INTRODUCTION

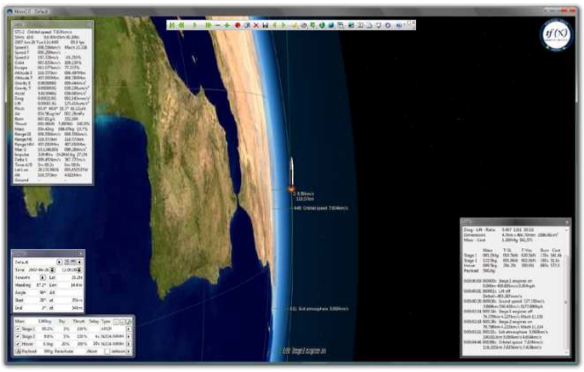
Moon2.0 is an open source toolkit to design low cost space missions. This program covers all the phases of a typical space mission: spacecraft and propellant design, satellite and attitude control, trajectory simulation, ground station coverage, etc.

This reference manual of the **Moon2.0** simulator concerns to the aerospace knowledgement, simulation, rocketry and implementation of mini-launchers. **Moon2.0** has BSD license of open source; it is allowed to copy, modify and use if the following conditions are kept:

NOTE: This simulator is intended for educational or experimental use only and may have some bugs and imprecise data. The simulated trajectory may vary from the real mission. If you plan to build and launch a real rocket use a commercial simulator. This source code is provided "as is" and without any warranties. Use at your own risk.

GRAPHICAL INTERFACE — In-flight references

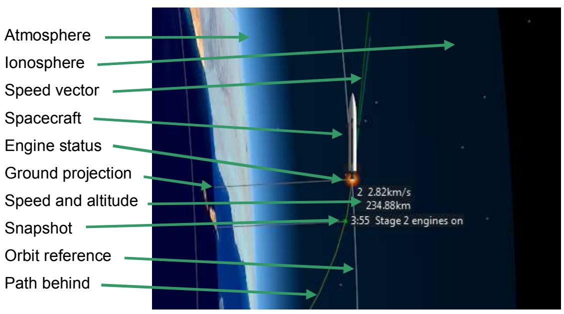
In this section the Graphical User Interface is presented.



The main window is an OpenGL 3D viewer that shows the progress of the spacecraft trajectory during the mission simulation. Additional panels are available to define the spacecraft and trajectory parameters. A set of predefined missions is provided including: sub-orbital flights, LEO and GEO orbits, Moon landing and deep space missions. Use the *Toolbar* at the top of the main window to control the simulation, show or hide auxiliary panels, load predefined presets or configure the program.

Use the **Panels** button in the *Toolbar* to show or hide the auxiliary panels. The 3D viewer and the simulation can be configured with the *Options* panel. Press the **Render**, **Simulation**, **Events**, **Screen** or **Viewer** buttons in the *Toolbar* to access the program configuration. The simulator runs by default in full screen mode. Press **F11** to exit this mode or press **Escape** to exit the application. To access the program documentation, press **F1** or press the **Help** button in the *Toolbar*. Also, a tooltip with a short description is available in all the text boxes and buttons of the panels.

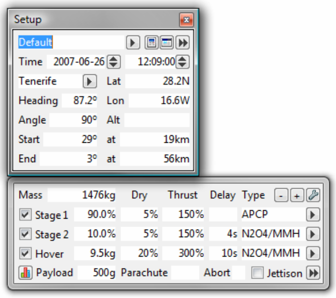
By default, the camera of the 3D viewer will follow the spacecraft. This can be changed with the **Follow** button in the *Toolbar*. Click and drag with the right mouse button on the main window to rotate the camera and view the scene from a better point of view. Also, use the mouse wheel to zoom in and out the camera. Click with the left button on any object to show an overlay with information about the object. A context menu is available in the 3D viewer by clicking with the right button. This menu is useful to access the main commands when all the auxiliary panels are hidden.



Additionally there are 10 panels: *Setup*, *Stages*, *Help*, *Data*, *Log*, *Graph*, *Propellant editor*, *View*, *Link*, *Options* and 13 auxiliary panels: *Web browser*, *Video and 360° players*, *Trajectory editor*, *Burn editor*, *Payload camera*, *Remote control*, *Notepad*, *3D Graph*, *Input graph*, *Color selector*, *Preset editor*, *Search* and *Information overlay*. See the "*Panels*" section for more information about all these panels.

MISSION DESIGN — Quick start

Basically, a mission is defined in the *Setup* and *Stages* panels. Enter the launch date and time, the launch coordinates and the parameters of the trajectory in the *Setup* panel. Select the number and parameters of the stages and the payload in the *Stages* panel. All the parameters of the mission can be saved in presets for later use. Press the **Presets** button in the *Toolbar* to access the **Presets** menu and save the current mission or load the predefined missions that come with the simulator.



Once all the mission parameters are defined, press the **Play** button in the *Toolbar* to start the simulation. Press this button again to pause it or the **Reset** button to restart it. The simulation speed can be adjusted with the **Slow down** and **Speed up** buttons. The simulator automatically generates snapshots when an important event occurs like *Stage engines off*, *Satellite deployed*, etc. Use the **Next** or **Previous** snapshot buttons to navigate through the spacecraft trajectory. The current simulation data will be shown in the *Data* panel and a log with important events will be registered in the *Log* panel. See the "*Tutorials*" section for more information about the design of LEO, GEO and Moon landing missions.

Mission design procedures

Procedure to design mini-launchers:

- Define the *Payload* mass
- Define the number of stages and its performances: *Mass*, *Dry mass*, *Thrust*, *Stage delay*, *Area*, *Length* and *Type*

Procedure to put a satellite in orbit:

- Adjust the total *Mass* until the required orbital speed is reached (see the table of key speeds below)
- Adjust angles and altitudes for the minimum energy trajectory until the desired orbital altitude is reached
- Adjust the *Delay* time between the two last stages until perform a null vertical speed at the burn out

Procedure to put a lunar rover on the Moon:

- Adjust the total Mass until the required escape velocity is reached (see the table of key speeds below)
- Adjust the launch *Date* and *Time* in such a way that the Moon's orbital plane is in the same plane as the launcher heading plane and the launcher trajectory touches the Moon

Key speeds at burn out:

- LEO orbital speed at 250 km: 7.756 km/s
- GEO orbital speed at 35.786 Mm: 3.075 km/s
- Escape velocity at 130 km: 11.069 km/s

MOUSE COMMANDS — OpenGL Viewer

LEFT BUTTON — **SELECT OBJECT / FREE CAMERA MODE**

- Select an object
- Move the camera (forward and backward)
- Move the camera (left and right)

RIGHT BUTTON — **CONTEXT MENU / ROTATE CAMERA**

- Show context menu
- Rotate the camera (pitch)
- Rotate the camera (yaw)

MOUSE WHEEL — **CAMERA ZOOM**

- Zoom in and out

DIRECT KEYS — Global configuration

F1	Show Help panel	F7	Show Propellant editor
F2	Show Data panel	F8	Show View panel
F3	Show Log panel	F9	Show Link panel
F4	Show Graph panel	F10	Show Options panel
F5	Show Setup panel	F11	Full screen mode
F6	Show Stages panel	F12	Show Toolbar
Esc	Exit program		

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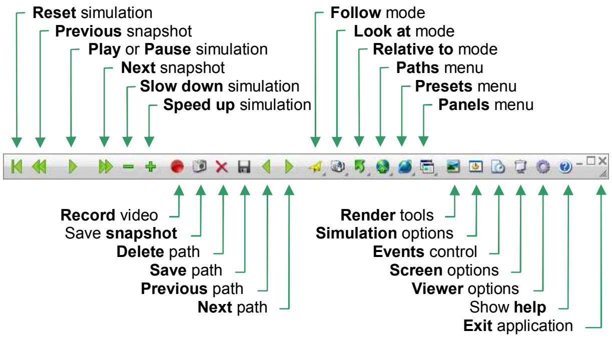
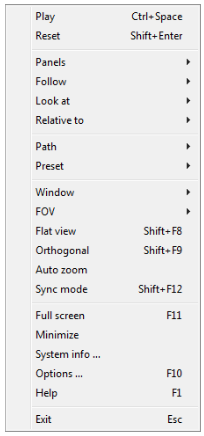
AUXILIARY TOOLS **Toolbar and context menu**



Press **F12** to show or hide the *Toolbar*. Right click on it to access the context menu or left click on the right side and drag the mouse to move the *Toolbar*. If the *Toolbar* is hidden, a context menu can also be accessed when the right mouse button is pressed in the 3D viewer.



Play or **Pause**: Play or pause the simulation.

Reset: Reset the simulation.

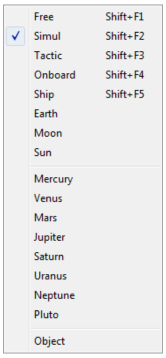
Previous or next snapshot: Pause the simulation and jump to the previous or the next snapshot. The simulator automatically generates time and event snapshots so you can navigate backward and forward through the trajectory with these buttons.

Increase or decrease time speed: Speed up or slow down the simulation. Use these buttons to increase the time speed when no important events occur or decrease it in critical phases of the trajectory like take off, landing or satellite deployed.

Record video: Start or stop the video recording. A video of the simulation will be recorded in AVI format and saved in the *Videos* folder. Configure the video size and quality in the *Screen* tab of the *Options* panel.

Save snapshot: Save the current state of the simulation in a snapshot so it can be restored to this point when navigating through the trajectory.

Panels: Use this menu to show or hide all the auxiliary panels. Select *Google Earth* to link the simulator to the *Google Earth*[1] main window. Use *Onboard sensor* to show the *View* panel in *Onboard* follow mode. Also, use the *Links* sub-menu to access a list with useful web links and the *Switch to* menu to select a panel from the list of all the panels currently active.



Follow: Select the target for the camera *Follow* mode. *Free* sets the camera in "free" mode. *Simul* follows the spacecraft and its orientation. *Tactic* keeps the camera aligned with the Earth or the Moon ground level. *Object* follows the selected object. *Onboard* emulates the sensor device selected in the *Options→Sensor* option.

Look at: Select the target for the camera *Look at* mode and the target for the *Onboard sensor* mode when there is no ground stations available. *Free* sets the camera in "free look" mode. *Object* looks at the selected object. Note that the target selected for the *Onboard sensor* mode has no effect if a target list is defined in the *Setup* panel.

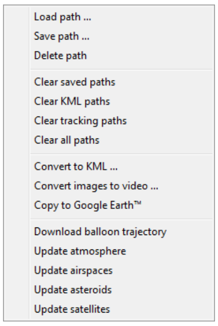
Relative to: Select the target for the *Relative to* mode. All the path points, snapshot points, vectors and distances presented in the 3D viewer and the *Data* panel will be relative to the selected planet. *Auto* selects *Air* when the spacecraft is inside the atmosphere, *Earth* when it is outside, *Moon* when it is near the Moon and *Sun* when it is far from Earth. When the spacecraft is near a planet, it will also be used as target. Use the *Target* sub-menu to select the desired target planet for the mission or select *Auto* to use the nearest planet as target. The trajectory path will be presented relative to this planet. Also, the planet position at the end of the mission time and the *Pause* options of the planet events will be limited to the selected planet.

Path: Trajectories can be stored in memory and then selected as needed using this menu, the buttons in the *Toolbar* or the **Ctrl+1** to **Ctrl+9** keys. Use this menu to load or save all the stored trajectories in a binary file or a *KML* format file. If there are no stored paths in memory then the current path is saved. Use the *Clear* options to delete the specified paths.

You can export the trajectories to a KML file so you can view the path in *Google Earth*. Select *KML files* in the drop down list of the *Save* dialog to generate a KML file. The current orbit can also be saved as *NORAD two-line*

[1] Google Earth http://earth.google.com

element[2] format by selecting the *TLE files* format when saving the path. To specify a NORAD catalog number add the string “SN-NNNNN” to the end of the preset name. For example: “LEO 3 Stages SN-00345”.



You can import trajectories from KML, CSV or NMEA files by selecting *KML files*, *CSV files* or *NMEA files* in the drop down list of the *Load* dialog. These trajectories will be shown in the 3D viewer with a different color from normal paths. The *Convert to KML* option will convert the NMEA or CSV output from a GPS to a KML file so the trajectory can be easily displayed.

Also, when loading a *Preset*, if a KML or CSV file with the same name exists, it will be loaded and the launching site will be set to the highest point in this path. This can be used to emulate a launch from a balloon or an airplane.

The *Copy to Google Earth* option copies all the stored paths to the *Google Earth* viewer when the link is active.

The *Convert images to video* option is useful to convert a sequence of image files to a video file in AVI format. Select the image files to convert in the *Open* dialog. The video will be stored in the same folder as the images using the name of the first image. The settings for the video file can be configured in the *Screen* tab of the *Options* panel.

Use the *Download balloon trajectory* option to calculate and download the trajectory of a *balloon*[3] using the current launching date, time and coordinates and the altitude for the balloon burst altitude. This trajectory will be saved as a KML file with the same name of the current preset.

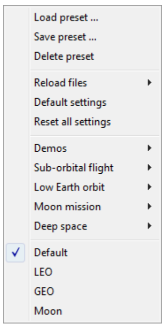
Use the *Update atmosphere* option to download and update the *NOAA-NWS GFS Atmospheric Model*[4] used in the *Atmosphere* render tool. This model is updated four times each day because the atmosphere parameters change constantly. Also, the model can calculate the weather forecast up to 8 days in the future with a 3 hours step. Select the desired date and time of the model in the *Date* and *Time* text boxes located at the *Setup* panel before updating the model. The downloaded files will be saved to the *Atmosphere* folder.

Use the *Update airspaces* option to rebuild the database used in the *Airspaces* render tool. This option will process all the KML files in the *Airways* folder to update the “Airspace.bin” file. For every file found, an airspace zone with the same name will be created. These files are updated frequently and can be downloaded from the *Lloyd Bailey 3D Airspace*[5] web page. See the “*Airspace files*” section for more information about downloading these files.

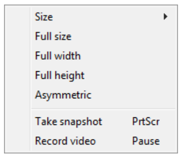
Use the *Update asteroids* option to download and update the orbital data of all the available asteroids and comets from the *Lowell Observatory*[6] and *NASA* servers. The size of the full database is about 150 MB and contains about 600,000 asteroids and 4,000 comets. New asteroids and comets are discovered almost every day so it is recommended to update the files as frequently as possible. The links to these files are stored in the “Info.ini” file located at the *Data* folder.

Use the *Update satellites* option to download and update the trajectories of the satellites in orbit around Earth. These trajectories change constantly due to the atmospheric drag, the gravity of the Moon and the Sun and the corrections done by the satellite engines. Because of this, it is recommended to update them as frequently as possible. The location of the files to download is defined in the “Satellites.csv” file inside the *Satellites* folder. The files will be also downloaded in this folder and contain a list of the trajectories in TLE format. To show a group of satellites, use the *Satellites* option in the *Options* panel. Also, use the *Satellite distance* option and the *Satellite proximity* event to detect the proximity of a satellite to the spacecraft.

Preset: It has information about the launch configuration, the orbit, the launcher and other parameters. With this menu the preset can be saved in a text file and loaded when needed. These files are located at the *Presets* folder. *Default.ini* is the preset where the current mission is saved automatically on exit.



Use the *Demos* menu to play some demonstration presets. These demos use the *Sync mode* and *Follow→Object* features as can be seen in the “*Sync mode*” section below. Select *Default settings* to restore the 3D viewer configuration to the default settings at any time or after a demo has been played. Note that the demos can not be started when a simulation is in progress. Also, use the *Reset all settings* option to reset all the simulator settings to defaults. Be aware that the current configuration will be lost. The *Reload files* menu is useful to reload the simulation data files if they were modified from an external editor.



Window: With these commands you can resize the main window to a specific size or the size of a multiple monitor desktop. Use the *Asymmetric* option to move the 3D render to the left and avoid the display border when an even number of displays are used. You can also take a screen snapshot in PNG format or record a video of the simulation in AVI format. These files will be stored in the *Videos* folder.

FOV: Set the field of view of the camera in the 3D viewer. Use *Default* in *Onboard sensor* mode to restore the default FOV of the sensor lens.

Flat view: Toggle between Flat and Spherical view.

Orthogonal: Toggle between Orthogonal and Conic view.

Auto zoom: In this mode, the simulation will automatically change the time speed and zoom in and out the camera respect to the spacecraft altitude.

Sync mode: Activate or deactivate the synchronization mode. When this mode is active, the simulation will be always synchronized with the real date and time. Note that the *Sync mode* can not be activated when a normal simulation is in progress. See the “*Sync mode*” section below for more information about this mode.

Full screen: Toggle *Full screen* window mode.

Minimize: Use this command to minimize the main window.

System info: Show information about the 3D graphics and the computer.

Options: Show or hide the *Options* panel.

Help: Show or hide the *Help* panel.

Customize the Toolbar and show extra buttons

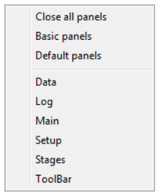
The *Toolbar* can be configured to show more buttons or hide the buttons that are not needed. Also, it can be resized to adjust its size to the main window size. Right click on it to access the context menu and specify the desired size or select the *Customize* option to configure the *Toolbar* buttons. In this mode, activate or deactivate the buttons that must be shown and finally, select *Customize* again to return to the normal mode. You can use the small buttons on the right to minimize, maximize or close the application.

Apply changes: Use this command to apply the changes to some parameters and return to a predefined point when a simulation is in progress. Some of the parameters that will be updated are related to the spacecraft trajectory like **Earth and Moon parking orbit delays**, **Thrust and lift limits**, **Braking distance**, **Stage delay** and other parameters are related to the spacecraft design like **Parachute**, **Electrical power**, **Emissivity** or the attitude control like **Control** and **PID**. Also, the first time this button is pressed, the current point of the trajectory will be saved. The next time the button is pressed, the simulation will return to this point. Press the button twice to clear this point so a new point can be defined.

Next step: Advance only one simulation step. Use this command to calculate the simulation step by step when an important event is in progress.

Increase or decrease time step: Use these buttons to adjust the time step of the simulation when more precision for the calculation of the trajectory is needed.

Switch to panel menu



In case there are many panels on the screen and some of them are hidden, you can switch to any panel with the *Switch to* menu. Press **Ctrl+Tab** at any time to show this menu and select a panel from the list to bring it to the front. Also, select the *Close all panels*, *Basic panels* or *Default panels* options to show a predefined set of panels.

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[2] NORAD two-line element format
http://celestrak.com/columns/v04n03

[3] Balloon trajectory forecasts
http://weather.uwyo.edu/polar/balloon_traj.html

[4] GFS Atmospheric Model
http:// www.emc.ncep.noaa.gov/index.php?branch=GFS

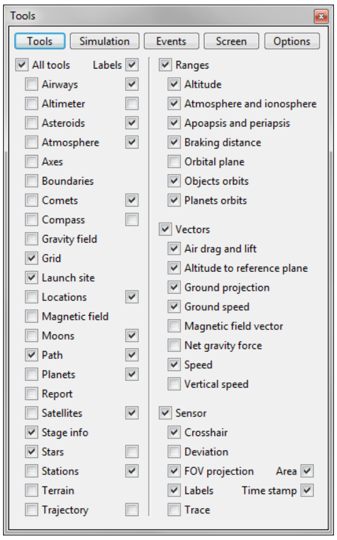
[5] Lloyd Bailey 3D Airspace
http://www.lloydbailey.net/airspace.html

[6] Lowell Observatory
http://www.lowell.edu

PANELS **Options panel**

Press **F10** to show or hide the *Options* panel. Use this panel to change the program configuration. The options are divided in 5 pages: *Tools*, *Simulation*, *Events*, *Screen* and *Options*. Press the buttons on the top of the panel to access the desired page.

Tools: Show or hide some elements in the 3D viewer:



Airways	**Ctrl+W**	Airways, airspaces, airports and seaports
Altimeter	**Ctrl+E**	Auto-scaled altimeter
• Distances	**Alt+E**	Distance as circles in the reference plane
Asteroids	**Ctrl+X**	Asteroids orbiting around the Sun
Atmosphere	**Ctrl+D**	Earth atmosphere layers
• Atmosphere glow	**Alt+D**	Earth and Mars atmosphere glow
Axes	**Ctrl+A**	Simulator and object 3D axes
Boundaries	**Ctrl+N**	Land and water boundaries
Comets	**Ctrl+Z**	Comets orbiting around the Sun
Compass	**Ctrl+I**	Compass aligned to the reference plane
• Compass grid	**Alt+G**	Grid aligned to the reference plane
Gravity field	**Ctrl+G**	Gravity field of the planets
Grid	**Ctrl+O**	Parallels and meridians in planets
Launch site	**Ctrl+U**	Launch site and North and South Poles
Locations	**Ctrl+L**	Predefined locations and cities
Magnetic field	**Ctrl+M**	Magnetic field of the Earth
Moons	**Ctrl+Q**	Natural satellites of the planets
Path	**Ctrl+P**	Spacecraft current trajectory
• Snap points	**Alt+N**	Saved snapshot points
Planets	**Ctrl+Y**	All the planets in the solar system
Report	**Ctrl+J**	Presentation tool
Satellites	**Ctrl+H**	Artificial satellites around the Earth
Stage info	**Ctrl+S**	Current stage number
Stars	**Ctrl+F**	Starfield background
• Star tracker	**Alt+S**	Nearest stars used in the star tracker
Stations	**Ctrl+K**	Ground radio-station network
Terrain	**Ctrl+T**	Planets terrain
Trajectory	**Ctrl+C**	Spacecraft trajectory prediction
• Planets position	**Alt+C**	Planets position at mission time

• Ranges … **Ctrl+R**

Altitude	Distance to the nearest planet center
Atmosphere and ionosphere	Earth atmosphere and ionosphere planes
Apoapsis and periapsis	Planets apoapsis and periapsis
Braking distance	Braking distance for the hover stage
Orbital plane	Spacecraft orbital plane
Objects orbits	Orbits of asteroids, moons and satellites
Planets orbits	Orbits of all the planets

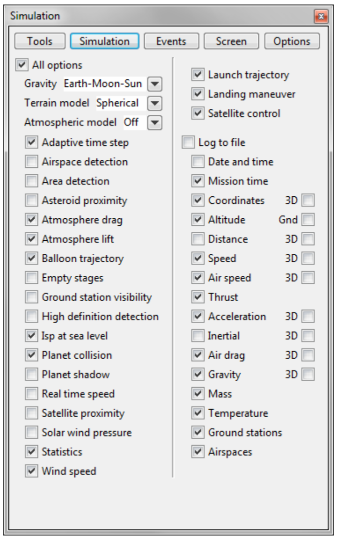
• Vectors … **Ctrl+V**

Air drag and lift	Atmosphere drag and lift forces
Altitude to reference plane	Altitude relative to the reference plane
Ground projection	Altitude relative to the nearest planet
Ground speed	Speed relative to the planet surface
Magnetic field vector	Vector aligned with Earth magnetic field
Net gravity force	Gravity minus centripetal acceleration
Speed	Speed relative to the planet center
Vertical speed	Vertical speed relative to the planet

• Sensor … **Ctrl+B**

Crosshair	Crosshair at the center of the image
Deviation	Deviation angles respect to the target
FOV projection	Field of view projection on ground
• Area	Visible area and pixel size
Labels	Locations labels and information
• Time stamp	Time of the mission
Trace	Target projection over X and Y axes

Simulation: Activate or deactivate some elements in the simulation. Use these options to see how every simulation element affects the spacecraft trajectory. Turning off *Statistics*, *Sun gravity or planets gravity* will improve the simulation speed if they are not needed. The *Matrix* terrain model uses ground elevation data from *USGS GTOPO30*[7], geoid elevation data from *NGA*[8] and *NASA elevation data*[9] to detect the ground over sea level. Note that 750 MB of RAM memory is needed to load the full world terrain. See the "*Terrain files*" section for more information about terrain and geoid files.



• Gravity model …

No gravity	Do not apply gravity force
Earth gravity	Apply only Earth gravity force
Earth-Moon gravity	Apply Earth and Moon gravity force
Earth-Moon-Sun gravity	Apply Earth, Moon and Sun gravity force
All planets gravity	Apply all planets gravity force

• Terrain model …

Spherical terrain	Use a spherical planet model
Ellipsoidal terrain	Use an ellipsoidal planet model
Matrix terrain	Use elevation data if available

• Atmospheric model …

Atmospheric model: off	Do not use the atmospheric model
Atmospheric model: low	Use the model with no interpolation
Atmospheric model: med	Use the model with Z axis interpolation
Atmospheric model: high	Use the model with X, Y, Z axes interpolation

Adaptive time step	Increase time step in deep space zones
Airspace detection	Detect the presence inside any airspace
Area detection	Detect the presence inside country boundaries
Asteroid proximity	Detect the proximity of asteroids and moons
Atmosphere drag	Apply atmosphere drag force
Atmosphere lift	Apply lift force using the lift to drag ratio
Balloon trajectory	Simulate the trajectory of the balloon
Empty stages	Simulate the trajectory of the empty stages
Ground station visibility	Detect the visibility of the ground radio-stations
High definition detection	Calculate detection every simulation time step
Isp at sea level	Reduce thrust due to atmospheric pressure
Planet collision	Detect collision with planets ground
Planet shadow	Do not apply solar heat if obscured by a planet
Real time speed	Run the simulation at real time speed
Satellite proximity	Detect the proximity of the satellites
Solar wind pressure	Apply solar wind pressure
Statistics	Calculate statistics for *Data* panel
Wind speed	Apply the atmospheric model wind speed

Launch trajectory	Apply attitude control in the launch trajectory
Landing maneuver	Apply attitude control in the landing maneuver
Satellite control	Apply attitude control in satellite deployed

Log to file: Use this option to activate the recording of the selected simulation parameters to a CSV format file. Every time that the simulation is started, a new file will be created at the *Logs* folder using the current time stamp as the file name. The data generated for every simulation loop will be recorded in the file until the simulation is paused.

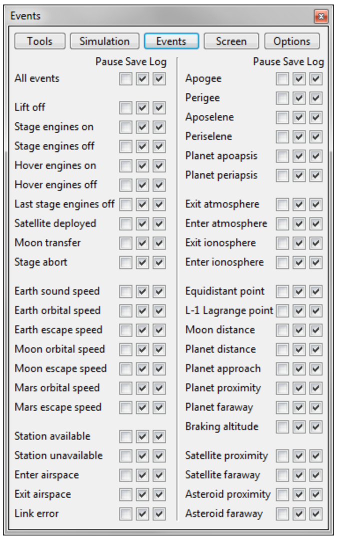
Date and time	Current date and time in UTC format
Mission time	Elapsed time from the start of the mission [s]
Coordinates	Polar coordinates: latitude and longitude [degrees]
• 3D	• Cartesian coordinates: X, Y, Z [m]
Altitude	Altitude relative to the sea level [m]
• Gnd	• Altitude relative to the ground level [m]
Distance	Distance to the nearest planet center [m]
• 3D	• X, Y, Z components of the *Distance* vector [m]

[7] USGS GTOPO30
https://lta.cr.usgs.gov/GTOPO30
[8] NGA EGM2008 Earth Gravitational Model
http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm2008
[9] NASA elevation data
http://pds-geosciences.wustl.edu/dataserv/holdings.html

Speed	Speed relative to the nearest planet center [m/s]
• 3D	• X, Y, Z components of the *Speed* vector [m/s]
Air speed	Speed relative to the atmosphere [m/s]
• 3D	• X, Y, Z components of the *Air speed* vector [m/s]
Thrust	Thrust of the spacecraft engine [N]
Acceleration	Acceleration including the gravity [m/s²]
• 3D	• X, Y, Z components of the *Acceleration* vector [m/s²]
Inertial	Acceleration without the gravity [m/s²]
• 3D	• X, Y, Z components of the *Inertial* vector [m/s²]
Air drag	Atmosphere drag deceleration [m/s²]
• 3D	• X, Y, Z components of the *Air drag* vector [m/s²]
Gravity	Gravity of the nearest planet [m/s²]
• 3D	• X, Y, Z components of the *Gravity* vector [m/s²]
Mass	Total mass [kg]
Temperature	Static temperature [K]
Ground stations	Number of ground stations available
Airspaces	Number of airspaces detected

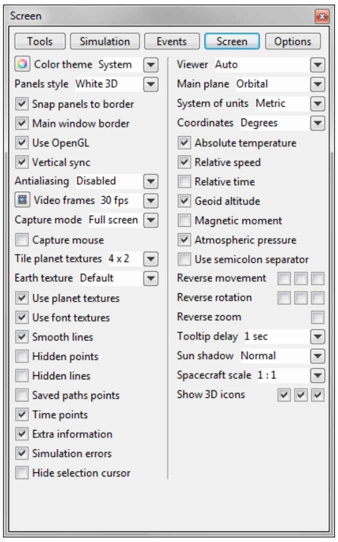
Note that only the metric system is used and the 3D Cartesian vectors use the ecliptic coordinate system, except for the *Cartesian coordinates* that use an ECEF (Earth Centered, Earth Fixed) coordinate system.

Events: Pause the simulation, save a snapshot or add a log entry to the *Log* panel when an event is triggered.



All events	Activate or deactivate all events
Lift off	The spacecraft has lifted off the ground
Stage engines on	A stage has started the engines
Stage engines off	A stage has stopped the engines
Hover engines on	The hover stage has started the engines
Hover engines off	The hover stage has stopped the engines
Last stage engines off	The last stage has stopped the engines
Satellite deployed	The satellite is deployed after burn out
Moon transfer	The hover stage is deployed after burn out
Stage abort	The sequence is aborted after a stage burn out
Apogee	The maximum altitude from Earth is reached
Perigee	The minimum altitude from Earth is reached
Aposelene	The maximum altitude from Moon is reached
Periselene	The minimum altitude from Moon is reached
Planet apoapsis	The maximum altitude from a planet is reached
Planet periapsis	The minimum altitude from a planet is reached
Exit atmosphere	The spacecraft has exited the atmosphere
Enter atmosphere	The spacecraft has entered the atmosphere
Exit ionosphere	The spacecraft has exited the ionosphere
Enter ionosphere	The spacecraft has entered the ionosphere
Earth sound speed	The Earth sound speed is reached
Earth orbital speed	The Earth orbital speed is reached
Earth escape speed	The Earth escape speed is reached
Moon orbital speed	The Moon orbital speed is reached
Moon escape speed	The Moon escape speed is reached
Mars orbital speed	The Mars orbital speed is reached
Mars escape speed	The Mars escape speed is reached
Equidistant point	The equidistant point Earth-Moon is reached
L-1 Lagrange point	The L-1 Lagrange point Earth-Moon is reached
Moon distance	The Moon orbital distance from Earth is reached
Planet distance	The planet orbital distance from Sun is reached
Planet approach	The spacecraft entered the planet gravity influence
Planet proximity	The spacecraft is near than the planet radius
Planet faraway	The spacecraft exited the planet gravity influence
Braking altitude	The spacecraft has reached the braking altitude
Station available	A ground radio-station has become available
Station unavailable	A ground radio-station has become unavailable
Enter airspace	The spacecraft has entered an airspace or area
Exit airspace	The spacecraft has exited an airspace or area
Satellite proximity	A satellite has entered the proximity zone
Satellite faraway	A satellite has exited the proximity zone
Asteroid proximity	An asteroid, comet or moon is near the spacecraft
Asteroid faraway	An asteroid, comet or moon is moving away
Link error	A link error with the external device has occurred

Screen: Change the configuration of the 3D viewer, the panels and the video recording.



Color theme: Change the color theme for all the panels and the 3D viewer. *System* is the current desktop color theme. Press the button to show the *Color selector* and change the color of a specified element of the 3D viewer or the text font used in all the panels, the 3D viewer and the *Report* tool.

Background: Change the color of the 3D viewer background.

Panels style: Select Basic 2D or Advanced 3D style for all the panels.

Snap panels to border: Activate this option to snap all the panels to the main window border.

Main window border: Show or hide the 3D viewer window border.

Use OpenGL: Toggle between OpenGL / 3D and GDI / 2D render.

Vertical sync: Toggle the screen vertical synchronization. Deactivate this option to increase the frame rate when the *View* panel is used.

Antialiasing: Activate this option to smooth pixel edges in the 3D viewer.

Video frames: Select the frames per second for the video recording. Higher frame rates needs also higher CPU / GPU power. Press the button to configure some advanced options for the video recording like compression codec, video quality and keyframe interval.

Capture mode: Use the entire screen, the main window or the *View* panel for the image and video recording. Select the *Onboard* mode to enable the automatic video recording of the *Onboard sensor* view when specific events are triggered. Use the *Pause* options in the *Events* tab to activate these events. Select ☑ to start the video recording and ☒ to stop it. Also, press the **Record** button in the *Toolbar* to deactivate this mode.

Capture mouse: Include the mouse icon in the video recording.

Tile planet textures: Use texture tile if your graphic card can not handle large textures. See the "*High definition textures*" section for more information about using optional texture files.

Earth texture: Select the texture used in the Earth 3D model.

Use planet textures (Alt+X): Use textures for the 3D models of the planets.

Use font textures (Alt+F): Use textures for the labels in the 3D viewer.

Smooth lines (Alt+Q): Antialiased lines in the 3D viewer.

Hidden points (Alt+W): Show the points hidden behind the planets.

Hidden lines (Alt+Z): Show the lines hidden behind the planets.

Saved paths points (Alt+H): Snapshots of the paths saved in memory.

Time points (Alt+M): Auto-generated time snapshots.

Extra information (Alt+I): Extra information in some labels of the 3D viewer.

Simulation errors: Show a popup message with information about invalid parameters in *Setup* and *Stages* panels.

Hide selection cursor: Activate this option to hide the cursor of the selected object after a short time.

Viewer: Use this option to select a predefined configuration for the 3D viewer according to a specific type of mission.

Main plane: Select the reference plane for the 3D viewer. *Ecliptic* is the Earth orbital plane, *Equatorial* is the Earth equatorial plane and *Orbital* is the Moon orbital plane.

System of units: You can choose metric or English units for the *Data*, *Log* and *Graph* panels and the 3D viewer.

Coordinates: Use degrees only, degrees and minutes or degrees, minutes and seconds in latitude and longitude coordinates.

Absolute temperature: Show temperatures in absolute scale using **K** and **R** degrees or relative scale using **C** or **F** degrees.

Relative speed: Show the speed relative to the atmosphere instead of relative to the planet center.

Relative time: Show time stamps in the *Trajectory* render tool relative to the current time instead of the mission start time.

Geoid altitude: You can choose between Geoid or Ellipsoid altitudes.

Magnetic moment: Show the attitude control force as a magnetic moment.

Use semicolon separator: The comma is used in some countries as a decimal point. To avoid this, some applications for these countries that work with CSV files like Microsoft Excel, use the semicolon instead of the comma. Activate this option to generate CSV files compatible with this software.

Reverse movement: Use this option to reverse the movement of the camera in any of the X, Y and Z axes when using the mouse in the 3D viewer.

Reverse rotation: Use this option to reverse the rotation of the camera around any of the X, Y and Z axes when using the mouse in the 3D viewer.

Reverse zoom: Use this option to reverse the zoom of the camera when using the mouse in the 3D viewer.

