1.5.1 ORBIT5S

Orbit5S is the primary piloting software program used in spacesim at the present time. It models the position, velocity, and gravity of the sun, all of the planets, most of the larger moons, and many other smaller objects within our solar system. It manages all of the pilot controls that allow the spacecraft to be navigated to any of the modeled objects and either enter into an orbit around them or land on them (if they have a solid surface). Orbit5S is a 2-dimensional simulation. Ignoring the third spatial dimension keeps the complexity of piloting a spacecraft to a manageable level. You won't have to take a year off school to perfect your skills.

Orbit5S is just one component of the spacesim simulation network. Most of the other software components use output from Orbit5S, but Orbit5S does not need most of them to run itself. Output from the engineering software, Orbit5SE, is necessary for the proper functioning of Orbit 5S. Orbit5SE is described in section 1.6. Orbit5S will run, although not update its fuel state, as long as Orbit5SE has been started and has had the engine systems turned on properly. Once this has been done, the Orbit5SE software can be closed. Orbit5S can then be started and it will run using the last data output file from Orbit5SE.

In order to use the orbit software effectively, it is important to understand the intricacies of controlling a vehicle in space and, in particular, a vehicle in orbit. In an environment without friction or drag, but with ever-changing gravity, many of the intuitive assumptions with which we have become accustom will not only not work, but may cause serious accidents to occur.

1.5.1.1 Motion in Space

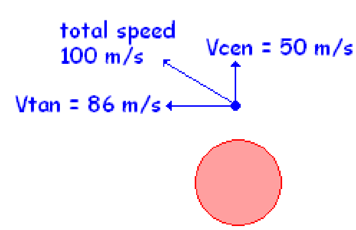
In space there is no set frame of reference (such as the lines of latitude and longitude that we use for compass directions on earth). However, we can use what ever planet or moon we are in orbit around or travelling to as a temporary reference point. Even with a reference point, the compass directions have no meaning high above the surface of a planet.

In our 2-dimensional simulation, there are two components of direction that are important to us. We use them for describing speed, distance, and engine thrust. One component is direction towards or from the planet (in-and-out, or centripetal direction). This can be towards (negative) or away (positive). The other direction is side-to-side relative to the planet (the tangential direction). This usually is described as being counter clockwise (ccw) or clockwise (cw). Most objects in our solar system rotate and revolve (move around another object) in a counter clockwise direction. Because of this, counter clockwise orbits around a planet are normal for spacecraft operation.

Motion must always be described in relation to some planet or other object. The Orbit5S software allows you to specify two different such objects at the same time: the reference object (usually the one about which you are in orbit) and the target object (usually your destination). The velocities and distances displayed by the software always are in relation to one or the other of these two objects. It is important to keep track of which object has been selected for the target and reference, or you may misinterpret the data displayed by the software.

It is very rare that a spacecraft moves only towards a object (except when landing) or only sideways with respect to an object (except while in a circular orbit). More often, the motion is a combination of the two. It usually is useful to consider each of these components of motion separately, however, when planning different orbital manoeuvers.

Consider the situation shown to the right. A spacecraft is moving away and counter clockwise relative to a planet. The total velocity is 100 m/s (up and to the left as drawn). You could consider the centripetal and tangential velocities separately (the ORBIT5S displays them for you). In this case, the tangential velocity (Vtan) is 86 m/s counter clockwise and the centripital velocity (Vcen) is 50 m/s outward. These two velocities add up to the 100 m/s total velocity that the spacecraft actually has. Knowledge of separate velocity components is useful in many circumstances, such as determining how to circularize a non-circular orbit (see below).

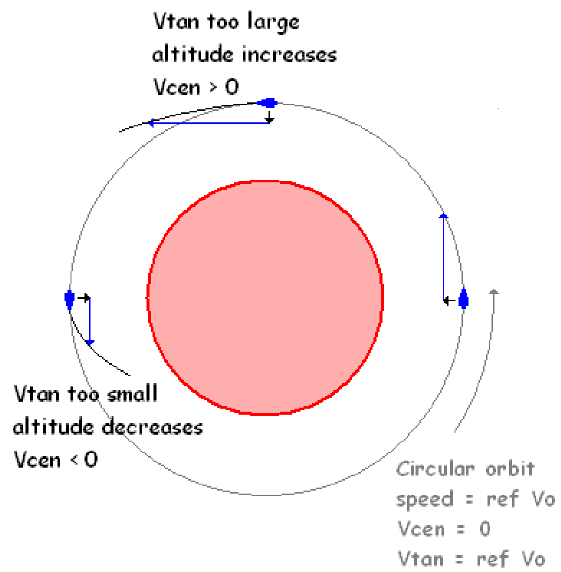


Unlike on an planet or in an atmosphere, all changes in the velocity of an object must be accomplished using the engines. This includes speeding up, slowing down, ***and*** changing direction. For example, if you want to slow down, you must fire your engines to push the spacecraft in the direction opposite to that in which you are presently travelling. If you want to make a 90º turn to the left, you must use the engines to both push the spacecraft backwards to stop motion in your current direction and push the spacecraft towards the direction that you wish to travel. This is explained in more detail in section 1.5.3

1.5.1.2 Motion in Orbit

In orbit, an object is always falling towards the Earth (or what ever other planet about which you are in orbit). This is because of gravity. In a low-earth orbit, there is almost as great a force of gravity as on the surface of the earth. This should seem reasonable, because compared to the radius of the earth (6370 km) being only 300 km farther up should not make much difference.

Spacecraft can carry only so much fuel; not enough to counter-act gravity for more than a few hours (even our spacecraft). So, they avoid falling back to earth by moving sideways fast enough to keep missing it! On the diagram to the right, in each time interval, the spacecraft on the right falls a certain distance (black arrow). If, in the same time interval, it moves sideways just right distance (the blue arrow) to end up still at the same height above the earth.



Gravity does decrease the higher above the earth you go. Thus, you need less sideways speed to stay in orbit when you are farther from the earth.

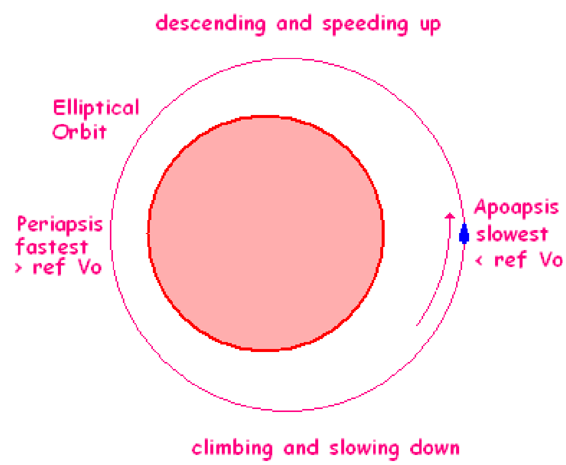
The correct tangential speed (Vtan) for a given orbital height is **ref Vo**. Since the height does not change in a perfectly circular orbit, Vcen should be zero.

As long as the orbit is above the atmosphere, there is no drag to slow the spacecraft down and the Vtan speed will remain constant. Thus, as we will see in section 1.5.2, the job of the engines in getting a spacecraft into orbit is to: 1) push the spacecraft up to the correct altitude, and 2) to accelerate it sideways to the correct ref Vo speed. Once this is done, the engines are not needed unless we wish to make adjustments to the orbit.

Non-Circular Orbits

If an orbit is not circular (elliptical), its speed will change continuously.
For example, if the Vtan is too slow (less that ref Vo), the spacecraft will not move sideways far enough to stay at its altitude and it will start to descend. Almost all orbits are somewhat elliptical.

