



SSVG User's Guide

Solar System Voyager

植月修志 (Shushi Uetsuki/whiskie14142)

July 23, 2021

Revision 1.5.0 (for SSVG version 1.5.0 or later)

Contents

What is SSVG?	1
What's new in recent Versions	1
Version 1.5.0.....	1
What Can We Get with SSVG?	2
How to Use this Document	4
License of SSVG	5
License of this Document.....	5
Contact the Author.....	5
How to Use SSVG	6
Install and Uninstall SSVG.....	6
Windows Executable.....	6
Python Scrips (Source Programs).....	6
Run SSVG	8
Windows Executable.....	8
Python Scripts.....	8
Run Flight Plans	8
Open a Flight Plan	8
Execute a Maneuver	10
Execute Maneuvers	12
Review the Recent Flight.....	12
Fly New Probe	14
Create New Flight Plan	14
Start the Spaceflight	15
Fly Away from the Space Base.....	16
Accelerate the Probe.....	17
Decelerate the Probe	18
Accelerate the Probe Laterally	19
Fly the Probe Freely	20
Fly the Probe toward Mars	20
Gravity Assist of Jupiter	21
Flight Plan toward Venus	24
Create a New Flight Plan	24
START Maneuver	24
FLYTO Maneuver (1).....	26

CP Maneuver	26
FLYTO Maneuver (2).....	26
FLYTO Maneuver (3).....	27
Flight Plan toward Small Celestial Body.....	27
Sample of Small Celestial Bodies.....	27
Reference Manual	29
Basic Terms.....	29
Probe.....	29
Space Base	29
Maneuver	30
Flight Plan	31
Target	31
Chemical Propulsion Engine	32
Electric Propulsion Engine	32
Solar Sail.....	32
Trajectory and Orbit.....	33
Windows and Operations.....	34
Overview.....	34
SSVG Window.....	35
3D Orbit Window.....	38
Show Orbit Window.....	40
Flight Review Window	42
Review Throughout Window.....	44
Maneuver Editor Window	46
New Flight Plan Window	48
Edit Probe Properties Window	49
Select New Target Window	49
FTA Setting Window.....	50
START Optimize Assistant Window.....	51
CP Optimize Assistant Window.....	54
Maneuver Description Window	57
Maneuver Description Editor Window.....	58
Coordinate systems.....	59
Ecliptic Coordinate System.....	59
Orbit Local Coordinate System	59
Solar Sail Coordinate System.....	60
B-plane Coordinate System	61

Miscellaneous Information	62
Folders for Users	62
Time	62
Numerical Integration of the Probe Trajectory	63
Two-body Motion of the Probe	63
Position and Velocity of Planet	63
Position and Velocity of Small Celestial Body	63
Propulsion Systems and Rocket Equation	64
Get SPK File of Small Celestial Body	65
Operational Log	67
Thrust Vector Mode	67
Extending to Other Languages	68
Samples of Flight Plans	70
About Planetary Ephemeris Files	70
System Configuration	71
References	72

What is SSVG?

SSVG (Solar System Voyager) is simulation software. It allows us to fly our own spacecraft in the solar system. Each Probe (spacecraft) in SSVG has three propulsion systems; they are a Chemical Propulsion Engine, an Electric Propulsion Engine, and a Solar Sail.

In SSVG, we send off our Probe to its voyage from one of the Space Bases maintained in space; we do not need to launch the Probe from the surface of the Earth.

In SSVG, we compose a Flight Plan to fly our Probe to its destination. The major part of the Flight Plan is Maneuvers that instruct the Probe about its operations. The Maneuver of SSVG has seven types. One type is for starting a spaceflight, another is for flying the Probe, and others are for activating or deactivating one of the propulsion systems.

Throughout the composition of a Flight Plan, SSVG draws positions and orbits of the Probe on a three-dimensional (3D) chart, and we can manipulate (rotate, zoom, etc.) it. SSVG draws positions and orbits of the Target (a celestial body at which the Probe is targeting) on the chart as well.

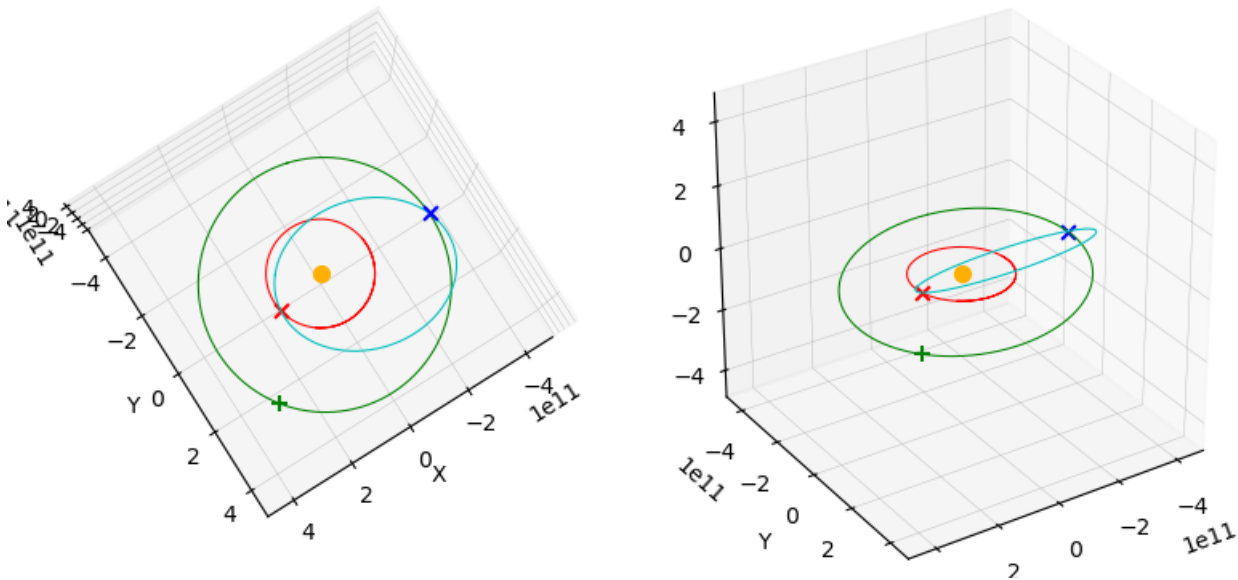


Figure 1 3D charts of SSVG

What's new in recent Versions

Version 1.5.0

Accepts Latest Planetary Ephemeris File

SSVG version 1.5.0 (and later) can use the file “de440.bsp”, one of the latest planetary ephemeris files provided by NASA/JPL. You can use the older file “de430.bsp”, but the installer of SSVG does not contain the file. See the [About Planetary Ephemeris Files](#) subsection for more detail.

Projection type of the 3D Orbit was Improved

SSVG version 1.5.0 (and later) can use Parallel Projection to draw figures on the 3D Orbit Window. You can choose Perspective Projection also. See the [System Configuration](#) subsection for more detail.

What Can We Get with SSVG?

What can we get with SSVG? There are several samples.

Change Orbit of the Probe

Do you have any questions for spaceflight as follows?

- When I accelerate my spacecraft, how does it change the orbit?
- When I accelerate it more violently, what happens?
- When I decelerate it, what happens?
- When I accelerate it laterally, what happens? By the way, which direction is “lateral” in the outer space?

We can look for the answers to these questions by ourselves. In SSVG, we can change the velocity of the Probe, see the resulting orbit drawn on the 3D chart, and manipulate (rotate, zoom, etc.) the chart to grasp the shape and the orientation of the orbits.

Unplanned Space Flight

Do you dream of flying in the space freely?

In the actual world, making a spacecraft arrive at the desired celestial body is hard to achieve, even if the spacecraft is in the outer space. Because significant orbital transitions require a large amount of propellant, an actual spacecraft should be launched into an orbit carefully designed in advance, and the spacecraft should fly to its destination only with small intermediate orbital corrections. Almost all spaceflights are such pre-planned ones.

In SSVG, we have entirely different choice for the strategy to perform a spaceflight. We can fly the Probe with a “Try and Discover” manner.

Gravity Assist

Do you know a gravity assist? Do you want to try it?

A fly-by of a spacecraft around a planet changes the orbit of it sometimes slightly, sometimes violently. We can use the orbital change to assist our spaceflight. In this case, we call the fly-by “gravity assist” or “swing-by.”

Because Jupiter is the heaviest and the nearest planet of giant planets of the solar system, the gravity assists around it played essential roles on many space flights bound to the outer region of the solar system.

SSVG computes realistic trajectories of the Probe, including gravity assists around planets. SSVG provides a convenient tool to use gravity assists for spaceflights. Let us try some gravity assists around Jupiter in SSVG.

Replication of Actual Spaceflights

Do you not have any questions for actual spaceflights as follows?

- How fast was the spacecraft relative to the Earth when leaving?

- How fast was the spacecraft relative to the celestial body when arriving?
- What was the reason for the spacecraft left the Earth just on the day?
- What was the reason for the spacecraft arrived at the celestial body just on the day?
- The spacecraft flew to the destination after a swing-by of Jupiter; why did it not fly direct?

We can replicate actual spaceflights as Flight Plans of SSVG. During the composition of the Flight Plans, we will find answers to previous questions by ourselves.

Two pictures of Figure 2 show a replicated trajectory of Voyager 2, one of the most famous space probes of NASA/JPL. It left the Earth in 1977, with tremendous speed of about 10 kilometers (6.25 miles) per second. It visited all of four giant planets sequentially and completed observations of all of them, and even now, it is continuing its spaceflight beyond the boundary of the solar system.

The left side picture of Figure 2 shows the entire replicated trajectory from 1977 to the end of 2020. A small ellipse in green shows the orbit of Neptune, which is the outermost giant planet of the solar system. At the end of 2020, the space probe is about 20 billion kilometers (12.5 billion miles) away from the Sun; this distance is 133 times the distance of the Earth from the Sun. The right-side picture shows a close-up. At several places, the trajectory of the space probe (curved line in blue) indicates steep bents provided by the gravity assists around the giant planets.

Although we intended to replicate the actual spaceflight, the trajectory is not so accurate.

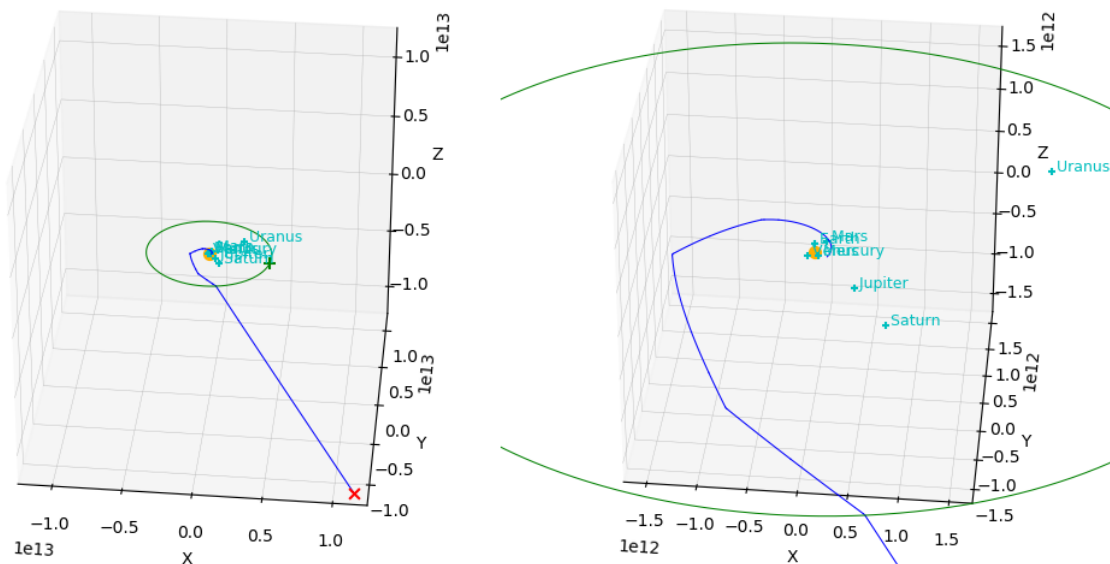


Figure 2 Replicated trajectory of Voyager 2

Composition of feasible Flight Plan

Do you want to compose a “feasible” Flight Plan?

In SSVG, we can choose any flight path of spaceflight. On the other hand, we cannot do so in an actual spaceflight; an actual spacecraft should use very “economical” passes because a spaceflight imposes a strict limitation for propellant.

Feasibility of a space flight has many aspects, but efficiency (small initial velocity, small delta-V of orbital transitions, etc.) is one of the largest keywords. Let us compose an efficient Flight Plan in SSVG. Achieving this, we have to decide two key parameters appropriate for the spaceflight, the date to leave the Earth and the flight time. SSVG has tools to decide them, powerful and easy to use.

Electric Propulsion

Do you want to use electric propulsion?

During recent years, electric propulsion systems of ion thrusters or Hall-effect thrusters were playing essential roles in several space missions exploring asteroids and Ceres, a dwarf planet. They have a large advantage in propellant efficiency over conventional chemical rockets. However, they have a disadvantage in the magnitude of the thrust. A typical electric propulsion system accelerates a spacecraft very slowly (up to ten meters per second for twenty-four hours). Because of the low thrust, an orbital transition requires a very long time (e.g., one hundred days) in many cases. It makes the planning of spaceflights difficult.

Rest assured. The electric propulsion engine in SSVG is very easy to use and very powerful. It can be used for low-thrust & long-time orbit transitions, and for high-thrust & short time orbit transitions either. Let us fly our Probe with the electric propulsion engine.

Solar Sail

Do you want to use a solar sail?

Solar sails are large mirrors attached to the spacecraft. They generate the thrust by reflecting the sunlight. Solar sails have a significant advantage in a spaceflight; they need no propellant and no energy to generate the thrust. However, we need very large sails to accelerate a spacecraft, because the pressure of the sunlight is very small. With current technologies, it is difficult to spread, turn, and hold such large sails in space.

No problem. In SSVG, we can spread the solar sail of a Probe at any time, to any size, and to any orientation. Let us fly our Probe with the solar sail.

How to Use this Document

This document (SSVG_UsersGuide-en.pdf) was reviewed with Adobe Acrobat Reader DC. The software can be downloaded from the following URL.

<<https://get.adobe.com/reader/>>

This document (a PDF document) has bookmarks of each chapter, section, etc. For convenience, we recommend that you turn ON the “Show Bookmarks” function (or equivalents) of the PDF reader in use.

In this document, links are in colored characters with an underline. Links to the internet are in blue (see the third line of this section). Links to each bookmark of this document are in green (e.g., [License of SSVG](#)).

License of SSVG

SSVG is free software; you can redistribute it and/or modify it under the terms of the GNU General Public License as published by the Free Software Foundation; either version 3 of the License, or (at your option) any later version.

This program is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU General Public License for more details.

You should have received a copy of the GNU General Public License along with this program; if not, see <<http://www.gnu.org/licenses>>

The source code (scripts of Python) of this program can be retrieved from:
<<https://github.com/whiskie14142/SolarSystemVoyager/>>

SSVG uses following programs and modules:

Python: <https://www.python.org/>
Numpy: <http://www.numpy.org/>
Scipy: <http://scipy.org/>
matplotlib: <http://matplotlib.org/>
PyQt: <https://riverbankcomputing.com/software/pyqt/intro>
jplephem: <https://github.com/brandon-rhodes/python-jplephem/>
julian: <https://github.com/dannyzed/julian/>
pytwobodyorbit: <https://github.com/whiskie14142/pytwobodyorbit/>
spktype01: <https://github.com/whiskie14142/spktype01/>
spktype21: <https://github.com/whiskie14142/spktype21/>
PyInstaller: <http://www.pyinstaller.org/>
Inno Setup : <http://www.jrsoftware.org/isinfo.php>

License of this Document

This document is dedicated to the public domain (CC0 1.0).
<<https://creativecommons.org/publicdomain/zero/1.0/>>

Contact the Author

E-mail: <<mailto:whiskie14142@gmail.com>>

Please note that it may take time to reply.

How to Use SSVG

Install and Uninstall SSVG

We distribute SSVG in two formats: one is an executable of Microsoft Windows with related modules and files, and another is a set of scripts (source programs) of Python with related files. You may use one of them or both.

Windows Executable

Install

You can get a Windows executable of SSVG from following web pages.

<http://whsk.sakura.ne.jp/ssvg/index-en.html> (*)

https://www.freewarefiles.com/Solar-System-Voyager-SSVG-program_112419.html

You can download an installer package named “SSVG_x_x_x_setup.exe” (x_x_x is a version number). Download it and run the installer package; the wizard will guide the installation process.

SSVG will be installed as follows by default.

- Installation folder:
[user root]¥AppData¥Local¥SSVG
(Note that “AppData” is a hidden folder)
- Group and shortcuts of the Start menu of Windows:
SSVG Solar System Voyager (a group)
Run SSVG (a shortcut to run SSVG)
User’s Guide (a shortcut to open the document you are reading now)
- Shortcuts on the Windows desktop:
SSVG (a shortcut to run SSVG)
SSVG User’s Guide (a shortcut to open the document you are reading now)

(*) You can download an old type distribution package of SSVG (a ZIP file) also, from the page.

Uninstall

To uninstall SSVG, follow standardized uninstall procedures of Windows; open the Control Panel of Windows and run “Uninstall a program” in “Programs”. You will find a line of “SSVG version x.x.x”; right-click the line and execute “Uninstall.”

PC environment

We tested SSVG on Windows 10 (64-bit version).

The required minimum size of the display is 1024 x 1280 pixels.

Installation of SSVG consumes roughly one-giga bytes of disk space.

Upgrade installation from older versions

Install the newer version of SSVG into the same folder. All SPK files and Flight Plan files will be maintained.

Python Scripts (Source Programs)

Install

If you have Python 3.8 with Numpy/Scipy/matplotlib/PyQt5, you may run SSVG in your Python

environment. You can retrieve a set of Python scripts (source programs) of SSVG and related files from GitHub.

<<https://github.com/whiskie14142/SolarSystemVoyager/>>

On the mentioned web page of GitHub, click “Clone or download.” You will get a ZIP file; open it with your convenient tool, and copy the “source” folder on your PC with its contents. We recommend you to rename the folder to “SSVG_x_x_x” (x_x_x should be the version number).

Uninstall

Delete installed folder with its contents.

PC environment

Python 3.8

The required minimum size of the display is 1024 x 1280 pixels.

Packages used and their versions

Numpy 1.20.1

Scipy 1.6.2

matplotlib 3.2.2

PyQt 5.9.2

jplephem 2.16

julian 0.14

pytwobodyorbit 1.0.0

spktype01 1.0.0

spktype21 0.1.0

The last five modules (jplephem, julian, pytwobodyorbit, spktype01, and spktype21) are on the Python Packages Index (PyPI), you can install them with pip commands.

Setup a Japanese Font

If you are using a Japanese environment, you need to set up a Japanese font for the matplotlib module. Go along with the following instructions.

- Copy a font file into the font folder of matplotlib
 - The ZIP file of SSVG downloaded from GitHub contains the font file. Name of the font file is `ipaexg.ttf`, and the path of the file within the ZIP file is:
`font¥ipaexg00301¥ipaexg.ttf`
 - The font folder of matplotlib is in your Python environment. The path is something like:
`[Python root]¥Lib¥site-packages¥matplotlib¥mpl-data¥fonts¥ttf`
- Erase font cache file of matplotlib. The path of the file is something like:
`[User root]¥.matplotlib¥fontList.json`

Get a Planetary Ephemeris File

Installed scripts of SSVG do not contain an essential data file to compute positions and velocities of the Sun and planets. Get the data file (a planetary ephemeris file, named `de440.bsp`) from following link, and place it in the “SSVG_data” folder within the folder of SSVG.

<http://naif.jpl.nasa.gov/pub/naif/generic_kernels/spk/planets/de440.bsp>

Upgrade installation from older versions

Previous procedures install new version of SSVG into a new folder. Copy following files from older installation to newer installation.

- SPK files you have downloaded: copy all of them into “SSVG_data” folder of newer installation
- Flight Plan files you have created: copy all of them into “SSVG_plan” folder of newer installation

Run SSVG

Windows Executable

Double click the shortcut of SSVG on your Windows desktop. Otherwise, open Start menu of Windows, open “SSVG Solar System Voyager” group, and click “Run SSVG.” A command prompt window appears, and then SSVG starts its execution.

Python Scripts

Run SSVG.py from Python. SSVG.py is contained within the folder in which SSVG is installed.

Run Flight Plans

Open a Flight Plan

On executing SSVG, we see two windows; they are SSVG window and 3D Orbit window. Because we have no valid Flight Plan yet, those windows do not display any meaningful information.

Click the “File” menu on the menu bar of the SSVG window, and execute the “Open” command. We see files within “SSVG_plan” folder; we can find several samples of Flight Plan. Select “sample_Mars” (or “sample_Mars.json” in some environments) among them and open it.

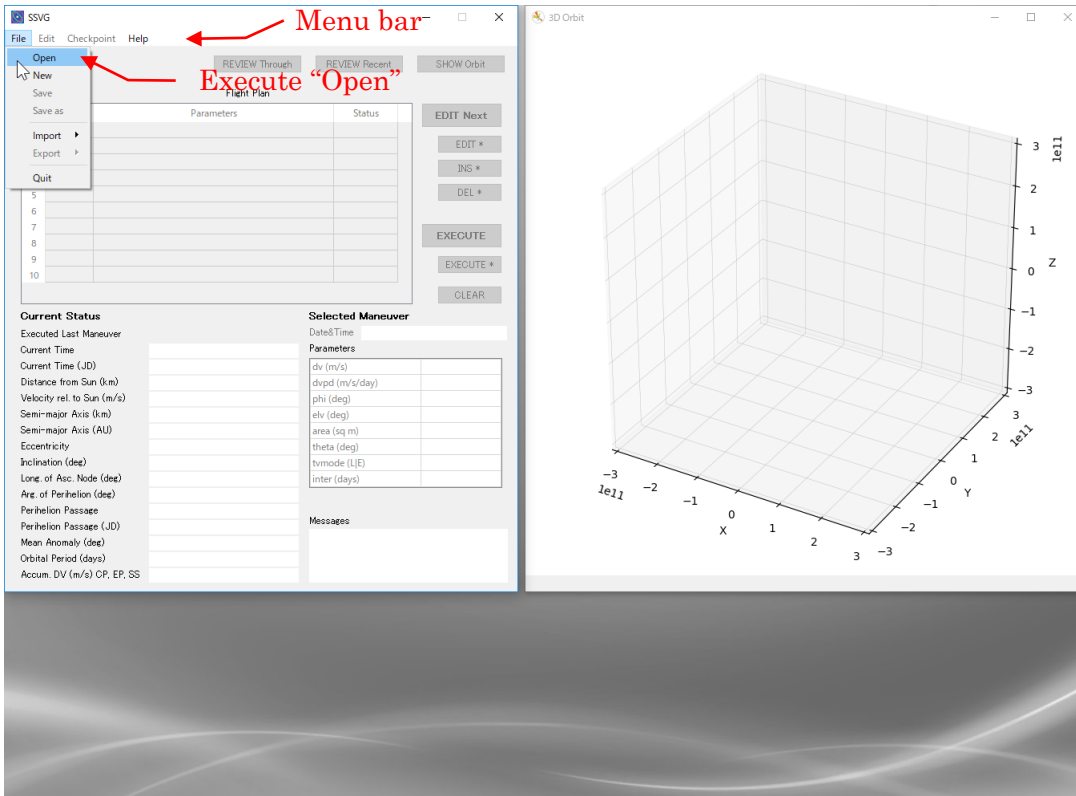


Figure 3 Execute "Open"

In this Flight Plan, a Probe named "MarsExp" starts its flight from a Space Base named "Earth L2", and flies to Mars. The SSVG window displays the Flight Plan as a table. Each line (row) of the table contains a Maneuver that instructs the Probe to execute an operation. We call the table "Maneuver Table" (see the following figure). As we execute Maneuvers in the table one by one, from top to bottom, the Probe flies from the Space Base to Mars.