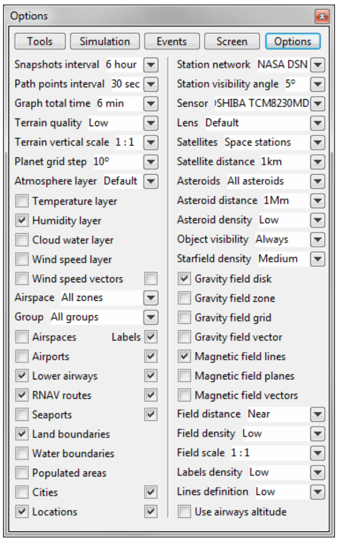
Tooltip delay: Time to wait before the tooltips are shown. Select *Disable* to disable the tooltips.

Sun shadow: The shadow of the sunlight can be modified with this option.

Spacecraft scale: Select the icon size of the spacecraft, the ground station and the tracking object in the 3D viewer.

Show 3D icons: Show or hide the icons of the spacecraft, the ground station and the tracking object in the 3D viewer.

Options: Use this panel to access the program configuration.



Snapshots interval: This option sets the time elapsed between two auto-generated snapshots.

Path points interval: Set the time step for the points in the trajectory line.

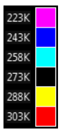
Graph total time: Change the graph recording time.

Terrain quality: Specify the level of detail of the terrain.

Terrain vertical scale: Use this option to increase the terrain vertical scale.

Planet grid step: Set the step of parallels and meridians in degrees.

Atmosphere layer: Use this option to select the layers that will be shown for the Earth *Atmosphere* render tool. Select a specific layer to show only the desired layer, *Current* to show the layer at the spacecraft altitude or *All layers* to show all the available layers. The *Default* option will automatically adjust the number of layers that will be shown. Also, use the *Field density* and *Field scale* options to adjust the layers parameters.



Temperature layer: This layer shows the temperature of the air using the color table shown in the 3D viewer overlay.

Humidity layer: This layer shows the relative humidity of the air where opaque zones of the layer represent 100 % humidity and transparent zones represent 0 % humidity.

Cloud water layer: This layer shows the mixing ratio of the cloud water in the air using the transparency of the layer. When this layer is combined with the humidity layer, magenta color is used for the layer instead of white.

Wind speed layer: This layer shows the wind speed using the color table shown in the 3D viewer overlay.

Wind speed vectors: This layer shows the wind speed as vectors pointing to the wind direction and using the same color table as the wind speed layer.

Airspace: Select the airspace zone used in the *Airways* render tool.

Group: Use this option to select a group of the selected airspace zone.

Airspaces: Show the airspaces inside the selected airspace zone.

Airports: Show the airports inside the selected airspace zone.

Lower airways: Show the lower airways inside the Spanish airspace.

RNAV routes: Show the RNAV routes inside the Spanish airspace.

Seaports: Show the seaports of the world.

Land boundaries: Show the land boundaries of all the countries in the world. The land and water boundaries, the populated areas, the seaports and the cities tools use data from the *NACIS Natural Earth*[10] map data.

Water boundaries: Show the water boundaries of all the countries in the world at 200 nautical miles. This area is called *exclusive economic zone* and every country has control over the economic resources.

Populated areas: Show highly populated areas in the world.

Cities: Show the cities of the world.

Locations: Show the predefined locations.

Station network: Select the active ground radio-station network. The radio-stations are stored in the "Stations.csv" file at the *Stations* folder. Note that this setting has no effect when a target list is defined in the *Setup* panel and only the radio-stations that are defined in the list are shown.

Station visibility angle: Specify the minimum angle above the horizon from which the radio-station can detect the spacecraft.

Sensor: Specify the sensor device emulated by the *Onboard* follow mode in the *View* panel. These sensors are defined in the "Sensors.lst" file located at the *Sensors* folder.

Lens: Use this option to change the default lens for the selected sensor.

Satellites: Select the group of satellites that will be displayed in the 3D viewer. Use the *Update satellites* option in the *Path* sub-menu to download and update the trajectories of the satellites.

Satellite distance: Specify the distance used in the satellite proximity detection.

Asteroids: Select the group of asteroids and minor planets that will be displayed in the 3D viewer.

Asteroid distance: This is the distance used in the detection of asteroids, minor planets, comets and moons.

Asteroid density: Select the density of the asteroids, minor planets, comets and moons shown in the 3D viewer. By default, only the most important objects are loaded. If a computer with a good CPU and graphic card is used, the density of the objects can be increased. It is recommended to disable the labels of the objects and the *Ranges→Altitude* option in the *Tools* tab of the *Options* panel when more than 100 objects are shown.

The orbital data of the comets is stored inside the "Comets.ini" file located at the *Planets* folder. The data for the moons of the planets is located in the same folder, inside the files with the name of the parent planet and the ".Moons.ini" string added to the file name. This data has been extracted from the *NASA Solar System Dynamics*[11] web page.

Object visibility: Use this option to hide the labels of asteroids, minor planets, comets, moons and satellites that are far from the camera position. Objects that are beyond this distance will be shown only as small points.

Starfield density: You can choose the starfield density for the background. The list of the stars is stored in the "Stars.ini" and "StarTracker.ini" files located at the *Planets* folder.

Gravity field: Select the style of the *Gravity field* render tool.

- **Disk** Circles around the planets as a function of their gravity.
- **Zone** Semi-transparent plane with the gravity applied to every point.
- **Grid** 2D grid with the vertical scale as a function of the gravity.
- **Vector** Vector grid oriented to the gravity force direction.

Magnetic field: Select the style of the Earth *Magnetic field* render tool. This tool uses the *NOAA World Magnetic Model*[12].

- **Lines** Polylines connecting the North and the South poles.
- **Planes** Semi-transparent planes with the magnetic field polylines.
- **Vectors** Vector lines located at the spacecraft altitude where the green part of the line points to the Earth magnetic North Pole.

Field distance: Drawing distance of the Gravity and Magnetic fields tool.

Field density: Level of detail of the Gravity and Magnetic fields tool and the Atmosphere layers.

Field scale: Adjust the scale of the Gravity field tool when the spacecraft is near the Sun or far from it. Also, the scale of the vectors used in the Atmosphere layers can be adjusted with this option.

Labels density: Select the labels density of the airports, seaports and cities.

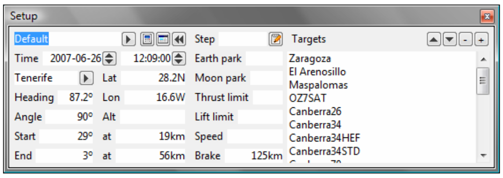
Lines definition: Select the definition of the lines used in the land and water boundaries and the populated areas.

Use airways altitude: Use the airways altitude or show them at sea level.

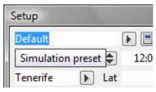
[10] NACIS Natural Earth map data
http://www.naturalearthdata.com
[11] NASA Solar System Dynamics
http://ssd.jpl.nasa.gov
[12] NOAA World Magnetic Model
http://www.ngdc.noaa.gov/geomag/WMM

PANELS — Setup panel

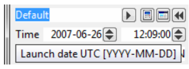
Press **F5** to show or hide the *Setup* panel. This panel allows all the functions related to the mission design.



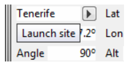
Simulation preset
Press the arrow button to load a predefined preset:
LEO: Put a WikiSat satellite of 20 grams in LEO orbit.
GEO: Put a WikiSat satellite of 20 grams in GEO orbit.
Moon: Put a PicoRover lunar rover of 500 grams on the Moon.



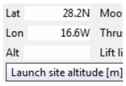
Launch date and time
This simulator uses an algorithm[13] to calculate the position of the planets depending on the launch *Date* and *Time*. Here you can select the desired launch date in UTC time format. Use the buttons to easily adjust the starting simulation time and the position of the Earth, the Moon and the planets. Double click on the buttons to select the real time.



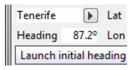
Launch site
Select the desired launch site by pressing the button. Use *Selected* to copy the selected object coordinates.



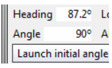
Launch site coordinates
Latitude and longitude in degrees and altitude in meters of the launch site.



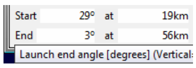
Launch initial heading
Desired orbit plane in degrees. Compass standard rule is used for a plant view where 0 degrees is North. You can use less propellant if the initial heading is East.



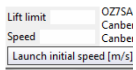
Launch initial angle
This is the launch initial pitch angle where 0 degrees is horizontal and 90 degrees is vertical.



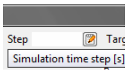
Launch trajectory arc
Used to follow a launch trajectory of minimum energy from *Start* angle in degrees at a given altitude in meters to the *End* angle in degrees at a given altitude in meters.



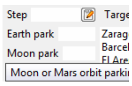
Launch initial speed
The *Launch initial speed* is used to emulate a launch from an airplane or a moving vehicle.



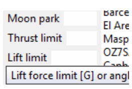
Simulation time step
Time step of the simulation main loop. Lower values give better result accuracy but require more CPU power.



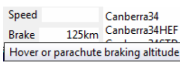
Earth, Moon and Mars parking orbit delay
This will emulate an Earth, Moon or Mars parking orbit. When the orbital speed is reached, the engine will stop for a specified time. After the delay, it will restart again to continue the sequence or the satellite will be deployed.



Thrust and lift limits
Engine thrust and lift force limits in G factor units. Use this to keep G force felt by the spacecraft under the structure or payload limits.



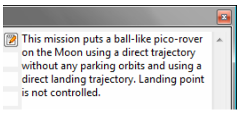
Braking distance
Lunar lander or parachute braking distance. This parameter is optional.



Show stages, trajectory editor and extended parameters
Press the button to show or hide the *Stages* panel with parameters for the stages and the payload or the button to show or hide the *Trajectory editor*. Press the button to show or hide the extended mission parameters and the button to switch between the targets list and the mission overview.

Targets list
This list defines the ground radio-stations as targets, sorted by priority, for the attitude control of the satellite. You can select items in the *Search* panel or the 3D viewer and use the buttons to add or remove them and the buttons to move them up or down in the list. See the "*Onboard sensor*" section below.

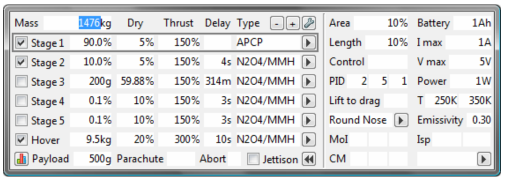
Mission overview
This is the description of the mission. You can put here all the information related to the trajectory or the spacecraft design.



[13] Source http://www.stargazing.net/Kepler/mean.html

PANELS — Stages panel

Press **F6** to show or hide the *Stages* panel. Here you specify the stages, hover and payload performances:



Mass Total mass (propellant + structure + payload). Use a percent ratio in every stage to specify a fixed mass distribution.

Dry Dry mass without propellant. You can use a *Mass* percent ratio.

Thrust Thrust at sea level, burn rate or burn time. Use a percent ratio to scale *Thrust* to *Mass*.

Delay This is the time elapsed before the stage is triggered.

Type Select a stage propellant or a real engine from the list. Add a "xN" string to specify a N multi-stage. For example: "APCPx5".

Area Stage front area, diameter or percent ratio of the total length.

Length Stage length. Use a percent ratio to specify the dry volume.

Control Attitude control thrust limit. Use a percent ratio to scale the control thrust to the main thrust. The default is unlimited thrust.

PID *Proportional*, *integral* and *derivative*[14] parameters of the attitude control algorithm. Use these parameters to adjust the reaction time and the stability of the attitude control. See the "*Attitude control*" section for more details.

Lift to drag Lift to drag ratio.

CD Drag coefficient. You can specify a fixed drag coefficient or press the button to select a predefined drag curve.

MoI Moment of inertia of the stage around X, Y and Z axes as described in the "*Attitude control*" section. Default is the moment of inertia of a cylinder aligned with the Z axis.

CM Center of mass relative to X, Y and Z axes.

Battery Electrical charge of the main battery.

I max Maximum allowable current of the electronic components.

V max Maximum allowable voltage of the electronic components.

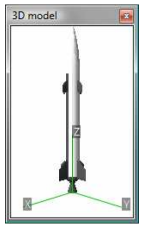
Power Electrical power consumption of the electronic components.

T min / max Minimum and maximum operating temperatures of the stage.

Emissivity Emissivity factor of the stage materials.

Isp Specific impulse of the propellant at sea level and in vacuum. This is optional and it will override the propellant default values.

Model 3D model for the selected stage and the upper stages in the 3D viewer. The *Emissivity* and *CM* parameters are calculated from the 3D model. See the "*OpenGL icons*" section below.



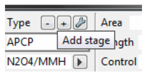
Payload Payload mass.

Parachute Parachute diameter or front area. Use a percent ratio to scale the parachute diameter to the spacecraft diameter.

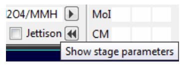
Abort Last usable stage number. After the specified stage burn out, the launching sequence will be aborted.

Jettison Activate this option to jettison the upper stages from the selected abort stage. This can be used to calculate an empty stage trajectory.

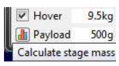
Add or remove stages
Use the button to add or duplicate the selected stage and the button to remove it from the panel.



Show extended stage parameters
Press the button to show or hide the parameters of the selected stage and the 3D model panel.



Calculate stages
This button calculates the optimum stage mass distribution.



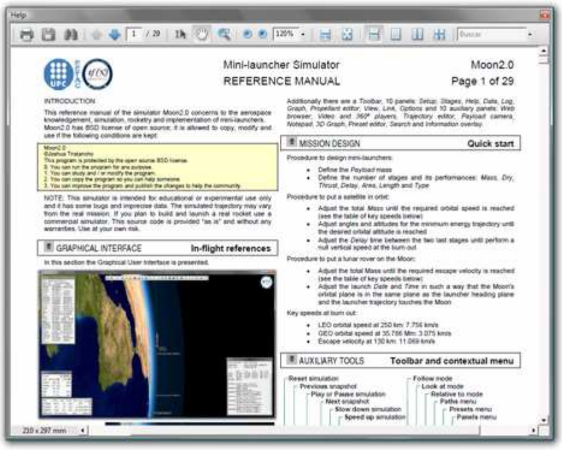
Tool tip text
There is a help tool tip in every text box or check box of the *Setup*, *Stages*, *Propellant editor*, *Link*, *Options*, *Search*, *Trajectory editor* and *Preset editor* panels and in the parameters of the *Data* and *Graph* panels. Stop the mouse pointer over the text box or the panel a few seconds to show the tool tip.

Text boxes
Text boxes in panels accept numbers and units and there is a default unit shown by the *Tool tip text*. SI prefixes of *IUPAC*[15] can be used. You can use multipliers like: Tm, Gm, Mm and km, and dividers like: dm, cm, mm, um, nm and pm. You can also use English units like: ft, in, lb, lbf, kn or mph. Scientific notation is also allowed like: 1.23e-3lb or 5.03E12m.

[14] PID controller design http://www.controlguru.com/pages/table.html
[15] IUPAC http://old.iupac.org/reports/1993/homann/index.html

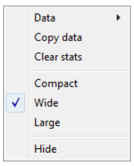
PANELS — Help panel

Press **F1** to show or hide the *Help* panel. The reference manual can be accessed from this panel using *Adobe Reader*[16].

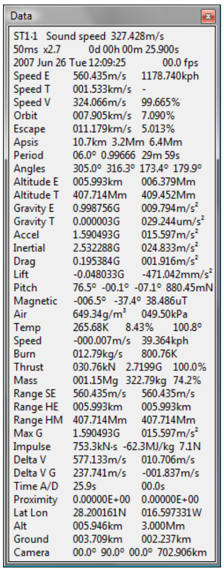


PANELS — Data panel

Press **F2** to show or hide the *Data* panel. Use the context menu to change the panel style, select the visible data items or copy the data to the clipboard.



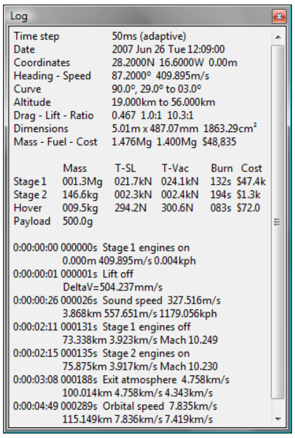
- **First row** is the current stage on command and the label for this stage.
- **Second row** is the simulation time step, scale of time and the elapsed time (day, hours, etc.) for the capture showed by the OpenGL viewer)
- **Third row** is the simulation date and time in UTC time format and the render frames per second.
- **Speed E** is the spacecraft speed relative to the Earth and to its atmosphere.
- **Speed T** is the spacecraft speed relative to the nearest planet and to its surface.
- **Speed V** is the spacecraft vertical speed relative to the nearest planet and the gravity minus the centripetal acceleration in percent ratio.
- **Orbit** is the orbital speed for the current altitude and percent reached.
- **Escape** is the escape velocity for the current altitude and percent reached.
- **Apsis** is the orbital periapsis, semi-major axis and apoapsis.
- **Period** is the orbital inclination, eccentricity and period.
- **Angles** is the orbital argument of periapsis, longitude of ascending node, mean anomaly and true anomaly.

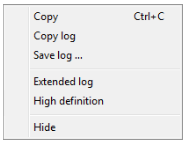


- **Altitude E** and **Altitude T** is the altitudes respect to the center and above main level of the Earth and the nearest planet.
- **Gravity E** and **Gravity T** is the gravity factor and acceleration felt by the spacecraft due to the Earth and the nearest planet.
- **Accel** is the total acceleration felt by the spacecraft.
- **Inertial** is the acceleration felt by the spacecraft without the gravity.
- **Drag** is the drag force caused by the friction with the atmosphere.
- **Lift** is the lift force generated by the spacecraft wings and main body.
- **Pitch** is the spacecraft pitch angle respect to the horizontal vector, the deviation angle, the angle of attack and the attitude thrust.
- **Magnetic** is the Earth magnetic field declination, inclination and strength.
- **Air** is the atmosphere density and pressure.
- **Temp** is the atmosphere temperature, relative humidity and wind heading, visible only if the atmospheric model is available.
- **Speed** is the atmosphere vertical and horizontal wind speed, visible only if the atmospheric model is available.
- **Burn** is the propellant burn rate and the spacecraft static temperature.
- **Thrust** is the thrust due to the engine in acceleration terms, factor and percent of throttle.
- **Mass** is the current spacecraft mass, burned mass and percent of the remaining propellant.
- **Range SE**, **Range HE** and **Range HM** are the maximum and minimum speed and height respect to the Earth and respect to the Moon.
- **Max G** is the maximum G force.
- **Impulse** is the total impulse, the specific orbital energy and the maximum attitude control thrust.
- **Delta V** is the delta-V due to the engine thrust and to the drag.
- **Delta V G** is the delta-V due to the gravity drag and to the lift.
- **Time A/D** is the accelerating time during takeoff and the decelerating time during the landing phase.
- **Proximity** is the probability of collision between the spacecraft and the satellites or the asteroids.
- **Lat**, **Lon** and **Alt** are the coordinates as a projection pointing to the center of the nearest planet. The camera distance is also presented.
- **Ground** is the distance to the ground and the ground level, visible only if the terrain model is available.
- **Camera** is the camera yaw, pitch and roll angles and altitude relative to the main level of the nearest planet.

PANELS — Log panel

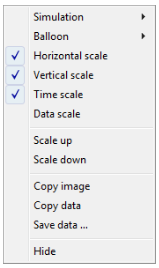
Press **F3** to show or hide the *Log* panel where a definition of the mini-launcher and a register of the events are presented. Use the *Copy log* option in the context menu to copy all the text to the clipboard or the *Save log* option to save the log to a text file. Select the *Extended log* option to show more detailed information about the mission and the parameters of the spacecraft or the *High definition* option to increase the precision of the numbers in the messages.

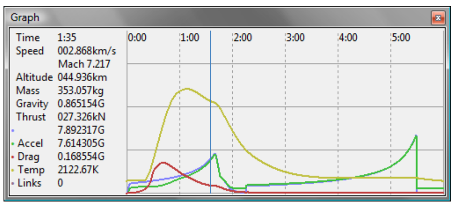




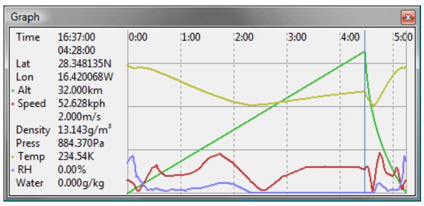
PANELS — Graph panel

Press **F4** to show or hide the *Graph* panel. This panel shows a graph with the most important time-dependent parameters of a simulation or a balloon trajectory. The graph can be configured with the context menu. Use the *Simulation* and *Balloon* sub-menus to activate or deactivate some elements in the graph. Select *Copy data* or *Copy image* to copy the data or the graph image to the clipboard. Use the *Save data* option to save the graph data to a file in CSV format. For the spacecraft trajectory, green is the total acceleration, blue is the engine thrust, red is the atmosphere drag and yellow is the static temperature. The background color of the graph will become magenta when ground stations are available and gray when airspaces are detected.





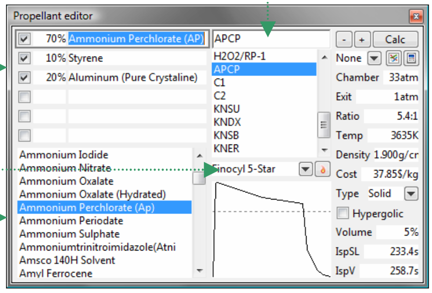
For the balloon trajectory, green is the altitude, red is the horizontal speed, yellow is the air temperature and blue is the air relative humidity.



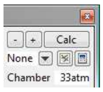
16 Adobe Reader http://www.adobe.com

PANELS — Propellant editor

Press **F7** to show or hide the *Propellant editor*. This panel shows the list of all available propellants and chemical components. Select a propellant to change its performances and components:

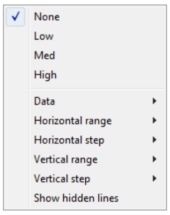


- List of the chemical components in the database
- Thrust curve graph
- Component name and mass or mixture percent ratio[17]
- List of the propellants



Select the propellant components and mixture ratio, the combustion *Chamber* and nozzle *Exit* pressures and then press the *Calc* button to calculate the propellant performance using the *CPROPEP*[18] simulator. You can add or remove a propellant from the list with using the [-] [+] buttons. The optimal mixing ratio of the propellant components can be calculated automatically by pressing the button. The precision of the propellant calculation can be adjusted with the text box on the left. Press the button to show the configuration menu. Select *None* to use mixture ratios with no decimal digits or *Low*, *Med* or *High* to use 1, 2 or 3 digits.

Press the button to generate a graph of the propellant performance. This graph will be shown in the *3D Graph* panel and it will be also automatically exported to a CSV file in the *Graphs* folder using the name of the current propellant. The parameter used in the graph can be defined in the *Data* sub-menu of the configuration menu. Also, the range and step of the horizontal and vertical axes of the graph can be defined in this menu. Activate the *Show hidden lines* option to show all the lines in the graph or deselect it to avoid drawing the lines over those below. Press the button to show the *Burn editor* and calculate the thrust curve of a solid propellant engine.

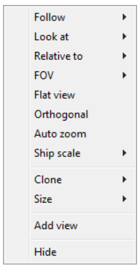


These are the parameters of the propellant:

Chamber	Combustion chamber pressure.
Exit	Nozzle exit pressure.
Ratio	Nozzle throat to exit expansion area ratio.
Temp	Combustion chamber temperature.
Density	Propellant density (in normal conditions).
Cost	Propellant cost.
Type	Liquid, solid or hybrid.
Hypergolic	Hypergolic propellant (auto ignited).
Volume	Propellant volume correction due to bulkheads.
IspSL	Specific impulse at sea level.
IspV	Specific impulse in vacuum.

PANELS — View panel

Press **F8** to show or hide an extra 3D view. Right click on it to show the context menu. You can select a specific *Follow*, *Look at* and *Relative to* modes to see the simulation from a different point of view. The *FOV* sub-menu and the *Flat view*, *Orthogonal* and *Auto zoom* options have the same functionality as the main 3D viewer. Hide or change the size of the 3D icons with the *Ship scale* sub-menu. Use the *Clone* sub-menu to copy the 3D view configuration to or from the main 3D viewer. Also, select the *Add view* option or press **Ctrl+Alt+F8** to add more *View* panels.

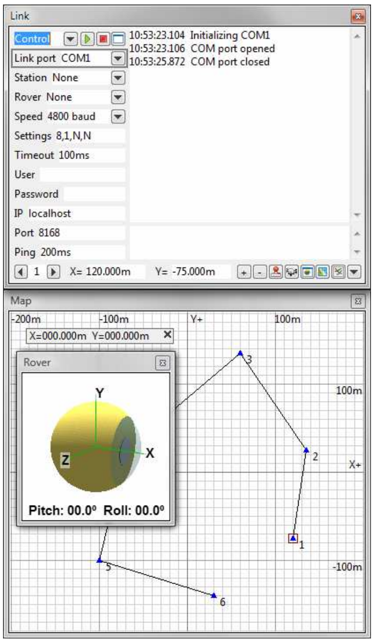


PANELS — Link panel

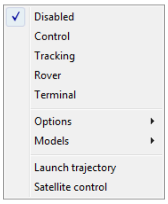
Press **F9** to show or hide the *Link* panel. Use this panel to configure and activate an external link. You can use an external device to take control of the simulation using a protocol described in the "*Hardware-in-the-loop*" section below. Select the *Control* link mode and specify in *Link port* any available COM port to use a RS-232 serial connection or *Network* to use an UDP-IP network connection.

You can also use the *Tracking* link mode to track the position of a real object. This mode can process the *NMEA*[19] commands "$GPGGA" or "$GPRMC" from an external GPS connected to a serial port or the *Audio* input. Also, it can use the *APRS*[20] tracking service to track the object position. The ground station position can be set to the current launching coordinates in the *Setup* panel with the *Fixed* option. The *Select* option is useful to set the current position to any selected ground station or location in the 3D viewer. For the tracking object, a satellite can also be selected with this option.

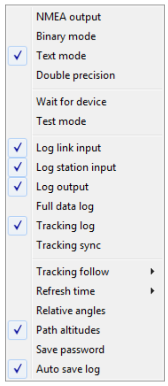
Use the *Rover* link mode to control and track the position of a vehicle connected to a serial port. The *Terminal* link mode is useful to connect the simulator to any device and send commands to it or receive information from this device. Also, use the *Graph* mode to read data from a device and generate a graph. See the "*Hardware-in-the-loop*", "*Black-box connection example*", "*GPS Tracking*" and "*Rover Tracking*" sections for more details.



Click the arrow button at the top of the panel to show the configuration menu and select the desired connection type or the elements of the simulation that must be implemented by the external device. The text box on the right shows a register of the link events and protocol errors.



In the *Options* sub-menu, use the *NMEA output*, *Binary mode*, *Text mode* and *Double precision* options to define the type of data used in the *Control* mode. Activate *Wait for device* to synchronize the simulator with the external device. The *Test mode* option is useful to test the events log output without any connected device. Select the *Log link input*, *Log station input*, *Log output* and the *Full data log* options to activate the log of the messages received by the device. Also, the *Tracking log* option activates the log of the tracking objects position. Activate the *Tracking sync* option to synchronize the simulation with the tracking object position. Use the *Tracking follow* options to select the object that the camera will follow. Select the refresh time of the server read process in the *Refresh time* sub-menu. The *Relative angles* option shows the angles in the labels relative to the ground station. Select *Path altitudes* to show or hide the ground projection of the tracking path. Activate the *Save password* option to save the password used to login in the server. Use the *Auto save log* option to save the events log to a file. Use the *Models* sub-menu to select a different 3D model for the rover, the ground station and the tracking object.

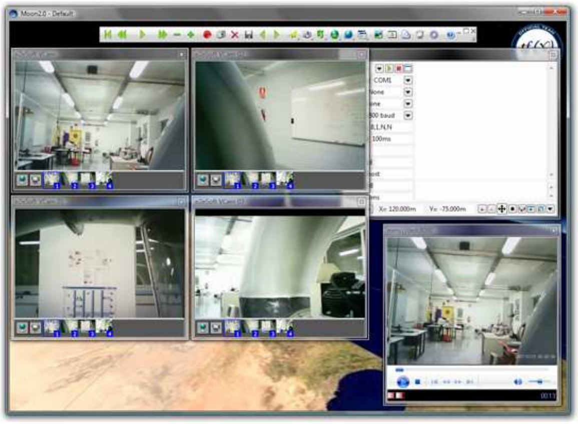


[17] Source http://www.astronautix.com/props/index.htm
[18] CPROPEP http://sourceforge.net/projects/rocketworkbench

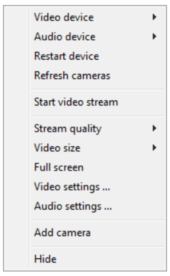
[19] National Marine Electronics Association http://www.nmea.org
[20] APRS tracking service http://aprs.fi

AUXILIARY PANELS Payload camera

Press **Ctrl+Alt+F2** or the button in the *Link* panel to show the *Payload camera*. This panel shows the video input from any video device connected to the computer. It can be used to show the live video from the camera of the payload, like a rover or a satellite. Press the button again, press **Ctrl+Alt+F7** or use the *Add camera* option in the context menu to open multiple instances of this panel and show the video input of all the connected devices. Note that the number of video devices that can be shown at the same time is limited in some computers and the video input can be seen as a blank screen.



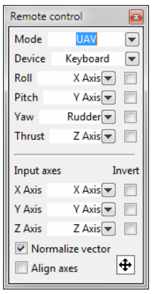
When this panel is shown, all the available cameras will be scanned and a thumbnail of every device will be placed in the *Camera selector* at the bottom of the window. Click on a camera thumbnail in the selector, press the **1** to **9** keys or use the context menu to select the video and audio devices that the panel will show. Press the button or use the *Refresh cameras* option in the context menu to refresh the thumbnails of the cameras.



Click on the button or select *Start video stream* in the context menu to activate the video streaming of the selected device in MMS stream format. If the video streaming is successfully activated, the URL address of the streaming server will be shown in the popup message and it will be also copied to the clipboard. This URL can be used in the *Video player* or any player that supports the MMS streaming protocol to connect a remote computer to the streaming server and show the live video from the onboard camera of the payload.

Also, select *Restart device* to restart the video device if it was disconnected and connected again. With the *Stream quality* options, the bandwidth of the video stream can be adjusted for slow network connections. Select *Video settings* or *Audio settings* to access the advanced device settings. The video can be resized with the *Video size* sub-menu and the *Full screen* option. Press **Ctrl+F11** or double click on the video to switch to full screen mode and press **Escape** to exit this mode.

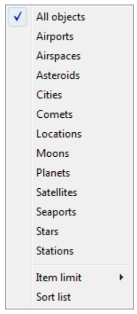
AUXILIARY PANELS Remote control



Press **Ctrl+Shift+F2** or the button in the *Link* panel to show or hide the *Remote control* panel. Use this panel along with the *Rover* link mode to control a vehicle connected to the computer. This panel is also shown automatically when the *Rover* link mode is selected and closed when the mode is deactivated. Select the type of vehicle in the *Mode* option and the control device in the *Device* option. You can configure any input axis and connect it to a specific control parameter. Finally, click the button to activate the remote control and click it again to deactivate it. You can also use the *Input axes* options to configure the axes read from the inertial sensor in the *Control* and *Rover* link modes. Also, select the *Align axes* option to align the axes to the launch site or activate *Normalize vector* to normalize the input vector. See the "*Hardware-in-the-loop*", "*Black-box connection example*" and "*Rover Tracking*" sections for more details.

AUXILIARY PANELS Information, Search and Ruler

Click with the mouse on any object in the 3D viewer to select it and show the *Information* overlay with basic parameters. Click on the icon or press **Alt+Enter** to show the *Web browser* with extended information about the object. To deselect it and hide the *Information* overlay, click on any empty space.



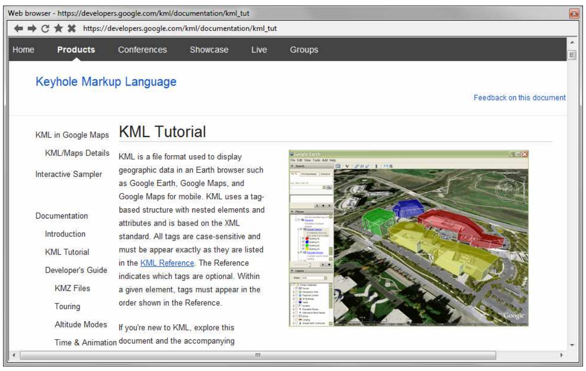
Also, click on the icon or press **Ctrl+F3** to show the *Search* panel. You can use this panel to search objects in the database. Type any word in the upper text box and the program will search the database for objects that match the specified word. Click on any object in the results list to select it or double click it to activate the *Follow→Object* mode on the object. At the top of the panel, press the arrow button to access the search options. Here you can select the limit of the search results and the type of the objects used in the search. Select the *Sort list* option to sort the list items by name.

Hold the **Ctrl** key and click with the mouse on an object in the 3D viewer to add it to the selection *Ruler* tool. This tool is useful to calculate the distance between two objects or the angle between three objects. If an object was already selected when adding the object, it will be used as center point. If no object was selected, the spacecraft will be used instead. A line connecting the two objects and the distance between them will be shown in the 3D viewer. Use **Ctrl+click** on another object to add it to the selection. Two lines connecting the center point and the other two objects, the two distances and the angle between the two lines will be shown. In the *Tactic* follow mode, the azimuth and elevation angles will also be shown. When this tool is no longer needed, click on any empty space to unselect the items and hide it.

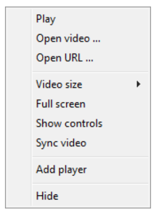
Hold the **Shift** key and click with the mouse on a planet in the 3D viewer to change the *Relative To* mode of the camera. Use **Shift+click** on any empty space to reset the mode to *Auto*.

AUXILIARY PANELS Web browser

Press **Ctrl+Alt+F3** to show or hide the *Web browser*. Use this panel to navigate through the project's web page hosted by Google. There is also a list of useful web links in the *Panels→Links* sub-menu with information about astronautics and science. Use the *Application folder* option to browse all the folders and files of the simulator. Press **Ctrl+F12** to show or hide the toolbar and **Ctrl+F11** to switch to full screen mode. Use the buttons in the toolbar to navigate through the web pages or access the *Links* menu.



AUXILIARY PANELS Video player



Press **Ctrl+F4** to show or hide the *Video player*. This panel can be used as a video player to play video files. Right click on the video to show the context menu and access the player options. Select *Open video* to open a video file or *Open URL* to open a video stream in a remote server. Also, you can use the *Video stream* option in the *Panels* sub-menu to open an URL stream. The *Open URL* option can be used to connect the player to the stream server of the *Payload camera* panel in the same computer or in a remote computer and show the live video from the onboard camera of the payload.

The video can be resized with the *Video size* options or it can be played at full screen size with *Full screen*. Press **Escape** to exit this mode. Also, show or hide the player controls with the *Show controls* option. The *Sync video* option will synchronize the simulation with the current video. Press **Ctrl+Alt+F6** or use the *Add player* option to add more *Video player* panels.

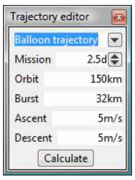
AUXILIARY PANELS — 360º player

Press **Ctrl+Alt+F4** to show or hide the *360º player*. This panel can play video files in a panoramic format. This video recording technique uses several video cameras with a normal FOV (field of view) like 60º or 90º to span the total FOV of the video to a wider angle up to 360º. This player can play up to 10 video files at the same time so the resulting panoramic video can be watched from any angle.

