Applications of STK at Amsat-DL

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1 Acknowledgement

We wish to express our gratitude to AGI for providing AMSAT-DL with a free license of STK.

2 Introduction

AMSAT-DL is a non profit organization of radio amateurs building and operating satellites. Traditionally, AMSAT-DL has been relying on self-build tools and programs to do orbital path prediction. This report documents experiments and projects undertaken with STK, a commercial tool for orbit and attitude simulations.

3 Experiments with STK

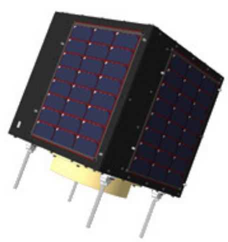
3.1 Unitec-1

3.1.1 General

Unitec-1 shown in Picture 1 is a small satellite built by 21 Japanese Universities. Its primary mission is to evaluate the performance of 6 onboard computers (OBC) in the hazardous environment of space. The OBC were build by groups of students. The satellite's trajectory brings it on a solar orbit between the paths of Earth and Venus.

Receiving a data signal over distances of several million kilometers is not trivial and requires a sophisticated ground segment. AMSAT-DL refurbished and now operates a 20m dish in Bochum/Germany (see picture Picture **3** and 4). Unitec-1 approached AMSAT-DL for support the project as additional ground station.

Unitec-1 was launched onboard an H-2A rocket together with Akastuki (Venus climate orbiter), and Ikaros (solar kite experiment) from Tanegashima/Japan on May 21th 2010 6:58 local time.



Picture 1: Unitec 1

Picture 2: Unitec-1 Mission Patch

Picture 3 The Radom in Bochum

Picture 4: The Dish Antenna

3.1.2 STK for the Computation of Tracking Data

The tracking program of the dish in Bochum requires a set of the spacecraft's state vectors (time, position and velocity) in J2000 coordinate as input to compute the azimuth, and the elevation of the dish for a given instant in time. It also calculates the frequency corrected by Doppler shift for the receiving radio. The software uses NASA's TLE file format as input format.

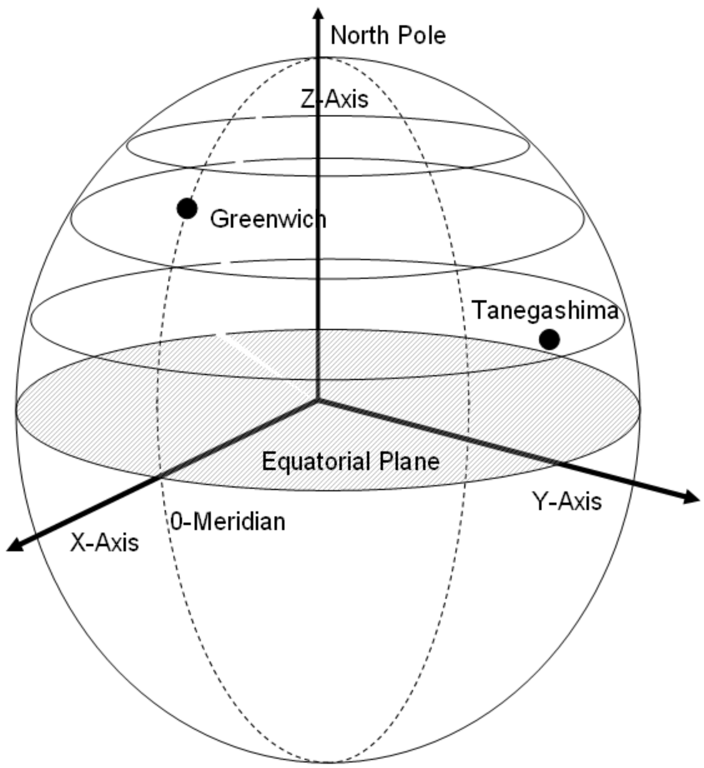
As most other launching agencies, Jaxa uses a true inertial coordinate system defined at the instance of launch to describe the initial state vector (epoch time, position, and velocity) of the trajectory. Picture 5 shows the ECI system.