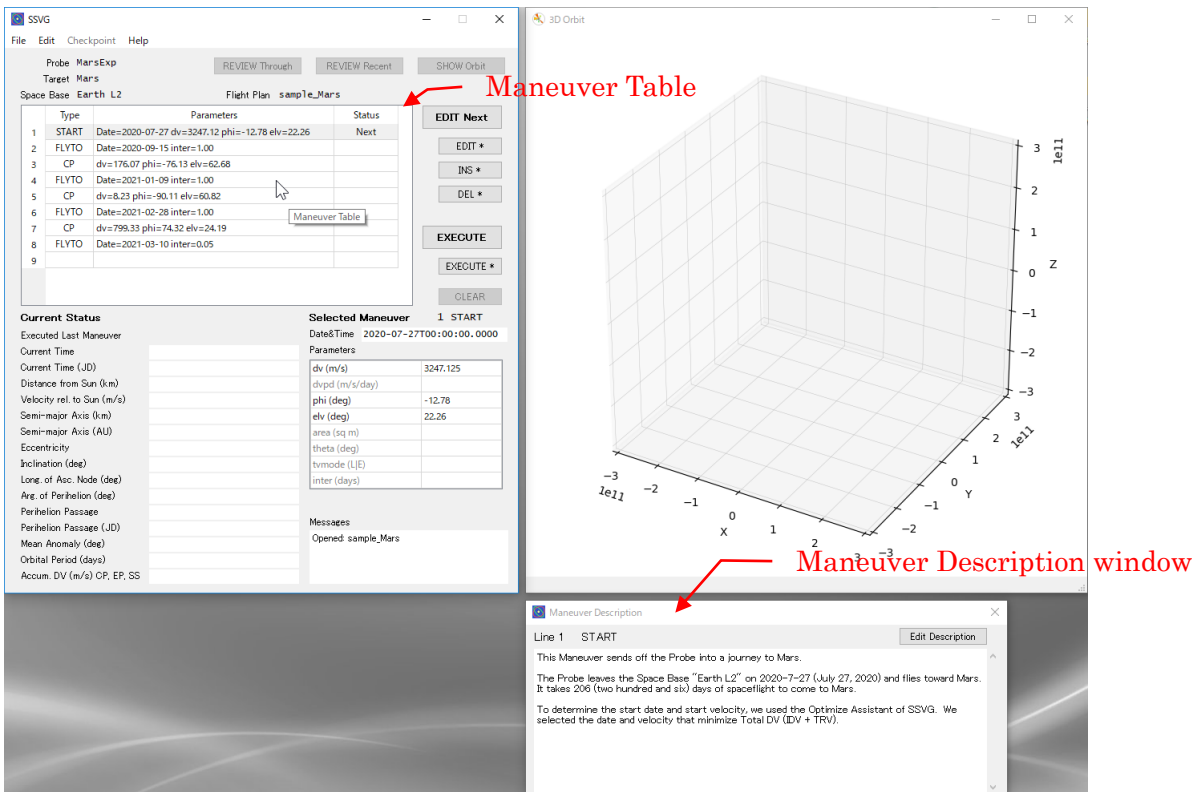


Figure 4 Maneuver Table

At this point, SSVG opens a window named “Maneuver Description” below the 3D Orbit window. The window shows the description of the selected Maneuver.

Execute a Maneuver

The Maneuver Table contains three columns labeled as Type, Parameters, and Status, respectively. The Maneuver Table contains one line (row) with a “Next” in the Status column. It indicates that SSVG will execute the line in the next execution. We call the line as Next Line.

Click [EXECUTE] button of the SSVG window. SSVG executes the Maneuver in the Next Line, and it opens a new window named “Show Orbit” (see the following figure).

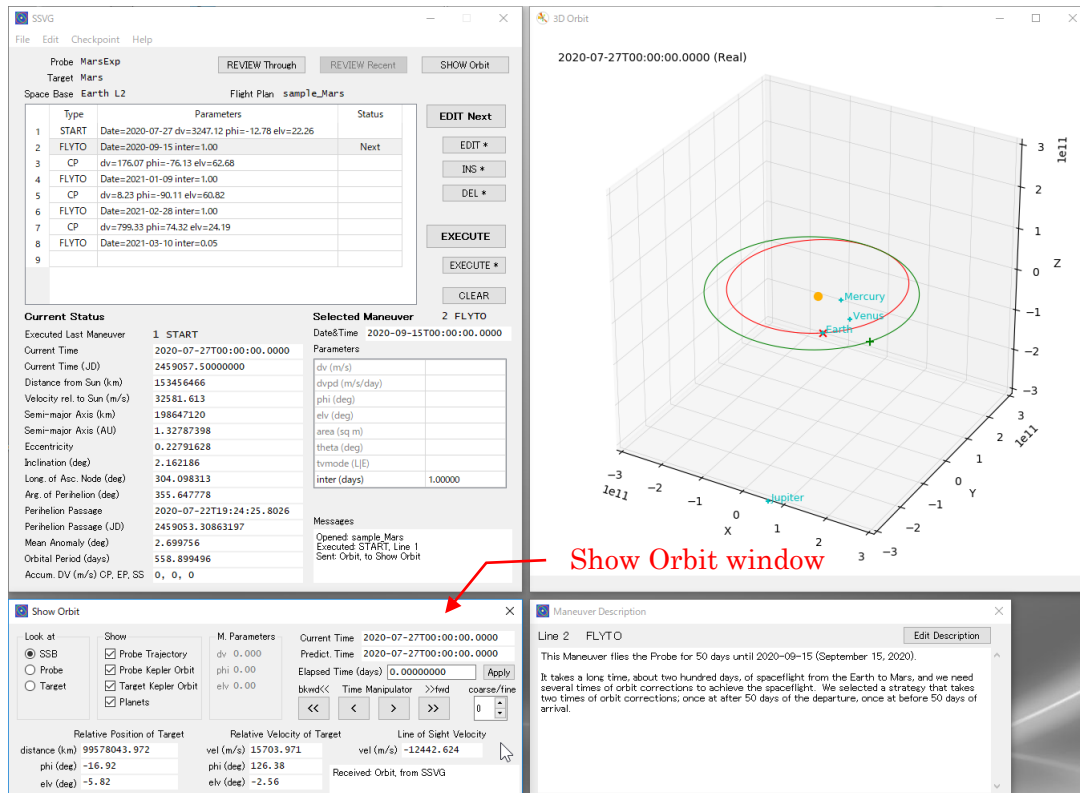


Figure 5 Show Orbit window

At the same time, the 3D Orbit window displays the following information as a three-dimensional (3D) chart that shown in the following figure.

- The Probe (an X mark in red)
- The orbit of the Probe (a curved line in red)
- The Target (a + mark in green)
- The orbit of the Target (a curved line in green)
- The Sun (a small disk in orange)
- Planets (+ marks and names in cyan)

At this point (just after you opened sample_Mars and clicked [EXECUTE] once), the Probe left the space base just now and started its journey to Mars.

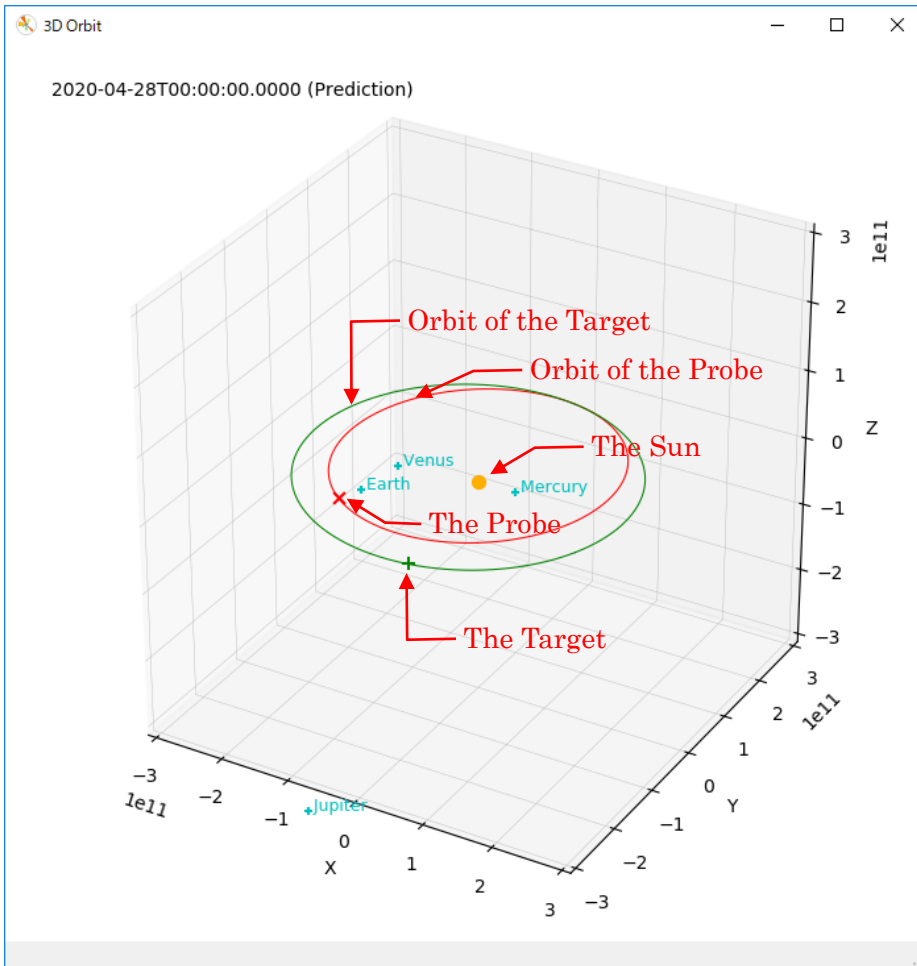


Figure 6 Information displayed on the 3D Orbit window

Let us try manipulating the 3D chart displayed on the 3D Orbit window. Place the mouse cursor on the 3D Orbit window, and move it up and down or right and left with the left button held down; it makes the 3D chart rotate. Move the mouse cursor up and down with the right button held down; it makes the chart zoom in and out. In addition, you can resize the 3D Orbit window by dragging each side or corner of the window.

Some operations on the Show Orbit window manipulates the 3D chart; click the [$>>$] button in the “Time Manipulator” (see the following figure) several times. The operation changes the 3D chart to show positions of the Probe, Mars (the Target), and other planets in the future.

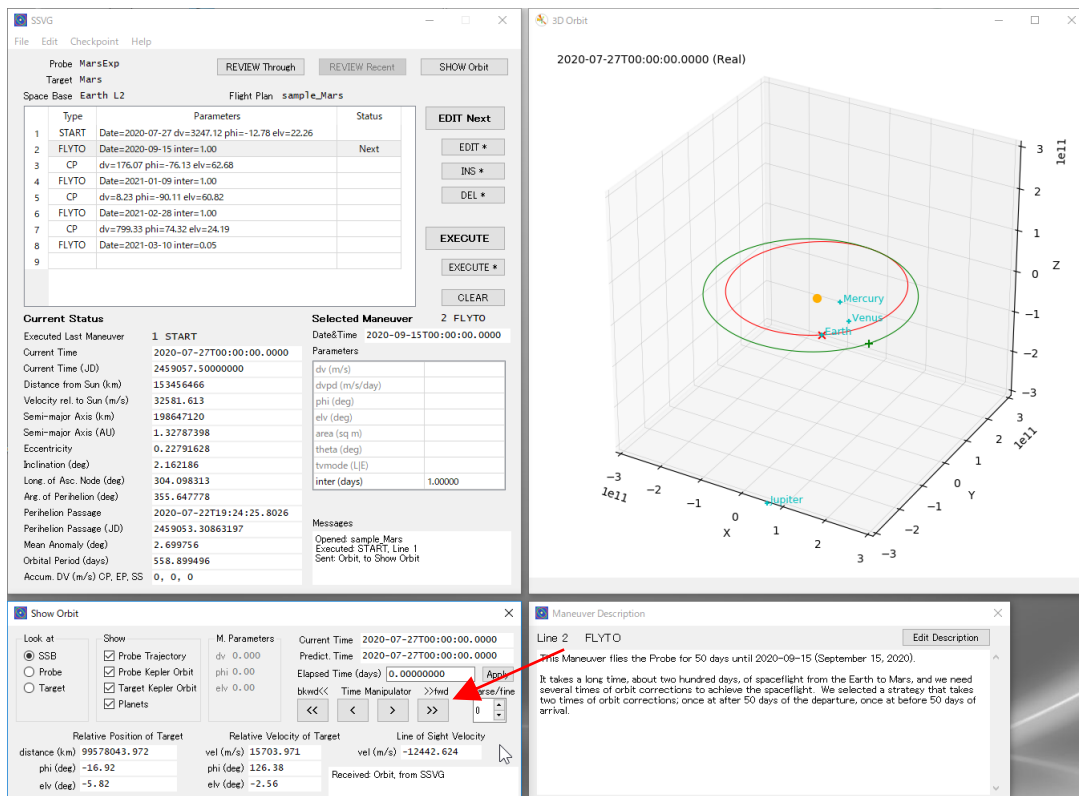


Figure 7 Time Manipulator

Execute Maneuvers

Let us execute the next three Maneuvers. Click the [EXECUTE] button three times; SSVG will execute three Maneuvers next in the table one by one, toward the bottom of the table: the Maneuvers in the second, third, and fourth line (row).

In SSVG, there are seven types of Maneuvers. This sample uses three types of Maneuvers as follows:

START Maneuver: The Probe starts the spaceflight with a specified velocity.

FLYTO Maneuver: The Probe flies until a specified time.

CP Maneuver: The Probe uses the Chemical Propulsion Engine and makes an orbital transition.

You can see explanations of all seven types of Maneuvers in [Maneuver](#) subsection.

Review the Recent Flight

Immediately after the execution of a FLYTO Maneuver, you can review the flight. At this point, we can review the FLYTO Maneuver in the fourth line (row) of the Maneuver Table. Click the [REVIEW Recent] button of the SSVG window. A Flight Review window replaces the Show Orbit window. With clicking buttons of its Review Manipulator (see the following figure), you can see the progress of the flight on the 3D Orbit window. As you click the [>] button repeatedly, you see the Probe (the X mark in red) flies on its orbit toward Mars (the Target: the + mark in green).

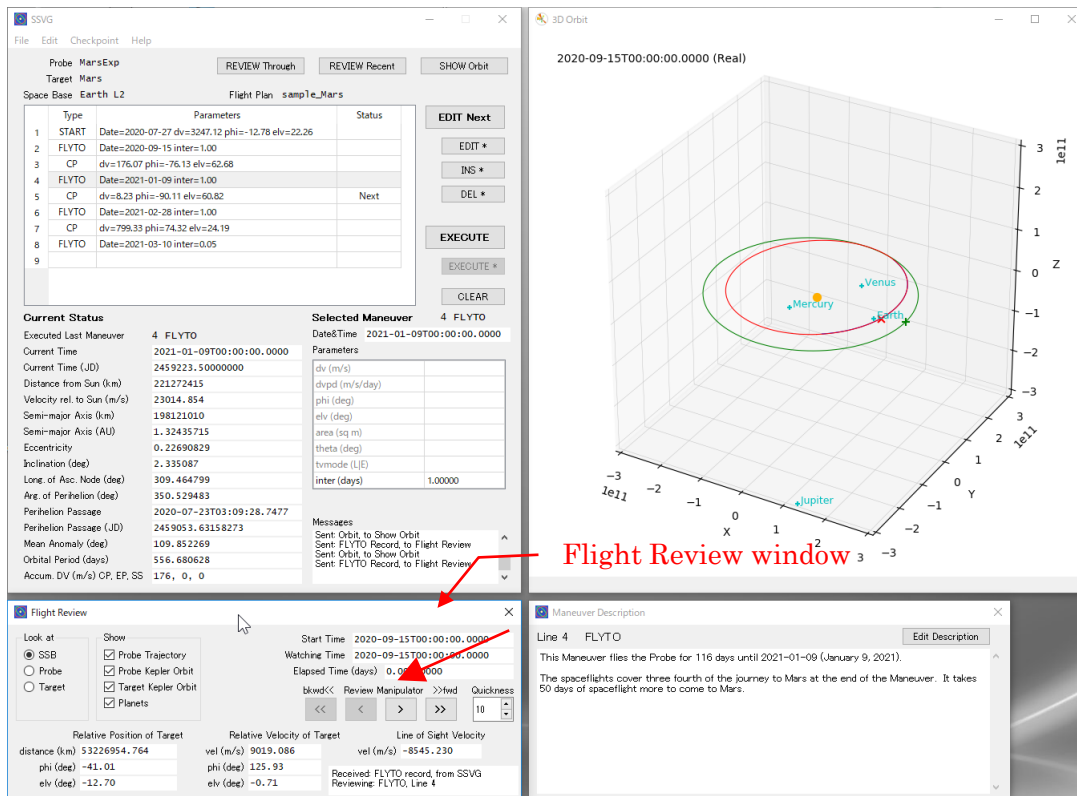


Figure 8 Flight Review window

Let us review the last FLYTO Maneuver of this Flight Plan. Click the [EXECUTE] button several times on the SSVG window, and let the ninth line (a blank line) of the Maneuver Table shows a “Next” in the Status column. Then click the [REVIEW Recent] button on the SSVG window to review the last Maneuver.

At this point, the Probe is very close to the Target (Mars); the distance is less than 9000 kilometers (5625 miles). Because the distance is very short in the scale of the solar system, the chart on the 3D Orbit window displays the Probe and the Target at almost the same position. We need to get a close-up view of the Target and the Probe to make detailed observations.

Let us place the Target at the center of the chart, get a close-up view, and review the flight. The hints for these operations are as follows:

- How can we place the Target at the center of the chart?
Select the [Target] radio button in the “Look at” group on the Flight Review window.
- How can we get a close-up view of the chart?
Place the mouse cursor on the 3D Orbit window, and move it downward with the right button held down.
- How can we rotate the chart?
Place the mouse cursor on the 3D Orbit window, and move it up/down or right/left with the left button held down.
- How can we follow the flight?
Click the buttons of the “Review Manipulator” on the Flight Review window.

If you want to know precise manipulation methods, see [3D Orbit Window](#) and [Flight Review Window](#) subsections.

Fly New Probe

Let us compose a Flight Plan of a new Probe.

Create New Flight Plan

To create a new Flight Plan, click the “File” on the menu bar of the SSVG window, and execute the “New” command. A New Flight Plan window appears.

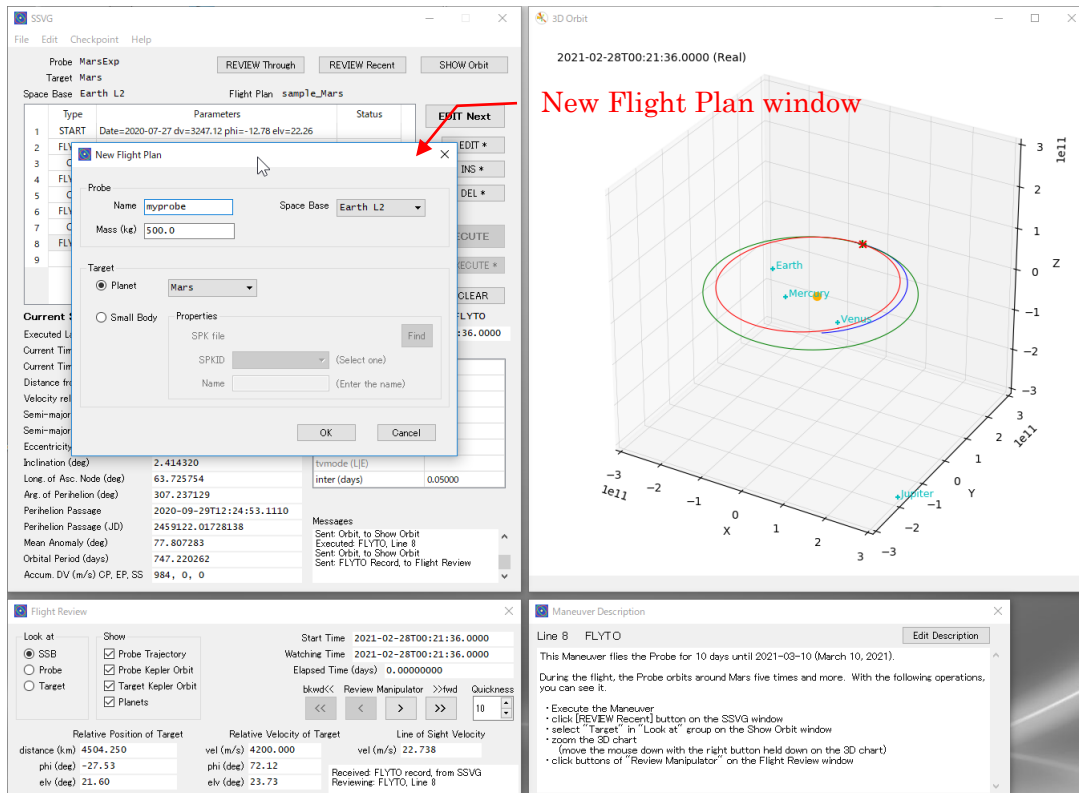


Figure 9 New Flight Plan window

With the “Probe” group, we can specify the name and mass of the Probe, but in this case, let us use the default values. We can select one of the Space Bases in the drop-down list, but let us use the default “Earth L2” now. This Space Base is orbiting the Sun with the Earth. Its position is approximately 1.5 million kilometers (940 thousand miles) away and opposite to the Sun, from the center of the Earth.

On the “Target” group, let us select the “Planet” radio-button, and select Mars as a Target in the drop-down list.

When you clicked the [OK] button, SSVG creates a new Flight Plan and displays it on the Maneuver Table. Because the Flight Plan has not any Maneuvers yet, the Maneuver Table is empty but one blank line with a “Next”.

It is a good custom to save an editing Flight Plan at the adequate timing. Let us click the “File” of the menu bar, and execute the “Save as” command to save the Flight Plan with an appropriate name.

Start the Spaceflight

Let us add the first Maneuver to the Flight Plan. The Maneuver should start the spaceflight of the Probe. The Maneuver Table is empty but a line with a “Next” in the “Status” column. Click the [EDIT Next] button to edit the line. A Maneuver Editor window appears, and a Show Orbit window also appears below the Maneuver Editor window.

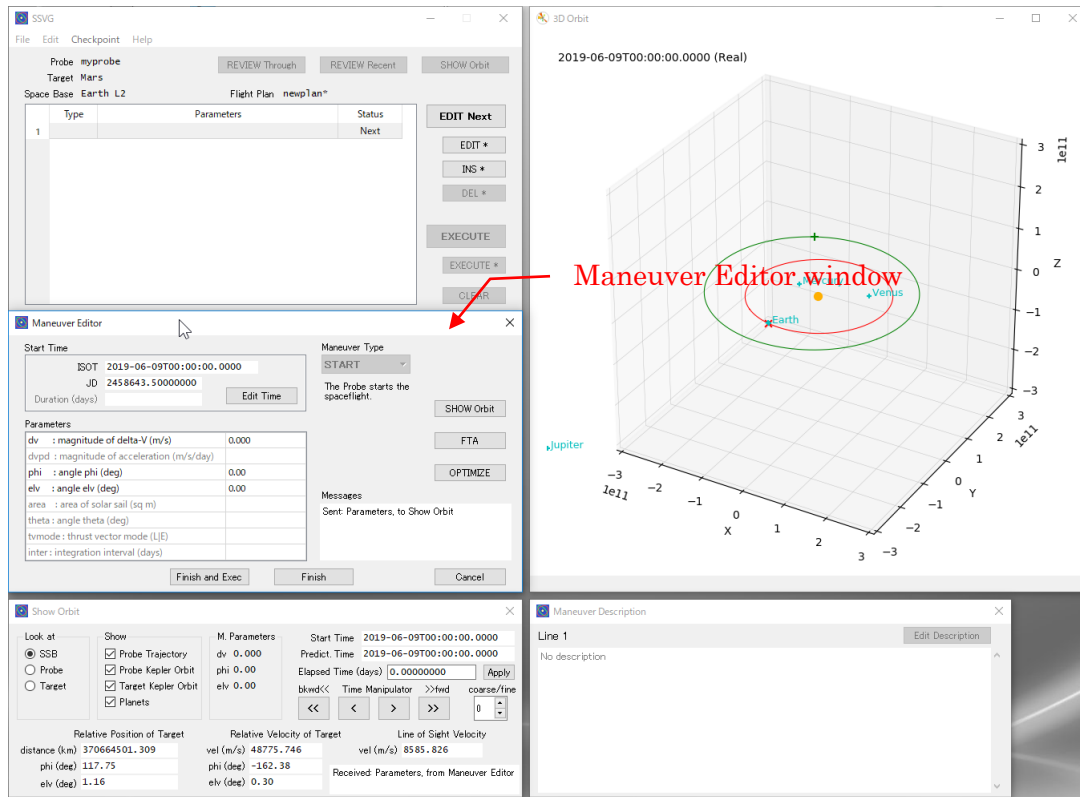


Figure 10 Maneuver Editor window

In this case, the Maneuver Editor is editing a START Maneuver, and the 3D Orbit window shows the current position and orbit of the Probe and other objects. On the Maneuver Editor window, the Start Time is zero o'clock of the current date (the day we are operating SSVG). The three parameters (dv, phi, and elv) in a table named “Parameters” are zero for each. Those parameters specify the start velocity (magnitude and direction) of the Probe. The Start Time and the parameters are editable now.

Now, let us edit the parameter dv and modify the value from 0.000 to 2500. Click the “0.000” in the first line (row) of the Parameters Table, and rewrite the value from 0.000 to 2500 (see the following figure). Leave other parameters (phi and elv) unchanged. This modification changes the magnitude of the delta-V (*1) of the Maneuver from zero to 2500 (in meters per second). The direction of the delta-V is the same as the velocity of the Space Base (*2).

(*1) For a START Maneuver, delta-V means the velocity of the Probe relative to the Space Base when it leaves the Space Base.

(*2) In this case, velocity means the one relative to the Sun.

