, displaying the boundaries of each interval and its duration. This information is called the Access Time and should be available in a text report for telecommunication purposes [9].

### ***Reference Frames***

To compare the simulation results with other sources, or even to adapt them to a specific analysis, it is often necessary to perform the transformation of coordinates between different reference frames. It was considered useful to provide the following options: Earth Mean Equator (EME) J2000, Ecliptic J2000, EME B1950, and Body Fixed B1950 [9].

### ***Time Formats***

There are several possible formats to express time and date. Having a feature in the AM allowing the conversion between some of them, will allow not only the comparison of data with other sources, but also the adjustment to a particular user's need. For this reason it was decided to provide time in the following formats: Gregorian UTC, Gregorian LCL, Julian UTC, Julian LCL, Time from Epoch (seconds, minutes, hours, or days), Mission Elapsed Time, YYDDD, Modified Julian Date (MJD), and Julian Date (JD) [9].

Since the time in STA is saved in the MJD format, all the necessary conversions should consider it as the starting point.

### ***Conversion of Units***

The AM should be able to convert three types of units: length, velocity, and angle units, in order to allow a better post processing of the produced data [9]. The more options the AM has, the more suitable it would be for the user's different needs.

Four length units should be available: metres (m), kilometres (km), nautical miles (nm), and astronomical units (AU). Apart from the metre, these are widely used units for large distances and are therefore applicable in an astrodynamics context. The metre is not only the SI unit for length, but it also very useful when small distances are considered.

It is also useful to have the possibility to calculate angles in both radians and degrees, and therefore this feature is included as a requirement.

Additionally, velocity parameters should appear in km/s, the most used unit in astrodynamics for velocity, and also in m/s as the SI unit for velocity.

### ***Output***

To analyse the data it is often useful to have different formats available, providing different perspectives on the same problem. For this reason, it was decided to include three different types of output in the AM [9]: a text report, with the values of the selected parameters in different columns, a 2D, and a 3D plot .

### III.AM'S INTERFACE

#### III-1. Interface with other STA modules

The communication between the AM and the other modules is done through files: to access the Coverage and Communication data, the AM should read the files generated by the Coverage Module and select the necessary information. Although a RAM based interaction was considered due the computational effectiveness, its complexity and effort required to implement it were deemed incommensurately larger than the possible gains.

#### III-2. AM's Graphical User Interface (GUI)

The functioning of the AM depends on its interaction with the user, since he/she is responsible for defining all the properties of the analysis. With a single Graphical User Interface (GUI), the AM should recognize the user's options and access the corresponding information in STA. It is therefore essential to build a GUI capable of collecting the necessary specifications but whose functioning is as simple as possible.

Since there are three outputs available (text report, 2D, or 3D plot), and each of them has its own options to be specified, it was decided to implement an interactive GUI with three layouts, one for each output type, as shown in Figures 2 and 3. According to the selected output the layout changes and only the corresponding options appear, which simplifies the user's analysis.

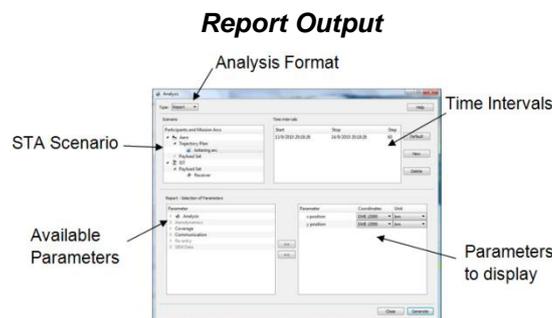


Figure 2: GUI layout for the Report output.

Figure 2 shows the areas existent in the Report layout.

The STA Scenario, is a copy of the Scenario View in the STA's main window and corresponds to the visible interaction between the AM and Space Scenario. This area was included to allow the visualization of the participants involved in the mission, and the corresponding trajectories and payload identifiers. By selecting the elements the user wishes to include in the analysis process, the AM is able to access their corresponding properties.

The Time Intervals is the area of the GUI containing the time specifications, allowing the analysis to be run for the selected intervals, provided that each interval is included within the propagation time, otherwise no data would be available to analyse. This feature allows the study of a specific moment in the propagated trajectory, which can be useful for longer space missions.