Picture 6 depicts the tool chain to compute and verify the state vectors describing the trajectory. STK takes an initial state vector in the inertial coordinate system defined by Jaxa, propagates the orbit, transforms it into the J2000 coordinate system, and writes the trajectory as a set of state vectors in reference to J2000 into a file. The state vectors are then reformatted into TLE format by an additional perl script.

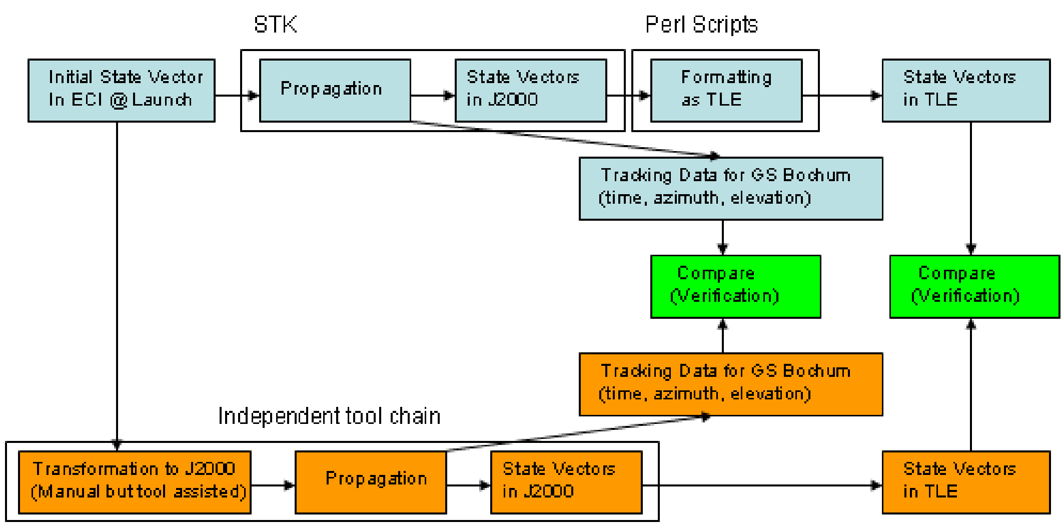
To verify the tracking data, an additional tool chain was employed to create an independent set of state vectors and tracking data. These were then compared. Once verified, the tracking data was then validated by comparing it to the output of a tracking program written by project UNITEC-1.

Picture 7 shows 2 trajectory of Unitec-1, one described in Jaxa's ECI frame, and the other one in J2000. The trajectories lie almost on top of each other and do not diverge by much. The angular distance as seen from earth is in the order of 10^{-4} °. The beam width of antenna in Bochum is around 0.18°. The accuracy of the computed trajectories converge 2-3 orders of magnitude better than required.

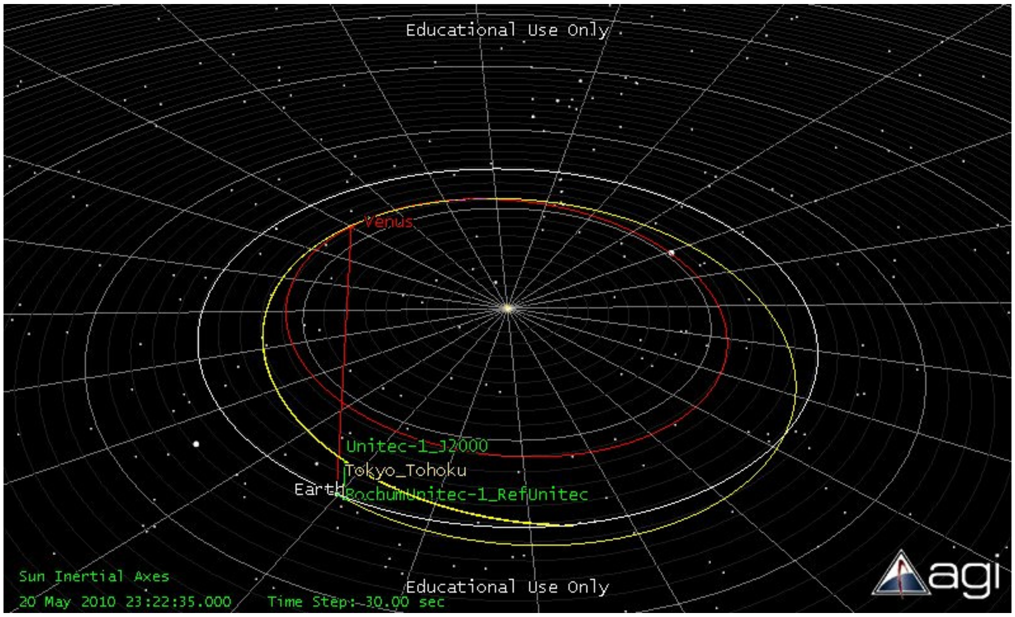
The first access window of Unitec-1 opens at around 8 hours after launch over Japan. At around 20 hours after launch, the satellite flies for the first time over Europe. Picture 8 intuitively explains the access windows: The observer looks on top onto the earth. Unitec-1 is separated above South America and then directly enters the orbit to Venus by leaving earth with hyperbolic velocity. It takes a while before Japan and later on Europe move below Unitec-1, and a communication window to the satellite opens.



