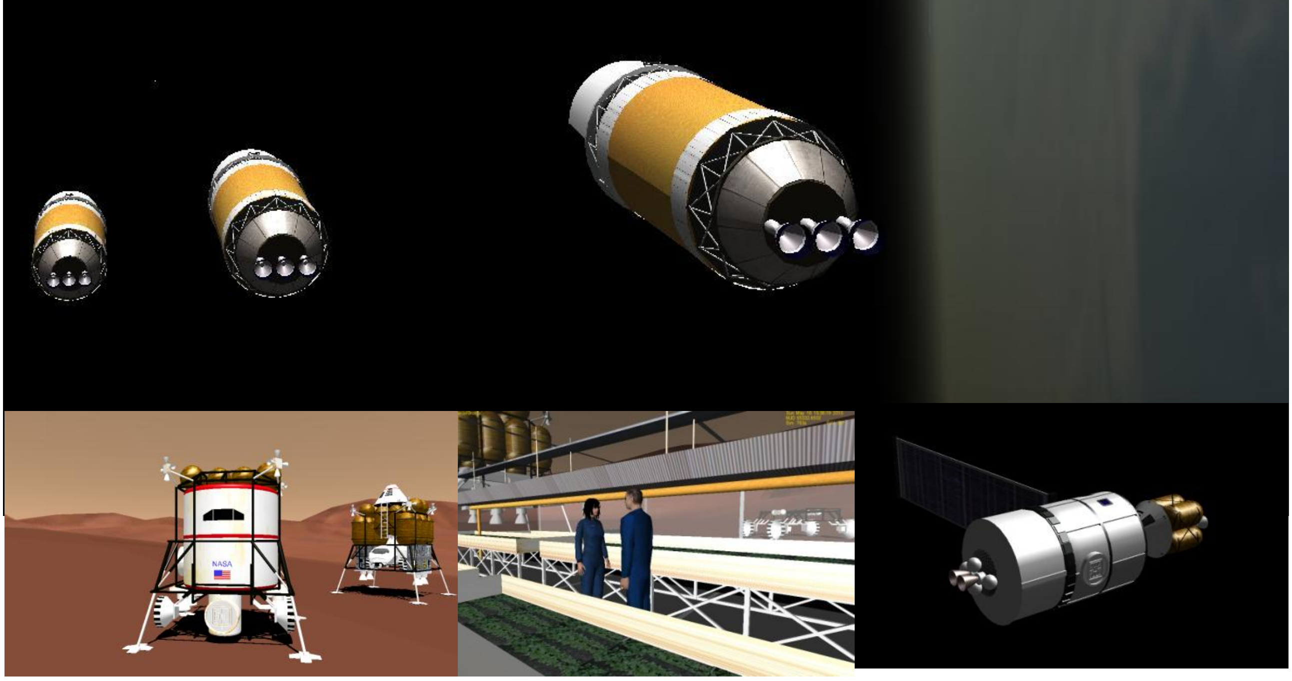
Mars Design Reference Mission 1 (v1.4)

Mark Paton



Contents

1. Quick Guide

This add-on aims to test out Entry, Descent and Landing (EDL) of the landers in the NASA Design Reference Mission 1.0. Eventually, if time permits, the add-on will move from testing to a complete add-on simulating a full mission to Mars with launchers and an Earth Return Vehicle.

Installation: Unzip into Orbiter directory. The version now includes its own modules, built in flight computers and autopilots. No further add-ons are required for the main scenarios.

Basically you can land from orbit by first **pressing "q"** and then **pressing "u"**. This will bring you to a soft touchdown. To land where you want on the surface however requires a bit more work from the pilot.

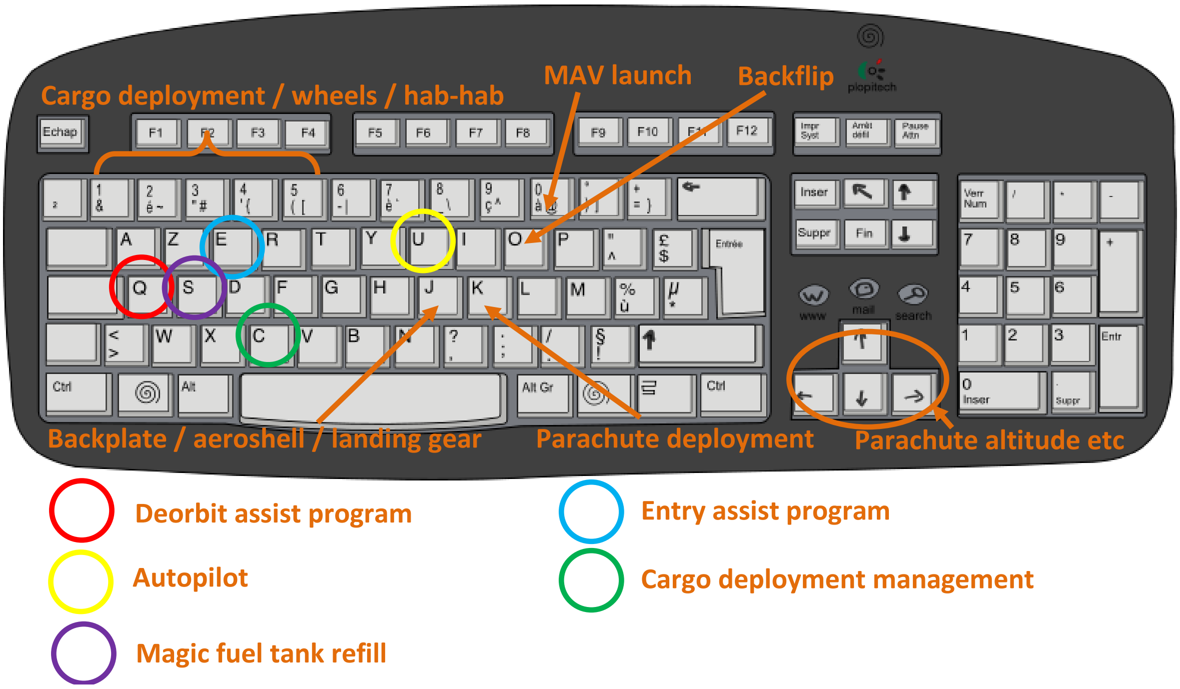
Lander keys:
o – perform aeroshell back-flip
k – deploy parachutes
j – jettison connector, backplate, aeroshell, deploy legs, cargowheels
u – activate deorbit burn, entry, descent and landing autopilot
e – display entry flight computer info on HUD
q – display deorbit flight computer info on HUD
w – toggle function of arrow keys – HUD text / CoM / etc
s – magic fuel tank refill
p – open airlock
b – info on UMmu crew
m – add crew
c – grapple cargo (shift-c to release)
1 – null downrange (approach) / descent velocity (powered descent)
2 – null crossrange with bank / null translation vel
3 – null crossrange with rcs / heading to target
4 – n/a / fly "glide path" to landing point
6 – deploy pressurized rover, deploy habitat wheels
7 – crew EVA
8 – select crew / info on cargo
9 – select crew / select cargo from disk (shift-9 add cargo)
0 – Launch MAV (press twice), extend habitat passage
arrow keys – various parameters

Tele-rover keys:
1 – decrease sounding rocket launch angle
2 – increase sounding rocket launch angle
3 – launch sounding rocket
4 – 20 second launch countdown
5 – load new rocket

Sounding rocket keys:
1 – toggle on and off the weather data

Earth Return Vehicle
1 – deploy/retract solar panel
j – jettison backplate and aeroshell

Some of the most important keys:



Things to note:

1. For the deorbit and entry autopilots to do their jobs well requires that the adjustment of the orbit inclination so it passes over the target landing location and the orbit is roughly circular with an altitude greater than 120 km.

2. Deorbit burn, entry, descent and landing are fully automatic. The autopilot has to be activated by **pressing "u"** (remember to press q first to activate the deorbit burn program). Different autopilots programs are available for guidance and control of the lander to the target landing site.

3. You can expect to parachute in directly on top of your target coordinates!Tthe guidnace, navigation and control programs have improved since the last release. The closest I have achieved lander release over the target has been less than 100 metres.

4. The arrow keys are used to change the coordinates the text output location of the flight programs and autopilots on the HUD, change the parachute deployment altitude, shift the centre of mass, descent velocity and some other parameters.

5. UMmu messages are shared with messages on the HUD from this add-on. You have to wait 15 seconds then the UMmu message will clear.

2. UMmu and UCGO compatibility status and keys

I have made this add-on compatible with Dan Steph's UMmu and UCGO add-on which allows users to exchange crew and cargo between ships in Orbiter that are UMmu / UCGO compatible. The UCGO / Ummu add-on has to be installed in your Orbiter folder. The UMmu / UCGO addon can be found by following the link below:

UMmu / UCGO URL : : http://orbiter.dansteph.com

The following UMmu functions are available with the DRM1 ships:

- Transfer of crew between docked ships (habitat lander, Mars Ascent Vehicle)
- EVA from 3 "ships" (habitat lander , Mars Ascent Vehicle and the pressurized rover)
- Saving crew to and loading crew from scenarios
- Loading of crew members while running a scenario

The UMmu keys for all ships are as follows:

- key 7 – perform EVA (i.e. exit the ship)
- key 8 – select crew member
- key 9 – select previous crew member
- key p – toggle airlock door between open and closed
- key b – obtain information about crew
- key m – add a crew

You can have up to 6 crew members. See UMmu documentation for further details. There is an example scenario with crew members added in the "other addons" folder along with the rest of the scenarios.

If you don't have UMmu installed you still run the scenarios except a message will pop up at the bottom of the screen (try to ignore it).

The UCGO keys for all ships are as follows:

- key 8 – info on cargo
- key 9 – select cargo from disk (shift-9 to add the cargo)
- key c – grapple cargo (shift-c to release cargo)

3. Introduction

The purpose of this technical/experimental Orbiter project is to virtually try out the landing system proposed in a NASA early Design Reference Mission (DRM) from the 1990s for landing humans on Mars and to have some fun doing it. At the moment the focus is on the landers. Expansion to a full simulation of a manned mission to Mars based on DRM 1 is planned but may take a few months.

Deorbit and entry flight routines are built into the landers C++ code to guide the pilot to a precise landing. This system is being developed to enable a landing of the crewed lander next to deployed cargo. So far the precision is about 3 km of targeted coordinates with tests so far. It is possible to deploy the parachutes within the 1 km of a previous landed vehicle if you take note of what coordinates you were targeting previously and do the same again!

The landers are based the DRMs by NASA which are basically working documents to communicate information to interested parties and are not supposed to be complete solutions to the problem of sending humans to Mars. Further details of these DRMs can be found on the internet. This add-on aims to simulate the DRM 1.0 landers.

DRM 1.0
http://ares.jsc.nasa.gov/HumanExplore/Exploration/EXLibrary/DOCS/EIC044.HTML

DRM 3.0 (with some details of DRM 1.0)
ston.jsc.nasa.gov/collections/TRS/_techrep/SP-6107-ADD.pdf

3.1 DRM 1.0 landers

1. Cargo lander with Mars Ascent Vehicle (MAV), pressurised rover, other cargo (see web links above). The MAV + lander is often referred to just as “MAV” which may be confusing.

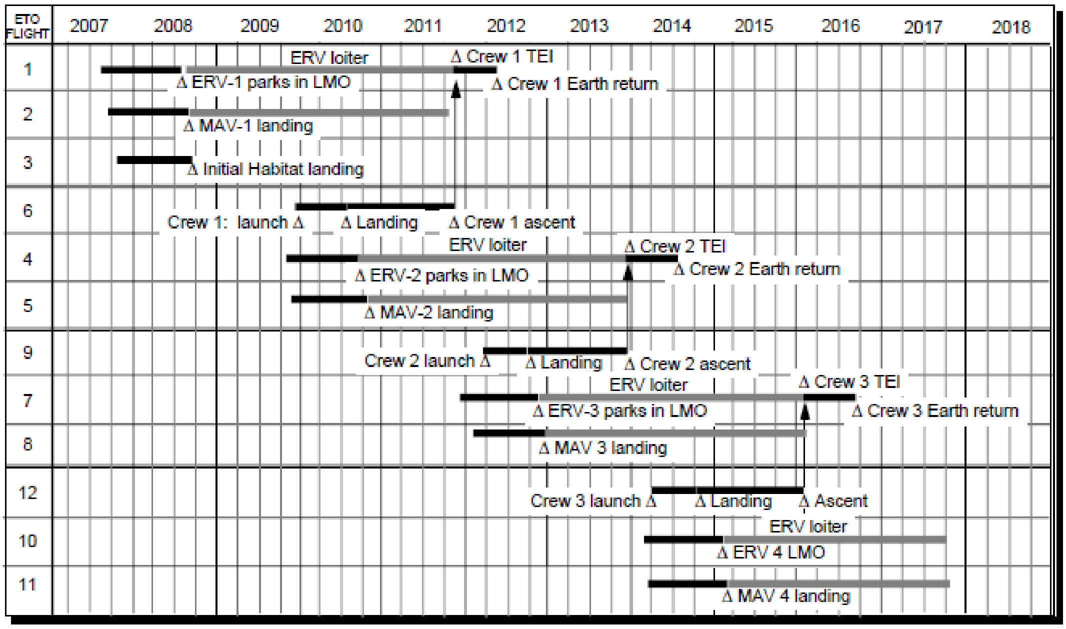
2. Surface habitat 1. Used as a safe haven and to deliver non-perishable consumables. It is referred to as the Mars Surface Lander (MSL).

3. Crewed surface habitat 2. Same as surface habitat 1 except it is crewed.

Landers are delivered in biconic aeroshells with base diameters of 10 m.

Mission summary

In 2007 the cargo lander and spare surface habitat (landers 1 & 2) are launched and landed on the surface. In 2007 the Earth Return Vehicle (not included in the add-on) is also launched to be put into a parking orbit around Mars. In 2009 the crew is then sent to Mars in the second surface habitat lander (lander 3). After spending 540 days on surface crew leave the surface in the Mars Ascent Vehicle (MAV) and rendezvous with the ERV. They then transit Mars to Earth in the ERV habitat and use the MAV capsule to land on Earth.



ERV:	Earth Return Vehicle
MAV:	Mars Ascent Vehicle
TEI:	Trans Earth Injection
LMO:	Low Mars Orbit

Diagram from NASA special publication 6107 (DRM 1) page 3-45

Figure 3-7 Mars Reference Mission sequence.

3.2 DRM 3.0 landers (just for interest, not included in this add-on)

1. Cargo lander. This was repackaged to fit inside an aeroshell with a 7.5 m base diameter.

2. Crewed surface habitat. The habitat is integrated with the aeroshell reducing the base diameter of the aeroshell to 7.5 m. Living volume augmented with inflatable habitat. Wheels removed from habitat.

