



Introduction:

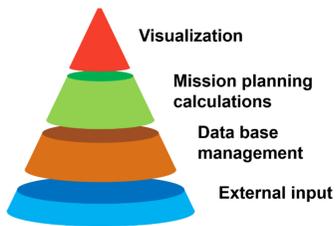
During the last decade the amount of CubeSats operated by universities all around the globe increased rapidly. The requirements vary from mission to mission but at least pass times for TM/TC link are required for most of these satellites. To calculate these times trajectory data needs to be available and accurate pointing for high gain antennas has to be computed. Besides other functionalities described in the following, the **Attitude and Orbit Simulation Tool (AOST)** developed is able to produce this trajectory and attitude data out of NORAD TLE's. In 2017 the University of Stuttgart launched the small satellite shown above called Flying Laptop (FLP). This spacecraft was taken as an example to test the AOST during its development.



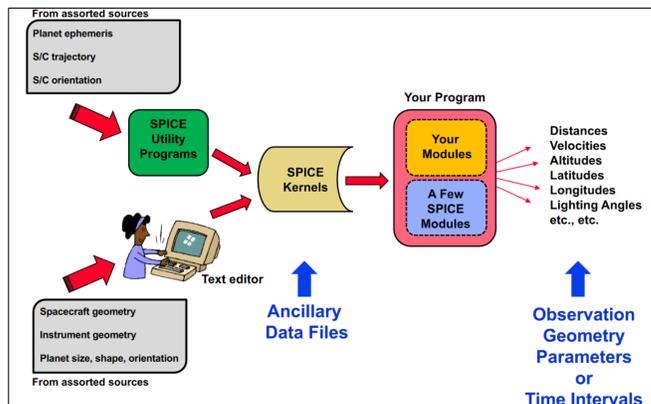
Keim, IRS, University of Stuttgart

Attitude and Orbit Simulation Tool:

The AOST connects well documented and tested open source programs (SPICE, SpicePy, Cosmographia) using python scripts to create automated modules relevant for mission planning purposes. These modules convert TLE's (from the external input layer) to so called SPICE kernels and add own SPICE kernels to an internal data base. Together with some manually written kernels these modules represent the AOST data base management layer. Modules executing mission planning calculations as the already mentioned pass times with the help of predefined SpicePy routines represent the next layer. The top layer of the AOST uses Cosmographia to visualize 3D scenarios based on the internal data and calculation outputs.



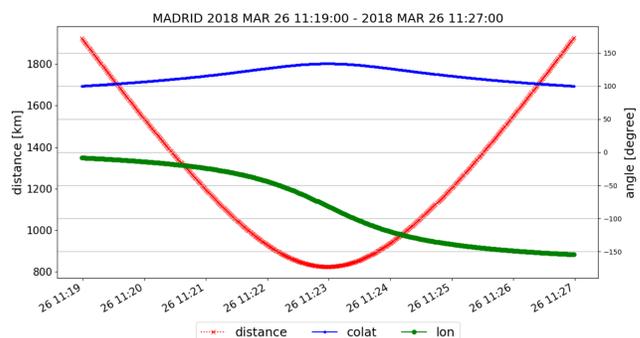
SPICE:



https://naif.jpl.nasa.gov/pub/naif/toolkit/docs/Tutorials/pdf/individual/docs/03_spice_overview.pdf

The Spacecraft Planet Instrument C-matrix Event (SPICE) toolkit is an open-source program developed by the Navigation and Ancillary Information Facility (NAIF). SPICE is used by NASA and ESA to store past and future trajectory and attitude data for most of their interplanetary missions. This data base is used to review or plan scientific observations in combination with other tools. In order to organize that data base, it is subdivided into so called **SPICE kernels** regarding to the type of information stored. SPICE utility programs convert external data or user defined input to SPICE kernels. The SPICE toolkit does not only serve as a data base but also ships with SPICE functionalities which represent fixed input-output routines mainly focused on time and coordinate conversions or geometric calculations. These functionalities can be used with different computer languages as C, MatLab, FORTRAN, IDL or python. The AOST project is using **SpicePy**, the python version.

Pass times:

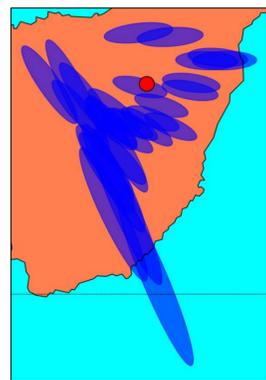
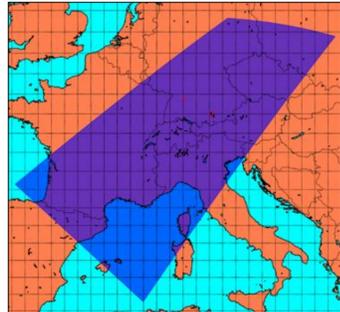


The **pass times** module is designed to detect every pass above a minimal elevation of a topocentric target system. The user needs to tell the module the overall time frame of interest, the target and the minimal elevation limit. This module is needed to specify downlink times to ground stations but can also be used to determine times when the satellite could theoretically see a specific target.

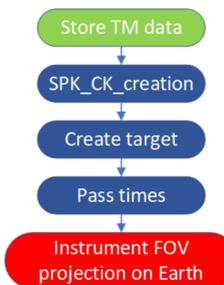
From : 2018 MAY 08 10:16:40.429
To : 2018 MAY 08 10:26:43.821

Instrument FOV projection on Earth:

This routine **projects the FOV of an instrument at a specific time epoch onto a map of the Earth surface**. It either can be used to check the landscape which should be visible on pictures downlinked from the satellite (shown right) or to continuously overlap multiple FOVs to find the ground track of the instrument during a pass (shown below).