The video files must have the same name like “WikiSat”, followed by a number from 0 to 9. When the open dialog is shown, select the first video file in the list, for example “WikiSat1.wmv”. All the video files in the list with the same name: “WikiSat1.wmv”, “WikiSat2.wmv”, “WikiSat3.wmv”, … will be automatically opened and played. If the screen is large enough, all the videos will be shown. If the width of the panoramic video is too large to fit in the screen, the window will be resized to the screen width. Press the **Num4** or **Num6** keys in the numeric keypad to change the view position, so the rest of the videos that do not fit in the screen can be visible. The angle of the current position is shown in the window caption. Press the **Num5** key to reset the position to 0º. Also, press the **Space** key to play or pause all the videos. The videos can be resized so they fit inside the screen limits. Press the **Num+** or **Num-** keys in the numeric keypad to change the zoom level. Press **Ctrl+F11** to switch to full screen mode and press **Escape** to exit this mode.

AUXILIARY PANELS — Trajectory editor

Press **Ctrl+F5** to show or hide the *Trajectory editor*. Use this panel to automatically calculate a trajectory.

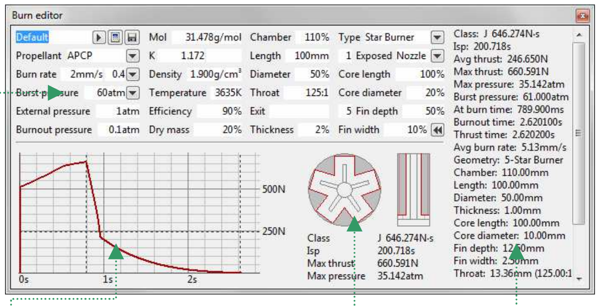


- **Balloon trajectory** calculates the trajectory for a high altitude balloon launch. Define the desired *Burst* altitude, the estimated *Ascent* and *Descent* rates and the *Mission* time for fixed-volume balloons.
- **Low Earth orbit** adjusts the parameters of the current preset for a low Earth orbit. Define the desired *Orbit* altitude or period.
- **Medium Earth orbit** adjusts the parameters of the current preset for medium or high Earth orbits like geostationary orbits. Define the desired *Orbit* altitude or period.
- **Moon mission** adjusts the parameters of the current preset for a trajectory that lands on the Moon. Define the desired parking *Orbit* altitude and the estimated *Mission* time.

When the required parameters are defined, press the *Calculate* button to start the calculation of the trajectory. If there are any errors in the input parameters, a warning will be shown and the errors will be corrected. Review the corrections and press the button again to continue with the calculation. At any time, you can press the button to abort the process. See the “*Balloon trajectory*”, “*Low Earth orbit mission*”, “*GEO orbit mission*” and “*Moon landing mission*” sections below for more information about mission design.

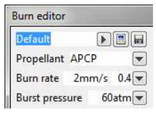
AUXILIARY PANELS — Burn editor

Press **Ctrl+Shift+F7** to show or hide the *Burn editor*. Use this panel to calculate the thrust curve of an engine that uses solid propellant.

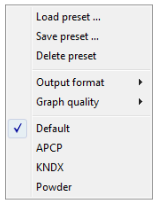


- Information about the engine specifications
- Propellant cross and longitudinal sections
- Thrust curve graph
- Input parameters of the engine and the propellant

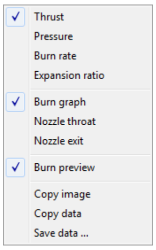
To calculate a thrust curve, enter the required parameters of the engine and the propellant in the data text boxes and press **Enter**. The thrust curve, the cross and longitudinal sections of the propellant and the information about the engine specifications will be updated. Use the *Propellant* list to retrieve the data from a propellant designed with the *Propellant editor*. The *Burn rate* parameter uses two elements, **a** and **n** that define the burn rate as a function of the combustion chamber pressure. This is calculated using the formula: *Burn rate* = **a** · *Pressure*[atm] ^ **n**. Also, press the ▼ button to select a predefined burn rate curve. These curves are defined as BRN files in the *Engines* folder. All the parameters related to the size of the engine and the propellant can be specified as a fixed number or as a percent ratio of the engine or propellant sizes. In this way, all the parameters can easily be scaled by changing only the total length or the propellant length. Use the **Up** and **Down** cursor keys in the text boxes to quickly adjust these parameters and find the optimal point. If any parameter is out of range, the preview of the graph will not be generated and a short description of the invalid parameter will be shown.



Press the button near the *Preset* text box to save the curve as a custom engine in ENG file format or a generic thrust curve in CUR file format. These files will be saved in the *Engines* folder and they can be used in the *Stages* panel or the *Propellant editor*. The format of the file that will be saved or the quality of the graph can be selected in the *Preset* menu. Press the ▶ button to show this menu. Also, use this menu to save the current burn preset or load a preset previously saved. The preset files will be saved as INI files in the *Engines* folder and the current preset will be saved on exit as *Default*. Press the button to calculate the optimal nozzle *Throat* and *Exit* parameters.



Move the mouse pointer over the graph to show the parameters and the propellant burn progress at a specific burn time. Right click on it to access the context menu and select the parameter that will be shown in the graph. If the nozzle parameters have been calculated, use the *Burn graph*, *Nozzle throat* or *Nozzle exit* options to select the graph that will be shown. Activate *Burn preview* to show a small burn progress when the cursor in the graph is hidden. Select the *Copy data* or *Copy image* options to copy the data at the current position and the engine specifications or the graph image to the clipboard. The graph can also be saved in CSV file format with the *Save data* option.



These are the input parameters of the simulation:

Preset	Name of the burn preset, generic curve or custom engine.
Propellant	List of available propellants from the *Propellant editor*.
Burn rate	Burn rate of the propellant or predefined burn rate curve.
Exponent	Exponential parameter of the burn rate (optional).
Max pressure	Motor chamber burst pressure or maximum material stress.
Ext pressure	Pressure outside the motor chamber.
Burn pressure	Pressure at the end of thrust.
Mol	Effective molar mass of the propellant mixture.
Kmix	Ratio of specific heats of the propellant mixture.
K2ph	Ratio of specific heats of the two phase flow (optional).
Density	Density of the propellant.
Temperature	Temperature of the combustion chamber.
Efficiency	Efficiency of the nozzle.
Dry mass	Engine dry mass or percent ratio of the total mass.
Chamber	Length of the motor chamber or percent of the propellant.
Length	Length of the propellant or percent of the motor chamber.
Diameter	Diameter of the propellant or percent of the propellant length.
Throat	Diameter or area of the nozzle throat or burn area ratio.
Exit	Diameter or area of the nozzle exit or expansion area ratio.
Thickness	Thickness of the motor chamber or percent of the diameter.
Type	Type of geometry used in the propellant design.
Segments	Number of segments in which the propellant is divided.
Exposed	Ends of the propellant exposed to burning.
Core length	Length of the propellant core or percent of the length.
Core diameter	Diameter of the propellant core or percent of the diameter.

Fins Number of fins in *Star Burner* geometry.
Fin depth Length of the propellant fins in *Star Burner* geometry.
Fin width Width of the propellant fins in *Star Burner* geometry.

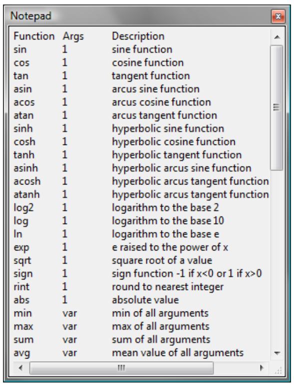
Press the ⏩ button to show or hide the engine specifications:

Class Engine classification and total impulse.
Isp Specific impulse.
Avg thrust Average engine thrust.
Max thrust Maximum engine thrust.
Max pressure Maximum combustion chamber pressure.
Burst pressure Burst pressure of the combustion chamber.
At burn time Time of the maximum combustion chamber pressure.
Burnout time Time of the propellant burnout.
Thrust time Time of the end of thrust.
Avg burn rate Average propellant burn rate.
Geometry Geometry of the propellant core.
Chamber Length of the motor chamber.
Length Length of the propellant.
Diameter Diameter of the propellant.
Thickness Thickness of the motor chamber walls.
Core length Length of the propellant core.
Core diameter Diameter of the propellant core.
Fin depth Length of the propellant fins in *Star Burner* configuration.
Fin width Width of the propellant fins in *Star Burner* configuration.
Throat Diameter of the nozzle throat and burn to throat area ratio.
Exit Diameter of the nozzle exit and nozzle expansion ratio.
Volume Propellant volume.
Mass Propellant mass and loading volume ratio.
Dry mass Engine dry mass (without propellant) and dry mass ratio.
Total mass Engine total mass (with propellant).

See the "*Thrust curve calculation*" section below for more information about the design of solid propellant engines.

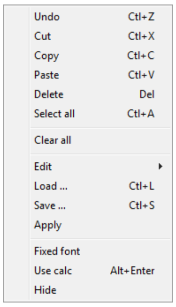
AUXILIARY PANELS — Notepad editor

Press **Ctrl+F6** to show or hide the *Notepad editor*. With this panel you can edit all the text files used in the simulator or another text file.



Use the context menu to access the panel options. In the *Edit* sub-menu there is a list of all the data files that can be edited in text format. Select *Apply* to save, apply the changes and reload the modified file. Use the *Load* and *Save* options to edit any text file or the *Clear all* option to clear all the text in the editor and create a new text file. Also, select *Fixed font* to use a fixed width font for the text.

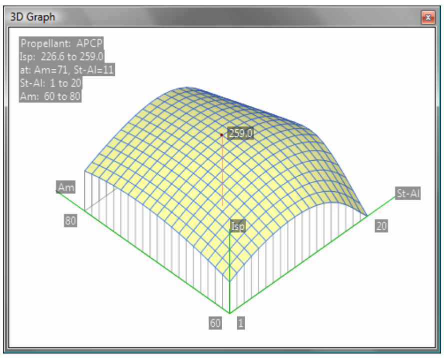
This panel can also be used as a text calculator by selecting the *Use calc* option or by pressing **Alt+Enter**. This calculator uses the *muParser* [21] open source library and can be useful to adjust the mission trajectory parameters or any other type of calculation. Type a mathematical expression that you want to calculate and then press **Enter**. The list of all available functions, operators and variables can be accessed by selecting *Edit→Functions* and *Edit→Variables* in the context menu. Variables can be created or assigned with the expression "variable=value" and deleted using "variable=".



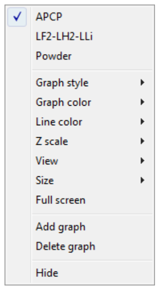
All the text in the editor and the variables will be automatically saved on exit to the "Notepad.txt" and "Variables.lst" files in the *Data* folder to use them the next time the simulator is started.

AUXILIARY PANELS — 3D Graph

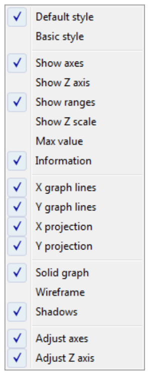
Press **Ctrl+F9** to show or hide the *3D Graph* panel. Use this panel to show the 3D graph of a propellant performance generated by the *Propellant editor*.



Click on the panel and drag the mouse with the left or right buttons to move or rotate the graph and use the mouse wheel to zoom in and out. Double click on any empty space to change the camera point of view so the graph can be seen from different angles. Click on any point in the graph to select it. The value and the position of this point will be shown. Also, double click on the point to center the camera on it. Click on any empty space to deselect it. Click with the right button on the panel to show the context menu. At the top of this menu, a list with all the available graphs will be shown. Select a graph to load it and show it on the panel. These graphs must be stored in the *Graphs* folder using a CSV format file. Press **Ctrl+Alt+F9** or use the *Add graph* option to add more *3D Graph* panels. Also, select *Delete graph* to delete the CSV file of the current graph.



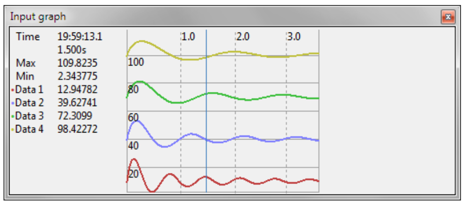
The graph shown in the panel can be configured with the options in the context menu. Use the *Graph style* sub-menu to show or hide some elements in the graph. The *Default style* option restores the graph to the default configuration and the *Basic style* option hides all the elements but the graph itself. Select the *Information* option to see some information about the graph ranges, the position of the maximum Z value in the graph and the color table used in the *Auto* color mode. Also, activate the *Max value* to show the maximum Z value as a vertical red line. When a graph is loaded or generated, the panel automatically adjusts the graph ranges so it can be seen centered on the panel. Deactivate the *Adjust axes* options to disable this feature. Also, deactivate the *Solid graph* option to see the lines behind the graph or select *Wireframe* to show the graph as transparent lines only. Use the *Shadows* option to show or hide the shadows in the graph.



The color of the graph and the lines can be changed using the *Graph color* and *Line color* sub-menus. Select *Auto* to draw the graph using a color table as a function of the Z values. Use the *Z scale* sub-menu to adjust the vertical scale of the graph. This option is useful for graphs that are very flat and the Z values are very similar. Select *Auto* to automatically adjust the Z scale. Use the *View* sub-menu to change the point of view of the camera. Activate the *Orthogonal* option to use an orthogonal view and deactivate it to use a conic view. If this option is activated, the graph can be represented in 2D mode when the camera is aligned with the X, Y or Z axes. Change the panel size with the *Size* sub-menu and the *Full screen* option.

AUXILIARY PANELS — Input graph

Press **Ctrl+Shift+F9** or the button in the *Link* panel to show or hide the *Input graph*. Use this panel to read data in comma-separated format from any device and generate a graph in real time. This panel is also shown automatically when the *Graph* link mode is selected and closed when the mode is deactivated.



To generate the graph, configure the parameters of the connection in the *Link* panel and then select the *Graph* mode. The device must send the data in text format represented by numbers, separated by commas and terminated with a semicolon or an *End of line* character, like *CR*(13), *LF*(10), *CR-LF*(13-10) or *NULL*(0). Up to 8 numbers can be sent in a line, the rest will be ignored. Every time a line of data is received, the graph will increase the time pointer and it will be updated automatically so the data can be seen in real time. This is an example of a line of data that will generate 4 graph lines:

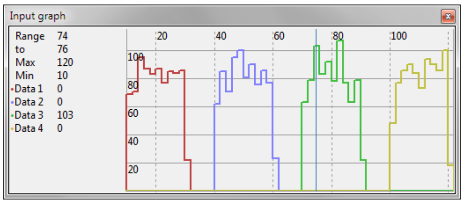
```
12.9,39.6,72.3,98.4;
```

For every number specified in the line, the simulator will generate a graph of different color, using the time of arrival of the data for the horizontal axis of the graph. The vertical axis will be adjusted to the minimum and maximum values from all the visible graphs. Optionally, a command can be specified in the first parameter of the line. You can use the "I" or "INIT" command without parameters to clear and initialize the graph. The rest of the commands not starting with a number will be ignored. This way, it can be compatible with other protocols, like a device that uses the "A" command to send the data from its inertial sensor. The labels of the graphs can also be defined with the "I" command so they can be identified in the graph panel:

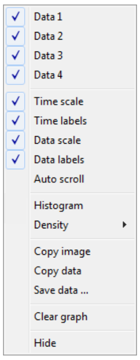
```
I,Data 1,Data 2,Data 3,Data 4;
```

The simulator will clear the graph every time the link is started but not when the link is stopped.

21 muParser math library http://muparser.sourceforge.net



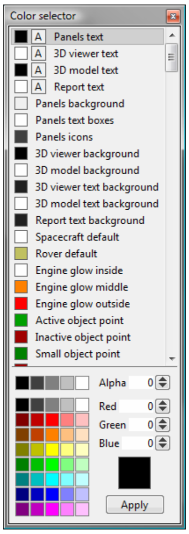
The graph can be configured with the context menu. Use the options at the top of this menu to activate or deactivate any element in the graph. Select the *Copy data* or *Copy image* options to copy the data or the graph image to the clipboard and the *Save data* option to save the graph data to a file in CSV format. Use the *Clear graph* option to clear all the data in the graph. When the data is received, the cursor is automatically moved to the end of the graph. You can activate or deactivate the automatic scroll with the *Auto scroll* option in the context menu. When this option is deactivated, move the mouse over the graph to show the data at a specific time on the left side of the panel. Also, click and drag the graph or use the mouse wheel to scroll the graph. Activate the *Histogram* option to generate a histogram of the data received. You can use the *Density* menu to increase or decrease the number of steps of the histogram. Select the *Double precision* option in the *Link* panel menu to increase the precision of the numbers in the graph.



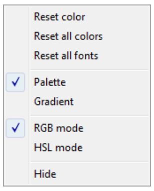
AUXILIARY PANELS — Color selector

Press **Ctrl+F10** to show or hide the *Color selector*. Use this panel to change the color of all the elements in the 3D viewer and the text of the panels. Click on any element of the list to select it and show the current color assigned to that element. Also, click on the [A] button to change the text font used for the element.

The color components of the selected element are shown in the lower part of the panel. To select a different color, click on a sample of the palette on the left. Click on the samples at the top of the palette to change the transparency of the color. Note that some elements do not use transparency and this value will be ignored. The color can also be specified with the text boxes of the components. Enter the desired value for every color component or press the [⇕] buttons near the text boxes. The selected color will be shown in the box near the *Apply* button. Press this button to apply the new color to the selected element and update the 3D viewer.

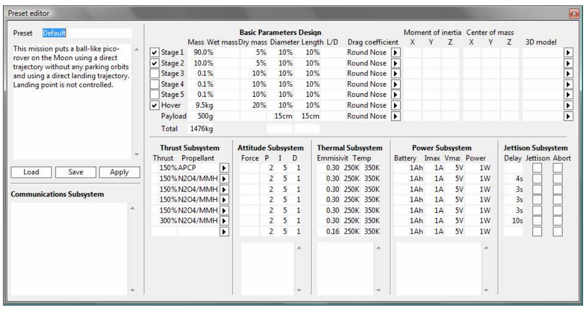


Right click on any element of the list, the color palette or the color sample to show the context menu. Select *Reset color* or double click on the color sample to reset the selected color to the default color. Use the *Reset all colors* option to restore the default color for all the elements in the list or the *Reset all fonts* option to restore the default fonts. The type of the palette can be selected with the *Palette* and *Gradient* options. Use the *Gradient* palette mode to select the color with more precision. Also, use the *RGB mode* or *HSL mode* options to change the type of the color components. *RGB mode* uses *Alpha*, *Red*, *Green* and *Red* components in a range of 0 to 255. HSL mode uses *Alpha*, *Hue*, *Saturation* and *Luminance* components in a range of 0 to 100, except *Hue* that uses a range of 0 to 360.



AUXILIARY PANELS — Preset editor

Press **Ctrl+Alt+F12** to show or hide the *Preset editor*. This panel can be used to modify all the parameters of the mission and the spacecraft. Press the *Load* button to load a preset from a file. Then press the *Apply* button to apply the changes to the simulator so you can test it or press the *Save* button to apply and save the changes to a file.



TUTORIALS — PicoRover to the Moon

The general procedure for a mission design is as follows:

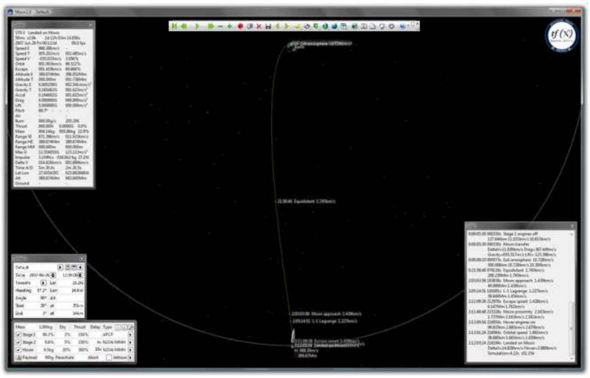
- Decide the purpose of the mission, kind of trajectory and the number of vehicles involved.
- Design if required a new propellant using the *Propellant* editor.
- Design the launcher, the payload and the hover if required using the *Setup* panel and the *Stages* and payload panel. Choose the aerodynamics parameters like Lift to Drag ratio and type of launcher tip.
- Design the basic mission parameters like the launch moment. *Launch date and time*, *Launch site coordinates* and other especial parameters. In example from an aircraft launch: *Launch initial heading*, *Launch initial speed*; and from a balloon, *Launch altitude* and *Launch initial pitch*. Also design the *Launch trajectory arc*. There is no other option in this simulator to define this path. There are some options for the trip like *Orbit parking delay*, *Abort stage*, and *Braking distance*.
- Design each launcher stage: *Stage mass*, *Dry mass*, *Thrust*, inter-stage *Delay* and basic construction parameters such as the *Stage diameter or front area*, *Stage length*, *Stage emissivity* and type of engine or type of *Stage propellant* used.

There are some parameters that shall be adjusted during the simulation such as the *Launch trajectory arc*, the inter-stage Delay or others. There is an automatism for adjusting a low Earth orbit mission and a Moon landing mission described in the next two sections. For any other type of mission these parameters should be adjusted by hand. The *Data panel* or the *Graph panel* can help you to adjust these parameters. Also you can use any remote control method to develop any part of the mission like *Hardware-in-the-loop* because you can use real hardware for a subsystem.

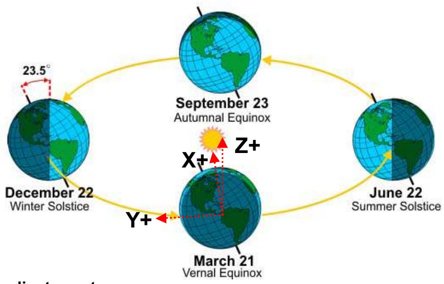
Depending on the type of mission there are different procedures to follow. Here we present an example of a ball-like rover to the Moon.

This is the procedure to design a mission to the Moon:

- Decide the Payload mass. Here is 500 grams of a PicoRover.
- Decide the number of stages and the performances. In this example there are 2 stages and the hover. Best mass distribution is 90% - 10%. Also use a direct trajectory of minimum energy like 29º at 19 km to 3º at 56 km.
- Next step is to adjust the total mass until we reach the escape velocity. This is 1,476 kilograms.
- We need to adjust the launch date and time depending on the launch site. In our example it is *Canary Islands*: 28.2ºN, 16.6ºW and 0 m. A direct trajectory is used to obtain the best performance, but the range for possible launch dates is limited. The launch *Date and time* and the *Initial heading* must be adjusted so the launcher orbital plane and the Moon orbital plane intersect at the point where the Moon will be located at the end of the trajectory. This is 2007-06-26 at 12:09:00 UTC and 87.2º.



Propellant cost is only $48,835. Gross mass is 1,476 kg and dimensions are 487 mm diameter by 5.01 m long. Time to arrival is 2d 12h 6m. There is a video available in http://www.youtube.com/watch?v=MKRx0s1HPSo.



Simulator coordinate system

This simulator uses the ecliptic coordinate system as a reference frame. The **X** axis is aligned with the *Vernal Equinox* and the **Y** axis with the *Summer Solstice*. The **Z** axis is perpendicular to the ecliptic plane, which is the plane where the Earth orbits around the Sun.

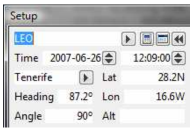
TUTORIALS — Low Earth orbit mission

This is the procedure to design a mission in order to inject a satellite in a low Earth orbit. The parameters of the "LEO" preset are shown as an example:

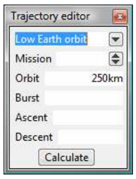
- Define the basic parameters for the mission:

• Launching site coordinates:	Tenerife: 28.2ºN, 16.6ºW
• Orbital altitude:	250 km
• Orbital period:	89 minutes 30 seconds
• Initial heading:	87.2º
• Number of stages and propellant used:	2 stages, APCP
• Payload mass:	20 g

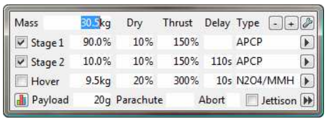
- Press the **Preset** button in the *Toolbar* and select "LEO" to reset all the mission parameters to a LEO orbit defaults. At any time press the **Reset simulation** button in the *Toolbar* to apply the changes for the initial parameters in the simulation. In the *Log* panel a mission briefing will be shown with basic parameters like stages mass or initial speed.



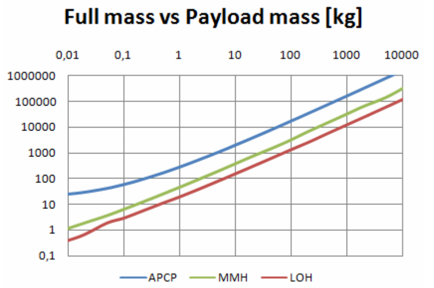
- Enter the launching site latitude and longitude in the **Lat** and **Lon** text boxes at the *Setup* panel. Also, enter the initial altitude in the **Alt** text box or leave it blank to specify a ground level.
- Press the button in the *Setup* panel to show the *Trajectory editor* and select the *Low Earth orbit* mode. Enter the desired orbital altitude in the **Orbit** text box.

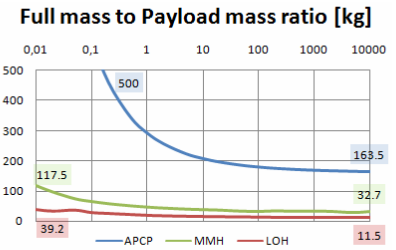


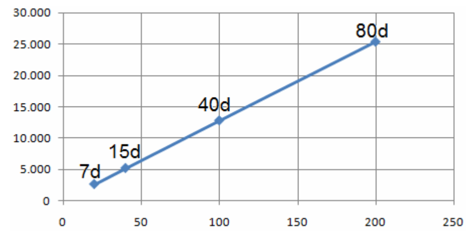
- Enter the initial trajectory heading in the **Heading** text box at the *Setup* panel. Best performance is achieved using 90º heading to use all the initial Earth rotation speed. The resulting orbital plane inclination depends on this parameter but also on the launching site latitude. For example, an Equatorial orbit can only be achieved by launching the spacecraft from the Equator or by using an orbital plane change maneuver. On the other hand a Polar orbit can be achieved from any point in the Earth surface.



- Press the [-] [+] buttons at the *Stages* panel to add or remove stages and define the desired number of stages. Make sure that the check box on the left of the **Stage** label is checked.
- Select the propellant or stage type in the **Type** text box at the *Stages* panel for every stage by pressing the button on the right side.
- Enter the stage mass percentage in the **Mass** text box for every stage on the left side of the *Stages* panel. This parameter is useful to scale all the stages when the total mass is adjusted to achieve the desired orbital speed and altitude. Usually, 90% - 10% for a 2 stages launcher and 80% - 15% - 5% for a 3 stages launcher are good mass distributions. Depending on the payload mass and the type of propellant used in every stage, this parameter should be re-adjusted to obtain a better performance.
- Enter the payload mass in the **Payload** text box at the *Stages* panel.
- The next step is to define the *Launch trajectory arc* adjusting the parameters: Full **Mass**, **Start** angle and last stage **Delay** located at the *Setup* and *Stages* panels. In this way, the payload will be deployed at the orbital altitude, at the exact orbital speed and with a null vertical speed.
- The process of adjusting the trajectory can be done automatically by the simulator by pressing the *Calculate* button in the *Trajectory editor*. This process can take several minutes, depending on the CPU power of the computer used. To cancel the process at any time, press the **Escape** key, the *Stop* button or the button in the popup message. The algorithm works well within the range of 150 km to 500 km orbital altitude. If the selected altitude is outside this range, the design parameters of the stages are incorrect or the performance of the propellant is too low, the algorithm will fail and these parameters must be corrected.
- In the case that the automatic algorithm can not adjust the trajectory, the process can be done by hand by following the next steps:
- To reach the desired orbital altitude and speed, the total mass of the launcher must be adjusted. Enter this value in the **Mass** text box located at the top of the *Stages* panel. Usually, this value can be from about 10 times the payload mass for a high performance propellant like LO2 / LH2, to about 1,000 times the payload mass for a small launcher with a low performance propellant like APCP. The following graphs show the full mass to payload mass ratio and can be useful to calculate the required launcher mass. These graphs have been calculated using the "LEO" preset for a 250 km orbit altitude and using APCP, N2O4 / MMH and LO2 / LH2 propellants for the stages. The horizontal axis shows the payload mass and the vertical axis of the first graph can be used to determine the launcher mass. The second graph shows the increment for the mass ratio of small launchers of less than 100 kg mass. This is due to their lower ballistic coefficient that increases the atmosphere drag. The same effect makes smaller payloads to slow down faster when in orbit and the total orbit time is reduced as is shown in the last graph.







- Clear the **Delay** text box for the first stage in the *Stages* panel and set a standard inter-stage delay of 3 seconds for the rest of the stages.
- Press the **Events control** button in the *Toolbar* and select the **Pause** check box for the **Last stage engines off** event. Make sure that all the rest of the **Pause** options are disabled.
- Press the **Play** button in the *Toolbar* to start the simulation and test the trajectory. When the burn out event is triggered, the simulation will pause. The next step is to reach the required orbital speed. The current orbital speed is shown inside the *Data* panel at the **Orbit** row as a percentage on the right side of the panel. If the orbital speed is below 100%, the total mass of the spacecraft must be increased. If it is above, the total mass must be decreased. Adjust this parameter, press the **Reset simulation** button in the *Toolbar* and repeat this step until an orbital speed of 100% is reached. Press the button in the *Toolbar* to speed up all this process.
- When the orbital speed is reached, if the spacecraft is above or below the desired orbital altitude, the trajectory angle must be adjusted. The current altitude is shown near the spacecraft icon or inside the *Data* panel at the **Altitude E** row. If the spacecraft is below the desired orbital altitude, increase the **Start** angle in the *Setup* panel. If it is above the orbital altitude, decrease the angle. When the final altitude is changed, also the burn out speed will change so the total mass must be re-adjusted to compensate the speed gain or loss. Repeat the simulation until an acceptable altitude at orbital speed is reached.
- Normally, at this point the spacecraft orbit will be eccentric. The last step is to convert it to a circular orbit. To achieve this, the vertical speed of the spacecraft must be null at burn out. The current vertical speed is shown in the *Data* panel at the **Speed V** row. If the vertical speed is positive, the inter-stage delay for the last stage must be increased. If it is negative, the delay must be decreased. As in the last step, when the delay is changed, the burn out speed and altitude also change. Re-adjust the total mass to compensate the speed deviation and the trajectory angle to compensate the altitude. Adjust the parameters and repeat the simulation until the vertical speed at burn out is close to zero and the required orbital speed and altitude are reached.

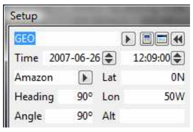
TUTORIALS — GEO orbit mission

This is the procedure to design a mission in order to inject a satellite in a medium or high Earth orbit. In this example, a GEO orbit (Geostationary Earth Orbit) will be used but this procedure can be useful to design any other type of medium or high Earth orbit. The parameters of the "GEO" preset are shown as an example:

- Define the basic parameters for the mission:

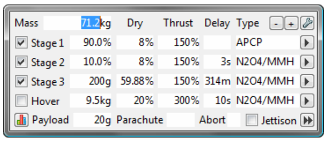
• Launching site coordinates:	Amazon: 0ºN, 50ºW
• Orbital altitude:	35,786 km
• Orbital period:	23 hours 56 minutes
• Parking orbit altitude (optional):	150 km
• Initial heading:	90º
• Number of stages and propellant used:	2 stages, APCP & N2O4/MMH
• Injection stage mass and propellant:	200 g, N2O4/MMH
• Payload mass:	20 g

- Press the **Preset** button in the *Toolbar* and select "GEO" to reset all the mission parameters to a GEO orbit defaults. At any time press the **Reset simulation** button in the *Toolbar* to apply the changes for the initial parameters in the simulation. In the *Log* panel a mission briefing will be shown with basic parameters like stages mass or initial speed.



- Enter the launching site latitude and longitude in the **Lat** and **Lon** text boxes at the *Setup* panel. Also, enter the initial altitude in the **Alt** text box or leave it blank to specify a ground level.

- Press the button in the *Setup* panel to show the *Trajectory editor* and select the *Medium Earth orbit* mode. Enter the desired orbital altitude in the **Orbit** text box. Alternatively, the orbital period can be used for this parameter. This is the time that the spacecraft will need to complete an orbit around the Earth. In this case, a GEO orbit is used, so the orbital period will be about 1 day to synchronize the spacecraft with the Earth rotation speed. In this way, it will appear motionless to ground observers, at a fixed position in the sky. The sidereal day of 23 hours and 56 minutes is used because the Earth rotation around the Sun must be corrected.
- Enter the initial trajectory heading in the **Heading** text box at the *Setup* panel. Best performance is achieved using 90º heading to use all the initial Earth rotation speed. The resulting orbital plane inclination depends on this parameter but also on the launching site latitude. For example, an Equatorial orbit can only be achieved by launching the spacecraft from the Equator or by using an orbital plane change maneuver. On the other hand a Polar orbit can be achieved from any point in the Earth surface.