As the spacecraft descends, it speeds up because it is moving with gravity. Vtan gets faster and faster the lower it goes. Vcen starts to become negative (indicating decreasing distance from the planet) and gets more negative as the rate of descent increases. Eventually Vtan gets so high that the spacecraft starts moving sideways enough to counteract its descent, and Vcen starts to get less negative (the descent rate slows down). When Vtan is large enough, the descent stops (Vcen is zero again) and the spacecraft is at the lowest point of its orbit (the **Periapsis**). Note that the periapsis is on the opposite side of the planet from the apoapsis.
At the periapsis point, the spacecraft, having been accelerated by gravity to such an extent, is now travelling faster than the ref Vo for that altitude. Because of this, it moves sideways farther than needed to maintain its orbital height, and begins to climb.



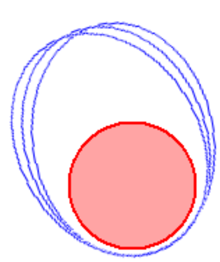
As it climbs, it moves against gravity, so it starts slowing down. Thus, Vtan begins to decrease. Vcen is positive, since the distance from the planet is increasing. Eventually, Vtan decreases so much that the rate of ascent begins to decrease (Vcen becomes less positive). The spacecraft will reach its high point (**apoapsis**) at about the same place as it was before, having slowed down to the same speed it had before (less than ref Vo) and the whole process starts over again.

This pattern will repeat continuously, as long as the periapsis is above the atmosphere. If not, drag will slow the spacecraft a little more at each periapsis and each periapsis and apoapsis will be a little lower. Eventually, the orbit will intersect the surface of the planet and the spacecraft will crash.

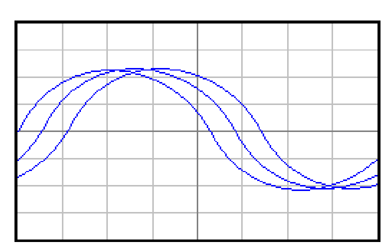
Real and Apparent Orbit Precession

Another peculiarity of an elliptical orbit is that the position of the periapsis and apoapsis shifts slightly, precesses, on each orbit. This precession is predicted by Newton's laws of motion. It only is very noticeable in orbits that are very elliptical.

The longitudinal shift in the orbits of spacecraft and satellites when viewed against the earth is not due to orbit precession. Rather, it is the result of both the latitudinal tilt (inclination) that most real orbits have and the fact that as a satellite orbits the earth, the earth also is rotating at a different rate under it. In the time it takes most satellites to complete an orbit (about 100 minutes), the earth rotates about 25º. We have real precession, but not apparent precession in our simulation as it is only 2-dimensional and our planets do not rotate.



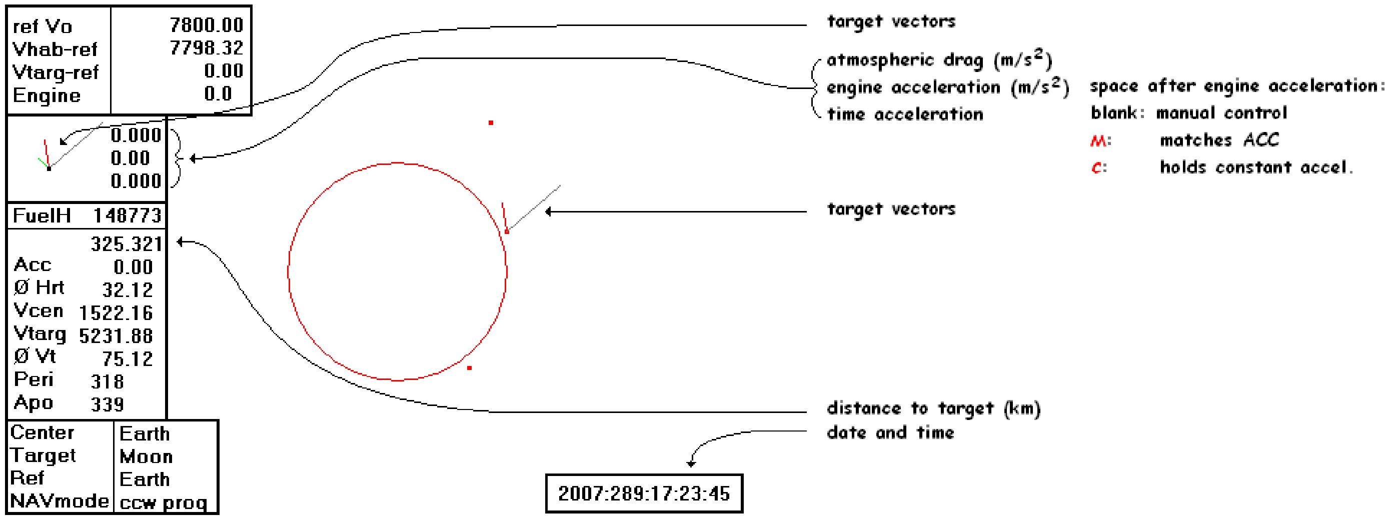
Real Orbit Precession



Apparent Orbit Precession

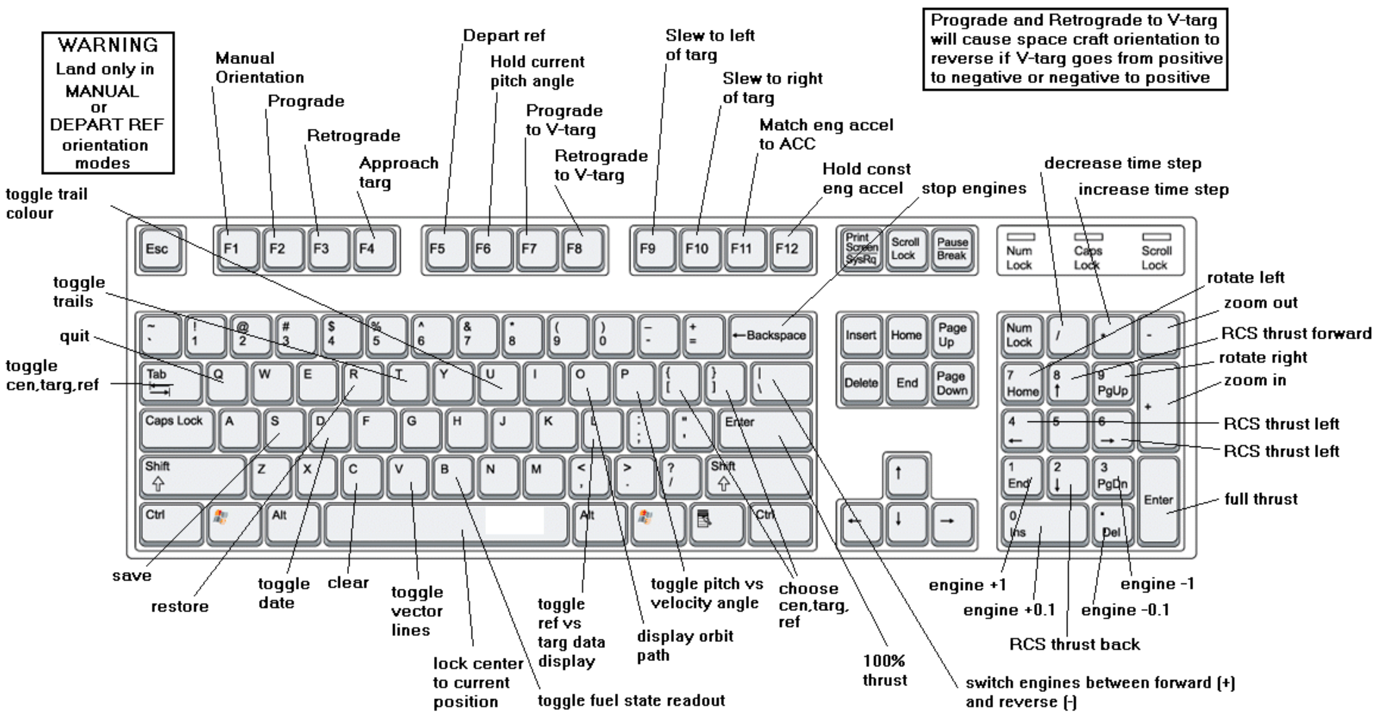
1.5.1.3 ORBIT5S User Interface

All information in Orbit5S is displayed on a single user interface screen.