To simplify the generation of a report it was decided to include two areas to define the parameters to be calculated. From the full list of the available parameters in the AM, listed in the Available Parameters area, the user is able to choose which ones should appear in the report by selecting them to the Parameters to display area. Additionally, he/she can define their output reference frames and units. For an easier identification, the parameters in the Available Parameters area are classified according to the field to which they belong: Analysis, Coverage, Aerodynamics, Communication, Re-entry, and Systems Engineering (SEM). Currently, only three sections allow the selection and calculation of parameters: Analysis, Coverage, and Communication.

#### 2D and 3D Plot Outputs

Figure 3 shows the areas of the GUI for both a 2D and 3D plot outputs. As observed, both layouts have the STA Scenario, Analysis Format, and Time Intervals areas in common with the layout shown in Figure 2.

In addition, it was included one area to specify the properties of each axis: the 2D plot layout has the x-axis and y-axis options areas, while the 3D plot layout has an extra area to define the z-axis options. Each of these areas contains a list of all the available parameters in the AM. To assign a particular variable to a certain axis (x, y, or z), the user must select one parameter from a field (Analysis,

Coverage, or Communication), and specify the units and reference frames. Since only one parameter per axis is allowed, due to the nature of the Plotting Module by the time the AM design was defined, this selection method was considered the more user-friendly.

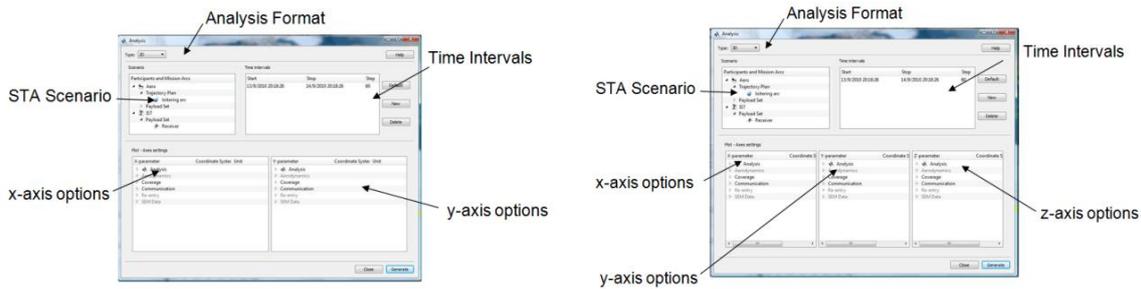


Figure 3: GUI's layout for the plotting options: 2D plot, on the left, and 3D plot, on the right.

#### IV. THE ANALYSIS PROCESS WITH THE AM

This section includes an explanation of the necessary process to generate one of the three outputs available in the AM.

This module can only be called after the Propagate instruction is given to STA, otherwise no data would be available to analyse. The user can call the AM through the “Tools” menu in STA’s main window, as shown in the figure below.

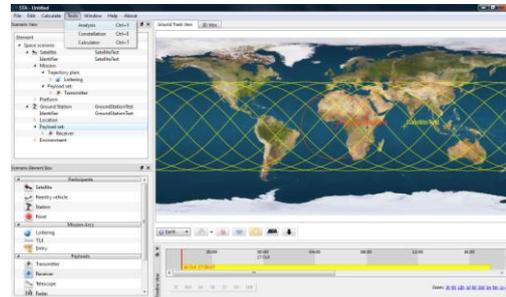


Figure 4: Calling the AM from the “Tools” menu of STA (STA screenshot, Windows view).

For a matter of convenience, we will analyse separately the steps to obtain a text report and a 2D or 3D plot.

#### Report Generation

To generate a text report with the AM, the user should select one or more Mission Arcs from the STA Scenario area, and insert and select one or more time intervals in the corresponding area. Additionally, it is necessary to choose the parameters to calculate by including them in the Parameters to display area. Clicking on their specifications, it is possible to select the reference frames and units in which the output should be displayed, as shown in Figure 6 (image on the left).

Once all the options are defined and the user presses the “Generate” button, the report appears as shown in Figure 5 (image on the right).

