Landing humans on Mars:

```
ENTRY, DESCENT AND LANDING
Mark Paton 16.01.07

MTSV for Irving et al. (2006)


    Planet mass Ae+B (kg)............
    Planet radius (m)................
    Lander area (m2).................
    Lander mass (kg).................
    Lander fuel (kg).................
    Lander thrust (N)................
    Lander isp (s^-1)................
    Lander rocket descent altitude st
    Lander target touchdown speed (m/
    Shield area (m2).................
    Shield mass (kg).................
    Shield L/D.......................
    Shield angle of attack for L/D...
    Shield nose radius (m)...........
    Shield release event.............
    Shield release time (s)..........
    First chute area (m2)............
    First chute mass (kg)............
    First chute deploy speed (m/s)...
    Second chute area (m2)...........
    Second chute mass (kg)...........
    Second chute deploy speed (m/s)..
    Second chute release altitude (m)
    TOTAL MASS AT ENTRY (kg).........
    Entry speed (m/s)................
    Entry angle (deg)................
    Entry height (m).................
    Maximum simulation time (big time
    Time step size for trajectory cal
    Do you want data saved?..........
    Specific heat ratio..............
    Atmosphere gas constant..........
       Upper limit of atmosphere sect
    L  0.............................
    L  1.............................
    L  2.............................
    L  3.............................
    L  4.............................
    L  5.............................
    L  6.............................
    L  7.............................
    L  8.............................
    L  9.............................
    L  10............................
    L  11............................
    L  12............................
    L  13............................
    L  14............................
    L  15............................
    L  16............................
    L  17............................
    L  18............................
    L  19............................
    L  20............................
    L  21............................
```

Mark Paton

Finnish Meteorological Institute

ILMATIETEEN LAITOS

www.fmi.fi/research_space/space.html

Virtual prototyping of a piloted Mars lander

ISDC Dallas 2007

Landing humans on Mars:

Virtual prototyping of a piloted Mars lander

A. Piloted Landers 1950s onwards

B. Tools for virtual prototyping
   1. Mars Local-Area Model (MLAM)
   2. Aerobrake 2D (A2D)
   3. The Orbiter space flight simulator (Orbiter)

C. A piloted Mars Lander
   1. Virtual prototyping the mission (Orbiter)
   2. EDL system design (A2D / Orbiter)
   3. The effect of Mars winds (A2D / MLAM)

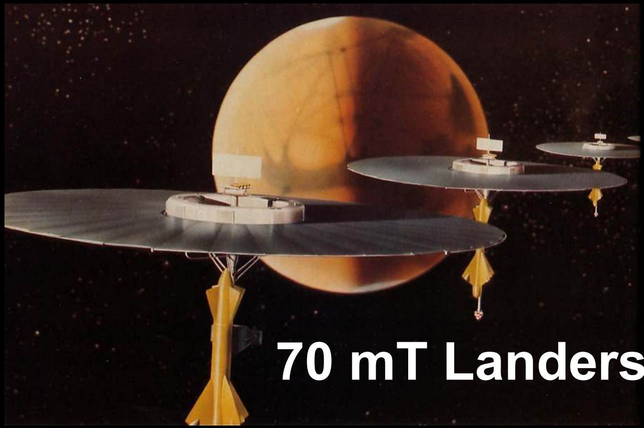
Also see Irving et al. (2006)

NEW!

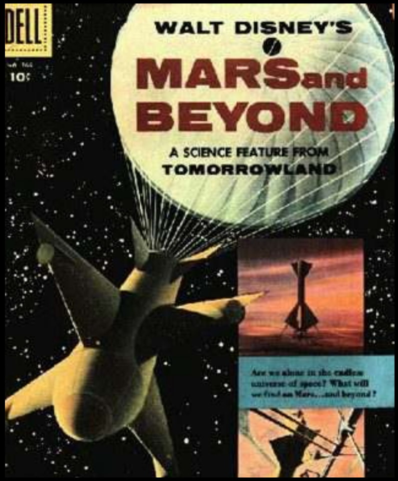
A. Piloted Landers 1950s onwards

Landing on Mars 1950s style: Thinking big!

Stuhlinger (1954)



70 mT Landers



Disney

Parachutes and retro rockets

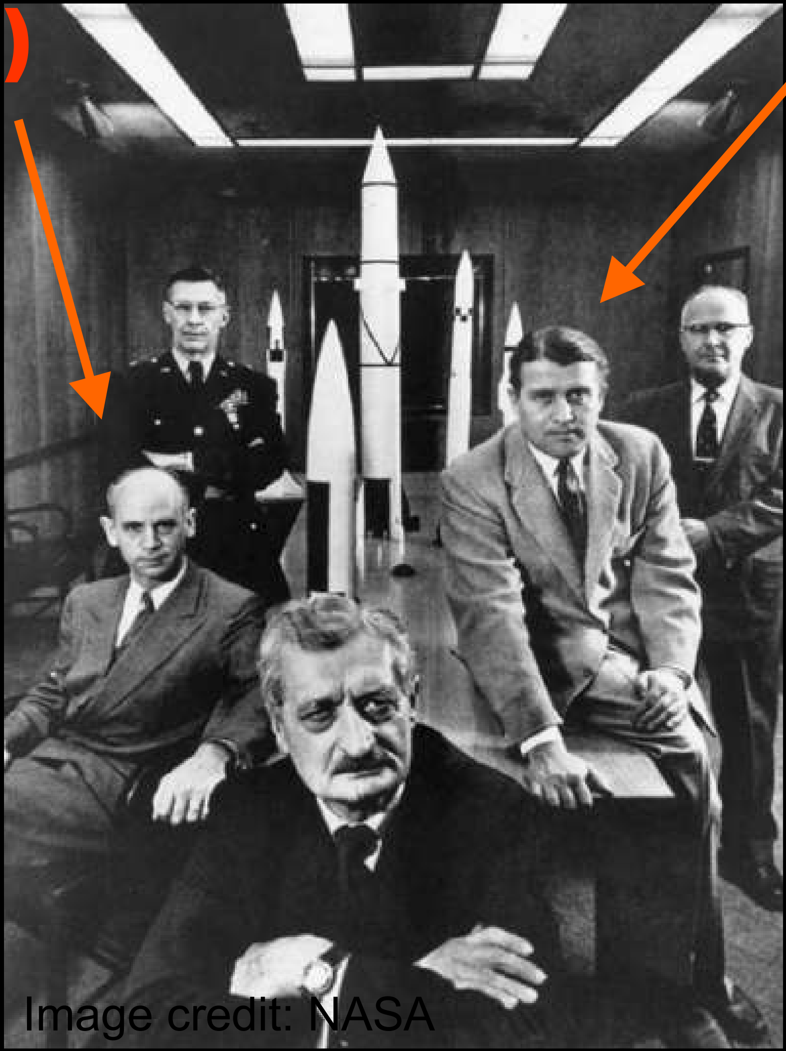


Image credit: NASA

Braun (1952)

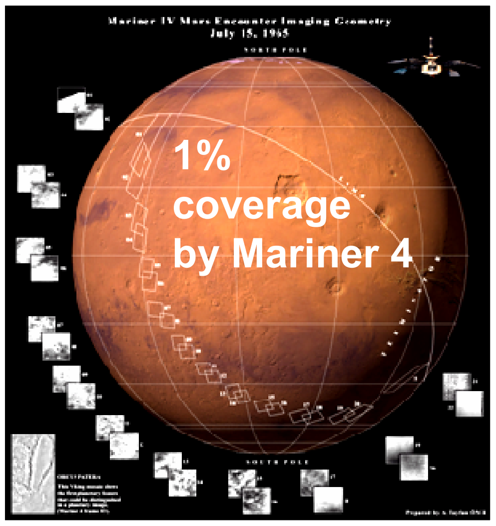
177 mT Gliders

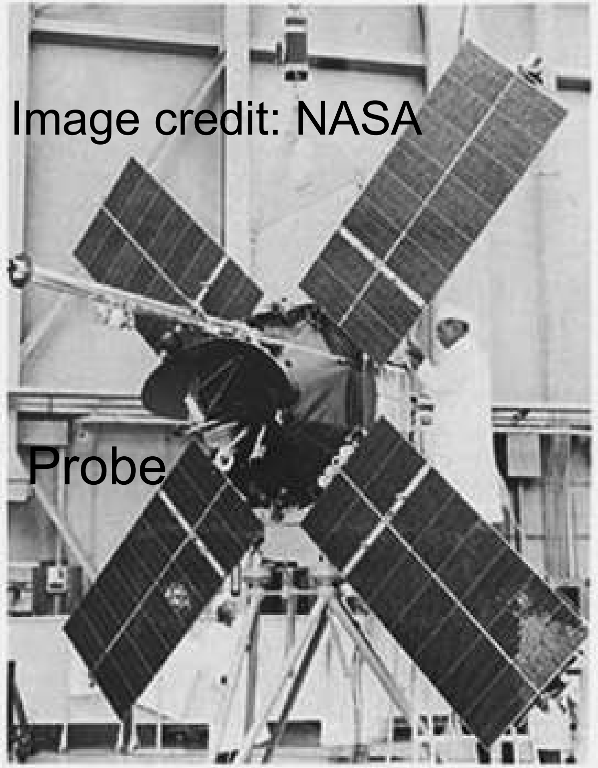
Reach half-way around Mars!

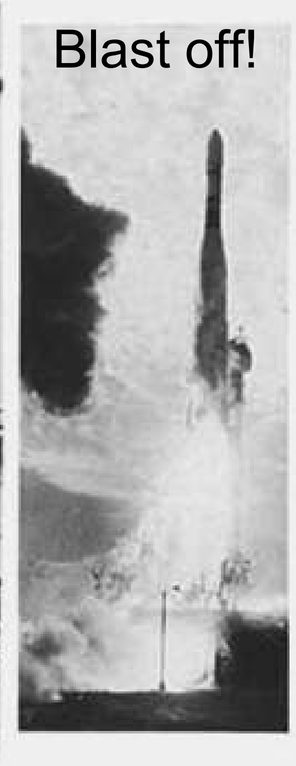
Paintings by Chesley Bonestell

Surface pressure of Mars was thought to be 10x higher than that measured by Viking in the 1970s. Braun's gliders are too small. Stuhlinger's approach resembles more recent Lander designs.

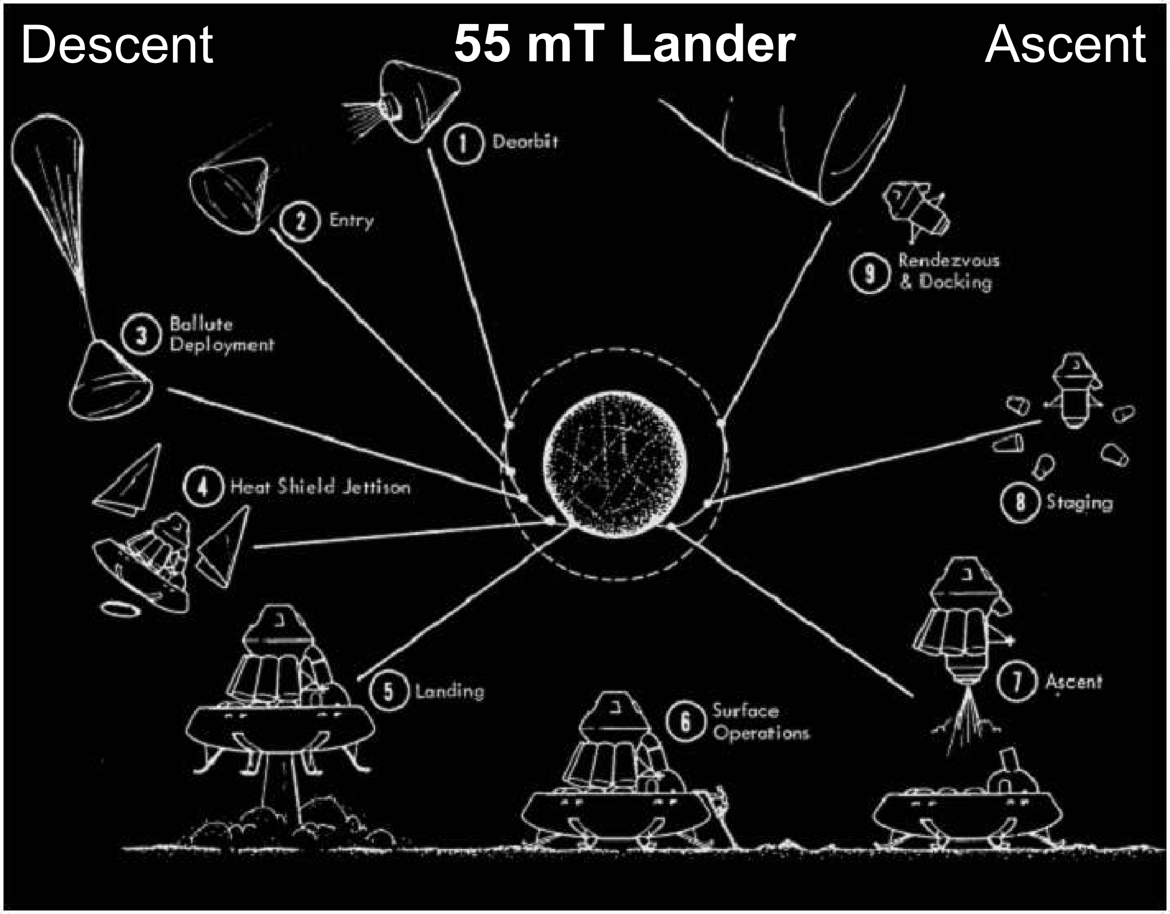
Mission planning 1960s: Rise of the robots







Mariner 4 (1964)



Boeing Company (1968)

In 1965 Mariner 4 measured the density of the Martian atmosphere and found it to be 100x less dense than Earth. These findings were used in the design of a Lander (by North American Rockwell) for the Boeing 1968 study.

Mission plannings 1970s/1980s: The case for Mars

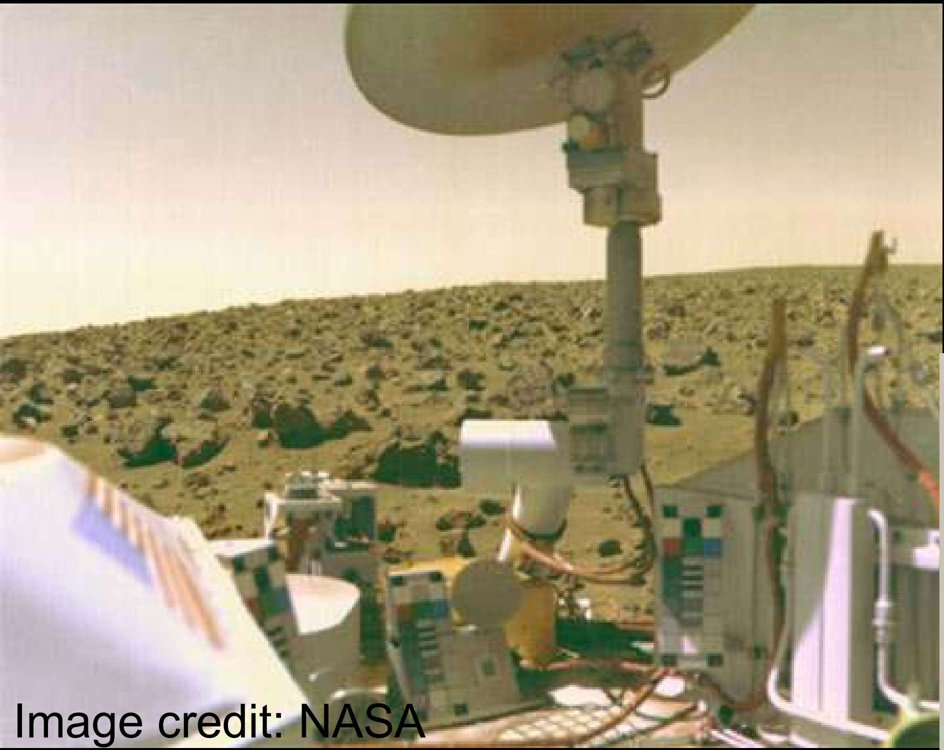


Image credit: NASA

Viking (1976)

Viking 1 & 2 analysed the composition of the Martian environment and found it to be rich in resources.