All controls are manipulated using the computer keyboard.

Keyboard Controls for ORBIT5S



ORBIT5S controls are lower case. CEN, TARG, and REF choices are upper case.

ORBIT5Sm extra controls

a: dock with AYSE	x: toggle telemetry	y: record path
w: ignite SRBs	( ): AYSE release/load fuel	Z: load and display path
g: deploy parachute	{ }: HAB release/load fuel	z: display path

1.5.1.4 ORBIT5S Controls (Case Sensitive)

Engines:

Ins	-0.1 %	\	Reverse Engines
Del	+0.1 %	**BckSp**	Stop Engines
End	-1.0 %	**ENTER**	Full Thrust
PgDn	+1.0 %	**Arrows**	Thrusters (up=ahead, down=back, left, right)
F11	match engine accel. to ACC	**F12**	maintain constant engine accel.
b	toggle fuel state read-out		

Navigation:

Home	rotate ccw	**PgUp**	rotate cw	**F1**	manual orientation
F2	ccw prograde	**F3**	ccw retrograde	**F4**	approach targ
F5	depart ref	**F6**	hold current pitch angle	**F7**	proVtarg
F8	retro Vtarg				

F9 slew left of target (toggles between left (-) and no slew)

F10 slew right of target (toggles between right (+) and no slew)

v Toggle approach to target vector & approach to target velocity vector ON/OFF

TAB Toggle Select: CENTER, TARGET, REFERENCE
Select objects from the list below **or**
Scroll through items using '[' and ']' keys

p toggle between display of pitch angle and velocity to target angle

l (lower-case "L") toggle between dsiplaying target vs reference data in orbit data box
reference data shows 'r' notation when reference readout is selected

o project orbit path relative to reference or target
this shows the path that the spacecraft would take relative to the reference object ***if*** the engines were shut off at that point in time. It is less accurate if there are any other objects with significant gravity nearby.

space lock center position at current habitat position relative to target object

Solar System Objects for selecting target, reference, and center of view (case sensitive)

0	Sun	=	Io	J	Triton
1	Mercury	>	Europa	K	Charon
2	Venus	?	Ganymede	L	Habitat
3	Earth	@	Callisto	M	Ceres
4	Mars	A	Tethys	N	Comet Borrelly
5	Jupiter	B	Dione	O	Vesta
6	Saturn	C	Rhea	P	AYSE drive Module
7	Uranus	D	Titan	Q	Sedna
8	Neptune	E	Iapetus	R	Quaoar
9	Pluto	F	Ariel	S	ISS
:	Moon	G	Umbriel	T	Detachable Habitat Module
;	Phobos	H	Titania	U	OCESS Launch Pad
<	Deimos	I	Oberon		

Other Controls

+	Zoom In	**-**	Zoom out
c	refresh screen	`	Toggle data display on/off
t	display trails	**u**	display colour-coded trails
*	increase frame rate	/	decrease frame rate

******do NOT use frame rate greater than 2 seconds when in a low altitude orbit******

q End program   **s** Save data to a file

r Restore data from a file (timed backup file is called "ORbackup")

d display time & date (toggles between **off**, **mission time**, **mission elapsed time**, **event elapsed time**)

1.5.1.5 ORBIT5S Screen Data Display

ref Vo: displays the correct orbital speed (m/s) for the current distance from the reference object.

Vhab-ref: displays the total speed (m/s) of the habitat relative to the reference object (magnitude only, not direction)
this will match the ref Vo when in a stable, circular orbit

Vtarg-ref: displays the speed (m/s) of the target relative to the reference object (will be zero if targ = ref).

Engine: Current engine thrust in percent of maximum (can exceed 100% with increased risk of engine failure)
“SRB” indicates active solid rocket booster; “AYSE” indicates docked (ORBIT5tM only)

Target Vectors: grey vector (direction to target) shows direction towards centre of the target object.
red vector (velocity) shows the habitat velocity direction relative to the target object
green vector (pitch) shows orientation of spacecraft; the direction that positive thrust will push the spacecraft

Drag: Shows the acceleration due to atmospheric drag in m/s^2 (yellow when parachute is deployed)

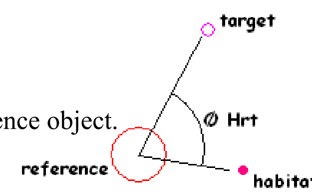
Engine Accel: Shows the acceleration of the habitat or AYSE drive resulting from the engine thrust in m/s^2
If followed by ‘**M**’ this indicates that the engines are matching their thrust to the current ACC to the target
If followed by ‘**C**’ this indicates that the engine acceleration is being held constant.
(normally, engine acceleration increases with constant thrust as fuel is used up and total mass decreases)

Frame Rate: Shows the simulation frame rate (0.125 and 0.250 are real time, all others are accelerated)

Fuel: Displaces the current fuel load
can toggle between habitat fuel (H), AYSE drive unit fuel (A), and the vernier thruster pressure reserve (RCS)

Distance: Displays distance (in km) to the target object.

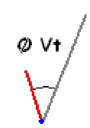
Acc: Displays the engine thrust needed to bring the habitat to a stop at the surface of the current target object.
Only displays correctly when habitat is moving directly or nearly directly towards the target object.
This reading takes into account: gravity of target object
distance to target object’s surface
relative speed toward target object (Vcen)



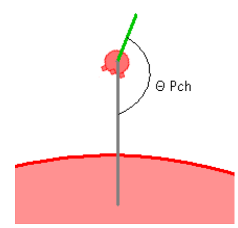
Θ Hrt: Displays the angle between the habitat and target relative to the center of the reference object.

Vcen: Shows centripetal speed (in-and-out speed) (m/s) relative to **target** object.

Vtan: Shows tangential speed (side-to-side speed) (m/s) relative to **target** object
Should be near **zero** when in a circular orbit and when the target is the same as the reference.



Θ Vt: Angle between the direction to target vector (grey) and the velocity to target vector (red)



Θ Pch: Pitch angle: angle between the front-back axis of the spacecraft (green vector)
and the center of the target (grey vector)

Peri: Displays the projected minimum altitude (km) from reference or target object in the
current orbit (periapsis).

Apo: Displays the projected maximum altitude (km) from reference or target object in the
current orbit (apoapsis).

Center: The object on which the display is centered

Target: The destination object; can be the as the reference object to facilitate certain orbit calculations

Reference: The object for which orbital statistics are calculated.

NAVmode:
Manual: orientation remains fixed in the inertial frame unless manual orientation controls are used
ccw prog: maintains correct orientation for counter clockwise (prograde) orbit
ccw retro: maintains correct orientation for a clockwise (retrograde) orbit
App targ: maintains an orientation directly towards the target object
Deprt ref: maintains an orientation directly away from the reference object
hold targ: maintains current pitch angle relative to the target or reference
pro Vtrg: maintains an orientation in the same direction as the target velocity vector
ret Vtrg: maintains an orientation directly opposite the target velocity vector
If preceded by a ‘+’, the target vector points to the right side of the target (right slew)
If preceded by a ‘-’, the target vector points to the left side of the target (left slew)

Date: Displays year: day: hour: min: sec; toggles between **date**, **mission elapsed time**, **event elapsed time**, and **off**

1.5.2 Planetary Launch Procedure

1) Select the current planet as **reference** and **target** object (see section 1.5.4)
2) Select habitat as center position ("L")
3) Press <space> to lock current center position.
4) Press F5 for automatic **depart ref** orientation.
5) Press v to activate approach velocity vector if desired.
6) a) Consult GUIDO for lead angle when launching to intercept orbiting target.
   e.g. to intercept ISS from earth, lead ISS by 18º.
7) Set engine for liftoff.
8) Adjust thrust to exceed local gravity by a factor of 3 or more (at least 30 m/s^2 on earth), if possible.
   a) on low gravity planets, HAB engines are sufficient to achieve desired thrust.
   b) on higher gravity planets, such as the earth, one of two strategies must be used.
      i) depart with the minimum fuel load to achieve the mission (a few thousand kilograms if docking with AYSE)
      ii) use the solid rocket boosters (SRBs).