The mass of both landers are reviewed, down from ~90 mT at entry for DRM 1.0 to ~60 mT at entry for DRM 3.0. The backup habitat is scrubbed from the mission. The smaller aeroshell and lower mass mean a less expensive launcher can be used and bring costs down.

Mission summary

In 2011 a cargo lander with the MAV (lander 1) are launched to Mars as well as an ERV into orbit around Mars. In 2014 the crew is launched in the surface habitat lander (lander 2) towards Mars.

3.3 Orbiter version of DRM 1.0 landers

Included in this add-on are my Orbiter models of a cargo lander and habitat landers based on information in NASA's Design Reference Mission reports. The landers are based on the DRM 1.0 landers with a 90 mT entry mass. The back-up habitat is now simulated, just with a copy of the crewed habitat so a base can be visualised. I have added retro rockets to the aeroshell for the deorbit burn. The aeroshells use a centre of mass/pressure shift mechanism to do a back-flip. A basic Earth Return Vehicle is included with functioning engines and deployable solar panel.

Launch of the landers is simulated with Velcro rockets. A Nuclear Thermal Rcoket is included with basic engine definitions.

4. Lander mass and landing system numbers

Mass budget (kg)

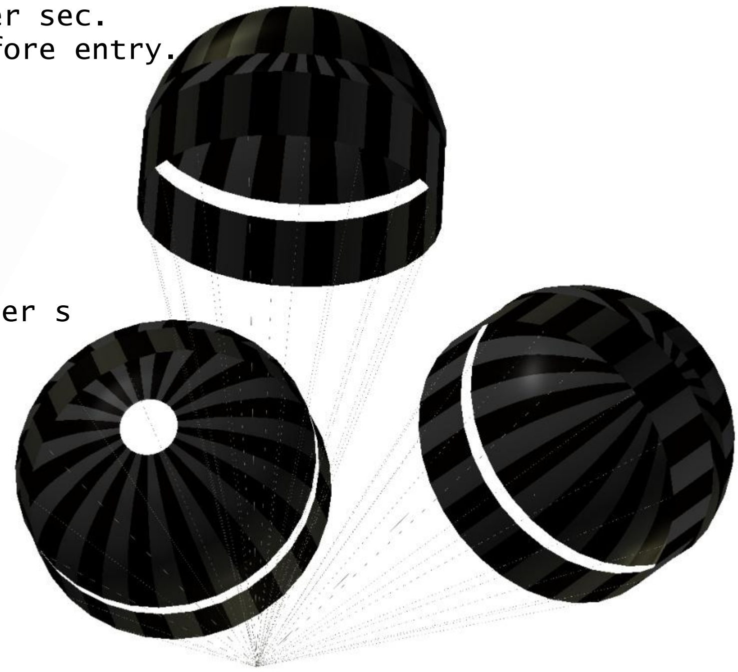
```
Entry and Descent Systems (same for both landers)
-------------------------
Aeroshell               : 16000
Backplate               : 1000
Main parachutes         : 700

LANDER 1 (cargo lander)
-----------------------
Lander                  : 4670
Pressurised rover       : 15500
MAV                     : 8050
Cargo 1                 : variable (0 to 32700 kg)
Hydrogen feedstock      : not budgeted in yet
Lander propellant       : variable (11970 to 44670 kg)
Total lander mass       : 72890
Cargo lander at entry   : 90890

LANDER 2 (crew lander)
----------------------
Habitat lander          : 60710
Propellant              : 11970
Total lander mass       : 72980
Crew lander at entry    : 89980
```

Other information

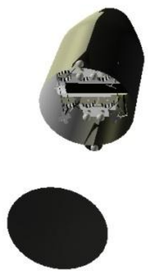
```
Aeroshell
---------
Lift over drag             : 0.45
Angle of attack            : 20
Wing area                  : 171
Drag coefficient at 0 AoA  : 0.4

Parachutes
----------
Parachute diameter            : 50 m
Drag coefficient              : 0.45
Number of main parachutes     : 4

Engines
-------

Hover engine thrust           : 150 kN
Number of hover engines       : 4
Specific impulse              : 380 s
```

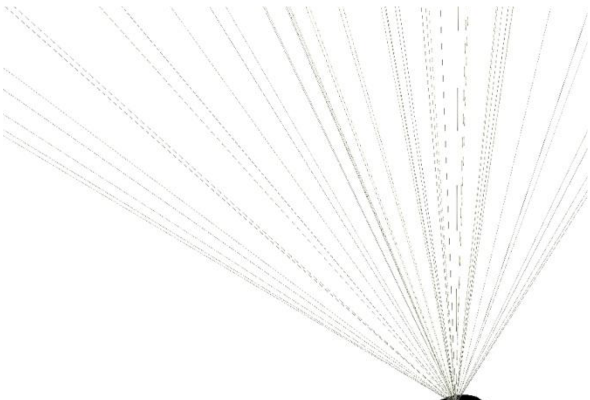
5. Landing vehicle operations

1. Entry at 100 km and 3.6 km per sec. Jettison connector (press j) before entry.

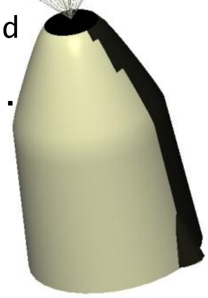


2. Back-flip at 12 km and 1.2 km per s activated by autopilot or press o. Takes 25 s to complete



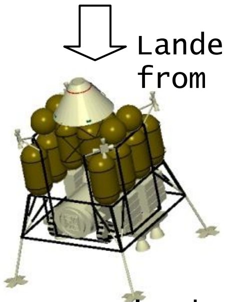


3. Parachutes deployed at 9 km and 0.95 km per s. Use autopilot or press “k”. Eject backplate by pressing “j” if not using autopilot.

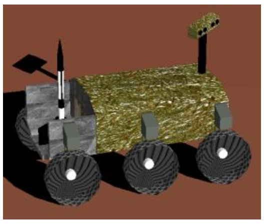


4. Lander is released by pressing “j” at 4 km and 0.12 km per s.

Either autopilot or use numpad keys if piloting manually

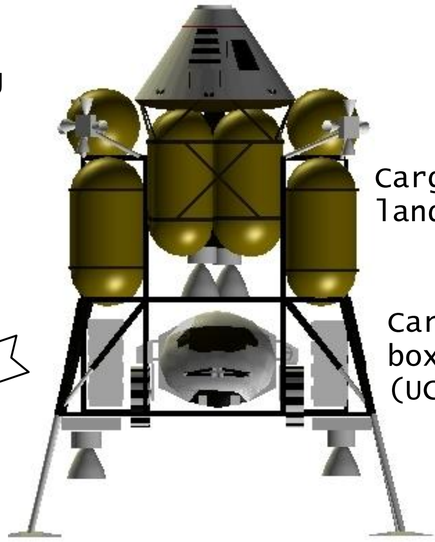


Lander dropping from aeroshell



Telerover is deployed via UCGO. See section 1 for keys.

MAV (press “0”)



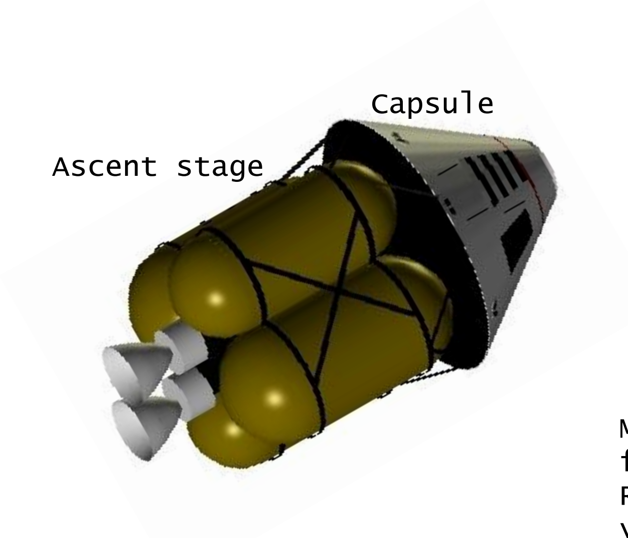
Cargo lander

Cargo box (UCGO)

Pressurised Rover (press “6”)

Capsule

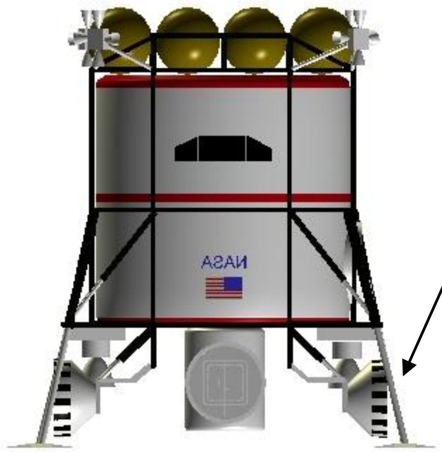
Ascent stage



Mars Ascent Vehicle can be launched **pressing “0” twice**. The ladder will be deployed and then retracted. The ascent stage can be jettisoned by **pressing “j”**. The MAV capsule parachutes can be deployed by **pressing “j”**.

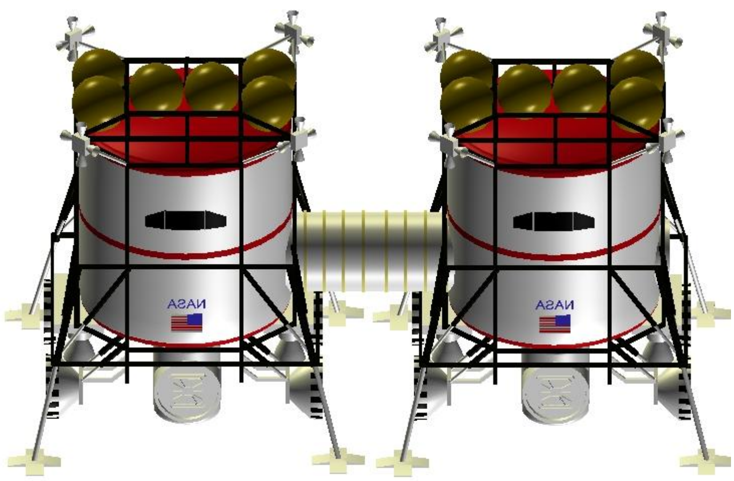
MAV has a docking port at the front for docking with an Earth Return Vehicle (not modelled yet). The capsule, in this add-on, can also be used to re-enter into the Earth’s atmosphere.

Habitat lander



The wheels of the habitat can be released by **pressing “j”** and then used to grapple and distribute cargo around the base

A connecting passageway can be deployed from a habitat lander by **pressing “0”**

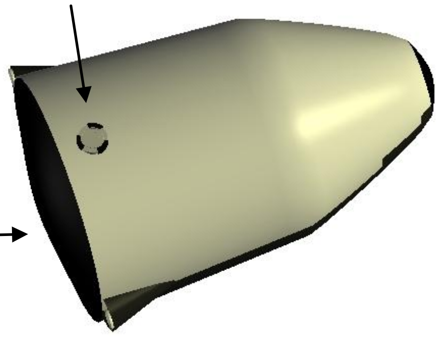


Wheels can be lowered from repositioning of a habitat on the surface - **Press “6”**

The aeroshell has two docking ports. Docking port 1 is intended for the crew. Docking port 2 is for connection to a propulsion stage.

Docking port 1

Docking port 2



6. Configuration of the landers using the Orbiter scenario files

It is possible to configure the landers in the DRM1 scenarios by changing the numbers that follow the word CONFIG in set-up for the scenario. The line with CONFIG is read when Orbiter starts up and is used by the add-on so it knows which state it is in when a scenario is saved.

The 4 numbers represent configuration states of the cargo lander. These represent various configurations of the lander. Below is a list of what they refer too and what the values represent.

1. Fuel tank level : empty (0) or full (1)
2. Pressurised rover : deployed (0) or stowed (1)
3. Mars Ascent Vehicle : launched (0) or stowed (1)
4. Aeroshell : released (0) attached (1) connector (2)

So if the first number is set to zero, i.e. CONFIG 0 1 1 1, then the cargo lander will not have any fuel on board. If the first number is set to 1 then the fuel will be add so the total mass of the lander equals the same as the habitat lander which is 92890 kg. The amount of fuel added depends on the amount of cargo added. So if no cargo is on board the maximum amount of fuel that can be added is 47200 kg. If a full load of cargo is on board (32700 kg) then the maximum amount of fuel that can be added is 15000 kg.

If the 4th number is set to zero, i.e. CARGO 1 1 1 0, then the aeroshell and backplate will be missing. If the 4th number is set to 1, i.e. 1 1 1 1, then the aeroshell and the backplate will be present. If the 4th number is set to 2, i.e. 1 1 1 2, the the aeroshell will be present with a connecting ring that connects the aeroshell to Wishbone's NTR stage.

Below is some text from a scenario showing examples of the landers in different states. The full scenario can be found in the "extras" folder along with the DRM1 scenarios and is named, "04. Examples of lander configurations".

```
BEGIN_SHIPS
cargolander1:DRM1_cargo
  STATUS Landed Mars
  POS -128.1892067 17.6125798
  HEADING 46.31
  AFCMODE 7
  PRPLEVEL 0:0.949199
  NAVFREQ 0 0
  CARGO 1 0 1 0
END
cargolander2:DRM1_cargo
  STATUS Landed Mars
  POS -128.1882067 17.6125798
  HEADING 46.31
  AFCMODE 7
  PRPLEVEL 0:0.949199
  NAVFREQ 0 0
  CARGO 1 0 1 0
END
cargolander3:DRM1_cargo
  STATUS Landed Mars
  POS -128.1872067 17.6125798
  HEADING 46.31
  AFCMODE 7
  PRPLEVEL 0:0.949199
  NAVFREQ 0 0
  CARGO 1 1 1 0
END
END_SHIPS
```

In a similar way the habitat lander can be configured for the deployment of its wheels and connecting passageways. The wheels can be deployed by setting the first value to zero e.g. CARGO 0 1 0. The passageway can be deployed by setting the second value to zero e.g. CARGO 1 0 0.

7. Adding Isidis Highlands terrain

To install the terrain requires a little bit of work. Firstly the mesh needs to be obtained from Foxtrot's Isidis Highlands addon on avsim.com. This requires you to login, download the addon and then extract the mesh into the Orbiter mesh file. Secondly the texture needs to be extracted from the Mars landmarks addon by alexander_spb on Orbit Hanger Mods (link at bottom of page) and placed in the Orbiter texture folder. Thirdly the confiuration file needs to be updated in the sub-subfolder called "base" in the subfolder Mars in the Orbiter main configuration folder.