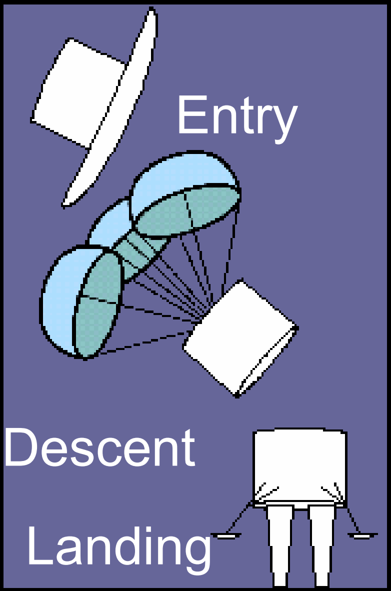
CfM II plans for a permanent Martian base using cyclers and reusable shuttles. Refueling using In-situ Resource Utilization (ISRU).

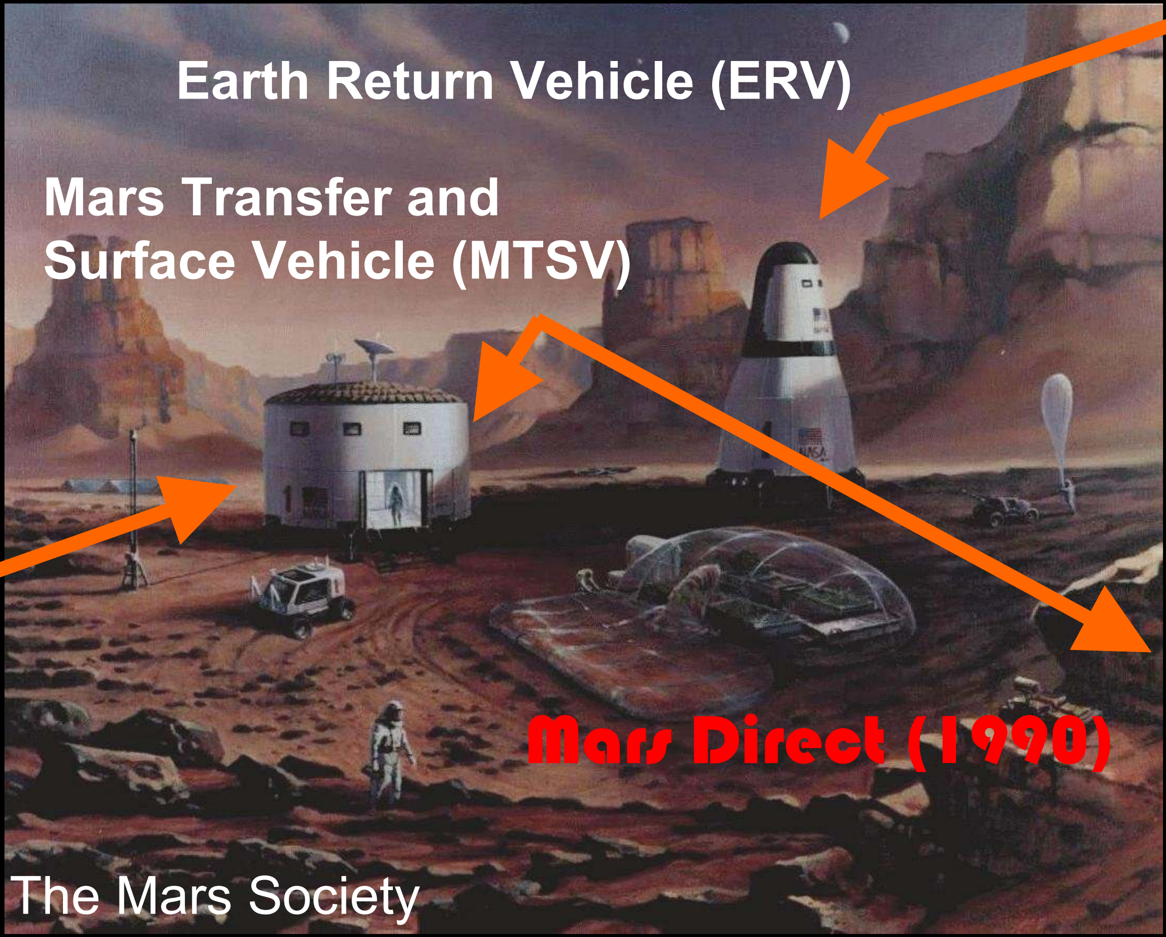
The Case for Mars II (1984)

Painting by Carter Emmart

Mission planning 1990s: Reference Missions

Blunt body EDL?





Earth Return Vehicle (ERV)

Mars Transfer and Surface Vehicle (MTSV)

Mars Direct (1990)

The Mars Society

Many approaches to landing on Mars. Direct to Mars, Earth orbit assembly, direct entry, entry from orbit (aerocapture or propulsive?), ISRU, Earth return from Mars surface of Mars orbit? Nuclear propulsion? A question of mass? What is the mass of the EDLS? EDLS is an unknown…….

ERV stays in orbit

Drake, B. G. (Editor), 1998, Reference Mission 3.0

NASA DRM 3.0 (1998)

EDL?

Mass?

Slender body

Mission planning in the naughties: Starting the simulation

Mars Desert Research Station **All Terrain Vehicles for exploring**

The Mars Society has two operation analogue stations, F-MARS and MDRS (shown here). The aim of these stations is to optimise the productive exploration of Mars by humans. Conduct useful field research to understand geology, biology and environmental conditions on Earth and on Mars. Generate public support for sending humans to Mars. These stations can also help to define the mass requirement for a surface mission (i.e the payload….the Lander).

Images from Merikallio, S., 2003, Simulating Mars: The Mars Desert Research Station

Section A: conclusions + new questions

- Early Mars Lander design were heavily influenced by our knowledge of the Mars atmopshere. Landers only stayed on the surface for a short time.
- These days missions designs for landing humans on Mars are dependant on ISRU. The drive for cost effectiveness dictates long stays on the surface.
- There are a number of EDLS proposed to get humans onto the surface and have not been fully described. All require landing large mass and pin-point targeting.
- Work is ongoing to define the surface mission with analogue simulations but what about the design of Entry, Descent and Landing systems to get there in the first place?
- EDL systems are being investigated by several workers e.g. Braun et al.

Question 1

What about integrating the Lander and EDLS with the rest of the mission? How useful is virtual prototyping (experimenting using computer simulations)?

Question 2

What about realistic EDL scenarios for piloted Landers? What can that tell us? Poorly understood Martian weather (dust storms) plays havoc with Lander EDLS……..what simple but practical investigations can be made to begin to understand Martian weather?

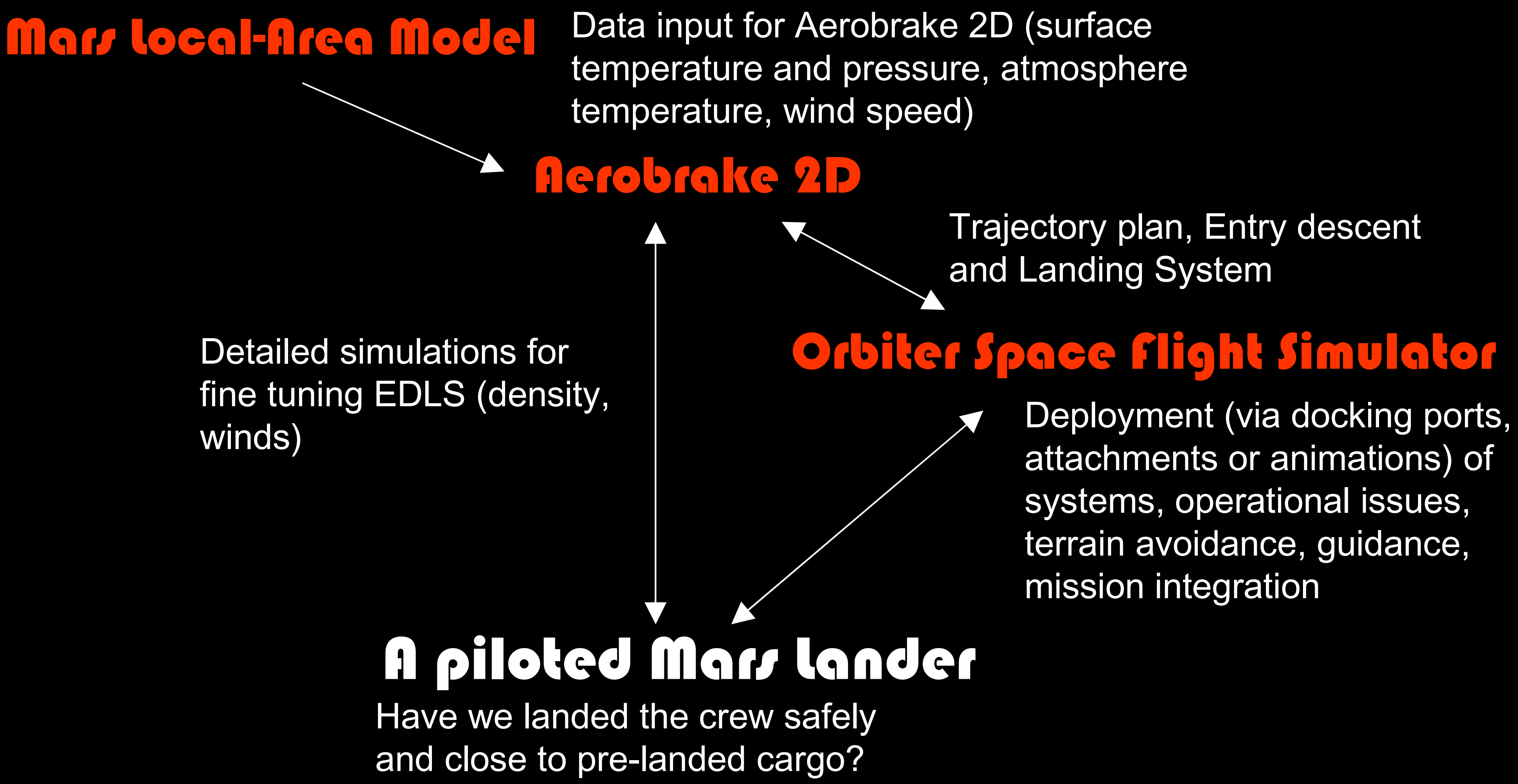
B. Tools for virtual prototyping

What is virtual prototyping?

- Firstly a virtual prototype is a computer simulation of a system with a degree of functional realism. Here the system(s) are those of the Mars Lander (heat shield, parachutes etc).
- Virtual prototyping is the process of using this prototype for test and evaluation of specific characteristics of a design. In this case it is landing on Mars!
- Virtual prototyping can, to varying degrees, replace costly and time consuming real world tests

Virtual prototyping tools

Results and feedback flow diagram



Mars Local-Area Model

Data input for Aerobrake 2D (surface temperature and pressure, atmosphere temperature, wind speed)

Aerobrake 2D

Trajectory plan, Entry descent and Landing System

Orbiter Space Flight Simulator

Detailed simulations for fine tuning EDLS (density, winds)

Deployment (via docking ports, attachments or animations) of systems, operational issues, terrain avoidance, guidance, mission integration

A piloted Mars Lander

Have we landed the crew safely and close to pre-landed cargo?

University of Helsinki and the Finnish Meteorological Institute

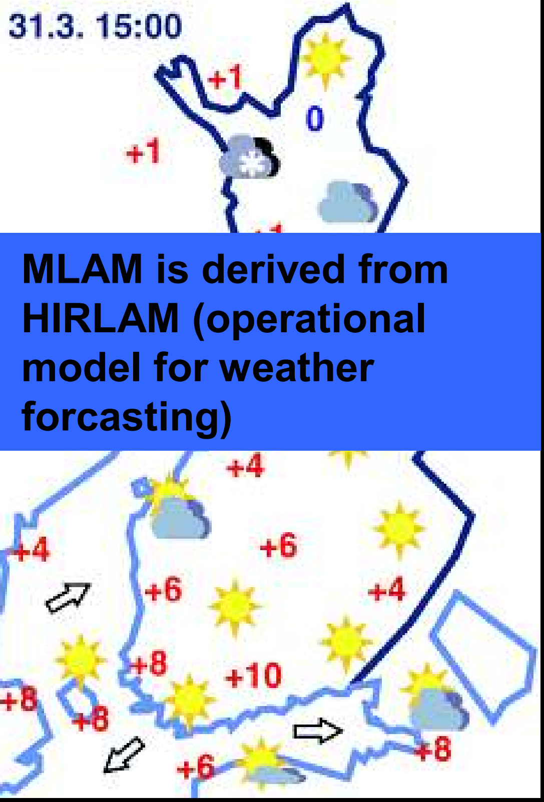
Mars Local-area Model

- MLAM is a mesoscale atmosphere simulation for Mars
- It has been developed jointly by the University of Helsinki and the Finnish Meteorological Institute (also in Helsinki)
- It is derived from an operational model used for weather prediction on Earth (HIRLAM)
- Numerically solves fundamental thermal and mechanical equations for each atmospheric gridbox
- The grid covers part of the globe (several 1000s km) and boundary conditions are obtained from Global Circulation Models (GCMs)
- MLAM surface and atmospheric data can be viewed by an earth science data graphics package called the Grid Analysis and Display System (GraDS)
- Wind speed, for example, is output as vector pairs, one south to north, labelled v, the other west to east, labelled u. The data can be output into a text file if necessary using a specially written script.
- MLAM has been checked against meteorological measurements made on Mars by the Vikings and Pathfinder. Also recently MLAM output has been compared to TES data (surface temperature) from Mars Global Surveyor and found to be in good agreement.