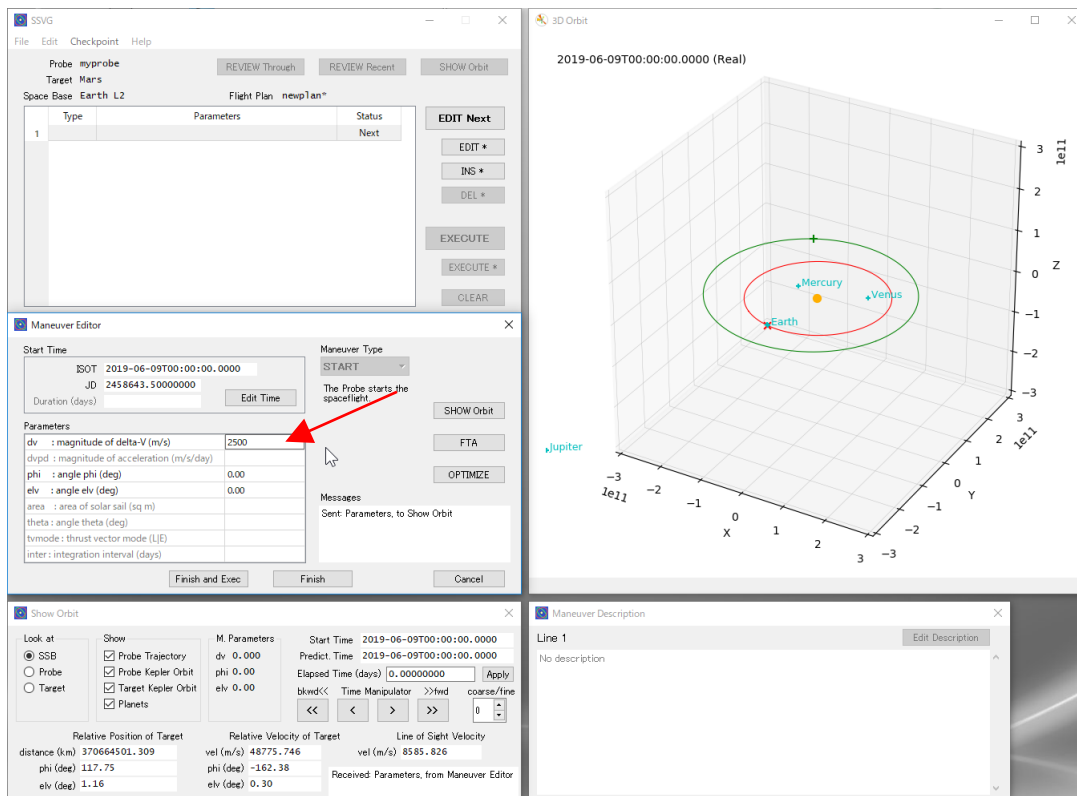


Figure 11 Maneuver Editor window (editing a START Maneuver)

Click the [SHOW Orbit] button on the Maneuver Editor window. The modified parameter is applied temporarily to the Show Orbit window and the 3D Orbit window.

Click the [Finish and Exec] button on the Maneuver Editor window. SSVG stores the START Maneuver into the Maneuver Table and executes it. The Probe is on its journey now. Confirm that the Maneuver Table on the SSVG window contains the START Maneuver and the indication of “Next” is on the second line (row).

Fly Away from the Space Base

Our Probe began its spaceflight, but it has not moved yet. Let the Probe fly away from the Space Base. We use a FLYTO Maneuver to fly the Probe; let us add it to the Maneuver Table.

Confirm that the second line of the Maneuver Table is a blank line with a “Next” on the “Status” column, and click the [EDIT Next] button of the SSVG window. A Maneuver Editor window appears again. In this case, you should click the drop-down list of Maneuver Type and select the “FLYTO”. The Maneuver Editor window becomes the one for a FLYTO Maneuver, and a Show Orbit window appears again.

Let us add a FLYTO Maneuver that flies the Probe for 50 days. On the Show Orbit window, click the [>>] button of the Time Manipulator (see the following figure) for five times. Clicking this button changes the prediction time; at the same time, it changes “End Time” of the FLYTO Maneuver on the Maneuver Editor window. Every time you click the button, the “End Time” of the Maneuver Editor window (ISOT, JD, and Duration) goes ahead by ten days.

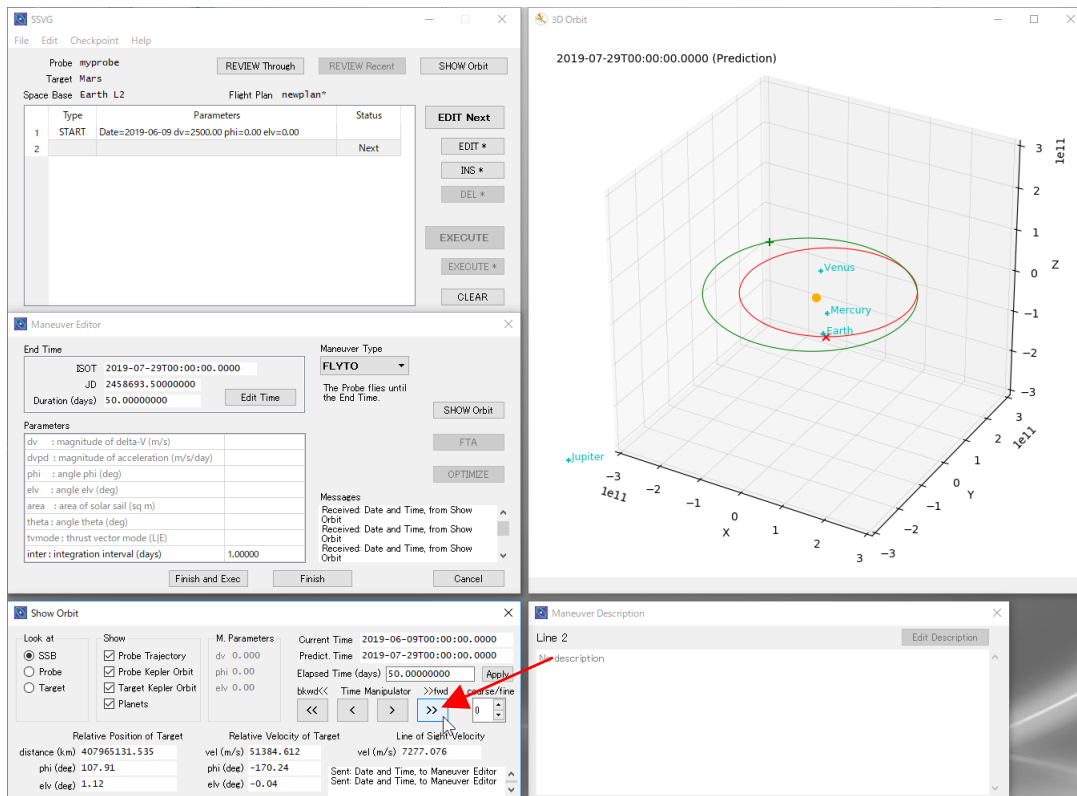


Figure 12 Set the End Time ahead

Confirm that the “Duration” on the Maneuver Editor window indicates 50 (days), and click the [Finish and Exec] button. SSVG stores the FLYTO Maneuver into the Maneuver Table and executes it. When the computation of the flight trajectory completes, the results are applied to the chart on the 3D Orbit window and to the “Current status” of the SSVG window. At this point, SSVG sets its “Current Time” forward, to the End Time of the FLYTO Maneuver.

Accelerate the Probe

Now, let us accelerate the Probe to find out what happens to the orbit of the Probe. For this purpose, we use a CP Maneuver that utilizes the Chemical Propulsion Engine of the Probe.

Confirm that the third line of the Maneuver Table is a blank line with a “Next” on the “Status” column, and click the [EDIT Next] button on the SSVG window. A Maneuver Editor window appears. Select “CP” for the Maneuver Type of this window.

For a CP Maneuver, there are three parameters to be specified, dv, phi, and elv. The parameter dv defines the magnitude of the delta-V. A delta-V is the velocity vector to be added to the Probe by this Maneuver, velocity increment in other words. The pair of phi and elv defines the direction of the delta-V.

Let us change the value for dv from 0.000 to 3000. Click the cell with 0.000 (see the following figure), and rewrite the value to 3000. Leave the values for phi and elv unchanged. With these parameters, the CP Maneuver accelerates the Probe by 3000 meters per second. It means that the Maneuver adds 3000 meters per second to the magnitude of the velocity of the Probe and does not change the direction of the velocity.

Now, click the [SHOW Orbit] button of the Maneuver Editor window. The Maneuver Editor applies the Parameters of the editing Maneuver to the Show Orbit window and the 3D Orbit window immediately, and you can find out the consequences of the Maneuver. Note that the applying is temporary and you need to execute the Maneuver to make it permanent.

If you wish, try other values for the parameter Δv . When you edit the value and click the [SHOW Orbit] button, SSVG shows you another orbit every time.

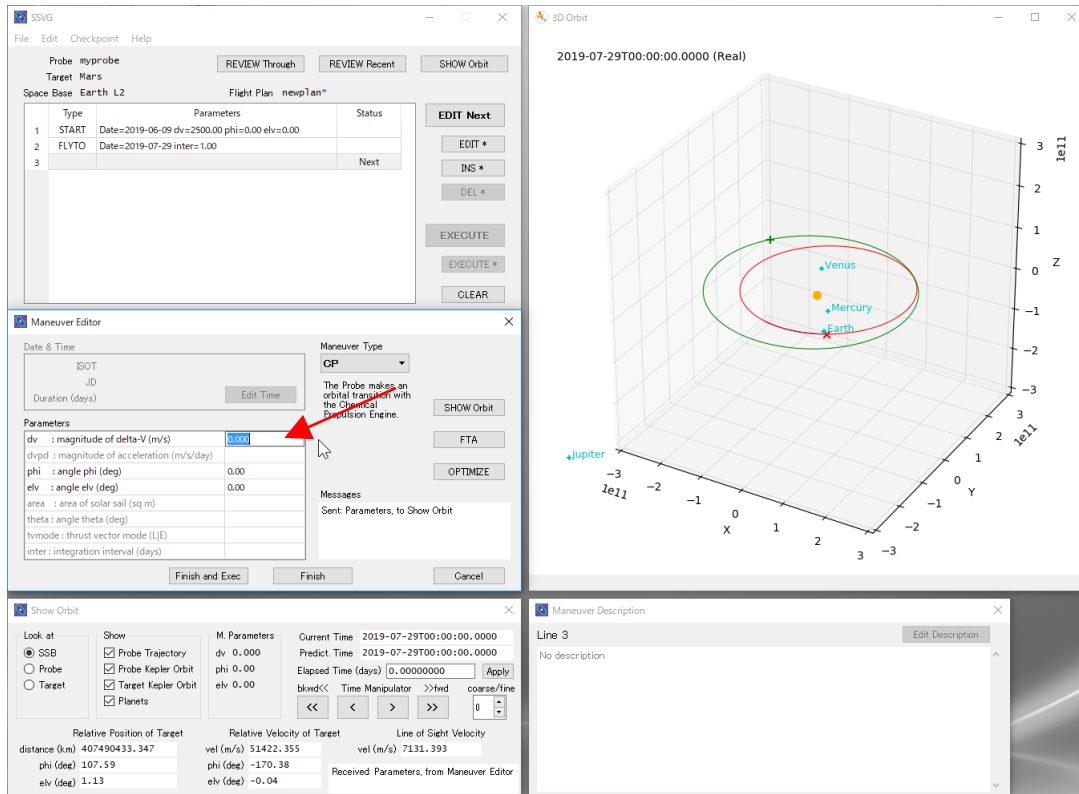


Figure 13 Maneuver Editor window for CP

Decelerate the Probe

When we do not accelerate but decelerate the Probe, what happens for the orbit? When we accelerate the Probe in other directions, what happens for the orbit?

Looking for answers to these questions, we need to assign appropriate values for parameters ϕ and elv . See the next figure. On the figure, ΔV indicates delta-V, which is the velocity vector to be added to the velocity of the Probe by the CP Maneuver.

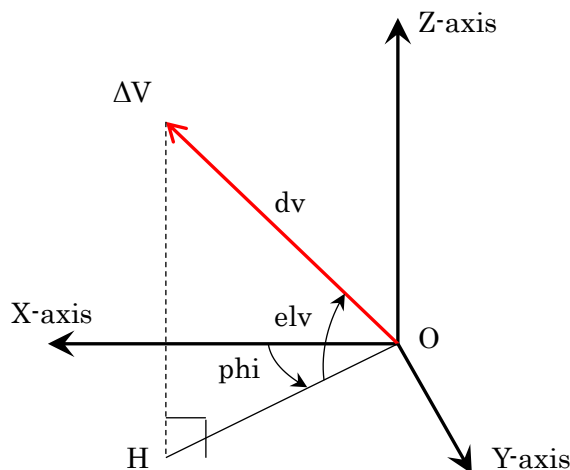


Figure 14 Defining parameters for delta-V

The origin (point O) of the axes is a Probe. The orbital plane of the Probe about the Sun defines the X-Y plane, and the velocity vector of the Probe defines the X-axis. The Z-axis is normal to the orbital plane of the Probe. The direction of Y-axis is to approach the Sun, it is perpendicular to both X- and Z-axes, and it completes the right-handed Cartesian frame. In SSVG, we call this coordinate system “Orbit Local Coordinate System.”

Drop a perpendicular line from the point of the ΔV to the X-Y plane, and name the foot point as H. The parameter phi is the angle from the X-axis to the line segment OH. The parameter elv is the angle from the line segment OH to the ΔV .

As you know already, the parameter dv is the magnitude of ΔV . We measure the parameter dv in meters per second, and the parameter phi and elv in degrees.

Let us study parameters to decelerate the Probe. For deceleration, ΔV should have the opposite direction for the current velocity of the Probe. In the coordinate system of Figure 14, the velocity vector of the Probe has the same direction to the X-axis. Therefore, the ΔV should be a vector opposite to the X-axis; it means parameter phi should be 180.0 (degrees) and parameter elv should be 0.0 (degrees). Try to decelerate the Probe and observe the orbits for several values of the parameter dv.

Accelerate the Probe Laterally

Let us accelerate the Probe laterally, precisely speaking, accelerate the Probe to a direction that is perpendicular to the velocity vector of the Probe. See the figure in [Decelerate the Probe](#) again.

Because the direction of the velocity vector of the Probe is the same as the X-axis, any direction perpendicular to it lies on the Y-Z plane. Let us use the following four directions as major examples.

- The direction of the Y-axis
- The direction opposite to the Y-axis
- The direction of the Z-axis
- The direction opposite to the Z-axis

The following table shows the values of parameters phi and elv for the four directions, along with the two directions described in the previous two subsections.

Table 1 Parameters for each Accelerating Directions

Parameters	Accelerating Directions					
	X-axis (acceleration)	Opposite to X-axis (deceleration)	Y-axis	Opposite to Y-axis	Z-axis	Opposite to Z-axis
phi	0	180	90	270 or - 90	(any value)	(any value)
elv	0	0	0	0	90	-90

Let us try these parameters on the Maneuver Editor window. Enter a set of parameters (dv, phi, and elv) into the “Parameters” table on the Maneuver Editor window, and click the [SHOW Orbit] button to observe the orbit of the Probe. Then, try other sets, repeatedly.

When these trials satisfied you, click the [Finish and Exec] button on the Maneuver Editor window to finish the editing of the CP Maneuver.

For observing orbits, it is very important to rotate the chart on the 3D Orbit window. In some cases, acceleration of the Probe results in the change of orbital inclination.

Fly the Probe Freely

In the previous subsections, we used the following three types of Maneuvers.

- **START** Maneuver: The Probe starts its spaceflight from a Space Base.
- **FLYTO** Maneuver: The Probe flies until a specified time.
- **CP** Maneuver: The Probe performs an orbital transition using its Chemical Propulsion Engine.

Only using these three types of Maneuvers, we can fly the Probe freely, to anywhere we like in the solar system. Can you believe it? Try it by yourself.

We can change the orbit of the Probe by a CP Maneuver. However, the orbital change is not enough to fly the Probe freely. It is important to use FLYTO Maneuvers combined with CP Maneuvers. For example, once you added a CP Maneuver to change the orbit, in many cases need you a FLYTO Maneuver that flies the Probe, prior to another CP Maneuver.

Let us add Maneuvers one by one, and execute each of them.

As we saw many times, a typical way to add a Maneuver into the Flight Plan is to edit the last line (a blank line, sometimes with a “Next”) of the Maneuver Table. When we finish the editing, the Maneuver Editor stores the Maneuver in the line, and a blank line appears as a next one. However, there are other ways to edit the Maneuver Table.

We can delete a line, and we can add a blank line as follows:

- Delete a line: select the line and click the [DEL *] button
- Insert a blank line: select a line where you want to insert, and click the [INS *] button

To edit a line (a Maneuver) of the Maneuver Table, we strongly recommend that you make the line be the “Next Line” prior to the editing.

The Maneuver Table has a line with a “Next” in the “Status” column; we call the line “Next Line.” Only when we edit the “Next Line” can we use all functions of the Maneuver Editor; otherwise, we cannot use some of the key functions.

You can move the “Next” indicator with the following operations of buttons on the SSVG window.

- When you click the [EXECUTE] button, the indicator moves downward by one line
- When you click the [CLEAR] button, the indicator moves to the top line

Fly the Probe toward Mars

Fly the Probe toward Mars, the fourth planet next to the Earth, orbiting around the Sun. Let us create a new Probe, and fly it away from the Space Base by following [Create New Flight Plan](#), [Start the Spaceflight](#) and [Fly Away from the Space Base](#) subsections.

In this Flight Plan, the Target is Mars. The orbit of the Target is an ellipse in green on the 3D Orbit window; the position of the Target is the + mark in green. Let us compose a Flight Plan toward Target. Use CP Maneuvers and FLYTO Maneuvers only. The goal is, the mark of the Probe (the X mark in red) has an overlap with the mark of the Target on the 3D Orbit window, after the execution of the last Maneuver of the Flight Plan.

There are some hints to compose the Flight Plan.

- To predict the positions of the Probe and the Target at time points in the future, click the [>>] button or the [>] button in the “Time Manipulator” group, on the Show Orbit window.
- To observe the orientations of the orbits and the relative positions of the Probe and the

Target, rotate the chart on the 3D Orbit window.

- To zoom-up,
 - place the Target at the center of the chart by selecting the [Target] radio button in the “Look at” group on the Show Orbit window,
 - place the mouse cursor on the 3D Orbit window and move it downward with the right button held down.

How did it go? I am afraid you have experienced many difficulties. When we flew the Probe, the Target also moved during the flight. When we accelerated the Probe, the size of the orbit changed also. Moreover, the inclination between the two orbital planes, one of the Probe and the other of the Target, would have made the spaceflight difficult.

It is okay. In SSVG, we can use a powerful tool that assists us in composing a Flight Plan to fly the Probe to the Target. The tool provides parameters of a CP Maneuver that allows the Probe to reach Target. We call the tool FTA, and we will see it in the following subsection.

Gravity Assist of Jupiter

Let us try an orbit transition by gravity assist (swing-by) of Jupiter.

For this purpose, we have to put the Probe into an orbit that flies by Jupiter. Let us use the following steps.

- Create a new Flight Plan. Use the following values for the parameters:
 - Target: Jupiter
 - Space Base: Earth L2
- Add and execute a START Maneuver. Use the following values for the parameters. To edit the Start Time, click the [Edit Time] button in the “Start Time” group.
 - Start Time: 2020-03-26T00:00:00.0000
 - dv: 9130.000
 - phi: -4.70
 - elv: -8.00
- Add and execute a FLYTO Maneuver. The Duration of the flight is 428 days. To edit Duration, click the [Edit Time] button in the “End Time” group and select “Edit by Duration” radio button.
(The End Time becomes 2021-05-28T00:00:00 by ISOT, 2459362.5 by JD)

When you complete the previous steps, save the Flight Plan and do one more operation. Click the Checkpoint on the menu bar of SSVG window, and execute Create command. An indication of “checkpoint” will appear on the Status column of the second line of the Maneuver Table. You will see the usage of the Checkpoint in the later part of this subsection.

At this point, the Probe is on an orbit that brings it Jupiter in 150 days. By clicking the [>>] button on the Show Orbit window several times, you can look see it by yourself.

Note that the orbit of the Probe, provided by Show Orbit window, is a two-body orbit. SSVG computes the orbit using the gravitational pull of the Sun only.

Now, let us add a CP Maneuver, which makes an orbital correction to adjust how the Probe flies by Jupiter. Click the [EDIT Next] button to start editing, and select CP for Maneuver Type.

To obtain the parameters for the CP Maneuver, we use FTA function of SSVG. Click the [FTA]

button on the Maneuver Editor window. The FTA Setting window appears.

On this window, we specify the execution conditions of the FTA as follows:

- Time to arrival: specify a time length the Probe takes to come at the targeting point with a two-body orbit.
- Precise targeting: specify a targeting point to which the Probe flies with a two-body orbit. The targeting point can be the center of the Target or a point near the Target. We can use one of the two coordinate systems, B-plane coordinate system or Orbit Local coordinate system, to specify the point. We use the B-plane coordinate system in this subsection.

For the first case of gravity assist, let us operate the FTA Setting window as follows (see the following figure):

- In the “Time to Arrival” group,
 - Select the [Specify Now] radio button,
 - Enter 150 into the “Time to Arrival (days)” field.
- In the “Precise Targeting” group,
 - Select the [B-plane Coordinates] radio button.
- In the sub-group of the [B-plane Coordinates], enter the following values (*):
 - Into the “offset distance (km)” field: 5000000 (five million)
 - Into the “beta (deg)” field: 0.0

(*) Two parameters of B-plane coordinates specify the position (distance and direction from the target) of the nearest point of the imaginary path of the Probe to the Target. See [B-plane Coordinate System](#) subsection.

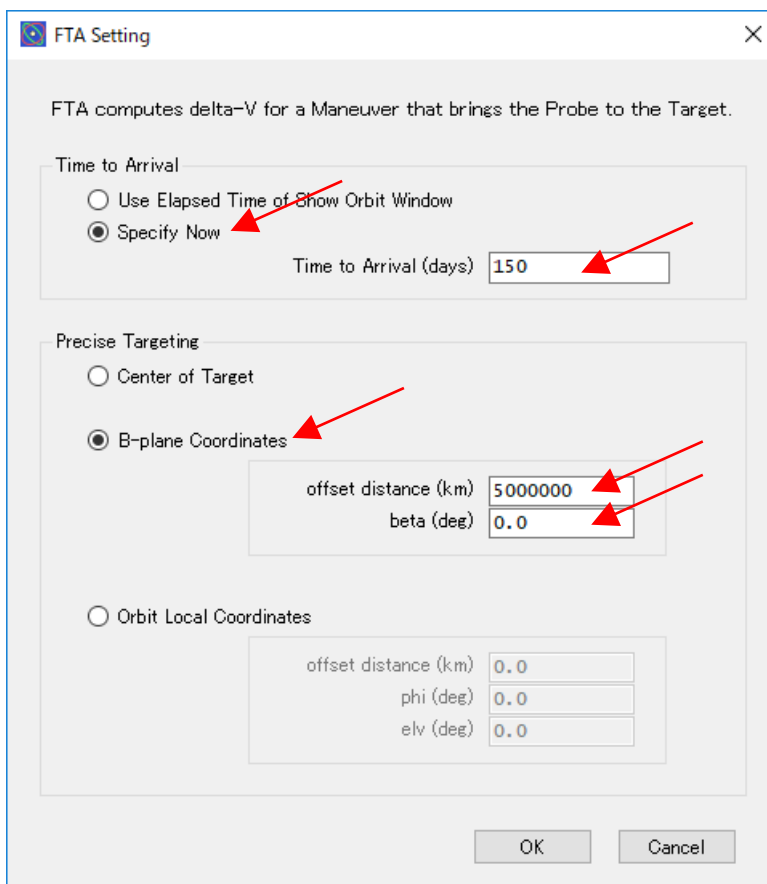


Figure 15 Setting the FTA function

Finish the previously mentioned operations and click the [OK] button. A dialog informs you of the results of FTA. Check the results and click the [OK] button. The Maneuver Editor receives the results (values for parameters Δv , ϕ , and elv).

Click the [Finish and Exec] button of the Maneuver Editor window. SSVG stores and executes the CP Maneuver.

Now, the Probe is on an orbit to fly by Jupiter. Fly the Probe and let it make an orbital transition by gravity assist around Jupiter. Add a FLYTO Maneuver into the Flight Plan and execute it. The fly-by occurs 150 days after the current time, let us use 300 days as the duration of the FLYTO Maneuver.

Let us look-see how the Probe flew by Jupiter. Click the [REVIEW Recent] button on the SSVG window. A Flight Review window replaces the existing Show Orbit window. By clicking the buttons in the “Review Manipulator” of the Flight Review window, we can follow movements of the Probe and Jupiter. If you set a check mark on the “Probe Kepler Orbit” checkbox in the “Show” group of the Flight Review window, you see the two-body orbit of the Probe for every step of the flight.