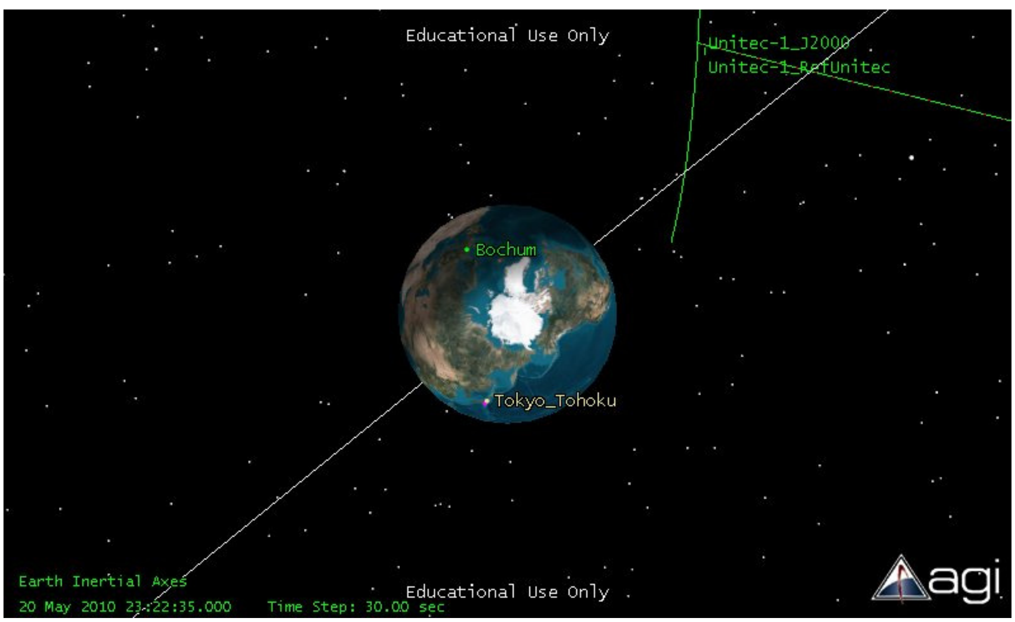
Picture 5: ECI system defined at the instant of launch in Tanegashima



Picture 6: Computing and verifying the tracking data



Picture 7: Heliocentric View



Picture 8: Departure from Earth

3.1.3 Results

During its first pass, Unitec-1 was heard in Japan. Around 20 hours after the launch, it became visible over Europe. By that time however, Unitec-1 had already ceased to function. No signal could be received by 2 ground stations in Europe, and subsequently during its next pass over Japan.

Computation of the trajectories of the 2 other passengers of the flight, Akasuki and Ikarus, using STK showed that they were flying in the vicinity of Unitec-1. Using the tracking data of Unitec-1, Akasuki and Ikaros could be received with high signal strength just by setting the radio to their respective downlink frequencies. That actually proved the tracking data to be correct.