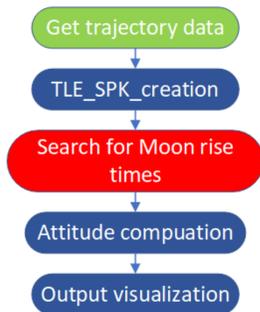
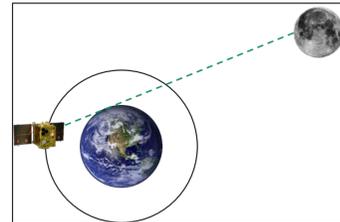


It can be seen that some intersection ellipses are stretched compared to others which is caused by the low elevation of the satellite for these times. According to this module, the GS (red dot) was at least once inside the FOV. To generate these plots the required attitude and trajectory data needs to be stored in the lowest layer of the AOST. This data will then be converted to SPICE kernels. If the target/GS does not exist it needs to be created. The pass time module calculates the start and end times of each pass. In a last step this data will be used to run the module described here.



Moon rise finder:

The **moon rise finder** module is an example how to customize constellation searches for specific geometric events. It focuses on a scenario "Moon rise behind Earth". In order to make use out of this module the steps shown besides have to be performed. In an initial step the an TLE needs to be stored in the "External Data" layer of the AOST program. Using TLEs a module called TLE SPK creation converts the data to a SPICE SPK kernel. At that point this

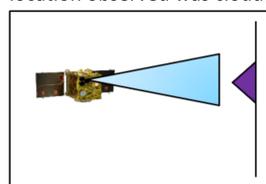
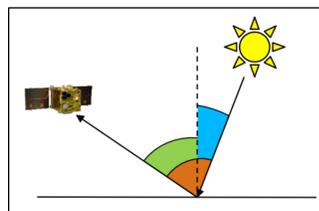


module gets used to calculate the moon rise times using **SpicePy** geometry finder routines. The CK propagation module computes the SC attitude in order to point to the event of interest in a next step.

In the end these newly generated kernels can be visualized using Cosmographia as shown in the figure above (FOV view of the moon rise).

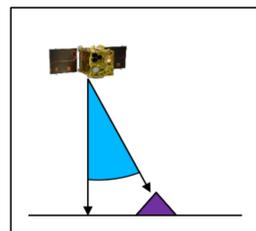
Further calculation modules:

The **illumination finder** module should be used to compute times of similar illumination conditions if special requirements exists regarding light reflection angles. It might also be used if one picture taken could not be used as the location observed was cloudy but



a similar photo without clouds is needed. The **target in FOV** module can be used to calculate the times a target appears inside an instrument FOV.

The **off-nadir angle** module was requested by the Flying-Laptop team and might represent a more specific use case. It computes the minimal angle (appearing at the highest elevation of the SC in the topocentric target frame) between the SC sub-observer point and a target. This output can then be used in the CK propagation module to create SPICE CK kernels for an off-nadir visualization. This demonstrates the adaptability of different routines to be combined to user-requested modules.



Cosmographia:



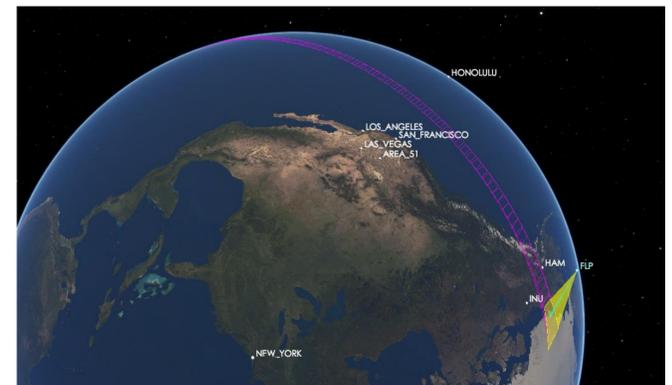
Cosmographia is a SPICE-enhanced visualization tool. This program uses the data stored in SPICE kernels to create a 3D scenario. To display the Flying Laptop satellite and user defined targets or observations within Cosmographia some catalog files are needed which are automatically generated within the AOST. It should be noted that Cosmographia provides some additional pre-implemented functionalities as SC-Sun or SC-Earth vectors, surface maps for planets, a time manipulator, a search for objects and much more.

Cosmographia sensor:



The **Cosmographia sensor** module displays a default sensor view for the user defined sensor. In the figure above the observer is located inside the instrument looking in its boresight direction. The yellow boundaries represent the end of the instrument FOV. This view is useful to crosscheck with already taken pictures or to find new observation opportunities for example a "moon rise".

Cosmographia observations:



This module represents an easy interface to load observations into Cosmographia. To achieve that the user needs to define the start and end time for the overall observation as well as the timestep between separate subobservations. The picture above uses an instrument (yellow FOV) to take subobservations (purple) every 20 s for 30 min. So far this **Cosmographia observation** module was not used for real mission planning for the FLP project but might be of interest in the future.

AOST Source Code:

https://bitbucket.org/m_grass/mpt/src/master/

AOST Virtual machine:

<https://oc.irs.unistuttgart.de/index.php/s/Pfkp8WsTabyYSC>

To exclude compatibility issues, it is recommended to use the virtual machine available. (password: BobMartha)

SPICE toolkit:

<https://naif.jpl.nasa.gov/naif/toolkit.html>

SPICE kernels:

ftp://naif.jpl.nasa.gov/pub/naif/toolkit_docs/C/req/kernel.html

SPICE utility programs:

<https://naif.jpl.nasa.gov/naif/utilities.html>

SpicePy:

<https://spicepy.readthedocs.io/en/master/>

Cosmographia:

<https://cosmoguide.org/>

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