When the review satisfied you, let us try other cases of gravity assist. We have a list of parameters for FTA, they guide the Probe to different gravity assists and result in the Probe different orbital transitions consequently. See the following table.

Table 2 FTA Parameters for Gravity Assists

Parameters in B-plane Coordinates		Feature of fly-by
offset distance (km)	beta (deg)	
5000000	0	behind Jupiter, a moderate distance (*)
3000000	0	behind Jupiter, a short distance
2000000	0	behind Jupiter, a very short distance
5000000	180	before Jupiter, a moderate distance
3000000	180	before Jupiter, a short distance
3000000	270	above the north pole, a short distance
3000000	90	above the south pole, a short distance

(*) We tried this case already, in the previous part of this subsection

To try these cases, we need to edit the third line (the CP Maneuver) of the Maneuver Table. If you wish to edit the line and use FTA, the line must be a “Next Line”. If the second line of the Maneuver Table indicates a “checkpoint”, you can use the resuming function of SSVG (*). Click the “Checkpoint” on the menu bar, and execute the “Resume” command. The third line (the CP Maneuver) will be the “Next Line”. As long as the “checkpoint” indication is on the second line, you can use the resuming function as many times as desired.

(*) Otherwise, try the following steps:

- Click the [CLEAR] button on the SSVG window. The first line will be the “Next Line”.
- Click the [EXECUTE] button twice. The third line will be the “Next Line”.
- Click the “Checkpoint” on the menu bar, and execute “Create” command. The indication of a “checkpoint” appears on the second line, and you can use the “Resume” function to try other cases of gravity assist.

Then, you can edit the CP Maneuver on the third line by clicking [EDIT Next] button. Try gravity assist again. You can try parameters not contained in the previous table.

For more information about FTA and B-plane coordinates, see [FTA Setting Window](#) and [B-plane](#)

[Coordinate System](#) subsections.

Flight Plan toward Venus

Let us create a Flight Plan toward Venus, the twin planet of the Earth. In this section, we compose a Flight Plan that is “feasible” with current rocket technologies. In this section, a “feasible Flight Plan” means:

- From a Space Base around the Earth, the Probe flies to Venus direct,
- With a small initial velocity (six kilometers per second or less),
- With a few and small intermediate orbital corrections.

If this Flight Plan is an actual one, feasibility includes limitation about the start time of the spaceflight. Let us create a Flight Plan that starts its spaceflight on or after September of 2019.

Create a New Flight Plan

Create a new Flight Plan by executing the New command from the File menu of SSVG window. Select Venus for Target. Next, we select one of the Space Bases, “Earth L1” or “Earth L2”. Which one is better? Each Space Bases lies 1.5 million kilometers from Earth, but the direction is opposite each other. “Earth L1” lies in the direction of the Sun, but “Earth L2” lies in the opposite.

When we select one of the Space Bases, we should consider the initial flight direction of the Probe. If it is inward, approaching to the Sun, “Earth L1” is better to minimize the gravitational influence of the Earth the Probe suffers in the very early phase of the spaceflight. If the initial flight direction is outward, leaving from the Sun, “Earth L2” is better by the same reason.

In fact, there are two feasible paths to reach Venus from the Earth. The first one is the short path that takes roughly 100 days, and the second one is the long path that takes roughly 200 days. In this section, we use the short path. Because the Probe flies inward from the Earth on the short path, the “Earth L1” is more desirable than “Earth L2”.

If we do not have such a working knowledge, try both Space Bases and select a better one.

START Maneuver

Let us add a START Maneuver as the first Maneuver.

Click the [EDIT Next] button of the SSVG window. A Maneuver Editor window for a START Maneuver appears.

For a START Maneuver, we specify the Start Time of the spaceflight and the initial velocity with which the Probe leaves the Space Base. They determine an orbit of the Probe. Because this Flight Plan is for a direct flight to Venus, it should bring the Probe to Venus. At the same time, the feasibility of the Flight Plan requires a small value for the magnitude of the initial velocity.

SSVG has a powerful tool to assist us to find such favorable orbits, the Optimize Assistant. Let us use it now.

Click the [Optimize] button on the Maneuver Editor window. A START Optimize Assistant

window appears (see the following figure).

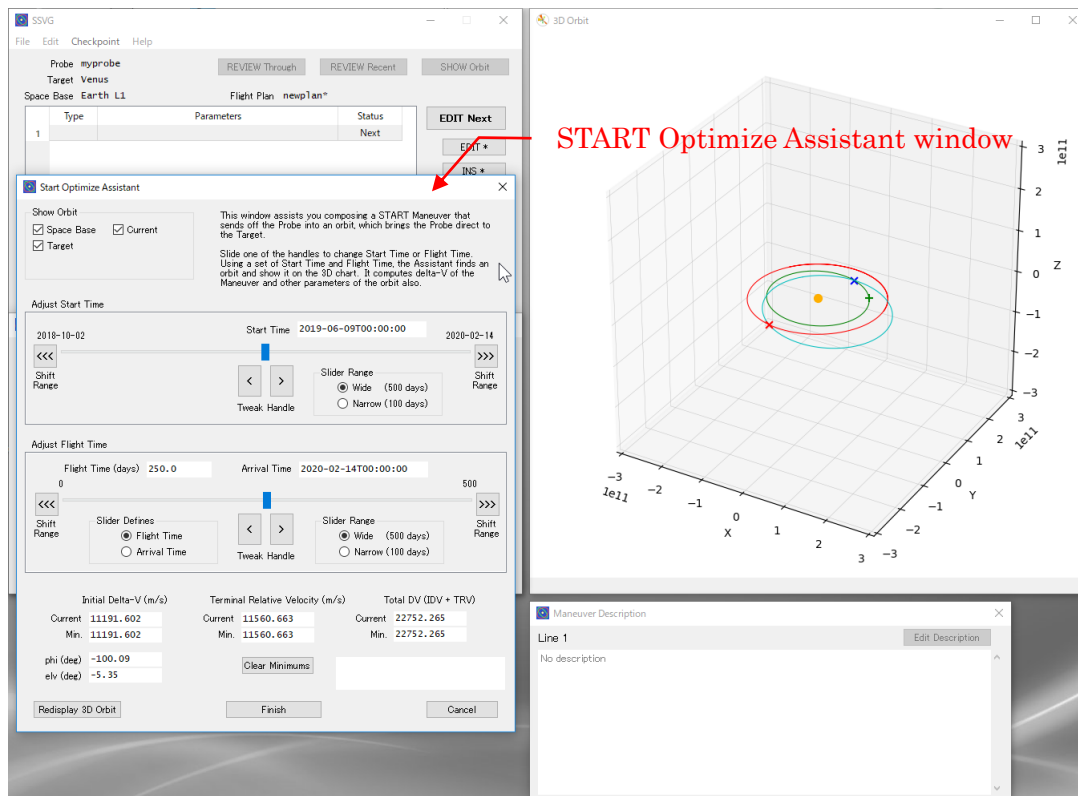


Figure 16 START Optimize Assistant window

In the middle area of the START Optimize Assistant window, there are two large groups of items named “Adjust Start Time” and “Adjust Flight Time” respectively.

We use these two groups to adjust the Start Time of the spaceflight, and the Flight Time to the Target, respectively. From Start Time and Flight Time, SSVG finds a two-body orbit and draw it on the 3D Orbit window. (*) At the same time, SSVG computes and displays the following values:

- Initial Delta-V: the initial velocity of the Probe (magnitude and direction)
- Terminal Relative Velocity: the magnitude of the relative velocity of the Target when the Probe arrives
- Total DV: the sum of the Initial Delta-V and the Terminal Relative Velocity

(*) The 3D Orbit window shows the following marks and lines.

- An X mark in red: the Probe at the Start Time
- A + mark in green: the Target at the Start Time
- An X mark in blue: the Probe and the Target at the arrival
- A curved line in red: the trajectory of the Space Base
- A curved line in green: the two-body orbit of the Target
- A curved line in cyan: the two-body orbit of the Probe
- A small disk in orange: the Sun

When you move slider handle, Start Time or Flight Time change; it changes values and orbit mentioned above also. With this information, you can find favorable Start Time and Flight Time.

When we click one of the [<<<] or [>>>] buttons, slider shifts its range by half of its length. See [START Optimize Assistant Window](#) subsection, for more information.

Let us set the Start Time and the Flight Time to the following initial values by moving slider handle and clicking the [<<<] or [>>>] buttons of each group.

- Start Time: 2019-09-01T00:00:00.000000 (September 1, 2019)
- Flight Time: 100 (one hundred days)

Then, let us look for favorable Start Time and Flight Time.

When you find favorable Start Time and Flight Time, make a note of the Flight Time and the Arrival Time, and click the [Finish and Apply] button. The Optimize Assistant applies the Start Time and the initial velocity to the Maneuver Editor window.

Click the [Finish and Exec] button of the Maneuver Editor window. SSVG stores and executes the START Maneuver.

FLYTO Maneuver (1)

Let us fly the Probe until the mid-time of the spaceflight. Click the [EDIT Next] button on the SSVG window. Select FLYTO for the Maneuver Type, edit parameters, and click the [Finish and Exec] button on the Maneuver Editor window.

CP Maneuver

Add a CP Maneuver for a mid-course correction of the orbit. Click the [EDIT Next] button on the SSVG window, and select CP for the Maneuver Type on the Maneuver Editor window.

At this point, we have to decide the details of the approach, when and where will the Probe approach Venus.

To minify the delta-V of the orbital correction, let us use the time when the Probe comes to the closest point to Venus with the current orbit, as the time of fly-by. We can choose the place of the fly-by as we like.

Let us use FTA function of SSVG to get the parameters of the Maneuver. Move the predicted position of the Probe to the closest point to Venus (*1) by clicking the buttons in the Time Manipulator on the Show Orbit window, and click the [FTA] button on the Maneuver Editor window. On the FTA Settings window, you will see the input field for the “Time to Arrival” contains an appropriate flight time.

(*1) If you wish to minify the time step of the button operations of the Prediction Time manipulation, set the “coarse/fine” spinner to -1, -2, or less.

In the Precise Targeting group of the FTA Setting window, select the radio button of “B-plane Coordinates”. See [B-plane Coordinate System](#) subsection, and set appropriate parameters. Click the [OK] button and confirm the results of FTA. The Maneuver Editor window receives the results.

At this point, you can check the results on the 3D Orbit window. Try a close-up view of the Target.

If you satisfied, click the [Finish and Exec] button on the Maneuver Editor window.

FLYTO Maneuver (2)

Fly the Probe until five days before the day of fly-by. Add a FLYTO maneuver, and execute it.

FLYTO Maneuver (3)

Fly the Probe for ten days, until five days after the fly-by. Add a FLYTO Maneuver and use 0.01 for parameter `inter` in it. The parameter defines the integration interval of trajectory computation. SSVG computes and stores the points of the trajectory at the interval.

After executing this Maneuver, click [REVIEW Recent] button on the SSVG window, and review the flight. We will see how the Probe flies by Venus.

If you wish to insert the Probe into Venus orbit, review the last FLYTO Maneuver to find the time point the Probe being at closest to Venus. For the time point, you can see the relative velocity of the Target. If you modify the last FLYTO Maneuver to end the flight at the time point and add a CP Maneuver that decelerates the Probe to reduce the relative velocity of the Target to an appropriate value (*), the Probe will enter Venus orbit. You will confirm it by adding and executing a FLYTO Maneuver and reviewing it.

(*) The coordinate system of the values of “Relative Velocity of Target” on the Show Orbit window is identical to the one of ΔV of a CP Maneuver. You can use the values of “Relative Velocity of Target” as references for the parameters of the CP Maneuver.

Flight Plan toward Small Celestial Body

We can choose one of the small celestial bodies of the solar system such as asteroids, comets and dwarf planets, for the Target of SSVG. Except for the Moon of Earth, we cannot choose any moons of planets for the Target.

Choosing a small celestial body for the Target of SSVG, we need an SPK file that provides positions and velocities of the body.

The HORIZONS system of NASA/JPL provides us SPK files of small celestial bodies. We can get appropriate SPK files by requesting to the HORIZONS system. For more information about HORIZONS system, see <<http://ssd.jpl.nasa.gov/?horizons>>.

Note that the HORIZONS system can generate SPK files of several different types, but SSVG can read only binary files for asteroids, comets, and dwarf planets. We have a sample to request such a file to the HORIZONS system in the subsection of “[Get SPK File of Small Celestial Body](#).”

Once we have acquired an SPK file for a small celestial body and imported it, we can choose the celestial body as the Target when we create a new Flight Plan, or when we edit an existing Flight Plan. See [New Flight Plan Window](#) subsection.

Sample of Small Celestial Bodies

The following table contains a list of small celestial bodies.

Table 3 Samples of small celestial bodies

IAU No.	Name	Type	SPKID (*1)	Features
1	Ceres	Dwarf Planet	2000001	The largest body in the asteroid belt (*2). Dawn (*2) explored it precisely.
2	Pallas	Asteroid	2000002	A large body in the asteroid belt (*2). It has large orbital inclination.
3	Juno	Asteroid	2000003	A large body in the asteroid belt (*2).
4	Vesta	Asteroid	2000004	A large body in the asteroid belt (*2). Dawn (*3) explored it precisely.
433	Eros	Asteroid	2000433	One of the near-earth asteroids.
617	Patroclus	Asteroid	2000617	One of the Trojans (*4).
1566	Icarus	Asteroid	2001566	One of the near-earth asteroids.
1862	Apollo	Asteroid	2001862	One of the near-earth asteroids.
3753	Cruithne	Asteroid	2003753	One of the near-earth asteroids. The orbital period is very near to one year of the Earth.
4179	Toutatis	Asteroid	2004179	One of the near-earth asteroids.
25143	Itokawa	Asteroid	2025143	One of the near-earth asteroids. Hayabusa (*5) brought back the samples of it.
101955	Bennu	Asteroid	2101955	One of the near-earth asteroids. OSIRIS-REx (*6) is expected to bring back the samples of it.
162173	Ryugu	Asteroid	2162173	One of the near-earth asteroids. Hayabusa-2 (*5) brought back the samples of it.
1P	Halley	Comet	1000036	One of the most famous periodic comets.
2P	Encke	Comet	1000025	A comet with very short orbital period.
67P	Churyumov-Gerasimenko	Comet	1000012	A comet with very short orbital period. Rosetta (*7) explored it precisely.

(*1) SPKID is an identification number of a celestial body in the HORIZONS system.

(*1) Because a large part of asteroids has orbits between Mars orbit and Jupiter orbit, we often call the area the “asteroid belt” or the “main belt.”

(*2) Dawn is a space probe of USA. It was launched in 2007 and explored Vesta and Ceres precisely.

(*3) There are many asteroids around Lagrangian points L4 and L5 of Jupiter. We call them the Trojan asteroids or simply the Trojans.

(*4) Hayabusa and Hayabusa-2 are space probes of Japan. Hayabusa was launched in 2003 and had returned to the Earth in 2010. Hayabusa-2 was launched in 2014 and had returned to the Earth in 2020.

(*5) OSIRIS-REx is a space probe of USA. It was launched in 2016, and we are expecting its return to the Earth in 2023.

(*6) Rosetta is a space probe of the European Space Agency, ESA. It was launched in 2004.

Reference Manual

Basic Terms

Probe

In SSVG, Probe is a spacecraft. A Probe starts its spaceflight from a Space Base, uses its propulsion systems, and flies toward its destination.

A Probe has three propulsion systems, a Chemical Propulsion Engine, an Electric Propulsion Engine, and a Solar Sail. These propulsion systems are very powerful and very easy-to-use. They are described in other subsections.

In SSVG, a Probe can orbit any planet; it can rendezvous with a small celestial body; but it cannot observe planets or small celestial bodies, because it has no observation systems.

Space Base

In SSVG, a Probe starts its spaceflight from a Space Base; we do not launch it from the surface of the Earth or other planets. We suppose that each Space Base has an installation, something like a catapult, to send off the Probes with specified velocity.

All eight planets of the solar system have two Space Bases for each. One is at Lagrangian point L1 of the planet, and another is at L2 of the same planet.

Two Lagrangian points of a planet, L1 and L2, lie on the Sun-planet line (*1). L1 is in the direction of the sun from the planet, and L2 is in the opposite.

L1 and L2 are special points. When you place an object at one of them and give it appropriate velocity, the object keeps the relative position with the planet and the Sun for a long period.

(*1) L1 and L2 of the Earth are on the line through the Sun and the barycenter of the Earth-moon system.

Precisely speaking, Lagrangian points L1 and L2 can be defined only when the planet has a circular orbit and there are no other planets in the solar system. Because no orbit is a perfect circle and the solar system has other planets, these points (L1 and L2) are approximations. Objects placed at L1 (or L2) gradually drift away with time. In SSVG, we suppose that there are mechanisms to hold Space Bases at prescribed positions.

The distance from a planet to L1 is almost the same to the one to L2, but those distances are different for each planet. SSVG computes a distance from multiplying the distance between the planet and the Sun by a "Distance Factor"; SSVG uses the distance for both L1 and L2.

The following table is a complete list of Space Bases in SSVG.

Table 4 Space Bases

Planet	Space Bases at L1	Space Bases at L2	Distance Factor	Average Distance from planet (million kilometers)
Mercury	Mercury L1	Mercury L2	0.00381	0.22
Venus	Venus L1	Venus L2	0.00934	1.0
Earth	Earth L1	Earth L2	0.01008	1.5
Mars	Mars L1	Mars L2	0.00476	1.1
Jupiter	Jupiter L1	Jupiter L2	0.06828	53
Saturn	Saturn L1	Saturn L2	0.04568	66
Uranus	Uranus L1	Uranus L2	0.02442	69
Neptune	Neptune L1	Neptune L2	0.02580	120

Maneuver

In SSVG, Maneuver is an instruction to the Probe about the spaceflight. To achieve a spaceflight, we define a sequence of Maneuvers and execute them.

SSVG maintains the sequence of Maneuvers as a table on its main window (SSVG window). That is the Maneuver Table. Each line (row) of the Maneuver Table contains a Maneuver; we can edit each line (Maneuver) in it, we can add a line (a Maneuver) to it, and we can delete a line (a Maneuver) from it. As we execute Maneuvers in the Maneuver Table one by one, from top to bottom, the Probe leaves a Space Base and flies toward its destination.

In SSVG, Maneuver has one of the seven types. The following table is a complete list of them. Each Maneuver of different type requires different parameters. See [Maneuver Editor Window](#) subsection for precise information for those parameters.

Table 5 Types of Maneuvers

Types	Descriptions
START	<p>The Probe starts the spaceflight.</p> <p>The Maneuver requires Start Time and delta-V (magnitude and direction) as parameters. The delta-V is relative to the Space Base. After the execution of the Maneuver, the Probe flies with a vector sum of two velocities, the delta-V and the velocity of the Space Base.</p> <p>The execution of the Maneuver sets the Start Time of the Maneuver to the current time of SSVG.</p> <p>The first Maneuver of the Maneuver Table must be a START Maneuver; we cannot use a START Maneuver at any other places.</p>
CP	<p>The Probe makes an orbital transition with the Chemical Propulsion Engine.</p> <p>The Maneuver requires magnitude and direction of delta-V as parameters. After the execution of the Maneuver, the Probe flies with a vector sum of the two velocities, the previous velocity of the Probe and the delta-V.</p> <p>The execution of the Maneuver does not affect the current time of SSVG.</p>
EP_ON	<p>The Probe turns on the Electric Propulsion Engine.</p> <p>The Maneuver requires a magnitude of delta-V of a one-day operation, the direction of delta-V, and thrust vector mode as parameters.</p> <p>We can use the Maneuver for a Probe that has turned on its Electric Propulsion Engine. In this case, the Probe changes parameters of the Electric Propulsion Engine to the provided ones.</p> <p>The execution of the Maneuver does not affect the current time of SSVG.</p>
EP_OFF	<p>The Probe turns off the Electric Propulsion Engine.</p> <p>The Maneuver requires no parameters.</p> <p>The execution of the Maneuver does not affect the current time of SSVG.</p>
SS_ON	<p>The Probe turns on the Solar Sail.</p> <p>The Maneuver requires area and orientation of the Solar Sail and thrust vector mode as parameters.</p> <p>We can use the Maneuver for a Probe that has turned on its Solar Sail. In this case, the Probe changes parameters of the Solar Sail to the provided ones.</p> <p>The execution of the Maneuver does not affect the current time of SSVG.</p>
SS_OFF	<p>The Probe turns off the Solar Sail.</p> <p>The Maneuver requires no parameters.</p> <p>The execution of the Maneuver does not affect the current time of SSVG.</p>
FLYTO	<p>The Probe flies until the End Time.</p> <p>The Maneuver requires End Time of this flight and interval of numerical integration as parameters.</p> <p>SSVG computes the actual trajectory of the Probe by numerical integration, using the gravitational pull of the Sun, planets, and the Moon of Earth, and accelerations from the Electric Propulsion Engine and the Solar Sail.</p> <p>The execution of the Maneuver sets the End Time of the Maneuver to the current time of SSVG.</p>

In SSVG version 1.4 and later, each Maneuver can contain its descriptions. A description is a text string of arbitrary length, and SSVG displays the description of the selected Maneuver on

the Maneuver Description window. In addition, we can edit the description on the Maneuver Description Editor window.

A Maneuver can contain descriptions of different languages, and SSVG treats them independently.

For example, when we run SSVG in an English environment, it displays descriptions of English. If we add a new description, SSVG stores it as a description of English.

Flight Plan

In SSVG, Flight Plan is a set of information about a Probe, a Target, and a sequence of Maneuvers to fly the Probe.

To compose a Flight Plan, we create a new Flight Plan with no Maneuver and add Maneuvers one by one.

We can save a Flight Plan into a file, and SSVG stores it with an extension of “json”.

When creating a Flight Plan, we define name and mass of the Probe, select one of the Space Bases from which the Probe starts its spaceflight, and choose a celestial body as the Target. However, we can change all of them later. For example, let us consider a Flight Plan in which a Probe flies toward Saturn after a swing-by of Jupiter. On the first phase of the flight (until the swing-by), we choose Jupiter as the Target, and on the second phase, choose Saturn.

Target

In SSVG, Target is a celestial body. The 3D chart of SSVG shows the position and orbit of it. Some windows display the relative position and relative velocity of it from the Probe. Some tools, FTA and Optimize Assistants, use it to compute parameters of a Maneuver.

For example, if you wish to use FTA to obtain the parameters of a CP Maneuver of an orbital transition that allows the Probe to arrive at a celestial body, you must choose the celestial body as the Target.

On the other hand, the selection of the Target does not affect the execution of any Maneuvers, including FLYTO Maneuvers that compute flight trajectories of the Probe.

Celestial bodies can we choose as a Target are in the following two groups:

- Planet: the group contains eight Planets, Pluto, and the Moon of Earth. When we choose one of them as a Target, we need no special data files.
- Small body: the group contains small celestial bodies such as dwarf planets, asteroids, and comets, confined to those for which the HORIZONS system of NASA/JPL provides SSB (*) centered SPK files. When we wish to choose a small celestial body as a Target, we should get the SPK file for it. See [Get SPK File of Small Celestial Body](#) subsection. Except for the Moon of Earth, we cannot choose any moons of planets as a Target.

(*) SSB means the Solar System Barycenter.

Chemical Propulsion Engine

In SSVG, Chemical Propulsion Engine is a simplified model of liquid propellant rocket engine of actual spacecraft.

The Chemical Propulsion Engine has the following features.

- It can change the velocity of a Probe at an instant.
- It does not consume any propellant.
- Its acceleration contains no errors (both in the magnitude and in the direction). However, there are limitations in the number of decimals of parameters.

Electric Propulsion Engine

In SSVG, Electric Propulsion Engine is a simplified model of electric propulsion device, such as ion thruster or Hall-effect thruster, of actual spacecraft.

The Electric Propulsion Engine has the following features.

- We can turn it on or off at an instant.
- We can change its parameters in a blink.
- It does not consume any propellants.
- It has no limitation in its thrust.
- Its thrust contains no errors both in the magnitude and in the direction. However, there are limitations in the number of decimals of parameters.

There are two modes of the operation of the Electric Propulsion Engine. They are L and E of the Thrust Vector Mode. See [Thrust Vector Mode](#) for details.

Solar Sail

In SSVG, Solar Sail is a large mirror that produces the thrust by reflecting the sunlight.

The Solar Sail has the following features.

- It is a perfect double-sided mirror.
- We can turn it on or off in a blink.
- There is no limitation in its largeness and direction.
- We can change its parameters in a blink.
- The total mass of the Probe contains the mass of it.
- Its largeness and direction contain no errors. However, there are limitations in the number of decimals of parameters.

There are two modes of the operation of the Solar Sail. They are L and E of the Thrust Vector Mode. See [Thrust Vector Mode](#) for details.

It is useful to know the characteristics of Solar Sail as a propulsion device to achieve orbit transition. Some of them are as follows: (see [Solar Sail Coordinate System](#) subsection about theta and elv)

- The Solar Sail achieves its maximum thrust when the plane of the sail faces directly to the Sun. Unfortunately, the thrust of the case has only a radial component and no transverse component; the radial component is not effective to change orbital energy, orbital angular momentum, or orbital inclination in many situations.
- In many situations, the transverse component of the thrust is effective to change the

orbital energy, the orbital angular momentum, or the orbital inclination.