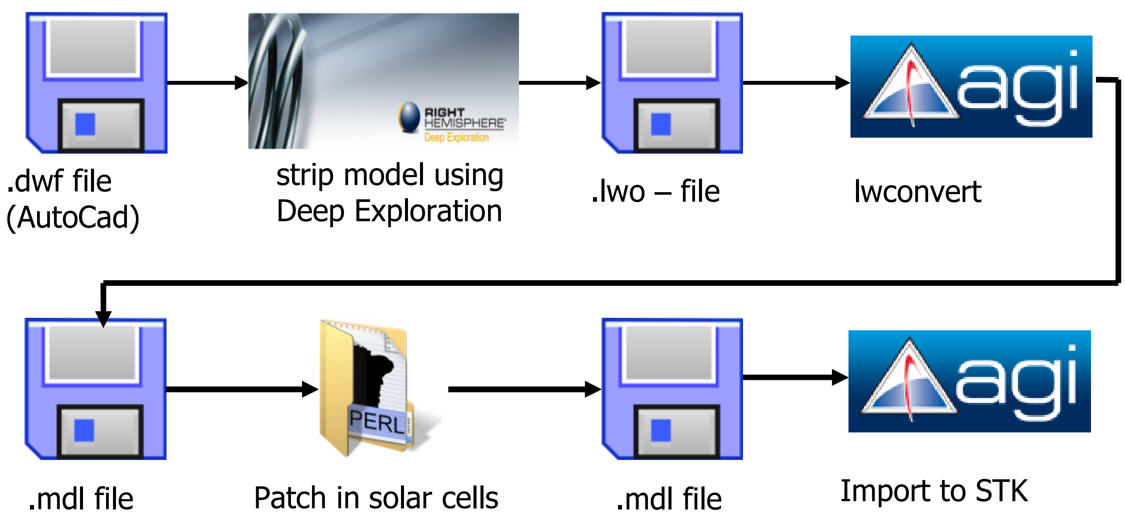
Even though no contact could be established to UNITEC-1, the mission was certainly not a complete failure for AMSAT-DL. Operational procedures as well as the tracking software were improved, the necessity for contingency plans was discovered, and additional associates were trained to setup and control the ground station in Bochum. Last but not least, it demonstrated that enough AMSAT-DL members are willing to dedicate their spare time to support projects like this. All in all, we learned a lot.

4 Phase 3 E

To familiarize ourselves with STK, we conducted several experiments with STK in the context of Phase 3E. Phase 3E is radio amateur satellite that AMSAT is currently building.

4.1 Importing CAD data into STK

STK offers the representation of computed data in 3D using custom designed objects, like satellites, or ground facilities. Phase 3E was designed using Autocad. For the import, a lengthy tool chain is required.



Picture 9: Importing AutoCad data into STK

First, the CAD model was loaded into Deep Exploration, and stripped of its interior components. Only the skin of the satellite remains. This keeps the number of polygons to be processed and displayed later on in STK smaller, thereby improving performance. Also the file size of the model (.mdl) can be reduced by about 50 % (6 MB instead of almost 12 MB). The file is than stored as a light wave object.

Lwconvert, a tool obtained from AGI, transforms the light wave object into a mdl-file. Mdl-files can be natively read by STK. Lwconvert reorients the axis of the model by default. To have consistent coordinate systems in all tools, this option needs to be turned off.

Solar cells are part of the CAD model. The conversions however do declare them as solar cells in STK. Luckily, the solar cell follow a naming convention. Their object names start with the string “solar cell”. A perl script identifying the objects representing the solar cells by object name patches their description in the mdl file:

1) The parameter “FaceEmissionColor” is commented out for objects representing solar cells.