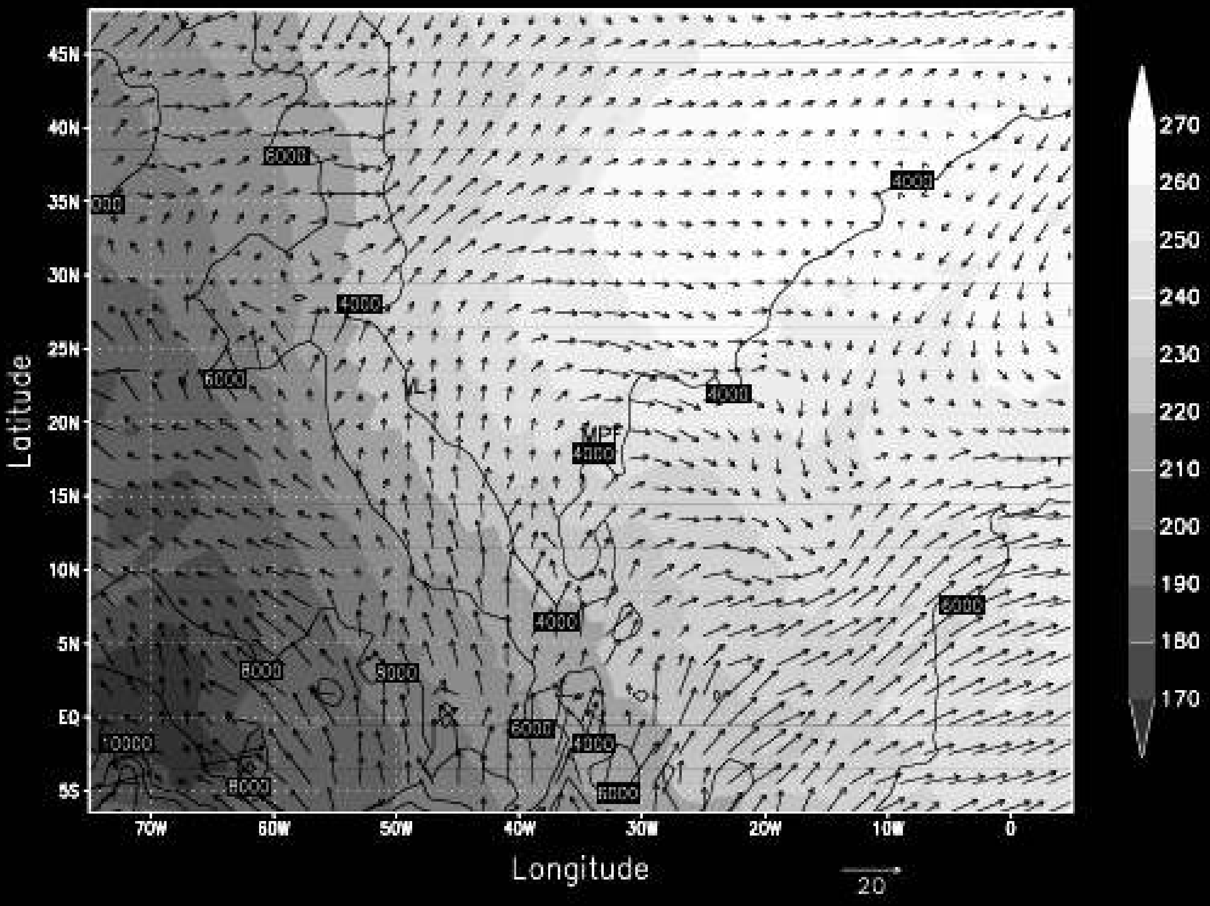
University of Helsinki and the Finnish Meteorological Institute

Mars Local-Area Model

ILMATIETEEN LAITOS
Finnish Meteorological Institute

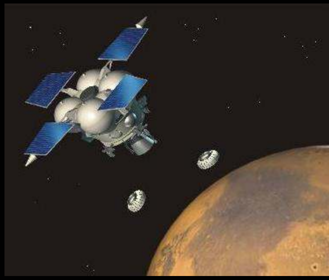


MLAM is derived from HIRLAM (operational model for weather forcasting)



Viking (NASA)

Phoenix (NASA)



MetNet (FMI, BSC, IKI)

Figure 1: A MLAM forecast of ground temperature (greyscale; in K) and 1.5 m level winds (arrows; in m/s; the arrow below the image denotes 20 m/s) over topography (contours; in m from Mars' lowest elevation) in the VL1 and MPF landing region (the landing sites are marked with "VL1" and "MPF"). Season is summer solstice ($L_s = 90°$) and local time is 1100 at 0°W (0900 at 30°W — the MPF longitude). (Silli et al., 2005)

Aerobrake 2D (A2D)

Features:

Multi-level (vertical) atmosphere only limited by available data (temperature, winds)

Rotation of the atmosphere.

Aeroshell, parachutes, heat shield release, powered descent.

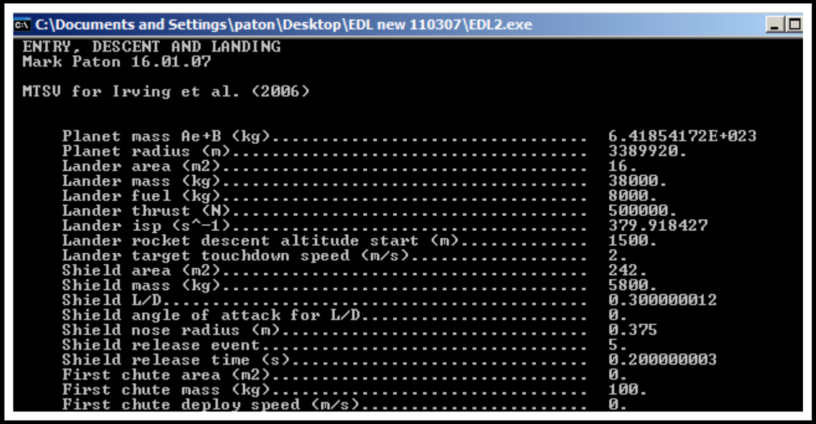
Varying lift and drag controlled by Mach number and/or guidance computer commands (from real flights)

A2D simulates the motion of an object under gravitational and aerodynamic forces in a two dimensional plane. Suitable for setting up EDL trajectories in a 3D simulator such as Orbiter or even to investigate real EDL trajectories (like the effect of winds which Orbiter does not simulate)

A2D has been developed since 2004

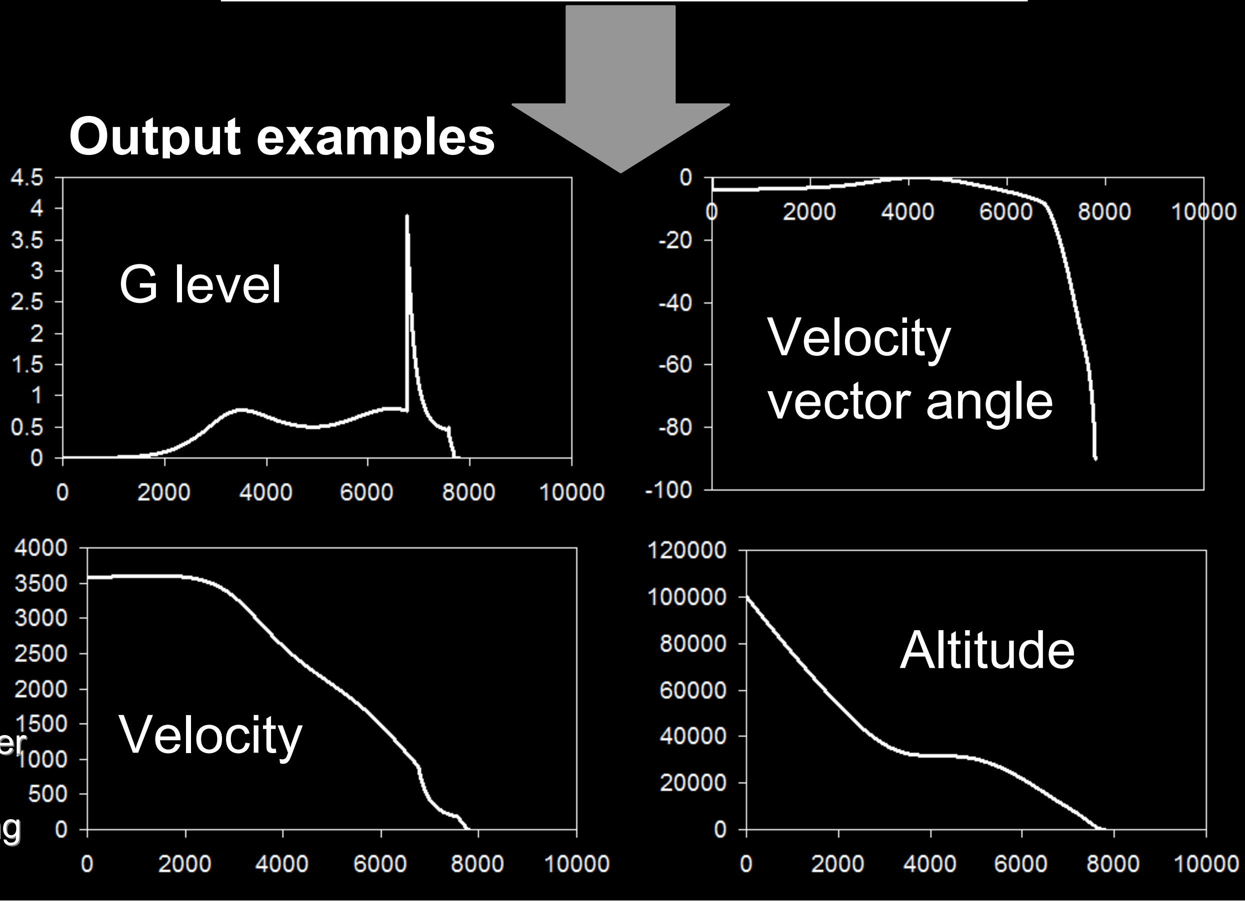
1. Bridges et al., 2004, A very public fireball
2. Paton, M. D., 2005, Penetrometry of NEOs and other Solar System bodies, PhD thesis
3. Irving et al., 2006, VP of human Mars Missions using the Orbiter space flight sim.

FORTRAN PROGRAM

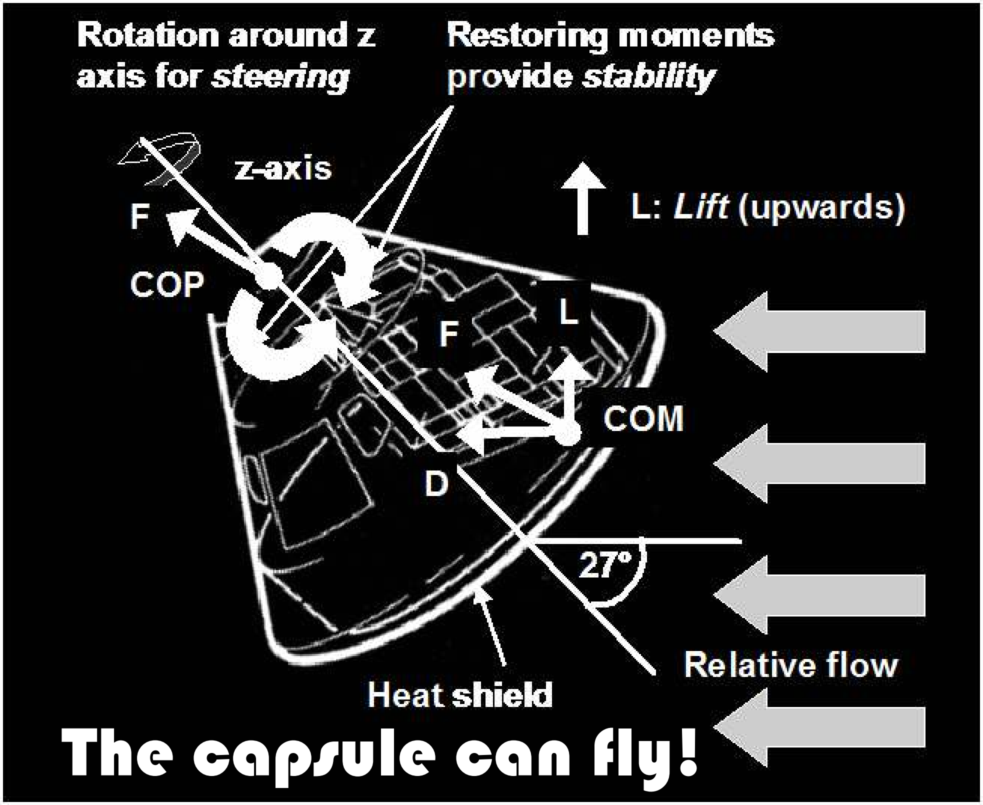


```
ENTRY, DESCENT AND LANDING
Mark Paton 16.01.07

MTSV for Irving et al. (2006)


    Planet mass Ae+B (kg)................................  6.41854172E+023
    Planet radius (m)....................................  3389920.
    Lander area (m2).....................................  16.
    Lander mass (kg).....................................  38000.
    Lander fuel (kg).....................................  8000.
    Lander thrust (N)....................................  500000.
    Lander isp (s^-1)....................................  379.918427
    Lander rocket descent altitude start (m).............  1500.
    Lander target touchdown speed (m/s)..................  2.
    Shield area (m2).....................................  242.
    Shield mass (kg).....................................  5800.
    Shield L/D...........................................  0.300000012
    Shield angle of attack for L/D.......................  0.
    Shield nose radius (m)...............................  0.375
    Shield release event.................................  5.
    Shield release time (s)..............................  0.200000003
    First chute area (m2)................................  0.
    First chute mass (kg)................................  100.
    First chute deploy speed (m/s).......................  0.
```

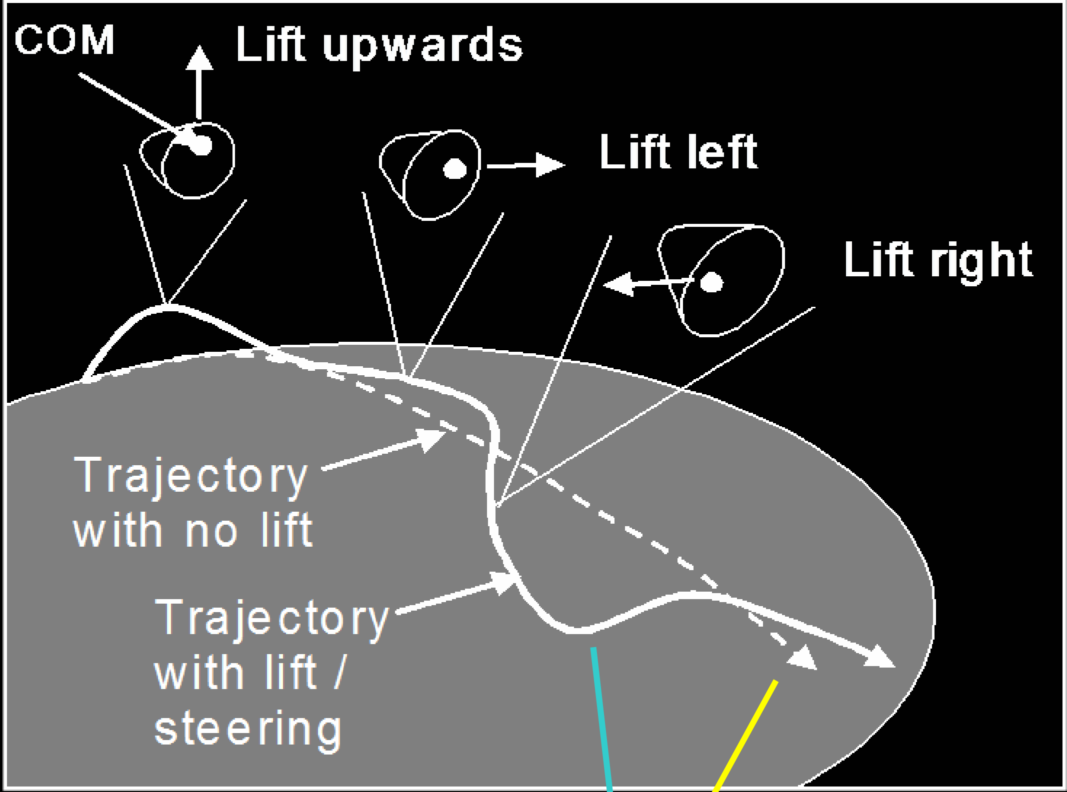
Output examples

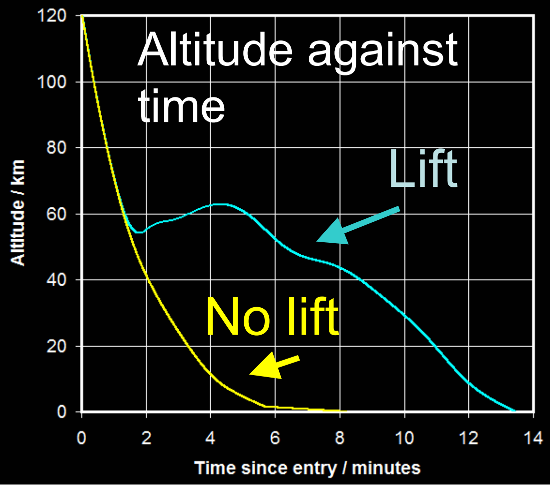


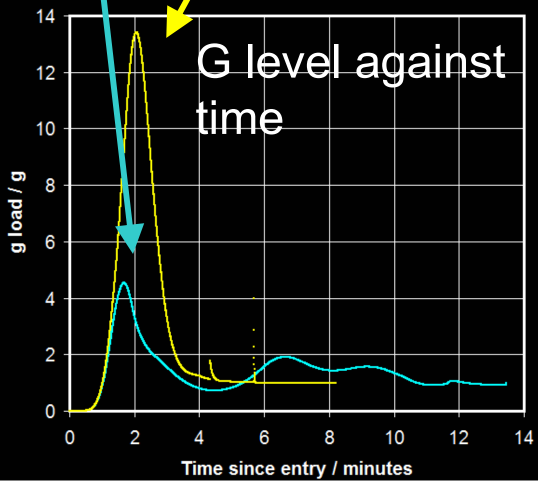
Validation: flying Apollo style



The capsule can fly!