- Press the buttons at the *Stages* panel to add or remove stages and define the desired number of stages. Make sure that the check box on the left of the **Stage** label is checked. For this type of trajectory, the last stage will be used as an injection stage.
- Select the propellant or stage type in the **Type** text box at the *Stages* panel for every stage by pressing the button on the right side. Note that, if a parking orbit is needed, the stage engine used for the last stage before the injection stage must use a linear thrust curve. This is because the stage engine must be stopped and restarted during the parking orbit maneuver.
- Enter the stage mass percentage in the **Mass** text box for every stage on the left side of the *Stages* panel, except for the injection stage that will be defined later. This parameter is useful to scale all the stages when the total mass is adjusted to achieve the desired orbital speed and altitude. Usually, 90% - 10% for a 2 stages launcher and 80% - 15% - 5% for a 3 stages launcher are good mass distributions. Depending on the payload mass and the type of propellant used in every stage, this parameter should be re-adjusted to obtain a better performance.
- Enter the injection stage mass in the **Mass** text box for the last stage on the left side of the *Stages* panel. This stage will be used to accelerate the spacecraft to the orbital speed when the desired orbital altitude is reached. Define the stage parameters like the rest of the stages except for the stage **Mass** that must be fixed. Usually, this value can be from about 1.5 times the payload mass for a high performance propellant like LO2 / LH2, to about 30 times the payload mass for a low performance propellant like APCP. In this example, a high dry mass ratio will be used because the stage is very small and lower dry mass ratios would be difficult to achieve.
- Enter the payload mass in the **Payload** text box at the *Stages* panel.
- The next step is to define the *Launch trajectory arc* adjusting the parameters: Full **Mass**, **Start** angle, last stage and injection stage **Delay** and injection stage **Dry** mass, located at the *Setup* and *Stages* panels. In this way, the payload will be deployed at the orbital altitude, at the exact orbital speed and with a null vertical speed.
- The process of adjusting the trajectory can be done automatically by the simulator by pressing the *Calculate* button in the *Trajectory editor*. This process can take several minutes, depending on the CPU power of the computer used. To cancel the process at any time, press the **Escape** key, the *Stop* button or the button in the popup message. The algorithm works well for orbital altitudes above 500 km. If the selected altitude is below this point, the design parameters of the stages are incorrect or the performance of the propellant is too low, the algorithm will fail and these parameters must be corrected.
- In the case that the automatic algorithm can not adjust the trajectory, the process can be done by hand by following the next steps:
- In this example, the first step will be to design a parking orbit that will be used later to adjust the position of the satellite in the geostationary orbit. This step is optional for other types of orbits, but it is still recommended to use it to design an efficient trajectory.
- To reach the parking orbit altitude and the orbital speed, the total mass of the launcher must be adjusted. Enter this value in the **Mass** text box located at the top of the *Stages* panel. Depending on the orbital altitude, this value can be from about 10 to 100 times the payload mass for a high performance propellant like LO2 / LH2, to about 1,000 to 15,000 times the payload mass for a low performance propellant like APCP. If a parking orbit is needed, liquid propellant should be used for the last stage before the injection stage, so the engine thrust can be adjusted. In this example, a mixed combination of APCP and N2O4 / MMH propellants are used, so the total mass of the launcher is about 3,000 times the payload mass.
- Clear the **Delay** text box for the first stage in the *Stages* panel and set a standard inter-stage delay of 3 seconds for the rest of the stages.
- Press the **Events control** button in the *Toolbar* and select the **Pause** check box for the **Stage abort** event. Make sure that all the rest of the **Pause** options are disabled. Enter the number of the last stage before the injection stage in the **Abort** text box at the *Stages* panel. In this example, 2 stages are used before the injection stage, so the number will be 2.
- Press the **Play** button in the *Toolbar* to start the simulation and test the trajectory. When the stage abort event is triggered, the simulation will pause. The next step is to reach the required orbital speed. The current orbital speed is shown inside the *Data* panel at the **Orbit** row as a percentage on the right side of the panel. If the orbital speed is below 100%, the total mass of the spacecraft must be increased. If it is above, the total mass must be decreased. Adjust this parameter, press the **Reset simulation** button in the *Toolbar* and repeat this step until an orbital speed of 100% is reached. Press the button in the *Toolbar* to speed up all this process.
- When the orbital speed is reached, the spacecraft trajectory must be adjusted for a short Earth parking orbit. This orbit will be useful later to adjust the position of the satellite in the orbit. In this example, an orbit of 150 km altitude is used because the delta-V loss due to the atmosphere drag of one orbit at this altitude is less than 1 m/s. First, enter the parking orbit altitude in the **End at** text box at the bottom of the *Setup* panel. Then, activate the **Pause** check box for the **Earth orbital speed** event in the *Options* panel. Restart the simulation and when the orbital speed is reached or the stage abort event is triggered, the simulation will pause.
- If the spacecraft is above or below the parking orbit altitude of 150 km, the trajectory angle must be adjusted. The current altitude is shown near the spacecraft icon or inside the *Data* panel at the **Altitude E** row. If the spacecraft is below the orbital altitude, increase the **Start** angle in the *Setup* panel. If it is above the orbital altitude, decrease the angle. Repeat the simulation until an altitude of 150 km at orbital speed is reached.
- Normally, at this point the spacecraft orbit will be eccentric. The next step is to convert it to a circular orbit. To achieve this, the vertical speed of the spacecraft must be null at burn out. The current vertical speed is shown in the *Data* panel at the **Speed V** row. If the vertical speed is positive, the inter-stage delay for the last stage before the injection stage must be increased. If it is negative, the delay must be decreased. When the delay is changed, the altitude at orbital speed also changes. Re-adjust the trajectory angle to compensate the altitude deviation. Adjust the parameter and repeat the simulation until the vertical speed at orbital speed is slightly above zero and the required parking orbit altitude is reached.
- Once the trajectory is adjusted for the parking orbit, the total mass must be re-adjusted to reach the desired orbital altitude. Before adjusting this parameter, deactivate the **Pause** check box for the **Stage abort** and the **Earth orbital speed** events in the *Options* panel and activate the **Apogee** event. In this example, the orbital period will be 23 hours and 56 minutes that corresponds to an orbital altitude of 35,786 km. These two parameters can be calculated from each other using the following equation, where **T** is the orbital period in seconds, **a** is the semi-major axis of the orbit in meters and **μ** is the standard gravitational parameter:

$$T = 2\pi\sqrt{a^3/\mu}$$

- Restart the simulation and when the spacecraft reaches the apogee it will pause. If the vertical speed adjusted in the previous step was negative, an apogee event can occur before the last stage burn out. Continue the simulation until the last stage burns out. When the apogee is reached after the burn out, if the spacecraft is above or below the desired orbital altitude, the total mass must be adjusted. If the spacecraft is below the desired orbital altitude, increase the total mass in the *Setup* panel. If it is above the orbital altitude, decrease the total mass. Repeat the simulation until an altitude of 35,786 km is reached at the trajectory apogee.
- When the orbital altitude is reached, depending on the correction made for the total mass, the altitude and vertical speed at orbital speed in the parking orbit could be slightly changed. To check this, activate the **Pause** check box for the **Earth orbital speed** event in the *Options* panel and deactivate the **Apogee** event. Run the simulation and check the altitude and vertical speed at orbital speed. If the parameters are not correct, re-adjust the last stage delay to compensate the vertical speed deviation and the trajectory angle to compensate the altitude. Repeat the simulation until the vertical speed at orbital speed is slightly above zero and the required orbital altitudes at the parking orbit and at the trajectory apogee are reached.
- The last step is to adjust the inter-stage **Delay** and the **Dry** mass of the injection stage to reach the orbital speed at the trajectory apogee with a null vertical speed. The required delay will be approximately the time elapsed between the last stage burn out and the apogee event. Look in the *Log* panel for the time stamp of the last *Stage engines off* and the *Apogee* events and calculate the time elapsed between them. Enter this value in the **Delay** text box of the injection stage. Then, clear the **Abort** text box in the *Stages* panel, deactivate the **Pause** check box for the **Stage abort**, **Earth orbital speed** and **Apogee** events in the *Options* panel and activate the **Last stage engines off** event.
- Restart the simulation and when the injection stage burns out it will pause. If the vertical speed is positive, the inter-stage delay for the injection stage must be increased. If it is negative, the delay must be decreased. Also, if the orbital speed is below 100%, the dry mass of the injection stage must be decreased. If it is above, the dry mass must be increased. Repeat the simulation until the orbital speed is reached with a null vertical speed.
- Finally, use the **Earth park** delay in the *Setup* panel to adjust the position of the satellite in the orbit. This is useful in the geostationary orbit used in this example because the satellite is located at a fixed position in the sky.

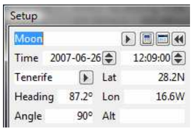
TUTORIALS **Moon landing mission**

This is the procedure to design a mission that deploys a rover on the Moon surface using an Earth parking orbit and a direct landing trajectory. The parameters of the “Moon” preset are shown as an example:

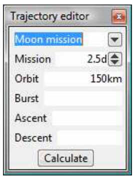
- Define the basic parameters for the mission:

• Launching site coordinates:	Tenerife: 28.2ºN, 16.6ºW
• Launching date and time:	2007-06-26, 12:09:00 UTC
• Total mission time:	2.5 days
• Parking orbit altitude:	150 km
• Initial heading:	87.2º
• Number of stages and propellant used:	2 stages, APCP & N2O4/MMH
• Hover mass and propellant used:	9.5 kg, N2O4/MMH
• Payload mass:	500 g

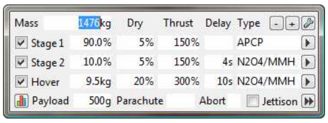
- Press the **Preset** button in the *Toolbar* and select “Moon” to reset all the mission parameters to a Moon mission defaults. At any time press the **Reset simulation** button in the *Toolbar* to apply the changes for the initial parameters in the simulation. In the *Log* panel a mission briefing will be shown with basic parameters like stages mass or initial speed.



- Enter the launching site latitude and longitude in the **Lat** and **Lon** text boxes at the *Setup* panel. Also, enter the initial altitude in the **Alt** text box or leave it blank to specify a ground level.
- Enter the launching date and time in the **Time** text boxes located at the top of the *Setup* panel. Note that for the type of trajectory used in this example, the launching time must be adjusted later, so the spacecraft trajectory intercepts the Moon. Usually, there will be two moments in the day where this condition will be true. To avoid this, the initial heading could be adjusted instead, but at the cost of performance.



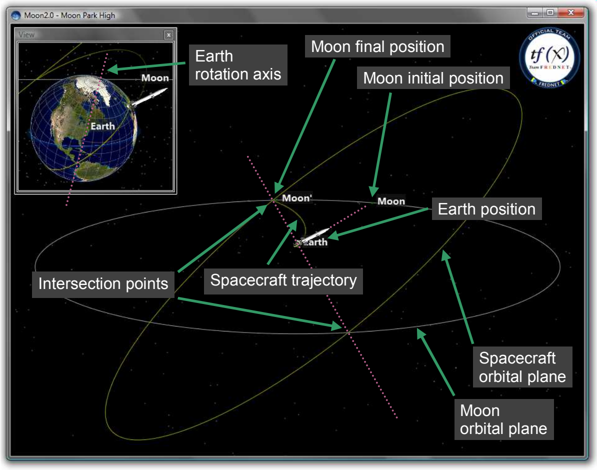
- Press the button in the *Setup* panel to show the *Trajectory editor* and select the *Moon mission* mode. Enter the desired total mission time in the **Mission** time text box and the parking orbit altitude in the **Orbit** text box.
- Enter the initial trajectory heading in the **Heading** text box at the *Setup* panel. Best performance is achieved using 90º heading to use all the initial Earth rotation speed. The resulting orbital plane inclination depends on this parameter but also on the launching site latitude. The orbital plane along with the launching date and time are very important for this type of mission because the spacecraft orbital plane and the Moon orbital plane must intersect at the point where the Moon will be located at the end of the trajectory. Also, note that the Moon orbital plane inclination is never beyond 28º of latitude and it also rotates around the Earth through the years. Therefore, for some locations under 28ºN or above 28ºS latitude, both orbital planes sometimes will be almost parallel and it will be difficult to find a point where they intersect. In this case, choose another launching date or change the initial heading.



- Press the [-] [+] buttons at the *Stages* panel to add or remove stages and define the desired number of stages. Make sure that the check box on the left of the **Stage** label is checked.
- Select the propellant or stage type in the **Type** text box at the *Stages* panel for every stage by pressing the button on the right side. Note that the stage engine used for the last stage must use a linear thrust curve. This is because the stage engine must be stopped and restarted during the parking orbit maneuver.
- Enter the stage mass percentage in the **Mass** text box for every stage on the left side of the *Stages* panel. This parameter is useful to scale all the stages when the total mass is adjusted to achieve the required escape speed. Usually, 90% - 10% for a 2 stages launcher and 80% - 15% - 5% for a 3 stages launcher are good mass distributions. Depending on the hover and payload mass and the type of propellant used in every stage, this parameter should be re-adjusted to obtain a better performance.
- Activate the check box on the left of the **Hover** label to define the lander stage. This stage is used to decelerate the spacecraft when it approaches the Moon surface at the altitude specified in the **Brake** text box at the extended parameters of the *Setup* panel. The later the brake the better the stage performance. Define the stage parameters like the rest of the stages except for the stage **Mass** that must be fixed. Usually, this value can be from about 1.5 times the payload mass for a high performance propellant like LO2 / LH2, to about 30 times the payload mass for a low performance propellant like APCP. In this example, N2O4/MMH propellant is used and the dry mass of the stage is increased to 20% to include the mass of all the devices used for navigation, braking altitude detection and attitude control. The mass is about 20 times the payload mass. Also, the stage engine must use a linear thrust curve because the engine thrust must be adjusted during the braking maneuver.
- Enter the payload mass in the **Payload** text box at the *Stages* panel.
- The next step is to define the *Launch trajectory arc* adjusting the parameters: Full **Mass**, **Start** angle, last stage **Delay**, **Earth park** delay and launching **Time**, located at the *Setup* and *Stages* panels. In this way, the payload will be deployed at the Moon surface safely. In this example, a low Earth parking orbit of 150 km of altitude is used so the trajectory can be adjusted for almost every location in Earth and every date and time. A more efficient trajectory without parking orbit could be used but then the launching location, date and time options will be reduced to a small range and the mission design will be more complex.
- The process of adjusting the trajectory can be done automatically by the simulator by pressing the *Calculate* button in the *Trajectory editor*. This process can take several minutes, depending on the CPU power of the computer used. To cancel the process at any time, press the **Escape** key, the *Stop* button or the button in the popup message. The algorithm works well for locations above 28ºN or under 28ºS latitude. If the selected latitude is in the range of 28ºS to 28ºN, the algorithm could fail to reach the Moon. This can be corrected by adjusting the initial heading or the launching date, as described in the previous steps. Also, if the design parameters of the stages are incorrect or the performance of the propellant is too low, the algorithm will fail and these parameters must be corrected.
- In the case that the automatic algorithm can not adjust the trajectory, the process can be done by hand by following the next steps:
- To reach the parking orbit altitude and the escape speed, the total mass of the launcher must be adjusted. Enter this value in the **Mass** text box located at the top of the *Stages* panel. Usually, this value can be from about 100 times the payload mass for a high performance propellant like LO2 / LH2, to about 15,000 times the payload mass for a low performance propellant like APCP. For this type of mission, liquid propellants should be used for the last stage and the hover stage so the engine thrust can be adjusted. In this example, a mixed combination of APCP and N2O4 / MMH propellants are used, so the total mass of the launcher is about 3,000 times the payload mass.
- Clear the **Delay** text box for the first stage in the *Stages* panel and set a standard inter-stage delay of 3 seconds for the rest of the stages.
- Press the **Events control** button in the *Toolbar* and select the **Pause** check box for the **Last stage engines off** event. Make sure that all the rest of the **Pause** options are disabled.
- Press the **Play** button in the *Toolbar* to start the simulation and test the trajectory. When the burn out event is triggered, the simulation will pause. The next step is to reach the required escape speed. The current escape speed is shown inside the *Data* panel at the **Escape** row as a percentage on the right side of the panel. If the escape speed is below 100%, the total mass of the spacecraft must be increased. If it is above, the total mass must be decreased. Adjust this parameter, press the **Reset simulation** button in the *Toolbar* and repeat this step until an escape speed of 100% is reached. Press the button in the *Toolbar* to speed up all this process.
- When the escape speed is reached, the spacecraft trajectory must be adjusted for a short Earth parking orbit. This orbit will be useful later to adjust the trajectory and reach the Moon. In this example, an orbit of 150 km altitude is used because the delta-V loss due to the atmosphere drag of one orbit at this altitude is less than 1 m/s. First, enter the parking orbit altitude in the **End at** text box at the bottom of the *Setup* panel. Then, activate the **Pause** check box for the **Earth orbital speed** event in the *Options* panel. Restart the simulation and when the orbital speed is reached, the simulation will pause.
- If the spacecraft is above or below the parking orbit altitude of 150 km, the trajectory angle must be adjusted. The current altitude is shown near the spacecraft icon or inside the *Data* panel at the **Altitude E** row. If the spacecraft is below the orbital altitude, increase the **Start** angle in the *Setup* panel. If it is above the orbital altitude, decrease the angle. Repeat the simulation until an altitude of 150 km at orbital speed is reached.
- Normally, at this point the spacecraft orbit will be eccentric. The next step is to convert it to a circular orbit. To achieve this, the vertical speed of the spacecraft must be null at burn out. The current vertical speed is shown in the *Data* panel at the **Speed V** row. If the vertical speed is positive, the inter-stage delay for the last stage must be increased. If it is negative, the delay must be decreased. When the delay is changed, the altitude at orbital speed also changes. Re-adjust the trajectory angle to compensate the altitude deviation. Adjust the parameter and repeat the simulation until the vertical speed at burn out is close to zero and the required orbital altitude is reached.
- When the trajectory is adjusted for the parking orbit, also the burn out speed will change so the total mass must be re-adjusted to compensate the speed gain or loss. This time, the required escape speed will be 99.66% instead of 100% because this is the required speed to reach the Moon distance from Earth in about 2.5 days. For a mission time of 1.5 days, the escape speed will be 101.75%. The maximum mission time possible is about 5 days and is achieved using an escape speed of 99.19%. To reach the required escape speed, deactivate the **Pause** check box for the **Earth orbital speed** event in the *Options* panel and make sure that the **Last stage engines off** event is still active. Repeat the simulation until an escape speed of 99.66% is reached.
- When the escape speed is reached, depending on the correction made for the burn out speed, the altitude and vertical speed at orbital speed could be slightly changed. To check this, activate again the **Pause** check box for the **Earth orbital speed** event in the *Options* panel. Run the simulation and check the altitude and vertical speed at orbital speed. If the parameters are not correct, re-adjust the last stage delay to compensate the vertical speed deviation and the trajectory angle to compensate the altitude. Repeat the simulation until the vertical speed at orbital speed is close to zero and the required orbital altitude and escape speed are reached.
- At this point, the spacecraft trajectory will be good enough to reach the Moon distance in the required mission time. But in most cases, the spacecraft will not intercept the Moon. To check the trajectory, deactivate the **Pause** check box for the **Earth orbital speed** and **Last stage engines off** events and activate the **Moon distance** event in the *Options* panel. Also, press the **Follow** button and select *Ship* to align the

camera with the Moon orbital plane and zoom out until you see the entire scene. Then, run the simulation to see the direction of the spacecraft trajectory.

- To intercept the Moon with the type of trajectory used in this example, two more parameters must be adjusted: the **Earth park** delay and the launching **Time**. To help with this process, press the **Tools** button and activate the *Orbital plane* tool. This tool will show the spacecraft orbital plane as two yellow circles projected over the Earth surface and at the Moon distance. Also, activate the *Planets position* check box on the right side of the *Trajectory* tool. This tool shows the position of the planets at the end of the **Mission** time specified in the *Trajectory editor*. The "Moon Park High" preset is shown as an example:



- Usually, the spacecraft orbital plane and the Moon orbital plane will intersect at two points, as seen in the picture. But in some cases, if the latitude of the launching site is in the range of 28ºS to 28ºN, the two orbital planes could be almost parallel, making difficult or impossible to find or adjust the intersection points. This can be corrected by adjusting the initial heading or the launching date, as described in the previous steps.
- Using the parking orbit that was adjusted before, the spacecraft trajectory can be directed to any of the two intersection points. By adjusting the **Earth park** delay, the trajectory will be rotated around the spacecraft orbital plane axis. Also, by adjusting the launching **Time**, the trajectory and the spacecraft orbital plane will be rotated around the Earth rotation axis so the intersection points can be adjusted to the desired position. These two parameters must be adjusted so the spacecraft orbital plane and the Moon orbital plane intersect at the point where the Moon will be located at the end of the trajectory. If the *Planets position* tool is activated, this point will be shown as *Moon'* in the 3D viewer. In this example, a mission time of 2.5 days is used. So in the time that the spacecraft reaches the Moon, it will rotate around the Earth about 33º. This rotation will be about 20º for a mission of 1.5 days and about 65º for a slow mission of 5 days.
- Press the **Reset simulation** button in the *Toolbar*. Then, click and drag up or down the button near the launching **Time** text box in the *Setup* panel, to adjust the launching **Time**. Also, you can double click on it to select the current real date and time. The Earth will rotate around its axis and also, the launching site and the spacecraft orbital plane will rotate too so the intersection points can be adjusted. Adjust the launching **Time** until any of the two intersection points coincides with the *Moon'* point.
- The next step is to adjust the **Earth park** delay in text box located at the extended parameters of the *Setup* panel, so the spacecraft trajectory points to the selected intersection point. In this example, a 150 km parking orbit has been selected. The time needed to complete an orbit at this altitude is 87.5 minutes. To rotate the trajectory 1 degree, the **Earth park** delay must be increased 0.243 minutes. This value must be equal or greater than "0m" and lower than "87.5m". If the required value gets out of this range, subtract or add 87.5 to the value to make it fit into this range. In any text box using time units, the value can be entered as seconds, minutes, hours or days. Just add a "s", "m", "h" or "d" at the end of the number. Run the simulation to see the direction of the spacecraft trajectory and adjust the **Earth park** delay until the final position of the spacecraft is aligned with the Moon orbital plane and reaches the *Moon'* point. Note that, when the spacecraft is near to the Moon, its gravity will change the shape of the final part of the spacecraft trajectory and it will be moved away from the spacecraft orbital plane. To correct this, adjust the launching **Time** as described in the previous step.
- Repeat the last two steps until the spacecraft touches the surface of the Moon at the required coordinates. These coordinates are shown in the *Data* panel at the **Lat Lon** row.
- If the **Hover** stage performance is not good enough or the **Brake** altitude is set too low, the spacecraft will crash on the Moon surface. The remaining propellant for the current stage is shown as a percentage in the *Data* panel at the right side of the **Mass** row. If this value is equal to 0%, it means that the **Hover** engine performance is too low. Increase its performance and repeat all the process from the beginning if the **Hover** mass is changed. If the remaining propellant is greater than 0%, it means that the **Brake** altitude is too low. Increase the **Brake** altitude in the *Setup* panel or the **Hover** engine thrust in the *Stages* panel and repeat the simulation.

TUTORIALS — Balloon trajectory

This is the procedure to calculate the trajectory for a balloon that will launch the spacecraft from a high altitude. The parameters of the balloon and the parachute must be specified before the trajectory can be calculated. A typical mission for a small payload of 4 kg mass is used as an example:

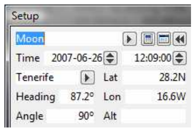
- Define the basic parameters for the balloon trajectory:

• Launching site coordinates:	Tenerife: 28.2ºN, 16.6ºW
• Launching date and time:	2007-06-26, 12:09:00 UTC
• Balloon burst altitude:	32 km
• Balloon ascent rate:	5 m/s
• Balloon weight:	1.6 kg
• Parachute terminal velocity:	5 m/s
• Payload mass:	4 kg

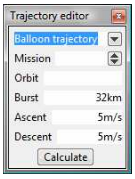
- The size and weight of the balloon will be determined by the required payload mass. For every type of balloon, the manufacturer will give the specific parameters for a given payload mass. The following table can be used to determine these parameters:

Balloon Weight	Burst Altitude	Ascent Rate	Payload Mass
10 g	8,000 m	1.5 m/s	25 g
30 g	11,000 m	2.0 m/s	75 g
50 g	13,000 m	3.0 m/s	125 g
100 g	16,000 m	4.0 m/s	250 g
200 g	18,000 m	5.0 m/s	500 g
300 g	19,000 m	5.0 m/s	750 g
350 g	21,000 m	5.0 m/s	875 g
400 g	23,000 m	5.0 m/s	1,000 g
500 g	27,000 m	5.0 m/s	1,250 g
600 g	28,000 m	5.0 m/s	1,500 g
750 g	29,000 m	5.0 m/s	1,875 g
800 g	30,000 m	5.0 m/s	2,000 g
950 g	31,000 m	5.0 m/s	2,375 g
1,000 g	32,000 m	5.0 m/s	2,500 g
1,200 g	33,000 m	5.0 m/s	3,000 g
1,500 g	35,000 m	5.0 m/s	3,750 g
1,600 g	36,000 m	5.0 m/s	4,000 g
2,000 g	38,000 m	5.0 m/s	5,000 g

- Enter the launching date and time in the **Time** text boxes located at the top of the *Setup* panel. Also, enter the launching site latitude and longitude in the **Lat** and **Lon** text boxes and the initial altitude in the **Alt** text box or leave it blank to specify a ground level.



- If a KML path was already loaded or calculated, press the **Path** button in the *Toolbar* and select *Clear KML paths* to delete it. Then, press the **Reset simulation** button to apply the changes to the launching site parameters. Also, press the **Follow** button and select *Tactic* to have a better view of the launching site.
- Press the button in the *Setup* panel to show the *Trajectory editor* and select the *Balloon trajectory* mode. Enter the balloon burst altitude in the **Burst** text box. If no burst altitude is specified, a 32,000 meters altitude will be used as default. Enter "0" to indicate that there is no burst. Also, enter the balloon ascent rate in the **Ascent** text box. If no ascent rate is specified, a 5 m/s rate will be used as default.

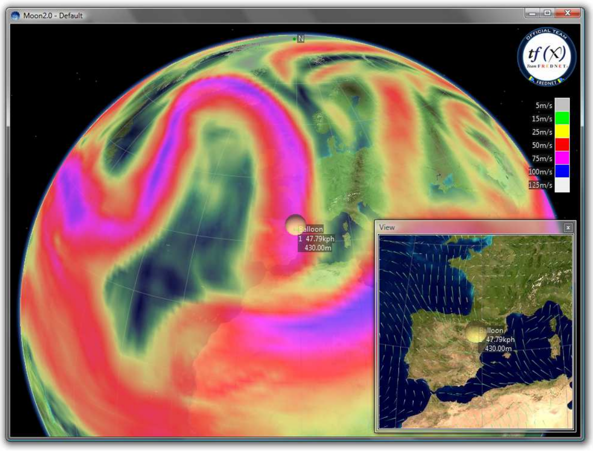


- The last parameter needed for the trajectory prediction is the terminal velocity at sea level when the balloon explodes at the burst altitude and falls down. Enter this parameter in the **Descent** text box. This parameter is determined mainly by the size of the parachute used and the mass of the balloon and the payload. The terminal velocity of any object that is not designed to slow down the falling speed is about 50 to 70 m/s. But the balloon itself can slow down the speed up to 25 m/s after it bursts. If no terminal velocity is specified, a 5 m/s velocity will be used as default. The following table can be used to calculate the terminal velocity at sea level using the payload mass and the parachute diameter:

Parachute Payload	0.5 m	0.75 m	1.0 m	1.5 m	2.0 m
100 g	2.9 m/s	1.9 m/s	1.4 m/s	1.0 m/s	0.7 m/s
200 g	4.0 m/s	2.7 m/s	2.0 m/s	1.3 m/s	1.0 m/s
500 g	6.4 m/s	4.3 m/s	3.2 m/s	2.1 m/s	1.6 m/s
750 g	7.8 m/s	5.2 m/s	3.9 m/s	2.6 m/s	2.0 m/s
1,000 g	9.0 m/s	6.0 m/s	4.5 m/s	3.0 m/s	2.3 m/s
1,500 g	11.1 m/s	7.4 m/s	5.5 m/s	3.7 m/s	2.8 m/s
2,000 g	12.8 m/s	8.5 m/s	6.4 m/s	4.3 m/s	3.2 m/s
3,000 g	15.6 m/s	10.4 m/s	7.8 m/s	5.2 m/s	3.9 m/s
4,000 g	18.1 m/s	12.0 m/s	9.0 m/s	6.0 m/s	4.5 m/s
5,000 g	20.2 m/s	13.5 m/s	10.1 m/s	6.7 m/s	5.0 m/s

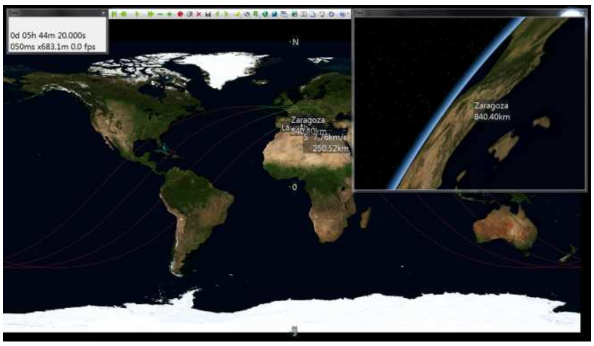
- The algorithm for the balloon trajectory prediction uses an atmospheric model to determine the parameters of the atmosphere at every point of the trajectory. These parameters change constantly every day so they should be updated as frequently as possible. The atmospheric model can also calculate the weather forecast up to 8 days in the future with a 3 hours step. To update the model, press the **Path** button and select the *Update atmosphere* option. The file of the model for the selected date and time will be downloaded from the server. If a file for the same date and time was downloaded before, a dialog box will prompt for overwriting the file. Do this only if the file was downloaded using the forecast feature. In this way, the old file can be replaced with a better forecast for the model.

- In a balloon trajectory there are two elements that are very important: the wind speed at the ground level and the wind speed and direction at the upper layers of the atmosphere. The *Atmosphere* tool is useful to measure the wind speed at any atmosphere layer. Press the **Tools** button and select the *Atmosphere* check box. Then, press the **Options** tab and activate the *Wind speed layer* or the *Wind speed vectors* options. The layer can be selected with the *Atmosphere layer* option. The wind speed at the ground level is shown in the picture as colored vectors in the small window and the wind speed at the 250 millibar atmosphere layer is shown in the main window. The colors of the vectors indicate the speed of the wind: white and green for a low speed wind, yellow for a medium speed wind and red, magenta and blue for a high speed wind.



- A high altitude balloon is designed to minimize its weight and this makes it very fragile. Medium or high wind speeds of more than 10 m/s, can make the balloon explode before it can be released. Also, the wind at upper layers of the atmosphere is important to determine the direction and the distance of the balloon trajectory. Usually, the winds with higher speeds are located at an altitude of about 10 km in the 250 millibar atmosphere layer. In this layer, high speed winds called jet streams, with a speed of more than 50 m/s, can make the balloon travel long distances in a short period of time. To minimize this effect, the balloon ascent rate must be higher than 5 m/s and the descent rate must not be lower than 5 m/s. This will reduce the time that the balloon is exposed to high speed winds. This video is an example of a balloon traveling 700 km due to jet streams: http://www.youtube.com/watch?v=wx5e9T5cAuA
- Finally, press the *Calculate* button in the *Trajectory editor* to calculate the trajectory. The path will be shown in the 3D viewer and the launching point of the current preset will be set at the balloon burst point. The trajectory will be also saved as a KML file with the same name as the current preset. Press **F4** to show the *Graph* panel and see detailed information about all the parameters in the trajectory. These parameters can be saved in a CSV format file using the context menu of the panel.

TUTORIALS — **Onboard sensor**



This is the procedure to install a sensor onboard the satellite. This sensor will follow a ground station or a planet if the *Tools→Stations* tool is activated and the proper group of stations is chosen in *Options→Station network* option. This option can be seen by selecting the *Onboard sensor* option in the *Panels* sub-menu and selecting the proper sensor in *Options→Sensor* option:

- Add your sensor in the "Sensors.lst" file in the *Sensors* folder. Each line contains comma separated parameters like: Trade mark and model, Lens type [inches], Horizontal FOV [degrees], Width [pixels], Height [pixels], Zoom, Web link
- Add your group of ground stations or target points in the "Stations.cvs" file inside the *Stations* folder. Each line contains comma separated parameters like: Group, Point name, Latitude [degrees], Longitude [degrees], Altitude [meters].
- In this example, select in *Options→Station network* the group of stations called *ARAGON*.
- Activate the *Tools→Stations* tool.
- In this example, select in *Options→Sensor* the *TOSHIBA TCM8230MD* camera sensor.
- Activate the *Onboard sensor* option in *Panels* sub-menu.
- In order to hide the labels, unselect the *Tools→Sensor→Labels* tool.

Every sensor comes with a default lens specified in the "Sensors.lst" file, but this lens can be replaced by one of the lenses listed in the "Lenses.lst" file inside the *Sensors* folder. This file contains comma separated parameters like: Trade mark and model, Lens type [inches], Focal length [millimeters], FNO (Brightness), Horizontal FOV [degrees], Vertical FOV [degrees], Web link. To replace the sensor lens, select it in the *Options→Lens* option. Be aware that only lenses that match the sensor lens type can be used for that sensor.

Notice that this is a realistic simulation of the sensor view and the size of the window can not be changed. The texture quality can improve the sensor accuracy up to a limit. For best performance, the 3D terrain model can be activated in *Tools→Terrain*. For every ground station in range, the distance to the station and the elevation angle will be shown near the station label. Also, the field of view of the sensor and the ground projection will be shown in the main 3D viewer. The sensor window in *Follow mode→Onboard* will show information about the sensor resolution at the bottom of the view if both *Tools→Sensor→FOV projection* and *Tools→Sensor→Labels* options are activated. This information shows the covered area size and the pixel size (in meters per pixel or feet per pixel) of this particular sensor projection at the distance over any surface in the planet. This tool is useful to know the picture resolution of each pixel when a satellite is mapping the surface of a planet. All these elements can be deactivated with the *Tools→Sensor* option so that the image is as close as possible to the sensor view.

An example of a sensor based on a 1.3 Mpix camera for the "Sensors.lst" file:

```
TOSHIBA TCM8230MD,0.1666667,57.4,660,492,1,
http://www.sparkfun.com/datasheets/Sensors/Imaging/TCM823
0MD.pdf
```

An example of a ground station located at Zaragoza (Spain) for the "Stations.csv" file:

```
ARAGON,Zaragoza,41.65,-0.883333,263
```

A predefined list of ground stations can be defined in the *Setup* panel so the attitude control of the satellite can use them as targets. It is sorted by priority, where the first ground stations have higher priority over the last ones. In this way, when more than one ground station become available, the satellite will point to the one that has the highest priority. This list will be saved with the current preset.

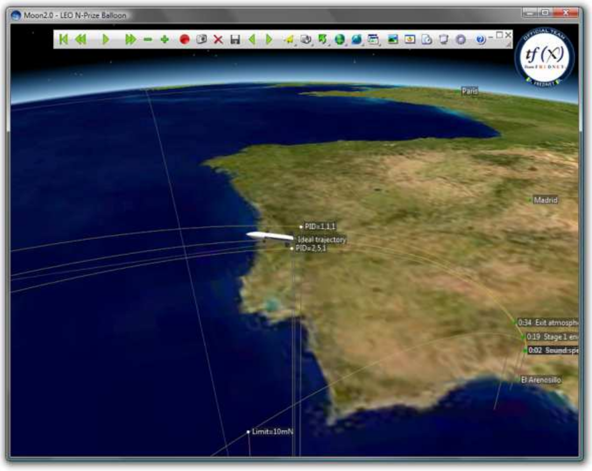
To define a target list, press the button in the *Setup* panel to show the extended mission parameters and the button to activate the target list. The *Search* panel will be shown. In this panel the ground stations can be searched by typing in the text box any word that matches the name of the ground stations or the name of their group. In this example, type "wikisat" to show all the ground stations of this group in the list. Select all the items in this list by using the context menu and selecting the *Select all* option. In the *Setup* panel, press the + button to add all the selected items to the target list. Also, you can drag and drop the items from one list to another.

Next, in the *Search* panel, type "aragon" to show the ground station "Zaragoza" that was defined before and add it to the target list. This item will be placed in the last position of the list, but it must have the highest priority. To do this, select it in the target list and press the button to move it to the first position in the list. Finally, type "nasa dsn" in the *Search* panel to show all the ground stations of this group and add them to the target list.

There is a video available in http://www.youtube.com/watch?v=yybJAlJhym4

TUTORIALS — **Attitude control**

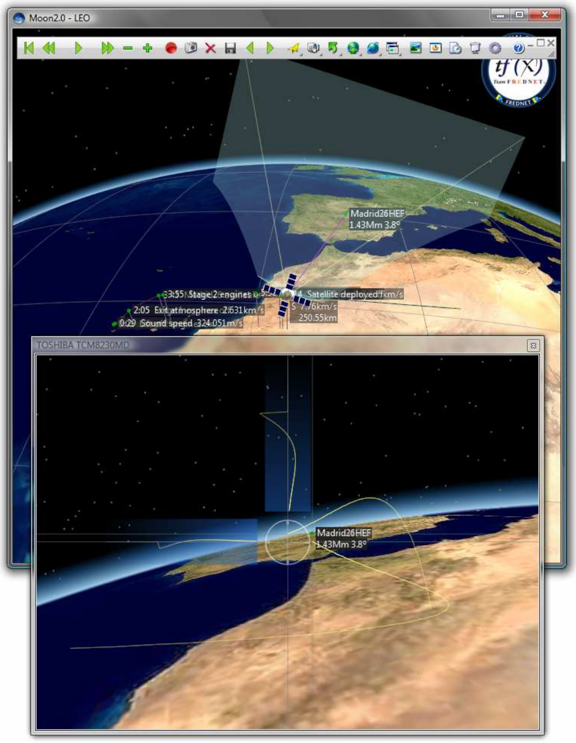
Attitude control is simulated during each stage burn to control the trajectory and in flight when the satellite is deployed to follow any ground station on the ground. The default software algorithm includes a PID module to simplify the design related to the attitude control subsystem. The PID module simulates the actual attitude control system on board the launcher. This allows tune up the control system to obtain an optimum control, and determine how attitude changes affect the final trajectory. A different PID controller can be defined for each stage. The control parameters are the control force and the PID gains, which can be adjusted in the stage parameters panel, accessed from the *Stages* panel by clicking the lower right arrow button. Then the stage is selected by clicking over the desired one in the *Stages* panel.