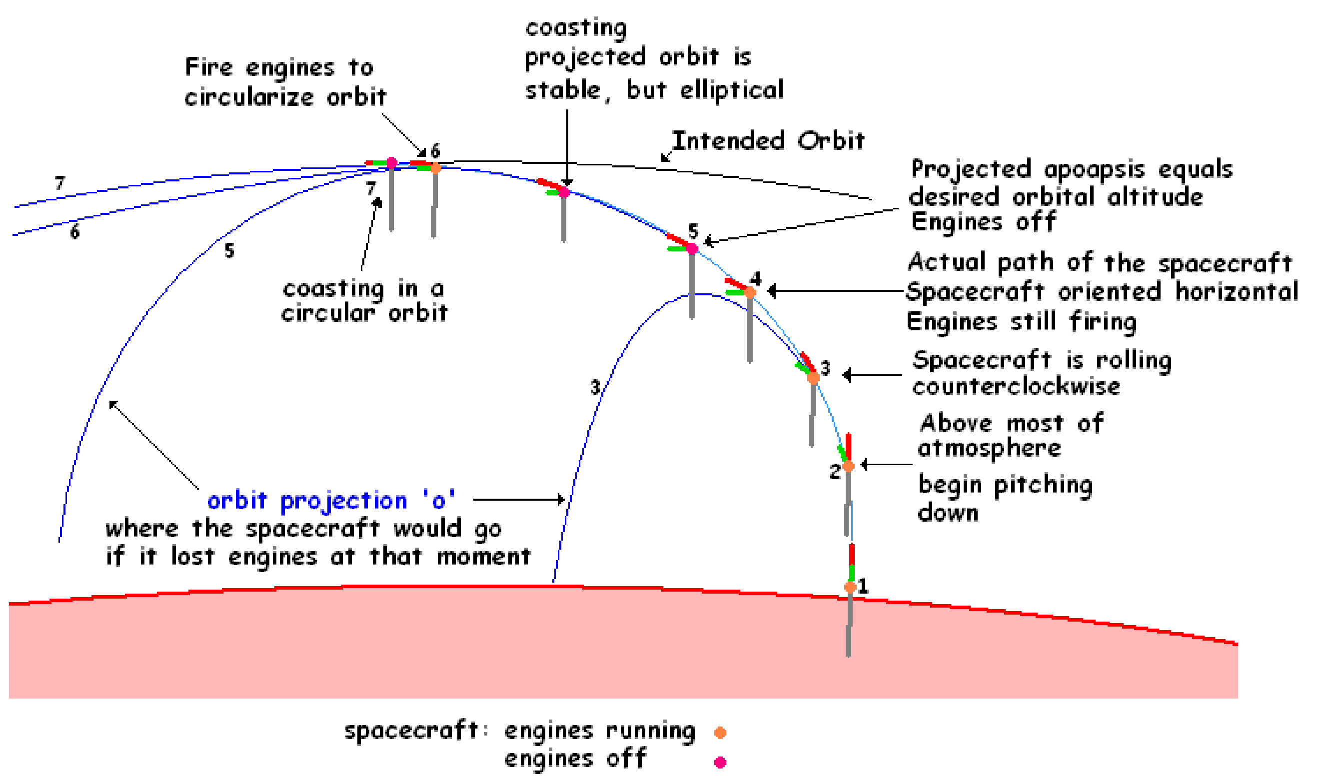
   Solid rocket boosters with main engines will produce more than a 30 m/s^2 acceleration with a full fuel load.

   WARNING

   Once solid rocket boosters are ignited, they cannot be stopped - the HAB is going to fly!
   SRBs are exhausted in 2 minutes. They do ***NOT*** operate for long enough to achieve a stable orbit.
   Always run main engines at local gravity to test their function before igniting the SRBs.
9) Press F1 for manual orientation control once clear of the surface.
10) Launch profile: GUIDO will provide an exact profile for a given departure:
    - maintain near vertical ascent until clear of most of the atmosphere,
    - gradually pitch towards horizontal to achieve ref Vo while maintaining vertical speed until ref Vo is reached
    - ref Vo will not be reached until apoapsis, but tangential speed must be built up as fast as possible.

It is safer to establish a stable low orbit and increase it later than to launch directly to a high orbit.
In a launch directly to high orbit, ref Vo and a stable orbit are reached much later.
If engines fail before ref Vo is reached, a crash landing is likely.

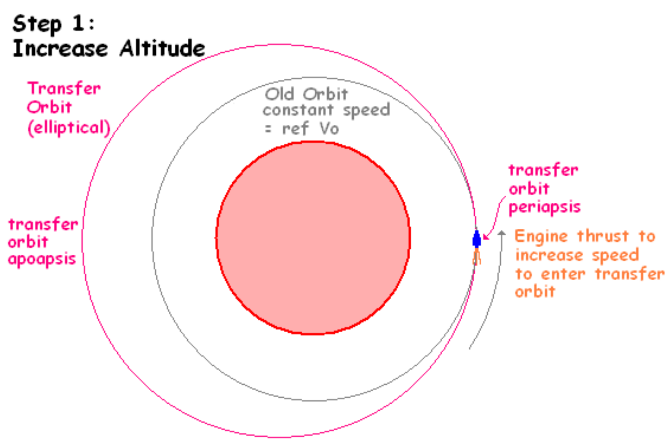
11) When projected apoapsis is within 10% of the desired apoapsis, select NAVmode ccw prog or ccw retro depending on orbit.
12) When projected orbit is stable (will not intersect earth's surface) stop engine.
13) When desired apoapsis is approached (Vcen falls below approximately 200 m/s), set engine thrust until Vtan equals Vref.
14) At apoapsis, select NAVmode **dep ref**; use positive or negative engine thrust to zero out Vcen.
15) Select NAVmode **ccw prog**; use positive or negative engine thrust to achieve Vtan equal to ref Vo.

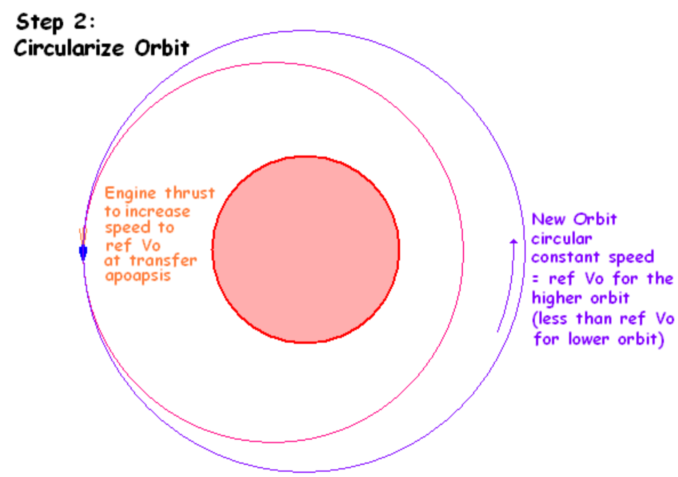


1.5.3 Adjusting an Orbit

1.5.3.1 Increasing the Altitude

1) Set both the target and reference objects to be the planet about which you are in orbit.
2) Orient the spacecraft in the direction of the orbit (green vector should line up with the red vector).
   - select NAVmode ccw pro (Press F2) for a prograde (counter clockwise) orbit
   - select NAVmode ccw retro (Press F3) for a retrograde (clockwise) orbit.
3) Set engine thrust to produce a 5 to 10 m/s^2 acceleration (you can use greater acceleration as you gain experience) (Step 1).
4) GUIDO will give you data on acceleration and duration of engine thrust.
   If GUIDO data is not available, continually press 'o' to project your new orbit while the engines are on.
   - once the apoapsis projection equals the desired orbital altitude, stop engines
   - reduce thrust as desired apoapsis projection is approached to avoid overshooting
5) Coast with engines off until spacecraft climbs to apoapsis. This elliptical orbit is the **transfer orbit**.
6) Just before apoapsis, set engine thrust to accelerate Vtan to match ref Vo. This will circularize your orbit (Step 2).