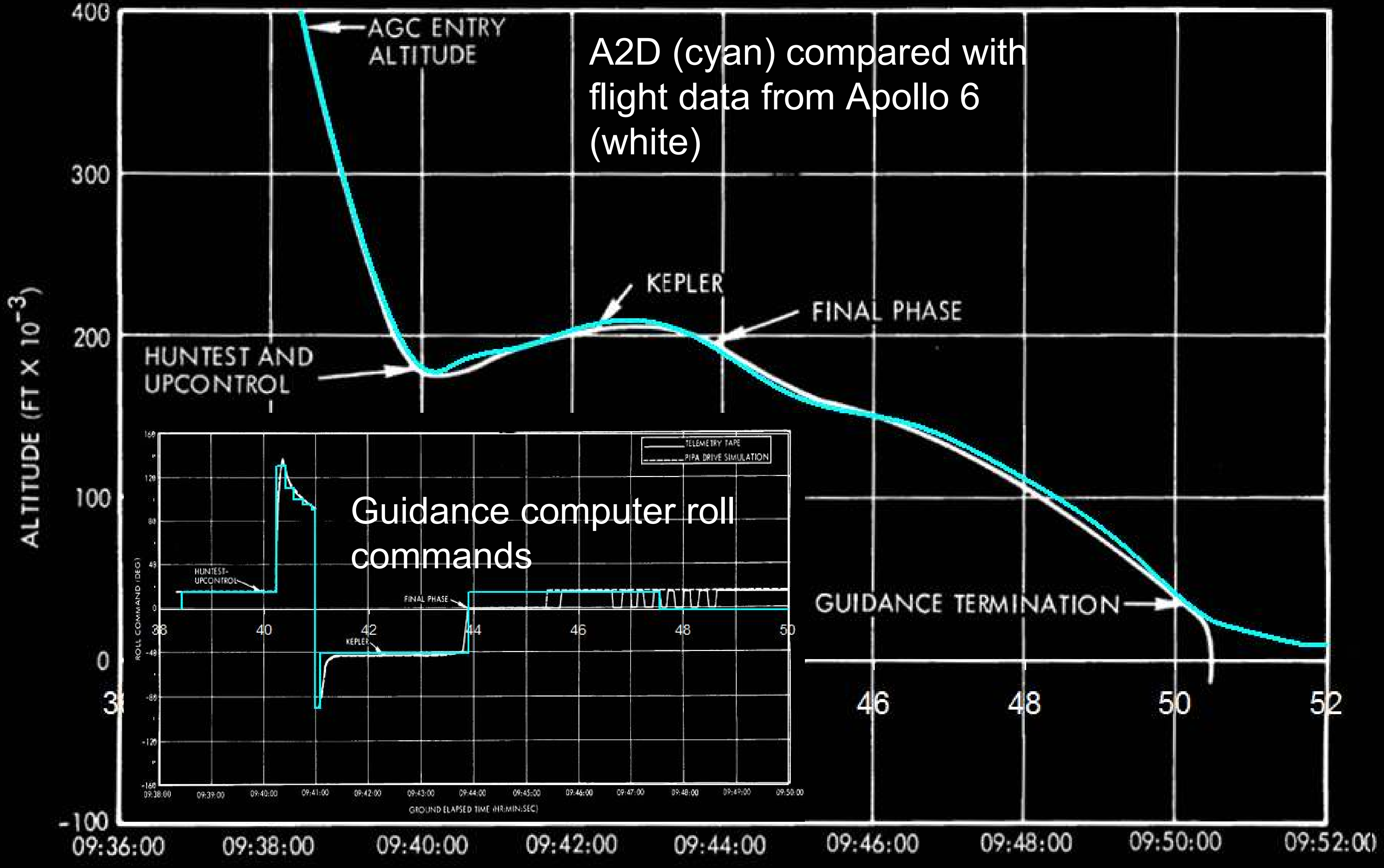






The Apollo CM was chosen over Mars entry probes for validation as the Earth's atmosphere is more stable and well known than Mars. Also for Apollo there are extensive simulations and flight data easily accessable on the internet.

Validation: A2D compared with reconstructed Apollo 6 flight data



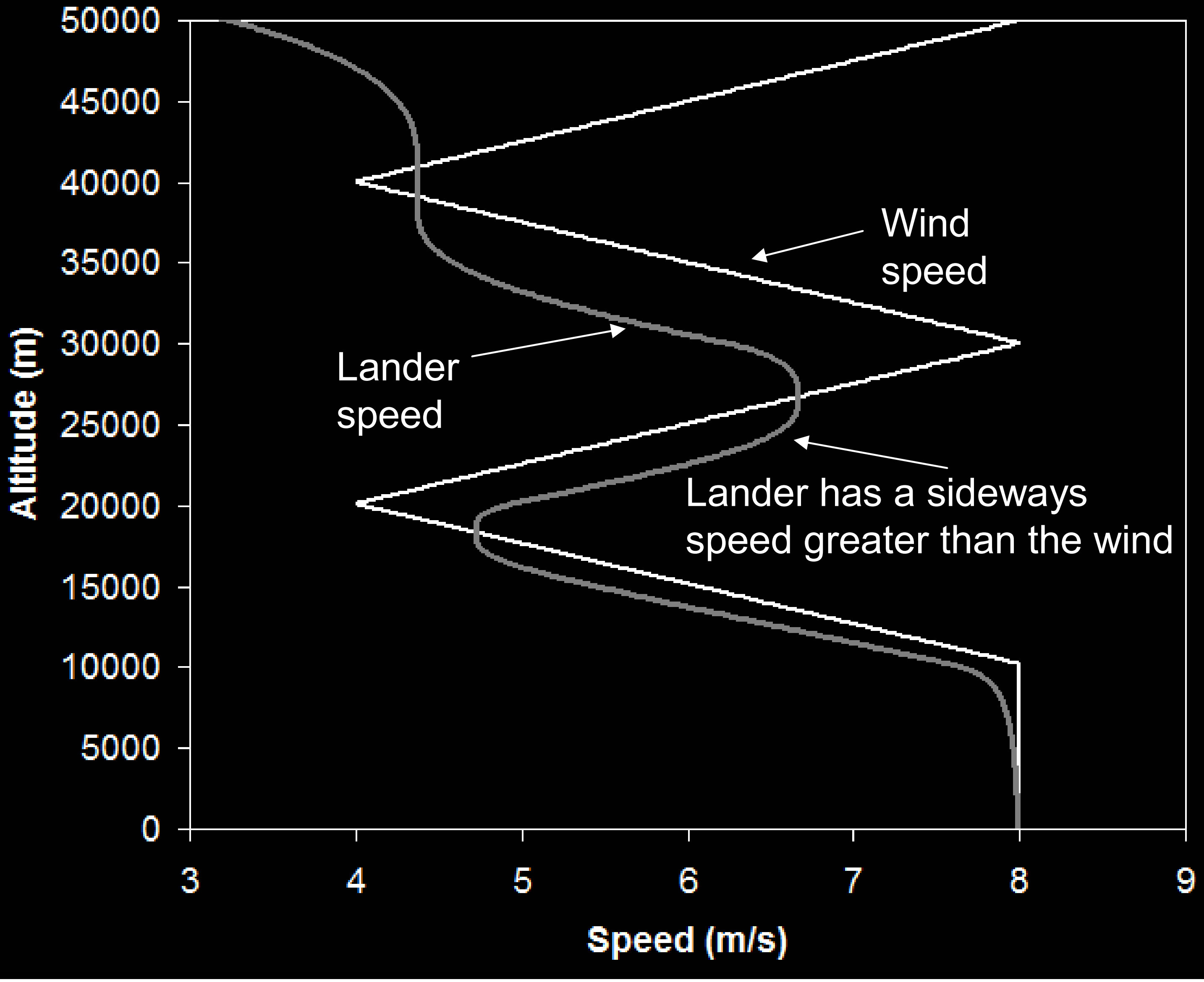
A2D (cyan) compared with flight data from Apollo 6 (white)

Guidance computer roll commands

Original figures from Bolling, L., 1968, Apollo 6 entry postflight analysis

Winds in A2D: Just checking.....

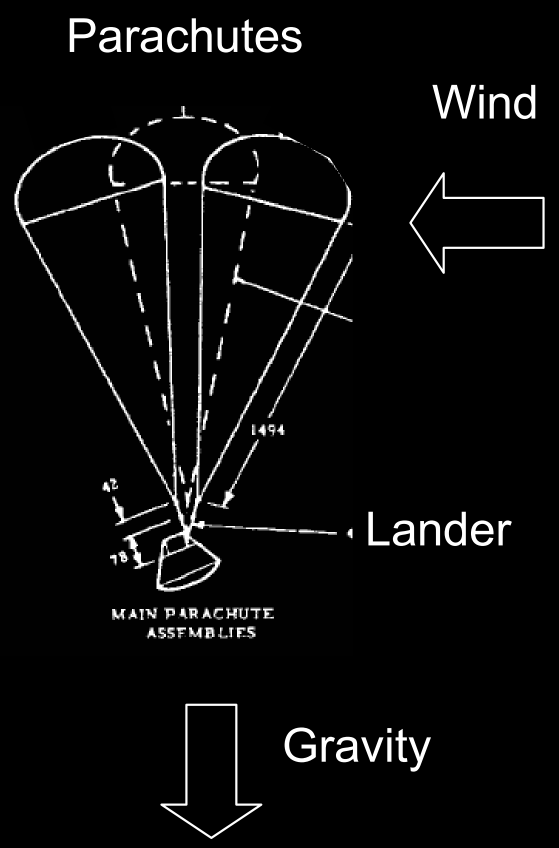
Lander is dropped from an altitude of 100 km with parachutes deployed. The winds vary from 8 to 4 metres per second in a zig-zag fashion (white). The wind blows the Lander sideways at a speed (grey) depending on how the wind speed is changing.



Wind speed

Lander speed

Lander has a sideways speed greater than the wind



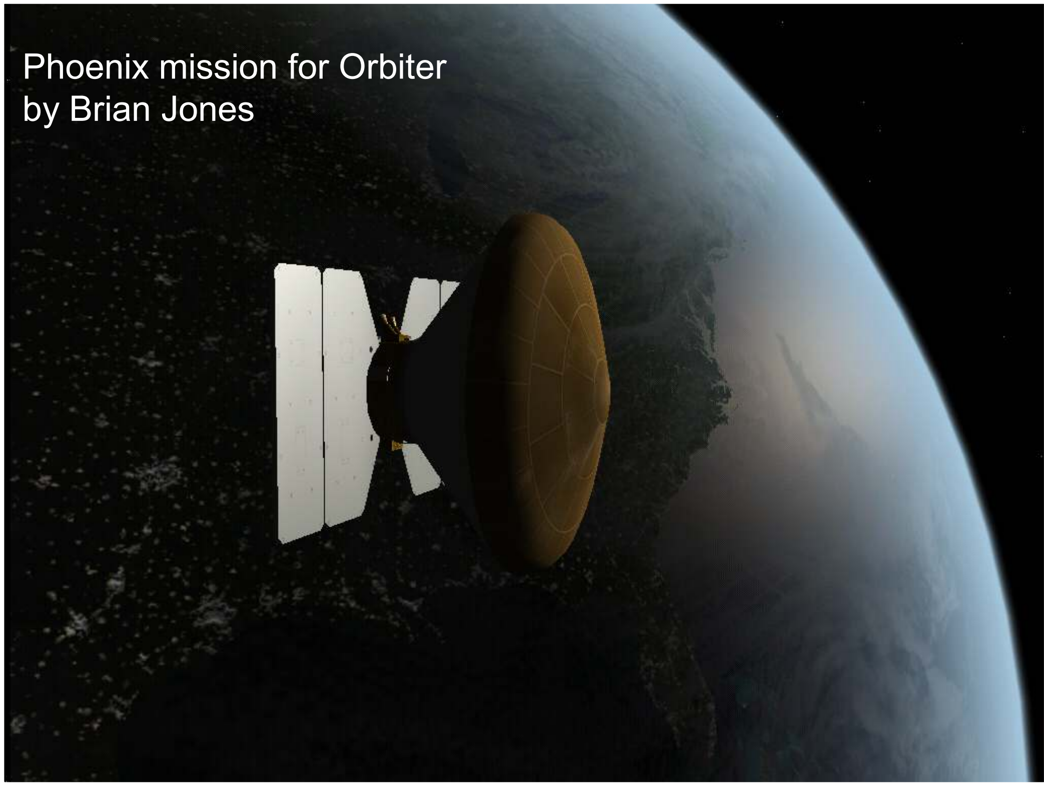
Orbiter space flight simulator

- Orbiter is a real-time space flight simulator – it features
- Modeling of atmospheric flight (launch and reentry), sub-orbital, orbital and interplanetary missions
- Newtonian mechanics, rigid body rotation, static atmospheric flight model
- Planet positions from public perturbation solutions; time integration of state vectors or osculating elements
- Developed since 2000 as an educational and spacecraft simulation tool (Schweiger, 2004 & 2006)
- Includes a versatile API and SDK to allow users to create ”add-ons” that expand Orbiter’s capabilities in many ways
- Completely new spacecraft, propulsion systems, flight instruments, etc can be defined and flown
- Orbiter is freeware, courtesy of its author Dr. Martin Schweiger (University College London). www.orbitersim.com

www.orbitersim.com

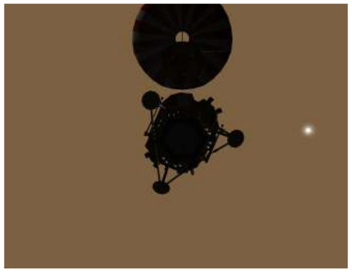
Orbiter space flight simulator

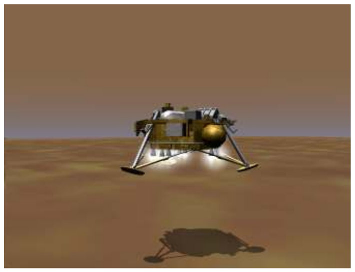
Deltaglider model by Roger "Frying Tiger" Long.
Instrument panels by Martin Shweiger.

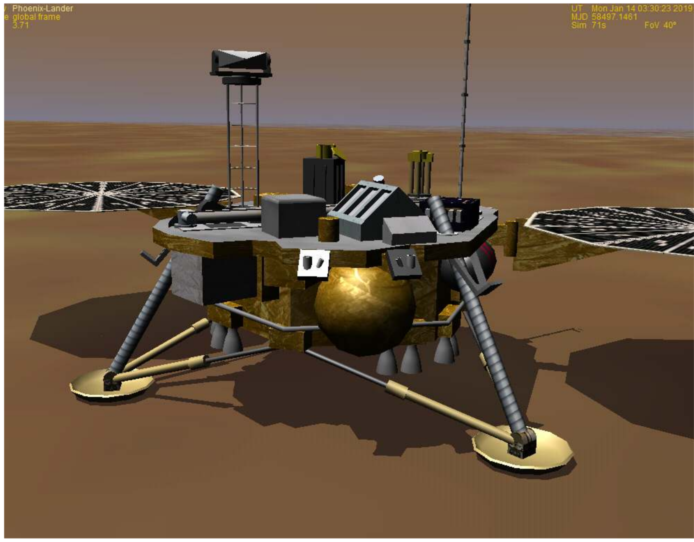


Phoenix mission for Orbiter
by Brian Jones

Screen shots from the Orbiter space flight simulator. Above shows a view from inside the cockpit of a fictional spacecraft called the Deltaglider, which is provided with the Orbiter base package. The view also shows the blue oceans of Earth and some white streaks of clouds and on the horizon is a band of atmospheric haze. The virtual cockpit is interactive; buttons can be activated with the mouse. To the right are screen shots from the Phoenix mission in Orbiter. The mission can be simulated from launch to touchdown on Mars.







