Landing

There are two components to landing from orbit.
1) Reduce the orbital speed (Vtan) so that the spacecraft can start to fall towards the planet.
2) Control the final descent to the surface using engines, and perhaps parachute, so that the spacecraft slows its Vcen continuously and reaches a Vcen close to zero, at the moment of touchdown.

Stage 2 of Landing: final descent
Start ORBIT5tm.exe
Press <**enter**> at the first prompt.
Press '**x**' to turn telemetry tracking off.
Press '**r**' and reload the file "**test2a**"
Press <**spacebar**> to lock the viewing position.
Press '**p**' to display Vcen and Vtan.
press '**r**' to pause the simulation.

Your Situation:

1) ref Vo	7964.78	
2) V hab ref	10.03	This is equal to Vcen, since Vtan is so small.
3) V targ ref	0.00	zero, since targ and ref both are set to the earth.
4) Engine	65.6	Your engines are at 65.6%
5)	0.018	This is the atmospheric drag in m/s^2
6)	10.06	This is the engine thrust level in m/s^2
7)	0.250	This is the simulation frame rate (it needs to be 0.25 or less)
8)	2.262	This is the distance above the surface of the target (earth) in km
9) Acc	10.11	This is the engine thrust level (m/s^2) needed to stop at the surface
10) θHrt	0.00	
11) Vcen	-10.05	You are descending at 10.05 m/s
12) Vtan	0.01	Your sideways speed is nearly zero; your are going straight down

Acc is a critical bit of information for this maneuver. It helps you select an engine output level. It takes into account your distance from the surface, your speed, and the current gravity.

Acc shows you what engine acceleration you need to come to a stop at the surface of the target. If your engine acceleration (**6**) matches Acc exactly, your speed will decrease at just the right rate to reach zero right at the moment of touchdown. In practice, the gradual increase in gravity and limits of precision mean that Acc will change over time and engines will need to be adjusted continuously.

To land:
A) - adjust the engine percentage (**4**) until engine acceleration (**6**) matches Acc.
- Vcen gradually will get less negative as you approach the surface
- Near the surface, Vcen should be less negative than -2 m/s

B) - to land more slowly (at a lower Acc), increase engines so engine acceleration > Acc
- Acc will start to drop and Vcen will decrease more rapidly than before
- When Acc is small enough, reduce engine thrust until engine acceleration = Acc again

C) - if Acc ever exceeds the maximum acceleration that you engines can deliver, you will crash!
- Use maximum possible engine output to crash as gently as possible
- If you are very far away from the target, you can try to pass to one side of it.

Fuel Load: there are advantages and disadvantages to having more fuel

advantages:	- you have more time to spend hovering and adjusting descent
	- you have more fuel to run electrical systems after landing
disadvantages:	- it takes a higher % engine to achieve a given engine acceleration
	- your maximum recoverable Acc is lower

Maneuvers to Practice

1) Hovering

1) press <enter> to un-pause the simulation
2) Increase engine thrust (PgDn for large changes, Del for small changes) a few percent.
    a) Notice that Vcen gets less negative and Acc decreases.
    b) When Vcen falls to zero, reduce engine thrust (End for large changes, Insert for small) until the engine acceleration equals Acc (which will reflect the target's gravity).
    c) assess the situation;
        - a perfect hover is Vcen=0 and Vtan=0 and distance (**8**) does not change
        - it is not unlikely that you will ever maintain Vcen =0
        - if Vcen>0 then you are rising (distance (8) will increase:
            - reduce engine thrust a bit until Vcen falls to zero, then
            - increase engine thrust until engine acceleration = Acc
        - if Vcen<0 then you are falling
            - increase engine thrust a bit until rises to zero, then
            - decrease engine thrust until engine acceleration = Acc
    d) You will have to continually adjust engines as described in part 2c
3) Watch the fuel readout. ***Can you hover for an unlimited period of time?***
4) If the situation gets out of control, reload file "**test2a**" and start again.