- To gain a transverse component of the thrust, we need to incline the plane of the sail. Well, how much inclination is the best?
- A magic angle maximizes the transverse component of the thrust of the Solar Sail. It is about 35.26 degrees. (*)
- If we wish to make the orbit larger as rapidly as possible, a simple answer is $\theta = 35.26$ and $\text{elv} = 0.0$ (let the Thrust Vector Mode be L).
- If we wish to incline the orbit as rapidly as possible, a simple answer is $\theta = 0.0$ and $\text{elv} = 35.26$ or -35.26 (let the Thrust Vector Mode be L).

(*) The precise value is $\sin^{-1}\left(\frac{1}{\sqrt{3}}\right)$

Trajectory and Orbit

In SSVG, we use both terms of Trajectory and Orbit to express flight paths of Probes. We use the two terms differently as follows:

Trajectory

In SSVG, Trajectory is a realistic flight path of a Probe computed by numerical integration. The computation uses the following forces that affect to the Probe.

- The gravitational pull of the Sun
- The gravitational pulls of eight planets and the moon of Earth
- The thrust of the Electric Propulsion Engine and of the Solar Sail

We use the term “actual trajectory” for the same meaning.

Orbit

In SSVG, Orbit is an idealized flight path of a Probe that indicates the two-body motion about the Sun. To compute an Orbit, SSVG uses the gravitational pull of the Sun only and do not use other forces including the gravitational pulls of planets and the thrusts of propulsion systems.

We use the terms “two-body orbit” and “Kepler orbit” for the same meaning.

Windows and Operations

Overview

SSVG uses the following four areas on our PC screen to show its windows.

1. Main area: the SSVG window shows itself in this area.
2. Chart area: the 3D Orbit window shows itself in this area.
3. Control area: one of the Show Orbit window, Flight Review window, or Review Throughout window shows itself in this area.
4. Description area: the Maneuver Description window shows itself in this area.

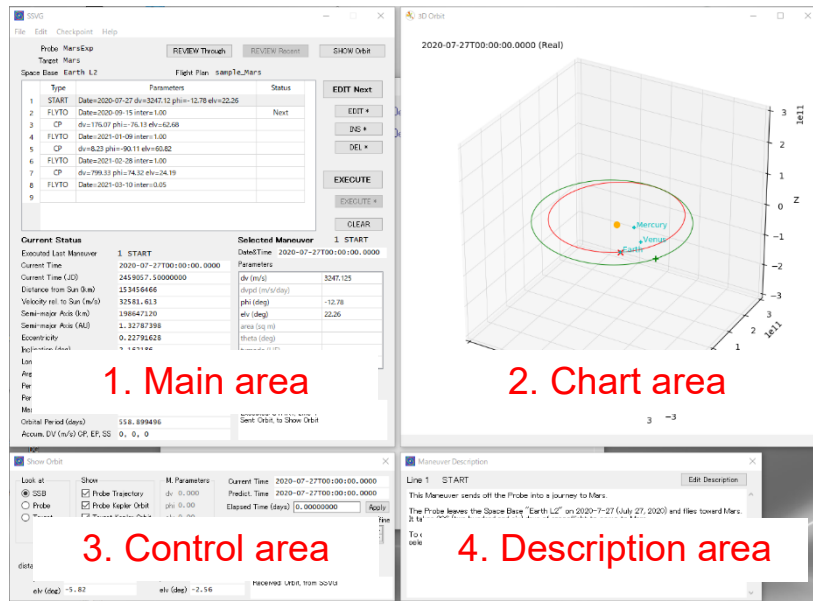


Figure 17 Four areas of SSVG

The following table contains a list of the windows of importance.

Table 6 Windows of importance

Window Name	Description	Area
SSVG	The main window of SSVG	1
3D Orbit	The window to show 3D chart	2
Show Orbit	The window to observe the current state of the Probe	3
Flight Review	The window to review the recent FLYTO Maneuver	3 (share)
Review Throughout	The window to review the executed all Maneuvers	3 (share)
Maneuver Editor	The window to edit a Maneuver	1 (overlap)
New Flight Plan	The window to create a new Flight Plan	1 (overlap)
Edit Probe Properties	The window to edit the properties of the Probe	1 (overlap)
Select New Target	The window to select a celestial body as new Target	1 (overlap)
FTA Setting	The window to specify the execution conditions of FTA	1 (overlap)
START Optimize Assistant	The window of the Optimize Assistant for a START Maneuver	1, 3 (overlap)
CP Optimize Assistant	The window of the Optimize Assistant for a CP Maneuver	1, 3 (overlap)
Maneuver Description	The window to show the description of a Maneuver	4
Maneuver Description Editor	The window to edit the description of a Maneuver	4 (overlap)

SSVG Window

SSVG window is the main window of SSVG. It exists all the times when SSVG is running.

On the SSVG window, there are the following items and groups:

- Menu bar: it contains several commands to execute important functions of SSVG.
- Buttons: there are three groups of buttons: REVIEW/SHOW buttons, EDIT buttons, and EXECUTE buttons.
- Maneuver Table: it contains a list of Maneuvers of the current Flight Plan.
- Current Status: it shows the status of the Probe, immediately after the execution of a Maneuver.
- Selected Maneuver: it shows the parameters of the Maneuver contained in the selected line of the Maneuver Table.
- Other Information: Probe name, Target name, Space Base, and Flight Plan name show themselves above the Maneuver Table.
- Messages: messages from SSVG show themselves.

The screenshot shows the SSVG window with the following components and annotations:

- Menu bar:** File, Edit, Checkpoint, Help
- REVIEW/SHOW buttons:** REVIEW Through, REVIEW Recent, SHOW Orbit
- Maneuver Table:** A table with columns Type, Parameters, and Status. The selected maneuver is line 3, CP.
- EDIT buttons:** EDIT Next, EDIT *, INS *, DEL *
- EXECUTE buttons:** EXECUTE, EXECUTE *, CLEAR
- Current Status:** Executed Last Maneuver: 2 FLYTO. Parameters include Date, Time, Distance from Sun, Velocity, etc.
- Selected Maneuver:** 3 CP. Parameters include dv (m/s), dvpd (m/s/day), phi (deg), elv (deg), area (sq m), theta (deg), tvmode (L|E), inter (days).
- Messages:** Executed: FLYTO, Line 2. Sent: Orbit, to Show Orbit.

Type	Parameters	Status
1	START Date=2020-07-27 dv=3247.12 phi=-12.78 elv=22.26	
2	FLYTO Date=2020-09-15 inter=1.00	
3	CP dv=176.07 phi=-76.13 elv=62.68	Next
4	FLYTO Date=2021-01-09 inter=1.00	
5	CP dv=8.23 phi=-90.11 elv=60.82	
6	FLYTO Date=2021-02-28 inter=1.00	
7	CP dv=799.33 phi=74.32 elv=24.19	
8	FLYTO Date=2021-03-10 inter=0.05	
9		

Figure 18 SSVG window

Menu bar

Table 7 Menu bar of the SSVG window

Menu Item	Command	Description	
File	Open	SSVG opens a Flight Plan from a file.	
	New	SSVG creates a new Flight Plan. See New Flight Plan Window .	
	Save	SSVG saves the current Flight Plan into the current file.	
	Save as	SSVG saves the current Flight Plan with a specified name.	
	Import	SPK file	SSVG imports an SPK file and stores it into the SSVG_data folder.
		Flight Plan file	SSVG imports a Flight Plan file and stores it into the SSVG_plan folder.
	Export	Current Flight plan file	SSVG exports the current Flight Plan.
	Quit	SSVG terminates itself.	
Edit	Probe	SSVG starts the editing of the properties of the Probe. See Edit Probe Properties Window . When we edit the properties of the Probe, SSVG will clear the execution state of the Flight Plan.	
	Target	SSVG starts the selection of a celestial body as new Target. See Select New Target Window . No change in Target does affect the execution state of the Flight Plan.	
Checkpoint	Create	SSVG creates a new Checkpoint (*1).	
	Resume	SSVG resumes the execution state (*2) of the Checkpoint.	
Help	User's Guide	SSVG opens the SSVG User's Guide (this document) by the default application program for PDF documents.	
	Home Page	SSVG opens the SSVG home page by the default web browser.	
	about SSVG	It opens a dialog of the information about SSVG.	

(*1) The command creates a Checkpoint with the current execution state (*2) of the Flight Plan and adds a "checkpoint" on the Maneuver Table. When you execute the "Resume" command, it restores the state of the Checkpoint. When you clear the execution state of the Flight Plan by clicking [CLEAR] button or by other means, the Checkpoint will be lost.

(*2) An execution state contains the line number of the recently executed Maneuver, current time, current position and velocity of the Probe, flight trajectories of the Probe, and so on.

Buttons

Table 8 Buttons on the SSVG window

	Face Name	Description
REVIEW/SHOW Buttons	REVIEW Through	SSVG opens a Review Throughout window that allows us to review through all executed Maneuvers. If the 3D Orbit window does not exist, SSVG opens it.
	REVIEW Recent	SSVG opens a Flight Review window that allows us to review the recently executed FLYTO Maneuver. If the 3D Orbit window does not exist, SSVG opens it.
	SHOW Orbit	If it does not exist, SSVG opens a Show Orbit window that allows us to observe position and orbit of the Probe. If the 3D Orbit window does not exist, SSVG opens it.
EDIT Buttons	EDIT Next	SSVG opens a Maneuver Editor window and starts editing of the Maneuver in the Next Line of the Maneuver Table.
	EDIT *	SSVG opens a Maneuver Editor Window and starts editing of the Maneuver in the selected line. If the line is an executed one, SSVG will clear the execution state of the Flight Plan when we finish the editing (*).
	INS *	SSVG inserts a blank line before the selected line of the Maneuver Table. If the line is an executed one, SSVG clears the execution state of the Flight Plan (*).
	DEL *	SSVG deletes the selected line of the Maneuver Table. If the line is an executed one, SSVG clears the execution state of the Flight Plan (*).
EXECUTE Buttons	EXECUTE	SSVG executes the Maneuver in the Next Line of the Maneuver Table.
	EXECUTE *	SSVG executes Maneuvers in the Maneuver Table in succession, from the Next Line through the selected line.
	CLEAR	SSVG clears the execution state of the Flight Plan. The first line of the Maneuver Table becomes the Next Line.

(*) If there is a Checkpoint above the selected line, SSVG does not clear the execution state, but resumes the execution state of the Checkpoint instead.

Maneuver Table

Maneuver Table is a sequential list of Maneuvers contained in the current Flight Plan. Each line (row) of the table contains one Maneuver.

Maneuver table has a column for the line number and three columns as follows:

- Type column: it shows the type of Maneuver.
- Parameter column: it shows shortened values of parameters of the Maneuver.
- Status column: it shows “Next”, “checkpoint”, or blank. If this column is not a blank, it means as follows:
 - Next: this line is the Next Line.
 - checkpoint: this line contains a Checkpoint.

We can manipulate the Maneuver Table as follows:

- Click a line: SSVG selects the line.
- Double click a line: SSVG opens a Maneuver Editor Window and starts editing of the Maneuver in the line. If the line is not a Next Line, we cannot use a part of functions of the Maneuver Editor. If the line is an executed one, SSVG clears the execution state of the Flight Plan when we finish the editing.

Current Status

SSVG displays the following information as Current Status.

(A pair of brackets, [], shows supplementary words, characters, or explanations)

- Executed Last Maneuver [the line number of the recently executed Maneuver and the type of Maneuver]
- Current time [ISOT and JD]
- Distance [of the Probe] from the Sun
- Velocity rel.[ative] to the Sun
- [Keplerian orbital elements of the Probe]
 - Semi-major Axis
 - Eccentricity
 - Inclination
 - Long.[itude] of Asc.[ending] Node
 - Arg.[ument] of Perihelion
 - Perihelion Passage [Time]
 - Mean Anomaly
 - Orbital Period
- Accum. DV CP, EP, SS [Accumulated Delta-V for CP, EP, and SS. In this field, SSVG displays accumulated delta-V for each propulsion system; the first is of Chemical Propulsion Engine, the second is of Electric Propulsion Engine, and the last is of Solar Sail.]

Selected Maneuver

SSVG displays the following information of the Maneuver contained in the selected line of the Maneuver Table.

- The line number of the selected line and the type of Maneuver
- Date&Time: Start Time for START Maneuver, or End Time for FLYTO Maneuver
- Parameters: other parameters of the Maneuver (see [Maneuver Editor Window](#) for precise information)

Other Information

SSVG displays the following information above the Maneuver Table.

- Probe Name: name of the Probe
- Target: name of the Target
- Space Base: name of the Space Base
- Plan File: the current file name of the Flight Plan

Messages

SSVG displays messages about its behavior.

3D Orbit Window

3D Orbit window shows a three-dimensional (3D) chart that contains the position and orbit of the Probe, the position and orbit of the Target, the position and name of each planet, and so on.

SSVG controls the 3D chart through one of the following windows.

- Show Orbit window
- Flight Review window
- Review Throughout window
- START Optimize Assistant window
- CP Optimize Assistant window

The next figure shows an example of the 3D Orbit window.

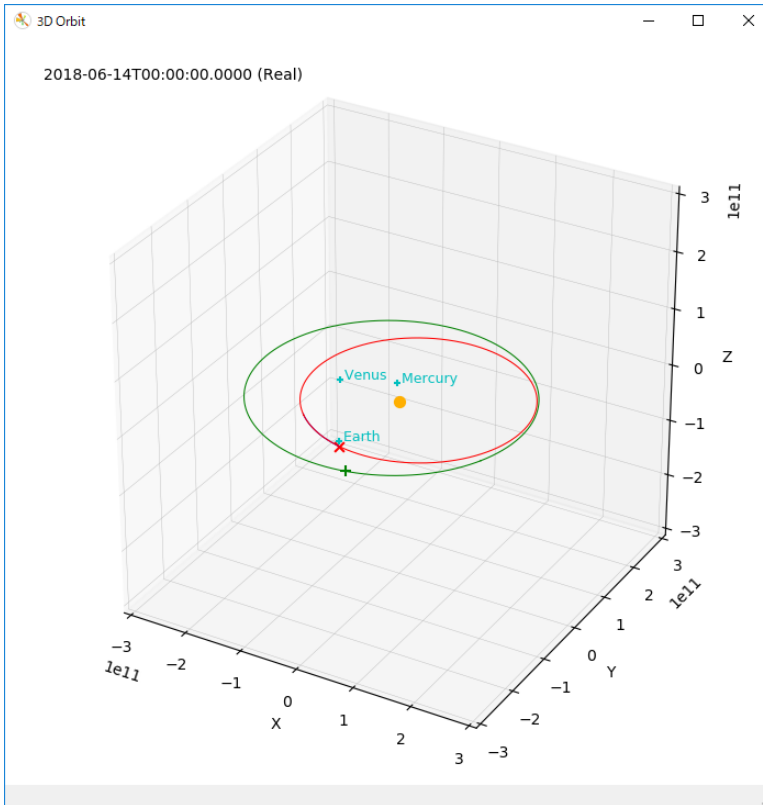


Figure 19 3D Orbit window

The next table contains a complete list of items that can be displayed on the 3D orbit window.

Table 9 Items on the 3D Orbit window

Items	Descriptions
An X mark in red	The Probe: when reviewing a Maneuver, the state of the propulsion systems and the information about the Maneuver may appear next to the mark.
A curved line in red	The two-body orbit of the Probe When using the START Optimize Assistant, it indicates the trajectory of the Space Base. When using the CP Optimize Assistant, it indicates the current orbit of the Probe.
A curved line in blue	The Actual trajectory of the Probe
A + mark in green	The Target
A curved line in green	The two-body orbit of the Target
An X mark in blue	The place where the Probe arrives at the Target, for the START Optimize Assistant and the CP Optimize Assistant
A curved line in cyan	The considering two-body orbit of the Probe, for the START Optimize Assistant and the CP Optimize Assistant
A small disk in orange	The Sun
+ marks and names in cyan	Planets and their names; the moon of Earth is indicated by a + mark without the name.
Three gridded planes with scales	Each plane is parallel to one of the three planes, X-Y, Y-Z, and Z-X of the ecliptic coordinate system. Each scale is parallel to one of the three axes, X, Y, and Z of the same coordinate system.
Time information	In the upper left corner of the window, SSVG displays the time corresponds to the positions of objects.

On the 3D Orbit window, we can manipulate the 3D chart by mouse.

Table 10 Manipulation of 3D Chart

What to do	How to do
Rotate	Place the mouse cursor on the 3D Orbit window, and move it up/down or right/left with the left button held down.
Zoom out and zoom in	Place the mouse cursor on the 3D Orbit window, and move it up/down with the right button held down.
Resize	By dragging each side or corner of the 3D Orbit window, you can resize the window with the 3D chart.
Place the Probe or the Target at the center of the chart	See Show Orbit Window , Flight Review Window , or Review Throughout Window subsections.

Show Orbit Window

Show Orbit window allows us to observe the state of the Probe. It displays information as follows:

- Into the 3D chart,
 - the Probe, its orbit, and its actual trajectory
 - the Target and its orbit
 - positions and names of the planets
- Into the window itself,
 - the relative position and the relative velocity of the Target from the Probe, including the line of sight velocity

We specify the time of information to be displayed. It can be not only the current time but also the time in the future or in the past. We call the time “Prediction Time” in SSVG. Show Orbit window computes and displays the position of the Probe and other information for the time.

Show Orbit window uses only one force, the gravitational pull of the Sun, to compute the position and orbit of the Probe and it does not use any other forces that affect the motion of the Probe, such as gravitational pulls of the planets. On the other hand, SSVG uses almost all forces for computation of the trajectory of the Probe in the execution of a FLYTO Maneuver.

Show Orbit window displays information only when the Prediction Time is within the time range of SSVG. If the Prediction Time is outside of it, the window does not display the Probe and the Target on the 3D Orbit window, and it does not renew relative positions and velocities of the Target. See [Time](#) subsection for the time range of SSVG.

A Show Orbit window appears when

- we executed a Maneuver
- we started editing of a Maneuver in the Next Line
- we finished or canceled editing of a Maneuver, and SSVG had executed at least one Maneuver already
- we clicked the valid [SHOW Orbit] button

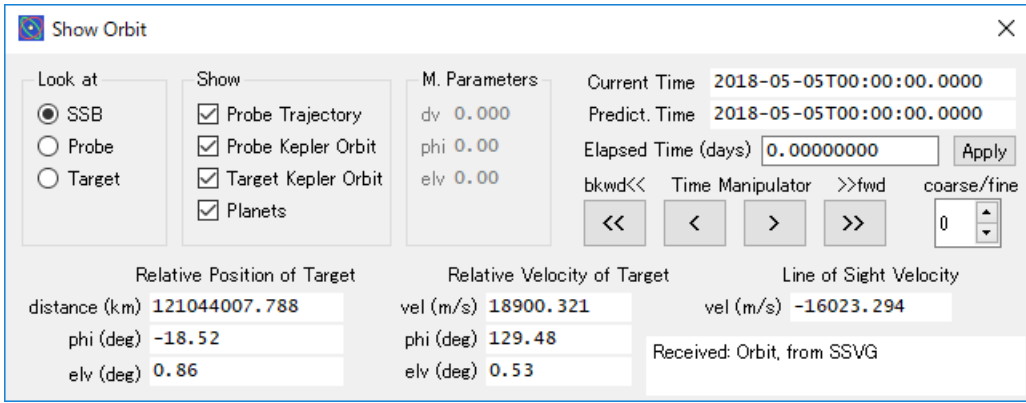


Figure 20 Show Orbit window

The following five groups of items are in the upper part of the Show Orbit window.

- Look at: three radio buttons to prescribe the center of the 3D chart
- Show: four check boxes to prescribe show/hide of items on the 3D chart
- M. Parameters: Maneuver parameters applied temporarily
- Items about time, three lines in the top-right corner
- Time Manipulator: four buttons and a spinner to manipulate the Prediction Time

Table 11 Upper part of the Show Orbit window

Group	Item	Explanation
Look at	SSB	When selected, SSB, the Solar System Barycenter, lies at the center of the 3D chart.
	Probe	When selected, the Probe lies at the center of the 3D chart.
	Target	When selected, the Target lies at the center of the 3D chart.
Show	Probe Trajectory	When checked, the actual trajectory of the Probe appears in the 3D chart.
	Probe Kepler Orbit	When checked, the orbit (Kepler orbit) of the Probe appears in the 3D chart.
	Target Kepler Orbit	When checked, the orbit (Kepler orbit) of the Target appears in the 3D chart.
	Planets	When checked, the marks and names of planets appear in the 3D chart.
M. Parameters	dv phi elv	The Maneuver parameters, applied temporarily by the Maneuver Editor window
Items about time	Current Time	The Current Time of SSVG
	Start Time	The Start Time, applied temporarily by the Maneuver Editor window
	Predict. Time	Prediction Time
	Elapsed Time (days) and [Apply] button	The elapsed Time from the Current Time or Start Time to the Prediction Time Edit this field and click the adjacent [Apply] button to modify the Prediction Time (*).
Time Manipulator (*)	[<<] button	Fast backward: The Prediction Time goes back by a tenfold step of the [<] button (*).
	[<] button	Backward: The Prediction Time goes back (*).
	[>] button	Forward: The Prediction Time goes forward (*).
	[>>] button	Fast forward: The Prediction Time goes forward by a tenfold step of the [>] button (*).
	coarse/fine	Spinner to specify the coarseness or fineness of the manipulation of the Prediction Time A larger value of it yields a coarse manipulation.

(*) While you are editing a FLYTO Maneuver in the Next Line, the Show Orbit window applies every change of

the Prediction Time to the End Time of the editing FLYTO Maneuver.

The lower part of the Show Orbit window contains positions and velocities of the Target relative to the Probe at the Prediction Time, as follows:

Table 12 Lower part of the Show Orbit window

Group	Item	Explanation
Relative Position of Target	distance	The distance of the Target from the Probe
	phi elv	The angle phi and elv of the relative position of the Target from the Probe, on the Orbit Local Coordinate System
Relative Velocity of Target	vel	The magnitude of the relative velocity of the Target from the Probe
	phi elv	The angle phi and elv of the relative velocity of the Target from the Probe, on the Orbit Local Coordinate System
Line of Sight Velocity	vel	The radial component of the relative velocity of the Target from the Probe, a positive value indicates the Target is coming away from the Probe

A text field is around the bottom-right corner of the window. SSVG displays messages about its behavior in it.

Flight Review Window

Flight Review window allows us to review the result of a FLYTO Maneuver. For each integration step of the Maneuver, it displays information as follows:

- Into the 3D chart,
 - the Probe, its actual trajectory, and its two-body orbit
 - the state of the Electric Propulsion Engine (*1)
 - the magnitude of the acceleration from the Solar Sail and its state (*2)
 - the Target and its orbit
 - positions and names of the planets
- Into the window itself,
 - the relative position and the relative velocity of the Target from the Probe, including the line-of-sight velocity

(*1) If the Electric Propulsion Engine is on, a string “EP(m)” appears next to the X mark of the Probe on the 3D Orbit window. The “m” of “EP(m)” indicates the Thrust Vector Mode (L or E) of the Electric Propulsion Engine.

(*2) If the Solar Sail is on, a string “SS(m) SSacc=n.nnn” appears next to the X mark of the Probe in the 3D chart. The “m” of “SS(m)” indicates the Thrust Vector Mode (L or E) of the Solar Sail. The “n.nnn” of “SSacc=n.nnn” indicates acceleration from the Solar Sail at the instant. The value means the magnitude of the delta-V from a one-day operation, in meters per second per day.

The Flight Review window displays information of an integration step of the Maneuver. The displayed step is the “current step”.

A Flight Review window appears when we clicked the [REVIEW Recent] button of the SSVG window.

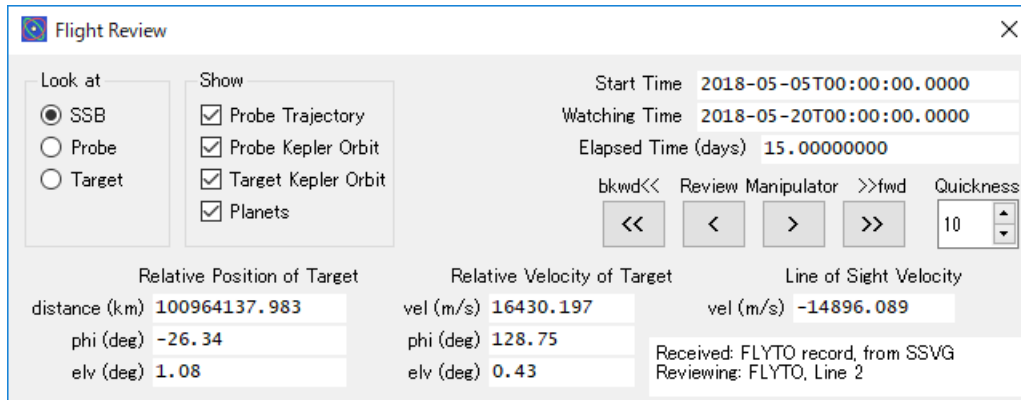


Figure 21 Flight Review window

The following four groups of items are in the upper part of the Flight Review window.