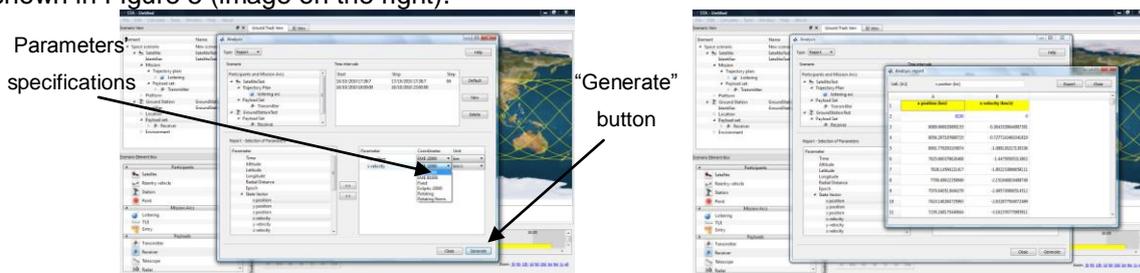


Figure 5: Report Specifications, on the left, and example of a text report, on the right. (STA screenshot, Windows view).

To calculate any Coverage or Communication parameter, the user should additionally select one transmitter and one receiver in the STA Scenario area, otherwise the module could not access their properties and a warning message will appear. For every time step during which there is no communication between the two antennas, the report includes the expression “No visibility”.

### Plot Generation

Similarly to the Report generation, the user should select one Mission Arc from the STA Scenario area and one time interval, as previously explained. To assign a parameter to a specific axis, the user just needs to select it in the corresponding options area, defining the reference frame and the units in which it should be calculated. Figure 6 shows examples of a 2D plot (left image) and a 3D plot (right image). Similarly to a report generation, when assigning a Coverage or Communication parameter to an axis, the user should select one transmitter and one receiver in the STA Scenario area.

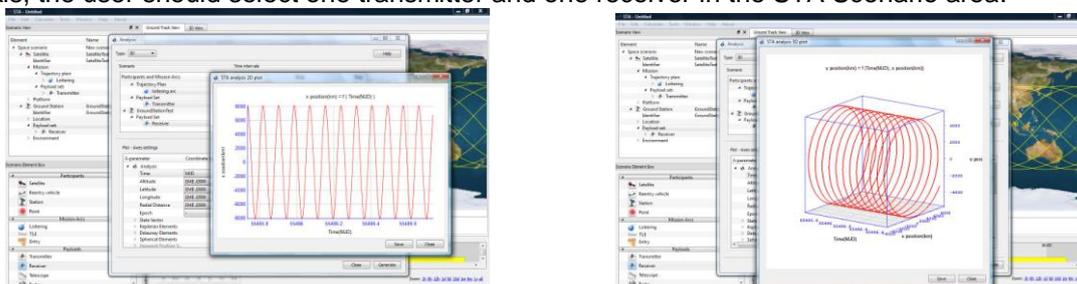


Figure 6: 2D plot example.

## IV. VERIFICATION AND VALIDATION

### Validation Plan

To verify and validate the results of the AM, it is necessary to perform a comprehensive set of tests that takes into account the different situations that might occur during the use of STA and more specifically of the AM. The set should be a representative sample of all the typified situations that can arise when using the module.

The AM generates essentially five different types of results: generation of trajectory data, including the state vector and all the sets of orbital elements, conversion of units (length, angle, and velocity units), calculation of different time formats, transformation of reference frames, and calculation of Access Time. The tests should provide the necessary conditions to perform all the available analysis and obtain the full list of results. This can be achieved considering a generic loitering as a satellite's trajectory plan, from which every data can be obtained (apart from Coverage and Communication parameters), and a second Space Scenario with both a satellite, a ground station, and the corresponding antennas in order to obtain the Access Time. Additionally, it is necessary to analyse the response of the module in situations during which the orbital elements are undefined or close to its boundaries, requiring the test of circular, equatorial, and highly elliptical orbits.

It is important to notice that the AM is not responsible for the propagation of the trajectory, which means that it is not the goal of these tests to evaluate the errors of the STA's numerical propagators. Additionally, the data obtained from the Coverage Module will not be tested since the calculation procedure does not involve the AM. Finally, and although the AM is currently able to interact with the Entry module and analyse re-entry Mission Arcs, this option will not be included in the verification and validation process due to bugs existent in the Entry module by the time these tests were performed.

### Validation requirements

Each STA parameter will be compared to the corresponding value obtained with STK, which is an already validated tool. The relative error between both results will be calculated through

$$error [\%] = \frac{|value_{STK} - value_{STA}|}{value_{STK}} * 100. \quad 1)$$

ESA has required a maximum relative error of 0.05% to validate the calculations of the module, and we will use this limit to analyse the obtained results.