Extension activity

5) Practice entering a climb (increase % engine) or a descent (reduce % engine) from a hover.
    a) Descending:
        i) reduce % engine slightly, Vcen will become negative
        ii) when Vcen is enough, raise % engine until engine acceleration and Acc match
        iii) go to step 2 to re-enter a hover
    b) Climbing:
        i) increase % engine slightly, Vcen will become positive
        ii) when Vcen is positive enough, lower % engine until Vcen stops changing.
        you will have to adjust % engine back and forth until Vcen is constant
        How do engine acceleration and Acc compare in a climb at constant Vcen?
        iii) go to step 2 to re-enter a hover

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2) Landing

press "**r**" and reload file "**test2B**"

1) a) reduce engine thrust a few percent until the Vcen equals about -12 m/s or so
    b) increase engine thrust until engine acceleration equals Acc
    c) you should see that Acc stays roughly the same
        -keep adjusting engines so that engine acceleration matches Acc
    d) you also should see that Vcen keeps getting less negative as you descend
2) When you are near the surface, Vcen should be approaching -2.00.
    - Vcen needs to be less negative than -2.00 when you touch down.
3) If you are uncomfortable with the descent rate, follow instruction set B on page 1.
4) You will know when you touch down when:
    - distance reads -0.000
    - the red velocity vector flips to point horizontally to the left
5) As soon as you touch down, stop the engines (press <**backspace**>)
6) Repeat these steps until you can land comfortably.

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3) Drifting

Drifting sideways is an important skill if you over-shoot or under-shoot your intending landing site.

Press “**r**” to reload file “**test2b**”
Notes: if things get out of control before step 6, reload “**test2b**”
if things get out of control after step 5, reload “**test2c**”
Acc is less accurate at predicting appropriate engine output when you are drifting sideways.

1) Press **F1** choose manual orientation mode
- at the bottom left of the screen you will see that NAVmode reads **MAN 0.0**
    - 0.0 means that the orientation is not changing (the spacecraft is not rolling)

To roll the spacecraft clockwise, press **PgUp**; to roll it counterclockwise, press **Home**
Each time you press either of these two keys, the ***roll rate*** changes by 0.5° per second
To stop the roll, you must press the opposite key until the roll rate indicates “**MAN 0.0**”

Pressing Home or PgUp produces a particular roll rate not a particular orientation You must zero out the roll rate once the spacecraft has reached the desired orientation.

2) Press **PgUp** once to start the spacecraft rolling at 0.5°/s clockwise (you will see **“MAN 0.5>**”) 
3) After 2 seconds, press **Home** to stop the roll (you will see “**MAN 0.0** ”)
The spacecraft will remain inclined slightly to the right. 
- remember: pressing **Home** - simply stops the spacecraft from rolling
  - it does not return the orientation to vertical!

4) a) Monitor **Vtan**: it should increase as the engines are now pushing slightly sideways as well as up
- we don’t want it to get too large or it will take too long to slow down again later
- we need it to get large enough, though, or we might run out of fuel before we are done 

b) Monitor **Vcen**:
- it will start to get more negative because the engines are no longer pushing straight up
- to keep the spacecraft at this altitude: increase engine output until Vcen = zero
  decrease engine output so Vcen stays zero

5) When Vtan gets large enough:
a) press **F5** to return to automatic **deprt ref** orientation mode (pointing straight up)
- we could manually roll back to vertical, but this is difficult to manage exactly 
- **Vtan** will stay constant or gradually decrease if air resistance is large

b) **Vcen** will start to increase (more positive) since the spacecraft is pointing straight up again
- reduce engine percentage until **Vcen** returns to zero
- increase engine percentage slightly so that **Vcen** stays at zero (what is was before 2)

6) When you have drifted far enough:
- press **F1** to select manual orientation mode
- press **Home** once to roll counter clockwise.
    - you should see “**MAN <0.5** ” indicating a counterclockwise roll of 0.5°/sec 

7) After 2 seconds: press **PgUp** to stop the roll
Vtan should start to decrease 
repeat the adjustments in step 4b to keep **Vcen** at zero

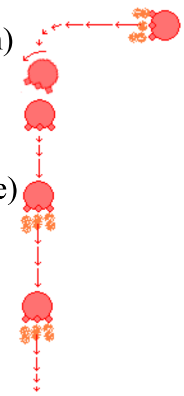
8) Just before **Vtan** = 0.00, press **F5** to return to an automatic vertical orientation. 
- **Vcen** will start to increase (get more positive) so repeat the adjustments in step 5b

9) You are now back to a stationary hover.