- Look at: three radio buttons to prescribe the center of the 3D chart
- Show: four check boxes to select show/hide of items on the 3D chart
- Items about time, three lines in the top-right corner
- Review Manipulator: four buttons and a spinner to manipulate the integration step to watch

Table 13 Upper part of the Flight Review window

Group	Item	Explanation
Look at	SSB	When selected, SSB, the Solar System Barycenter, lies at the center of the 3D chart.
	Probe	When selected, the Probe lies at the center of the 3D chart.
	Target	When selected, the Target lies at the center of the 3D chart.
Show	Probe Trajectory	When checked, the actual trajectory of the Probe appears in the 3D chart.
	Probe Kepler Orbit	When checked, the two-body orbit (Kepler orbit) of the Probe appears in the 3D chart.
	Target Kepler Orbit	When checked, the two-body orbit (Kepler orbit) of the Target appears in the 3D chart.
	Planets	When checked, the marks and names of planets appear in the 3D chart.
Items about time	Start Time	The Start time of the reviewing FLYTO Maneuver.
	Watching Time	The time of the current step.
	Elapsed Time (days)	The elapsed time from the Start Time to the Watching Time.
Review Manipulator	[<<] button	Fast backward: When we clicked, the current step goes back by the number of steps specified by Quickness.
	[<] button	Backward: When we clicked, the current step goes back by one.
	[>] button	Forward: When we clicked, the current step goes forward by one.
	[>>] button	Fast forward: When we clicked, the current step goes forward by the number of steps specified by Quickness.
	Quickness	A spinner to specify the number of integration steps of one operation of buttons [<<] or [>>].

The lower part of the Flight Review window contains positions and velocities of the Target relative to the Probe of the current step. Data items and their meanings are the same as the Show Orbit window. See [Table 12 Lower part of the Show Orbit window](#).

A text field is around the bottom-right corner of the window. SSVG displays messages about its

behavior in it.

Review Throughout Window

Review Throughout window allows us to review the all executed Maneuvers. For each Maneuver, it displays information as follows:

- Into the 3D chart,
 - the Probe with the line number of the Maneuver and type of it
 - for a FLYTO Maneuver,
 - the start and the end of the Maneuver
 - the state of the Electric Propulsion Engine (*1)
 - the magnitude of the acceleration from the Solar Sail and its state (*2)
 - the actual trajectory of the Probe, and two-body orbit of the Probe
 - the Target and its orbit
 - positions and names of the planets
- Into the window itself,
 - the relative position and the relative velocity of the Target from the Probe, including the line-of-sight velocity

(*1) If the Electric Propulsion Engine is on, a string “EP(m)” appears next to the type of the Maneuver. The “m” of “EP(m)” indicates the Thrust Vector Mode (L or E) of the Electric Propulsion Engine.

(*2) If the Solar Sail is on, a string “SS(m) SSacc=n.nnn” appears next to the type of the Maneuver. The “m” of “SS(m)” indicates the Thrust Vector Mode (L or E) of the Solar Sail, and “n.nnn” of “SSacc=n.nnn” indicates acceleration from the Solar Sail at the instant. The value means the magnitude of the delta-V from a one-day operation, in meters per second per day.

Review Throughout window displays information corresponded to one Maneuver. The Maneuver is the “current Maneuver”.

Except for FLYTO Maneuvers, the Review Throughout window displays information immediately after the execution of the current Maneuver. For a FLYTO Maneuver, it displays information of each integration step of the Maneuver.

A Review Throughout window appears when we clicked the [REVIEW Through] button of the SSVG window.

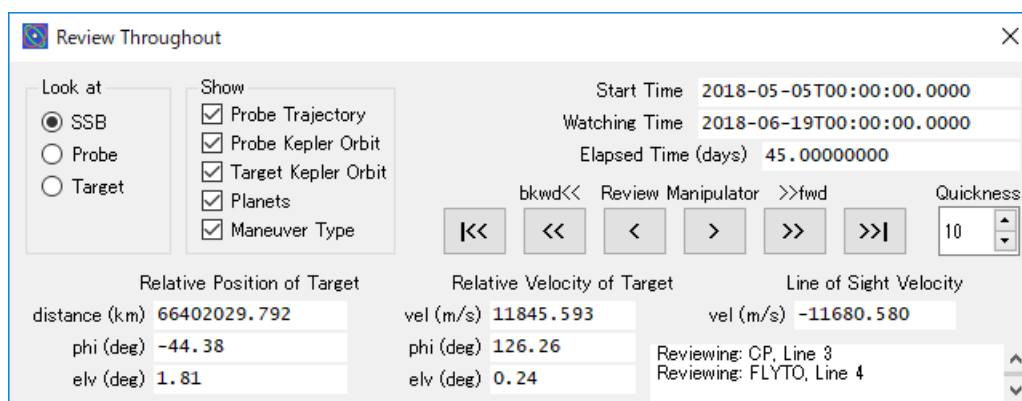


Figure 22 Review Throughout window

The following four groups of items in the upper part of the Review Throughout window.

- Look at: three radio buttons to prescribe the center of the 3D chart
- Show: five check boxes to select show/hide of items on the 3D chart
- Items about time, three lines in the top-right corner

- Review Manipulator: six buttons and a spinner to manipulate the current Maneuver or the integration step to watch

Table 14 Upper part of the Review Throughout window

Group	Item	Explanation
Look at	SSB	When selected, SSB, the Solar System Barycenter, lies at the center of the 3D chart.
	Probe	When selected, the Probe lies at the center of the 3D chart.
	Target	When selected, the Target lies at the center of the 3D chart
Show	Probe Trajectory	When checked, the actual trajectory of the Probe appears in the 3D chart.
	Probe Kepler Orbit	When checked, the two-body orbit (Kepler orbit) of the Probe appears in the 3D chart.
	Target Kepler Orbit	When checked, the two-body orbit (Kepler orbit) of the Target appears in the 3D chart.
	Planets	When checked, the marks and names of planets appear in the 3D chart.
	Maneuver Type	When checked, type of the Maneuver and other information appear next to the Probe in the 3D chart.
Items about time	Start Time	The Start Time of the Flight Plan
	Watching Time	The time of the current Maneuver For a FLYTO Maneuver, the time of the current integration step
	Elapsed Time (days)	The Elapsed time from the Start Time to the Watching Time
Review Manipulator	[<<] button	Go Previous: the previous Maneuver becomes the current Maneuver (*1).
	<<] button	(We can use the button to review a FLYTO Maneuver.) Fast backward: the current step goes back by the number of steps specified by Quickness.
	<] button	(We can use the button to review a FLYTO Maneuver.) Backward: the current step goes back by one.
] >] button	(We can use the button to review a FLYTO Maneuver.) Forward: the current step goes forward by one.
] >>] button	(We can use the button to review a FLYTO Maneuver.) Fast forward: the current step goes forward by the number of steps specified by Quickness.
] >>] button	Go Next: the next Maneuver becomes the current Maneuver (*2).
	Quickness	Spinner to specify the number of integration steps of one operation of buttons [<<] or [>>].

(*1) While reviewing a FLYTO Maneuver,

- If the current step is the first step of the Maneuver, the previous Maneuver becomes the current Maneuver.
- If the current step is not the first step of the Maneuver, the first step of it becomes the current step.

(*2) While reviewing a FLYTO Maneuver,

- If the current step is the last step of the Maneuver, the next Maneuver becomes the current Maneuver.
- If the current step is not the last step of the Maneuver, the last step of it becomes the current step.

The lower part of the Review Throughout window contains the position and the velocity of the Target relative to the Probe. Data items and their meanings are the same as the Show Orbit window. See [Table 12 Lower part of the Show Orbit window](#).

A text field is around the bottom-right corner of the window. SSVG displays messages about its behavior in it.

Maneuver Editor Window

Maneuver Editor window edits a Maneuver of the Flight Plan.

A Maneuver Editor window appears when

- we clicked the [EDIT Next] button of the SSVG window
- we clicked the [EDIT *] button of the SSVG window
- we double-clicked a line of the Maneuver Table of the SSVG window

We strongly recommend editing a Maneuver contained in the Next Line of the Maneuver Table. Otherwise, you can use only a part of the functions of the Maneuver Editor.

The following explanations in this subsection are for the case editing a Maneuver contained in the Next Line.

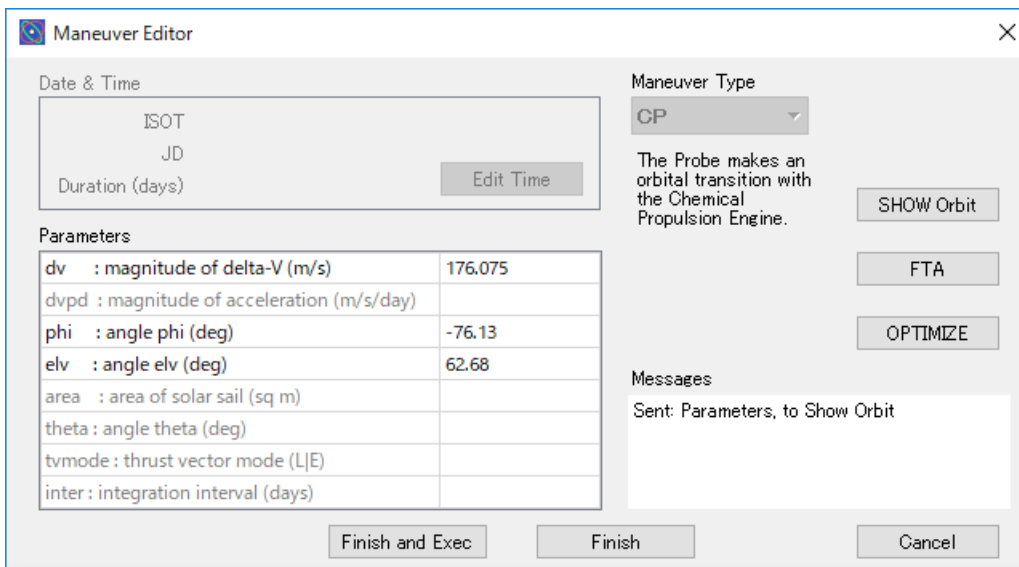


Figure 23 Maneuver Editor window

The following table explains the groups, the table, and the buttons of the Maneuver Editor window.

Table 15 Groups/Table/Buttons of the Maneuver Editor window

Group/ Table/Button	Relating Maneuver type	Explanation
Maneuver Type (a drop-down list)	all types	The drop-down list shows the type of Maneuver. When we edit a blank line of the Maneuver Table, click the list and select type of the Maneuver. The type of existing Maneuver is immutable.
Start Time (text fields and the [Edit Time] button)	START	The text fields show the Start Time of the spaceflight in two formats: ISO time (ISOT) and Julian Date (JD). To modify the Start Time, click the [Edit Time] button. When we modified the time, SSVG applies it to the Show Orbit window and 3D chart temporarily.
or End Time (text fields and the [Edit Time] button)	FLYTO	The text fields show the End Time and Duration (*1) of the FLYTO Maneuver. The End Time appears in two formats: ISO time (ISOT) and Julian Date (JD). To modify the End Time, click the [Edit Time] button. When we modified the time, SSVG applies it to the Show Orbit window and 3D chart temporarily. To modify the time, we can use the Show Orbit window also. When we manipulate the Prediction Time on it, SSVG applies the time to the End Time of the Maneuver.
Parameters (a table)	all types	The table shows the parameters of the Maneuver. The left column of it contains the name and a short explanation of each parameter. One in black is a valid parameter for the Maneuver, and one in grey is an invalid parameter. The right column of it contains the value of each valid parameter. See the next table for the details of the parameters. To modify each value of parameters, click the cell of it.
[SHOW Orbit] button	all types	SSVG applies edited parameters to the Show Orbit window and the 3D chart temporarily.
[FTA] button	START CP	SSVG invokes FTA function that helps us editing the Maneuver (*2). See FTA Setting Window subsection.
[Optimize] button	START CP	SSVG invokes Optimize Assistant that helps us optimizing the Maneuver. See START Optimize Assistant Window or CP Optimize Assistant Window subsections.
Messages (a text field)	all types	SSVG displays messages about its behavior in the field.
[Finish and Exec] button	all types	SSVG stores the Maneuver into the Maneuver Table and executes it.
[Finish] button	all types	SSVG stores the Maneuver into the Maneuver Table.
[Cancel] button	all types	SSVG cancels the editing.

(*1) Duration is the flight time of the FLYTO Maneuver. Maneuver Editor calculates the Duration from the current time of SSVG and the End Time of the FLYTO Maneuver. When we edit the Duration, Maneuver Editor calculates the End Time from the current time of SSVG and the edited Duration.

(*2) At this point, Maneuver Editor passes the Elapsed Time of the Show Orbit window to the FTA Setting window. The window uses it for the Time to Arrival.

The following table explains each parameter in the Parameters table.

Table 16 Parameters of Maneuver

Parameter	Valid for	Limit of Places (*1)	Description
dv	START CP	3	The magnitude of the delta-V, in meters per second
dvpd	EP_ON	3	The magnitude of the acceleration represented by delta-V from a one-day operation of the Electric Propulsion Engine, in meters per second per day
phi	START CP EP_ON	2	The angle phi to indicate the direction of the delta-V, in degrees See Orbit Local Coordinate System .
elv	START CP EP_ON SS_ON	2	The angle elv to indicate the direction of the delta-V or the orientation of the solar sail, in degrees See Orbit Local Coordinate System or Solar Sail Coordinate System .
area	SS_ON	1	The area of the Solar Sail, in square meters
theta	SS_ON	2	The angle theta to indicate the orientation of the Solar Sail, in degrees See Solar Sail Coordinate System .
tvmode	EP_ON SS_ON	N/A	The Thrust Vector Mode See Thrust Vector Mode .
inter	FLYTO	5	The interval of the numerical integration, in days (*2) SSVG computes positions and velocities of the Probe at this interval. The value of the parameter should be greater than or equal to 0.00001.

(*1) This column shows the limit of the number of places of decimals for the value of each parameter. When we enter more digits than the limit, Maneuver Editor will round the value.

(*2) When you use a small value for the parameter inter, consider carefully. With a very small value of inter and a long Duration, a FLYTO Maneuver may take a very long processing time in its execution.

New Flight Plan Window

New Flight Plan window creates a new Flight Plan. The window appears when we execute the New command of the File menu.

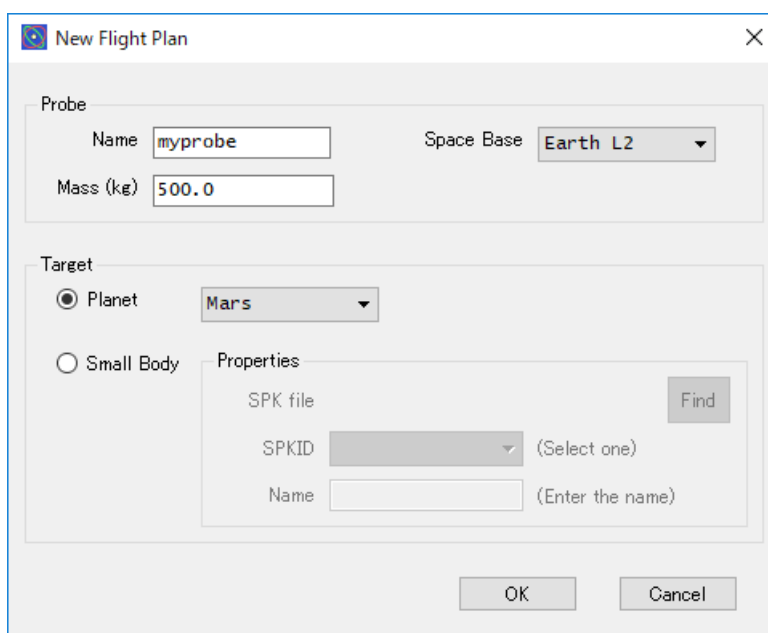


Figure 24 New Flight Plan window

The window has two item groups named Probe and Target. The latter contains one sub-group named Properties. The window has two buttons also. The following table explains all of them.

Table 17 Groups/Items of the New Flight Plan window

Groups	Items	Explanations	
Probe	Name (an input field)	The name of the Probe We can edit the name.	
	Space Base (a drop-down list)	The Space Base from which the Probe starts the spaceflight We choose a Space Bases in the drop-down list. See Space Base subsection.	
	Mass (an input field)	The total mass of the Probe, in kilograms We can edit the value.	
Target	Planet (a radio button with a drop-down list)	When selected, we choose one of the celestial bodies contained in the drop-down list as the Target. The drop-down list contains eight planets, the moon of Earth, and Pluto.	
	Small Body (a radio button with a subgroup)	When selected, we choose a small celestial body as the Target. We need an SPK file for the body, and we specify properties of the body in the Properties sub-group.	
	Properties	SPK file (a text field and [Find] button)	The field shows the path of the SPK file of the Target. To select an SPK file, click the [Find] button and open the SPK file (*1) of the small celestial body.
		SPKID (a drop-down list)	SPKID (*2) of the Target If the SPK file contains data for two or more celestial bodies, we must select the appropriate SPKID.
Name (an input field)		The name of the small celestial body We can edit the name.	
(buttons)	[OK] button	SSVG creates a new Flight Plan.	
	[Cancel] button	SSVG cancels creating a new Flight Plan.	

(*1) Get an SPK file of the small celestial body (see [Get SPK File of Small Celestial Body](#)), and import it in advance.

(*2) SPKID is an identification number of a celestial body in the HORIZONS system of NASA/JPL.

Edit Probe Properties Window

Edit Probe Properties window edits properties of the Probe of the Flight Plan. The window appears when we execute the Probe command of the Edit menu of SSVG.

Format and operation of the window are the same as the New Flight Plan window. See [New Flight Plan Window](#). We can modify the items of the Probe group.

Select New Target Window

Select New Target window choose a celestial body as the new Target of the Flight Plan. The window appears when we execute the Target command of the Edit menu of SSVG.

Format and operation of the window are the same as the New Flight Plan window. See [New Flight Plan Window](#). We can modify the items of the Target group.

FTA Setting Window

FTA Setting window specifies the values of parameters for the FTA function of SSVG.

The name FTA comes from Fixed Time Arrival guidance. The FTA function computes parameters for a Maneuver (a START Maneuver or a CP Maneuver) that makes the Probe have a two-body orbit that brings the Probe to a specified point (*) near the Target at a specified time.

(*) We call it the “Targeting Point.”

An FTA Setting window appears when we clicked the [FTA] button on the Maneuver Editor window.

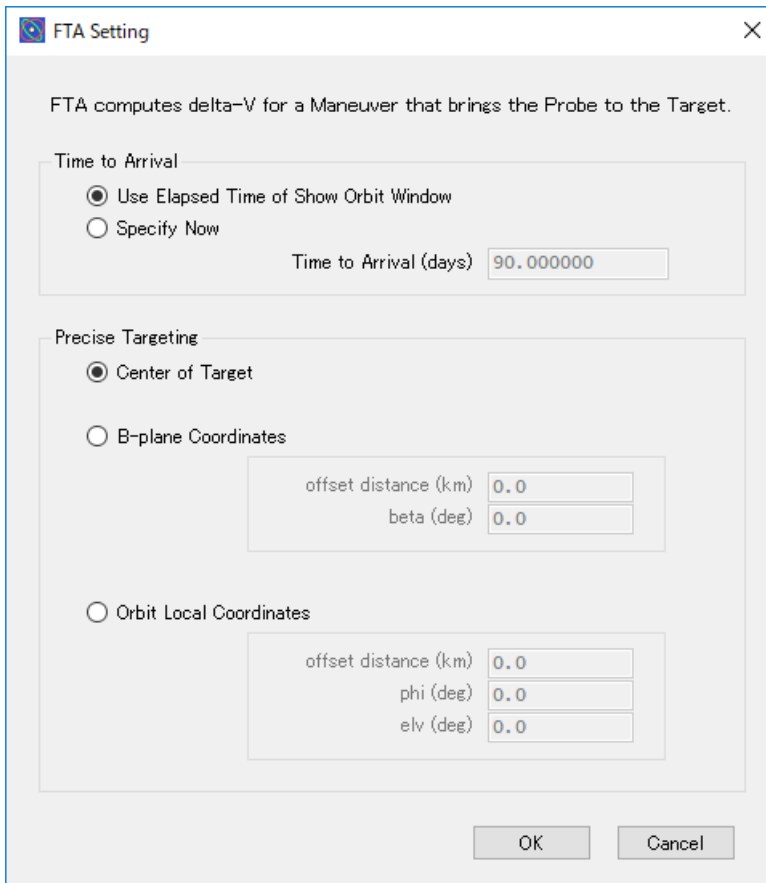


Figure 25 FTA Setting window

The FTA Setting window contains two groups of items, along with two buttons.

Table 18 Groups/Items of FTA Setting window

Group	Item	Description	
Time to Arrival (*1)	Use Elapsed Time of Show Orbit window (a radio button)	When selected, FTA uses the Elapsed Time of the Show Orbit window as the Time to Arrival.	
	Specify Now (a radio button)	When selected, FTA uses the value within the adjacent input field as the Time to Arrival.	
	Time to Arrival (days) (an input field)	The value of the Time to Arrival We can edit the value. The value must be greater than or equal to 1.0.	
Precise Targeting	Center of Target (a radio button)	When selected, the FTA uses the center of the Target as the Targeting Point.	
	B-plane Coordinates (a radio button)	When selected, we specify the Targeting Point with its B-plane Coordinates from the Target. See B-plane Coordinate System .	
	(subgroups)	offset distance (km) (an input field)	The distance of the Targeting Point, in kilometers
		beta (deg) (an input field)	The angle beta of the Targeting Point, in degrees
	Orbit Local Coordinates (a radio button)	When selected, we specify the Targeting Point with its Orbit Local Coordinates from the Target. See Orbit Local Coordinate System .	
	(subgroups)	offset distance (km) (an input field)	The distance of the Targeting Point, in kilometers
		phi (deg) (an input field)	The angle phi of the Targeting Point, in degrees
		elv (deg) (an input field)	The angle elv of the Targeting Point, in degrees
(buttons)	[OK] button	SSVG executes the FTA function and displays the results. When we confirm the results, SSVG applies them into the editing Maneuver (*2).	
	[Cancel] button	SSVG cancels the FTA function.	

(*1) Time to Arrival is the time difference between the Maneuver and the arrival of the Probe to the targeting point by a two-body orbit.

(*2) The results are parameters of dv, phi, and elv; SSVG stores them into “Parameters” table of the Maneuver Editor window. At the point, SSVG rounds the results as follows:

- dv: rounded to three decimal places
- phi and elv: rounded to two decimal places

START Optimize Assistant Window

START Optimize Assistant helps us optimize a START Maneuver that sends off a Probe into an orbit that brings the Probe directly to the Target.

The time of departure (the Start Time) of spacecraft and the length of spaceflight (the Flight Time) are important parameters for an efficient spaceflight.

START Optimize Assistant allows us to try various Start Time and various Flight Time, to compare efficiency between different trials, and to choose a favorable pair of them.

Note that the words “the current *something*” in this subsection means “*something* in the current trial,” except otherwise mentioned.

A START Optimize Assistant window appears when we click the [OPTIMIZE] button of the

Maneuver Editor window editing a START Maneuver.