First, it is important to provide a brief analysis on the precision of the module's results. The AM receives the state vector from the selected STA's propagator, which means that the expected error of its results will be influenced by the accuracy of the propagator's calculations. The ideal would be to adapt the number of output digits to the selected propagator and its own precision, however, in a first version of the AM, it was decided to display the output always with 16 digits, requiring a careful analysis. A future version of the module should consider the significant decimals for each type of propagator which will simplify the user's understanding and improve the AM's accuracy.

All the values displayed in the present document will have 16 digits if obtained through the AM, however intermediate calculations or additional explanations might have less digits if more practical.

To determine the accuracy of the propagation, and therefore conclude on the expected error of the AM's calculations, we will analyse the absolute error between the expected and the actual results for two extreme situations: a circular orbit and a highly elliptical orbit.

For a perfectly circular orbit the vis-viva equation (3), which governs the motion of an orbiting body in a Two-Body problem, is reduced to

$$v^2 = \frac{\mu}{r}, \quad 2)$$

where  $\mu$  is the gravitational parameter of the planet Earth ( $\mu = G \cdot \text{mass}$ ),  $r$  is the modulus of the position vector, and  $v$  the modulus of the velocity vector [7]. For the circular orbit test, the higher relative error between STA and STK's results occurs for the velocity vector. Using the corresponding values of velocity and position, and applying (2), we can compare the expected results with the values generated by STA, concluding that there is an absolute error of  $9.094947017729282 \times 10^{-013}$  between them.

The same analysis can be done for the test with a highly elliptical trajectory, where the vis-viva equation (3) cannot be simplified

$$v^2 = \mu \left( \frac{2}{r} - \frac{1}{a} \right). \quad 3)$$

Comparing the expected results with the actual values obtained through STA, we obtain an absolute error of  $9.094947017729282 \times 10^{-012}$ .

When analysing the results generated by the AM, we will focus on the highest values of relative error between STA and STK, as obtained with (1). If the obtained relative error is close enough to the limit imposed by ESA, we will analyse the corresponding values of STA by comparing them with the theoretical results that would be obtained with (2) and (3) in order to conclude their accuracy.

#### **IV-1. Verification and Validation Results**

According to the Validation plan, several situations were considered to test the functioning of the AM. This section includes the analysis of the obtained results.

##### ***Orbital elements***

For every situation tested, most of the higher values in the relative error are due to the difference of precision between STA and STK: if both tools had the same number of digits, the relative error would be null, respecting the condition imposed by ESA.

The remaining results correspond to "peaks" in the relative error. These "peaks", higher than 0.05%, appear due to the small value of the corresponding parameter (lower than the unit) which increases the fraction in (1). The absolute error, however, respects the constraints stated in the validation requirements explained above, and therefore the calculation of orbital parameters is considered to generate valid results.

##### ***Transformation of Reference Frames***

The data in every available reference frame has a relative error lower than 0.05%, validating the transformations of the AM.

##### ***Conversion of Units***

To analyse the accuracy of the AM's conversion routines, we focused on three parameters, one for each type of unit (length, angle, and velocity), and compared the obtained results with the values calculated through the theoretical expressions in [10].

The highest relative error was lower than the limit of 0.05%, validating the conversion process within the AM.

##### ***Time Formats***

The relative errors between STA and STK's results for the Julian Date (JD), Modified Julian Date (MJD), Time from Epoch (seconds, minutes, hours, or days), and YYDDD time formats are lower than the maximum limit of 0.05%, and the validation is considered to be successful.

However, the other available formats are not constituted by a single number and cannot therefore be algebraically added or subtracted. The verification and validation of formats as Gregorian LCL, Gregorian UTC, Julian LCL, Julian UTC, or Mission Elapsed Time was achieved comparing the reports generated by both STA and STK, through which it was concluded the accuracy of the AM's results.

### Altitude

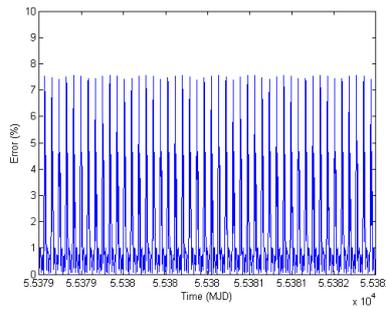


Figure 7: Relative error between the altitude values of STA and STK.

The AM performs a rough calculation of altitude, obtained through the radial distance of the considered spacecraft: the altitude is calculated subtracting the mean radius of planet Earth to the radial distance (Spherical elements). This method does not take into account the oblateness of the planet and the differences in altitude from place to place, generating only an approximation of the real value, considering the Earth as a sphere.