The control force is unlimited by default, but a thrust limit can be imposed to simulate the system constraints. Also a magnetorquer based system can be simulated for the satellite control. The PID has three gains: proportional, integral and derivative. An increase in the proportional gain reduces the overshot and the settling time (stabilization time). The integral gain accelerates the speed of the response and reduces the number of oscillations. The derivative gain reduces the overshot but also the response velocity. Too high or low values of any gain can destabilize the system or produce undesired responses.

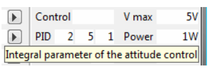
For example, in the *LEO N-Prize Balloon* preset, if the initial launch angle is set to 90º and the start and final angles to 30º, it requires from the control system a fast change of 60º in the attitude angle. Setting all the gains to 1, the initial overshot is about 8º, and the oscillations are very slowly damped. If the gains are set to 2, 5 and 1 respectively, the overshot is reduced to 4º, only two oscillations are performed and the launcher is stabilized at the correct angle in only 25 seconds. Attending to the control force, if it is limited to 10 mN, and the previous simulation is repeated, the overshot grows to 24º, and the launcher reach its final attitude angle in 31 seconds after two oscillations. Finally, if the control algorithm is disabled with the option *Simulation→Trajectory control*, the *ideal trajectory* can be calculated and compared with the *real trajectories* to determine which is closest to the ideal.

If the previous simulations are repeated with the end angle set to 0º, in no case the satellite is finally injected into orbit, but it can be seen how the trajectory is very dependent on the design of the control system as the apogee achieved are 463.3 km, 436.1 km and 255.2 km respectively.



Deviation and *Trace* are two visual tools available for the satellite control optimization. *Deviation* are two yellow lines over a blue background located at the upper and left sides of the sensor window. It shows graphically the relative angle between where the satellite is pointing and the point it should track, like a ground station, a planet, a star or the center of the Earth. The longitudinal and lateral deviation allow see the satellite's oscillations and responses in both X and Y axes to tune up the attitude control system accordingly. *Trace* are two yellow lines located at the right and bottom sides of the window. It works in the same way as *Deviation* showing the distance in the View panel from the point of view to the objective, which is affected by the satellite's roll. One or both of these tools can be activated with the option *Tools→Sensor→Deviation/Trace*. To visualize them, select the option *Panels→Onboard sensor* to show the sensor window.

As an example, in the *LEO* preset the control limit is set to 0.1 Am², which is a typical value for small magnetorquers. Also, the visibility angle for the ground stations is set to 0º. After the launch, the satellite starts the movement to point to *Madrid26 Ground Station* at 6 min 14.7 sec. After some oscillations the satellite finally points to the ground station at 6 min 40 sec. Using the *Deviation* tool, it is seen that the longitudinal axes stabilizes before than the lateral axes. The *Trace* tool allows determine when the system is completely stabilized. In this case the PID gains were as default 2, 5 and 1. If they are changed to 3, 5 and 2 respectively, the number of oscillations and their amplitude are reduced, and a smaller settling time of 6 min 37 sec is achieved.



PID controller basics

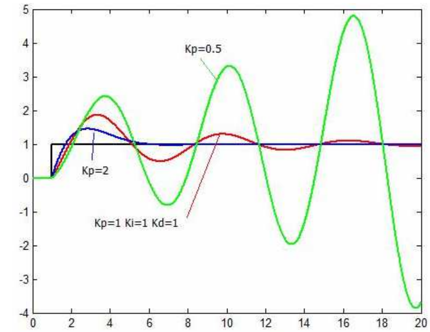
The PID controller algorithm involves three separate constant parameters: the proportional, the integral and derivative values, denoted **P**, **I**, and **D**. These values can be interpreted in terms of time: **P** depends on the present error, **I** on the accumulation of past errors, and **D** is a prediction of future errors, based on current rate of change. The proportional, integral, and derivative terms are summed to calculate the output of the PID controller. Defining **u(t)** as the controller output, the final form of the PID algorithm is:

$$\mathrm{u(t)} = \mathrm{MV(t)} = K_p e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{d}{dt} e(t)$$

where the tuning parameters are:

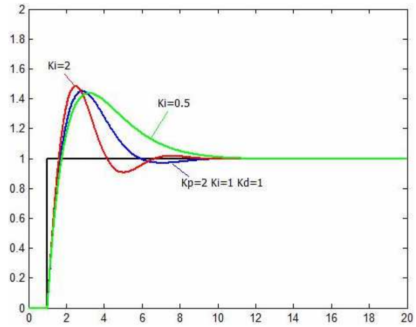
Proportional gain, Kp

Larger values typically mean faster response since the larger the error, the larger the proportional term compensation. An excessively large proportional gain will lead to process instability and oscillation.



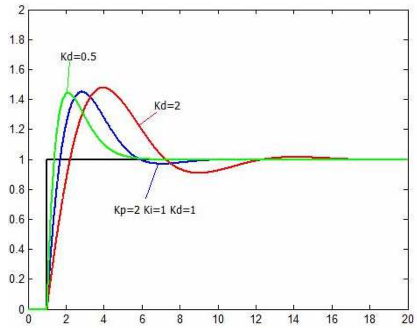
Integral gain, Ki

Larger values imply steady state errors are eliminated more quickly. The trade-off is larger overshoot: any negative error integrated during transient response must be integrated away by positive error before reaching steady state.



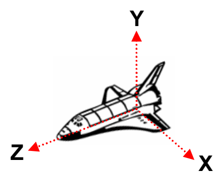
Derivative gain, Kd

Larger values decrease overshoot, but slow down transient response and may lead to instability due to signal noise amplification in the differentiation of the error.



Spacecraft coordinate system

These are the spacecraft rotation axes used in the simulator for the stages or payload design parameters and the calculations of the angular velocities and accelerations. *Pitch* corresponds to a rotation around **X** axis, *Yaw* around **Y** axis and *Roll* around **Z** axis. The origin of the axes is located at the center of mass of the spacecraft.

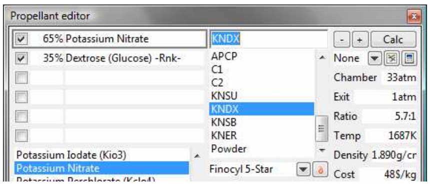


TUTORIALS — Thrust curve calculation

This is the procedure to calculate the thrust curve of an engine that uses solid propellant and generate a custom engine file that will be used later in a trajectory simulation. In this example, the parameters of the "KNDX" burn preset will be used. This preset defines a small rocket using a low performance propellant composed by potassium nitrate and dextrose (KNDX). These are the basic parameters of the rocket:

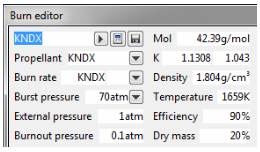
• Motor casing size:	110 x 62.4 mm (cylinder)
• Propellant size:	100 x 60 mm
• Propellant core size:	100 x 18 mm
• Propellant geometry:	Core burner (both ends exposed)
• Propellant type:	KNDX (65% Potassium Nitrate / 35% Dextrose)
• Nozzle throat / exit:	6.8 / 23.5 mm (12:1 expansion ratio)
• Maximum pressure:	70 atm
• Ambient pressure:	1 atm

Press **F7** to show the *Propellant editor* and select *KNDX* in the propellant list. This propellant uses 2 components: 65% of *Potassium Nitrate* and 35% of *Dextrose*.



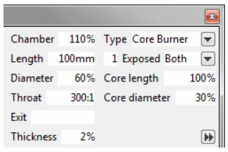
This is a typical mixing ratio of the two components but it can be modified to obtain a different propellant performance or combustion temperature. Check the mixing ratio and change it if necessary. Then, press the *Calc* button to recalculate the propellant parameters and the [+] button to save the changes. Once the propellant composition is adjusted, click the button or press **Ctrl+Shift+F7** to show the *Burn editor* and calculate the thrust curve.

Press the button at the top of the panel to show the *Preset* menu and select the *KNDX* burn preset. All the parameters of the propellant and the engine will be updated. Now select *KNDX* in the *Propellant* list to update the propellant parameters if they were modified in the previous step. Note that if the propellant is modified again in the *Propellant editor*, the parameters in the *Burn editor* will be automatically updated. All these parameters have an effect on the heat and the pressure of the gas that is generated when the propellant burns in the combustion chamber. This energy will be converted in thrust when the gas is accelerated through the nozzle. See more information about the calculation of the solid propellant performance at *Richard Nakka's Experimental Rocketry*[22]. These are the parameters related to the propellant performance:



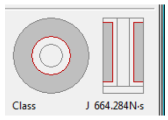
- **Burn rate:** Linear combustion rate of the propellant when it burns. It can not be calculated by the chemical simulator and must be obtained by empirical methods. This parameter is composed by two elements, **a** and **n** that define the burn rate as a function of the combustion chamber pressure. The **a** parameter is the burn rate at standard atmosphere pressure. The **n** parameter is optional and represents the exponent in the formula: *Burn rate* = **a** · *Pressure*[atm] ^ **n**. Also, press the button to select a predefined burn rate curve. In this example, the KNDX burn rate curve will be used. This curve determines the propellant burn rate as a function of the combustion chamber pressure. It is defined in a BRN format file located at the *Engines* folder. This file contains a list of pressure ranges in MPa followed by the corresponding **a** and **n** parameters used in the formula: *Burn rate*[mm/s] = **a** · *Pressure*[MPa] ^ **n**.
- **Mol:** Effective molar mass of the propellant components. This is calculated by the chemical simulator but can be corrected manually.
- **K:** Ratio of specific heats of the propellant. The first parameter is related to the gas in the combustion chamber and is calculated by the chemical simulator. The second parameter is optional and is related to the nozzle exhaust gas and the calculation of the thrust. This is only required for a two phase flow of the gas in the nozzle. This happens when the exhaust gas contains small solid particles that decrease the overall acceleration of the gas at the nozzle exit.
- **Density:** Density of the propellant. This is calculated by the chemical simulator but can be adjusted depending on the propellant preparation.
- **Temperature:** Temperature of the combustion chamber. This is calculated by the chemical simulator but can be corrected manually.

The next step will be to define the size of the engine and the propellant. All the parameters related to the sizes can be defined as a percent ratio. In this way, the rocket can easily be scaled by changing only the total length or the propellant length. Basically, a rocket launcher is composed of motor casing, propellant, combustion chamber and nozzle. When solid propellant is used, the motor casing and the combustion chamber are usually the same and the propellant is contained in it. In this example, the propellant is contained in a cylinder of 110 mm length and 60 mm inner diameter that will be used as a combustion chamber. It is recommended to leave a small distance between the end of the propellant and the nozzle. This area will work as an expansion chamber to absorb small pressure peaks due to small bubbles in the propellant grain. In this case, the distance will be 10 mm, so the propellant length is 100 mm. Enter these parameters in the text boxes:



- **Chamber:** Length of the combustion chamber. It can be specified as a percent ratio of the propellant length. Also, the volume of the combustion chamber can be specified together with the propellant diameter so it can be calculated. In this case, 110 mm is defined or 110% can also be used.
- **Length:** Length of the propellant. It can be specified as a percent ratio of the motor chamber length. Also, the volume or the mass of the propellant can be specified together with the propellant diameter so it can be calculated. In this case, 100 mm length is defined.
- **Diameter:** Diameter of the propellant. It can be specified as a percent ratio of the propellant length. Also, the volume or the mass of the propellant can be specified together with the propellant length so it can be calculated. In this case, 60 mm is defined or 60% can also be used.

Now the geometry of the propellant must be specified. This will determine the way in which the propellant is burned. In this example, the *Core Burner* geometry with both propellant ends exposed to burning has been selected. This geometry produces almost a linear thrust curve while maintaining the combustion chamber walls protected from heat. It is interesting to know that the configuration with only the nozzle end exposed is easier to build. But despite this, it has the problem that the propellant is asymmetrically exposed to the pressure and may fracture, resulting in a catastrophic explosion. This will also apply to the *Star Burner* geometry. On the other hand, the *End Burner* geometry does not have this asymmetric problem and produces a more linear thrust curve but the chamber walls are more exposed to the high temperature of the combustion. The propellant core is the part of the propellant that has been removed to increase the burning area. In this case, the core is defined as a cylinder of 18 mm diameter and the full length of the propellant to expose both ends of the propellant to burning. Enter the propellant core sizes and geometry in the text boxes:



- **Type:** Geometry of the propellant core. *Core Burner* defines the core as a cylinder centered in the propellant. The propellant burns from inside until the burning reaches the chamber walls. *Star Burner* is equivalent to *Core Burner* but it adds some fins to the propellant core to increase the burn rate. Finally, *End Burner* is defined by a simple cylinder without any core. The propellant burns from the end near the nozzle to the opposite side. When this geometry is used, the parameters of the core are not available.
- **Segments:** Number of segments in which the propellant is divided. This is used to increase the exposed area and produce a more linear thrust curve but in this example a single segment will be used.
- **Exposed:** Ends of the propellant that are exposed to burning. This can be *None*, *Nozzle* end and *Both* ends. Exposing both ends produces a more linear thrust curve. In this case, both ends are exposed.
- **Core length:** Length of the propellant core. This can be from zero to the full length of the propellant and it can be also specified as a percent ratio of the propellant length. It must be 100% when multi-segment or both ends exposed options are used. In this example, the full length of the propellant is used. That is, 100 mm length or 100% can also be specified.
- **Core diameter:** Diameter of the propellant core. This can be from zero to near the diameter of the propellant. Large core diameters produce more linear thrust curves but reduce the volume of the combustion chamber used by the propellant. In this example, a core of 18 mm diameter is specified or 30% of the propellant diameter can also be used.
- **Number of fins:** Number of fins in the *Star Burner* geometry. Increasing this number will accelerate the propellant burning. Enter a value of 1 to simulate a *C-Slot* geometry. This parameter is not used in this example.
- **Fin depth:** Length of the fins in the *Star Burner* geometry. This can be from zero to the radius of the propellant. Large values will produce a faster burning at the beginning while reducing the burn rate at the end. This parameter is not used in this example.
- **Fin width:** Width of the fins in the *Star Burner* geometry. Typical values range from almost zero to the radius of the propellant core. This parameter has a minor effect on the burn rate and it is often defined by the propellant mixing procedure. This parameter is not used in this example.

Finally, the parameters of the nozzle will be defined. The nozzle is an important part of a rocket because it converts the pressure of the gas in the combustion chamber to an acceleration of this gas and finally thrust. The shape of the nozzle is a key parameter in the thrust efficiency. The nozzle is defined by three parameters: the throat diameter, the exit diameter and the length. As described in this *article*[23] about nozzle design, a simple shape of a cone of 12º internal angle has a good efficiency. Better efficiency can be achieved by using a more complex shape, such a *Bell nozzle*. In the simulation, the nozzle length is not used because the algorithm does not calculate the complex flow of the exhaust gas. But an approximation can be obtained when the 12º angle of the cone is applied to the shape. The ratio of the throat area to the exit area is called *nozzle expansion ratio*. This parameter is important because it must be calculated so that the pressure of the exhaust gas is equal to the pressure outside the rocket. If the exit pressure is higher, the nozzle is *underexpanded* and part of the thrust is lost. If the exit pressure is lower, the nozzle is *overexpanded* and the exhaust gas flow is unstable so it may cause the nozzle to break. To help calculating this ratio, the nozzle *Exit* parameter in the text box can be left blank. In this way, the simulator calculates the ideal expansion ratio

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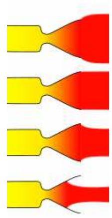


OVEREXPANDED

[22] Richard Nakka's Experimental Rocketry
http://www.nakka-rocketry.net/techs.html

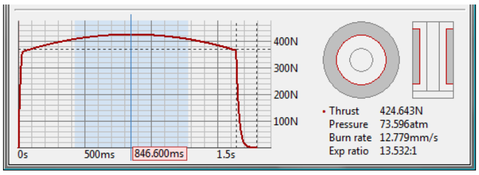
[23] Rocket engine nozzle
http://en.wikipedia.org/wiki/Rocket_engine_nozzle

at every point on the thrust curve and it can be seen in the thrust graph that will be generated later. Also, if the nozzle is highly overexpanded or the combustion pressure is very low, it can produce negative thrust. This will be shown in the graph as a red background. Note that a nozzle designed to work in vacuum will always be underexpanded because it can not expand to an infinite size. More information about nozzle design and thrust calculation can be found in this *NASA web page*[24]. The optimal nozzle parameters can also be calculated by pressing the button. In this example, a nozzle of 6.8 mm throat diameter and 23.5 mm exit diameter will be used. This corresponds to a 12:1 expansion ratio. The nozzle is designed so it has an efficiency of 90%. Enter the nozzle sizes and efficiency in the text boxes:

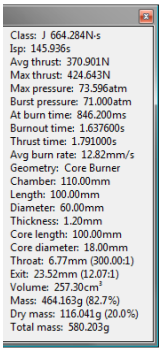
- **Throat:** Diameter of the nozzle throat. Also, it can be defined as a nozzle throat area to propellant burning area ratio. Typical values goes from 50:1 for a high performance propellant or high burn rates to 300:1 for a low performance propellant or low burn rates. In this example, 6.8 mm diameter is specified or a 300:1 ratio can also be used.
- **Exit:** Diameter of the nozzle exit. This can also be defined as a nozzle throat area to nozzle expansion area. Typical values goes from 3:1 for a low combustion chamber pressure and atmospheric external pressure to 10:1 for a high chamber pressure or 50:1 for a high chamber pressure and vacuum as external pressure. This parameter can be left blank so the simulator calculates the ideal nozzle expansion ratio at every point on the thrust curve. In this example, 23.5 mm diameter is defined or a 12:1 ratio can also be used.
- **Efficiency:** Efficiency of the nozzle. A value of 85% is typical for a low efficiency nozzle. Higher efficiency of 95% or above can be achieved with advanced nozzle shapes. In this case, an efficiency of 90% is defined.

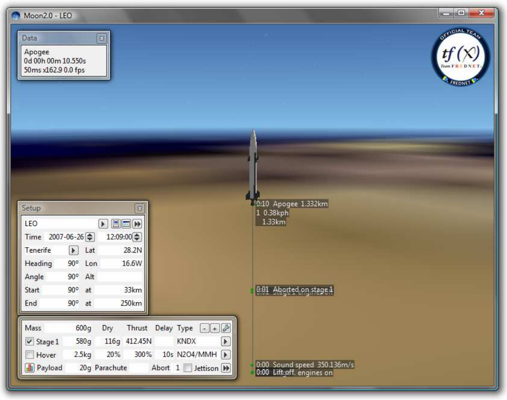
Some additional parameters like the combustion chamber mass and thickness, the external pressure or the end of thrust pressure will be defined. In this example, the cylinder that contains the propellant has an outer diameter of 62.4 mm, so the thickness of the walls is 1.2 mm. The dry mass of the rocket is 116 g. The dry mass is the mass of all materials without the propellant mass. This includes the combustion chamber, the nozzle and any material that does not burn in the combustion like the material that protects the chamber walls from the combustion heat. It also must include other components of the rocket like attitude control, thermal shield, parachute, etc. The maximum pressure that the cylinder can resist is 70 atm. We know the thickness of the cylinder walls so we can let the simulator calculate this pressure by specifying the maximum stress of the material. Also, the material density can be specified in the dry mass parameter so the mass of the cylinder can be calculated. Finally, the rocket is designed to work at standard atmospheric pressure, so the external pressure is 1 atm. The pressure gauge that determines the end of the thrust is 0.1 atm. Enter these parameters in the text boxes:

- **Thickness:** Thickness of the combustion chamber walls. This can also be specified as a percent ratio of the propellant diameter. In this case, 1.2 mm is defined or 2% can also be used.
- **Dry mass:** Dry mass of the engine (without the propellant mass). This can be specified as a percent ratio of the total mass. Also, the density of the combustion chamber material can be specified together with the thickness, so the mass can be calculated. In this example, a dry mass of 116 g is specified or 20% can also be used.
- **Burst pressure:** Motor chamber burst pressure. This is the maximum pressure that the motor chamber can resist. Also, the maximum stress of the material can be specified together with the thickness so the maximum pressure can be calculated. Press the button to select the maximum stress and density parameters from a list of common materials. This list is defined in the "Materials.lst" file at the *Engines* folder. In this example, a burst pressure of 70 atm is defined.
- **External pressure:** Pressure outside the motor chamber. This parameter is important in the design of the nozzle expansion ratio. In this example, a standard atmospheric pressure will be used so this will be 1 atm.
- **Burnout pressure:** The pressure gauge that determines the end of the thrust. This is used to stop the simulation at the point where the thrust generated is too low to be useful. In this case, 0.1 atm is defined.

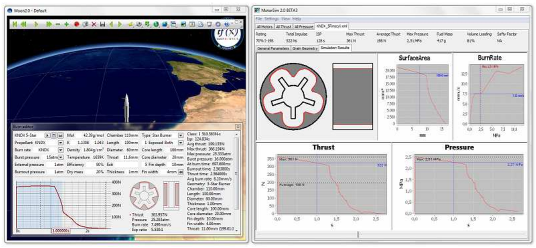


At this point all the parameters of the simulation are defined. Press **Enter** to start the simulation and calculate the thrust curve. The graph and the cross and longitudinal sections of the propellant will be updated. Press the button to show extended information about the engine specifications. There are some parameters related to the engine performance and the thrust curve like *Class*, *Isp*, *Maximum thrust* and *Burnout time*. Other parameters are related to the engine, nozzle and propellant sizes, the mass and the propellant core geometry. This information is useful if any parameter was specified as a percent ratio, mass, volume, density or material stress. The simulator will calculate the parameter and it will be shown here. Also, the propellant mass, volume and total mass will be calculated. In this example, note that the maximum pressure of 73.6 atm is higher than the selected chamber burst pressure. This is shown in the graph as a blue background. To correct this, select the *Aluminum alloy* option in the *Pressure* text box to recalculate the graph. This material increases the chamber burst pressure to 159 atm. This is high enough to resist the maximum pressure generated. Move the mouse pointer over the graph to show all the parameters and the propellant burn progress at a specific burn time. Right click on it to access the context menu and switch the parameter that will be shown in the graph. If the nozzle *Exit* parameter was left blank, select *Expansion ratio* in the context menu to show the ideal expansion ratio at every point of the thrust curve. The average expansion ratio will be shown in the extended information.



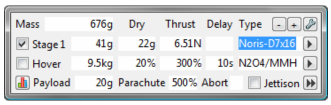


The last step is to generate a custom engine in ENG file format so it can be used in a trajectory simulation. Press the button near the *Preset* text box to save the curve as a custom engine. Now this engine can be used in a trajectory simulation. To test the engine, press the **Preset** button in the Toolbar and select the *LEO* preset. In the *Stages* panel, press the button to deactivate the *Stage 2*. Press the button in the *Type* text box of the *Stage 1* and select the *KNDX* custom engine from the list to update the parameters of the *Stage 1* with the engine calculated before. The *LEO* preset is designed to put a satellite in orbit and the spacecraft trajectory must perform a curve to reach the orbital speed. In this case, a vertical trajectory will be used because the total impulse of the small rocket will not be high enough to exit the atmosphere. Change the trajectory angles in the *Start* and *End* text boxes of the *Setup* panel to a 90º angle. To start the trajectory simulation, press the **Play** button in the Toolbar. The small rocket will reach an apogee of about 1 km and a maximum speed of Mach 1 at burnout in only 1.5 seconds. Note that if the custom engine is modified in the *Burn editor* and saved to a file, the parameters of the engine in the *Stages* panel will be automatically updated.

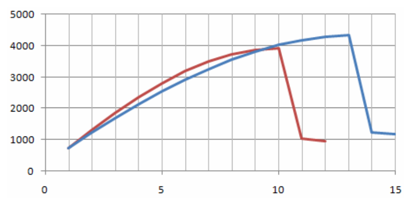


The *Burn editor* has been compared with the *MotorSim 2.0*[25] simulator using a *Finocyl 5-Star* geometry. There are small differences because *MotorSim* does not calculate the efficiency loss when the nozzle is overexpanded.

TUTORIALS — Multistage



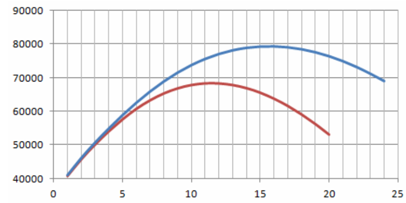
The *LEO Multistage Balloon* preset is an example of a multistage launcher using the small Noris Raketen D7 custom engine. Only one "Noris-D7" stage is defined but it is repeated one or more times to find the optimal number of stages. The string "xN" is added to the stage *Type* in the *Stages* panel to emulate a multistage of "N" components.



[24] NASA - Rocket thrust equations
http://www.grc.nasa.gov/WWW/K-12/rocket/rktthsum.html

[25] MotorSim 2.0 rocket motor simulator
http://content.billkuker.com/projects/rocketry/software/motorsim-2-0

Starting from one stage and adding more, the apogee altitude increases until the total mass is too high for the thrust of a single stage. Then the overall performance decreases to a point where the first stage can not lift off. The first example shows the apogee altitude reached using a multistage of 1 to 15 "Noris-D7" components and starting at ground level. The red graph is calculated using 1 second of inter-stage delay. The blue graph is calculated without using delay. The highest altitude of about 4 km is achieved using 13 stages with no inter-stage delay.



The same simulation is repeated but this time starting at 35 km of altitude. The maximum apogee of 79 km is achieved using 16 stages with no delay.

TUTORIALS — Custom engines

RASP was the original rocket flight simulator, started by the model rocket pioneer G. Harry Stine. Many iterations later, it is still in use as wRASP. It reads motor data from text files with the ".ENG" extension. This format, named "RASP" or "ENG", has become the standard for motor data interchange. This simulator can read the RASP ENG file format and use it as a custom stage engine. Put the .ENG file inside the *Engines* folder and select it in the *Type* drop-down box of any stage in the *Stages* panel. This is a description of the file format taken from the *ThrustCurve*[26] web site.

The Header Line

Blank lines and lines beginning with semicolons are ignored at the beginning of the entry. The first line interpreted is the "header line", which contains info on the motor itself. The header contains seven pieces of info, separated by spaces. All seven must be present for the entry to be read successfully. Here's a sample fragment, with a few comments and the header line:

```
; Rocketvision F32
; from NAR data sheet updated 11/2000
; created by John Coker 5/2006
F32 24 124 5-10-15 .0377 .0695 RV
```

1. motor name
2. diameter
3. length
4. delays
5. prop. weight
6. total weight
7. manufacturer

1. **Motor name.** This is the common name of the motor, as you would like to see it listed in your simulator program.
2. **Diameter.** This is the casing diameter in millimeters (mm).
3. **Length:** This is the casing length, also in millimeters (mm).
4. **Delays.** This is the list of available delays, separated by dashes. If the motor has an ejection charge but no delay use "0" and if it has no ejection charge at all use "P" (plugged).
5. **Propellant weight.** The weight of all consumables in the motor. For solid motors this is simply the propellant itself, but for hybrids it is the fuel grain(s) plus the oxidizer (such as N_2O). This weight is expressed in kilograms (kg).
6. **Total weight.** The weight of the motor loaded and ready for flight, also in kilograms (kg).
7. **Manufacturer.** The motor manufacturer abbreviated to a few letters. NAR maintains a list of manufacturer abbreviations in the combined master list. This list is available in PDF format at: http://nar.org/SandT/pdf/CombinedList.pdf

Data Points

Starting immediately after the header line, the remaining lines contain sample data points. Each sample specifies a time in seconds (s) and a thrust in Newtons (N) as two floating-point numbers, separated by spaces and usually preceded by a few spaces for readability.

```
; Rocketvision F32
; from NAR data sheet updated 11/2000
; created by John Coker 5/2006
F32 24 124 5-10-15 .0377 .0695 RV
   0.01 50
   0.05 56
   0.10 48
   2.00 24
   2.20 19
   2.24  5
   2.72  0
;
```

An implicit first point at 0,0 is assumed and should not be specified explicitly. The final point must have a thrust of zero and it indicates the motor's burn time. The points should be in increasing order of time and the thrusts should trace out the thrust curve as representatively as possible. After the final data point, the entry may contain comments and blank lines, but nothing else.

[26] RASP ENG file format http://www.thrustcurve.org/raspformat.shtml

TUTORIALS — Low-cost access to space

This tutorial shows how to use the *Trajectory editor* in order to design a launcher capable of injecting a femto-satellite with a mass of 100 grams or less into a 250 km LEO orbit. This tutorial will show how the total mass will grow with the payload mass but also the mission time will be increased.

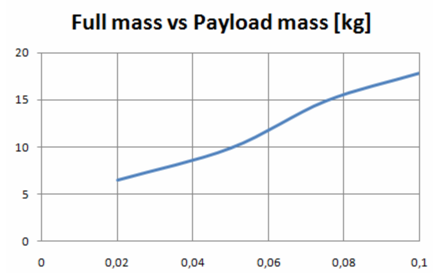
Nowadays, the access to the space is very limited by the available launchers of the space agencies that are focused on heavy payloads for few tons. There is a need of lighter, quicker and cheaper launching method for small payloads. This simulator is contributing to the low-cost access to space with a project called *QuickFAST*, an European platform to provide independent access to space. In the list of mission presets we have included three cases inside the category of femto-satellite payloads: 20g, 50g and 100g. In this tutorial we will use the *Trajectory editor* to design a quick access to the space for a femto-satellite of 75 grams. The designed orbit will be a circular orbit of 250 km of altitude and an inclination with more than 50 degrees because we want to cover most of Europe territory. This inclination demands for extra propellant since the desired launching place is the **#GranCanariaSpaceport**.

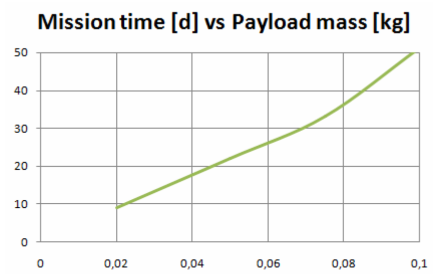
As an example of how to automatically calculate a LEO trajectory for a small payload of 75g we will use the *LEO QuickFAST 50g* preset. These are the basic parameters of the mission:

- Launching site coordinates: Las Palmas: 28.2696ºN, 16.6427ºW
- Orbital altitude: 250 km
- Orbital period: 89 minutes 30 seconds
- Initial heading: 40º
- Number of stages and propellant: 2 stages, C1-C2
- Payload mass: 75 g

Press the **Preset** button in the *Toolbar* and select the *LEO QuickFAST 50g* preset to load the mission parameters. Change the *Payload* mass in the *Stages* panel to 75g. The rest of the parameters, like the trajectory *Heading* in the *Setup* panel or the number of stages and propellant in the *Stages* panel are the same in this mission so they do not need to be changed. Now press the button in the *Setup* panel to show the *Trajectory editor* and select the *Low Earth orbit* mode. Enter the desired orbital altitude in the **Orbit** text box, in this case 250km. Press the *Calculate* button to automatically calculate the trajectory. An error message will be shown because the *Mass* and *Thrust* parameters of at least one stage must be variable. This way the simulator can adjust the total size and mass of the launcher to determine the required value. In this example, the *Mass* and *Thrust* parameters of both stages were fixed values so they have been automatically changed to variable values. Review the corrections and press the *Calculate* button again to start the calculation. This time the simulator will calculate the trajectory, adjusting the launcher parameters for a total mass of 14 kg. Now you can press the **Play** button in the *Toolbar* to test the trajectory and calculate the satellite coverage area and the mission time. Also, you can change the preset name to *LEO QuickFAST 75g* and save it to the disk.

The following graphs have been generated using the simulated trajectories of the *LEO QuickFAST 20g*, *50g*, *75g* and *100g* mission presets:





The results show how the total mass will grow with the payload mass from 6 kg for a payload of 20 grams to 18 kg for a payload of 100 grams. In addition, the mission time depends on the payload mass as well from 9 days for a payload of 20 grams to 51 days for a payload of 100 grams. Depending on the femto-satellite mission it should be selected the payload mass for the required duration.

A quick mission where the satellite is only required for few days should be burned as soon as possible to leave the orbit free for another mission. In the opposite, if the event to be observed by the femto-satellite camera is inside a time window or the event lasts for few weeks, it should be required a heavier femto-satellite. It should be taking into account that, since femto-satellites are based on batteries, the larger the mission the shorter number of photos per day can be taken. Otherwise, extra electrical power source will be required such as solar panels. The problem with solar panels is that they reduce the available mass for aboard sensors making difficult to accomplish the low mass requirements for a femto-satellite.

TUTORIALS Report tool

The *Report* tool can be used as a presentation tool to describe a mission or a simulation. It shows the text inside the "Report.txt" file located at the *Logs* folder. The text can be formatted in pages and then navigate through them using the ***Page down*** and ***Page up*** keys.

To activate this tool, click the *Render tools* button and select *Report* or press the ***Ctrl+J*** key. The first page will be shown as an overlay text over the simulation. Because the text is shown behind all the panels, it is recommended to hide all the panels that are not needed for the presentation. Press the ***Page down*** key to go to the next page or the ***Page up*** key to return to the previous one. Also, press the ***Home*** key to go to the first page or the ***End*** key to go to the last one. Press them again to return to the last page.

The text in the "Report.txt" file can be formatted in pages. The character used to split the text in pages is the vertical bar "|". If a line contains a vertical bar it will be treated as a page break and the rest of the line will be ignored. This line can be used as a comment for the page. To change the text font used for this tool, click the *Screen options* button in the *Toolbar* and select the *Report font* option.

To edit the "Report.txt" file, use the *Notepad* panel and select *Edit→Report* in the context menu. The text shown with the *Report* tool will be updated every second to reflect the changes made to the "Report.txt" file from an external editor or another application. But this function will not work if the simulation is paused.

This is a short example of the "Report.txt" file:

```
|Page 1, this line is ignored
REPORT TOOL
This is the text of the first page.
|Page 2, this line is ignored
FORMATTING THE TEXT
The character used for a page break is the vertical bar.
|Last page, this line is ignored
This is the text of the last page.
```

TUTORIALS Sync mode

The *Sync mode* synchronizes the simulation with the real date and time. When this mode is active, use the buttons in the *Toolbar* to change the time speed from real time to 10 years every step. The current scale of time will be shown in the second row of the *Data* panel.

If real time is selected, you can press the **Play** button at any time to deactivate the *Sync mode* and start the simulation at that point. If the time speed is greater than real time, the process can be paused or resumed, moved back and forward or resynchronized with the real time position with the buttons. Note that the *Sync mode* can not be activated when a normal simulation is in progress.

In the *Presets→Demos* menu there are some demo presets that use the *Sync mode*. The "Jupiter moons fly-by" demo will be used as an example of how to use the *Sync mode* and *Follow→Object* features.

Open the **Options** panel by pressing the button in the *Toolbar* and select *Viewer→Deep space* to change the 3D viewer settings to a deep space mission defaults. Also set the *Sun shadow* to *Dark* to show a more realistic shadow for the planets. Select the *Tools* tab in this panel and activate the *Moons* option so the moons of the planets are shown and can be selected. Close the *Options* panel.