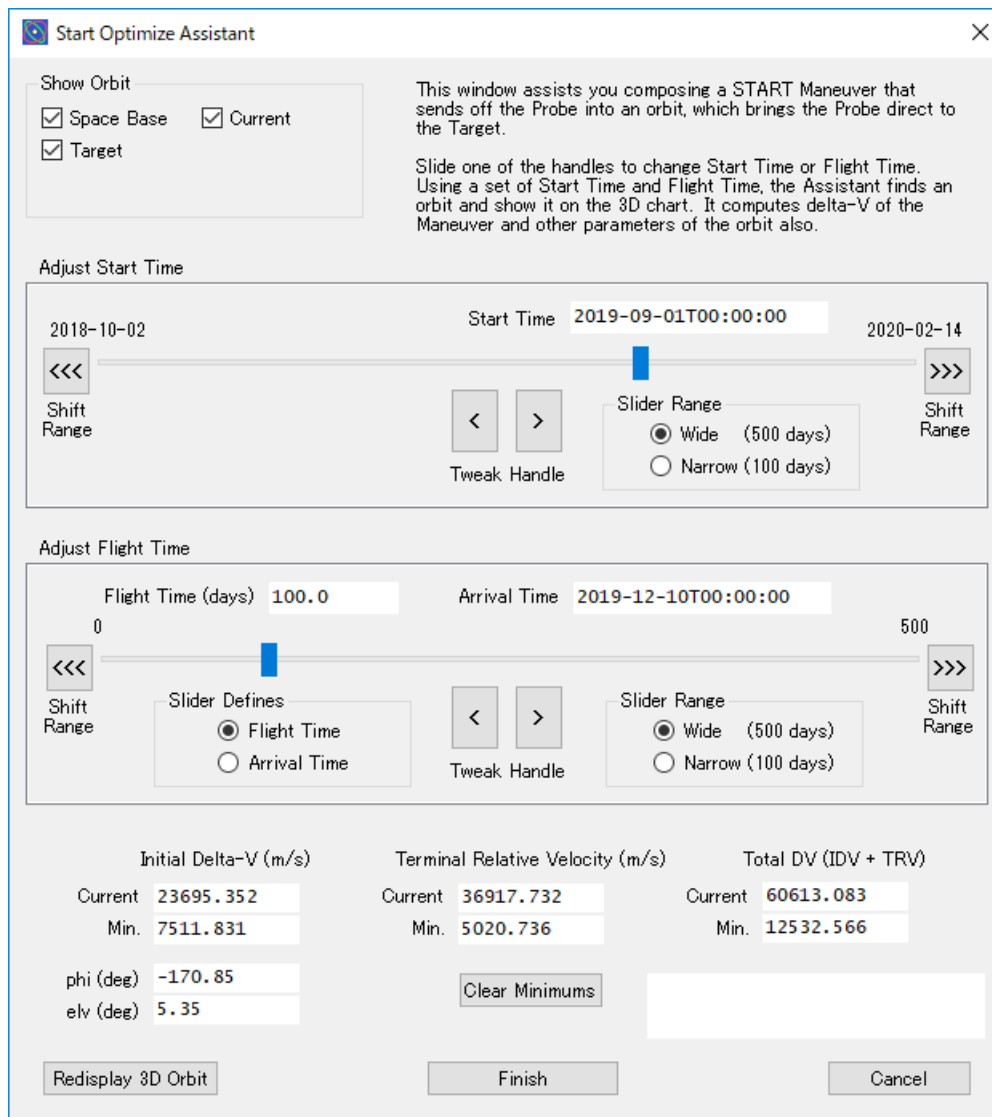


Figure 26 START Optimize Assistant window

In the top of the window, there is one group of items for options as follows:

Table 19 Options of the START Optimize Assistant window

Group	Item	Description
Show Orbit	Space Base (a check box)	When checked, the trajectory of the Space Base appears in the 3D chart as a curved line in red.
	Target (a check box)	When checked, the two-body orbit of the Target appears in the 3D chart as a curved line in green.
	Current (a check box)	When checked, the current two-body orbit of the Probe appears in the 3D chart as a curved line in cyan.

In the middle part of the window, there are two groups of items for adjusting the times. One is for Start Time, and the other is for Flight Time.

Table 20 Adjust Start Time and Flight Time

Group	Item		Description
Adjust Start Time	Start Time (a text field)		The current Start Time
	(a slider)		The slider to modify the current Start Time
	Shift Range	[<<<] button	The slider shifts its range toward the past by half of its length.
		[>>>] button	The slider shifts its range toward the future by half of its length.
	Tweak Handle	[<] button	The slider moves its handle toward the left by a pixel.
		[>] button	The slider moves its handle toward the right by a pixel.
	Slider Range	Wide (a radio button)	When selected, the range of the slider is 500 days.
		Narrow (a radio button)	When selected, the range of the slider is 100 days.
Adjust Flight Time	Flight Time (days) (a text field)		The current Flight Time in days
	Arrival Time (a text field)		The current Arrival Time
	(a slider)		The slider to modify the current Flight Time and the current Arrival Time
	Shift Range	[<<<] button	The slider shifts its range toward the shorter time (or toward the past) by half of its length.
		[>>>] button	The slider shifts its range toward the longer time (or toward the future) by half of its length.
	Tweak Handle	[<] button	The slider moves its handle toward the left by a pixel.
		[>] button	The slider moves its handle toward the right by a pixel.
	Slider Defines	Flight Time (a radio button)	When selected, the slider defines the Flight Time. If we modify the current Start Time, the Flight Time remains unchanged, but the Arrival Time changes.
		Arrival Time (a radio button)	When selected, the slider defines the Arrival Time, and SSVG calculates the Flight Time from it. If we modify the Start Time, the Arrival Time remains unchanged, but the Flight Time changes.
	Slider Range	Wide (a radio button)	When selected, the range of the slider is 500 days.
Narrow (a radio button)		When selected, the range of the slider is 100 days.	

In the bottom part of the window, there are three groups of items, four buttons, and a text field.

Table 21 Groups and Buttons in the bottom of the START Optimize Assistant window

Group	Item	Description
Initial Delta-V	Current	The magnitude of the current initial delta-V of the Probe, in meters per second
	Min.	The minimum value of the magnitude of the initial delta-V, up to the point of the operation
	phi	The angle phi of the current initial delta-V of the Probe, in degrees See Orbit Local Coordinate System .
	elv	The angle elv of the current initial delta-V of the Probe, in degrees See Orbit Local Coordinate System .
Terminal Relative Velocity	Current	The magnitude of the current relative velocity of the Target at the arrival of the Probe, in meters per second
	Min.	The minimum value of the magnitude of the relative velocity of the Target at the arrival of the Probe, up to the point of the operation
Total DV (IDV + TRV)	Current	The sum of the Current Initial Delta-V and the Current Terminal Relative Velocity
	Min.	The minimum value of the Current Total DV, up to the point of the operation
(None)	[Clear Minimums] button	SSVG clears all minimums.
	(a text field)	Messages about the behavior of SSVG
	[Redisplay 3D Orbit] button	The 3D Orbit window appears if not exists.
	[Finish] button	The START Optimize Assistant applies the current Start Time and the current initial delta-V into the Maneuver Editor window and closes itself.
	[Cancel] button	The START Optimize Assistant closes itself.

CP Optimize Assistant Window

CP Optimize Assistant helps us optimize a CP Maneuver that performs an orbital transition that makes the orbit bring a Probe to the Target direct.

The Flight Time of the Probe (from the orbital transition to the arrival at the Target) is very important for an efficient spaceflight, as well as the Maneuver Time, which is the time of the orbital transition.

A CP Optimize Assistant allows us to try various Maneuver Time and various Flight Time, to compare efficiency between different trials, and to choose a favorable pair of them.

Note that the words “the current *something*” in this subsection means “*something* in the current trial,” except otherwise mentioned.

CP Optimize Assistant window allows us to select a favorable Maneuver Time. However, there are the following important notices.

- Even if we selected a new Maneuver Time, SSVG does not apply the time to any Maneuvers, including the editing CP Maneuver. We must modify preceding FLYTO Maneuver or START Maneuver to use the results.
- To modify the Maneuver Time, CP Optimize Assistant assumes two-body motion of the Probe about the Sun. It does not yield appropriate Maneuver Time and delta-V if the assumption is not correct.

A CP Optimize Assistant window appears when we clicked the [OPTIMIZE] button of the

Maneuver Editor window editing a CP Maneuver.

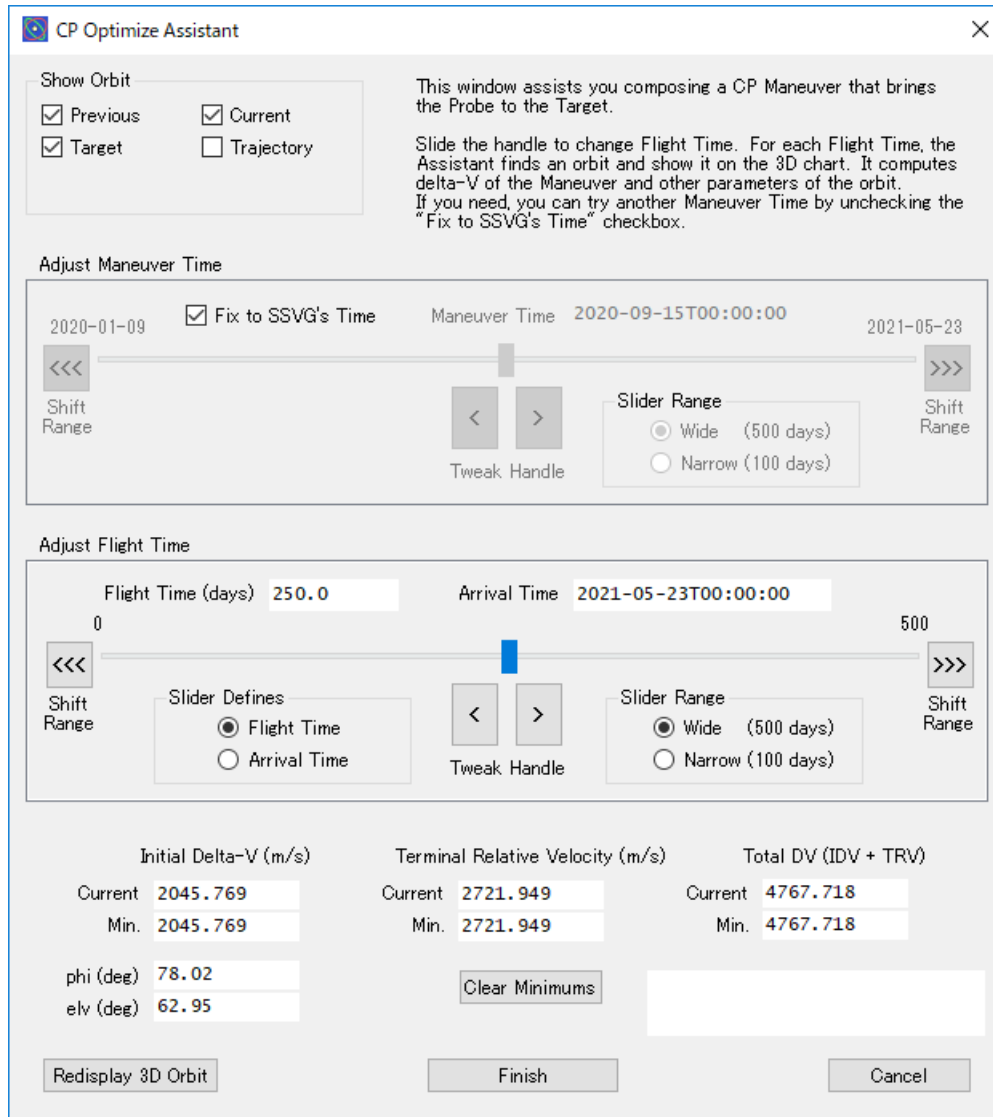


Figure 27 CP Optimize Assistant window

In the top of the window, there is one group of items for options as follows:

Table 22 Options of the CP Optimize Assistant window

Groups	Items	Explanations
Show Orbit	Previous (a check box)	When checked, the previous two-body orbit of the Probe appears in the 3D chart as a curved line in red.
	Target (a check box)	When checked, the two-body orbit of the Target appears in the 3D chart as a curved line in green.
	Current (a check box)	When checked, the current two-body orbit of the Probe appears in the 3D chart as a curved line in cyan.
	Trajectory (a check box)	When checked, the actual trajectory of the Probe in the past appears in the 3D chart as a curved line in blue.

In the middle part of the window, there are two groups of items for adjusting the times. One is for Maneuver Time, and the other is for Flight Time.

Table 23 Adjust Maneuver Time and Flight Time

Group	Item	Description	
Adjust Maneuver Time	Fix to SSVG's Time (a check box)	When checked, SSVG uses its time as Maneuver Time. We cannot modify the Maneuver Time. To modify the Maneuver Time, uncheck the box.	
	Maneuver Time (a text field)	The current Maneuver Time	
	(a slider)	The slider to modify the current Maneuver Time	
	Shift Range	[<<<] button	The slider shifts its range toward the past by half of its length.
		[>>>] button	The slider shifts its range toward the future by half of its length.
	Tweak Handle	[<] button	The slider moves its handle toward the left by a pixel.
		[>] button	The slider moves its handle toward the right by a pixel.
	Slider Range	Wide (a radio button)	When selected, the range of the slider is 500 days.
Narrow (a radio button)		When selected, the range of the slider is 100 days.	
Adjust Flight Time	Flight Time (days) (a text field)	The current Flight Time in days	
	Arrival Time (a text field)	The current Arrival Time	
	(a slider)	The slider to modify the current Flight Time and the current Arrival Time	
	Shift Range	[<<<] button	The slider shifts its range toward the shorter time (or toward the past) by half of its length.
		[>>>] button	The slider shifts its range toward the longer time (or toward the future) by half of its length.
	Tweak Handle	[<] button	The slider moves its handle toward the left by a pixel.
		[>] button	The slider moves its handle toward the right by a pixel.
	Slider Defines	Flight Time (a radio button)	When selected, the slider defines the Flight Time. If we modify the current Maneuver Time, the Flight Time remains unchanged, but the Arrival Time changes.
		Arrival Time (a radio button)	When selected, the slider defines the Arrival Time, and SSVG calculates the Flight Time from it. If we modify the Maneuver Time, the Arrival Time remains unchanged, but the Flight Time changes.
	Slider Range	Wide (a radio button)	When selected, the range of the slider is 500 days.
Narrow (a radio button)		When selected, the range of the slider is 100 days.	

In the bottom part of the window, there are three groups of items, four buttons, and a text field.

Table 24 Groups and Buttons at the bottom of the CP Optimize Assistant window

Group	Item	Description
Initial Delta-V	Current	The magnitude of the current delta-V of the orbital transition, in meters per second
	Min.	The minimum value of the magnitude of the delta-V, up to the point of the operation
	phi	The angle phi of the current delta-V of the orbital transition, in degrees See Orbit Local Coordinate System .
	elv	The angle elv of the current delta-V of the orbital transition, in degrees See Orbit Local Coordinate System .
Terminal Relative Velocity	Current	The magnitude of the current relative velocity of the Target at the arrival of the Probe, in meters per second
	Min.	The minimum value of the magnitude of the relative velocity of the Target at the arrival of the Probe, up to the point of the operation
Total DV (IDV + TRV)	Current	The sum of the current Delta-V and the current Terminal Relative Velocity
	Min.	The minimum value of the Total DV, up to the point of the operation
(None)	[Clear Minimums] button	SSVG clears all minimums.
	(a text field)	Messages about the behavior of SSVG
	[Redisplay 3D Orbit] button	The 3D Orbit window appears if not exists.
	[Finish] button	The CP Optimize Assistant applies the current delta-V into the Maneuver Editor window and closes itself (*).
	[Cancel] button	The CP Optimize Assistant closes itself.

(*) Even if we selected a new Maneuver Time, SSVG does not apply the time to any Maneuvers, including the editing CP Maneuver. We must modify preceding FLYTO Maneuver or START Maneuver to use the results. SSVG copies the Maneuver Time (ISOT format) into system clipboard to assist this modification.

Maneuver Description Window

Maneuver Description window shows the description of the Maneuver contained in the selected line of the Maneuver Table of the SSVG window. We call the Maneuver the “current Maneuver.”

The window appears when SSVG opens a Flight Plan. We can close the window, but it reappears when SSVG selects another line of the Maneuver Table.

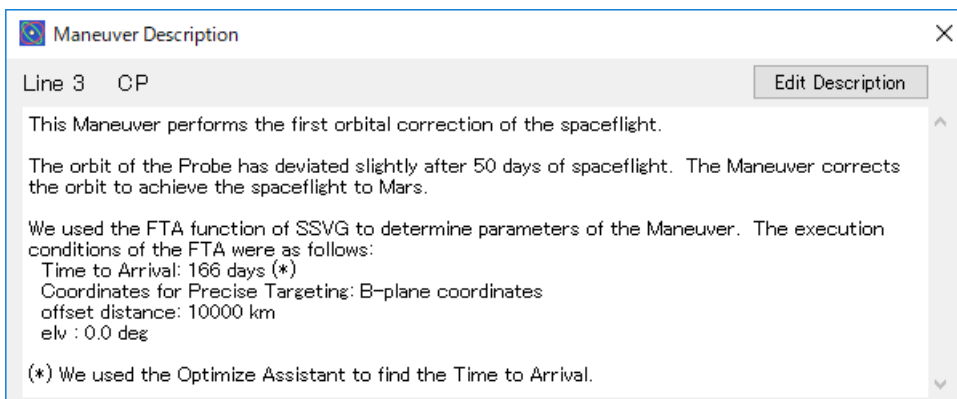


Figure 28 Maneuver Description window

The Maneuver Description window shows the line number and type of the current Maneuver at the top-left of the window. A button named Edit Description is in the top-right corner of the

window. When we click the [Edit Description] button, a window of Maneuver Description Editor appears on the Maneuver Description window to edit the description of the current Maneuver.

A text field to show the descriptions of the Maneuver covers almost all surface of the Maneuver Description window.

Maneuver Description Editor Window

Maneuver Description Editor window allows us to edit the description of the current Maneuver. The Maneuver contained in the selected line of the Maneuver Table of the SSVG window is the current Maneuver.

The Maneuver Description Editor window appears when we click the [Edit Description] button on the Maneuver Description window.

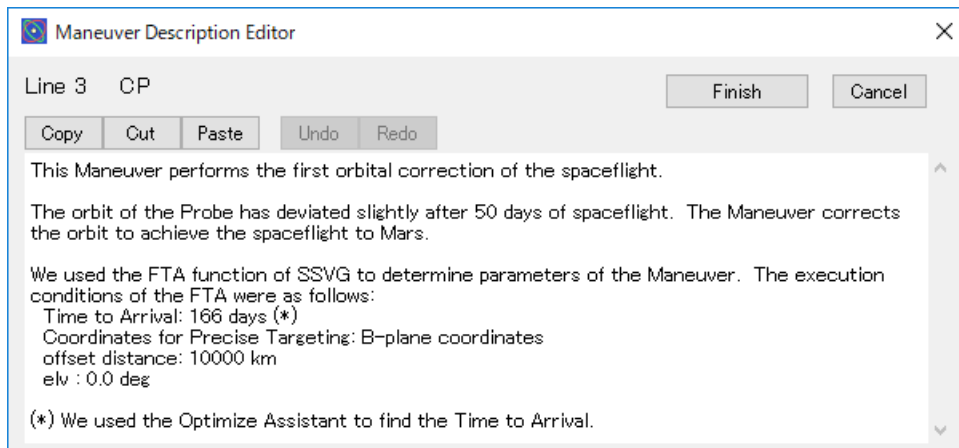


Figure 29 Maneuver Description Editor window

The Maneuver Description Editor window shows the line number and type of the current Maneuver at the top-left of the window.

A text field to edit the description of the Maneuver covers almost all surface of the Maneuver Description window.

The window contains the following seven buttons.

Table 25 Buttons of the Maneuver Description Editor Window

Face Name	Description
Finish	The window stores the description into the Flight Plan and closes itself. The Maneuver Description window shows the edited description.
Cancel	The window closes without storing the description.
Copy	The window copies the selected text string on the text field into the system clipboard.
Cut	The window cuts the selected text string and stores it into the system clipboard.
Paste	The window pastes the text string contained in the system clipboard into the cursor position of the text field.
Undo	The window undoes the latest operation about the text field.
Redo	The window redoes the latest undone operation about the text field.

Coordinate systems

Ecliptic Coordinate System

In SSVG, ecliptic coordinate system is an inertial Cartesian coordinate system fixed to the solar system.

The origin of the three axes (X, Y, and Z) is at the SSB, the solar system barycenter. The X-Y plane is parallel to the ecliptic plane, the orbital plane of Earth about the Sun. The X-axis directs to the vernal equinox. The Z-axis is perpendicular to the ecliptic plane, and it directs to the northern hemisphere. The three axes make up a right-handed Cartesian frame. We use the J2000 system for the ecliptic plane and the vernal equinox.

Orbit Local Coordinate System

In SSVG, we use orbit local coordinate system for an object that orbits around the Sun. It is a Cartesian coordinate system fixed to the object. The object is one of the Probes, one of the Space Bases, or one of the Targets.

The origin of the three axes (X, Y, and Z) is at the center of an object. The orbital plane of the object defines the X-Y plane. The velocity vector of the object relative to the Sun defines the X-axis. The Z-axis is perpendicular to the orbital plane, and its direction is the north pole of the orbit. The Y-axis completes the right-handed Cartesian frame.

It is useful to remember that the X-axis is the tangential line of the two-body orbit of the object.

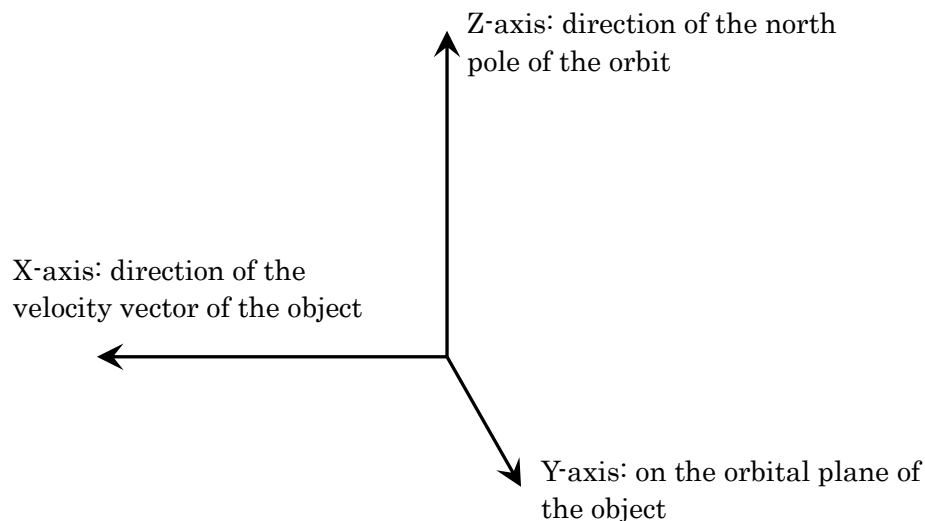


Figure 30 Orbit Local Coordinate System

The following figure shows polar coordinates (r , ϕ , elv) of a vector V on the orbit local coordinate system. Drop a perpendicular line from the point of V to the X-Y plane, and name the foot point as H . “ ϕ ” is the angle from the X-axis to the line segment OH . “ elv ” is the angle from the line segment OH to V . “ r ” is the magnitude, length, of V .

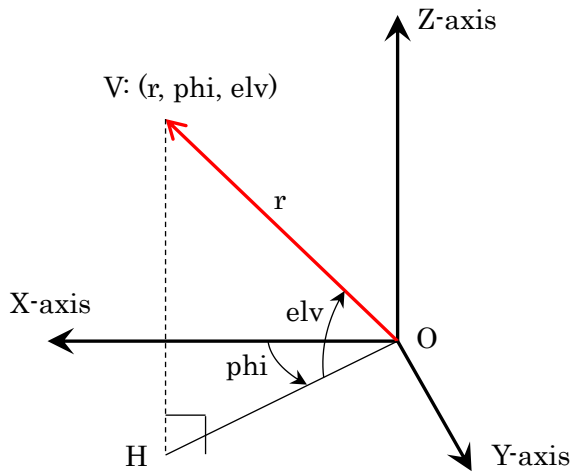


Figure 31 Polar Coordinates on Orbit Local Coordinate System

Solar Sail Coordinate System

In SSVG, we use solar sail coordinate system for an Probe. It is a Cartesian coordinate system fixed to the Probe.

The origin of the three axes (X, Y, and Z) is at the center of a Probe. The orbital plane of the Probe defines the X-Y plane. The position vector of the Probe from the Sun defines the X-axis. The Z-axis is perpendicular to the orbital plane, and its direction is the north pole of the orbit. The Y-axis completes the right-handed Cartesian frame.

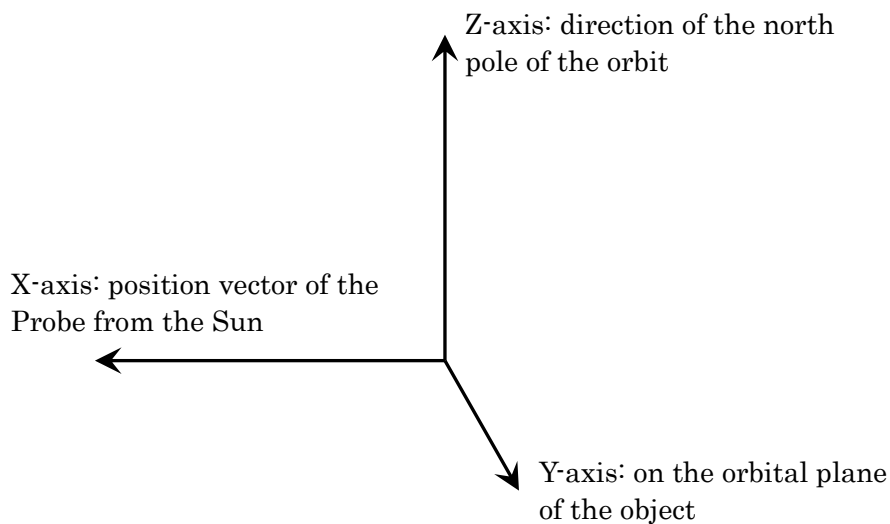


Figure 32 Solar Sail Coordinate System

In SSVG, we use the unit vector normal to the plane of sail to represent the orientation of a Solar Sail. The unit vector can be one of the two directions, but we can choose any one of them because the Solar Sail of SSVG is a double-sided mirror.