As observed in Figure 7, the relative error between STA and STK's altitude results, for a generic loitering Mission Arc (where all the orbital parameters are different from their boundary values), has a sinusoidal behaviour, with a maximum error of about 7.5%. For a mean altitude of 457 km, obtained through the maximum and minimum altitude values calculated by STA, this percentage is equivalent to about 34 km, similar to the 40 km difference between the polar radius and the equatorial radius of the Earth [11]. It is then possible to conclude that the error arises from considering the Earth's shape to be a sphere, and it should be improved in the future.

The analysis of radial distance, latitude and longitude is not included in this chapter, since these parameters are already obtained through the Spherical elements.

### Access Time

STK access time report				
Access	Start Time (ModJDate)	Stop Time (ModJDate)	Duration (sec)	
1	55378.18882873	55378.19582097	604.129	
2	55378.25645177	55378.26332897	594.190	
3	55378.67297028	55378.67917402	536.004	
4	55378.73995832	55378.74734055	637.825	

STA access time report				
Satellite: 1 Mission Arc: 1				
###Beginning of time 1###				
Start Time 1/7/2010 0:0:0##Stop Time 2/7/2010 0:0:0				
Access Time				
Access Number	Start Time (MJD)	Stop Time (MJD)	Duration of each access (seconds)	
1	55378.1888888889	55378.1958333333	600.0032545011064	
2	55378.2569444444	55378.2631944444	540.002928862402	
3	55378.6736111111	55378.6791666667	480.0026038523436	
4	55378.7402777778	55378.7472222222	600.0032545011064	

Table 1: Comparison of the Access Time calculated by STK and STA.

Comparing both reports in Table 1, we observe the same number of accesses (intervals during which the communication is possible) between the two considered antennas, however, the duration in seconds appears to be different for both tools. A close look at the results displayed above, shows that the Start and Stop times read from the Coverage Module do not exactly match STK's, which is responsible for the difference between the duration of each access. This issue is external to the AM's implementation.

## V.CONCLUSIONS

The development of the AM is a major milestone in the improvement of STA from its second to third version. The ability to analyse the produced data and the strong interaction it keeps with the user allow the software to be considered as a valuable competition when compared to already existent tools, such as STK or GMAT.

By use of the AM, it is now possible to generate completely customizable text reports, 2D plots, or 3D plots: for a better adjustment to the user's needs, he/she can select which parameters should be included in the analysis and the corresponding specifications such as units or coordinates. Additionally,

it is possible to define the intervals of time during which the analysis should be performed, as long as they are included within the propagation time. This feature can be particularly useful for long missions, since it allows the user to focus on the results of a smaller interval of time.

Unlike other STA modules, the AM needed to be integrated within the software from the early beginning of its development, which influenced the design process. The visible part of the AM is its graphical user interface, specifically designed to collect all the necessary specifications for a certain analysis and be able to communicate with the rest of the software, at the same time it should provide the required simplicity for an easy usage. This interaction was the most challenging feature to be implemented within the AM: it was necessary to implement a solution to collect all the data with the exclusive use of one GUI capable of recognizing the selections of the user and access the corresponding information in STA. At the same time, this accomplishment was the best legacy for future AM developers, since the interaction with the software is already implemented and the inclusion of new features and calculations becomes a simpler process.

For a successful communication with the rest of the software, it was necessary to understand the code of other STA modules and conduct the development of the AM accordingly. Due to this analysis of code external to the AM, some bugs were identified and corrected in the Loitering and Astro-Core modules, contributing for a better functioning of the software.

### **Future Work**

The AM is currently fully integrated in STA. However, it does not possess all the functionalities available in the Cambrian version of the software. The expansion of the module requires the implementation of the interaction with both the Re-entry Aerodynamics and the Systems Engineering modules, allowing the analysis of the produced parameters. It should be possible to analyse orbits defined through Two-Line elements and have more astrodynamics parameters available to calculate, such as ecliptic crossing times. The calculation of altitude should also be improved, in order to obtain more accurate results. Additionally, the plotting features should allow the plot of more than one parameter per axis, permitting multiple plots on a single window. As previously analysed, the precision of the AM's results should be adapted to the selected propagator, in order to provide more accurate data.

It is important to notice, however, that the expansion of the AM is as infinite as STA itself: as long as there are functionalities to be added to the software, the AM will have more data to analyse and more modules to interact with.

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