The steps are as follows :

1. Extract the mesh file called "isidis-highlands.msh" from the Isidis-Highlands addon and place it in the Orbiter mesh folder

2. Extract the texture file called "isidis-highlands.dds" from the Mars landmarks addon (link at bottom of page) and place it in the Orbiter texture folder

3. Extract the configuration file from the Mars lanmarks addon called Isidis-Highlands.cfg and place it in the Base folder for Mars (Config\Mars\Base)

4. Open the configuration file with notepad or some other text editor. Then change the number -4099 to -4109 so it looks as follows :

```
Base-V2.0
Name = Mars Isidis Highlands
Location = +85.87 +3.3
Size = 5000
Objectsize = 1500

; === List of visuals ===
BEGIN_OBJECTLIST
MESH
          FILE isidis-highlands
          POS 0 -4109 0
          ROT 0
          OWNMATERIAL
END
LPAD1
    POS 42240 0 1300
    SCALE 0 0 0
    TEX Lpad01
END
END_OBJECTLIST
```

Save and close the file and you should be ready to Rock 'n' Roll!

New textures for Martian landmarks:
http://www.orbithangar.com/searchid.php?ID=5493

8. Autopilot programs : a summary

There are a number of tools to help you land on the surface. These include programs to provide deorbit and entry information. There is a deorbit burn, entry, descent and landing autopilot which will take care of the landing. During entry the angle of attack can be changed manually to correct any errors made by the autopilot. Also the parachute deployment altitude can be changed to further correct errors when closer to your target.

7.1 Deorbit flight program

The deorbit assist program feeds into the timing of the autopilot deorbit burn or can be used to help the pilot to perform a manual deorbit burn. The program will calculate the deorbit burn location along a ships's orbit that places the location of entry into the atmosphere so the ship can reach close to the target coordinates just by hypersonic gliding.

There are two conditions that need to be met before the deorbit computer is useable with any degree of accuracy (if these are not it may still be able to land but the ship may not be able to reach the target coordinates).

1. The orbit needs to be approximately circular.

2. The orbit has to be positioned so it passes over the target at any time. As long as you leave at least one orbital period before you intend to land then you'll be A-ok.

The computer is then activated by **pressing "q"** one orbital period before you land i.e. when it passes the latitude of the target. This sets the target location. The program then works by simply tracking the distance you travel along the orbit path and using a previously calculated deorbit location. This is from knowing the hypersonic glide capability of the ship (which is determined with an "on board" simulation of the entry). The deorbit program displays the following information on the HUD screen. Remember to **press "u"** if you want the autopilot to perform the deorbit burn.

burn@ - distance until deorbit burn (km). This is the distance along the (final) orbital path, in the direction of motion, before the deorbit burn takes place.

so far – distance travelled so far (km). This is the distance between the base and the vehicle along the orbital path in the direction of motion. This will be different from the shortest distance between your current location and the target base that is displayed at the bottom of Orbiter's Map MFD.

to go – distance to go until deorbit burn (km). This is a countdown, in distance, until the deorbit burn will be performed.

glide distance – predicted travel distance in atmosphere (km). This is the distance the ship will travel during its hypersonic entry after it passes through the entry window at 120 km altitude.

The angle attack that the deorbit program uses to calculate the glide distance can be changed by toggling the arrow keys function with the **key "w"** and then using the **arrow keys.** The glide distance also takes into account parachute deployment which is set at 10 km altitude.

8.2 Entry flight program

Information is calculated by the flight program and displayed on the HUD to help guide the pilot to the target location. The program uses its own simplified model of the Martian atmosphere together with the equations of motion to calculate the trajectory and predict the landing location. By adjusting the angle of attack the vehicle can be guided to the base. The information doesn't feed into the autopilot as that was taken care of in the deorbit burn. The angle of attack can be changed to correct errors made during the burn.

The entry program output can be displayed on the HUD by **pressing e**. This will provide the following information.

text row 1. . . . .
glide the predicted hypersonic glide distance in kilometres
time time to chute deployment
lon chute longitude in degrees of the parachute deployment.
lat chute latitude in degrees of the parachute deployment.
alt os altitude offset to the parachute deployment altitude
wind adds wind forces to the parachute
text row 2. . . . .
tgt lon longitude of the target
tgt lat latitude of the target
x-tng the predicted crossrange for the landing
d-rng the predicted downrange for the landing
name the name of the target vessel or base
text row 3. . . . .
chute alt the altitude of the parachute deployment
max g maximum g level during entry
time amount of time in seconds before maximum g level
AOA The angle of attack. Changing this will affect the landing latitude and longitude. It can be changed by using pitch thrusters (if you have any fuel left) or by shifting the centre of mass (CoM).
CoM pos centre of mass position. This indicates the location of the centre of mass of the ship. Useful for changing the angle of attack when low on fuel.
LoD Lift over drag.
text row 4. . . . .
cur lon current longitude
cur lat current latitude
v lon velocity in the west to east direction
v lat velocity in the north to south direction
CoM Centre of Mass autopilot program. Changes the angle of attack so the predicted downrange is as small as possible.
bank bank control program. Banks the spacecraft to use aerodynamic forces to minimise the crossrange
rcs rocket control system control program. Fires the thrusters to minimise the crossrange. Can use quite a lot of fuel.

Manually reduce target miss by changing the angle of attack of the aeroshell (i.e. use **numpad 2 & 8** keys to pitch up and down or shift the centre of mass using the **arrow keys**, first select the function of the arrow keys by **pressing w**). The **altitude offset** can be changed using the arrow keys. Again **press w** to select the correct arrow key function.

8.3 Powered Descent program

The powered descent and landing autopilot flies the lander to a landing within 200 metres of a preselected target. The target that can be selected can be a base or a vessel. The autopilot operates a set of four programs similar to Orbiter's "navigation tools" like hold level and hold altitude. These are activated at preprogrammed altitudes and cannot be changed by the pilot. However the autopilot can be switched off and the individual programs can be operated individually by the pilot.

This output from this phase can be displayed, like the entry phase by **pressing e.**

range the distance to the target in metres
tgt lon target longitude
tgt lat target latitude
name name of the target vessel or base
tgt hd target heading
ship hd heading of the lander
v desc vertical descent speed (m/s)
set@ the descent speed set by the pilot or autopilot
eng ign@ the altitude when the descent engines are switched on. This number will increase until it reaches the current altitude whereupon the engines will throttle up.
dist lon the distance in the east to west direction from the target (in metres)
dist lat the distance in the south to north direction from the target (in metres)
v lon the velocity in the east-west direction (m/s)
v lat the velocity in the south-north direction (m/s)
vert vertical descent autopilot program
trans null translation velocity autopilot program
head turn lander to face target
final control final approach path

To change the descent speed **press w** to set the arrow keys function. Then press the up arrow and down arrow and the vertical descent program will adjust the descent speed. The target can also be changed by the arrow keys **press w** until either **target (vessel)** or **target (base)** is displayed at the top of the HUD. Then use the up and down **arrow keys** to move through the bases or vessels active in your install of Orbiter.

8.4 Cargo deployment

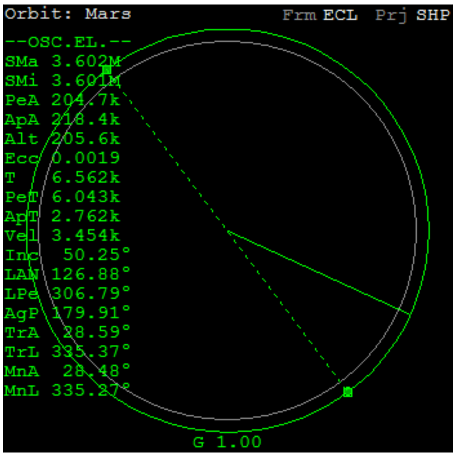
Cargo deployment is managed by another Orbiter add-on called UCGO. See UCGO documentation for details.

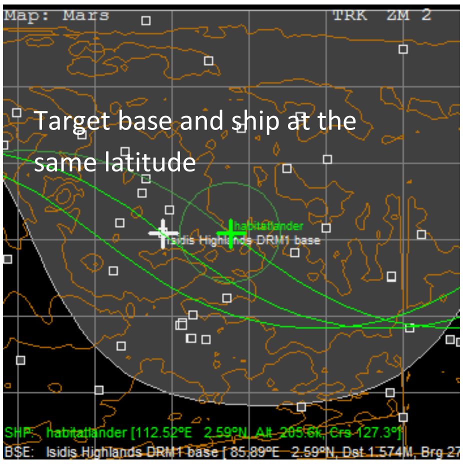
The UCGO cargo can be moved around the surface using a cargo transportation vehicle that consists of the habitat wheels and frame. This can be deployed from a habitat by **pressing J.** The “cargo wheels” can then load and unload standard UCGO cargo.

9. Landing tutorial

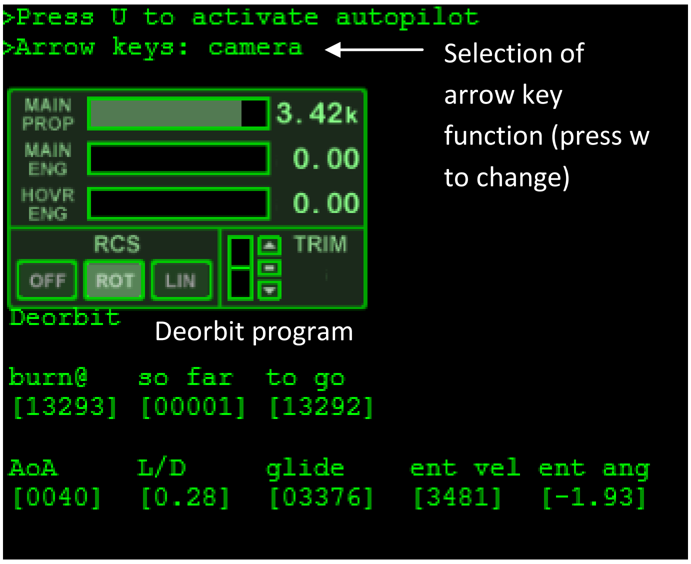
Load the scenario called “080527 0300 Deorbit autopilot activation”. The orbit has already been made circular and the orbital inclination adjusted so the orbit passes over the base called “Isidis-Highlands DRM 1 base” in just over one orbit’s time.

1. **Activation of the deorbit program** - Wait until the ship has passed over the base (it always has to be to the east of your target location if you are travelling west-east). Your ship’s latitude will rise to about 18.5°N latitude before descending again. When the ship has descended to 17.7°N **press “q”**. This will activate the deorbit program.

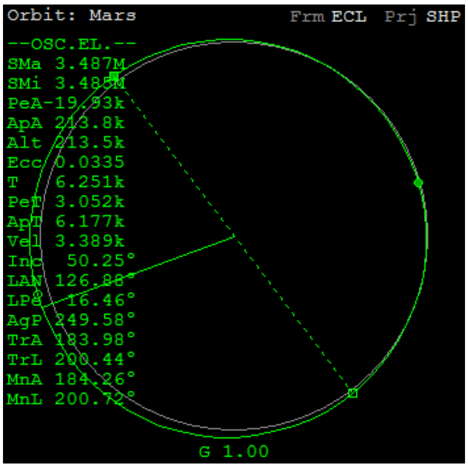


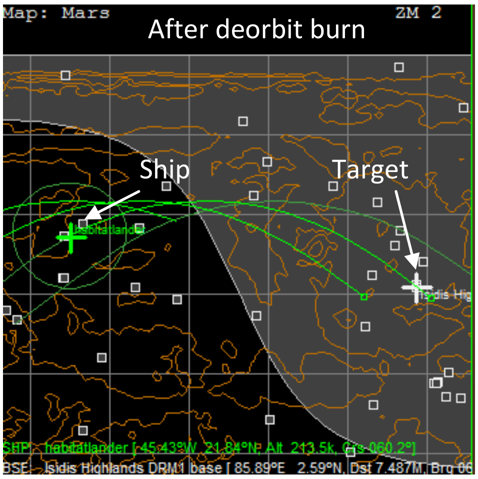


2. **Autopilot** - Once the deorbit program has been activated **press “u”** to activate the autopilot. The autopilot can just be left to do its job for the entire descent while you monitor the flight and perhaps make some adjustments during entry.

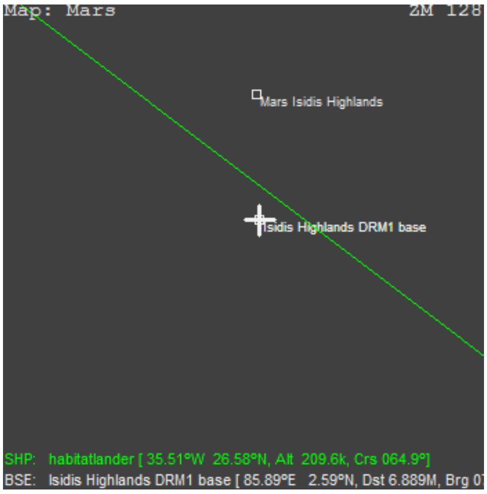


3. **Deorbit burn** - The deorbit program outputs the distance to go before the deorbit burn is performed, first row, third column of numbers. At 200 km to go the ship will be orientated retrograde in preparation for the burn. At 0 km the main engines will fire to bring the periapsis of the orbit down to -20 km below the surface i.e. the lowest part of the orbit will pass below the surface. Important: remember to open the engine doors by **pressing n.**

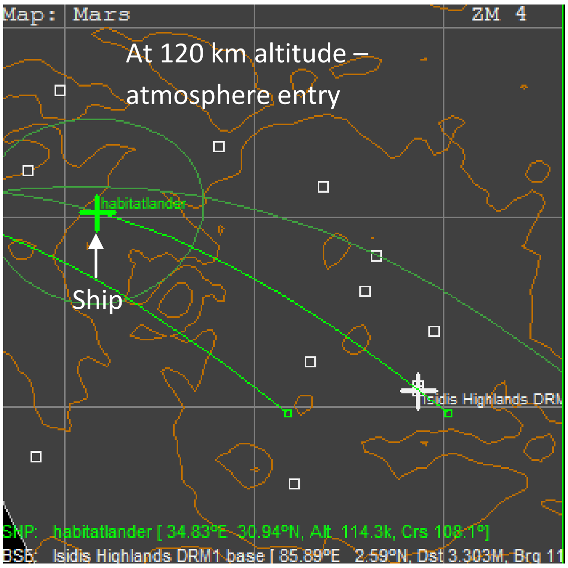




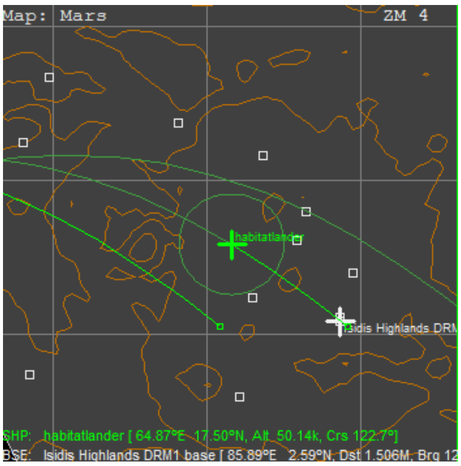
4. **Course correction burn** – during the deorbit burn the trajectory can move off to the side of the target base. To correct turn normal + and fire the main engines. Alternatively the translation thrusters can be used. It may be possible to correct errors (of several kilometres) during entry, below 30 km altitude, when the entry programs can be most effectively used.