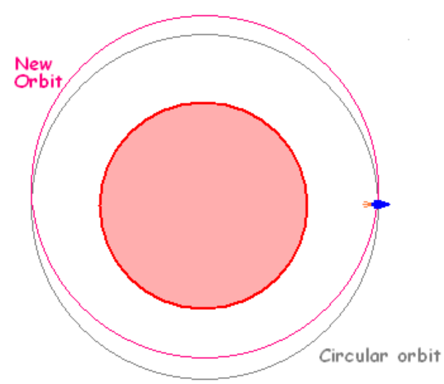




This method of increasing altitude is slow, but it has the advantage of safety. If engines fail after the first engine burn, the orbit will still be stable, although elliptical. The periapsis of the transfer orbit will be no lower than the original orbit.

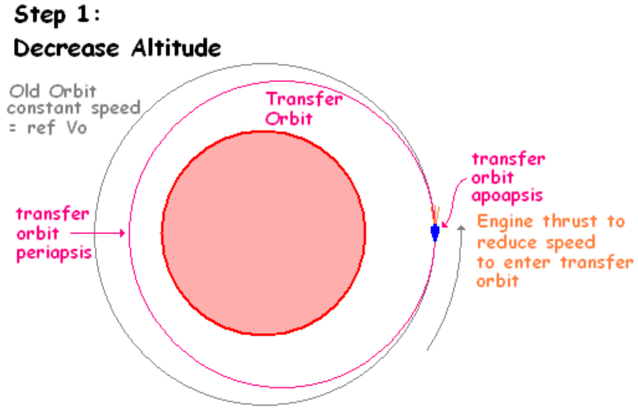
If you try to increase altitude by firing the engines to push directly away from the planet, you will reach apoapsis in one quarter of an orbit, rather than one half. However, the periapsis of this elliptical orbit will be much lower than that of the original orbit, perhaps dangerously close to the atmosphere or surface of the planet.

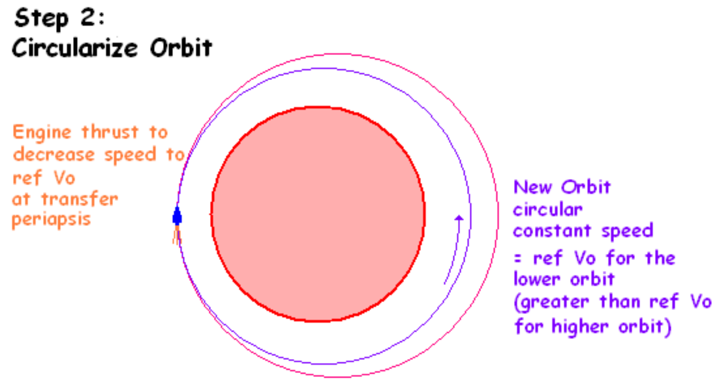
If engines fail after the first burn using this method, a crash landing is possible.



1.5.3.2 Decreasing the Altitude

1) Set both the target and reference objects to the planet you are orbiting.
2) Orient the spacecraft opposite the direction of the orbit (green vector should 180º from the red vector).
   Press F3 for a prograde orbit, F2 for a retrograde orbit.
3) Set engine thrust to produce a 5 to 10 m/s^2 acceleration.
4) GUIDO will give you data on acceleration and duration of engine thrust.
   If GUIDO data is not available, continually press 'o' to project your new orbit. Once the periapsis projection equals the desired orbital altitude, stop engines. Reduce thrust as desired periapsis projection is approached to avoid overshooting.
5) Wait until spacecraft descends to periapsis.
6) Just before periapsis, set engine thrust to ***reduce*** Vtan to match ref Vo. This will circularize your orbit.





1.5.3.3 Adjusting Velocity in Space

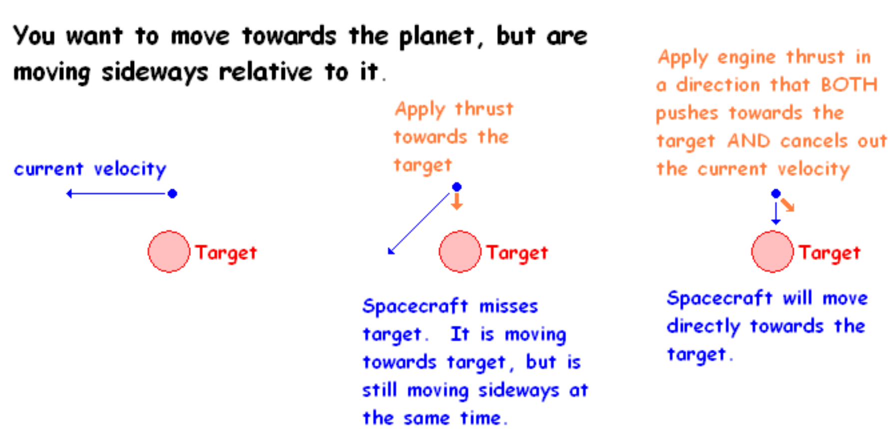
In space there is no friction. This is nice, because once the engines have imparted a speed to the spacecraft, we can turn the engines off and the spacecraft keeps moving. It is not so nice when it comes time to change the velocity. We cannot apply the brakes to slow down (they work with friction) or rotate the wheels to turn the spacecraft (that involves friction as well).

Speeding Up: - point the spacecraft in the direction that you are going (F7; **pro Vtrg**) and apply engine thrust
- if the spacecraft has any other orientation, it will change direction as well as speed

Slowing Down: - point the spacecraft opposite to the direction you are moving (F8; **ret Vtrg**) and apply engine thrust
- if the spacecraft has any other orientation, it will change direction as well as speed

Changing Direction:
This is more complex, because you must simultaneously reduce your speed in the direction you are going and increase your speed in the direction that you want to go.

For example:



Note: In this diagram, and in all that follow, the orange arrow indicates which direction the engines are pushing the spacecraft. In other words, it is in the same direction as the green vector arrow.

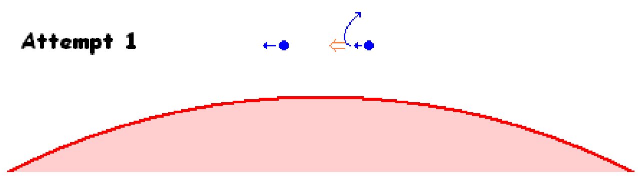
1.5.3.4 Adjusting Your Speed While In Orbit

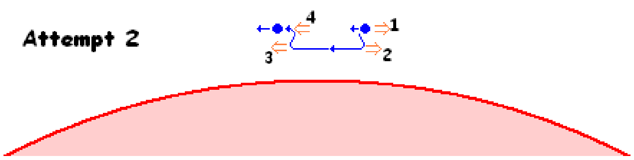
This is a very complex problem, because any change in speed will also affect the altitude, which will then further affect the speed. As an example, consider a spacecraft which must join up with an orbiting space station at the same altitude. The spacecraft is several kilometres behind the space station, moving at the same speed (since it is at the same altitude).