Now click with the right button on the 3D viewer to show the context menu and activate the *Sync mode*. The date and time of the simulation will be synchronized with the real time. By default the time speed of this mode is set to real time and is shown in the second row of the *Data* panel as "xReal". Use the buttons in the *Toolbar* to adjust the time speed to "x1 min" and press the **Pause** button to pause the synchronization. Then, in the *Setup* panel, click and drag the buttons on the right side of the *Date* and *Time* text boxes to set the date to "2012-03-12" and the time to "21:00:00" so the planets are moved to the desired position.

Then, press the **Follow** button and select *Jupiter* to move the camera to that planet. Zoom out the camera until the moons of Jupiter can be seen and click on *Europa* to select it. An overlay on the right side of the 3D viewer will show information about the moon. Press the **Follow** button again and this time select *Object*. The camera will move to the moon position and will follow it. Next, zoom in the camera until the moon can be seen well enough and rotate it until Jupiter appears in the background at the right side of the 3D viewer. Finally, press the **Play** button to start the fly-by of the moons around Jupiter.

At any time, use the context menu to deactivate the *Sync mode* or press the **Preset** button and select *Default settings* to restore the default configuration for the 3D viewer.

TUTORIALS Online maps

The *Map* panel can be used to display the most popular online maps like *Google Maps*[27] from Google, *Bing Maps*[28] from Microsoft and some other open-source maps like *OsmaRender* from the *OpenStreetMap*[29] project.

Right click on the map to access the context menu and the map options. In the *Map* sub-menu are listed all the available online maps. Select *Default* to deactivate the online maps. Some maps are designed to be used as an overlay and can be selected using the *Overlay* sub-menu.

To move the map, left click and drag the mouse and use the mouse wheel or the *Zoom* options to zoom in and out. Also, double click with the mouse on any position to move the map to that position and zoom in one level. With the *Full screen* option, the map can be resized to the entire screen. Press **Escape** to exit this mode. You can use the option *Follow mode* to follow the position of the spacecraft in the simulation and the *Show info* option to show or hide the current position and the cursor at the center of the map.

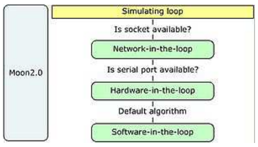
The current position of the map can be changed in the position text box. Click on it, enter the desired latitude and longitude separated by one space and press **Enter**. Also, enter the name of any city or village in the world to use the *Google Maps* search engine and find its coordinates. In this text box, press the arrow button to show the *Locations* menu and go to the desired location. Press the button to open the web browser with the main page of the current online map.

The definition of all the online map services is stored in the "Maps.ini" file located at the *Terrain* folder. The downloaded tiles for the maps will be saved also in the *Terrain* folder, inside a folder with the same name as the map service, for faster access to the map. This feature can be enabled or disabled with the *Download tiles* option in the context menu. Also, use the *Download map* sub-menu to download the visible area of the map from the minimum to the selected zoom level.

[27] Google Maps http://maps.google.com/maps
[28] Bing Maps http://www.bing.com/maps
[29] OpenStreetMap http://www.openstreetmap.org

TUTORIALS — Software-in-the-loop

This simulator has the ability to control the launcher in three ways: *Software-in-the-loop*, *Hardware-in-the-loop* and *Network-in-the-loop*. This is a very powerful tool in order to test any subsystem inside the mission thanks to the concept of black-box.



If you want to test any control algorithm, it is easy to change the current source because this is an Open Source project. You can select any part of the mission separated by the "`Case`" keyword in the function `Sub Nav()` inside the "Sys.bas" file located at the *Source* folder. You have in this file a definition of each variable and units.

TUTORIALS — Hardware-in-the-loop

The next level of control is to implement your own subsystem and testing it using a RS-232 connection. Select *Control* link mode in the *Link* panel and any available COM port in *Link port*. You may use the following protocol.

Either serial or socket connection uses **ASCII** text or **Binary** data. Use the *Options* sub-menu in the *Link* panel to select *Text mode* or *Binary mode* and *Double* or *Single* precision for 64 or 32 bit floating point numbers in *IEEE 754*[30] format. In *Text mode*, the proposed protocol is the same in both options and are comma separated numbers with an ending ";" character where decimal character is ".", negative values character is "-", optional positive values character is "+", exponential symbol is "e" or "E" and not a number characters are "NaN". Each block start with a code of four characters: INIT, DATA or CTRL. INIT and DATA blocks are sent from the simulator to the external device and CTRL block is replied by the external device.

`INIT.` This block is sent to the device at the start of the simulation or every time the connection is lost and could be used by the black-box as a reset command. The syntax for *Text mode* is:

`INIT,TimeStep,Date,Time,Lat,Lon,Alt,Speed,Heading, StartAngle,EndAngle,StartAlt,EndAlt,Abort,TotalMass, Stages,StageNMass,StageNDry,StageNThrust,StageNDelay, PayloadMass;`

Example:
INIT, .05,2007-06-26,12:09:00, 28.2,-16.6, 0, 409.895238938115, 87.2, 15, 88, 15000, 91000, 4, 34.7, 2, 31.212, 3.1212, 567.151258333333, 121, 3.468, .3468, 57.0093253333333, 3, .02;

The binary structure for *Binary mode* and *Double precision* in C++ syntax is:

```
typedef struct tagInitStage {
  double Mass, Dry, Thrust, Delay;
} InitStage;
```

```
typedef struct tagInitBlock {
  char Name[4]; double TimeStep; char Date[10], Time[8];
  double Lat, Lon, Alt, Speed, Heading, StartAngle,
    EndAngle, StartAlt, EndAlt, TotalMass, PayloadMass;
  char Abort, Stages; InitStage Stage[5];
} InitBlock;
```

`TimeStep:` Time step of simulation loop in seconds.

`Date, Time:` Launch date and time in UTC time format: YYYY-MM-DD, HH:MM:SS.

`Lat, Lon, Alt:` Launch geo-coordinates using the WGS84 system in degrees and altitude in meters respect to average sea level.

`Speed:` Relative initial speed respect to the planet's center with planet's rotation in meters per second.

`Heading:` Clockwise launch direction where Northing is 0 degrees. (0=North, 90=East).

`StartAngle, EndAngle:` Start and final angle of the launch trajectory where vertical (azimuth) is 90 degrees. (90=vertical, 0=horizontal).

`StartAlt, EndAlt:` Start and final altitude check point of the launch trajectory in meters.

`Abort:` Number of stages before abort.

`TotalMass:` Wet launcher mass in kilograms.

`Stages:` Number of stages without the hover and the payload. The **`StageN`** parameters are repeated for every stage.

`StageNMass:` Wet mass of stage N in kilograms.

`StageNDry:` Dry mass of stage N in kilograms.

`StageNThrust:` Thrust in vacuum of stage N in Newtons.

`StageNDelay:` Delay after stage N in seconds.

`PayloadMass:` Payload mass in kilograms.

`DATA.` This block is sent to the device each simulation loop. The syntax for *Text mode* is:

`DATA,T,M,Mt,Mf,F,Te,eG,eH,eX,eY,eZ,eA,eR,eVR,eVRX,eVRY, eVRZ,eVA,eVAX,eVAY,eVAZ;`

Example:
DATA, 0, 34.7, 34.7, 6.6092, 0, .222435897435897, 9.80060472243182, 6378137, -968534.704408334,-6278974.38685793,-563074.387898972, 9.31322574615479E-10, 9.31322574615479E-10, 409.895238938115,-403.764758270368, 64.7999721286988, -28.0907546200786, 1.43754951773129E-12,-5.04984942750752E-13, -1.22130777713281E-12, 5.65637814364806E-13;

The binary structure for *Binary mode* and *Double precision* in C++ syntax is:

```
typedef struct tagDataBlock {
  char Name[4];
  double T, M, Mt, Mf, F, Te, eG, eH, eX, eY, eZ, eA, eR,
    eVR, eVRX, eVRY, eVRZ, eVA, eVAX, eVAY, eVAZ;
} DataBlock;
```

`T:` Time stamp since the launch in seconds.

`M:` Current launcher mass in kilograms.

`Mt:` Current launcher wet mass without burned stages in kilograms.

`Mf:` Current launcher dry mass without burned stages in kilograms.

`F:` Current thrust in Newtons as a function of the thrust curve and the atmospheric pressure.

`Te:` Propellant consumption at full thrust in kilograms per second.

`eG:` Current planet's gravity in meters per second squared.

`eH, eX, eY, eZ:` Current altitude respect to the planet's center and its X, Y, Z components in meters.

`eA:` Current altitude respect to the sea level in meters.

`eR:` Current height respect to the ground in meters. This parameter is valid only when the altitude to the surface is less than one planet radius and the option "matrix terrain" is activated in the simulator.

`eVR, eVRX, eVRY, eVRZ:` Current relative speed respect to the planet's center and its X, Y, Z components in meters per second.

`eVA, eVAX, eVAY, eVAZ:` Current relative speed respect to the planet's atmosphere and its X, Y, Z components in meters per second.

`CTRL.` This block is expected by the simulator to be replied before the "timeout" interval has elapsed, if not then it goes to PAUSE mode. The syntax for *Text mode* is:

`CTRL,Tt,St,Nt,Rt,Ut,Vt,Wt;`

Example:
CTRL, 0, 2, 1, 1, .151852289219914, .984452730767299, 8.82819525355084E-02;

The binary structure for *Binary mode* and *Double precision* in C++ syntax is:

```
typedef struct tagCtrlBlock {
  char Name[4]; double Tt;
  char St, Nt, At, Bt; double Rt, Ut, Vt, Wt;
} CtrlBlock;
```

`Tt:` Time stamp since the launch in seconds to check the correct packet.

`St:` Current mission phase: Crashed=-2, Landed=-1, Launch=0, TakeOff=1, Landing=2, Revert=3, Satellite=4, Transfer=5, StandBy=6, Aborted=7. NOT YET IMPLEMENTED

`Nt:` Active stage (1, 2 … N). NOT YET IMPLEMENTED.

`Rt:` Thrust control from 0=stopped to 1=full throttle.

`Ut, Vt, Wt:` Attitude control vector. It must be a normalized vector if the *Normalize vector* option in the *Remote control* panel is not activated, that is to say: $Ut^2 + Vt^2 + Wt^2 = 1$. By default, this vector must also be defined in the simulator reference system that is aligned with the ecliptic plane (the plane XY where the Earth orbits around the Sun). If the *Align axes* option is activated, the axes must be aligned with the launch site. The Z+ axis corresponds to the vertical vector, the Y+ axis to the North and the X+ axis to the East. Note that the axes are always locked in the initial position so they not move while the Earth rotates during the launch maneuver. Also, the axes read from the external sensor of the device can be mapped or inverted with the options of the *Remote control* panel. To see the simulator X, Y, Z axes in the OpenGL viewer you may select the tool *Tools→Axes*.

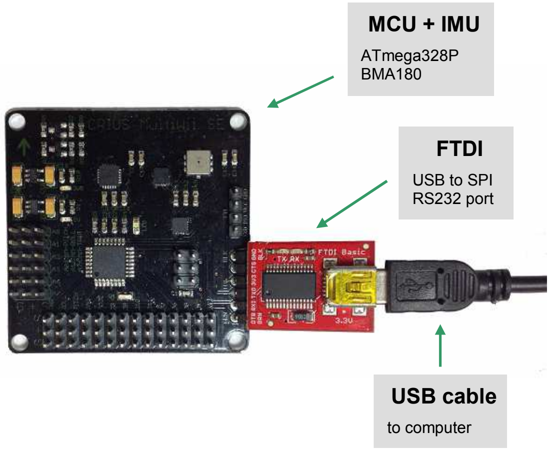
TUTORIALS — Network-in-the-loop

The last level of control is to implement your own subsystem and testing it using a UDP-IP connection type. Select *Control* link mode in the *Link* panel and *Network* in *Link port*. In *Text mode*, the size of INIT and DATA blocks must be 512 bytes and CTRL block must be 128 bytes. You may use the same protocol described before in the "*Hardware-in-the-loop*" section.

[30] IEEE 754 http://en.wikipedia.org/wiki/IEEE_754

TUTORIALS **Black-box connection example**

In this section an example of connection with an external device is presented using *Hardware-in-the-loop* and an open *Arduino* [31] microcontroller unit (MCU) as a black-box showed below. It is a reply of the *Arduino Mini* and has an inertial platform.



This is an example of *Arduino* code to test the communication. The simulator must be configured with the *Link* panel in *Control* mode and using a RS-232 connection type. The speed should be configured to 57600 baud thus the MCU is set to 115200 bauds because the clock is only 8 MHz. All the simulation control flags like *Launch trajectory* must be deactivated. The simulator ignores the commands.

```
// Globals
char data[512]; int i;

void setup() {
  Serial.begin(115200); i = 0;
}

void loop() {
  if (Serial.available() > 0)
    data[i++] = Serial.read();
  if ((i >= 512) || (data[i - 1] == ';')) {
    if (data[0] == 'I') {
      // Process INIT block
    } else if (data[0] == 'D') {
      // Process DATA block
      Serial.print("CTRL,0,1,1,1,0,1,0;");
    }
    i = 0;
  }
}
```

The following example uses the IMU of an *Arduino* to control the attitude of the launcher during the launch trajectory. The time stamp is copied to the CTRL block. The simulator must be configured in the *Link* panel in *Control* mode and using a RS-232 connection type. The simulation control flags must be deactivated except *Launch trajectory*. The simulator rotates the launcher following the commanded attitude vector. Note that the serial port configuration of the *Arduino* is set to 38400 bauds but sometimes it is not able to read all the information coming from the simulator. *Test mode* must be selected in the *Link* panel because only the time stamp in the DATA block is used. Also, the *Normalize vector* option in the *Remote control* panel must be activated because the inertial sensor data is sent without processing.

```
#define LED_PIN          13
#define BMA180_ADDRESS   0x80
#define I2C_SPEED        100000L

char data[512]; int i; // Data link
uint8_t rawADC[7];

#define toINT(LSByte, MSByte) ((int) ((unsigned int) \
  (MSByte) << 8) | ((unsigned char)(LSByte)))

void waitTransmissionI2C() {
  uint16_t count = 255;
  while (!(TWCR & (1 << TWINT))) {
    count--; if (count == 0) {TWCR = 0; break;}
  }
}

void i2c_rep_start(uint8_t address) {
  TWCR = (1 << TWINT) | (1 << TWSTA) | (1 << TWEN);
  waitTransmissionI2C();
  TWDR = address; TWCR = (1 << TWINT) | (1 << TWEN);
  waitTransmissionI2C();
}

void i2c_write(uint8_t data) {
  TWDR = data; TWCR = (1 << TWINT) | (1 << TWEN);
  waitTransmissionI2C();
}

uint8_t i2c_readAck() {
  TWCR = (1 << TWINT) | (1 << TWEN) | (1 << TWEA);
  waitTransmissionI2C();
  return TWDR;
}

uint8_t i2c_readNak() {
  TWCR = (1 << TWINT) | (1 << TWEN);
  waitTransmissionI2C();
  uint8_t r = TWDR;
  TWCR = (1 << TWINT) | (1 << TWEN) | (1 << TWSTO);
  return r;
}

void i2c_writeReg(uint8_t add, uint8_t reg, uint8_t val)
{
  i2c_rep_start(add + 0); i2c_write(reg); i2c_write(val);
  TWCR = (1 << TWINT) | (1 << TWEN) | (1 << TWSTO);
}

uint8_t i2c_readReg(uint8_t add, uint8_t reg) {
  i2c_rep_start(add + 0); i2c_write(reg);
  i2c_rep_start(add + 1);
  return i2c_readNak();
}

void init_imu() {
  PORTC |= 1 << 4; PORTC |= 1 << 5;
  TWSR = 0; TWBR = ((16000000L / I2C_SPEED) - 16) / 2;
  TWCR = 1 << TWEN;
  delay(10); i2c_writeReg(BMA180_ADDRESS, 0x0D, 1 << 4);
  delay(5);
  uint8_t control = i2c_readReg(BMA180_ADDRESS, 0x20);
  control &= 0x0F; control |= (0x01 << 4);
  i2c_writeReg(BMA180_ADDRESS, 0x20, control);
  delay(5); control = i2c_readReg(BMA180_ADDRESS, 0x30);
  control &= 0xFC; control |= 0x00;
  i2c_writeReg(BMA180_ADDRESS, 0x30, control);
  delay(5); control = i2c_readReg(BMA180_ADDRESS, 0x35);
  control &= 0xF1; control |= (0x05 << 1);
  i2c_writeReg(BMA180_ADDRESS, 0x35, control);
  delay(5); ADCSRA |= _BV(ADPS2); ADCSRA &= ~_BV(ADPS1);
  ADCSRA &= ~_BV(ADPS0);
}

void read_imu() {
  TWBR = ((16000000L / 400000L) - 16) / 2;
  i2c_rep_start(BMA180_ADDRESS); i2c_write(0x02);
  i2c_rep_start(BMA180_ADDRESS + 1);
  rawADC[0] = i2c_readAck(); rawADC[1] = i2c_readAck();
  rawADC[2] = i2c_readAck(); rawADC[3] = i2c_readAck();
  rawADC[4] = i2c_readAck(); rawADC[5] = i2c_readAck();
  rawADC[6] = i2c_readNak(); // Temperature
}

void setup() {
  pinMode(LED_PIN, OUTPUT);
  Serial.begin(38400);
  init_imu();
  i = 0;
}

void loop() {
  digitalWrite(LED_PIN, HIGH);
  if (Serial.available() > 0) {
    data[i++] = Serial.read();
    if ((i >= 512) || (data[i - 1] == ';')) {
      if (data[0] == 'I') {
        // Process INIT block
      } else if (data[0] == 'D') {

        // Process DATA block
        digitalWrite(LED_PIN, LOW);
        Serial.print("CTRL,");
        for (i = 5; (data[i] != ',') && (data[i] != ';')
            && (i < 512); i++) Serial.print(data[i]);
        Serial.print(",0,1,1,");

        // Include the vector control
        read_imu(); delay(10);
        Serial.print(toINT(rawADC[0], rawADC[1]) >> 2);
        Serial.print(",");
        Serial.print(toINT(rawADC[2], rawADC[3]) >> 2);
        Serial.print(",");
        Serial.print(toINT(rawADC[4], rawADC[5]) >> 2);
        Serial.print(";");
      }
      i = 0;
    }
  }
}
```

This example code is located at the "WikiLauncher_IMU.zip" file inside the *Source→Arduino* folder.

[31] Arduino MCU http://arduino.cc/en/Main/ArduinoBoardMini

TUTORIALS — GPS Tracking

This simulator can track the position of a real object and process the "$GPGGA" or "$GPRMC" *NMEA* [32] commands from an external GPS connected to a serial port or the *Audio* input. Also, it can use the *APRS*[33] tracking service to track the object position. In the *Link* panel, select the desired connection type in the *Link port* and *Station port* text boxes and then select the *Tracking* link mode to start the tracking. The position and the path of both objects will be shown in the OpenGL viewer.

The GPS must be configured to send the "$GPGGA" or "$GPRMC" NMEA commands through the COM ports or the *Audio* input. The *Audio* input must use a 6 kHz PWM (Pulse Width Modulation) signal with a MSB (Most Significant Bit first) bit order. An example of *Arduino* code is located at the "PWM_6kHz.zip" file inside the *Source→Arduino* folder. To use the APRS tracking service, select *APRS* in the port menu and specify the *User* and *Password* required to accessing this service. Note that the *Audio* and *APRS* modes can not be used in both *Link port* and *Station port* at the same time.

This is the description of the NMEA command "$GPGGA":

```
$GPGGA,hhmmss.ss,llll.ll,a,yyyyy.yy,a,x,xx,x.x,x.x,M,x.x,M,x.x,xxxx*hh
             1         2   3   4       5 6 7   8   9 10 11 12 13  14   15
```

1. Time of position in UTC
2. Latitude in ddmm.mm
3. N or S
4. Longitude in dddmm.mm
5. E or W
6. GPS quality indicator (0=invalid; 1=GPS fix; 2=Diff. GPS fix)
7. Number of satellites in use (not those in view)
8. Horizontal dilution of position
9. Antenna altitude above / below mean sea level (geoid)
10. Meters (antenna height units)
11. Geoidal separation (diff. between WGS-84 ellipsoid and mean sea level; N<0 = geoid is below WGS-84 ellipsoid)
12. Meters (geoidal separation units)
13. Age in seconds since last update from diff. reference station
14. Diff. reference station ID#
15. Checksum hexadecimal

Every time the position is received from the GPS or the APRS tracking service, the simulation launch coordinates will be updated in *Setup* panel. If the *Tracking Sync* option is activated, when the altitude is equal or greater than the launch altitude, the simulator will run the simulation so the real and the predicted trajectories can be compared. Also if the *Tracking Log* option is activated, the trajectories will be saved in a KML file inside the *Presets* folder.

TUTORIALS — Rover Tracking

The *Rover* link mode can be used to control a rover and track its position using a serial connection. In the *Link* panel, specify the desired COM port in *Rover port* and then select the *Rover* link mode. When the link is activated, the simulator will send the "I" command through the serial port with the list of the waypoints to the rover. This list can be edited using the buttons located at the bottom of the panel. Use the [+][-] buttons to add or remove waypoints from the list and the button to show de 2D map. You can change the X and Y positions of any waypoint by clicking and dragging the waypoint with the mouse in the map. Also click and drag the map to move it or zoom in and out using the mouse wheel.

```
I,X1,Y1,X2,Y2,...,XN,YN;
```

Example:
I,5.2,4,-3.1,9,-5.5,6,-7,-8.4;

XN,YN: Position X,Y of the point **N**, in meters.

After the "I" command is sent, the simulator will track the position sent by the rover using the "D" command. The rover can also send the "A" command to track the inertial sensor data. Every time that any of these commands are received, the position and attitude of the rover will be updated in the 2D map.

```
D,T,X,Y,Z;
```

Example:
D,10.2,-8,3.5,0;

T: Elapsed time since the start, in seconds.

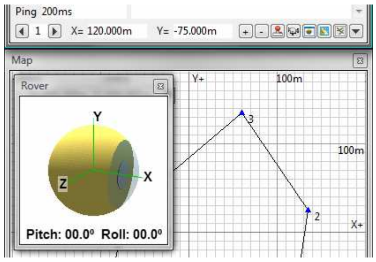
X,Y,Z: Position X,Y,Z of the rover relative to the landing site, in meters.

```
A,X,Y,Z;
```

Example:
A,0,0,9.8;

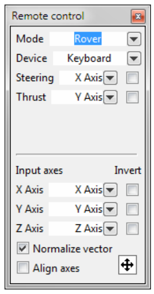
X,Y,Z: Accelerometer data from inertial sensor X,Y,Z axes, in meters per second squared.

If the rover sends the "A" command with the inertial sensor data, you can press the button to show the rover 3D model and its current attitude with pitch and roll angles in degrees. The axes can also be mapped with the options in the *Options→Input axes* sub-menu. Press the arrow button to access the command list. Use the *Add to command* sub-menu to add special characters to the end of the commands, like *NULL*, *CR* or *LF*. In this example, no terminating characters are used.



Remote control

Press the button to show the *Remote control* panel if it is not visible and then click the button at the bottom of the panel or press **Enter** to control the rover. By default, the input device used is the keyboard but also the mouse or a joystick can be selected in the *Device* option. If *Keyboard* is selected, you can press the arrow keys to control the rover. If *Mouse* is selected, click the button and drag the mouse in any direction. If *Joystick* is selected, just move the joystick to control the rover. In this mode, you can select the axes that control the *Steering* or the *Thrust* of the rover in the text boxes or invert the direction by clicking the check box near the axis. To deactivate the remote control just press the button again. When the remote control is activated, the simulator will send the following commands through the serial port:



Direct control commands:

F	Forward	The rover will move forward
B	Backward	The rover will move backward
L	Left	The rover will turn left
R	Right	The rover will turn right
S	Stop	The rover will stop
H	Halt	The rover will deactivate all the servos and wait

Waypoint mode commands:

I	Init	The rover will follow the waypoint list
D	Data	The rover sends the time elapsed and its position
A	Attitude	The rover sends the data from the inertial sensor

Configuration commands (optional):

C0;	Reset to default parameters
C1;	Show current parameters
C2;	Show time and position using a **D** command
C3;	Show inertial sensor data using an **A** command
CA130;	Steering neutral position, in degrees
CB180;	Steering left limit, in degrees
CC80;	Steering right limit, in degrees
CD71;	Thrust neutral position, in degrees
CE75;	Thrust forward limit, in degrees
CF66;	Thrust backward limit, in degrees
CG0.5;	Slow thrust step, in degrees
CH1;	Fast thrust step, in degrees
CI5;	Slow steering step, in degrees
CJ10;	Fast steering step, in degrees
CK50;	Servo update interval, in milliseconds
CL1000;	Standby delay, in milliseconds

Example:
SSSFFFFLFLFLFRFRFRFFFSSBBBBRBRBLBLBLSSSSSH

The time interval for the commands is defined in *Timeout*. The simulator will send the "S" command when no key is pressed or the joystick is not moved. If the **Space** key is pressed or the connection is closed, the "H" command will be sent to the rover to put it in standby mode.

Real-time configuration (optional)

To help adjusting the rover internal parameters without updating the *Arduino* code, the "C" command can be used. Every command starts with a "C", followed by a character, optionally a number for the parameter and always terminated with a semi-colon ";". Commands from "C0" to "C3" are debug commands and "CA" to "CL" are used to set a specific parameter for the rover. Type any command in the text box under the log of events and press **Enter** to send it to the Rover. When the rover is finally adjusted, these parameters can be written directly to the *Arduino* code and then the part for the real-time configuration can be removed from the code to free some memory. The list with all these commands is stored in the "Rover.ini" file inside the *Models* folder and can be edited with the *Notepad* panel. An example code for the *Arduino* MCU using the *Direct control* and the *Configuration* commands is located at the "PicoPilot_Antiroll.zip" file inside the *Source→Arduino* folder.

[32] National Marine Electronics Association
http://www.nmea.org
[33] APRS tracking service
http://aprs.fi

TUTORIALS **OpenGL Icons**

The *Models* folder contains the 3D models displayed during the flight. To personalize these models you can use a free version of *Caligari trueSpace3.2*[34] (TS3) that supports the extension .COB in ASCII format. This software is used to generate 3D objects and the simulator is able to open .COB format files in text version. There are 11 models for a common mission that corresponds with the current stage and the file name:

- Balloon "Balloon.cob" → "BalloonEmpty.cob"
- Stage 1 "Stage1.cob" → "Stage1Empty.cob"
- Stage 2 "Stage2.cob" → "Stage2Empty.cob"
- Stage 3 "Stage3.cob" → "Stage3Empty.cob"
- Stage 4 "Stage4.cob" → "Stage4Empty.cob"
- Stage 5 "Stage5.cob" → "Stage5Empty.cob"
- Hover "Hover.cob"
- Rover "Rover.cob"
- Satellite "Satellite.cob"
- Ground station "Station.cob"
- Tracking object "Tracking.cob"

You can put these files with the .COB extension in the *Models* folder so the simulator can use them. Optionally, every model can be located inside a folder with the same name as the model. If the object uses textures, they should be stored also in this folder. The model for every stage must contain the stage itself and all the upper stages, but only if they are visible. If the *Simulation→Empty stages* option is selected, a 3D model with the same name as the stage but with the "Empty" suffix will be used.

The center of mass parameter *CM* in *Stages* panel will be taken from the parameter **CentreOfGravity** inside the **PhAn** command. Also, the *Emissivity* parameter will be calculated as a mean value for all the polygons in the 3D model, based on the *Shininess* parameter **Ks**, inside the **Mat1** command.

The object loader is compatible with the following trueSpace3.2 commands: Caligari V00.01ALH, Grou V0.01, PolH V0.04, Unit V0.01, Mat1 V0.06, PhAn V0.04, Lght V0.04, Chan V0.08 and END V1.00. All these commands have Id, Parent and Size properties. The rest of the commands are ignored.

- **Caligari V00.01ALH** command ensures that this file was generated by trueSpace3.2 because the load algorithm was made efficient for speed and not for robust. Also, it is possible to write manually the file in text format if the rules are followed. In this sense, this reader is case sensitive and separations have to be done in the proper order as trueSpace3.2 does.
- **Grou V0.01** command groups objects. It has its own Name - center and Transform matrix. Grou command could have Units, PolH, Chan and Grou but can not have the rest of commands.
- **PolH V0.04** command is a polyhedron. It has its own Name - center, Transform matrix, World vertices, Texture vertices and Faces. PolH command could have Units, Mat1 and PhAn but can not have the rest of commands.
- **Unit V0.01** command has the number of units inside this object
- **Mat1 V0.06** command has few material properties, included textures.
- **PhAn V0.04** command has few physics and anatomy properties.
- **Lght V0.04** command has information about illumination.
- **Chan V0.08** command has rotations and translations through the time. It is used for dynamics.
- **END V1.00** command closes the object list.

[34] Caligari trueSpace https://en.wikipedia.org/wiki/TrueSpace

DIRECT KEYS **Advanced controls**

These are some special mouse and keyboard commands used for advanced control of the 3D viewer and the simulation.

Global keys for all the panels:

• ***F1***	Show or hide the *Help* panel
• ***F2***	Show or hide the *Data* panel
• ***F3***	Show or hide the *Log* panel
• ***F4***	Show or hide the *Graph* panel
• ***F5***	Show or hide the *Setup* panel
• ***F6***	Show or hide the *Stages* panel
• ***F7***	Show or hide the *Propellant editor*
• ***F8***	Show or hide the *View* panel
• ***F9***	Show or hide the *Link* panel
• ***F10***	Show or hide the *Options* panel
• ***F11***	Enter or exit full screen mode
• ***F12***	Show or hide the *Toolbar*
• *Shift* + ***F1*** *to* ***F5***	*Follow* modes from *Free* to *Ship*
• *Shift* + ***F6*** *to* ***F7***	*Relative to* modes *Auto* and *Earth*
• *Shift* + ***F8***	Flat view
• *Shift* + ***F9***	Orthogonal render
• *Shift* + ***F11***	Switch from OpenGL to GDI render
• *Shift* + ***F12***	Sync mode
• *Ctrl* + ***F2***	Show or hide the *Onboard sensor*
• *Ctrl* + ***F3***	Show or hide the *Search* panel
• *Ctrl* + ***F4***	Show or hide the *Video player*
• *Ctrl* + ***F5***	Show or hide the *Trajectory editor*
• *Ctrl* + ***F6***	Show or hide the *Notepad* panel
• *Ctrl* + ***F7***	Show or hide the 2D map
• *Ctrl* + ***F8***	Show or hide the Rover 3D model
• *Ctrl* + ***F9***	Show or hide the *3D Graph* panel
• *Ctrl* + ***F10***	Show or hide the *Color selector*
• *Ctrl* + ***F11***	Full screen mode for the active panel
• *Ctrl* + ***F12***	Show or hide the panel toolbar
• *Ctrl* + *Shift* + ***F4***	Open an URL with the *Video player*
• *Ctrl* + *Shift* + ***F7***	Show or hide the *Burn editor*
• *Ctrl* + *Shift* + ***F8***	Show or hide the Stage 3D model
• *Ctrl* + *Alt* + ***F2***	Show or hide the *Payload camera*
• *Ctrl* + *Alt* + ***F3***	Show or hide the *Web browser*
• *Ctrl* + *Alt* + ***F4***	Show or hide the *360º Player*
• *Ctrl* + *Alt* + ***F5***	Show or hide the logo
• *Ctrl* + *Alt* + ***F6***	Add an extra *Video player*
• *Ctrl* + *Alt* + ***F7***	Add an extra *Payload camera*
• *Ctrl* + *Alt* + ***F8***	Add an extra *View* panel
• *Ctrl* + *Alt* + ***F9***	Add an extra *3D Graph* panel
• *Ctrl* + *Alt* + ***F10***	Show or hide the *Google Earth* window
• *Ctrl* + *Alt* + ***F11***	Switch from 2D to 3D panels style
• *Ctrl* + *Alt* + ***F12***	Show or hide the *Preset editor*
• *Alt* + ***Enter***	Show information in the *Web browser*
• *Ctrl* + ***Enter***	Restart simulation
• *Shift* + ***Enter***	Reset simulation
• *Ctrl* + ***Space***	Play or pause simulation
• *Ctrl* + *Shift* + ***Enter***	Apply changes and repeat simulation
• *Ctrl* + *Alt* + ***Enter***	Recalculate the trajectory
• *Ctrl* + ***Tab***	Switch to panel menu
• ***PrtScr***	Take a screen snapshot
• ***Pause*** *or Ctrl* + *Alt* + ***PrtScr***	Start or stop the video recording
• ***Escape***	Exit program

Mouse commands for the *3D viewer*, *3D Graph*, *3D models* and View panels:

• ***Left*** *click* + *Drag*	Move camera in *X* and *Y* axes
• *Shift* + ***Left*** *click* + *Drag*	Move camera in *X* and *Z* axes
• *Ctrl* + ***Left*** *click* + *Drag*	Move *Launch* coordinates
• ***Right*** *click* + *Drag*	Rotate camera in *Pitch* and *Yaw*
• *Ctrl* + ***Right*** *click* + *Drag*	Rotate camera in *Pitch* and *Yaw* slowly
• ***Left*** *and* ***Right*** *click* + *Drag*	Rotate camera in *Roll*
• *Ctrl* + ***Left*** *and* ***Right*** *click* + *Drag*	Rotate camera in *Roll* slowly
• ***Center*** *click* + *Drag*	Change the camera *Zoom*
• *Ctrl* + ***Center*** *click* + *Drag*	Change the camera *FOV*
• *Wheel up and down*	Change the camera *Zoom*
• *Double click*	Reset camera *Yaw*, *Pitch* and *Roll*
• ***Left*** *click* on an object	Select the object
• *Shift* + ***Left*** *click* on a planet	Select the camera *Relative To* mode
• *Ctrl* + ***Left*** *click* on an object	Add objects to the selection *Ruler* tool
• *Double click* on an object	Activate the *Follow* mode for the object
• ***Right*** *click*	Show the camera context menu
• ***Center*** *click*	Change the camera *Follow* mode
• ***Cursors***	Move camera in *X* and *Y* axes
• *Ctrl* + [*Shift*] + ***Cursors***	Rotate camera in *Pitch* and *Yaw*
• *Shift* + ***Left*** *or* ***Right***	Rotate camera in *Roll*
• *Shift* + ***Up*** *or* ***Down***	Change the camera *Zoom*
• *Alt* + ***Up*** *or* ***Down***	Change the camera *FOV*
• *Alt* + ***Left*** *or* ***Right***	Move the center of the 3D viewer
• *Ctrl* + [*Shift*] + [*Alt*] + ***PageUp***	Move to the previous snap points
• *Ctrl* + [*Shift*] + [*Alt*] + ***PageDown***	Move to the next snap points
• *Ctrl* + ***1*** *to* ***9***	Load a path stored in memory
• *Ctrl* + ***F11***	Enter or exit full screen mode

Mouse commands for the *Toolbar*:

• *Ctrl* + ***Play*** *button*	Restart the simulation
• *Ctrl* + *Shift* + ***Play*** *button*	Advance the simulation one time step
• *Ctrl* + ***PrevSnap*** *button*	Move to previous 10 snap points
• *Ctrl* + ***NextSnap*** *button*	Move to next 10 snap points
• *Ctrl* + *Shift* + ***PrevSnap*** *button*	Move to previous 100 snap points
• *Ctrl* + *Shift* + ***NextSnap*** *button*	Move to next 100 snap points
• *Ctrl* + *Alt* + ***PrevSnap*** *button*	Move to the first snap point
• *Ctrl* + *Alt* + ***NextSnap*** *button*	Move to the last snap point
• *Ctrl* + ***SpeedUp*** *button*	Speed up the simulation slowly
• *Ctrl* + ***SpeedDown*** *button*	Slow down the simulation slowly
• *Ctrl* + ***Record*** *button*	Take a screen snapshot

• *Alt* + ***Record*** *button*	Activate *Onboard* video recording mode
• ***Center*** *click*	Customize toolbar buttons

Mouse and keyboard commands for the *Graph* panel and the *Input graph*:

• ***Left*** *click + Drag or Mouse wheel*	Move the graph position
• [*Ctrl*] + ***Left*** *or* ***Right***	Move the cursor position
• [*Ctrl*] + ***PageUp*** *or* ***PageDown***	Move the cursor position faster
• ***Home***	Move the cursor position to the start
• ***End***	Move the cursor position to the end
• ***Up*** *or* ***Down***	Increase or decrease vertical scale
• ***1*** *to* ***8***	Activate or deactivate a data graph
• ***Num+*** *or* ***Num+***	Adjust the histogram density
• *Double click*	Toggle auto-scroll mode
• ***Center*** *click*	Toggle histogram mode

Keyboard commands for the graph in the *Burn editor*:

• [*Ctrl*] + ***Left*** *or* ***Right***	Move the cursor position
• [*Ctrl*] + ***PageUp*** *or* ***PageDown***	Move the cursor position faster
• ***Home***	Move the cursor position to the start
• ***End***	Move the cursor position to the end
• ***Insert***	Go to the maximum pressure point
• ***Delete***	Go to the propellant burnout point

Mouse commands for the *Map* panel in *Waypoint editor* mode:

• ***Left*** *click + Drag*	Move the map position
• *Wheel up and down*	Zoom the map in and out
• *Double click*	Reset the map position and zoom

Mouse and keyboard commands for the *Map* panel in *Online map* mode:

• ***Left*** *click + Drag*	Move the map position
• [*Ctrl*] + [*Shift*] + ***Cursors***	Move the map position
• *Ctrl* + ***Left*** *click or* ***Center*** *click*	Move the map to the cursor
• *Double click*	Move and zoom the map to the cursor
• ***Center*** *click + Drag*	Zoom the map in and out
• *Wheel up and down*	Zoom the map in and out.
• ***PageUp*** *or* ***PageDown***	Zoom the map in and out
• *Ctrl* + ***F11***	Enter or exit full screen mode
• ***Enter***	Show coordinates and cursor

Keyboard commands for the coordinates text box in the *Map* panel:

• ***Up*** *or* ***Down***	Select a location in the position text box
• ***Enter***	Enter the map latitude and longitude

Mouse and keyboard commands for the *Video player* panel:

• ***Left*** *click or* ***Space***	Play or pause the video
• *Ctrl* + ***Left*** *click + Drag*	Move the video position
• *Shift* + ***Left*** *click + Drag*	Move the video position slowly
• ***PageUp*** *or* ***PageDown***	Move the video position
• *Shift* + ***PageUp*** *or* ***PageDown***	Move the video position slowly
• *Ctrl* + ***PageUp*** *or* ***PageDown***	Move the video position faster
• ***Home***	Move the video position to the start
• ***End***	Move the video position to the end
• *Alt* + ***Enter*** *or* ***Escape***	Exit from full screen mode
• *Ctrl* + ***F11***	Enter or exit full screen mode
• ***Escape***	Close the panel

Keyboard commands for the *360º player* panel:

• ***Num4*** *or* ***PageUp***	Move the view position to the left
• ***Num6*** *or* ***PageDown***	Move the view position to the right
• ***Num5*** *or* ***Home***	Reset the view position to 0º
• ***Num0*** *or* ***Space***	Play or pause all the videos
• ***Num+***	Increase the size of the videos
• ***Num-***	Decrease the size of the videos
• *Ctrl* + ***F11***	Enter or exit full screen mode
• ***Escape***	Close the panel

Keyboard commands for the *Notepad* panel:

• ***Enter***	Calculate result in calculator mode
• *Alt* + ***Enter***	Activate calculator mode
• *Ctrl* + ***Enter***	Calculate result in text mode
• *Shift* + ***Enter***	Repeat and calculate selected text
• *Alt* + ***Insert***	Show all defined variables
• *Alt* + ***F1***	Show all functions and operators

Keyboard commands for the *Web browser*:

• *Alt* + ***Left*** *or* ***Right***	Navigate backward or forward
• ***F5***	Reload the current page
• *Ctrl* + ***F11***	Enter or exit full screen mode
• *Ctrl* + ***F12***	Show or hide the toolbar

Command line switches:

quiet	Do not show splash screen at startup (also press *Shift*, *Ctrl* or *Alt*)
nosave	Do not save changes on exit (also press *Shift*, *Ctrl* or *Alt*)
gdi	Use GDI 2D render instead of OpenGL 3D render
nolog	Deactivate log write to “Log.txt” in the debug compiled executable

DOWNLOADS — Terrain files

The file “moon-20_terrain_world.rar” contains the Earth elevations, the file “moon-20_terrain_moon.zip” contains the Moon elevations and the file “moon-20_terrain_mars.zip” contains the Mars elevations. Currently, there are no elevations for other planets. There is a portable version with only Spain and Canary Islands which is the file “moon-20_terrain_spain.zip”. The file “moon-20_geoid_earth.zip” contains the Earth geoid altitude over ellipsoid. These files should be extracted and placed in the *Terrain* folder.

DOWNLOADS — High definition textures

The textures used for the Earth and the Moon can be improved by extracting and replacing the current ones in the *Textures* folder for one of the following files: “moon-20_compressed_textures_2K.zip” for a resolution of 2048 x 1024 pixels, “moon-20_compressed_textures_4K.zip” for a resolution of 4096 x 2048 pixels, “moon-20_compressed_textures_8K.zip” for a resolution of 8192 x 4096 pixels and “moon-20_compressed_textures_16K.zip” for a resolution of 16384 x 8192 pixels (for Earth only). Some video cards have problems with the DDS compressed texture format. The file “moon-20_uncompressed_textures.zip” is a set of textures in BMP format that work in almost all the video cards. You should extract and place these files in the *Textures* folder.

DOWNLOADS — Asteroids database

The file “moon-20_asteroids.gz” contains the asteroids database. This file should be extracted and placed in the *Planets* folder. Note that the asteroids trajectories are updated frequently and new asteroids are discovered almost every day. Because of this, it is recommended to download the updated version of this file from the Lowell Observatory server or using the *Update asteroids* option in the *Path* sub-menu.

DOWNLOADS — Airspace files

The file “moon-20_airspaces.zip” contains the KML files needed to rebuild the database used in the *Airspaces* render tool. Download this file and extract all the KML files in the *Airways* folder. These files are updated frequently and new versions of a specific zone can be downloaded from the *Lloyd Bailey 3D Airspace* web page. Download the updated KML or KMZ files and copy them to the *Airways* folder overwriting the older ones. If the airspace file is a KMZ file, it must be converted to KML before it can be processed. Use *Google Earth* to convert the file or simply change the file extension to ZIP and extract the KML file. Finally, use the *Update airspaces* option in the *Path* menu to rebuild the database.

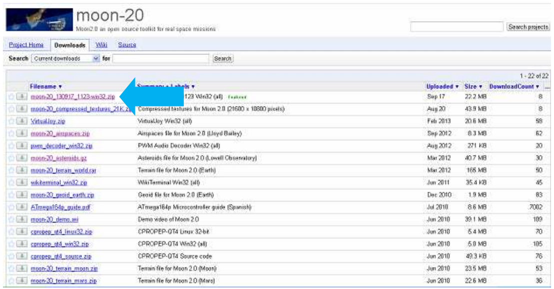
The “Airport.csv”, “Seaport.csv” and “City.csv” files in the *Airways* folder are CSV files with the list of all the airports, seaports and cities in the world. You can edit these files to update the data in the simulator. The “Airway.bin” and “Rnav.bin” files contain the information about the airways inside the Spanish airspace. Also, the “Country.bin” and “Populated.bin” files contain the data of the land and water boundaries of all the countries in the world and the highly populated areas. Currently no updates are available for these binary files.

TUTORIALS **NOTAM for a stratospheric balloon**

This is the tutorial to generate a report to request the publication of a NOTAM (NOtice To AirMen) to the Airworthiness Authority (AESA in Spain) as a result of an air activity, in our case a "non manned light free balloon" launch.

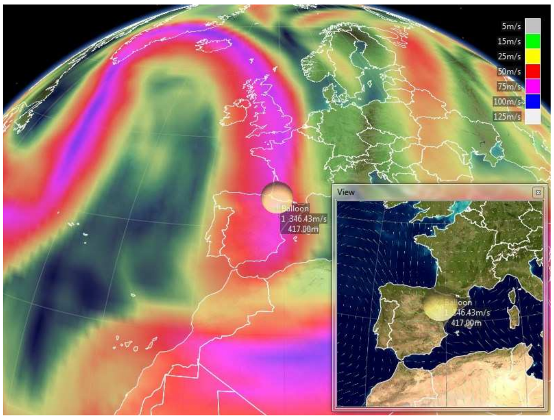
The report has to be sending by e-mail at least one month before the launch day to guarantee the necessary time to establish the contact between the Airworthiness Authority and both: The Airways Operator and The Military Staff. In case of necessity, some of the agencies can request extra information or directly notify the incompatibility of the launch, because of the air traffic or military maneuvers. The e-mail has to include the name of the organization responsible of the balloon launch and the person responsible of the organization (that has not to be the same of the launch) with his contact data. In case of civil responsibility, the contact with each person will be established. Civil Aviation indications breach may result in the prohibition of future launches requested by the organization of the air activity. Also we have to attach to the report: A study of winds before the launch and a compatibility study of the balloon trajectory with airways. Thus, we recommend the use of the tool called *Moon2.0*, which can be free downloaded here:

http://code.google.com/p/moon-20/downloads/list



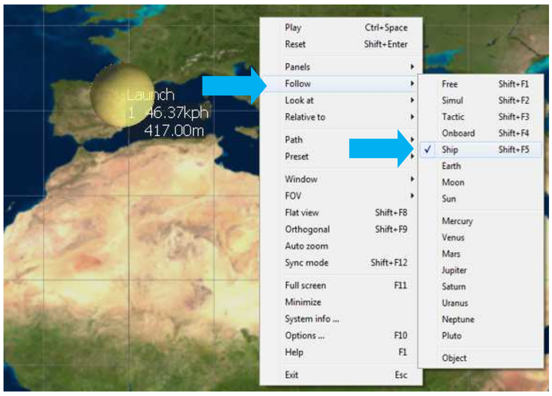
The last version has directly updated the balloon trajectory, which did not happen in old versions of *Moon2.0*. Another advance of this version is that the airspaces and airways are updated too, so we only have to activate the particular option to see that, like we explain later. But the most important advance is the tool that allows to know the exactly moment when the balloon enters and leave an aerospace or an airway; that allows us to know for how long the balloon is inside it.

The study of winds before the launch is as follows. The *Moon2.0* has a wind tool as was explained in the *Balloon trajectory* tutorial.



The compatibility study of the balloon trajectory with airways is as follows. To see the airways, first we will show the top view and for that we have to press the right button of the mouse and select the *Flat view* option, like the next figure shows.

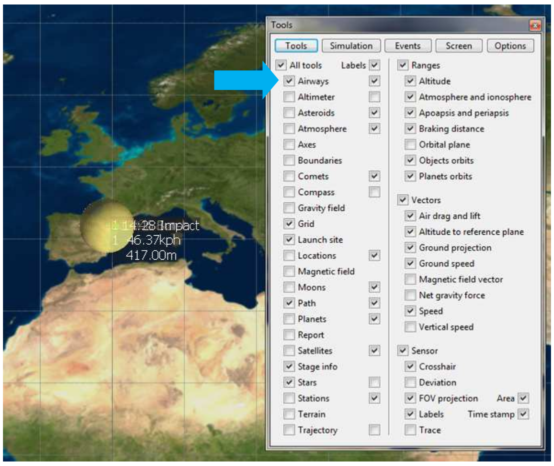
We recommend activate the tracing of the aircraft *(Follow ship)*, which we can found pressing the right button in the mouse and selecting the option showed in the next photo.



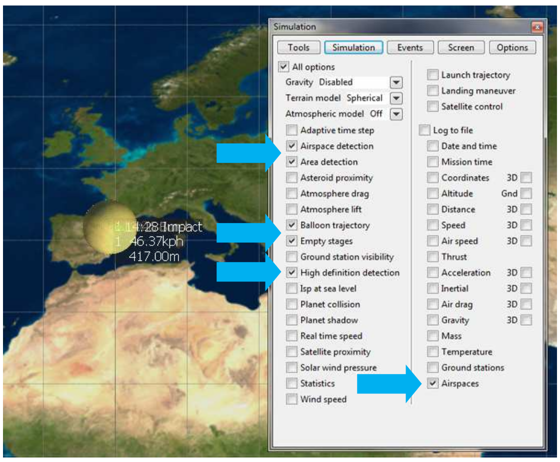
With the wheel of the mouse we can increase or decrease the zoom, which allows see better the interest areas.

After that, we will explain the steps to show the airways and airspaces and to select the option of airspace detection, which show us when the balloon enters and leaves a particular airspace.

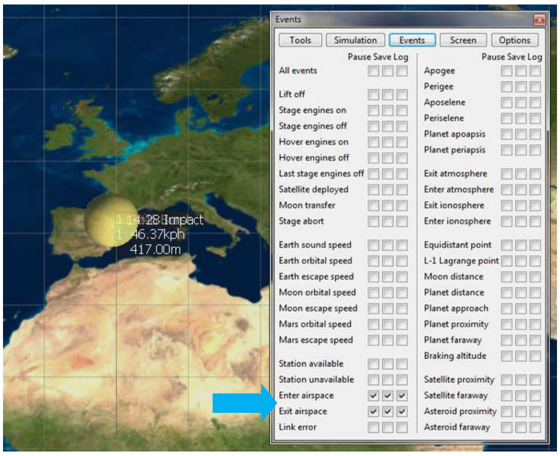
First of all, we have to press the **Options** button (*Viewer options)* of the tools menu and in the **Tools** tab we will select the check box option called *Airways*; like the next photo shows.



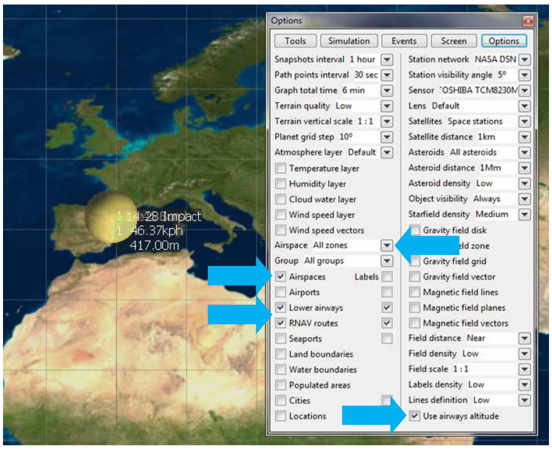
The next step is to click in the tab called **Simulation** and select the following check box options as next photo shows: *Airspace detection, Area detection, Balloon trajectory, Empty stages, High definition detection* and *Airspaces.*



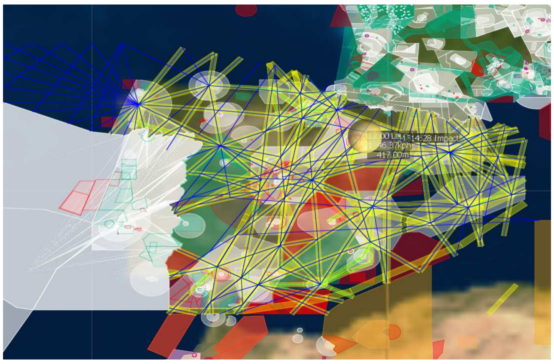
After that, we have to press in the **Events** tab and select the following check box options: *Enter airspace* and *Exit airspace*. In this tab, we can observe that there are three of for which case; the different check box option in front of the other tabs the **Pause**, which serves to stop the image when this event occurs and this allows us see better the characteristics of this event.



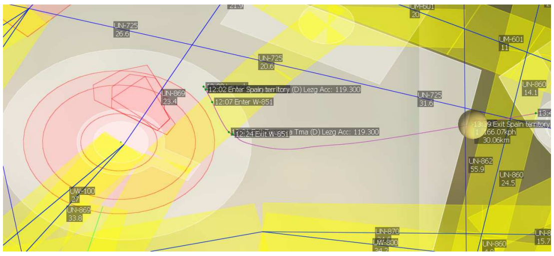
The last step is to press in the **Options** tab and here we will select the next options: *Airspaces, Lower airways, RNAV routes* and *Use airways altitude*, like the next photo shows. If we do not need the airspaces of all the zones, because our balloon does not cross them, we have the option to choose the airspaces that we need; this option is in the list called **Airspaces**, where we will select the zone that we want and this will appear in the place where now there is the name: *All zones*. Next photo shows this process.



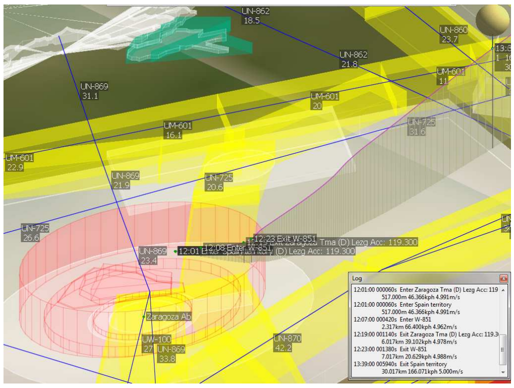
Observe that the Labels of *Airspaces* are not selected otherwise so many names impede a proper vision of the situation. After these steps, we can observe the airspaces and the airways like this:



Increasing the zoom, we observe in more detail airspaces and airways. This is one of the most important photos for the report because the controller will see the possible conflict with real traffic. The photo shows the time to airspace clearance, in this case 23 minutes after the balloon release.



In the next photo we can see an isometric view that shows the altitude of airspaces and airways. In this example the balloon, starting from the Zaragoza TMA, crosses the W-851 airway in 23 minutes and leave the Spanish airspace in 1 hour and 36 minutes when 30 km of altitude is reached. At 32 km the rocket will be ignited autonomously. Apart from this, we can observe the information given by the *Log* panel, in which are detailed the moment when the balloon enters and leave each airspace and airway.

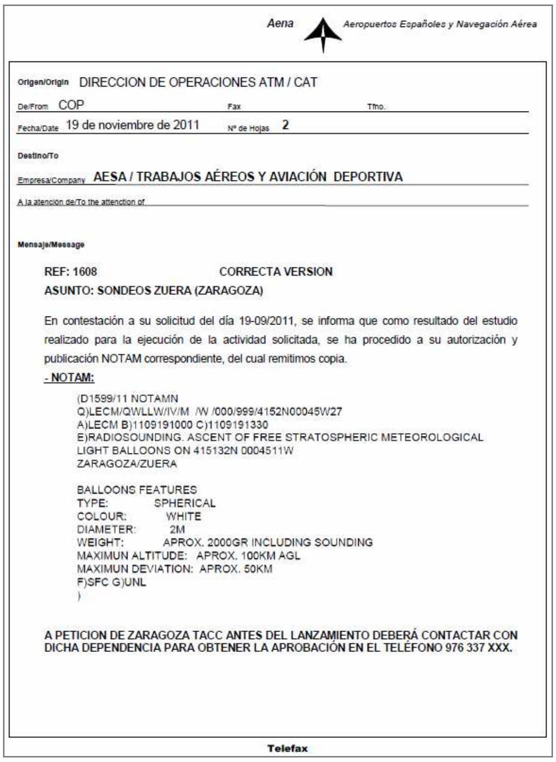


The report has to be sending to:

AESA. Servicio de Trabajos Aéreos y Aviación Deportiva

aviaciondeport.aesa@fomento.es

Our NOTAM will look similar to the following photo. In it we can observe the characteristic data of the launch. This information will be read by all the pilots affected before the starting of the flight.



Aena — Aeropuertos Españoles y Navegación Aérea

Origen/Origin DIRECCION DE OPERACIONES ATM / CAT
De/From COP Fax Tfno.
Fecha/Date 19 de noviembre de 2011 Nº de Hojas 2

Destino/To
Empresa/Company AESA / TRABAJOS AÉREOS Y AVIACIÓN DEPORTIVA
A la atención de/To the attention of

Mensaje/Message

REF: 1608 CORRECTA VERSION
ASUNTO: SONDEOS ZUERA (ZARAGOZA)

En contestación a su solicitud del día 19-09/2011, se informa que como resultado del estudio realizado para la ejecución de la actividad solicitada, se ha procedido a su autorización y publicación NOTAM correspondiente, del cual remitimos copia.

- NOTAM:

(D1599/11 NOTAMN
Q)LECM/QWLLW/IV/M /W /000/999/4152N00045W27
A)LECM B)1109191000 C)1109191330
E)RADIOSOUNDING. ASCENT OF FREE STRATOSPHERIC METEOROLOGICAL LIGHT BALLOONS ON 415132N 0004511W
ZARAGOZA/ZUERA

BALLOONS FEATURES
TYPE: SPHERICAL
COLOUR: WHITE
DIAMETER: 2M
WEIGHT: APROX. 2000GR INCLUDING SOUNDING
MAXIMUN ALTITUDE: APROX. 100KM AGL
MAXIMUN DEVIATION: APROX. 50KM
F)SFC G)UNL
)

A PETICION DE ZARAGOZA TACC ANTES DEL LANZAMIENTO DEBERÁ CONTACTAR CON DICHA DEPENDENCIA PARA OBTENER LA APROBACIÓN EN EL TELÉFONO 976 337 XXX.

Telefax

The regulation of non manned free balloons use is in the Regulation of air circulation of the Royal Decree 57/2002. The appendix S contains all the information about this type of activities. It is recommendable the reading of it before preparing a mission to know what we can do and what not.

References:

http://www.mtc.gob.pe/portal/transportes/aereo/regulaciones/docs/rap_rev15/rap101/rap_101_subparte_d_rev15.PDF

http://www.boe.es/boe/dias/2002/01/19/pdfs/C00001-00697.pdf (Spanish)

http://www.boe.es/boe/dias/1968/05/09/pdfs/A06766-06767.pdf (Spanish)

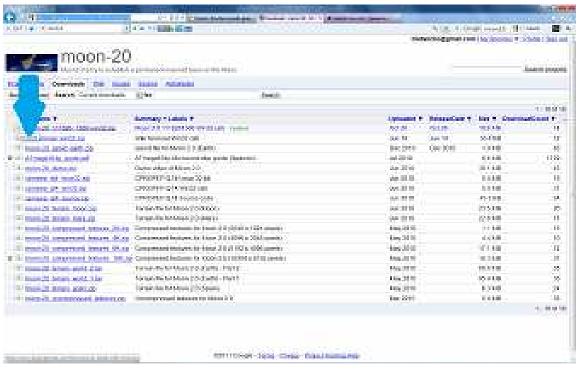
http://www.icao.int/Documents/annexes_booklet.pdf

TUTORIALS **NOTAM para globo estratosférico**

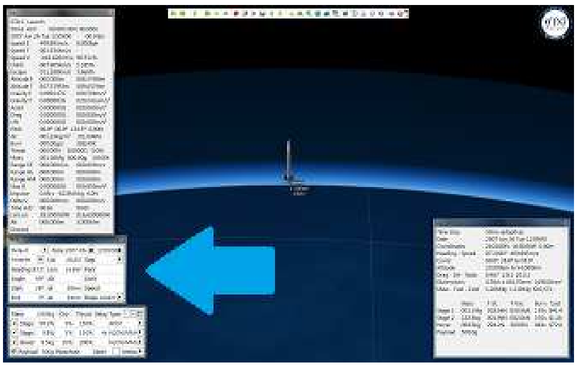
Este es el tutorial para generar un informe para solicitar a AESA (Aviación Civil) la publicación de un NOTAM (NOtice To AirMen) como resultado de una actividad aérea, en nuestro caso el lanzamiento de un "globo libre no tripulado".

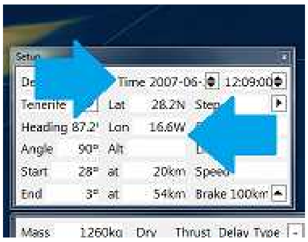
El informe debe ser enviado por e-mail al menos un mes antes del lanzamiento para garantizar que les dará tiempo de contactar con AENA y el Estado Mayor. En caso de necesidad, alguno de los dos organismos pueden solicitar información extra o simplemente notificar que el lanzamiento es incompatible, ya sea por tráfico aéreo o por maniobras militares. En el e-mail deberemos incluir el nombre de la organización responsable del lanzamiento, así como de la persona responsable de la misma (que no tiene que ser necesariamente el mismo que suelte el globo) con sus datos de contacto. En caso de responsabilidad civil se contactaría con dicha persona. El no cumplimiento de las indicaciones de Aviación Civil podría provocar que no dejen lanzar más a la organización que solicita la actividad aérea. Además debemos acompañar el informe con el estudio de vientos sobre la trayectoria del globo y compatibilidad con las aerovías. Por ello es recomendable usar una herramienta que se llama *Moon2.0* y que se puede descargar gratis aquí:

http://code.google.com/p/moon-20/downloads/list

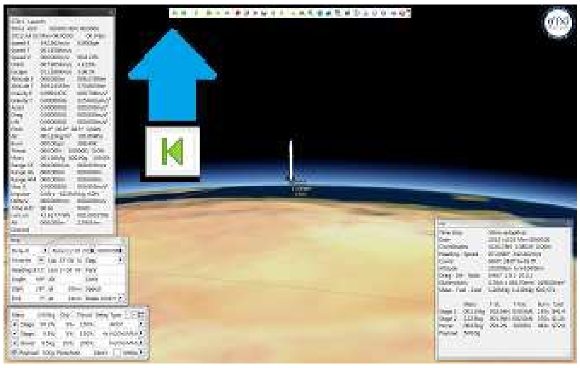


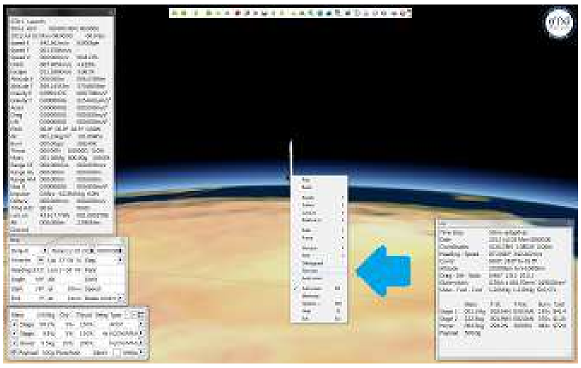
Introducir en el panel *Setup* la fecha y hora UTC y las coordenadas del lanzamiento como se muestra en la figura siguiente. Es decir, hay que rellenar con información válida los campos: *Launch date*, *Launch time*, *Launch site latitude*, *Launch site longitude* y *Launch site altitude*. Este último es importante para generar la trayectoria y tiene que ser la altura a la que creemos que llegará nuestro globo.



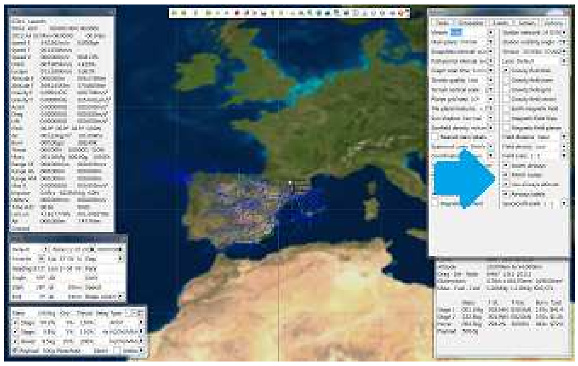


Una vez introducido los datos, pulsaremos el botón para reiniciar la simulación (*Reset simulation*) para ver los resultados, comprobando que la localización del lanzamiento así como la hora del día coincide con lo esperado. La hora es la *Universal Time Clock* o UTC o también hora del meridiano de Greenwich.

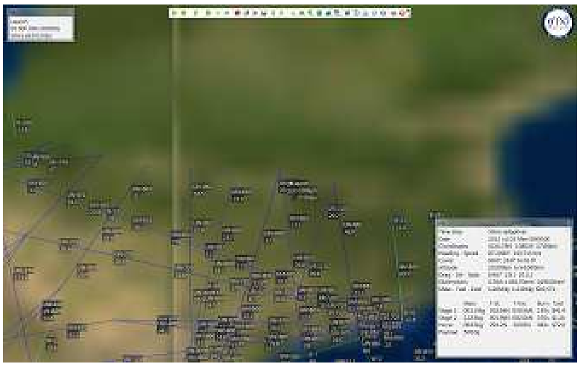


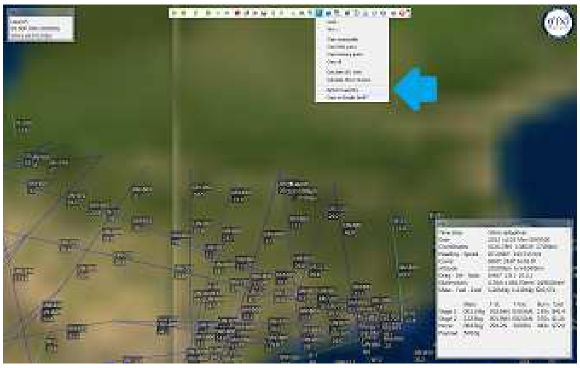


Para visualizar las aerovías, primeramente mostraremos la vista plana o llamada también vista ortogonal y para ello pulsaremos con el botón secundario del ratón sobre el cohete para sacar el menú contextual, marcando la opción *Flat view*, tal y como se muestra en la figura anterior. Recomendamos activar el seguimiento de la aeronave (*Follow ship*) que está en el menú contextual en el submenú *Follow* tal y como se muestra en la figura siguiente. Con la rueda del ratón podemos aumentar y disminuir el zoom para ver de cerca el área de interés.

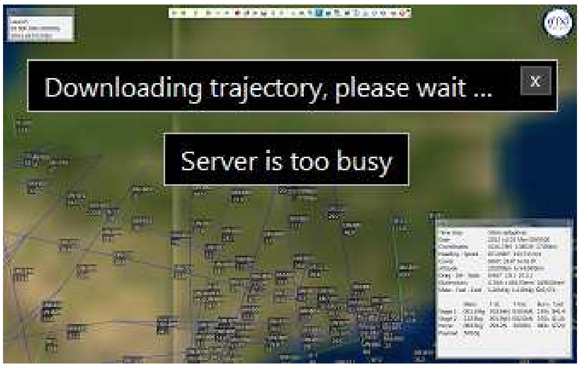


A continuación pulsaremos sobre el botón de opciones del visor (*Viewer options*) de la barra de herramientas y en la pestaña *Options* marcaremos las opciones siguientes: *Lower airways*, *RNAV routes*, *Use airways altitude* y *Airways labels*, tal y como se ve en la figura anterior. En ese momento aparecerán las aerovías inferiores en verde y las aerovías superiores en azul oscuro, como se muestra en la figura siguiente. Cerramos los paneles que no usemos, ajustamos la vista e imprimimos la pantalla para el informe.

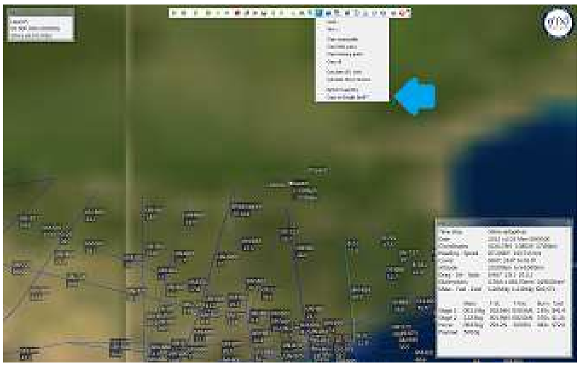




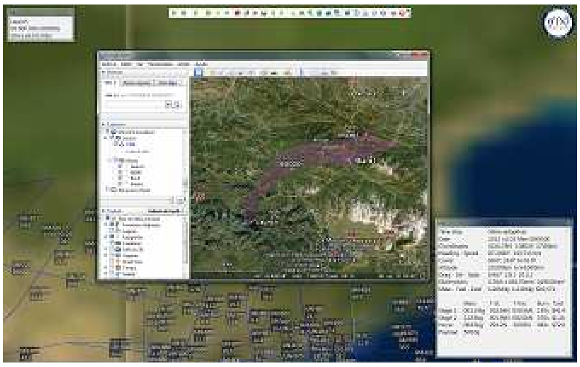
El siguiente paso es realizar una predicción de la trayectoria según los vientos. Es necesario tener conexión a Internet porque se usa un modelo de vientos muy preciso que se mantiene actualizado al día. Para ello usaremos la herramienta *Download balloon trajectory* en el botón *Path* de la barra de botones como se ve en la figura anterior. Cuando se conecta al servidor, aparece alguno de los mensajes de la figura siguiente. Es muy posible que salga el mensaje *Server is too busy* de servidor ocupado y deberemos intentarlo más tarde. El proceso tarda unos dos minutos por lo que si no sale el mensaje anterior de ocupado, es buena señal. Cuando termina, aparece la trayectoria del globo en el visor y el mensaje *Download completed* de descarga completada que se ve en la segunda figura.



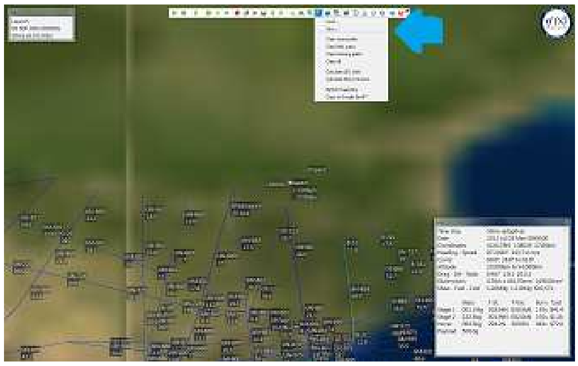
Por último vamos a exportar la trayectoria a Google Earth en formato KML para terminar el informe. Si tenemos Google Earth instalado podemos copiarlo directamente a través de la herramienta *Copy to Google Earth*™ en el botón *Path* de la barra de botones como se ve en la figura siguiente.

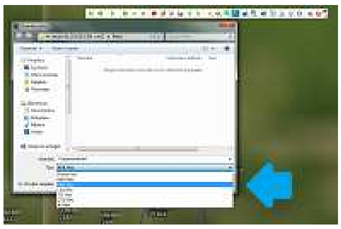


En la trayectoria se incluyen los puntos de lanzamiento, altura de control de 60.000 pies, la explosión del globo y el punto de predicción de impacto, tal y como se ve en la figura siguiente. Recomendamos poner el cursor sobre el punto de impacto antes de hacer la captura de pantalla para que queden registradas las coordenadas donde habrá que ir a buscar el globo.