4. **Entry preparations** - At 120 km altitude the ship will be turned prograde for entry into the atmosphere. At 100 km the ship will be leveled with the horizon so its heat shield is facing the planet's surface.

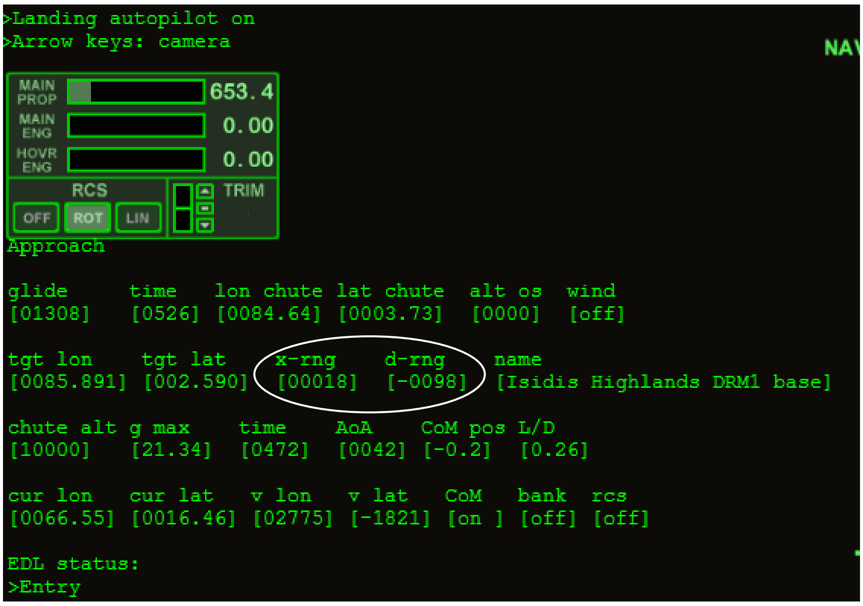


5. **Autopilot temporary deactivation** - At 50 km or when the fuel runs out, whichever happens first, the autopilot will release the ship from its level orientation and the aerodynamic forces will force its nose to pitch up and so create some lift. The lander will continue for while without any control from the autopilot using aerodynamic forces to maintain a stable descent. Note: If you want to save some fuel for the entry guidance programs to work minimise the crossrange then release the autopilot temporary at about 60 km altitude and disengage the autopilot (press u). Once below 50 km reactivate the autopilot by pressing u again.



6. **Entry program and piloting** - The entry program can be activated by **pressing "e"**. The downrange and crossrange from the target that the program thinks you will land at is predicted 2nd row down in the middle of the HUD text. This needs to be made as small as possible. The image below shows the distance displayed in kilometres (it will change to

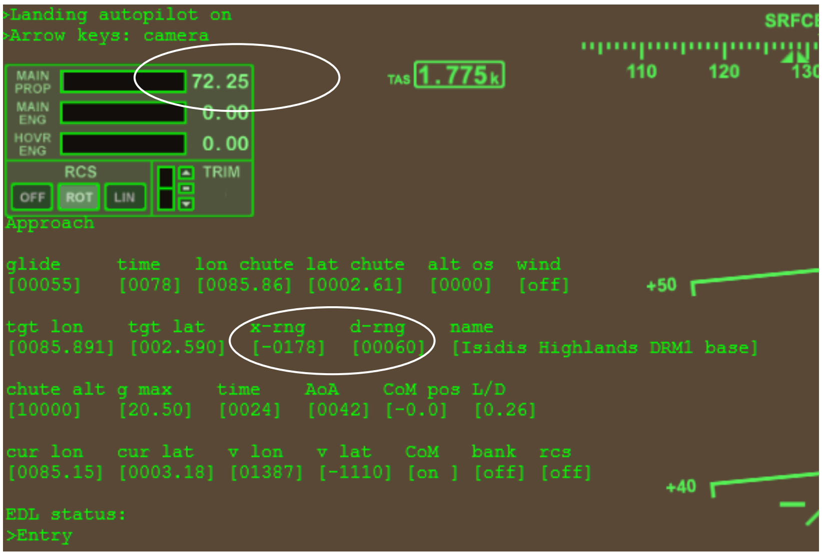
metres when below 10 km). Other useful information is included such as the **angle of attack** and the **parachute deployment altitude.**



7. **Changing lift to control landing location** - The predicted landing point can also be controlled by using guidance programs that control the cross-range (the predicted miss distance at right angles to the current flight path direction). See section 10.2. It is important to wait until below 30 km altitude before applying activating these programs as the downrange program needs to be stabilised first.

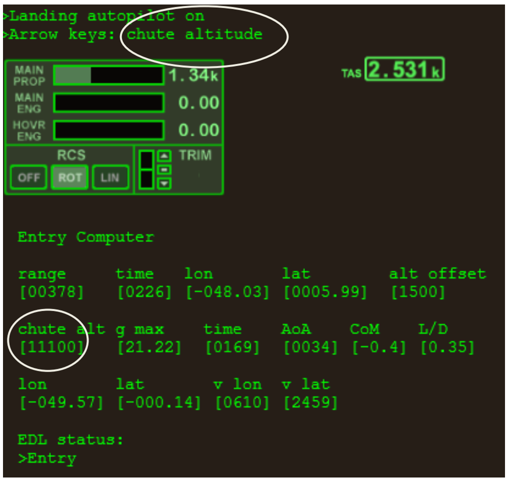
At an altitude of 30 km press 2 on the main keyboard. This will activate the bank program that will rotate some of the lift into the horizontal direction to reduce the crossrange. The crossrange will gradually decrease from about 10 km to less than 1 km at an altitude of 20 km.

When the crossrange is less than 500 metres the bank program will level the lander. This may take a bit of fuel so you may want to take manual control and level the lander yourself to save the fuel for fine tuning the crossrange. If you are not worried about using lots of fuel you can press 3 on the main keyboard which will activate the rcs program which uses the translation thrusters to null the crossrange. This is best used when the crossrange is quite small because large bursts of the thrusters will, together with the aerodynamic forces, create a torque on the lander.

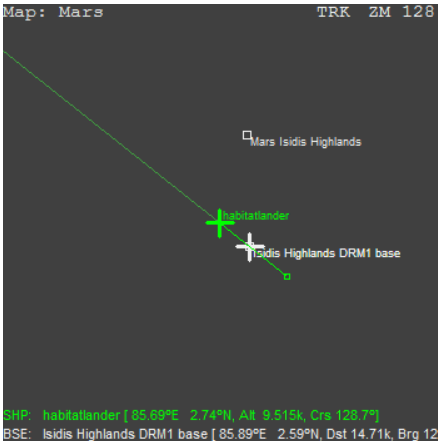


The downrange can be controlled manually by first switching off the CoM autopilot (by pressing 1 on the main keyboard) and selecting the change CoM function for the arrow keys by **pressing w.**

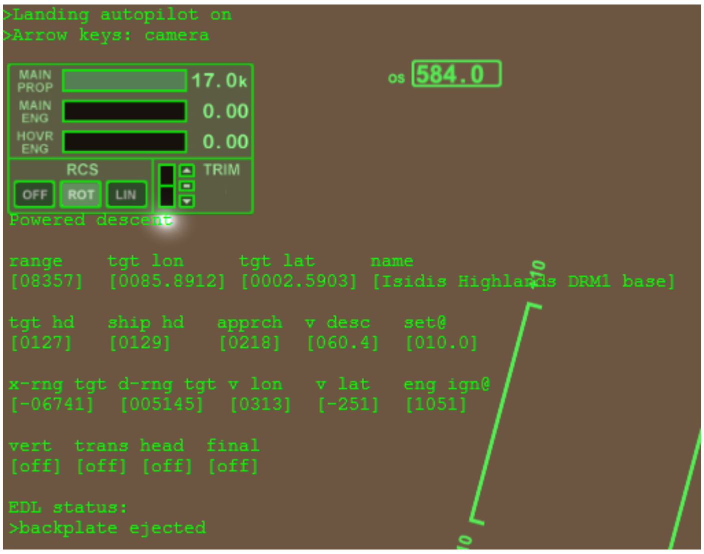
8. **Changing parachute deployment altitude to control landing location** - Closer to the base you may find that changing the angle of attack and lift does not have the required sensitivity for an accurate landing. Changing the parachute deployment altitude can also be used to shift the landing location. **Press "w"** until the second line in the top left of the screen reads: "**arrow keys: chute altitude**".



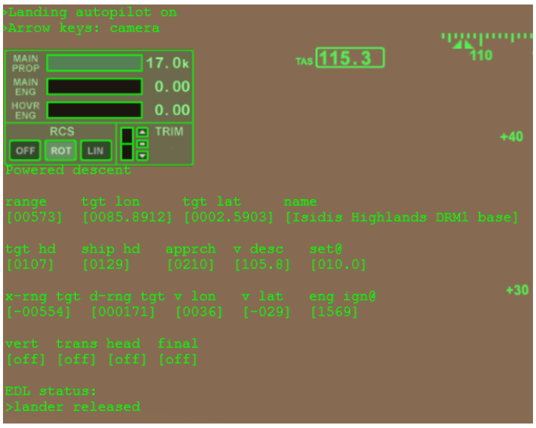
9. **Autopilot takes full control!** - At an altitude of 12500 metres above the parachute deployment altitude the autopilot will rotate the aeroshell so its backplate is facing forward ready to deploy the parachutes and release the lander. The parachute deployment altitude is set nominally at 10000 metres but this can be changed in 100 m steps as explained in step 8.

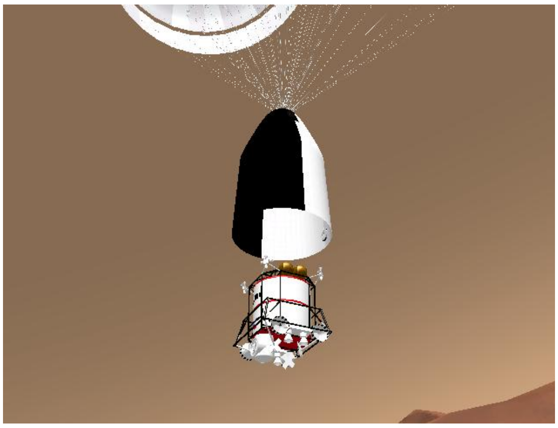


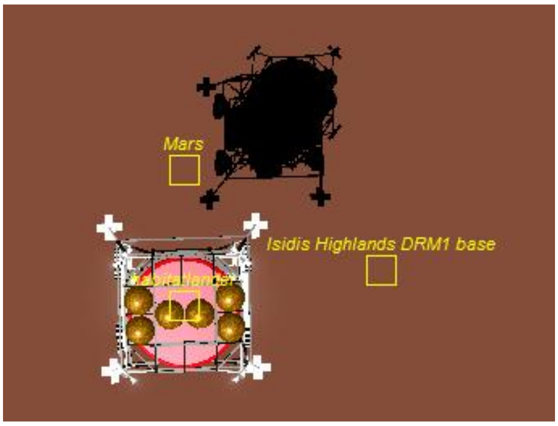
10. **Powered descent** – the powered descent program will be automatically activated at an altitude of 9 km when the backplate is ejected. It will provide information useful for guiding the lander to a precise landing. The status of the autopilot programs is also displayed.

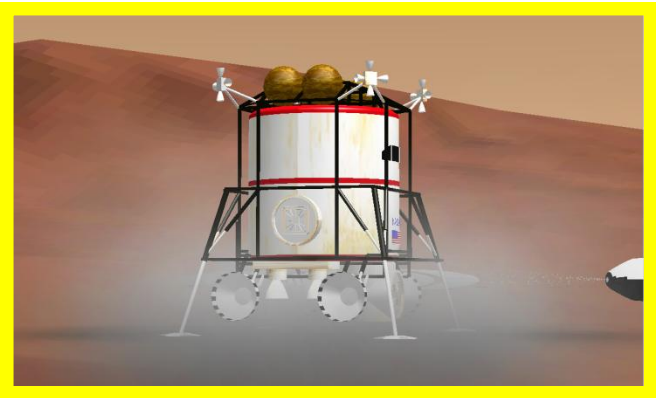


11. **The landing** - The lander will be released at 4000 m. The landing legs will automatically deploy at 3000 metres. The engine ignition altitude will depend on how fast you are travelling but it is normally around 2500 metres altitude. The autopilot will then control the vertical speed and horizontal speed for a gentle touchdown on the surface.









10. Autopilot programs : the details

There are a set of programs or routines built-in to the add-on that can be used to help the pilot (or autopilot) to land close to the deployed cargo and first habitat. There are three main stages to landing that assistance is provided. These are as follows.

1. Deorbit – countdown in distance to deorbit burn location
2. Entry - landing coordinates are predicted. Parachute deployment altitude and aeroshell angle of attack can be varied to fine tune the landing location.
3. Powered Descent – ignition altitude of the descent engines is predicted for a soft landing, forward velocity required to reach the target is predicted (not displayed: used by powered descent program)
4. Deorbit, Entry, Descent and Landing autopilot – an autopilot is provided to automatically land the cargo lander and habitats all the way from deorbit to landing although the precision landing can be managed by the pilot with entry programs to minimise the predicted downrange and crossrange.

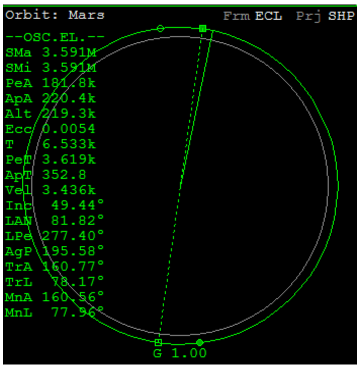
With a joint effort between the pilot and autopilot a precision of less than 100 m has been achieved when trying to land next to a base.