4) Initial Landing Maneuvers from Orbit

There are two ways of doing this:

I) The Easy Way



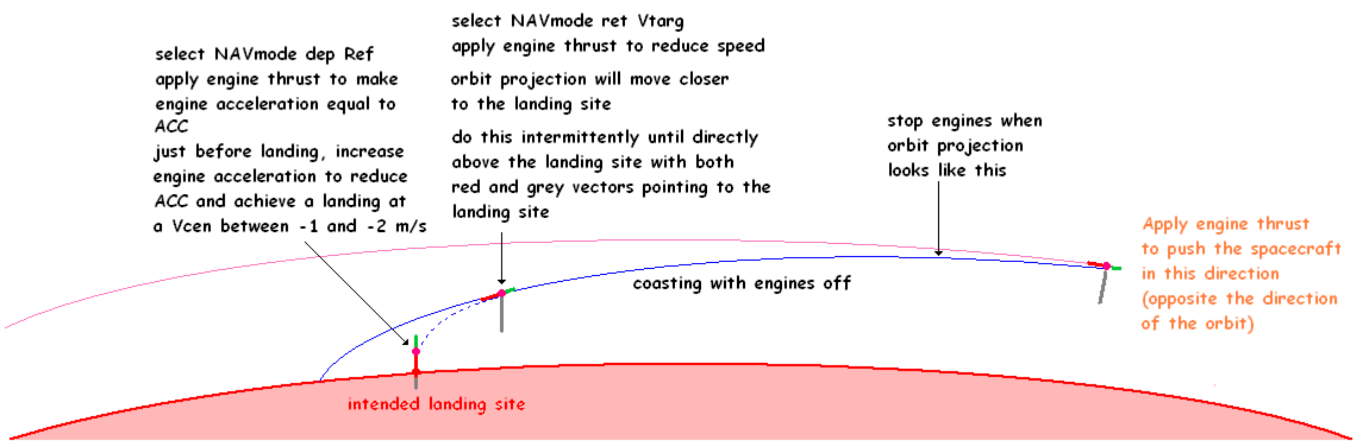
- point the spacecraft retrograde (pointing in the opposite direction to your motion)
- fire the engines at full thrust until Vtan is zero
- when Vtan=0, the spacecraft will be falling straight down
- point the spacecraft deprt ref
- fire the engines as much as needed to control descent (as in the previous exercise)
- turn engines off at touchdown

advantages:	- less work to plan,
	- fewer things to go wrong
	- a lot less hectic right at the end
	- works when there is no atmosphere
disadvantages:	- uses a lot of fuel

II) The Hard Way

- point the spacecraft retrograde
- fire the engines to slow the spacecraft just enough to cause it to enter the atmosphere
- let atmospheric drag do a lot of the slowing down work
- the spacecraft ends up drifting downward once it is very close to the ground
- use engines to control the descent to touch down

advantages:	- uses much less fuel
disadvantages:	- you need to be more precise
	- vertical descent starts when very close to the ground
	- there is little time to assess and set engines
	- if you are too fast, there is little time to correct



<u>Procedures</u>:

<u>A) Easy Method</u>

1) start ORBIT5tm.exe
   press <**enter**> at the first prompt.
   press '**x**' to turn telemetry tracking off.
   press '**r**' and reload the file "**test2d**"
   press '**p**' to display Vcen and Vtan.
2) Set center=OCESS ("**U**"), ref=earth ("**3**"), target=OCESS
3) Select ccw retro ("**F3**")

4) Monitor **θHrt** angle.
   When **θHrt** equals 17.5° set engine percentage needed to get engine acceleration of $15 m/s^2$
      - the more fuel you are carrying, the higher the engine % you will need
   Record the **θHrt** at which you *actually* initiated the engine burn as your starting Hrt.

5) Set target=earth (you do not need to watch **θHrt** any more)
6) Set NAVmode to "**retr Vtarg**"
7) Watch the process until the spacecraft is decending nearly vertically
   - when this happens, the red vector and grey vector almost will overlap
8) Set NAVmode to "**deprt ref**" (this is really important)
9) Watch **Acc**. It may be slightly higher than engine acceleration, but this is ok,
   you will get significant deceleration from atmospheric drag.
   With no atmosphere, if will be more important to not carry too much fuel!
   You can deploy the parachute as needed once drag drops below 10.