Attempt 1: If the spacecraft uses engine thrust to push towards the space station, it will move faster towards the space station for a brief time, but since it is moving faster than ref Vo it will increase in altitude and as it does this, it will slow down and get farther from the space station. The only way to avoid this would be to continuously push towards the earth with the engine to hold it at the proper altitude. This would use a lot of fuel.

The other big disadvantage with this method is that the spacecraft would need to slow down when it reached the space station. This would result in engine exhaust being aimed towards the space station, probably damaging it.

Attempt 2: The spacecraft pushes away from the space station to slow down[1]. If is far from the station at this point, so there is not danger from the exhaust. This will cause the spacecraft to slow down and move into a lower, faster orbit. Once the new orbit is circularized[2], the spacecraft will catch up with the space station. When it is near enough, it thrusts forward to speed up[3], which will cause it to move up to the space station's altitude. Once the orbit is re-circularized[4], the spacecraft will be in a stable orbit right beside the space station and at the same speed. All the engine burns near the space station will be aimed away from the station.





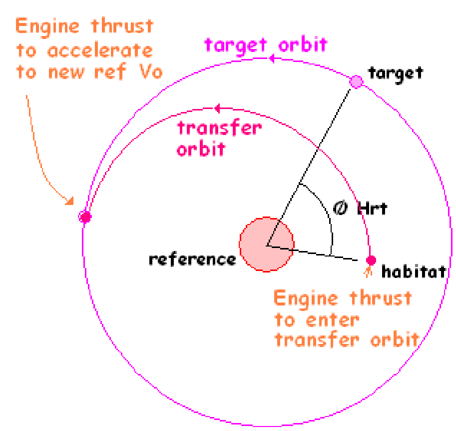
When you are very close to you target in orbit (the space station or AYSE drive unit), you can push towards, away, or to one side of the other with the vernier thrusters. The changes in speed are so small that the changes in altitude are easily compensated for.

1.5.4 Orbital Rendezvous

1) Choose Target and Reference as the current planet you are orbiting
2) **Stay set to choose CENTRE at all times to avoid inadvertent redirecting of the spacecraft.**

1.5.4.1 Low Energy Method (GUIDO provides angle timing and thrust data for transfer orbit burn)

1) Set NAVmode to ccw prog or ccw retro depending on orbital direction.
2) Initiate required thrust at required **Θ Hrt** angle for the required duration.



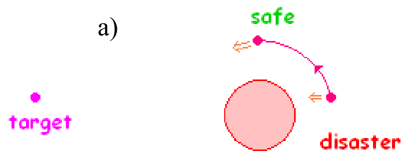
The correct thrust ensures that the apoapsis of the spacecraft is the same as the orbital altitude of the target. The correct angle at engine burn (**Θ Hrt**) ensures that the spacecraft and target are in the same place at the apoapsis. Thrust setting, duration, and Θ Hrt are provided by the TRANSORB software.

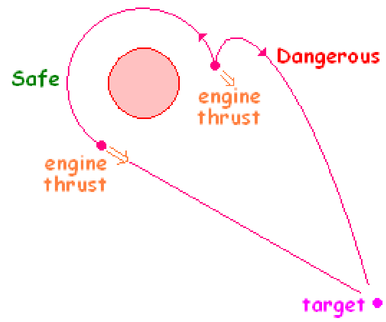
The engine burn must be made while behind the target since for much of the transfer orbit the spacecraft will be travelling much faster than the target.

3) When the spacecraft and target rendezvous at apoapsis, apply thrust to achieve the correct ref Vo.
4) Use engines to reduce ACC to zero (spacecraft is stationary with target).
5) Use vernier thrusters or fractional engine settings to join up with target if needed. (see 1.5.4.2 note 8 below for instructions on how to do this).

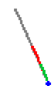
1.5.4.2 High Energy Method (Direct burn to rendevous)
In a high-energy rendezvous, the engines are used continuously. The are used to push towards the target for the first half of the manoeuver (pushing the spacecraft faster with time) until the half-way point. They are then used to push away from the target to continuously slow the spacecraft down to a stop at the target.

1) Select destination as target and reference.
2) a) **Wait until the destination is well over the horizon of the planet (grey vector should not point towards other objects).**
b) **If the target is behind the spacecraft relative to its orbit around the reference planet, wait for one half orbit so that the spacecraft is moving toward the target as it orbits the reference. This is important, because if you try to reverse direction while in orbit, your orbit may decay and the spacecraft may crash before you have a chance to build up speed in the reverse direction.**

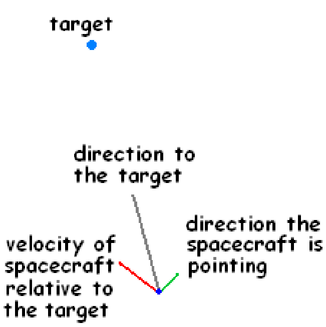
a)


b)


3) Select **app targ** orientation.
4) Initiate a 20 m/s^2 thrust until **ACC** approaches 20 m/s^2
If the red arrow is off to one side of the grey target vector, adjust the orientation of the spacecraft to compensate (see note 8 below) (select NAVmode **manual** to do this).


This is what you want to see.

5) Once ACC reaches 20 m/s^2 (higher if the target is very distant) select NAVmode **dep Ref**.
6) Adjust thrust so that engine acceleration matches **ACC**
7) Select **manual** orientation.
8) Adjust thrust vector to keep target vector (grey) and target velocity vector (red) in line with each other. Since both the spacecraft and target are orbiting around a planet, constant adjustments to the thrust vector (green) will be needed.



Display Vectors


a b c d

a) The spacecraft is moving at the correct speed, but is moving to the left of the target. The pilot is applying engine thrust and aiming the spacecraft 90° to the right of the target. This will cause the velocity of the spacecraft swing towards the target (the red vector will swing towards the grey one). The speed will not change.

b) The spacecraft is moving to quickly (ACC seems too large) and to the right of the target. The pilot is applying engine thrust and aiming the spacecraft away and to the left of the target. This will both slow the spacecraft relative to the target and swing the red vector to the left.

c) The spacecraft is moving too slowly and to the right of the target. The pilot is applying engine thrust and aiming the spacecraft towards and to the left of the target. This will speed up the spacecraft and swing the red vector towards the grey one.

d) This is what we want to see. The spacecraft in moving directly towards the target (red and grey vectors are superimposed. The thrust vector (green) is aimed away from the target as the spacecraft is applying thrust away from the target to continuously slow the spacecraft to a stop at the target.

Always return NAVmode to **dep ref** when the spacecraft velocity has been corrected.

9) When spacecraft is within a few hundred metres of the target, adjust thrust to reduce ACC to zero: set engine acceleration to exceed ACC until ACC drops to zero.
10) Use vernier thrusters or very low thrust engine pulses to join up with the target if needed (see 1.5.8).

1.5.5 Departure from Orbit to another planet

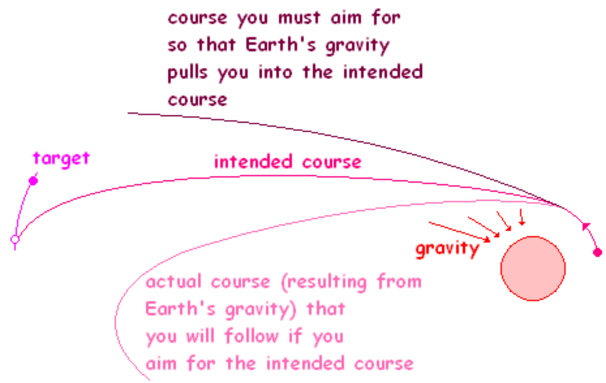
1.5.5.1 Low Energy Method

A) Transfer orbits between a planet and one of its moons works the same as a low energy rendezvous (1.5.4.1)

B) For low energy transfer orbits between planets, GUIDO must supply transfer orbit burn data.
Orbit projection is not valid at any significant distance from the reference object.