10.1 Deorbit program and autopilot

There are 5 key points to note:

- The orbit has to be roughly circular before engaging the deorbit program at the autopilot
- The orbital path has to be positioned (by changing the inclination) so it passes over the base
- The pilot starts the deorbit program at the same latitude as the base one orbital pass before you intent to land by pressing “d”. This effectively sets the target.
- Then the autopilot can be engaged by pressing “u”
- The autopilot, by itself is a bit dumb and will land you perhaps 100 km, maybe more, maybe less, from the base. Refinements can be made by the pilot using the entry program discussed in the next section

The deorbit program does most of the work for landing a ship close (~100 km) to its target. After which manual adjustments can be made using the entry program for a more precise landing. Before the deorbit burn is made the orbit needs to be roughly circular (this is a limitation of the current version of the program). An example is shown below. It doesn’t have to be exact because you can always change the angle of attack or parachute deployment altitude during entry to refine your trajectory.



Once the orbit is roughly circular the orbital inclination needs to be changed so the orbit passes over the base. This can be done by turning +normal or –normal to the orbital plane and engaging main engines. The figures below show the orbit set up for landing. On the left is a screen capture from **Map MFD**. This can be used to determine your orbital path into the future using the green lines. When you are at the latitude of your target coordinates base **press "q"** as shown in **figure 1.** This doesn't have to be exact. The countdown in distance to your deorbit burn will then start. Press **"u"** to engage the autopilot. The autopilot will automatically perform the burn for you and then orientate the ship for entry into the atmosphere when you reach an altitude of 120 km.

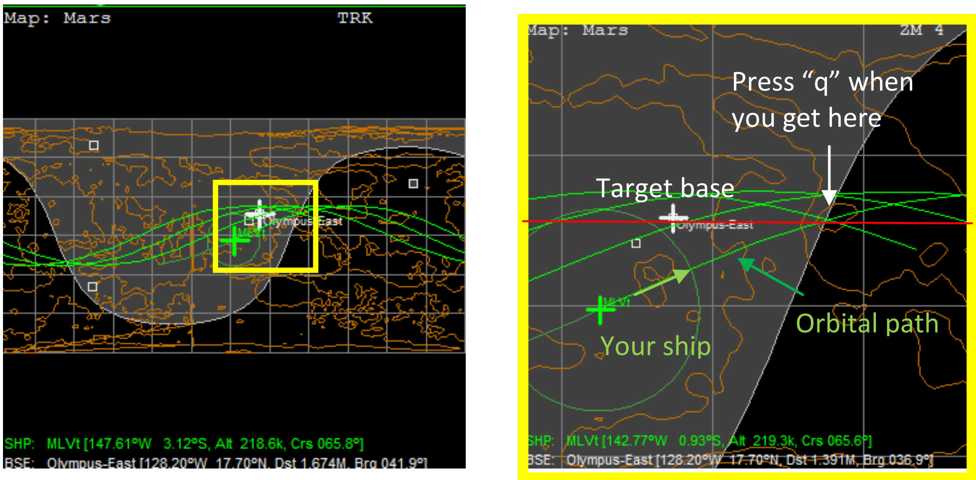


Figure 1 How to use Map MFD to engage the deorbit program. The left image is a screen capture of Map MFD. The right is the same image zoomed in so the details can be seen more clearly. Press "q" when you are at the same latitude as your target when you are at one orbit before you intent to path (and when Map MFD shows the next orbital path passing over your target).

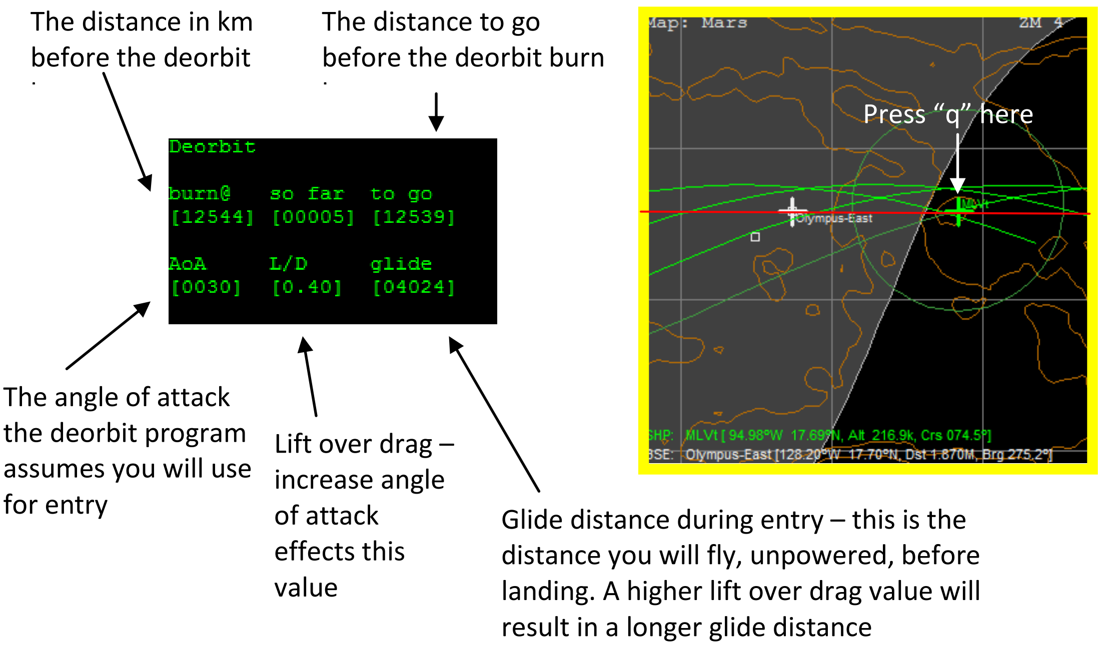


Figure 2 The deorbited program activated. The program information will be displayed on the HUD as shown on the left. On the right shows the moment when the deorbit program was started by **pressing “q”**. It is important to keep the program on or else the autopilot will not function correctly. Once the deorbit burn start the program will automatically turn off itself.

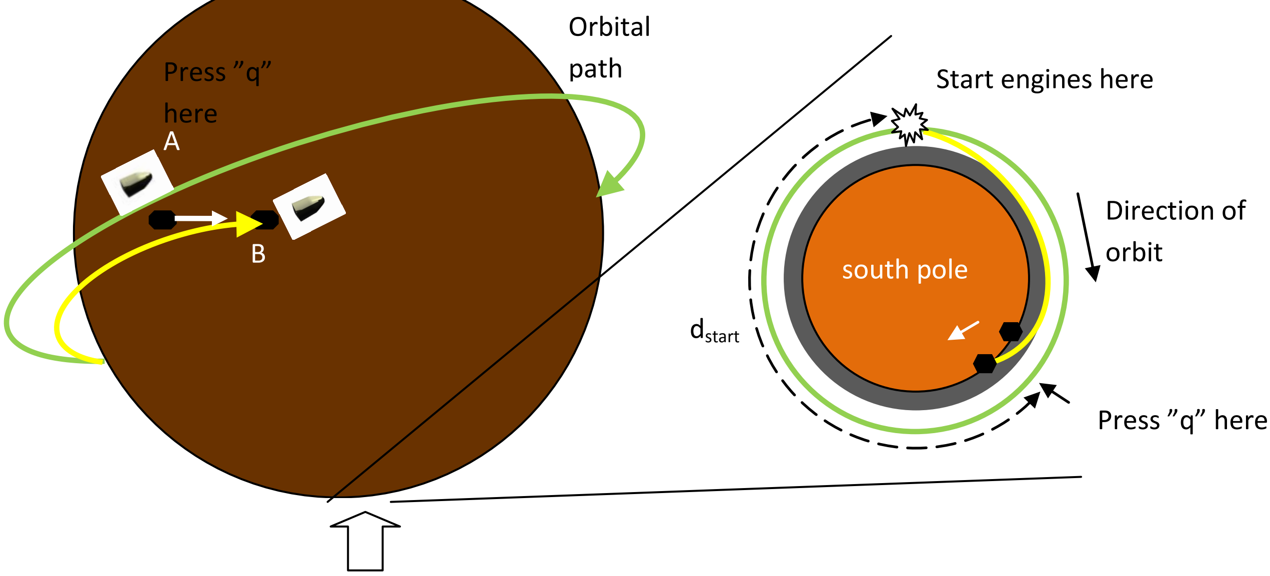


Figure 3 Deorbit path around planet. The black dot shows the motion of the target due to the planets rotation (shown with the white arrow). The diagram on the left shows a view of the path after deorbit (yellow line) around the planet from an angle. The diagram on the right shows a view of the deorbit path looking from below the planet. The distance, d_{start}, is the distance that the ship travels between activating the deorbit program and performing the deorbit burn.

10.2 Entry program

The entry program operates much the same as Aerobrake MFD which you may be familiar with or have heard about. However this program is based entirely on original computer code and takes into account the parachute deployment. As with Aerobrake MFD by changing the angle of attack of bank angle the predicted landing location will change and can be used for precision parachute deployment and landings. This information is used to fly the lander automatically, using the built-in programs, to minimise the predicted downrange and crossrange. Alternatively the programs can be stopped and the pilot can use the given information to fly to the target.

The entry computer uses the equations of motion and perturbations due aerodynamic forces to predict the landing location of the lander. It assumes the lander maintains a constant angle of attack. The pilot can vary the angle of attack during flight to modify the landing location. The altitude of the parachute deployment can also be changed to further modify the landing location. Adjusting the parachute deployment altitude is useful close to the target landing location as it has a greater effect on the distance travelled than the angle of attack. The effects on the trajectories are shown in figure 4.

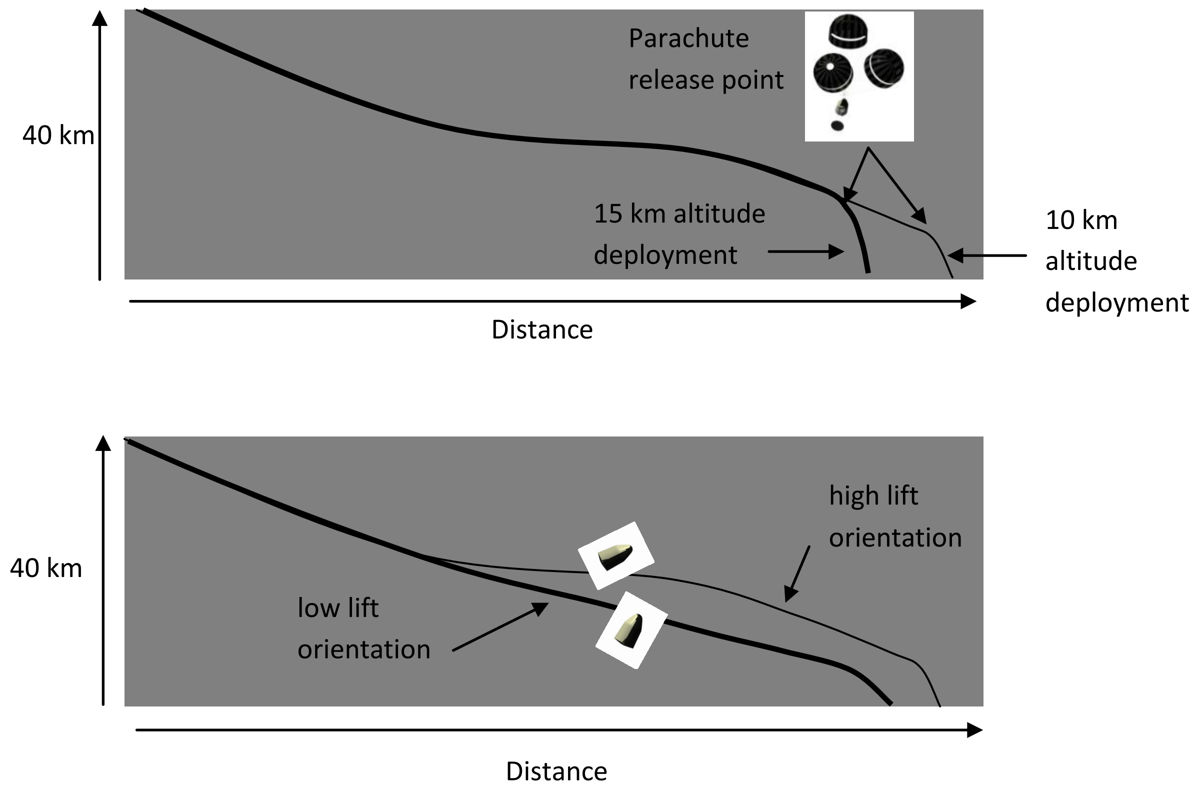
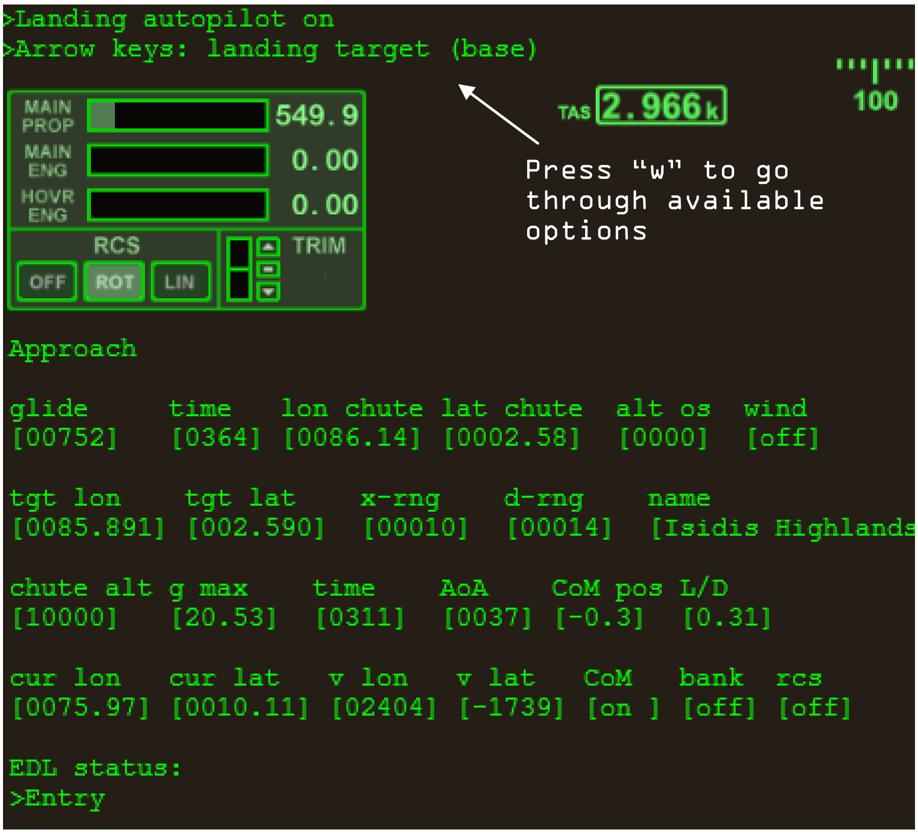


Figure 4 Effects of changing angle of attack and parachute deployment altitude on the trajectory. Top diagram shows the effect of deploying the parachute at different altitudes. The bottom diagram shows the effect of changing the angle of attack.