10) Land as you did for the previous exercise.

11) Once you touch down, set target=OCESS
12) Record the **θHrt**; the smaller it is, the better you did.

If you did not land at the launch pad, repeat the process.
Modifying the starting **θHrt** at which you start your engines:

   a) if you overshot the target, subtract the final **θHrt** from the starting **θHrt**,
   b) if you undershot the target, add the final **θHrt** to your starting **θHrt**.

When you repeat the process, initiate the engine burn at the modified **θHrt**.

If you wish, press "**Z**" and load "**land1**" to show you my best effort. Note, I was off a bit.
When you try again, press "**z**" each time you reset the screen.
   - see if you can follow my path as you land (or do better).

Alternatively, you can press "y" and record your own track once you have a starting **θHrt** that works.

B) Hard Method

1) start ORBIT5tm.exe
   press <**enter**> at the first prompt.
   press '**x**' to turn telemetry tracking off.
   press '**r**' and reload the file "**test2d**"
   press '**p**' to display Vcen and Vtan.
2) Set center=OCESS ("**U**"), ref=earth ("**3**"), target=OCESS
3) Select ccw retro ("**F3**")

4) Watch **θHrt**. When it equals 30º set engine percentage needed to get engine acceleration of $15 m/s^2$
   - the more fuel you are carrying, the higher the engine % you will need
   Record the **θHrt** at which you actually initiated the engine burn as your starting **θHrt**.

5) Set target= "**earth**"
6) Watch **Vhab-ref** near the top of the screen
   - stop engines when **Vhab-ref** = 6300 m/s
7) Set NAVmode to "**retr Vtarg**"
8) Watch distance to target (since target = earth, this is your altitude above the earth's surface).
   - when distance to target = 280 km set engine % to get engine acceleration of $15 m/s^2$
9) Watch atmospheric drag acceleration (top number of second box from top)
   - when drag goes above $50 m/s^2$ stop engines (or they will get damaged by ionization)
   - ***Record maximum drag experienced***
   - when drag falls below $50 m/s^2$ again, set engines back on to get $15 m/s^2$
10) Watch the process until the spacecraft is descending nearly vertically
   - when this happens, the red vector and grey vector almost will overlap
11) Set NAVmode to "**deprt ref**" (this is really important)
12) Watch **Acc**. It may be slightly higher than engine acceleration, but this is ok,
   - you will get significant deceleration from atmospheric drag.
   - you can deploy the parachute as needed once drag drops below 10.

13) Land as you did for the previous exercise.
14) Set target=**OCESS**
15) Record the final **θHrt**, the smaller it is, the better you did.

If you did not land at the launch pad, repeat the process.
Modifying the starting **θHrt** at which you start your engines:
   a) if you overshot the target, subtract the final **θHrt** from the starting **θHrt**,
   b) if you undershot the target, add the final **θHrt** to your starting **θHrt**.

When you repeat the process, initiate the engine burn at the modified **θHrt**.

This method can be used without an atmosphere, but there will be no atmospheric drag to help slow down the spacecraft. It may be advantageous to use this method to land without an atmosphere as it allows you to fix a landing site well in advance and coast down until you are nearer to the target to complete the speed reduction process. The path can be refined during the coasting period and the option exists to abort the landing with a minimal engine burn. However, there is a greater workload to be managed at lower altitude.

Different Landing Profiles

The steeper the descent into the atmosphere, the faster you are going when you reach the denser layers of air and the greater the drag deceleration. High-g deceleration is hard on crew and equipment.

To intersect the atmosphere at a shallower angle, we need to stop engines at a higher speed in step 6. A very shallow initial landing profile can be used. All that you need to ensure is that the periapsis of your orbit after stopping the engines in step 6 extends far enough into the atmosphere (under 100 km is a good starting point for a minimum periapsis) so that the spacecraft loses too much kinetic energy to rise back up into space.

Repeat the landing with a higher speed at engine cut-off: 7500 m/s to 7600 m/s.

- record initial **θHrt** at MES (main engine start)
- record the V hab-ref at MECO (main engine cut-off)
- record the maximum drag deceleration experienced
- record final **θHrt** on landing
- adjust the initial **θHrt** as before and try the procedure again to see if you can land at OCESS
- record the successful initial **θHrt**