TRANSORB software only will provide a first approximation of the burn duration and Θ Hrt. This is because TRANSORB only considers the effect of the gravity of the object at the centre of the orbit - in the case of the transfer orbits between planets, this is the sun. However, the gravity of the departure planet and destination planet will affect the path of the spacecraft. Thus, GUIDO will have to run a series of simulations on ORBIT5Sm to refine the parameters for the transfer orbit.

The target also is moving in its orbit. Since the transfer orbit takes a considerable length of time, it must be aimed at where the target will be at the apoapsis of the transfer orbit, not were the target is at the time the spacecraft enters the transfer orbit.



1.5.5.2 High Energy Method

1) Select destination as the **target** and current planet as **reference**.
2) a) **Wait until the destination is well over the horizon of the planet (grey vector should no point towards any other object).**
   b) **If the target is behind the spacecraft relative to its orbit around the reference planet, wait for one half orbit so that the spacecraft is moving toward the target as it orbits the reference. This is important, because if you try to reverse direction while in orbit, your orbit may decay and the spacecraft may crash before you have a chance to build up speed in the reverse direction.**
3) Select NAVmode **App targ**.
4) Set engine thrust to achieve 20 m/s^2 acceleration.
5) Once escape velocity has been reached, select NAVmode **manual**.
6) Set engine thrust to achieve the acceleration specified in the mission profile (usually 50% to 90% engine thrust).
7) Orient spacecraft so that the green orientation vector is on the other side of the grey target vector from the red velocity vector.
   Watch to see that the velocity vector moves towards the target vector.
   (See 1.5.4.2 note 8)
8) When velocity vector is superimposed on the target vector, select NAVmode **App targ**.
9) Watch that the velocity and target vectors remain superimposed. If the vectors become misaligned set NAVmode manual and go to step 8.

1.5.5.3 Rate Control

High-energy transfer orbits involve continuous engine thrust towards the target for half the orbit and continuous engine thrust away from the target to slow down for the other half of the orbit. These orbits use a lot of fuel but are orders-of-magnitude faster.

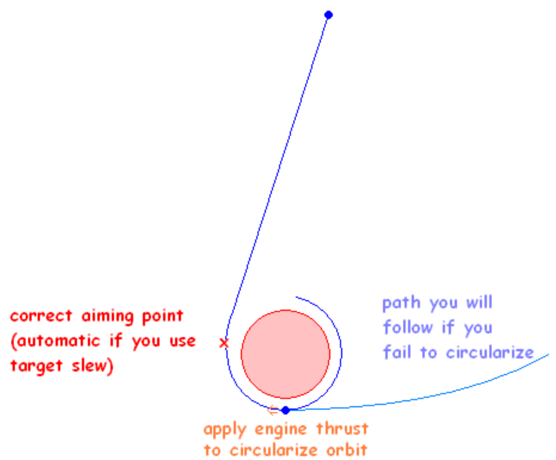
1) Monitor ACC regularly. **ACC must NEVER exceed maximum engine acceleration.**
   If ACC exceeds maximum engine acceleration, there are a few corrective options.
      1) Use NAVmode manual to alter the direction of the spacecraft so that it misses the target.
         Once the correct direction is achieved, select NAVmode **ret Vtarg**.
         Use maximum safe engine thrust to reduce speed.
         Once you are past the target and speed has been reduced to a manageable level, plot a new approach path to the target.
      2) If you have fuel to spare, dump fuel to lighten the spacecraft and increase maximum engine acceleration.
2) When **ACC** reaches the specified level (no more than 90% maximum engine acceleration):
   a) Stop engine (BckSp key)
   b) Select the target as the reference object
   c) Select NAVmode **dep Ref**
   d) If specified in mission profile, coast until ACC specified for engine restart is reached.
3) Set engine thrust to match engine acceleration to ACC.
4) Monitor **ACC** periodically to ensure that it is stable.
   Adjust engine thrust to re-establish specified ACC as needed.
5) Watch that the velocity and target vectors remain superimposed. If the vectors become misaligned set NAVmode manual and go to step 8 of 1.5.5.2 to re-establish correct course. Reset NAVmode to dep Ref.

1.5.6 Orbital Insertion from Approach (within a million kilometers of target surface, or so)
1) Press "v" to display target approach velocity vector on the main display.
2) Select target and reference as the destination.
3) Press F9 or F10 to slew the target vector to the left or right of the target.
4) Select NAVmode manual to adjust the velocity vector line up with target vector.
   Select NAVmode ret Vtarg.
   Repeat step 4 as needed until inserted into orbit.opposite direction to stabilize the approach velocity vector.
5) Use orbit projection ("o") to check velocities, especially if performing a tangential approach.
   Press "p" to display tangential and centripetal speeds relative to target object.
6) When within 5 planetary radii, turn off slew target NAVmode. Select NAVmode **ret Vtrg**.
7) Your goal is adjust thrust to slow the **Vhab-ref** and **Vtan** to the **ref Vo** velocity of the intended orbital altitude and the **Vcen** to zero before you reach your desired periapsis.

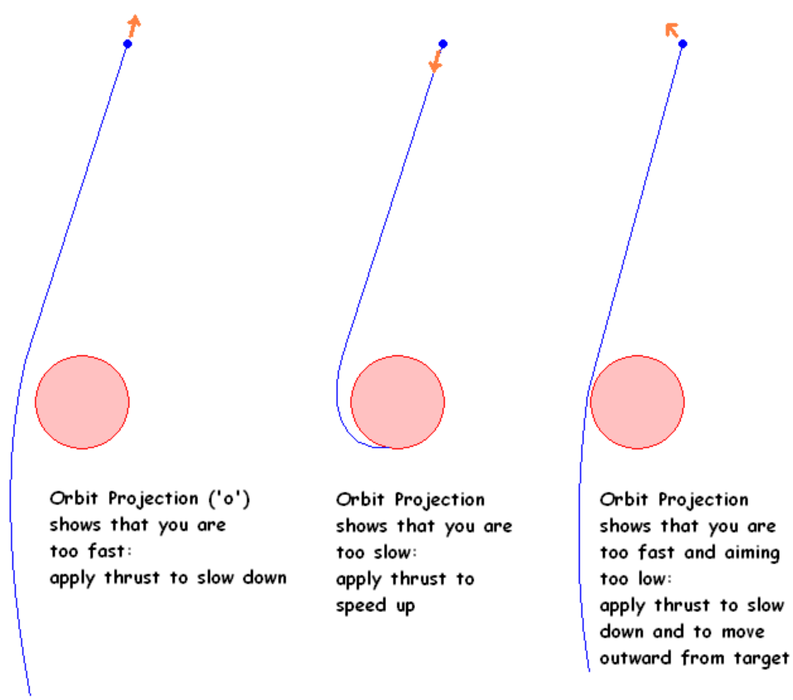
   If projected periapsis is correct, but speed is too great (more than can be adjusted for at periapsis), use engine thrust to reduce speed. When speed has been reduced, set NAVmode to dep Ref and use engine thrust to restore projected periapsis to desired altitude.

   If aerobraking is part of the plan for reduction of speed, GUIDO must run simulations to determine correct approach profile.

8) When orbit projection shows desired periapsis and speed is within limits, shut off engines and coast to periapsis.
   Use engine thrust periodically to counteract the effect of gravitational acceleration as you approach the planet.
9) When near periapsis, use engine thrust to reduce speed to ref Vo, thus circularizing the orbit.