It is assumed that the lander is travelling with the lift vector pointing upwards i.e. bank angle is zero. It is possible to adjust the landing location by banking as well although this is not really required if the orbital path is lined up well with the base before the deorbit burn.

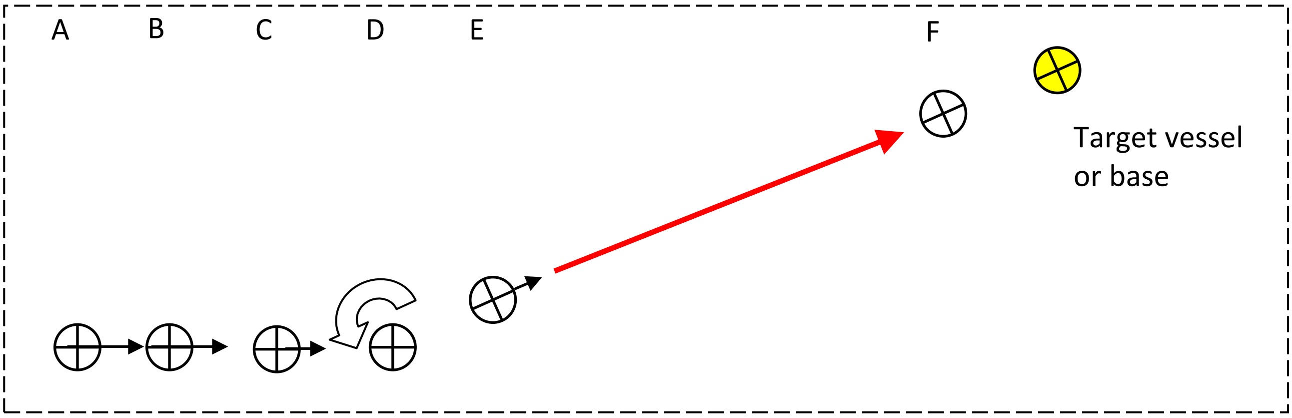
Figure 5 Explanations of the numbers on the HUD for the Approach phase of the landing.

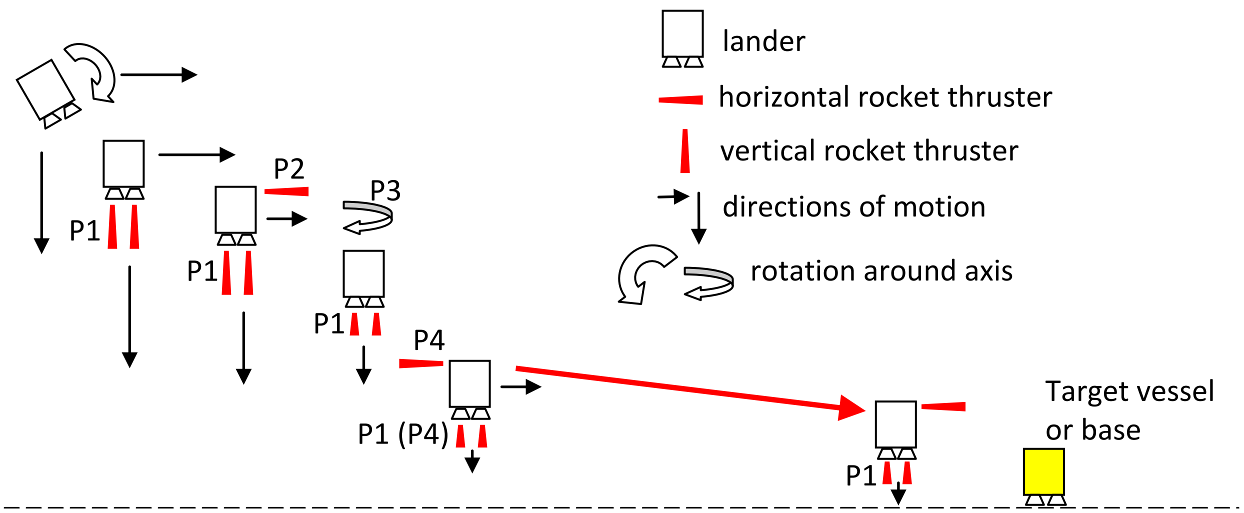
- Change the predicted longitude and latitude by either adjusting CoM or chute alt – **press "w"** and then use **arrow keys** to change them



10.3 Powered Descent programs

There are five programs (P1 to P4) that can be used in sequence to control the landing, either by the autopilot, or manually by the pilot. Below shows a schematic of how the autopilot controls the landing. After release the autopilot levels the lander with the horizon using Orbiter's built in attitude autopilot or "navigation tool". After the programs (P1, P2, P3, P4) are used to facilitate the landing. The descent programs are turned on by the autopilot using altitude data. The autopilot operates in 6 distinct stages (A to G) shown in the figure below.





P1 : program 1 controls rate of descent
P2 : program 2 reduces forward velocity to zero
P3 : program 3 turns lander to face target
P4 : program 4 moves lander toward target – feeds descent rate to P1

The powered descent landing stages are as follows:

A. Level the lander
B. Start descent engines (Program 1)
C. Reduce forward horizontal velocity to zero (Program 2)
D. Turn towards the target (Program 3)
E. Move towards the target (Program 4)
F. Reduce horizontal velocity to zero (Program 4) and land

10.4 Summary of events

- 200 km before scheduled deorbit burn the ship will be turned retrograde
- The main engines will be fired during the deorbit burn until the periapsis of the orbit is -20 km below surface of Mars
- At 120 km altitude the autopilot will prepare the ship for entry by turning it prograde using the Orbiter autopilot (or “navigation tool”)
- At 100 km the Orbiter prograde autopilot is turned off and the Orbiter hold level autopilot is turned on
- At 50 km altitude the Orbiter prograde autopilot is tuned off and the ship assumes an angle of attack of about 40 degrees
- At 12500 metres altitude (unless the parachute deployment altitude has changed) the ship will rotate performing a backflip ready to deploy parachutes
- At 10000 metres altitude the parachutes are deployed taking about 4 secounds to inflate with a maximum of about 20 g
- At 9000 metres the back plate is jettisoned
- At 4000 metres the lander is released
- At 3000 metres the lander landing gear is deployed
- At about 2500 metres the descent engines start
- The vertical and horizontal velocity is controlled for a soft landing less than 2 metres per second vertical velocity and less than 0.5 metres per second horizontal velocity less than 200 metres from the target

11. Orbital mechanics and aerodynamics

11.1 Deorbit burn location calculations

In the first estimate of the burn position the distance of entry altitude from base is calculated if burn is made at opposite side of planet. These first steps are calculated as follows:

I. Velocity at perihelion is

$$v_p = \sqrt{\frac{2GMr_a}{r_p(r_p+r_a)}}$$

where G is the gravitational constant, M is the mass of Mars, r_p, is the radius of periapsis, r_a, is the the radius of aposis.

II. The eccentricity is

$$e = \frac{r_p v_p^2}{GM} - 1$$

III. The true anomaly (angle from periapsis) is

$$\tau = acos\left[\frac{0.5(r_p+r_a)(1-e^2)}{er_{entry}} - \frac{1}{e}\right]$$

where r_{entry} is the radial position at predefined entry point (altitude = 120 km in this case).

IV. The distance along the ground from the entry altitude is

$$d_{free} = \tau r_{mars}$$

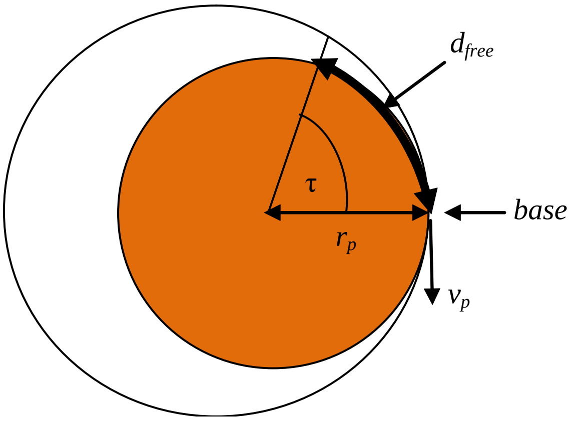


Figure 5 Diagram showing parameters used in the above calculations

Next the hypersonic glide distance during entry at a given angle of attack is calculated using a numerical solution to the equation of motions outlined in the following section. Figure 5 shows the distance of the path that is calculated numerically which is d_{glide}.

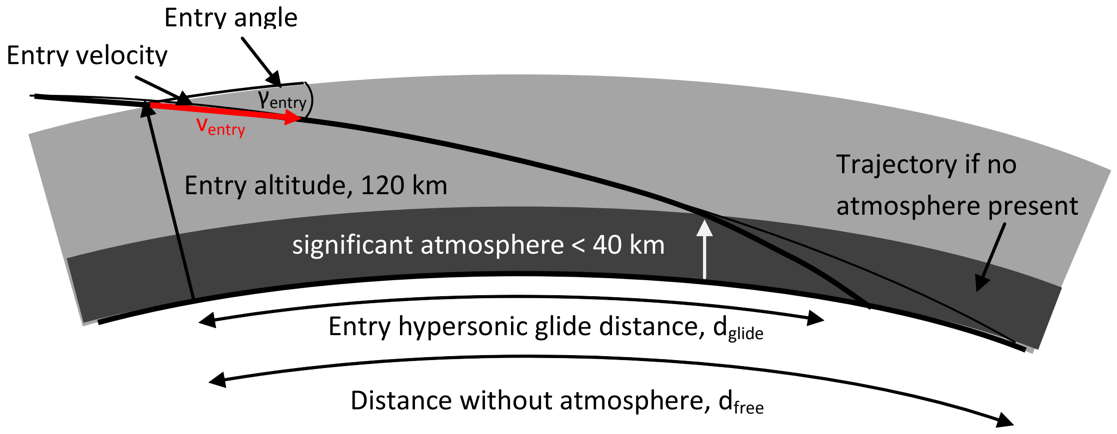


Figure 6 Diagram showing paths from the entry altitude with and without an atmosphere present.

The initial conditions that are given as input into this numerical routine are calculated in the following equation. It is assumed that the trajectory starts at a longitude and latitude of zero degrees and there is no rotation of the planet. The direction of travel is eastwards.

V. The angle if entry is

$$\gamma_{entry} = -atan\left[\frac{esin(\tau)}{1+ecos(\tau)}\right]$$

VI. The velocity at entry is

$$v_{entry} = \sqrt{\frac{0.5GM(r_p+r_a)(1-e^2)}{r_{entry}}}$$

VII. The radial and longitudinal velocity can be calculated as follows

$$v_r = v_{entry}sin(\gamma)$$

$$v_\theta = \frac{v_{entry}cos(\gamma)}{r}$$

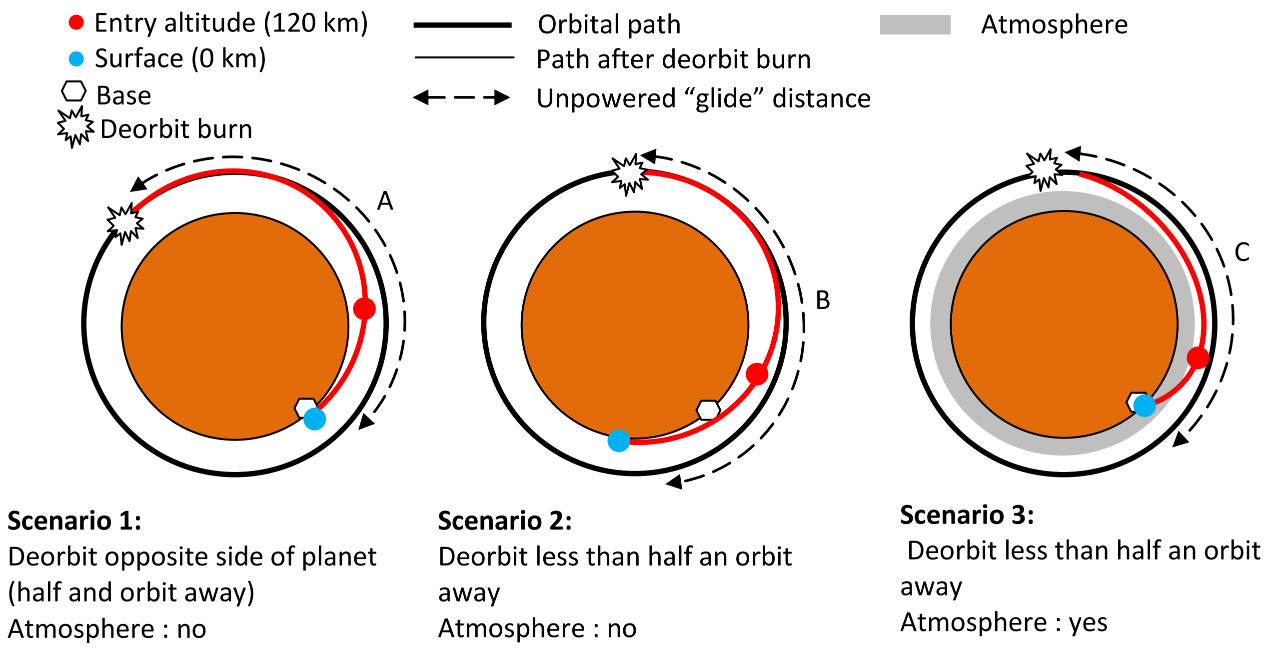


Figure 7 Diagram showing different deorbit scenarios for a planet without an atmosphere and a scenario used for calculating the deorbit location (scenario 3). Perspective is looking down at right angles to the orbital plane.

The distance of the burn from the base is then half the orbital path distance plus the distance calculated in step 1 minus the distance calculated in step 2

VIII. $d_{start} = \pi r_{Mars} + (d_{free} - d_{glide})$

11.2 Simulation of entry into the atmosphere

The coordinate system is base on a stationary equatorial frame of reference with its origin at the centre of Mars.

The frame of reference is stationary in inertial space i.e. it moves around the sun with Mars and its vertical axis is the same as the rotation axis of Mars but it does not rotate around the axis of Mars. The surface rotates around this axis and the longitude position relative to the surface has to be calculated separately.