Section B: summary

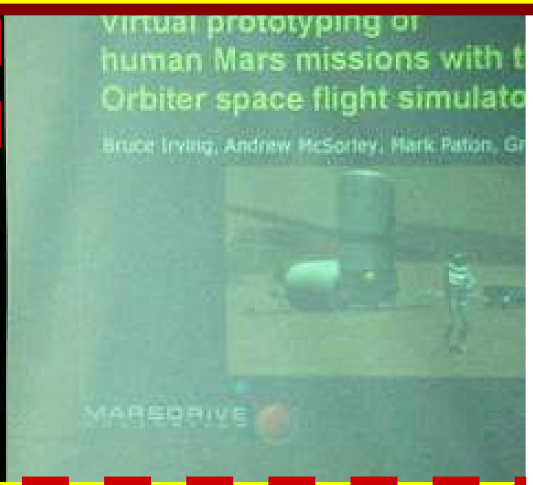
- Reliable models of the Martian atmosphere and weather exist. MLAM can be used to provide atmospheric data for EDL simulations.
- A simple 2D EDL tool (A2D) can provide useful information for prototyping landing systems and assesing deflection by the wind.
- The Orbiter space flight simulator is a great tool for prototyping spacecraft missions and trying out landing scenarios on Mars.

C. A piloted Mars lander

1. Virtual prototyping the mission (Orbiter space flight simulator)

Mars Society Conference 2006

Bruce Irving:
JPL Solar System Ambassador 2007



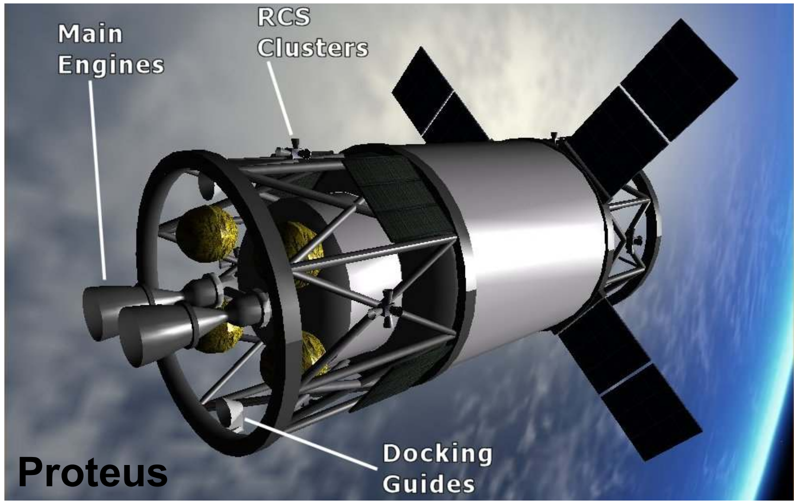
Virtual prototyping of
human Mars missions with t
Orbiter space flight simulato
Bruce Irving, Andrew McSorley, Mark Paton, Gr

These models are based on vehicles described in the Mars for Less mission (Bonin, 2006), similar to Mars Direct but using MLLVs and Earth orbit assembly

Ariane 5 modifications, Proteus booster model, interplanetary navigation by Andrew McSorley

```
Orbit: Earth          Frm EQU  Prj SHP
--OSC.EL.--
SMa 6.655M
SMi 6.655M
PeA 281.7k
ApA 285.5k
Alt 281.8k
Ecc 0.0003
T   5.403k
PeT 5.233k
ApT 2.532k
Vel 7.742k
Inc  28.52°
LAN 214.27°
LPe 355.33°
AgP 141.05°
TrA  11.28°
TrL   6.61°
MnA  11.28°
MnL   6.60°
G 1.00
```

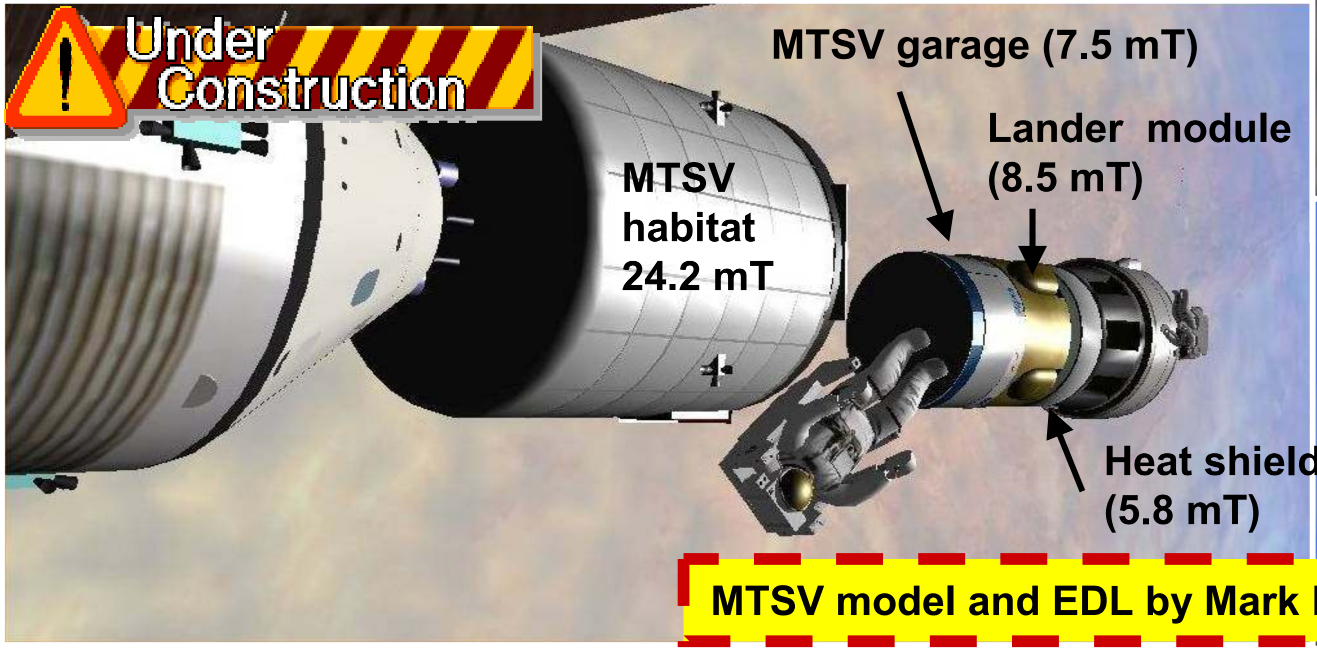
```
APPR/DOCK 1  VIS
TOF# 0.68               DST    CVEL
TVEL 0.01               4.00   0.82
```



Proteus

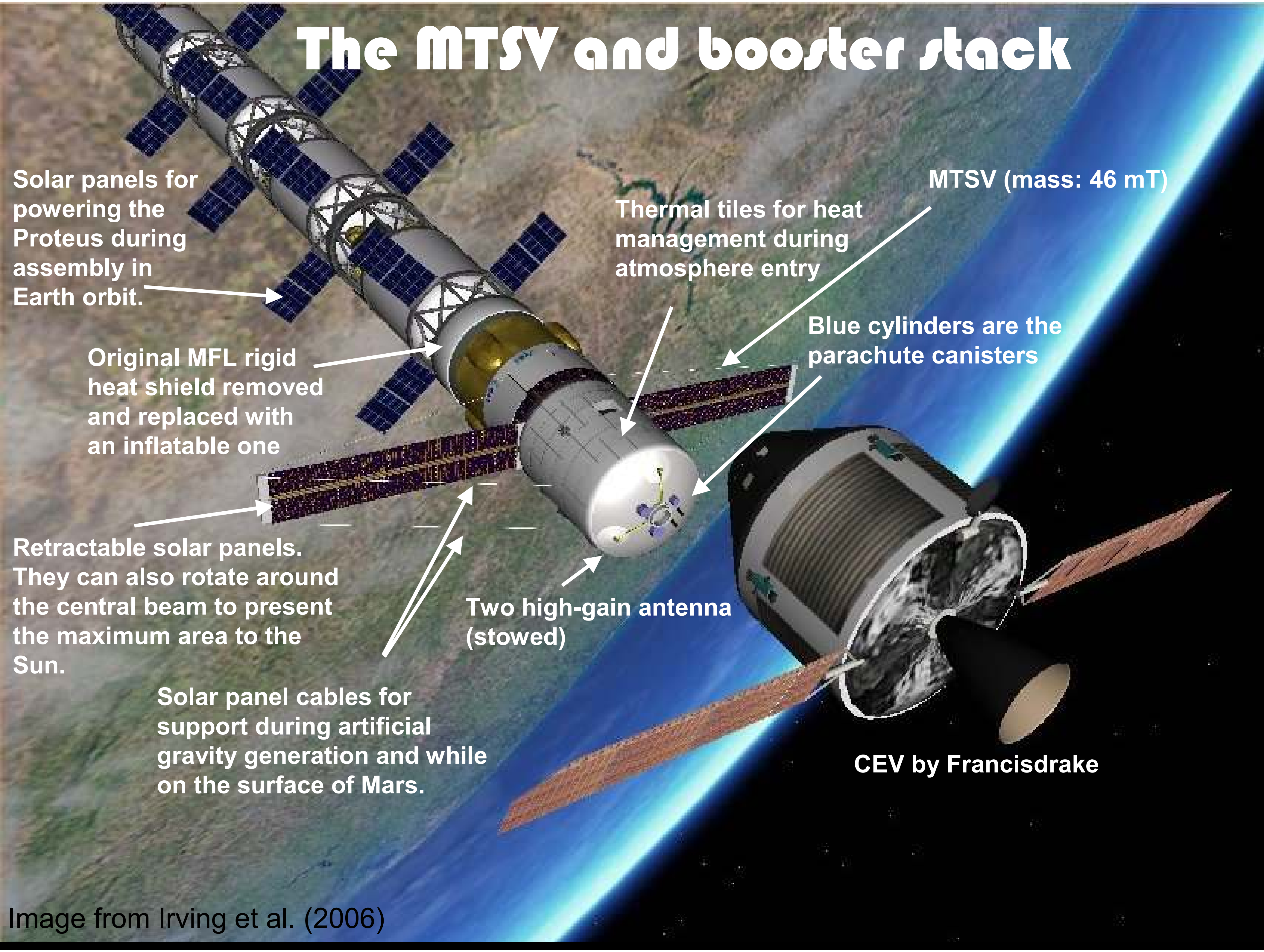
Original A5 by Thomas Ruth

Korou by "Papyref" & "Mustard"



MTSV model and EDL by Mark Paton

The MTSV and booster stack



Solar panels for powering the Proteus during assembly in Earth orbit.

Original MFL rigid heat shield removed and replaced with an inflatable one

Thermal tiles for heat management during atmosphere entry

MTSV (mass: 46 mT)

Blue cylinders are the parachute canisters

Retractable solar panels. They can also rotate around the central beam to present the maximum area to the Sun.

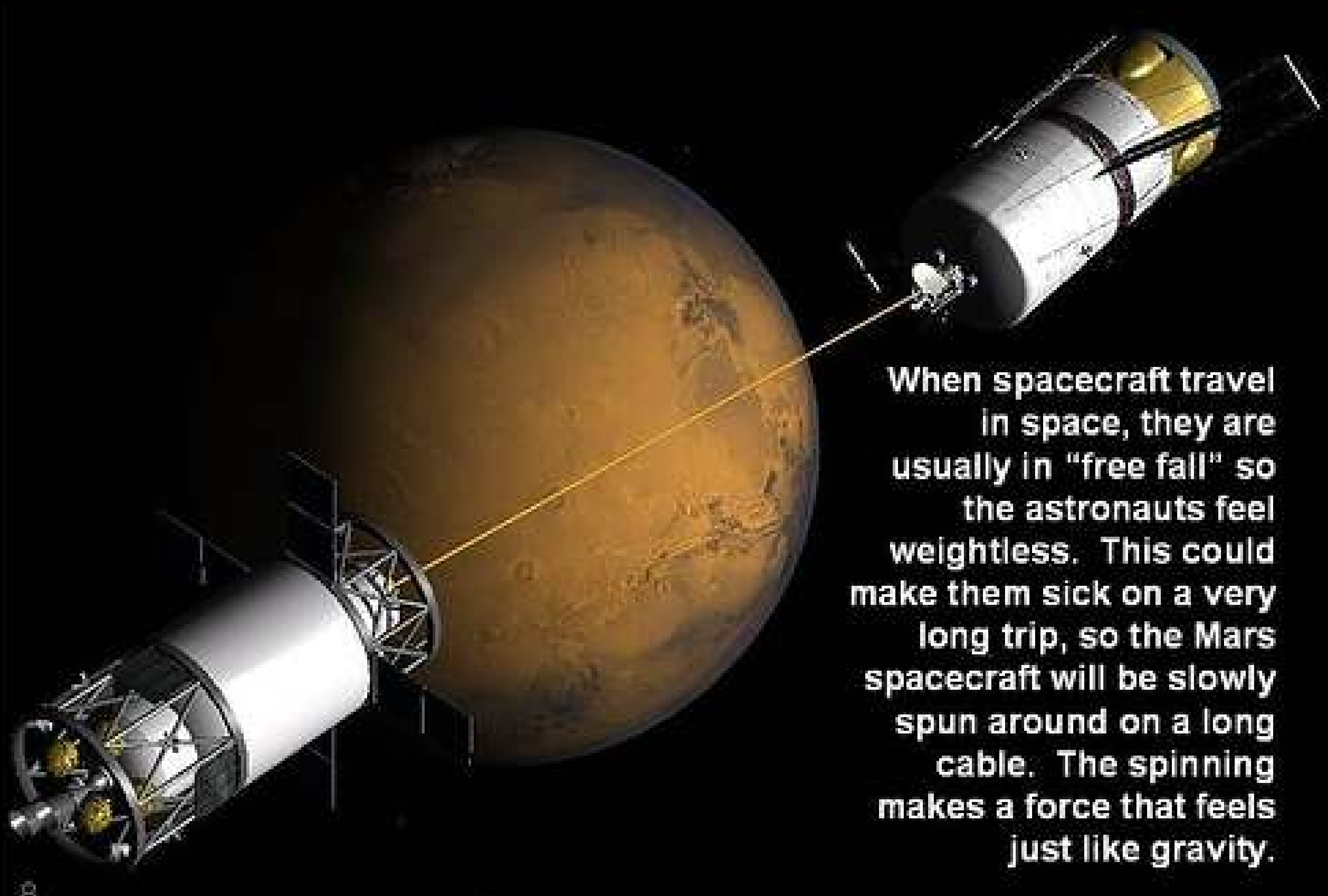
Two high-gain antenna (stowed)

Solar panel cables for support during artificial gravity generation and while on the surface of Mars.

CEV by Francisdrake

Image from Irving et al. (2006)

Arrival at Mars..........

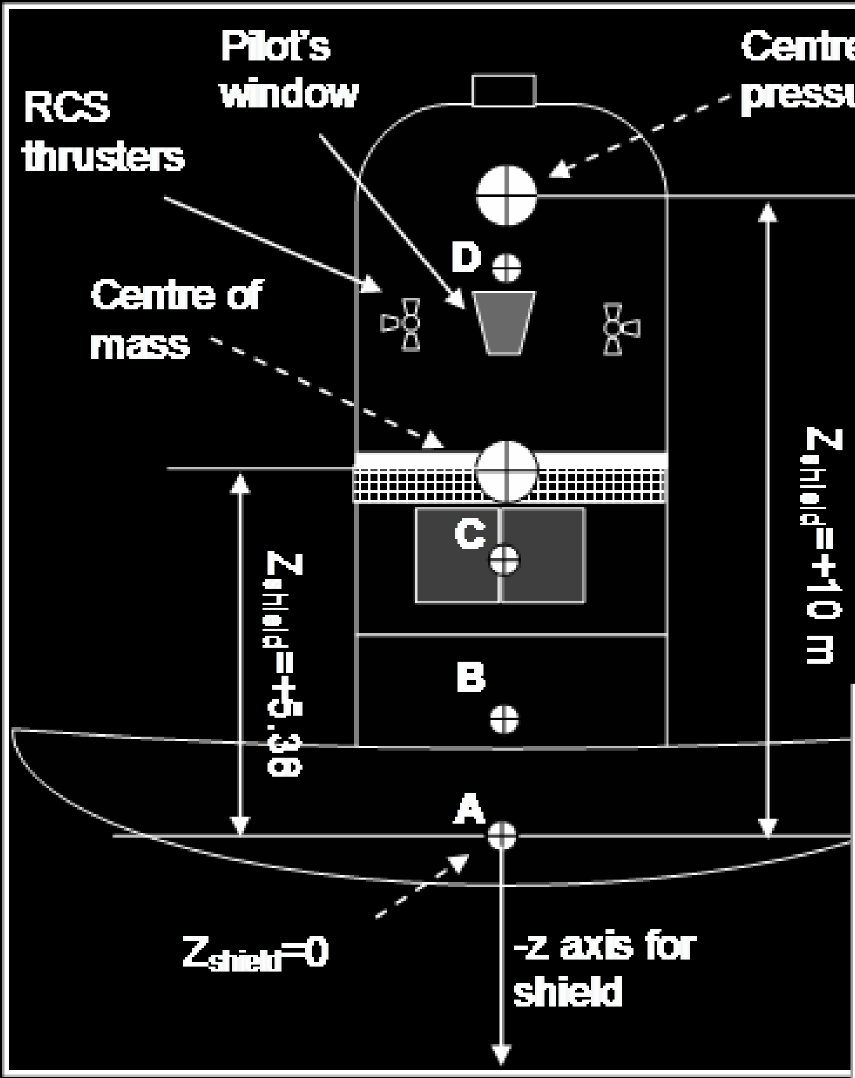


When spacecraft travel in space, they are usually in "free fall" so the astronauts feel weightless. This could make them sick on a very long trip, so the Mars spacecraft will be slowly spun around on a long cable. The spinning makes a force that feels just like gravity.