Some Potential Problems and the Corrective Actions

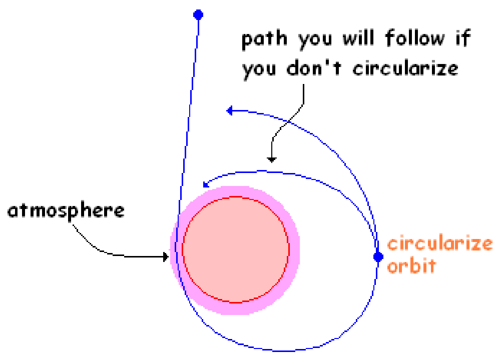


Aerobraking

Aerobraking is a technique to reduce speed at the destination with minimal expenditure of fuel. This is useful for very fast transfer orbits as the fuel load and total mass of the spacecraft can be minimized. It also is useful for very long voyages where the spacecraft may not have enough fuel for the return trip if it is used to slow down at the destination.

Aerobraking only works where the destination planet (or one nearby) has a thick atmosphere.

This technique is very dangerous and must be researched with the simulator to work out the exact mission profile. Typically, there is a window of only a few tens of kilometres above the surface of the destination planet that the spacecraft must pass through in order for the manoeuver to be successful. If you are too shallow (not far enough into the atmosphere) at the closest approach, your speed will not be reduced enough and you will not be captured into an orbit about the planet. If you are too deep (too far into the atmosphere), you will slow down too much and may crash. In a thick atmosphere, the engines may not have enough engine thrust to push your way up back into orbit.

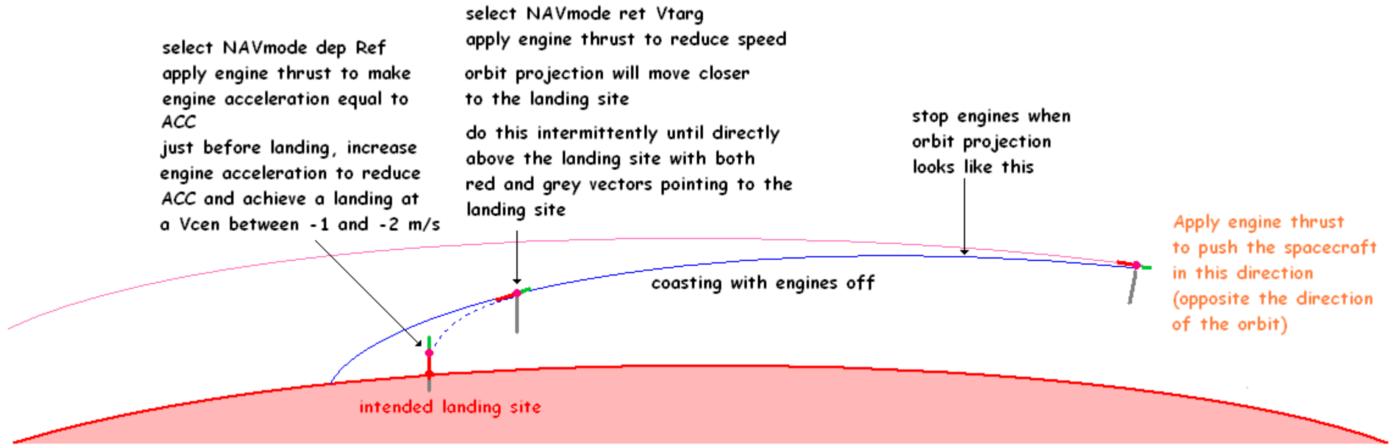


In this circularization manoeuver, you should have to increase the Vtan to match ref Vo, unless your braking manoeuver was too shallow. In the latter case, you will have too large a speed and will have to use engine thrust in the opposite direction to decrease speed.

1.5.7 Landing Procedure

If Docked to the AYSE drive unit, you must undock from the AYSE drive while in a stable orbit.
The AYSE drive unit cannot land without crashing. It must be left in orbit before landing.

1) Select the destination as target and reference.
2) Press v key to activate the approach velocity vector if not done already.
3) Select NAVmode **ccw retro** if in a counter clockwise orbit, (**ccw prog** if you are in a clockwise orbit).
 a) Consult GUIDO for appropriate engine acceleration and lead angle to your landing site.
 b) If GUIDO assistance is not available, use orbit projection to plan your landing.
4) Apply engine thrust rust until orbit projection intersects the surface just past the target.
 On a planet with a substantial atmosphere, the intersection should be farther past the target.
5) Coast until the spacecraft is nearing the target and ACC is approaching 50% of the planet's gravity.
6) Select NAVmode **ret Vtarg.**
7) Apply engine thrust to hold a constant ACC of not more than 50% larger than the planet's gravity.
8) When Vtan is zero (or very close), select NAVmode **dept Ref**.
 Do not land in any NAVmode except manual or dep Ref.
9) Increase engine thrust to lower ACC to 10% to 20% above local gravity.
10) **If ACC exceeds maximum engine acceleration**:
 @ Low Altitude: maintain maximum thrust and brace for hard landing
 @ High Altitude: Initiate Landing Abort Procedure
  - set maximum available engine thrust which may be more than 100% (consult engineer).
  - set NAVmode manual and rotate to about 45° above the horizon
  - maintain engine thrust until orbit projection shows that you will miss the planet's surface
11) If the approach velocity vector starts to point away from the centre of the target, rotate the hab slightly in the opposite direction to correct it then re-adjust the orientation to stabilize the approach velocity vector.
12) At 0.001 km altitude, stop adjusting engine setting.
 Do not land at an engine setting larger than 2 m/s^2 above local gravity
 Do not land at a speed greater than 2 m/s
 Do not land at a frame rate greater than 0.25



If landing in an atmosphere, delay applying engine thrust until atmospheric drag has fallen below 20 m/s^2.
Engine damage may occur with heat from atmospheric ionization.

1.5.8 Docking and Undocking

1.5.8.1 Docking

1) Establish a close orbit with which to be object docked. (see 1.5.4)
2) Use low thrust engine pulses to line up the hab with the docking hatch.
   For the AYSE drive unit, there is no specific docking hatch.
2) Orient the hab so that its docking hatch is parallel to the axis of the docking hatch of the space craft with which to be docked.
   The habitat docking hatch is centered between the engine pods.
   The habitat must be in the docking orientation (Depart Ref) in order to dock.
3) Use vernier engines to move the hab so that it is lined up with the docking hatch.
   The vernier engines fire a brief burst **once each time the key is pressed**. They **do not** stay on.
   Opposite vernier engines must be used to cancel out the velocity once the desired position is attained.
   Slow down gradually ahead of time to avoid over-shooting your desired position
4) Once in position, use vernier thrusters to push back towards the docking hatch.

   A) For ISS docking, **make contact at less than 2 m/s and at a frame rate of 0.25.**

   B) For AYSE drive unit docking, make contact at 10 m/s and continue inward to a distance of 300 m from the surface (-0.300 km distance). Come to a stop at that point.

   Alternatively, at a distance of less than 1000 km from the AYSE drive unit, set the hab in a stable orbit (see notes 13 and 14 in 1.5.2). Request engineer initiate AYSE AUTODOCKING.

   When engineer verifies that the hab is in position, AYSE drive and HAB can connected (see section 1.6).

1.5.8.2 Undocking

1) Apply 3-5 bursts from forward vernier thrusters to initiate a departure.
2) When at a distance of at least 1 km, use verniers to increase velocity relative to the docked object.
3) Wait until a separation of 20 km from docked object has been acheived.
4) Select NAVmode ccw prog or ccw retro as appropriate.
5) Use engine thrust to stabilize the orbit or achieve a different orbit.
   When altering the orbit, make certain that the new orbital velocity will not result in closure with the docked object.

1.5.8.3 Undocking and Docking with Longhouse Module

1) The Longhouse module can be detached while the habitat spacecraft is landed on a planet or moon. This is done from the engineering console (section 1.6)
2) The Longhouse module can be reattached from the engineering console. The habitat must be landed on the same planet as the module and within 80 metres.