Figure 8 shows the coordinate system for Mars. The three main spatial coordinates are longitude (θ), latitude (Ø) and radial distance from the centre (r). The heading (h) is the direction of travel relative to the vector pointing north from the current position.

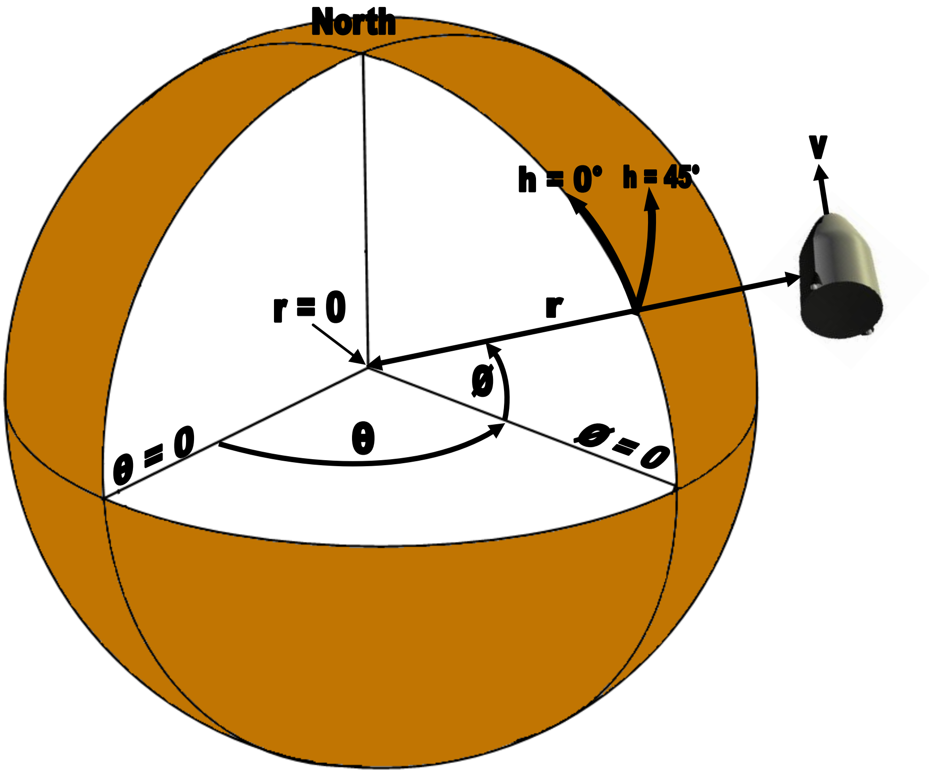


Figure 8 Diagram showing the coordinate system used to calculate the motion of the spacecraft.

The equations of motion are as follows:

$$\frac{\partial^2 r}{\partial t^2} = r\left(\frac{\partial\theta}{dt}\right)^2 (cos\emptyset)^2 + r\frac{\partial\emptyset}{\partial t} - \frac{GM}{r^2}$$

$$\frac{\partial^2 \theta}{\partial t^2} = 2\frac{\partial\theta}{\partial t}\frac{\partial\emptyset}{\partial t}\frac{sin\emptyset}{cos\emptyset} - \frac{2}{r}\frac{\partial r}{\partial t}\frac{\partial\theta}{\partial t}$$

$$\frac{\partial^2 \emptyset}{\partial t^2} = -\left(\frac{\partial\theta}{\partial t}\right)^2 cos\emptyset sin\emptyset - \frac{2}{r}\frac{\partial r}{\partial t}\frac{\partial\emptyset}{\partial t}$$

r is the radial distance from the centre of Mars

θ is the longitude
Ø is the latitude
γ is the flight path angle
h is heading
D is the drag force
L is the lift force
m is the mass
t is time

Motion through an atmosphere of a lifting body such as a capsule or shuttle type vehicle will generate lift forces when its undersurface (capsule heat shield or shuttle belly and wings) is at an angle to the oncoming flow. The impacting atmospheric molecules will transfer their momentum to the lifting body generating forces that cause lift, normal (90 degrees) to the direction of travel, and drag, opposite to the direction of motion.

The amount of lift and drag can be varied by changing the angle of attack (AoA) with the oncoming flow. Starting from an angle of 0° AoA with the nose into the flow no lift will be generated for a biconic lifting body as used for this project. As the AoA is increased the lift forces will increase as a greater surface area is presented to the flow. At the same time the drag forces will also increase. This is because both drag and lift forces are dependant on the surface area. The ratio of the lift to drag force (L/D) will first increase with increasing AoA up to about 30°, while the lift forces are dominating, and then decrease as the drag forces begin to dominate.

Figure 9 shows the essential parameters for modeling the motion of the vehicle through the atmosphere. The flight path angle (γ) is the angle between the velocity vector (direction of motion) and the horizon. The angle of attack (α) is the angle between the long axis, in this case the direction the nose is pointing, and the velocity vector. Normally the angle of attack will remain constant for extended periods of time while the flight path angle will vary as aerodynamic forces effect its motion.

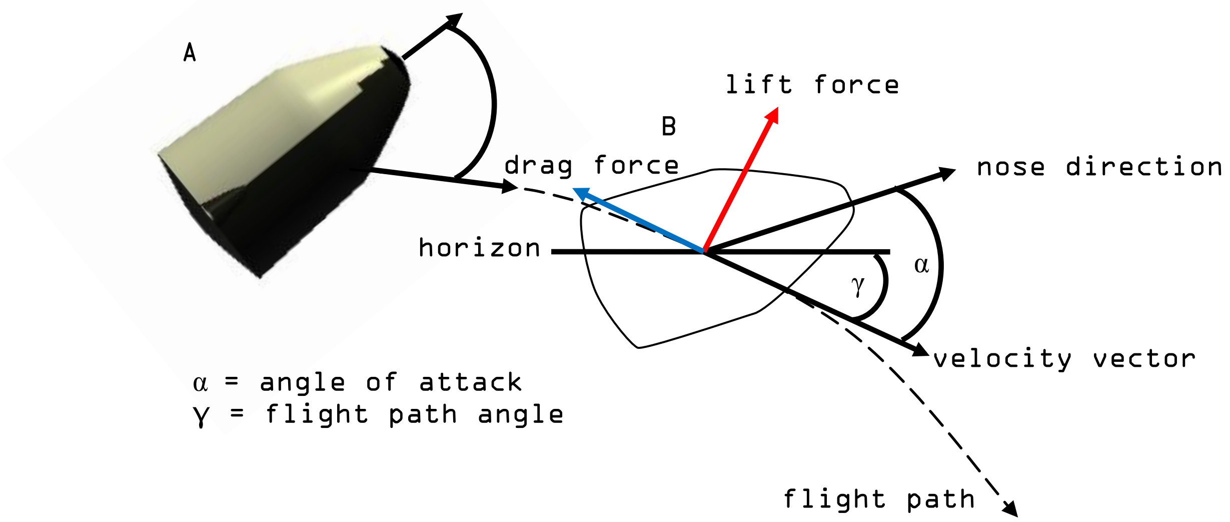


Figure 9 Essential parameters for calculating the path of a lifting body through the atmosphere.

The equations used to calculate the lift and drag forces are:

$L = 0.5 C_L \rho A v^2$

$D = 0.5 C_D \rho A v^2$

where C_L is the lift coefficient, C_D is the drag coefficient, ρ is the density of the local atmosphere, A is the reference area and v is the velocity. The lift and drag coefficients can be measured directly in a wind tunnel or calculated using a model. These coefficients describe the airflow around the vehicle and are dependent on the angle of attack. The figures below show what these look like for a biconic aeroshell used in this case.

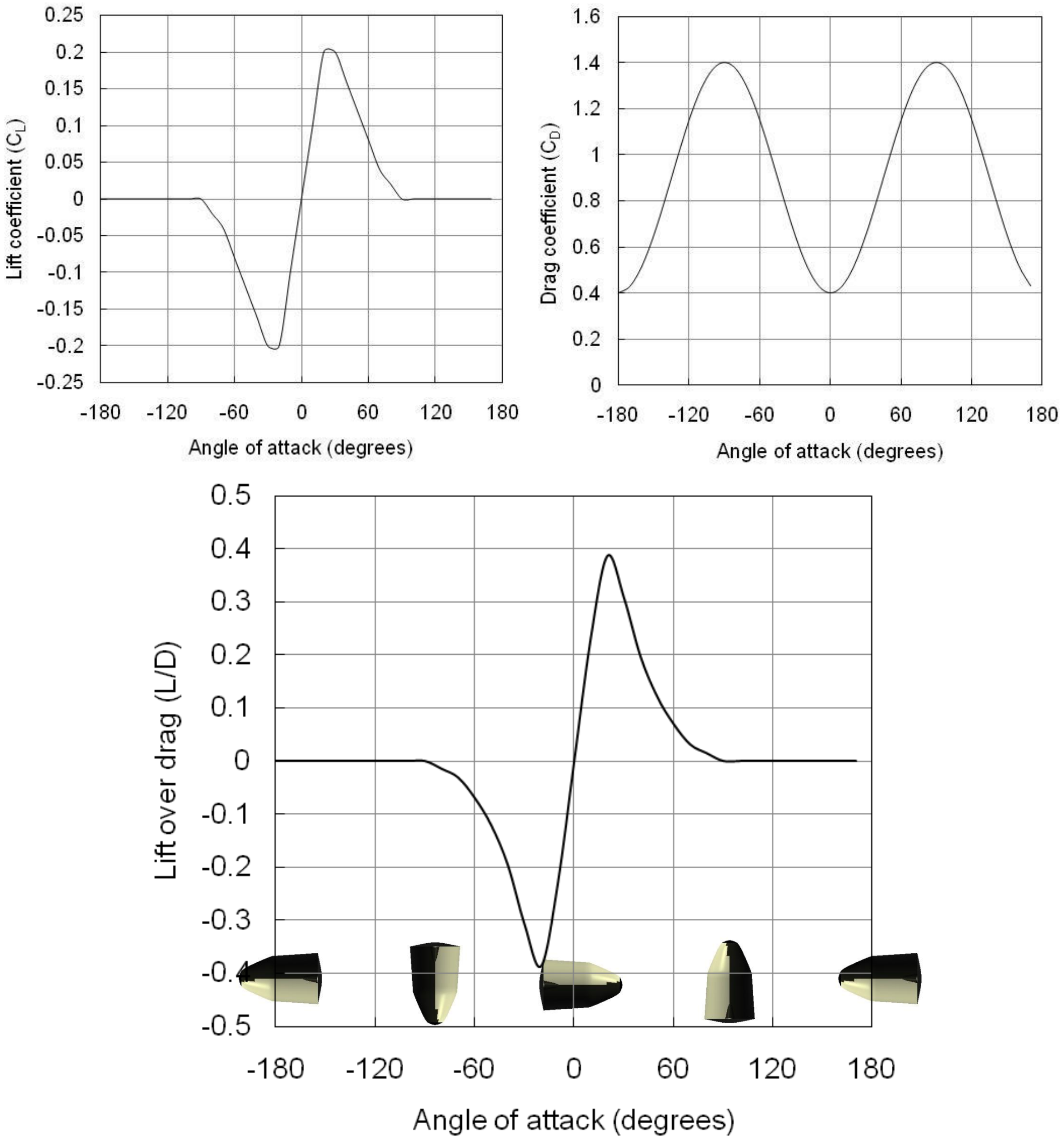


Figure 10 Aerodynamic properties of the lander aeroshell. These have been guesstimated from published information. It is assumed no lift is produced when the aeroshell has flipped over to keep things simple. On the bottom chart is shown the angle of attack using a rendering of the aeroshell. The flow is in the direction of left to right.

The local atmospheric density can be calculated with varying level of complexity depending on the accuracy required. At the moment the autopilot uses an exponential relationship that matches the density in Orbiter's atmosphere quite well. The atmosphere is defined as follows:

$$\rho = exp(-z/H)$$

where z is the altitude in metres and H is the scale height in metres. This has a value of 10000 for this model of the Martian atmosphere. The area is calculated from the cross-sectional area of the biconic when it is at an angle of attack of 90 degrees to the flow. This is roughly the length multiplied by the width which works out to be about 110 m^2. The velocity of the air past the biconic is little complicated as the rotation of the atmosphere with the planet needs to be considered. First of all the inertial velocity components of the spacecraft are considered.

Radial velocity : $v_r = \frac{dr}{dt}$

Longitudinal velocity : $v_\theta = r\left(\frac{\partial\theta}{\partial t} - \Omega\right)cos\emptyset$

Lateral velocity : $v_\emptyset = r\frac{\partial\emptyset}{\partial t}$

where Ω is the angular velocity of Mars (0.00007078 radians s^{-1}). The velocity for the drag and lift equations, v, can be calculated as follows:

$$v = \sqrt{v_r^2 + v_t^2 + v_p^2}$$

The equations of motion can then be updated by the accelerations due to the aerodynamic forces as follows:

$$\frac{\partial^2 r}{\partial t^2} = r\left(\frac{\partial\theta}{dt}\right)^2(cos\emptyset)^2 + r\frac{\partial\emptyset}{\partial t} - \frac{GM}{r^2} - \frac{D}{m}sin\gamma + \frac{L}{m}cos\gamma$$

$$\frac{\partial^2\theta}{\partial t^2} = 2\frac{\partial\theta}{\partial t}\frac{\partial\emptyset}{\partial t}\frac{sin\emptyset}{cos\emptyset} - \frac{2}{r}\frac{\partial r}{\partial t}\frac{\partial\theta}{\partial t} - \frac{D}{m}\frac{cos\gamma sinh}{rcos\emptyset} - \frac{L}{m}\frac{sin\gamma cosh}{rcos\emptyset}$$

$$\frac{\partial^2\emptyset}{\partial t^2} = -\left(\frac{\partial\theta}{\partial t}\right)^2 cos\emptyset sin\emptyset - \frac{2}{r}\frac{\partial r}{\partial t}\frac{\partial\emptyset}{\partial t} - \frac{D}{m}\frac{cos\gamma cosh}{r} - \frac{L}{m}\frac{sin\gamma sinh}{r}$$

where h is the heading. The heading is computed from the following code (recommend doing a bit of research on the internet to understand a bit more about its use):

```
h_x=atan2(sin(p2-oldp2)*cos(p3),cos(oldp3)*sin(p3)-sin(oldp3)*cos(p3)*cos(p2-oldp2));
h_y=2.0*PI;
h=h_x-int(h_x/h_y)*h_y;
```

The velocity and position can then be calculated using a numerical integration technique. The most basic being the Euler explicit method demonstrated here. The velocity is calculated as follows:

$$\left(\frac{\partial r}{\partial t}\right)_t = \left(\frac{\partial r}{\partial t}\right)_{t-\delta t} + \left(\frac{\partial^2 r}{\partial t^2}\right)_{t-\delta t}\delta t$$

$$\left(\frac{\partial\theta}{\partial t}\right)_t = \left(\frac{\partial\theta}{\partial t}\right)_{t-\delta t} + \left(\frac{\partial^2\theta}{\partial t^2}\right)_{t-\delta t}\delta t$$

$$\left(\frac{\partial\emptyset}{\partial t}\right)_t = \left(\frac{\partial\emptyset}{\partial t}\right)_{t-\delta t} + \left(\frac{\partial^2\emptyset}{\partial t^2}\right)_{t-\delta t}\delta t$$

The position is then calculated as follows:

$$r_t = r_{t-\delta t} + \left(\frac{\partial r}{\partial t}\right)_{t-\delta t}\delta t$$

$$\theta_t = \theta_{t-\delta t} + \left(\frac{\partial\theta}{\partial t}\right)_{t-\delta t}\delta t$$

$$\emptyset_t = \emptyset_{t-\delta t} + \left(\frac{\partial\emptyset}{\partial t}\right)_{t-\delta t}\delta t$$

where δt is the numerical time step, t subscript refers to values at the current time step, t-δt subscript refers to values from the previous time step calculations. A more accurate method would be to use the leapfrog method or a Runga-Kutta method (e.g. RK4).