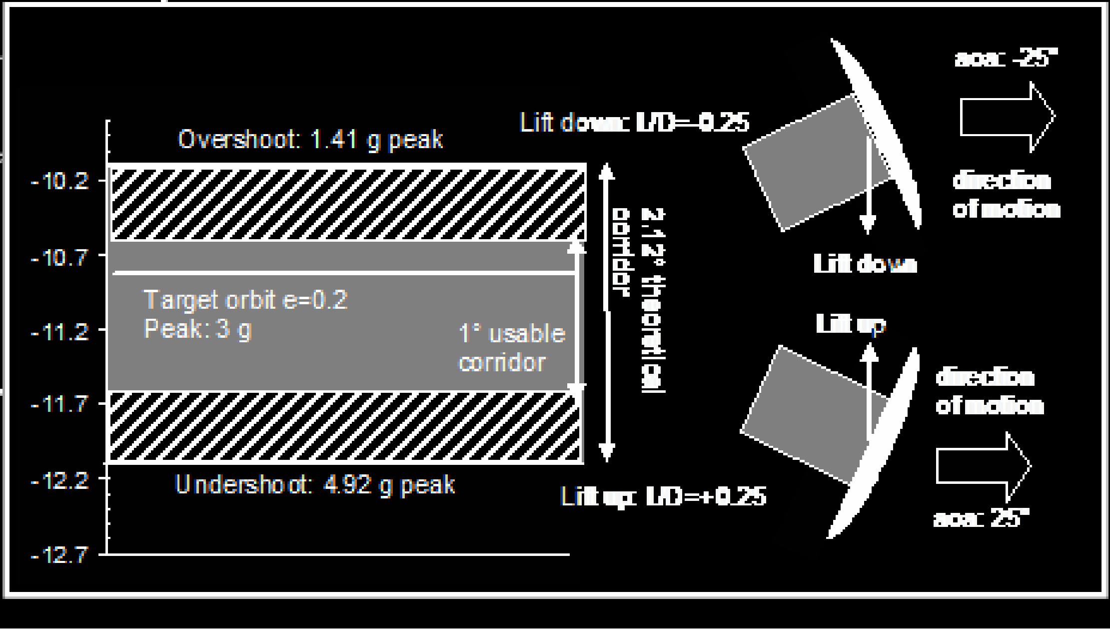
Image courtesy of Bruce Irving (from the e-book Mars…just imagine) Tether by ”MattW”

2. EDL system design (A2D / Orbiter)

Aerodynamic model



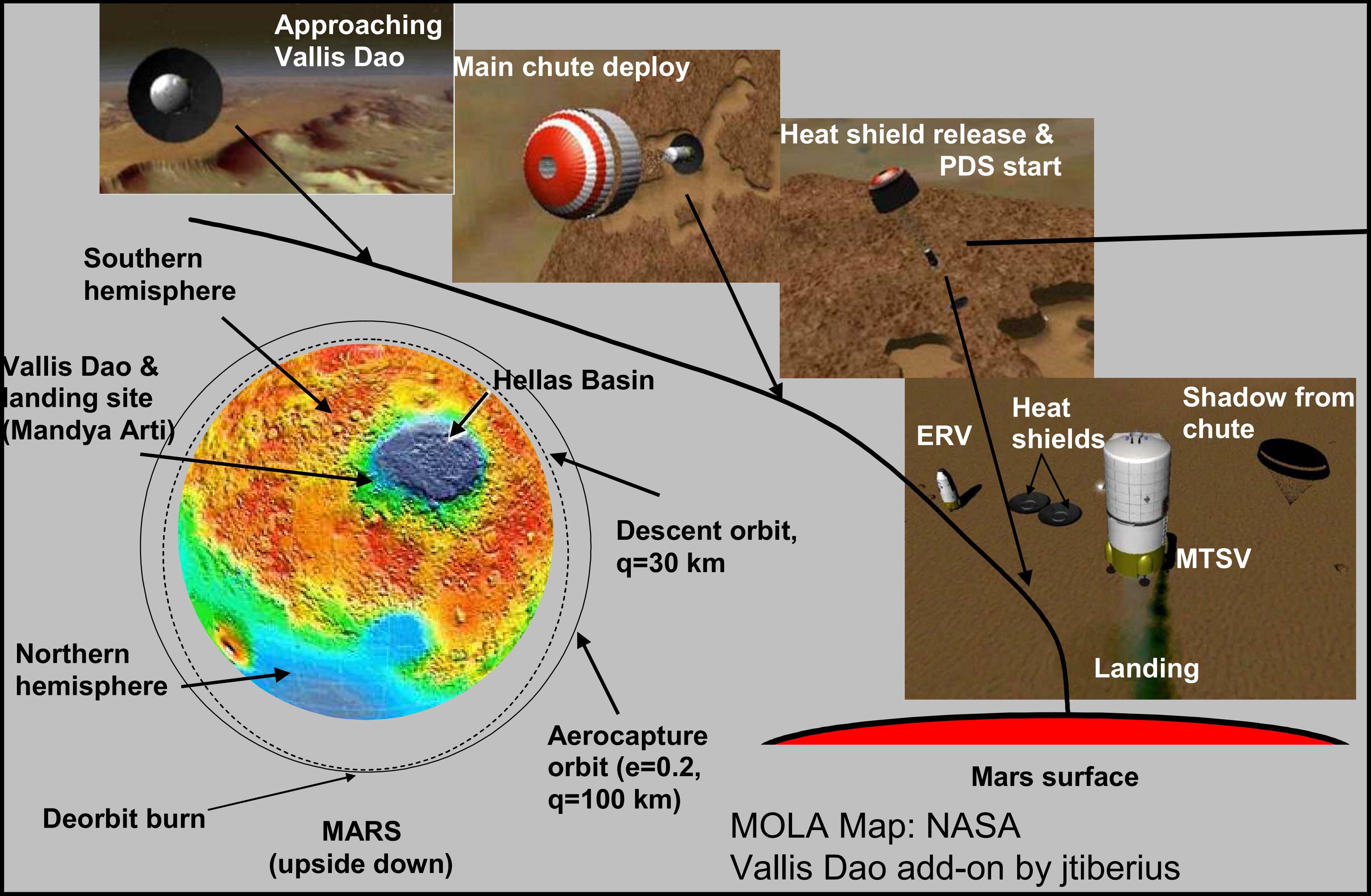
- Trial aerocapture flights in Orbiter highlighted the nessesity that the centre of pressure should be behind the centre of mass (left). The trial flights were set up using A2D.
- A2D was used to determine the width of the aerocapture coriddor (below) and establish that an Apollo type heat shield (L/D of 0.3) could be used with an area of ~250 m^2



- Ballistic coefficient ~200 kg/m^2
- Heating low enough for inflatable? Maybe!

There may be less mass to launch……but a large mass to land!! Bit tricky. ☺

EDL design for a piloted lander

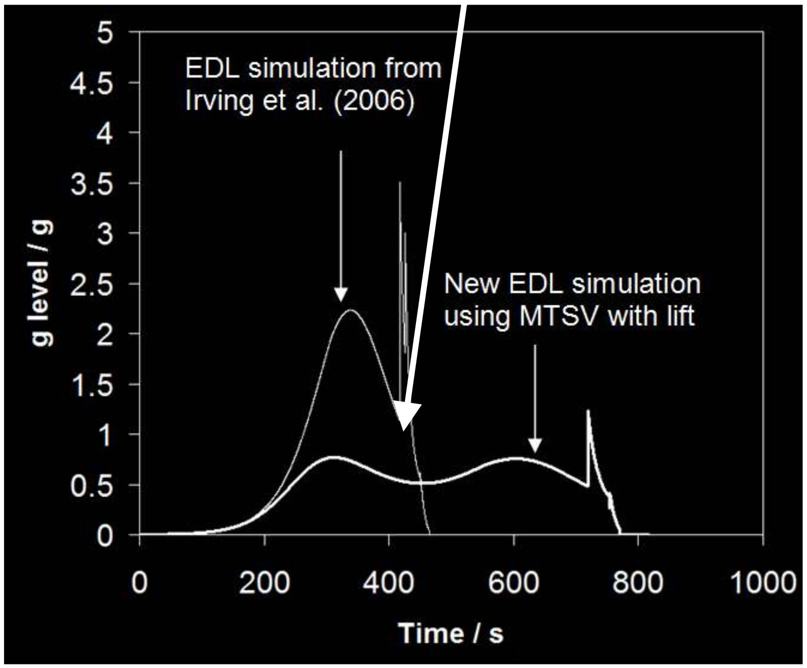


MOLA Map: NASA
Vallis Dao add-on by jtiberius

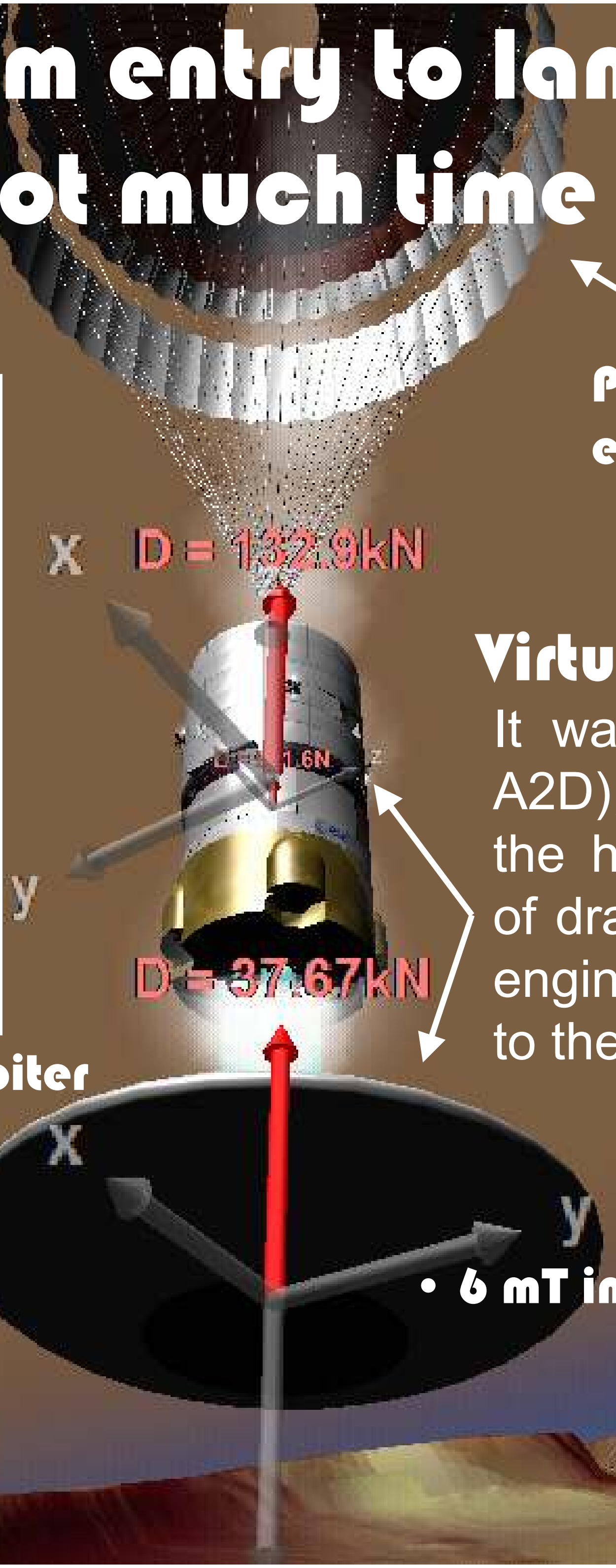
- Many trajectories first run in A2D (ballistic: L/D=0)
- Entry numbers for successful EDL then transfered to Orbiter

Transition from entry to landing, a bit dangerous, not much time

We are here



- A2D used for planning EDL in Orbiter



Parachute:
effective area 1050 m²

Virtual prototyping result:

It was found (using Orbiter & A2D), for positive seperation of the heat shield, a combination of drag from the parachute and engine thrust had to be applied to the Lander.

- 6 mT inflatable heat shield

16 m diameter heat shield:
effectiver area 242 m²

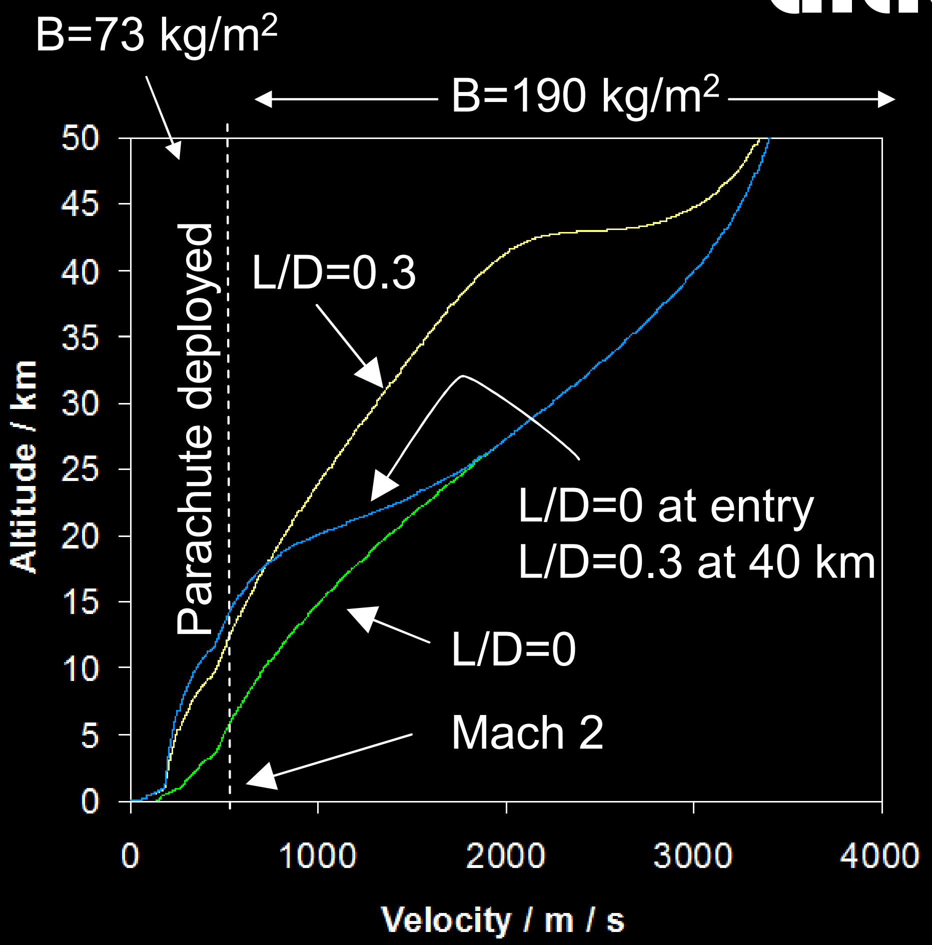
Conclusions 1

- As reported by Irving et al. (2006) shadowing of the solar panels by the large heat shield was seen to be a problem. The proposed solution was to use an inflatable shield.
- Also an inflatable heat shield offers a mass adavantage over a rigid heat shield
- Another thing…..during the VP work it was found that retro engines had to be fired to pull the Lander of the shield
- So virtual prototyping really helped identify problem areas especially with design of the Lander, its EDLS and its influence on other phases of the mission

3. The effect of Martian winds (A2D / MLAM)

NEW!