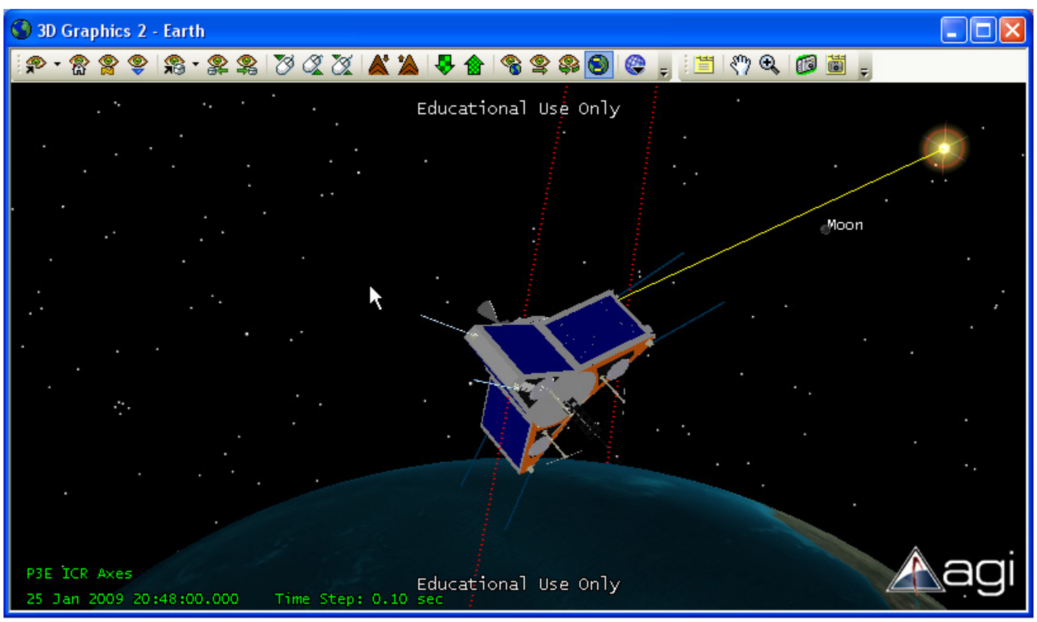
2) The parameter “Solarpanel <Name of solar panel” is added to each solar cell objects, e.g. solarpanel Arm1_1.

3) The solar panels are defined in the beginning of the mdl-file. Phase 3E has 6 solar panels, 2 on each arm. The perl scripts adds the following 6 lines:

   - SolarPanelGroup Arm1_1 0.2
   - SolarPanelGroup Arm1_2 0.2
   - SolarPanelGroup Arm2_1 0.2
   - SolarPanelGroup Arm2_2 0.2
   - SolarPanelGroup Arm3_1 0.2
   - SolarPanelGroup Arm3_2 0.2

   The value 0.2 defines the efficiency of the solar cells of one panel with 20%

Picture 10 shows the imported CAD data of Phase 3E in STK.



Picture 10: Phase 3E imported into STK

4.2 Estimating the solar power available to Phase 3 E

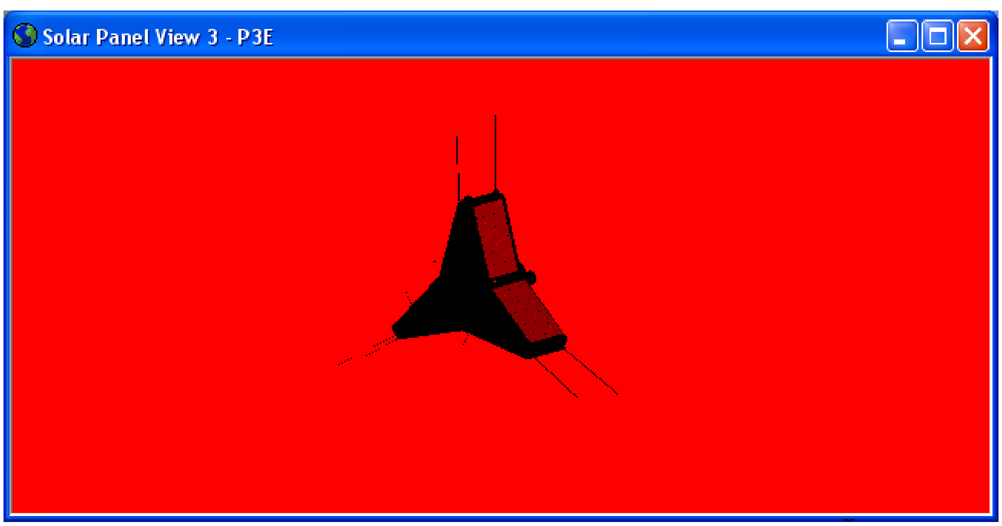
STK offers a tool to estimate the power available for a satellite. The algorithm is not too accurate as it does not consider the operating conditions of the solar cells (such as the temperature or degradation over lifetime). It allows however to get an idea about the power available at a particular orbit with a particular space craft. This tool will primarily put to work during the design phase of a mission, when its feasibility is evaluated.