The following figure shows the polar coordinates of the unit vector UV on the solar sail coordinate system. Drop a perpendicular line from the point of UV to the X-Y plane, and name the foot point as H. “theta” is the angle from the X-axis to the line segment OH. “elv” is the angle from the line segment OH to UV.

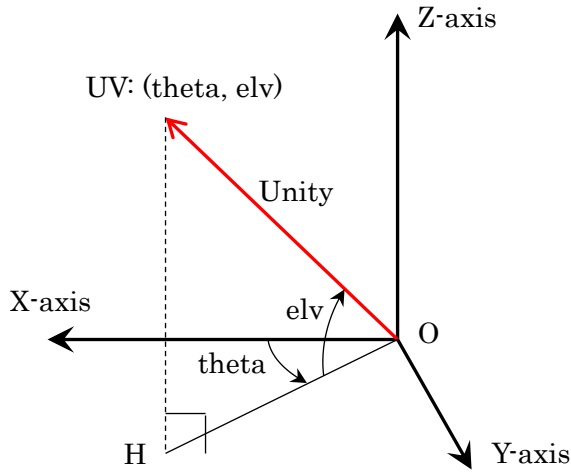


Figure 33 Polar Coordinates on Solar Sail Coordinate System

B-plane Coordinate System

In SSVG, we use B-plane coordinate system for a Target and a Probe that flies by the Target. It is a Cartesian coordinate system fixed to the Target.

We consider the two-body motion of a Probe about the Sun and define the followings.

- Relative Motion of the Probe: the two-body motion of the Probe relative to the Target
- B-point: the nearest point of Relative Motion of the Probe from the Target
- Relative Velocity: the velocity vector of the Relative Motion of the Probe at the B-point
- B-plane: the plane contains the B-point and perpendicular to the Relative Velocity

The origin of the three axes (R, S, and T) is at the center of the Target. The Relative Velocity defines the S-axis. The T-R plane is perpendicular to the S-axis. It contains the B-point, and it coincides with the B-plane.

The following vector cross product defines the T-axis. It is on the orbital plane of the Target about the Sun.

$$\vec{T} = \vec{S} \times \vec{H}_T$$

where

\vec{T} , \vec{S} : Vectors of T-axis and S-axis, respectively

\vec{H}_T : Angular momentum vector of the Target (its direction is the north pole of the orbit)

FTA function (see [FTA Setting Window](#)) of SSVG can use a B-point as the targeting point. We specify a B-point by two parameters, angle beta and offset distance d, of the B-plane coordinate system. We see them in the following figure. In the figure, the Relative Motion of the Probe passes through the B-plane from the near side to the far side.

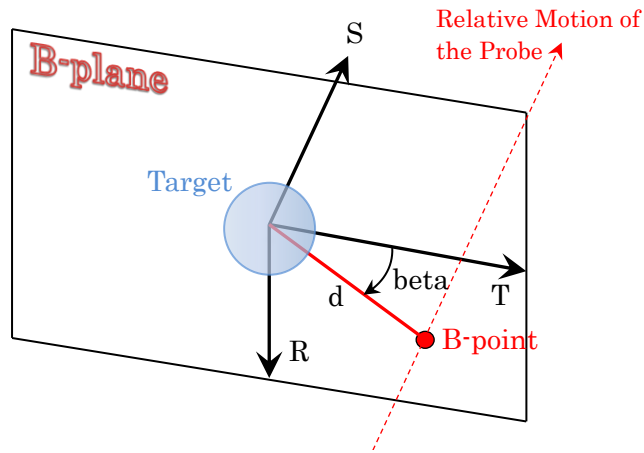


Figure 34 Two Parameters of B-plane Coordinate System

Miscellaneous Information

Folders for Users

We have four special subfolders (subdirectories) within the folder of SSVG. They are SSVG_data, SSVG_i18n, SSVG_log, and SSVG_plan. The usages of these folders are as follows:

- SSVG_data: to store SPK files and planetary ephemeris data files
The Import command of SSVG stores SPK files into the folder.
SSVG searches the folder to find an SPK file.
- SSVG_i18n: to store files for the internationalization
- SSVG_log: to store log files
- SSVG_plan: to store Flight Plan files
SSVG stores a new Flight Plan file into the folder by default.
The Import command of SSVG stores Flight Plan files into the folder.
SSVG searches the folder to find a Flight Plan file.

The folder of SSVG contains many other folders and files. We must not delete, move, or modify them, except otherwise mentioned.

Time

In SSVG, time is Barycentric Dynamical Time (TDB), except otherwise mentioned.

SSVG uses the Julian date (JD) for internal expression and user interface. It uses the ISO 8601 extended format (ISOT) with no time zone designators also, for the user interface (*). For example, SSVG displays 6 AM on January 1, 2020, as follows:

```
2020-01-01T06:00:00.0000 (ISOT)
2458849.75000000 (JD)
```

We can fly Probes within the time range of SSVG. The time range is:

```
From 0 AM, on December 31, 1549 (*)
Until 0 AM, on January 25, 2650
```

(*) SSVG uses the Gregorian calendar for date, except otherwise mentioned.

In addition, a Flight Plan that uses a small celestial body as Target can fly the Probe within the time range of the SPK file of the Target.

Numerical Integration of the Probe Trajectory

On executing a FLYTO maneuver, SSVG computes actual trajectory (positions and velocities) of the Probe by numerical integration of the forces that affect the motion of the Probe. SSVG considers the following forces and neglects any other forces.

- The gravitational attraction of the Sun
- The gravitational attractions of the eight planets and the moon of Earth
- The propulsive forces of the Electric Propulsion Engine and the Solar Sail

Note that SSVG does not consider the gravitational attraction of the small celestial bodies, including relatively heavy dwarf planets (e.g. Ceres or Pluto), for the computation of the actual trajectory of a Probe. Even if the Probe comes close to a small body, the body does not affect any gravitational attraction to the Probe.

Two-body Motion of the Probe

SSVG computes the actual trajectory of a Probe by numerical integration as mentioned above. However, all other computations about orbits, positions, and velocities of the Probe are performed based on the two-body motion about the Sun. Examples are as follows:

- Positions and orbits of the Probe, displayed on the 3D Orbit window
- Positions and velocities of the Probe, used to compute relative positions and relative velocities of the Target on the Show Orbit window
- FTA function
- Optimize Assistant (START Optimize Assistant and CP Optimize Assistant)

In addition, SSVG computes orbits of the Target displayed on the 3D Orbit window by two-body motion about the Sun.

Position and Velocity of Planet

SSVG computes positions and velocities of the eight planets, dwarf planet Pluto, and the Moon of the Earth from the SPK file de430.bsp provided by NASA/JPL.

Position and Velocity of Small Celestial Body

SSVG computes positions and velocities of a small celestial body from the SPK file of the body. We can request the generation of SPK files to the HORIZONS system of NASA/JPL. See [Get SPK File of Small Celestial Body](#) subsection.

Propulsion Systems and Rocket Equation

Although the three propulsion systems in SSVG do not consume any propellant, propellant on board and its consumption are one of the problems that attract large attention of designers of actual space flights.

We have an equation that governs the relationship between the magnitude of delta-V (velocity increment of an orbital transition) and the total mass of the spacecraft. We often call it the “rocket equation.”

$$\frac{m_0}{m_T} = \exp\left(\frac{\Delta V}{I_{sp} \cdot g}\right)$$

where

m_0 : The total mass of the spacecraft (before the orbital transition)

m_T : The total mass of the spacecraft (after the orbital transition)

ΔV : The magnitude of delta-V of the orbital transition

I_{sp} : Specific impulse of the propulsion system

g : Standard gravitational acceleration of the Earth

$\exp()$: Exponential function

The subtraction $m_0 - m_T$ yields propellant consumption during the orbital transition.

The following two tables show computational results of the rocket equation for two propulsion systems respectively. The first one is for a typical liquid propellant rocket engine with 300 seconds of I_{sp} . On the other hand, the second is for a typical ion engine with 3000 seconds of I_{sp} . For both computations, we assumed that the value of m_T (the total mass of the spacecraft, after the orbital transition) is 1.000.

Table 26 Results of Rocket Equation (Liquid Propellant Engine, $I_{sp} = 300$)

ΔV (meters per second)	m_0	Propellant Consumption ($m_0 - m_T$)	m_T
500	1.185	0.185	1.000
1000	1.405	0.405	1.000
2000	1.974	0.974	1.000
4000	3.895	2.895	1.000
8000	15.169	14.169	1.000
16000	230.094	229.094	1.000
32000	52943.095	52942.095	1.000

Table 27 Results of Rocket Equation (Ion Engine, $I_{sp} = 3000$)

ΔV (meters per second)	m_0	Propellant Consumption ($m_0 - m_T$)	m_T
500	1.017	0.017	1.000
1000	1.035	0.035	1.000
2000	1.070	0.070	1.000
4000	1.146	0.146	1.000
8000	1.312	0.312	1.000
16000	1.723	0.723	1.000
32000	2.967	1.967	1.000

Get SPK File of Small Celestial Body

The HORIZONS system of NASA/JPL generates SPK files for small celestial bodies (asteroids, comets, and dwarf planets) on demands. The HORIZONS system can generate SPK files in one of the two formats, ASCII or Binary. However, SSVG can read SPK files in Binary format only.

About the HORIZONS system, see <<https://ssd.jpl.nasa.gov/?horizons>>.

This subsection shows a procedure to request the generation of an SPK file to the HORIZONS system. Although the previous web page does not provide this procedure, it is one of the easiest ways to obtain an SPK file.

Before the request, we need

- to find the name, the number, the designation, or the SPKID of the body, and,
- to decide a time range in which we wish to fly the Probe. (*)

(*) At this time (June of 2019), the HORIZONS system can generate SPK files within the following time range.

- From 1000-Jan-01 (January 1, 1000)
- To 2101-Jan-01 (January 1, 2101)

You can check the time range by accessing the HORIZONS system with TELNET interface. See the previously mentioned web page of the HORIZONS system.

At first, open the “Asteroid & Comet SPK File Generation Request” page of HORIZONS system by clicking the following link.

<<https://ssd.jpl.nasa.gov/x/spk.html>>

The web browser shows the following page (the following figure shows the top half of the page).

Advanced Horizons Asteroid & Comet SPK File Generation Request

Fill in all necessary data and submit to produce a small-body SPK file on your system.
For general information on this program, click [here](#).

For information about each input, click on its title -- a window will open.

Object	<input type="text"/>
SPK start date (TDB)	<input type="text"/>
SPK stop date (TDB)	<input type="text"/>
E-mail contact address	<input type="text"/>
SPK file format	<input type="radio"/> ASCII <input type="radio"/> Binary

After clicking "Make SPK", please wait until the integration is complete.
It could take a minute or so to generate and stream data, depending on system load.

Optional (below): define your own object by supplying heliocentric J2000 ecliptic osculating elements.

Epoch (Julian Day Number,)

Figure 35 “Asteroid & Comet SPK File Generation Request” page

The top half of the page contains three push buttons and a table with input fields and radio buttons. The following table shows how to operate each item.

Table 28 Operations of SPK File Generation Request

	Item	Operation and Explanation
Table	Object (an input field)	Enter the name, the number, the designation, or the SPKID of the small celestial body.
	SPK start date (TDB) (an input field)	Enter the start date with the format of "YYYY-Mon-DD." For example, 2000-Jan-01 for January 1, 2000
	SPK stop date (TDB) (an input field)	Enter the stop date with the format of "YYYY-Mon-DD." For example, 2100-Dec-31 for December 31, 2100
	E-mail contact address (an input field)	Enter your E-mail address.
	SPK file format (two radio buttons)	Select the "Binary" radio button.
Buttons	[Look up]	When we clicked, the HORIZONS system shows the candidates of the small celestial body.
	[Make SPK]	When we clicked, the HORIZONS system generates an SPK file and the browser downloads it.
	[Clear Form]	When we clicked, the HORIZONS system clears all information entered.

Let us try to get an SPK file of the comet Halley.

Enter "Halley" into the "Object" field and click the [Look up] button. The browser shows two groups of text lines, as shown in the following figure.

```

Object Name      = 2688 Halley
Primary SPKID    = 2002688
Primary designation= 1982 HG1
Aliases          = 1978 UO, 1978 TE9, 1978 SH6, 1955 QN1, J82H01G

Object Name      = Halley
Primary SPKID    = 1000036
Primary designation= 1P
Aliases          = 1982 U1, 1909 R1, 1835 P1, 1758 Y1, 1682 Q1, 1607 S1, 1531 P1, 1456 K1, 1378 S1,
1301 R1, 1222 R1, 1145 G1, 1066 G1, 989, 989 N1, 912, 912 J1, 837, 837 F1, 760, 760 K1, 684, 684 R1,
66, 607, 607 H1, 530, 530 Q1, 451, 451 L1, 374, 374 E1, 295, 295 J1, 218, 218 H1, 1986 III, 1982i,
1910 II, 1909c, 1835 III, 1759 I, 1682, 1607, 1531, 1456, 141, 141 F1, 1378, 1301, 1222, 1145, 1066,
66 B1, -11 Q1, -86 Q1, -163 U1, -86, -239 K1, -239, -163, -11, 4000001

```

Figure 36 The Result of "Look up" of "Halley"

We can see as follows:

- The system found two objects named "Halley."
- The first one (2688 Halley) is an asteroid (search it on JPL Small-Body Database Browser <<https://ssd.jpl.nasa.gov/sbdb.cgi>>).
- The second one is comet Halley we wish to get the SPK file.

Copy the value of Primary SPKID of the second object (1000036) into the clipboard, and return to the previous page. SPKID is an identification number of a celestial body in the HORIZONS system.

Paste the SPKID into the Object field and click the [Look up] button. The result appears on the browser. It contains only one object, comet Halley. Return to the previous page.

Fill the remaining fields, select the SPK file format, and click the [Make SPK] button. The HORIZONS system generates an SPK file, and the browser downloads the file. The file name is 1000036.bsp (it is [SPKID].bsp).

Run SSVG, and import the downloaded SPK file (click the File menu, point the Import, and click

SPK file).

Now, we can select comet Halley as a Target of SSVG. The comet is supposed to come to the central region of the solar system in 2061.

Operational Log

SSVG records an operational log of each run. Each log file contains creating and editing history of the flight plans. SSVG stores the log file into the SSVG_log folder within the folder of SSVG.

Thrust Vector Mode

Thrust Vector Mode defines the way by which SSVG controls the thrust direction of two propulsion devices, Electric Propulsion Engine and Solar Sail, of the Probe. The value of tvmode, one of the parameters for EP_ON Maneuver and SS_ON Maneuver, assigns a state for the Thrust Vector Mode of a Maneuver. The tvmode has one of the two values, L or E. L came from Local and E came from Ecliptic.

When the tvmode is L, SSVG fixes the thrust direction in the local coordinate system of the Probe during an operating period (*) of a propulsion system. The local coordinate system is the orbit local coordinate system for the EP_ON Maneuver or the solar sail coordinate system for the SS_ON Maneuver.

When the tvmode is E, SSVG fixes the thrust direction in the ecliptic coordinate system during one operating period of a propulsion system.

For example, let us consider the operation of the Electric Propulsion Engine of a Probe.

(1) Add an EP_ON Maneuver with the following parameters:

dvpd = 10.0
phi = 0.0
elv = 0.0
tvmode = L

(2) Execute the EP_ON Maneuver.

(3) Add a FLYTO Maneuver to fly the Probe for 100 days.

(4) Execute the FLYTO Maneuver.

The Electric Propulsion Engine accelerates the Probe continuously on the line of the velocity of the Probe. The Probe changes direction with time and the thrust changes direction in the same manner.

(5) Add an EP_ON Maneuver with the following parameters:

dvpd = 10.0
phi = 0.0
elv = 0.0
tvmode = E

(6) Execute the EP_ON Maneuver.

At this point, SSVG computes the direction of the thrust of the Electric Propulsion Engine in the ecliptic coordinate system.

(7) Add a FLYTO Maneuver to fly the Probe for 100 days.

(8) Execute the FLYTO Maneuver.

The Electric Propulsion Engine accelerates the Probe continuously in the direction computed in (6). The direction of the thrust is on the line of the velocity of the Probe, at the beginning of the flight. The Probe changes direction with time, but the direction of the thrust stays unchanged.

The operations of the Electric Propulsion Engine and the Solar Sail are independent each other.

(*) An operating period of a thruster begins by the execution of an activating Maneuver of the thruster. The period ends with the execution of a deactivating Maneuver or another activating Maneuver of the thruster.

Extending to Other Languages

SSVG is internationalized software. You can extend the user interface of SSVG into other languages without modification of its Python scripts. The subsection describes how of the extending.

Note that most data files for the internationalization of SSVG have stored within SSVG_i18n folder. Except otherwise mentioned, we can find a file within the folder and you must store every file into the folder.

Tools

We use a Qt environment along with its two tools, Qt Linguist and lrelease. In my environment (Windows 10 and Anaconda 3.5), the tools are `linguist.exe` and `lrelease.exe` in `[Python root]¥Library¥bin`.

Procedures (part one)

If your language requires European font only, try the following procedures from (1) through (3). We assume the language is Spanish (the language code is “es”) in this description.

(1) Create SSVG translation file for Spanish

- Copy the SSVG translation file (source) for Japanese (`ssvg_ja.ts`) and create an SSVG translation file (source) for Spanish (`ssvg_es.ts`).
- Run the Qt Linguist and open `ssvg_es.ts`. Translate every source text in English into Spanish and replace Japanese text with it for all contexts except a context named Language.
- The Language context contains only one source text “en”. Translate this text to the text “es”. “es” is the language code of the language you are working on.
- Run the lrelease to create compressed SSVG translation file. In a Windows environment, try the following command on a command prompt window.

```
> lrelease -compress ssvg_es.ts
```

The lrelease creates a file named `ssvg_es.qm`. It is a compressed SSVG translation file for Spanish.

(2) Copy two Qt translation files

Copy two files, `qt_es.qm` and `qtbases_es.qm`, from your Qt environment into the SSVG_i18n folder. In my Qt environment, I find the two files in


```
[Python root]¥Library¥translations
```

The two files are not mandatory.

(3) Register font family name of your language

Open a file named `3DOrbitFont.json` within `SSVG_i18n` folder with your text editor. Add a line that combines language code and font name as follows:

before editing:

```
{
    "en": "sans-serif"
    "ja": "IPAexGothic"
}
```

after editing:

```
{
    "en": "sans-serif"
    "es": "sans-serif"
    "ja": "IPAexGothic"
}
```

When your language requires only European font, that is all. Run SSVG and check it. If the 3D Orbit window of SSVG shows invalid characters, it means you need to install an appropriate font file. Follow the procedures (part two) successively.

Procedures (part two)

In this description, the language of the example is Korean (the language code is “ko”).

(4) Get font file for your language

I recommend you to obtain a True Type font file. You need the font file (for example, `hangul.ttf`) and the font name (for example, `HangulFont`).

(5) Store the font file into appropriate folder

- If you are using a Windows executable of SSVG, store the font file into the folder `mpl-data¥fonts¥ttf` within the folder of SSVG.
- If you are using Python script of SSVG, store the font file into the font folder of the matplotlib module. The folder may be,

```
[Python root]¥Lib¥site-packages¥matplotlib¥mpl-data¥fonts¥ttf
```

In this case, you need to erase the font cache file of matplotlib module. In my environment, the file is

```
[user folder]¥.matplotlib¥fontList.json
```

(6) Register the font name

Open the file named `3DOrbitFont.json` within `SSVG_i18n` folder with your text editor. Modify it to combine the language code and the font name as follows:

before editing:

```
{
    "en": "sans-serif"
    "ko": "sans-serif"
    "ja": "IPAexGothic"
}
```

after editing:

```
{
  "en": "sans-serif"
  "ko": "HangulFont"
  "ja": "IPAexGothic"
}
```

That is all. Run SSVG and check it.

Samples of Flight Plans

SSVG has several samples of Flight Plans in the “SSVG_plan” folder within the folder of SSVG. We can open one of them easily by the Open command of the File menu. The samples are as follows:

sample_Mars

A Flight Plan for a Mars exploration mission

The Probe starts its spaceflight from Earth L2 Space Base. It uses only the Chemical Propulsion Engine for orbital transitions, and it arrives Mars after 216 days of spaceflight. It enters the Mars orbit after the arrival.

sample_Mars_ad-hoc

A Flight Plan toward Mars

The Probe starts its spaceflight from Earth L2 Space Base, and it flies toward Mars with a “Try and Discover” manner. It uses only the Chemical Propulsion Engine for orbital transitions, and it arrives Mars after 810 days of spaceflight. It enters the Mars orbit after the arrival.

sample_Mars_SS

A Flight Plan to Mars with the Solar Sail

The Probe starts its spaceflight from Earth L2 Space Base, and the initial velocity is 960 meters per second. It flies toward Mars using the Solar Sail only as propulsion systems. The space journey takes a little more than five years (1847 days) from the Space Base to Mars. The area of the Solar Sail is ten thousand square meters, and the total mass of the Probe is five hundred kilograms. The accumulated delta-V of the thrust of the Solar Sail is 7393 meters per second.

sample_Swingby

A Flight Plan to try a Jupiter swing-by

The Probe leaves Earth L2 Space Base on March 26 of 2020, and it makes a Jupiter swing-by on October 10 of 2021. See [Gravity Assist of Jupiter](#) subsection.

About Planetary Ephemeris Files

The installer file of SSVG (version 1.5.0 or later) contains a planetary ephemeris file “de440.bsp”. SSVG calculates the positions of the Sun and planets by using the file. Meanwhile, the older version of SSVG uses a file “de430.bsp”. You can get those files from NASA/JPL.

The former, “de440.bsp”, is the revised version of the latter, “de430.bsp”. The former uses a slightly different origin and provides slightly different positions of the Sun and planets. Because of the differences, a Probe runs through slightly different trajectories with newer and older SSVG for the same Flight Plan. If you run a Flight Plan designed by the older version on the newer SSVG and want to get the same trajectory, you should use the planetary ephemeris file “de430.bsp” with the newer SSVG. Please refer the [System Configuration](#) subsection.

If you wish to create a Flight Plan targeting one of the small celestial bodies, you should use a planetary ephemeris file that is compatible with the SPK file of the celestial body. You can get the SPK file of the celestial body from HORIZONS system of NASA/JPL, and the date you get the file affects the compatibility with the planetary ephemeris files. The critical date is April 12 of 2021.

- An SPK file got on the critical date, or earlier, is compatible with “de430.bsp”
- An SPK file got after the critical date is compatible with “de440.bsp”

If you use an incompatible planetary ephemeris to create a Flight Plan in which the Probe rendezvous with a small celestial body, the rendezvous may become less accurate.

System Configuration

SSVG (version 1.5.0 or later) contains a system configuration file named “SSVGconfig.json” in its installation folder. You can tweak the behavior of SSVG by editing the file.

Just after the installation of SSVG, the file includes the following lines.

```
{
  "system" : {
    "planetsSPK" : "de440.bsp",
    "3Dproj" : "ortho"
  }
}
```

The file (SSVGconfig.json) has the JSON format. The keys and available values are as follows.

Table 29 Keys and Values of the System Configuration file

1st Key	2nd Key	Available Value	Explanation	Remark
system	planetsSPK	de440.bsp	To read the file named “de440.bsp” for the planetary ephemeris.	initial value
		de430.bsp	To read the file named “de430.bsp” for the planetary ephemeris.	
	3Dproj	ortho	To use Parallel Projection to draw figures on the 3D Orbit Window.	initial value
		persp	To use Perspective Projection to draw figures on the 3D Orbit Window.	

References

1. 室津義定, 宇宙航行力学, 宇宙工学の基礎 I, 共立出版株式会社, Japan, 1998
2. Kluever, Craig A., Space Flight Dynamics, John Wiley & Sons Ltd, UK, 2018 (kindle version)
3. <https://ssd.jpl.nasa.gov/?horizons> Accessed June 5, 2019
4. <https://voyager.jpl.nasa.gov/> Accessed June 5, 2019
5. http://www.ieice-hbkb.org/files/11/11gun_02hen_04.pdf Accessed June 5, 2019
6. <http://www.ecei.tohoku.ac.jp/inuta/souzoukougaku/takasho/takasho01.htm> Accessed June 5, 2019
7. <http://astro-dic.jp/> Accessed June 5, 2019
8. <http://ccar.colorado.edu/imd/2015/documents/BPlaneHandout.pdf> Accessed June 20, 2018
9. https://en.wikipedia.org/wiki/Solar_sail Accessed June 5, 2019
10. <http://global.jaxa.jp/projects/sat/ikaros/> Accessed November 12, 2018
11. <https://ssd.jpl.nasa.gov/sbdb.cgi> Accessed June 5, 2019
12. <http://www.jaxa.jp/> Accessed June 5, 2019
13. <https://www.nasa.gov/> Accessed June 5, 2019
14. <https://www.esa.int/ESA> Accessed June 5, 2019
15. <https://www.nao.ac.jp/> Accessed June 5, 2019
16. <https://doc.qt.io/qt-5/reference-overview.html> Accessed June 5, 2019