What's the Parachute deployment altitude?



B=73 kg/m^2

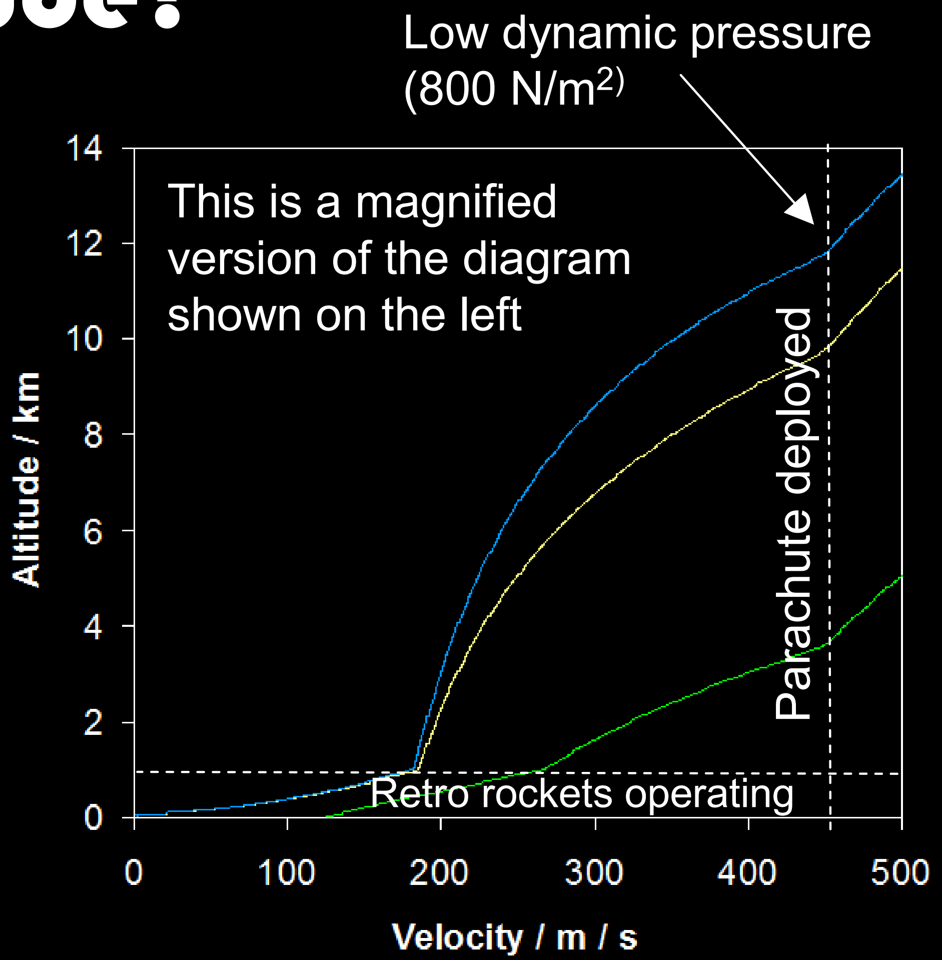
B=190 kg/m^2

L/D=0.3

L/D=0 at entry
L/D=0.3 at 40 km

L/D=0

Mach 2

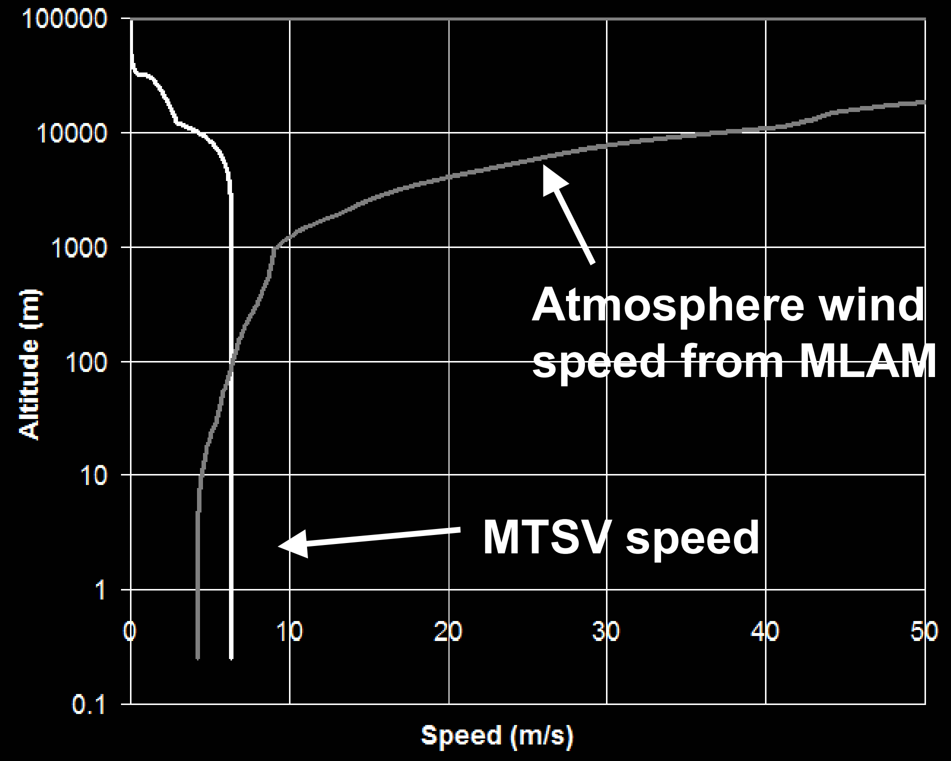


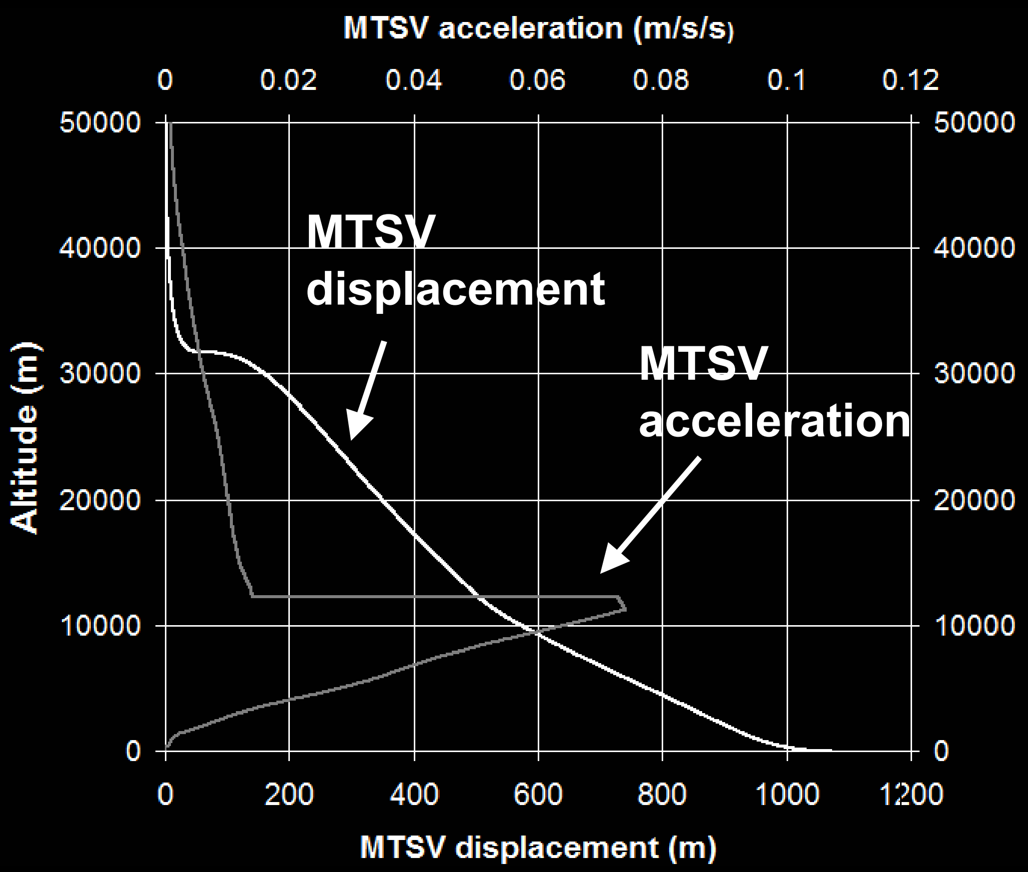
Low dynamic pressure
(800 N/m^2)

This is a magnified
version of the diagram
shown on the left

The left and right diagram show velocity-altitude plots for three identical MTSVs (46 mT at entry). One of them has vertical lift (yellow) another has zero lift (green) and another (blue) switches over from zero vertical lift to a vertical L/D of 0.3 after reaching an altitude of 40 km. The "switching on" of vertical lift (using bank modulation….) sends the MTSV into a region of low dynamic pressure and thermal heating (i.e. low Mach) suitable for the use of a Viking Lander type parachute. Here however the parachute is much larger at 30 m in diameter. The atmosphere model used here is based on that measured during entry of the Viking 1 Lander.

Displacement by Martian winds (MLAM & A2D)

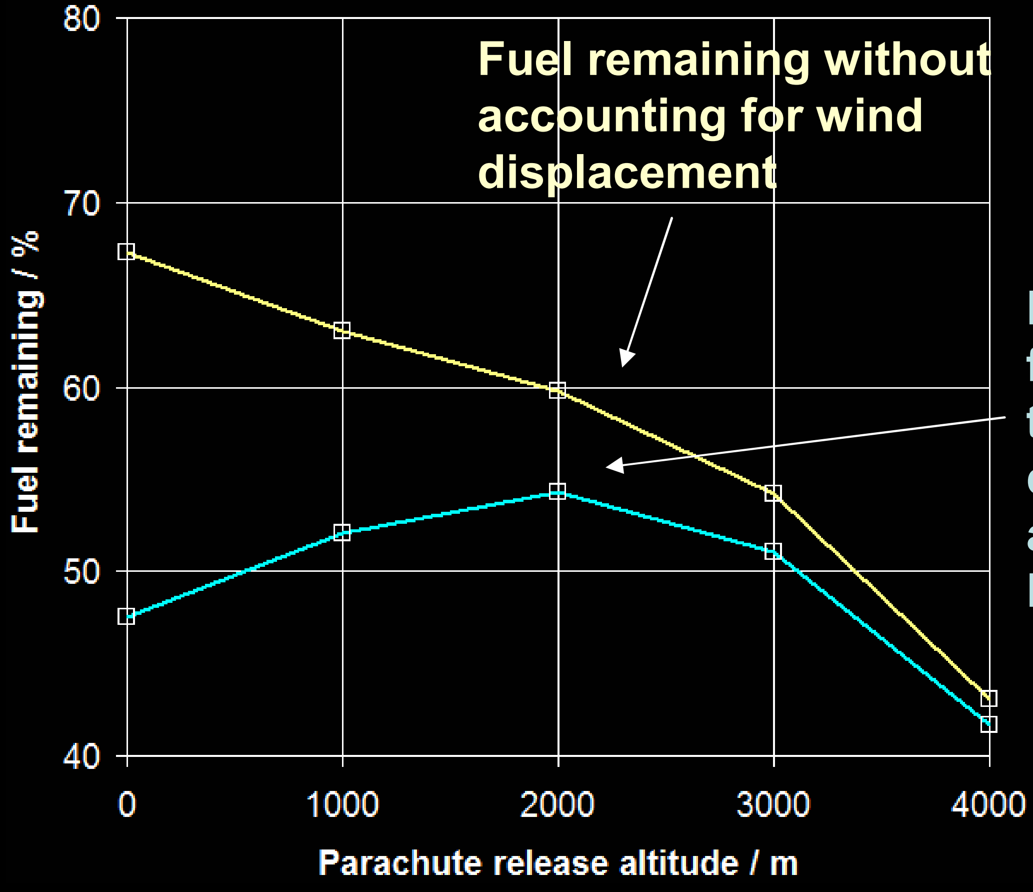




- Lander is displaced about 1 km to the side
- Winds are slower than the Lander sideways speed at the surface
- A L/D of 0.3 provides adequate control authority to compensate for wind drag during hypersonic entry. So..displacement on the parachute ~300 m.

Parachute release altitude (MLAM & A2D)

This chart is derived from A2D trajectory experiments. The MTSV is landed at 2 m s^{-1} on the surface. The parachute release altitude is varied and the percentage of fuel left is noted.



Fuel remaining without accounting for wind displacement

Fuel remaining calculated from the amount fuel used to correct for cross range displacement by a wind acting normal to the Lander's descent trajectory

- The optimal release altitude (in this case) is 2000 m
- The fuel saving is less than 1 mT or about 20 s of hover time
- Other wind profiles will probably produce similar results but the Martian winds need to be characterised somehow

Conclusions 2

- Preliminary detailed simulations using A2D and MLAM suggest fuel used during powered descent can be minimised by chosing an optimum parachute (or other large decelerator) release altitude
- This then provides a practical and useful reason for characterising the Martian winds at low altitude (using MLAM)
- Wind displacement is an issue for landing robotic Landers with pin-point accuracy