To estimate the power of a solar cell, STK uses the following formula:

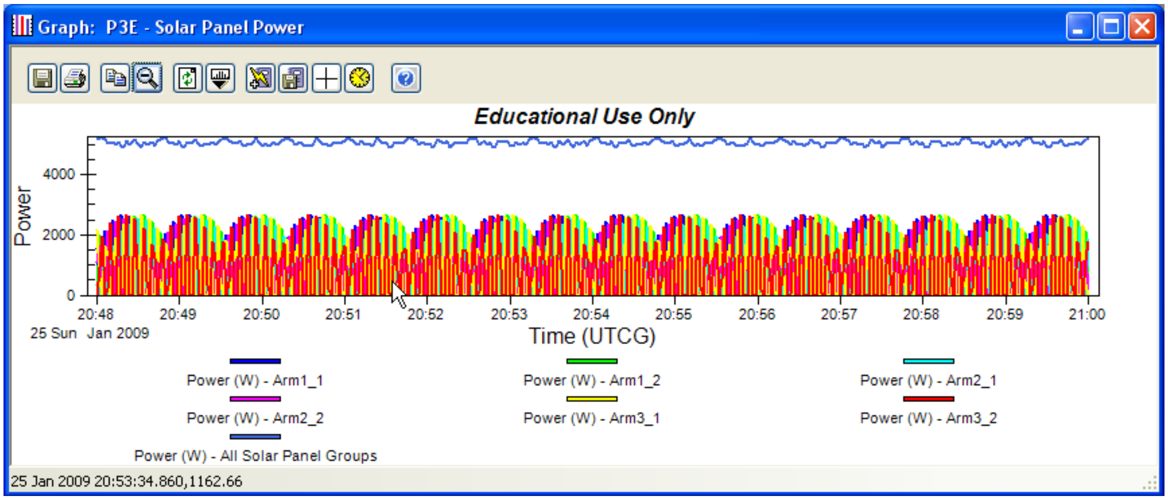
Power = SPE x SI x Effective Area x 1358 W/m^2

- SPE: Solar panel efficiency. It is declared in the SolarPanelGroup declaration (see chapter 4.1)
- SI: Solar intensity. This factor is 0 when the satellite is in eclipse. In the penumbra, it will be between 0 and 1. In full sun, it becomes 1.
- 1358 W/m^2 is the available power in the earth orbit.
- To determine the effective area of a solar cell, STK uses a ray tracing algorithm: STK looks from the direction of the sun onto the satellite, and counts the pixel of each solar cell. Depending on the angle under that the solar cell is illuminated, a value between 0 and 255 is assigned to each pixel. Both, the number of visible pixel and the sun angle of each pixel representing a solar cell make the effective area. STK can represent that graphically. In Picture 11, solar cells are represented in different shades of grey. The closer the sun angle of a solar cell becomes 90 °, the lighter the grey becomes. Structure is represented in black.

Picture 12 shows the power estimates of the individual solar arrays on the arm of Phase 3E as well as their total. As trajectory, a circular orbit with an inclination of 45 degrees was assumed. As the Autocad data describes the satellite's dimensions in centimetres, the power is given in centiwatts. The tool chain does not transform units. The simulation result matches the expected result well. Around 50 watts is what the Phase 3E design is expected to yield.



Picture 11: The Effective Area.



Picture 12: Power Estimates of Phase 3E

5 Outlook

STK has proven useful for trajectory calculations, visualization, and quickly estimating the available power. Going forward, we would like to model the attitude control system of Phase 3E. It soley relies on a sun sensor, and 3 magnetorquers as actuators. STK does not allow to describe a controller directly. It however offers the integration with other tools via a file interface. Further study will look on how to visualize attitude and trajectory data computed by Matlab/SL in STK, and use STK as an independent tool to verify the data computed by Matlab/SL.

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