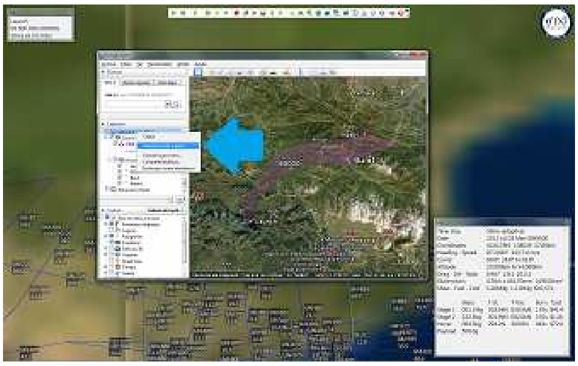


Para guardar el fichero en formato KML basta con guardar la trayectoria seleccionando el tipo de fichero correspondiente. Para ello usamos la herramienta *Save path* en el botón *Path* de la barra de botones como se ve en la figura siguiente.





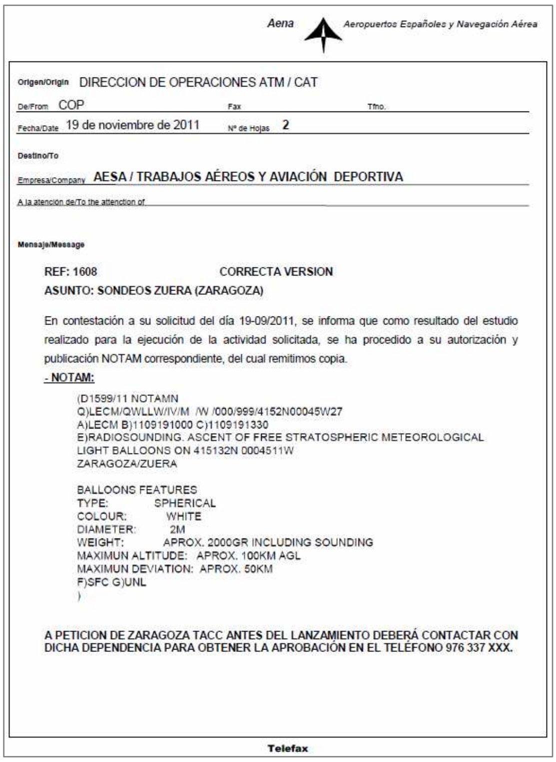
O bien usando el menú contextual del panel *Lugares* de Google Earth.



El informe debe enviarse a:

AESA. Servicio de Trabajos Aéreos y Aviación Deportiva
aviaciondeport.aesa@fomento.es

Nuestro NOTAM tendrá un aspecto parecido al de la figura siguiente. En él podemos observar los datos característicos del lanzamiento. Esta información la leen todos los pilotos afectados antes de iniciar el vuelo.



Aena — Aeropuertos Españoles y Navegación Aérea

Origen/Origin DIRECCION DE OPERACIONES ATM / CAT
De/From COP Fax Tfno.
Fecha/Date 19 de noviembre de 2011 Nº de Hojas 2

Destino/To
Empresa/Company AESA / TRABAJOS AÉREOS Y AVIACIÓN DEPORTIVA
A la atencion de/To the attenction of

Mensaje/Message

REF: 1608 CORRECTA VERSION
ASUNTO: SONDEOS ZUERA (ZARAGOZA)

En contestación a su solicitud del día 19-09/2011, se informa que como resultado del estudio realizado para la ejecución de la actividad solicitada, se ha procedido a su autorización y publicación NOTAM correspondiente, del cual remitimos copia.

- NOTAM:

(D1599/11 NOTAMN
Q)LECM/QWLLW/IV/M /W /000/999/4152N00045W27
A)LECM B)1109191000 C)1109191330
E)RADIOSOUNDING. ASCENT OF FREE STRATOSPHERIC METEOROLOGICAL
LIGHT BALLOONS ON 415132N 0004511W
ZARAGOZA/ZUERA

BALLOONS FEATURES
TYPE: SPHERICAL
COLOUR: WHITE
DIAMETER: 2M
WEIGHT: APROX. 2000GR INCLUDING SOUNDING
MAXIMUN ALTITUDE: APROX. 100KM AGL
MAXIMUN DEVIATION: APROX. 50KM
F)SFC G)UNL
)

A PETICION DE ZARAGOZA TACC ANTES DEL LANZAMIENTO DEBERÁ CONTACTAR CON DICHA DEPENDENCIA PARA OBTENER LA APROBACIÓN EN EL TELÉFONO 976 337 XXX.

Telefax

La normativa de uso de globos libres no tripulados se recoge en el Reglamento de circulación aérea del Real Decreto 57/2002. El apéndice S contiene toda la información sobre este tipo de actividades. Se recomienda su lectura antes de preparar una misión para saber qué se puede hacer y qué no.

References:

http://www.mtc.gob.pe/portal/transportes/aereo/regulaciones/docs/rap_rev15/rap101/rap_101_subparte_d_rev15.PDF

http://www.boe.es/boe/dias/2002/01/19/pdfs/C00001-00697.pdf

http://www.boe.es/boe/dias/1968/05/09/pdfs/A06766-06767.pdf

http://www.icao.int/Documents/annexes_booklet.pdf

REFERENCES — Interesting links

Simulator home page
http://code.google.com/p/moon-20

Adobe Reader
http://www.adobe.com

APRS tracking service
http://aprs.fi

Arduino community
http://arduino.cc/en

Astromechanics
http://www.stargazing.net/kepler/mean.html

Balloon trajectory forecasts - University of Wyoming
http://weather.uwyo.edu/polar/balloon_traj.html

Bing Maps
http://www.bing.com/maps

Caligari trueSpace 3D modeling software
https://en.wikipedia.org/wiki/TrueSpace

CelesTrak satellite tracking database
http://celestrak.com/NORAD/elements/master.asp

CPROPEP propellant simulator
http://sourceforge.net/projects/rocketworkbench

GFS atmospheric model
http://www.emc.ncep.noaa.gov/index.php?branch=GFS

Google Earth
http://earth.google.com

Google Maps
http://maps.google.com/maps

IEEE 754 floating point arithmetic standard
http://en.wikipedia.org/wiki/IEEE_754

IUPAC SI prefixes
http://old.iupac.org/reports/1993/homann/index.html

KML language used in Google Earth
http://code.google.com/apis/kml/documentation/kml_tut.html#placemarks

Lloyd Bailey 3D Airspace
http://www.lloydbailey.net/airspace.html

Lowell Observatory
http://www.lowell.edu

Material property data
http://www.matweb.com

MotorSim 2.0 rocket motor simulator
http://content.billkuker.com/projects/rocketry/software/motorsim-2-0

MSIS-E-90 atmosphere model
http://ccmc.gsfc.nasa.gov/modelweb/models/msis_vitmo.php

muParser math parser library
http://muparser.sourceforge.net

NACIS Natural Earth map data
http://www.naturalearthdata.com

NASA beginner's guide to aeronautics
http://www.grc.nasa.gov/www/k-12/airplane/guided.htm

NASA elevation data
http://pds-geosciences.wustl.edu/dataserv/holdings.html

NASA orbital debris reentry
http://orbitaldebris.jsc.nasa.gov/reentry/reentry.html

NASA Solar System Dynamics
http://ssd.jpl.nasa.gov

National Marine Electronics Association
http://www.nmea.org

NGA EGM2008 Earth Gravitational Model
http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm2008

NOAA World Magnetic Model
http://www.ngdc.noaa.gov/geomag/WMM

NORAD two-line element format
http://celestrak.com/columns/v04n03

PID controller design and tuning
http://www.controlguru.com/pages/table.html

OpenStreeMap project
http://www.openstreetmap.org

Propellants data base
http://www.astronautix.com/props/index.htm

RASP ENG file format
http://www.thrustcurve.org/raspformat.shtml

Richard Nakka's experimental rocketry
http://www.nakka-rocketry.net

Rocket propulsion
http://www.braeunig.us/space/propuls.htm

Solar wind and Atlantic South Anomaly
http://space.rice.edu/IMAGE/livefrom/sunearth.html

USGS GTOPO30 terrain elevation data
https://lta.cr.usgs.gov/GTOPO30

VERSION UPDATES **Source code**

2.0.091206.1320
- OpenGL viewer fully functional

2.0.091227.1042
- Lift / drag ratio physics and lift force limit in *Setup* window
- Statistics enable / disable in *Simulation* sub-menu
- Time & path points time selection in *Options* sub-menu
- *Preset* sub-menu
- Custom font for panels and 3D viewer labels
- Knots and Mach speed in *Data* panel
- Vertical speed in *Data* panel
- Compact *Setup* window mode

2.0.100106.1234
- Atmosphere and ionosphere transparency
- Gravity field around Earth and Moon
- Altimeter viewer tool
- Multiple paths commands and *Path* sub-menu
- Multiple display commands
- Team Frednet logo on the 3D viewer
- Sun texture

2.0.100115.1051
- Earth & Moon park orbit timer in *Setup* window

2.0.100120.0931
- Ground radio-station networks from “Stations.csv”
- Custom engines from .ENG files

2.0.100121.2012
- Some bugs fixed

2.0.100125.1627
- All data files moved to subdirectories
- Splash window at startup
- Sun shadow option in *Options* sub-menu

2.0.100202.2340
- Loop mode instead of timer to use 100% of the CPU
- Locations / propellants moved to subdirectories
- Camera distance in *Data* panel
- Second 3D viewer panel
- Separated default preset and config file
- Save path (not log) as KML

2.0.100206.1127
- Variables in config file
- Custom braking distance in *Setup* window
- 3D spaceship icon and size option
- Compact *Data* panel mode

2.0.100212.2033
- Date and time system to calculate all planets position
- All solar system planets
- Ecliptic reference plane only

2.0.100217.1539
- Variables in preset files
- Equatorial and orbital reference planes

2.0.100222.1921
- Elliptical planets orbits

2.0.100228.1516
- Sun gravity physics
- Earth-Moon-Sun gravity options in *Simulation* sub-menu
- All planets motion
- Spaceship orbit plane viewer tool
- Spaceship pitch angle in *Data* panel

2.0.100306.0051
- Resizable *Setup* panel and custom font
- All planets gravity physics
- All planets gravity option in *Simulation* sub-menu

2.0.100308.0349
- Textures for Earth, Moon and Sun in DDS format
- Textures for all planets in DDS format
- 3D models for all planets
- *Follow*, *LookAt* and *RelativeTo* modes for all planets

2.0.100314.1004
- 3D Viewer presets in *Options* sub-menu
- All planets collision detection

2.0.100321.1212
- Mars atmosphere and landing sequence

2.0.100326.1244
- Chemical calculator for the *Propellant editor*

2.0.100401.1219
- Separated *Setup* and *Propellant editor*
- Color themes option in *Options* sub-menu
- Thrust curve profiles
- Spaceship lift off detection

2.0.100402.1910
- Hidden lines option in *Tools* sub-menu
- Smooth lines option in *Tools* sub-menu
- Starfield background

2.0.100404.2029
- Data information in *Graph* panel

2.0.100411.1633
- Drag coefficient profiles in *Setup* panel
- Air pressure and temperature in *Data* panel
- Sound speed detection

2.0.100415.0032
- Planet approach detection
- Temperature and expansion ratio in *Propellant editor*

2.0.100420.2350
- Thermodynamics calculation
- Spacecraft temperature in *Data* and *Graph* panels
- Planet shadow option in *Simulation* sub-menu
- Graph time option in *Options* sub-menu
- Stars list and drag profiles moved to *Data* folder
- Altitude curve for Earth and Mars atmosphere

2.0.100428.1245
- Separated *Setup* and *Stages* panel
- Diameter, length and emissivity parameters in *Stages* panel
- Electrical power parameter in *Stages* panel
- Radio-stations visibility detection
- Radio-stations visibility in *Graph* panel
- *Log events* sub-menu in context menu
- *Auto save* sub-menu in context menu

2.0.100508.0003
- Add and remove stage buttons in *Stages* panel
- Angle of attack effect on lift force
- Lift force vector in 3D viewer
- Solar wind calculation
- Solar wind option in *Simulation* sub-menu

2.0.100511.2328
- Spherical and ellipsoidal terrain options in *Simulation* sub-menu

2.0.100518.2039
- Matrix terrain option in *Simulation* sub-menu
- Ground altitude in *Data* panel
- Added *Terrain* folder for “Terrain.bin” file
- Report file tool

2.0.100528.1248
- 3D model for Earth terrain
- Ground level in *Data* panel
- Terrain option in *Tools* sub-menu
- Grid step option in *Options* sub-menu
- Time and data scales in *Graph* panel

2.0.100603.1044
- English units in *Data*, *Log* and *Graph* panels
- Units option in *Options* sub-menu

2.0.100615.1308
- 3D model for Moon and Mars terrain
- Ground altitude for Moon and Mars
- Terrain scale and quality options in *Options* sub-menu
- Data relative to *Target* planet in *Data* panel

2.0.100623.1217
- Adaptive step option in *Simulation* sub-menu
- Take screen snapshot with F12 key

2.0.100712.1007
- *Link* panel added for external link control
- RS-232 and UDP-IP link protocols supported
- Arduino IMU source example in *Remote Control* section
- Arduino IMU source example in *Source/Arduino* folder
- Launch trajectory control flag in *Link* panel
- Landing maneuver control flag in *Link* panel
- Log input, output and full data options in *Link* panel
- Wait for device and test mode options in *Link* panel
- Added Link error event to identify inconsistent simulation
- Total impulse and specific orbital energy in *Data* panel

2.0.100719.0937
- Binary mode for link protocol
- Binary and text mode options in *Link* panel
- Double precision option in *Link* panel

2.0.100903.2053
- 3D models in .COB text format loaded from *Models* folder
- Added *Models* folder for custom 3D models
- Angular kinetics and trajectory correction for launch trajectory
- Target pitch angle and deviation in *Data* panel
- Propellant burn rate and burn time in *Stages* panel
- Spacecraft position of all paths in 3D viewer
- Default textures changed from DDS to BMP

2.0.100914.1623
- Import KML trajectories for *Path* sub-menu

2.0.100916.2306
- Presets in *Preset* sub-menu sorted by type of mission
- Trajectory control option in *Simulation* sub-menu
- Flat render mode and Flat view option in *Options* sub-menu
- *Flat view* and *Orthogonal* options in *View* panel context menu.

2.0.100920.2033
- 3D model for spaceship in Flat view
- Radio-stations visibility detection in Flat view
- Import and export snapshots in KML files

2.0.100924.2044
- Vertical sync option in *Options* sub-menu

- Import and export multiple paths in KML files

2.0.100930.1935
- Earth atmosphere glow render tool
- Separated options for *Vectors* and *Ranges* in *Tools* sub-menu

2.0.101013.0053
- Mars atmosphere glow render tool
- Target planet orbit added to *Ranges* sub-menu
- Clone view options in *View* panel context menu
- FOV option in *Options* sub-menu

2.0.101024.0009
- Gravity field option in *Options* sub-menu

2.0.101107.0056
- Added *Toolbar* panel
- Scale option for *Gravity field* render tool
- Total simulation time and speed in *Log* panel

2.0.101109.1648
- Added more buttons to the *Toolbar*
- Context menu and size option for the *Toolbar*
- Activate or deactivate all buttons in *Toolbar* context menu

2.0.101111.1420
- Hidden all objects that are obscured by the planets
- Customize option in *Toolbar* context menu

2.0.101122.1804
- Reference manual accessible in *Help* panel
- Added Onboard follow mode
- Added *Sensors* folder for onboard sensor list
- Sensors option in *Options* sub-menu
- Satellite control option in *Simulation* sub-menu
- Planet apoapsis and periapsis events

2.0.101129.1545
- Sensor Crosshair, FOV and Labels options in *Tools* sub-menu
- Video recording with **Ctrl+Alt+PrtScr** or *Toolbar* button
- Video record options added to *Options* sub-menu

2.0.101204.2233
- Added *Toolbar* folder for the *Toolbar* icons
- Added *Videos* folder to store recorded videos
- Video FPS option in *Options* sub-menu
- Added Google Earth link in *Panels* sub-menu

2.0.101205.2310
- Paths stored in memory are listed in *Path* sub-menu
- Copy to GE option added to *Path* sub-menu
- Help file accessible from *Help* panel in PDF format

2.0.101224.0933
- Tracking mode in *Link* panel for external GPS tracking
- Added Port 2 option in *Link* panel for second GPS tracking
- Added "Geoid.bin" file for Earth geoid elevation data
- Geoid altitude option in *Options→Units* sub-menu
- Save data option in *Graph* panel

2.0.110112.2002
- Rover link mode in *Link* panel for external rover tracking
- Added Port 3 option in *Link* panel for Rover link mode
- Waypoint list editor in *Link* panel for Rover link mode
- Tracking path saved in KML format file in *Presets* folder
- Tracking log option in *Link* panel
- Tracking sync option in *Link* panel
- Save log option in *Link* panel
- Added icons for waypoint list editor in *Images* folder
- Stage *Delay* used before the stage burn, not after it

2.0.110207.1028
- Balloon trajectory option in *Path* sub-menu
- Added *Web browser* panel
- *Links* menu to *Panels* sub-menu
- "Links.lst" file in *Data* folder with web links
- *Target* menu in *RelativeTo* sub-menu
- Added Planet proximity event

2.0.110210.2013
- Trajectory prediction tool in *Tools* sub-menu
- *Antialiasing* menu in *Options* sub-menu
- Added Planet faraway event

2.0.110219.1957
- Added *Notepad* panel
- Save log option moved to *Log* panel context menu
- Relative time option in *Options→Units* sub-menu

2.0.110303.1433
- *Notepad* variables saved in "Variables.lst" in *Data* folder
- Reference lines in 2D map of *Link* panel

2.0.110312.2036
- Added *Preset editor* panel
- Extended parameters for every stage in *Stages* panel
- Parachute, attitude control, electrical and thermal parameters
- Initial angle and overview in *Setup* panel
- Airways and RNAV routes in render tools

2.0.110318.1648
- PID controller parameters for the attitude control in *Stages* panel
- Maximum attitude control thrust in *Data* panel
- Add, Delete and Clear options in *Locations* sub-menu
- Add, Delete and Clear options in *Links* sub-menu

2.0.110411.1753
- PID controller and deviation angle for satellite control
- Moment of inertia parameters in *Stages* panel
- Onboard sensor option in *Panels* sub-menu
- Sensor Deviation and Trace tools in *Tools* sub-menu
- Degrees only and Magnetic moment in *Options→Units* sub-menu
- *Look at→Star* sub-menu for star tracking in Onboard sensor
- Added Default FOV option in *FOV* sub-menu
- Edit Model, Preset and Star tracker options in *Notepad* panel
- File "StarTracker.lst" in *Data* folder with brightest stars
- Labels option in *Options→Stars* sub-menu
- Magnetic field tool in *Options→Gravity* field sub-menu
- File "Wmm.cof" in *Data* folder for WMM 2010 model library
- TLE file format in Save path dialog

2.0.110419.1211
- Edit Report and Lenses options in *Notepad* panel
- Fixed font option in *Notepad* panel
- Added "Report.txt" example file to *Logs* folder
- File "Lenses.lst" in *Sensors* folder for sensor lenses list
- Lenses option in *Options→Sensors* sub-menu
- Magnetic lines and planes tool in *Options→Gravity field* sub-menu
- Report font option in *Options* sub-menu
- Star kinetics options in *Simulation* sub-menu

2.0.110510.1516
- Angle option in *Options→Stations* sub-menu
- Rover control buttons in *Link* panel
- Rover commands text box in *Link* panel
- Commands option in *Notepad* panel
- File "Rover.ini" in *Models* folder with rover commands list
- Center of mass and 3D model parameters in *Stages* panel
- Emissivity calculation from the 3D model materials
- 3D model lighting from the Sun and the nearest planet
- Multi-stage option for stage type in *Stages* panel

2.0.110517.1542
- Default 3D models in *Models* folder
- Rover 3D model view for the *Link* panel
- Stages and payload 3D model view in *Stages* panel

2.0.110526.2023
- Options in context menu moved to *Options* panel
- *Toolbar* events buttons changed to Events control button

2.0.110531.1205
- 3D model view in *Stages* panel moved to a 3D model panel
- Models list added to the *Link* panel commands menu
- Refresh models option added to Models menus

2.0.110614.1018
- Folder option for 3D models and textures in *Models* folder
- Support for BMP, JPG, PNG, TIF and GIF textures
- Added Station and Tracking 3D models to *Models* folders
- APRS tracking option for Tracking link mode
- Settings text box for COM port configuration in *Link* panel
- User and Password for server connection in *Link* panel
- Save password option in *Link* panel
- Save log option changed to Auto save log in *Link* panel

2.0.110623.2348
- Capture mode option changed in *Options* panel
- Added 3D models for the empty stages to *Models* folders
- Simulation of the balloon and the empty stages trajectories
- Added Balloon trajectory option to *Simulation* options
- Added Empty stages option to *Simulation* options
- Removed Star kinetics option from *Simulation* options

2.0.110717.2253
- Calculate LEO orbit option in *Path* sub-menu
- Screen and video options moved to *Screen* tab in *Options* panel
- Panels font option in *Options* panel

2.0.110727.1845
- Added *Video player* panel
- Added Real time speed option to *Simulation* options

2.0.110907.2045
- Calculate Moon mission option in *Path* sub-menu
- Airways option moved to *Options* tab in *Options* panel
- Magnetic field vector tool in *Tools* options

2.0.110913.1556
- Log to file options in *Simulation* options
- Tool tips for the parameters in *Data* and *Graph* panels
- *View* panel can be larger than desktop for high sensor resolutions

2.0.111014.1531
- 2D map detached from *Link* panel
- Online maps available for *Map* panel
- Map, link model and stage model options in *Panels* sub-menu

2.0.111026.1308
- Moon and Mars online maps for *Map* panel
- Search engine for *Map* panel
- Web links for the online maps added to *Links* menu

2.0.111201.1850
- Terminal link mode in *Link* panel
- RS-232 and TCP-IP link modes changed to Control mode
- Added global keys for all the panels
- Added *360º player* panel to play panoramic videos

2.0.120103.0311

- Satellites group and distance options in *Options* panel
- Satellite proximity added to *Simulation* tab in *Options* panel
- Ground station visibility added to *Simulation* tab in *Options* panel
- Added Satellite proximity event
- Update satellites option in *Path* sub-menu
- Added *Satellites* folder and "Satellites.csv" file for satellite data
- Load and convert NMEA log to KML file in *Path* sub-menu

2.0.120209.2025

- New appearance for the buttons in the panels and the *Toolbar*

2.0.120227.1852

- Added *Planets* folder for planets, moons and asteroids data
- Planets physical and orbital data in INI files at *Planets* folder
- Data files of stars and planet atmospheres moved to *Planets* folder
- Texture and 3D model for Saturn rings
- Some render options moved from *Tools* tab to *Options* tab
- Airways, star labels and magnetic field options moved to *Tools* tab
- Added asteroids, comets and moons render tools in *Tools* tab
- Added options to show or hide the labels in *Tools* tab
- Asteroid detection options in *Simulation* and *Events* tabs

2.0.120301.2046

- Object selection with left click on the 3D viewer
- Object information with double click on the 3D viewer
- *Information* overlay for the selected object

2.0.120306.1503

- Web information icon in the *Information* overlay
- Added *Sync mode* to the 3D viewer context menu

2.0.120315.1739

- Follow object mode in *Follow* sub-menu
- Double click an object to activate the *Follow* mode on it
- Textures and 3D models for the most important moons
- Add extra view option in *Panels* sub-menu
- Added Demos menu to *Presets* sub-menu
- Added Default settings option in *Presets* sub-menu

2.0.120330.1501

- Cursor for the selected object in the 3D viewer
- Added Hide selection cursor option to *Options* panel
- Added Object visibility option to *Options* panel
- Added Objects orbits option to *Tools* tab in *Options* panel
- Units options moved from *Options* tab to *Screen* tab
- Highlight orbit of the selected object in the 3D viewer
- Look at object mode in *Look at* sub-menu
- Auto-repeat function for the *PrevSnap* and *NextSnap* buttons
- Added *Search* panel to search objects in the database
- Icon for the *Search* panel in the *Information* overlay

2.0.120417.1508

- Target list for the satellite control in *Setup* panel
- Search objects by group in *Search* panel
- Sort list by name in *Search* panel
- Multi-selection in target list and *Search* panel list
- Object selection in all *View* panels

2.0.120507.1750

- Added *Payload camera* panel for video input and streaming
- Video and audio device selection in *Payload camera* menu
- Streaming video option in *Payload camera* menu
- Open URL option in *Video player* menu to play a video stream
- Video stream option in *Panels* sub-menu to play a video stream
- Window size options in 3D viewers and Video panels
- Added Compass tool to *Tools* tab in *Options* panel
- Added Switch to menu to *Panels* sub-menu with all active panels
- Minimize button in the message popup

2.0.120525.1934

- Added camera selector to *Payload camera* panel
- Video stream and Refresh camera buttons in camera selector
- Add View, Player and Camera options in *Panels* sub-menu

2.0.120619.0222

- Atmosphere tool added to *Tools* tab in *Options* panel
- Atmosphere layers options in *Options* panel
- Added Update atmosphere option to *Path* sub-menu

2.0.120626.1856

- Added *Atmosphere* folder for atmospheric model files
- Calculate balloon trajectory option in *Path* sub-menu
- Calculated balloon trajectory shown in *Graph* panel

2.0.120719.0047

- Added Simulation and Balloon menus to *Graph* panel
- Added Data menu to *Data* panel context menu
- Added atmosphere Temp and Speed rows to *Data* panel
- Atmospheric model option in *Simulation* tab of *Options* panel
- Wind speed option in *Simulation* tab of *Options* panel
- Added initial splash image to *Images* folder
- Option to create shortcuts in desktop and start menu at first run
- Added *Trajectory editor* for the trajectory calculation parameters
- Added button in *Setup* panel to show the *Trajectory editor*
- Calculate trajectory options moved to *Trajectory editor*
- Close all panels option in *Panels→Switch to* sub-menu

2.0.120728.1237

- Planets position tool using the mission time in *Trajectory editor*
- Selection Ruler tool when selecting objects with Ctrl+click
- Camera *RelativeTo* mode selection with Shift+click
- Spacecraft can be selected as an object
- Added Isp values in *Stages* panel to override propellant defaults
- Added Apsis, Period, Angles and Camera rows to *Data* panel
- Default panels option in *Panels→Switch to* sub-menu

2.0.120829.1622

- Audio tracking option for Tracking link mode
- Added Distances render tool to *Tools* tab
- Color table overlay for the Atmosphere render tool
- Added Magnetic field row to *Data* panel

2.0.120920.1530

- Heading and elevation for selection Ruler tool in *Tactic* mode
- Compass and Distances tools aligned with North in *Tactic* mode
- Select and Fixed tracking options for Tracking link mode
- Added Extended Log option to *Log* panel
- Removed Data panel style option from *Screen* tab
- Added Show 3D icons option to *Options* panel
- Added Tracking follow and Path altitudes options to *Link* panel
- Added Refresh time sub-menu to *Link* panel
- Options in *Link* panel menu moved to a sub-menu
- Added Update airspaces option to *Path* sub-menu
- Added "Airspaces.bin" and "Airports.csv" files to *Airways* folder
- Added Airspaces and Airports options to *Options* panel
- Some options in *Options* tab moved to *Screen* tab
- Added Object collision probability row to *Data* panel

2.0.120928.1359

- Enter and exit airspace events in *Events* tab of *Options* panel
- Airspace detection option in *Simulation* tab of *Options* panel
- Airspace detection data and background color in *Graph* panel
- High definition detection option in *Simulation* tab of *Options* panel
- Use font textures option in *Screen* tab of *Options* panel
- Panels style option in *Screen* tab of *Options* panel
- Color selection for the text in the panels and the 3D viewer
- Added Reset all settings option to *Preset* sub-menu
- Basic panels option in *Panels→Switch to* sub-menu
- Moved "Moon.dll" file to *Source* folder
- Added "DShow.dll" file to *Source* folder

2.0.121005.1403

- Color table overlay for the Gravity field render tool
- *Follow→None* and *LookAt→None* options changed to *Free*
- Free camera option in *Follow→Tactic/Object* camera modes
- Added labels option for Locations render tool in *Tools* tab
- Snap points check box moved to *Path→Labels* in *Tools* tab
- Added Apply changes button to the *Toolbar*
- Enhanced spacecraft model in GDI / 2D render

2.0.121021.1823

- System info option in 3D viewer context menu
- Added Rover, Station and Tracking model options to *Link* panel
- Added Relative angles option to *Link* panel
- Added "StationAntenna.cob" file to *Models* folder
- Ground station 3D icon points to the Tracking object
- Landing maneuver option in *Simulation* tab of *Options* panel
- Added Braking altitude event to *Events* tab of *Options* panel
- Added orbit time option to *Orbit* text box of *Trajectory Editor*
- Options in *Events* tab saved to the configuration file
- Active tab in *Options* panel saved to the configuration file
- Added images to some buttons in *Setup*, *Stages* and *Link* panels

2.0.121211.1808

- Real time speed for the balloon trajectory simulation
- Added Medium Earth orbit option to the *Trajectory editor*
- Added Minimize and Maximize buttons to the *Toolbar*
- Removed Exit application button from the *Toolbar*
- Added Inertial and Delta V G rows to *Data* panel
- Added "Seaport.csv" and "City.csv" files to *Airways* folder
- Added "Country.bin" and "Populated.bin" files to *Airways* folder
- Added Area detection and Log airspaces options to *Simulation* tab
- Added Seaports, Cities and Locations options to *Options* panel
- Added Land and Water boundaries options to *Options* panel
- Added Populated areas option to *Options* panel
- Some options in *Options* tab moved to *Screen* tab
- Added a button to calculate the propellant in *Propellant editor*
- Added a button to generate a graph in *Propellant editor*
- Precision options and configuration menu in *Propellant editor*
- Added *Graphs* folder for graphs generated by *Propellant editor*
- Added some CSV files with graph examples to *Graphs* folder
- Added *3D Graph* panel to show 3D propellant graphs
- Context menu in *3D Graph* panel with configuration options
- Reverse camera axes options in *Screen* tab of *Options* panel
- 3D model sub-menus in *Link* panel moved to the options menu

2.0.130117.1816

- Added View sub-menu to context menu in *3D Graph* panel
- Add and delete 3D graph options in *3D Graph* context menu
- Adjust Z scale option in *3D Graph* panel moved to Z scale menu
- Graph point selection with left click in *3D Graph* panel
- Option to add extra *3D Graph* panels in *Panels* sub-menu
- Added Data sub-menu to configuration menu in *Propellant editor*
- Added *Color selector* to configure all the colors in the 3D viewer
- Context menu in *Color selector* with color and font options
- Font configuration buttons in *Screen* tab moved to *Color selector*
- Video settings button in *Screen* tab converted to an image button
- Added some items to Sun shadow option in *Screen* tab
- Added Convert images to video option to *Path* sub-menu
- Added Boundaries tool to *Tools* tab in *Options* panel

2.0.130319.1853

- Added *Burn editor* to calculate the thrust curve of a solid propellant
- Calc button in *Burn editor* to generate thrust curves and engines
- Download map sub-menu in context menu of *Map* panel

2.0.130425.1110

- Removed Background option in *Screen* tab of *Options* panel
- Changed Panels style options in *Screen* tab of *Options* panel
- Atmospheric pressure option in *Screen* tab of *Options* panel
- Added options in *Color selector* for the panels and the 3D viewer
- Added options in *Color selector* for the *Burn editor* graph lines
- Calc button and output option changed in *Burn editor*
- Output format and Graph quality in Presets menu of *Burn editor*
- Burst pressure option and graph background in *Burn editor*
- Nozzle expansion calculation and graph background in *Burn editor*
- Chamber thickness and Maximum stress options in *Burn editor*
- Engine dry mass and End of thrust pressure options in *Burn editor*
- Mass or volume options for the propellant sizes in *Burn editor*
- Thrust, Pressure, Burn rate and Exp ratio in *Burn editor* graph
- Cursor in *Burn editor* graph to show data at specific burn time
- Engine specifications moved to a expanded panel in *Burn editor*
- Default and custom presets in *Burn editor* saved to *Engines* folder
- Burn rate curves loaded from BRN files in *Engines* folder
- Added “Materials.lst” for *Burn editor* materials in *Engines* folder
- Added context menu to graph in *Burn editor*
- Copy data and Save data options in *Burn editor* context menu
- Error detection of parameters in *Setup* and *Stages* panels
- Simulation errors option in *Screen* tab of *Options* panel
- Added High definition option in context menu of *Log* panel
- Added *Reload files* sub-menu to the *Presets* menu

2.0.130820.1053

- Added a button to calculate nozzle parameters in *Burn editor*
- Propellant burn progress at graph cursor position in *Burn editor*
- Added Burn preview option for default burn progress in *Burn editor*
- NMEA output and Align input axes options in *Link* panel menu
- Added Input axes mapping sub-menu to *Link* panel menu
- Mars distance event in *Events* tab changed to Planet distance
- *Relative to→Target* option affects also to the planet events
- Auxiliary panels moved to a sub-menu in *Panels* menu
- Added Application folder option to *Links* menu
- Added navigation buttons and address bar to *Web browser*
- Added Reverse zoom option to *Screen* tab of *Options* panel

2.0.130917.1123

- Time stamp, visible area and pixel size in *Onboard sensor* view
- Time stamp and FOV Area options in *Tools* tab of *Options* panel
- *Onboard* video capture mode in *Screen* tab of *Options* panel
- Satellite and asteroid faraway in *Events* tab of *Options* panel
- Balloon trajectory saved with preset in KML and CSV file formats
- Airspace and station detection in Balloon trajectory simulation
- Option to deploy the satellite in Moon park text box of *Setup* panel
- Added presets with Moon and Mars polar orbits for planet mapping
- Added Selected option to *Locations* sub-menu of *Setup* panel
- Added Tooltip delay option to *Screen* tab of *Options* panel
- Added 3D models for the stars of the star tracker
- Added nearest stars to the *Follow→Object* camera mode
- Camera distance limit increased to view all the nearest stars
- Added high zoom options to the camera FOV sub-menu

2.0.140128.1150

- Updated NOTAM tutorial in English version
- Added Asymmetric option to the 3D viewer context menu

2.0.140716.1905

- Added Ship scale option to *View* panel context menu
- Added Normalize axes option to *Options* sub-menu of *Link* panel
- Current atmosphere layer option in *Options* panel
- Added labels option for Wind speed vectors in *Options* panel
- Color options for gravity field, air temperature and wind speed
- Earth texture option in *Screen* tab of *Options* panel
- Added Clouds, Day, Night and White textures for Earth 3D model
- Planet textures converted from BMP to JPG format
- Added Total impulse option to Extended log in *Log* panel
- Error detection for the trajectory calculation in *Trajectory editor*
- Corrected an error in a component of the "Propellant.dat" file

2.0.141203.1252

- Graph link mode in *Link* panel
- Added a button to show the *Input graph* in *Link* panel
- Added *Input graph* panel to show the data in Graph link mode
- Context menu in *Input graph* with configuration options
- Added a button to show the *Remote control* in *Link* panel
- Added *Remote control* panel to configure the remote control
- Moved control buttons from *Link* panel to *Remote control* panel
- Moved Input axes option from *Link* panel to *Remote control* panel
- Added independent configuration for every link type in *Link* panel
- *Path→Convert to KML* option can also convert CSV files
- *Path→Update asteroids* option updates also the comets file
- Mission time used for fixed-volume balloons in *Trajectory editor*
- Graphs for the nozzle throat and exit calculation in *Burn editor*
- Added Copy image option to simulation, burn and input graphs

Current version

- Added Star Burner option to *Burn editor*