The initial conditions are obtained from Orbiter using the routine GetEquPos(θ,∅,r) for position and GetHorizonAirspeedVector(_V(v_θ,v_r,$v_\emptyset$)). where _V( ) refers to a vector quantity in the code. The values obtained from the GetHorizonAirspeedVector routine are in local horizon coordinates and have to be converted into angular quantities in the working stationary equatorial frame of reference.

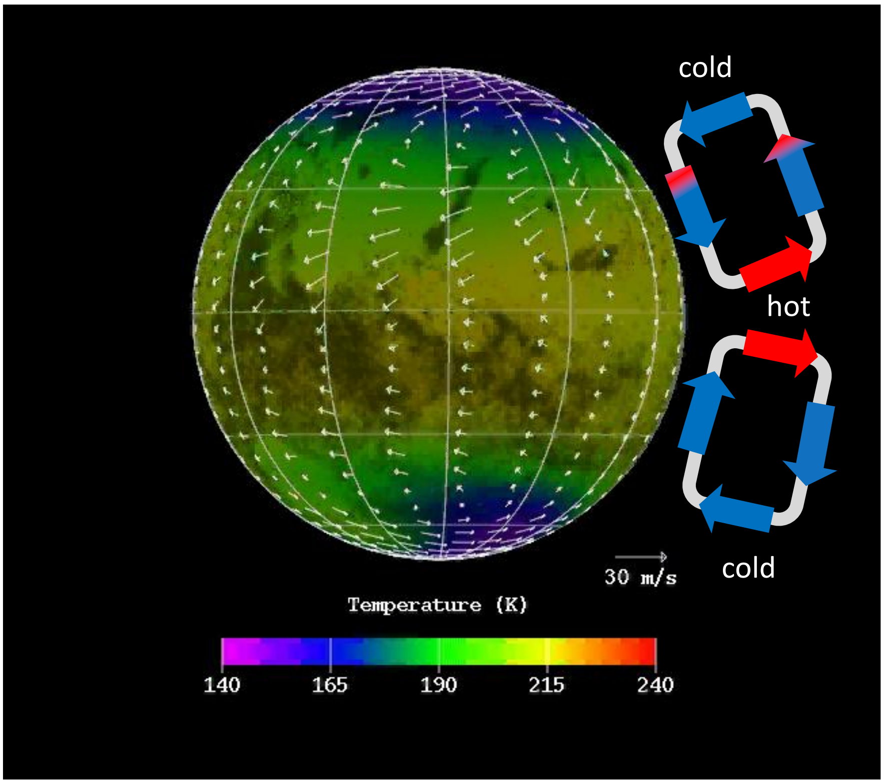
$$\frac{\partial\theta}{\partial t} = \frac{\frac{v_r}{r}+\Omega}{cos\emptyset}$$

$$\frac{\partial\emptyset}{\partial t} = \frac{v_t}{r}$$

12. Mars climate and the balloons

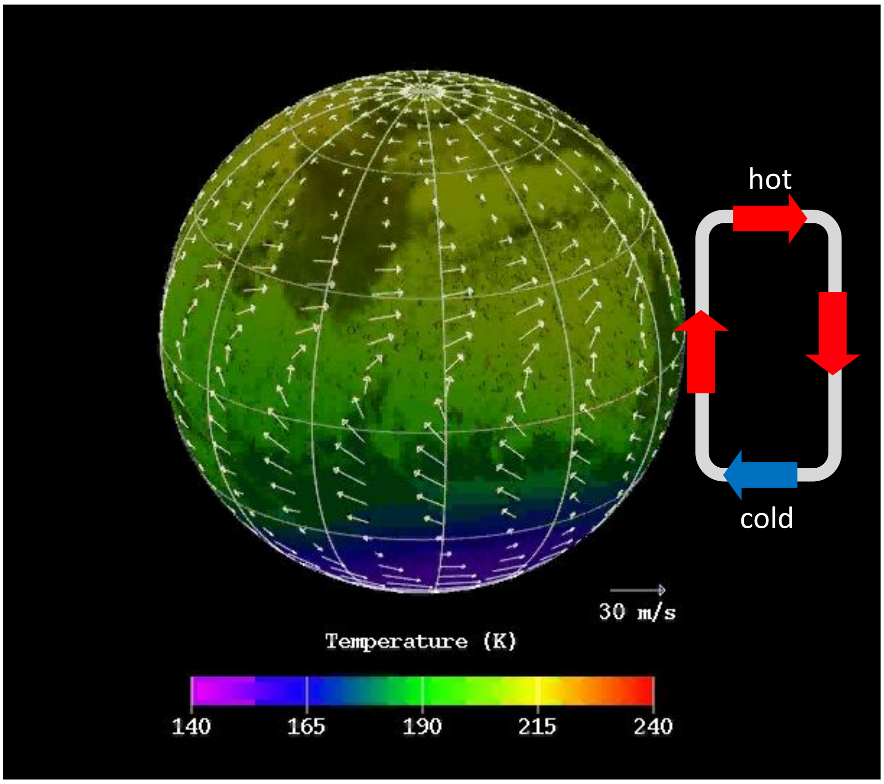
Even though the Martian atmosphere at the surface is 100x less dense than on Earth it is still thick enough to generate significant forces on “lightweight” objects. These are objects that have a high ratio of surface area to mass such as balloons and spacecraft that have deployed their parachutes. Mars has similar cycle of seasons to the Earth due to the nearly identical axial tilt relative to its orbital plane.

The circulation of the atmosphere and wind patterns can also follow a similar pattern to that on Earth. For example both Mars and Earth climates feature Hadley cells in each hemisphere. This is due to hot air rising at the equator and then descending in the cooler northerly latitudes to return to the equator along the surface. The north-south movement of the atmosphere coupled together with the rotation of the planet then causes the winds to appear as if they are coming from a easterly direction.



At the equinoxes the maximal heating occurs at the subsolar point (point with the surface at right angles to the sun’s rays). Therefore the upwelling of heat is at the equator. However as the seasons progress the subsolar point moves into either the northern or southern hemisphere. For example, after northern hemisphere spring, the subsolar point will move into the northern hemisphere reaching higher and higher latitudes until midsummer solstice where it will migrate down to the equator again.

As the northern hemisphere summer approaches the northern Hadley cell will decrease in size until it vanishes and only one cell survives that straddles the equator by the time the summer solstice is reached. At this time the upwelling will be in the northern hemisphere and the downwelling will be in the southern, winter, hemisphere as shown in the figure below. After the northern summer the northern cell will start to grow and the larger cell across the equator will reduce in size and migrate back down into the southern hemisphere. As southern hemisphere summer approaches the southern hemisphere cell will reduce in size and then it will be the turn of the northern hemisphere to grow and straddle the equator. As the southern hemisphere passes then the cell at the equator will move back into the northern hemisphere and the cell will reappear in the southern hemisphere and start growing. Close northern hemisphere spring and southern hemisphere autumn each hemisphere will have cells of roughly equal size. The cycle then repeats. On Earth the Hadley cells do not shrink and grow to such an effect because there is the moderating effect of the ocean.



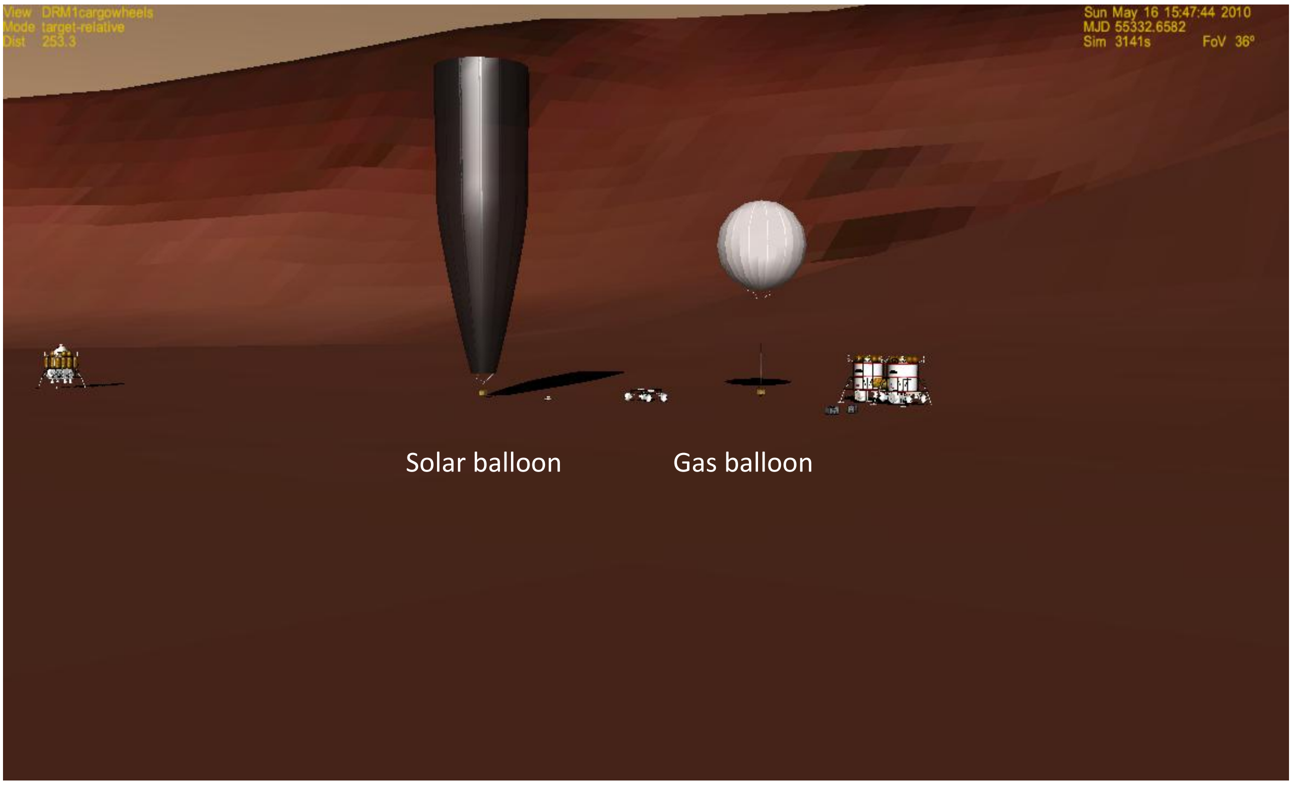
The model of the winds being developed for this addon are based on the longitudinal component (west-east) found in a presentation by Prof. Peter L Read www.atm.ox.ac.uk/user/read/DPA/DPA1.pdf

The south-north component is a combination of guesswork and information on the direction of the surface winds found on the Mars Today website http://humbabe.arc.nasa.gov/

12.1 Balloons

Two types of balloons are included that can be used to explore the structure of the winds on Mars. A solar balloon is included which is a type of hot air balloon that used solar radiation to provide the heat. To achieve lift it can only fly in the daytime so you need to wait until late morning to make your flight. The other balloon is a hydrogen balloon that can fly any time of the day.

The idea of including the balloons in the addon is that eventually these can be used to plan landings. Knowledge of the winds will be (probably) required to prevent the lander with parachutes being blown of course and also determine if the parachutes will collide with the lander once it is released. The balloons are also a fun way to fly over the Martian terrain and explore.



Solar balloon operation:

Press “1” to display wind and other information on the HUD
Press “2” to launch the balloon (when buoyancy force > weight)
Press “3” to open and close the vent (useful for changing altitude)

Gas balloon operation:

Press “1” to display wind and other information on the HUD
Press “2” to launch

13. Updates

Updates for this version

> revamped tel-operated rover to deploy sounding rocket for weather investigations

> Earth Return Vehicle added with basic functionality (engines, solar panel animation, Ummu)

> NTR propulsion stages, again with basic functionality, to trnasfer the landers and ERV to Mars

> Added the option of combining the NTR and landers as one vessel (useful for launches and easier rcs control

> Added breathable greenhouse

> Updated mesh for aeroshells and added rcs flames

> Option to add wind forces onto parachutes

> Added autopilots for the hypersonic approach phase to null crossrange and downrange of the predicted parachute deployment

Planned updates for next version

>> Improve precision of deorbit autopilot

>> Add DRM1 launcher

>> Internal meshes for habitats and capsule

>> Panels

14. Links

A couple of links to related add-ons

Wishbone's NTR core propulsion stage. Under development but essentially working. Keep up to date with developments here: http://www.orbithangar.com/searchid.php?ID=5215

80mileshigh Russian Mars Transfer Vehicle:
http://www.orbithangar.com/searchid.php?ID=4562

Sputnik's Velcro Rockets
http://orbithangar.com/searchid.php?ID=3388

Interplanetary MFD
http://orbithangar.com/searchid.php?ID=1844

Aerobrake MFD
http://orbithangar.com/searchid.php?ID=2139

15. Credits & acknowledgements

Credits

Mark Paton : Lander meshes and dll programming.

Wishbone : Surface fission reactor mesh and Olympus-East base.

Daniel Polli : UMmu code

Acknowledgements

Mike Blackstone : Testing of an early version of the add-on.

Bruce Irving : Inspiration from the virtual prototyping project of Mars for Less back in 2006 and more recently from involvement with the Go Play in Space tutorial.

On the Orbiter Forum : Thanks for all the useful comments and encouragments from members of the Orbiter forum that have improved this addon. http://orbiter-forum.com/showthread.php?t=21972