Putting it all together: landing on Mars

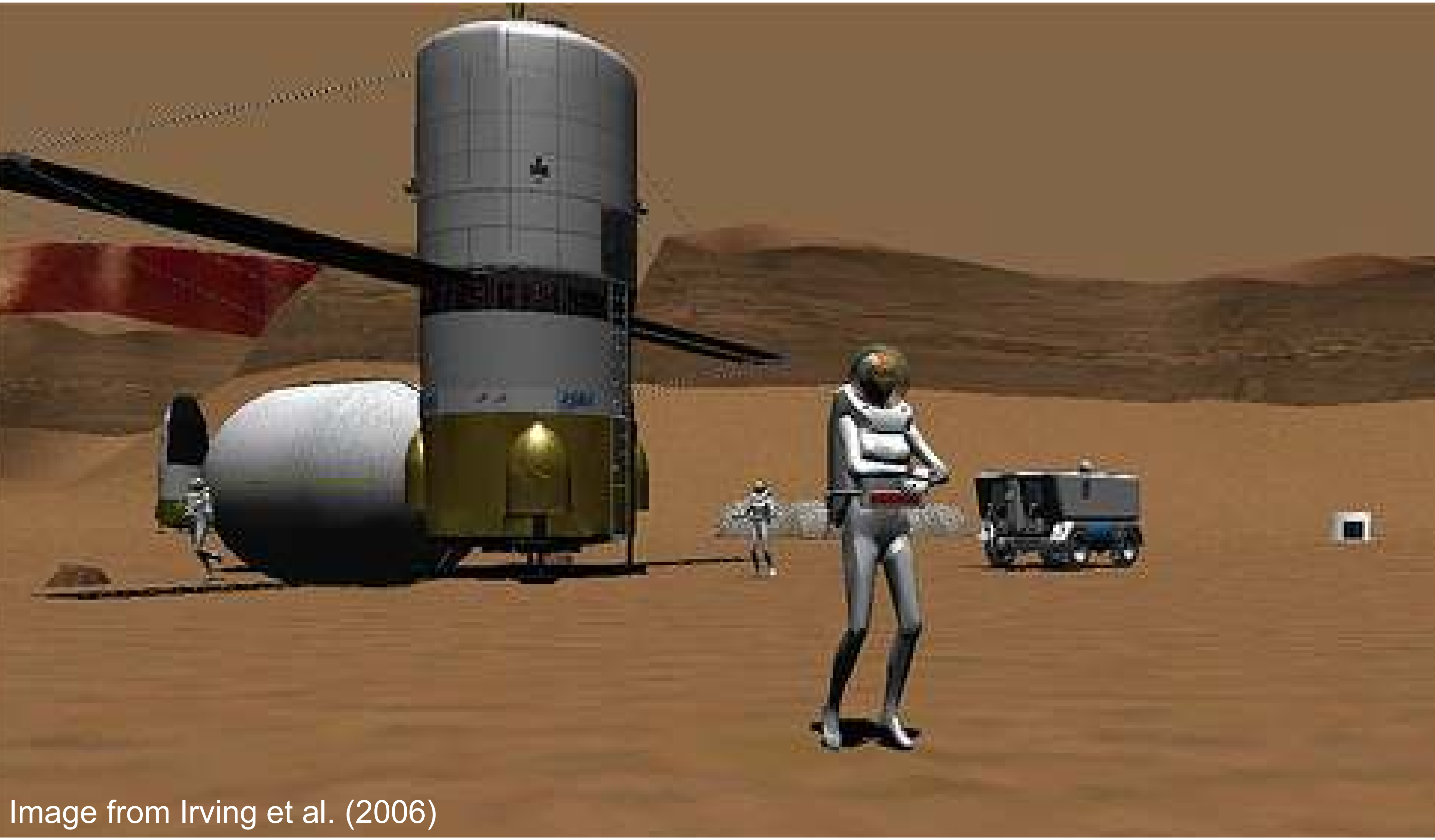
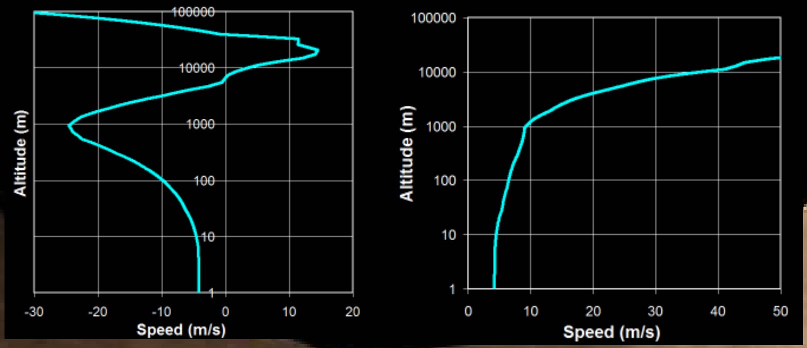


Image from Irving et al. (2006)

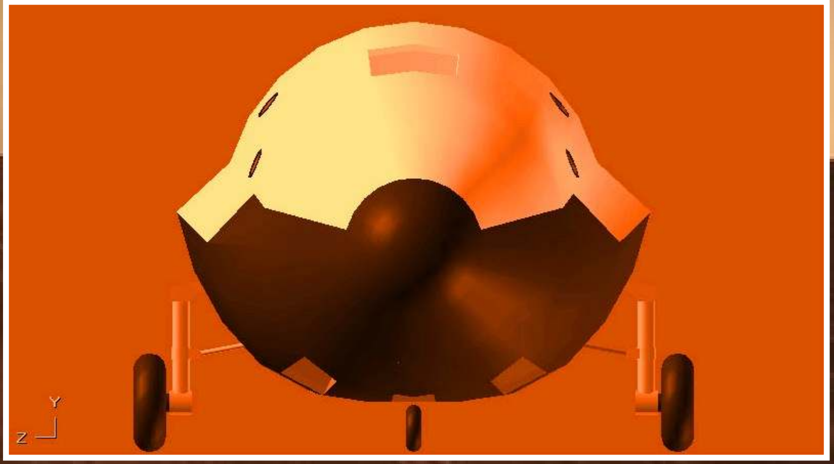
Landing on Mars: a description

1. Solar panels and antennas are retracted. Entry into the atmosphere is at an altitude of 100 km and a speed of 3.5 km/s. The MTSV has a mass of 46 metric tons.
2. **An Apollo type Earth-entry guidance system compensates for atmospheric uncertainties and winds.**
3. Maximum deceleration is just under 1 g and occurs 5 minutes after entry. Soon after the MTSV rolls over to increase the vertical lift. The crew watch craters and other features of the Hellas Basin rotate into view as the g levels ease off.
4. **The MTSV levels out at 40 km and travels over a distance of 300 km in 3 minutes**
5. At 8 minutes after entry the MTSV resumes its plunge towards the surface.
6. **Another deceleration peak occurs at 10 minutes after entry. Two minutes later at an altitude of 10 km a 30 m DGB parachute is fired out the back of the MTSV and the chute inflates in less than a second. A jolt is felt by the crew. Speed is 0.45 km/s.**
7. The MTSV slowly turns from a flight path angle of about 45 degrees into a vertical descent. The valley walls of Vallis Dao loom in the distance.
8. **The heat shield is released at an altitude of 1.5 km and immediately afterwards the retrorockets are ignited and pull the Lander of the shield. This is also the start of the powered descent phase. Soon after the parachute is released so as to minimise the displacement by the wind and preserve fuel.**
9. The Earth Return Vehicle and cargo is targeted and adjustments are made using rockets to bring the crew within 100 m.
10. **The final ton of fuel is eaten into as the Lander softley touches down throwing up clouds of red dust past the crew's window. Fourteen minutes after entry into atmosphere 34 metric tons of Lander and 4 human beings are on the surface of Mars.**
11. Solar panels and antennas are redeployed.

Future works



- ”Atmospheric modeling for realisitic EDL scenarios” – poster at IPPW-5, France June 2007
- Identify altitudes to release large aerodynamic decelerators to optimise fuel use during powered descent
- Virtual prototyping of biconic Landers to investigate EDLS



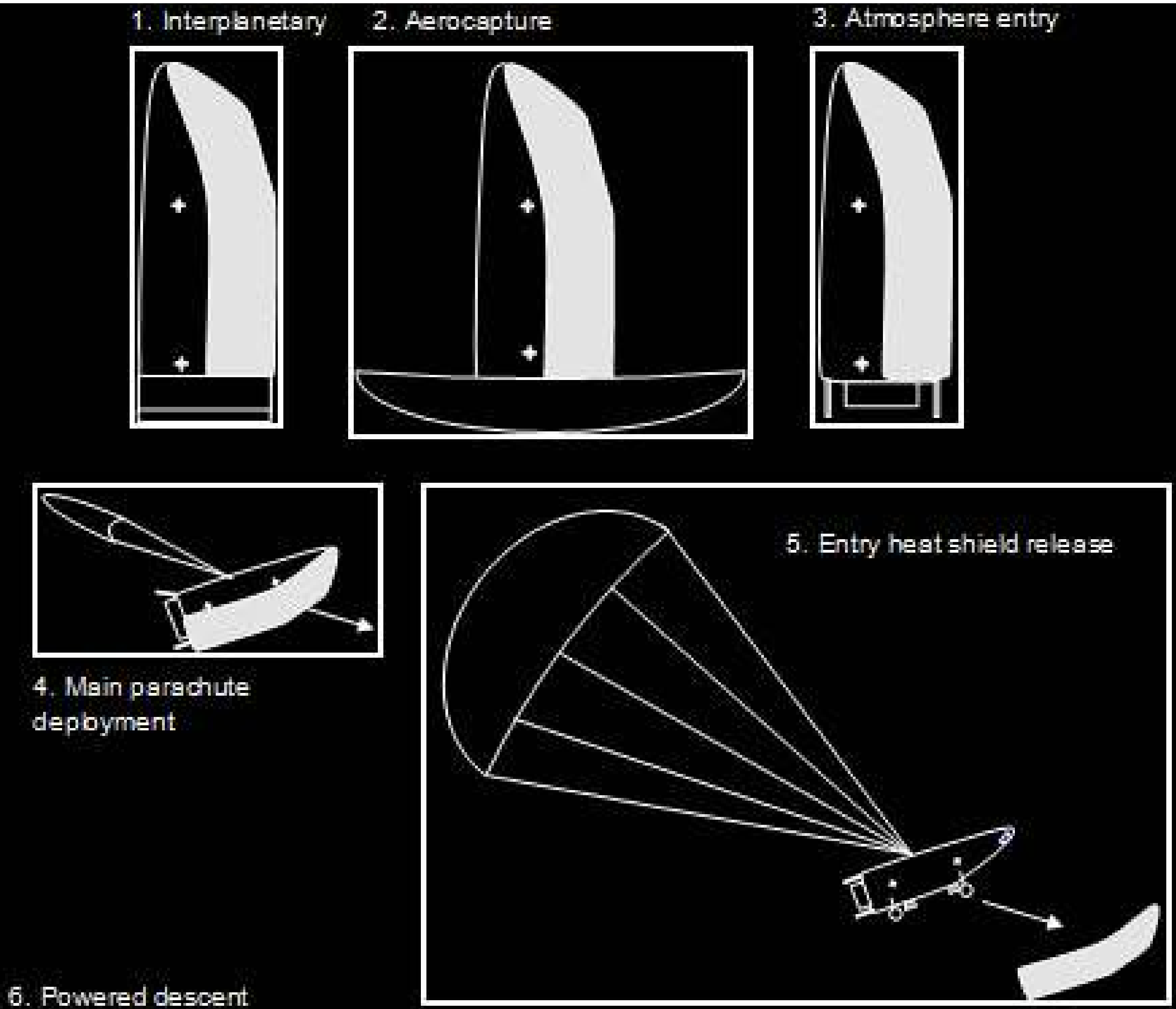
Model developed by Andrew McSorley

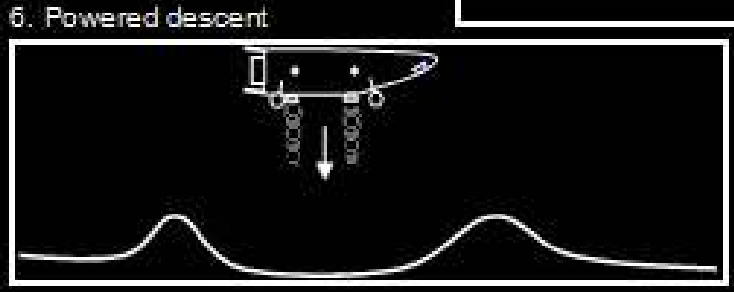
Background image credit: NASA

lessens learned: higher lift...

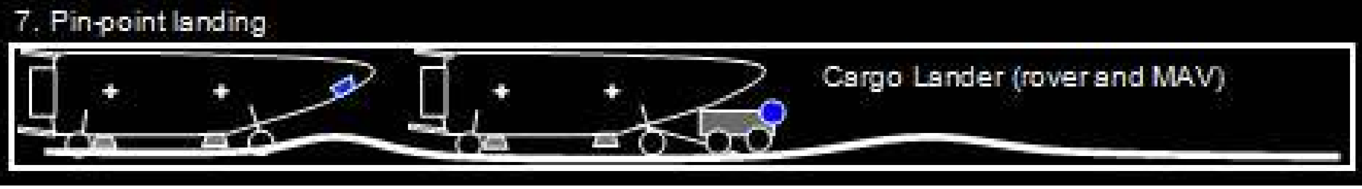
Light weight aerocapture heat shield to give a good payload adantage. Can be used without interfering with descent heat shield TPS. Descent heat shield can be released before PDS. Good payload efficiency. Easy to expose descent engines and landing gear.

Low L/D, a guidance algorithm and an accurate IMU can reduce error to <1 km at chute deploy. Also take care designing in lift at the expense of drag area (Braun & Manning, 2006).





Long biconic shape has mass disadvantage over squat Mars Direct design type. ~few (2?) mT



Acknowledgements

Thanks to the **Space Division, FMI** and **Walter Schmidt** for supporting this work. **Janne Kauhanen** for exporting MLAM data into a text file for me and answering numerous questions about MLAM. **Sini Merikallio** for providing images of her time at MDRS and her interest in this work. **Bruce Irving** for starting all this with the virtual prototyping paper and presentation at the Mars Society conference. **Andrew McSorley** for encouragement and assistance during the model building phase of the VP project. **Grant Bonin** for letting us play around with his Mars for Less mission. **The Open University** for use of a personal computer, for initial prototyping, and for the use of other supporting facilities. **Catherine Maguire** for being human (and an engineer), ”getting” the VP stuff and for invaluable e-mails of support. **Seth Hollingsead** for inviting me onto the Mars Direct for Orbiter group. **Urwumpe** on the Orbiter web forum for supplying me with a crucial piece of information on how the Apollo CM flies. And **Martin Shweiger** for the amazing Orbiter space flight simulator!

Thankyou very much for your attention ☺

References & links

Allouis, E., Ellery, A. and Welch, C. S., 2003, Parachutes and inflatable structures: parametric comparison of EDL systems: parametric comparison of EDL systems for the proposed Vanguard mission, Paper IAC-Q.3b.04, IAF Bremen

J. **Balaram**, R. Austin, P. Banerjee, T. Bentley, D. Henriquez, B. Martin, E. McMahon, G. Sohl, 2002, DSENDS – A high-fidelity dynamics and spacecraft simulator for entry, descent and surface landing, Jet Propulsion Laboratory, California Institute of Technology

Bolling, L., 1968, Apollo 6 entry postflight analysis, Mission Planning and Analysis Section, NASA, Manned Spacecraft Center, Houston, Texas

Bonin, G., 2006, Reaching Mars for less: The reference mission design of the MarsDrive Consortium, 25th International Space Development Conference, Los Angeles

Braun, B. D., Wells, G. W., Lafleur, J. W., Verges, A. A. and Tiler, C. W., Entry, Descent and Landing Challenges of Human Mars Exploration, *29th AAS Guidance and Control Conference*, AAS 06-072, Breckenbridge CO, 2006.

Braun, W., Das Marsproject, Umschau Verlag, 1952, 82 S.

CFM, 1984, see http://spot.colorado.edu/~marscase/cfm/cfm84/cfm84plan.html

Clark, B. C., 1978, The Viking results – The case for man on Mars, In: The future United States space program; Proceedings of the Twenty-fifth Anniversary Conference, Houston, Tex., October 30-November 2, 1978. Part 1. (A79-34860 14-12) San Diego, Calif., American Astronautical Society; Univelt, Inc., 1979, p. 263-278.

Condon, G., Tiggs, M., Crus, M. I, Entry, Descent, Landing and Ascent, 1999, In J. Larson and L. K. Pranke (eds.) *Human Spaceflight: Mission Analysis and Design*, New York: McGraw-Hill, pp. 272-330

DRM 1.0, NASA, see: http://exploration.jsc.nasa.gov/marsref/contents.html

Drake, Bret U, Editor, Reference Mission Version 3.0 - Addendum to the Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team, NASA Special Publication 6107-ADD EX13-98-036 June 1998.

Drake, B. G. (Editor), 1998, Reference Mission 3.0 Addendum to the Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team, Lyndon B. Johnson Space Center

Esa, 2005, Inflatable technology demonstrator, http://www.spaceflight.esa.int/irdt/factsheet.pdf

Franklin P. Dixon, Summary Presentation: Study of a Manned Mars Excursion Module," *Proceeding of the Symposium on Manned Planetary Missions: 1963/1964 Status*, NASA TM X-53049, June 12, 1964, pp. 443-523; paper presented at NASA Marshall Space Flight Center, Huntsville, Alabama.

Inranzo-Greus, D., 2005, Ariane 5 – A European launcher for space exploration, Towards a European Infrastructure for Lunar Observatories Workshop, Bremen

Irving, B., Bruce's space exploration and Orbiter related blog**,** http://flyingsinger.blogspot.com/

Irving, B., Sorley, A., Paton, M. and Bonin, G., 2006, Virtual prototyping of human Mars missions with the Orbiter space flight simulator, Mars Society Conference, Washington, DC

Hammock, D. M. and Jackson, B. G., 1963, Vehicle design for Mars Landing and Return to Mars Orbit, Exploration of Mars, AAS Technical Series, v15, ed. G. W. Morgenthaler

Keys, A. S., Hall, J. L., Oh, D. and Munk, M. M., 2006, Overview of a proposed flight validation of aerocapture system technology for planetary missions, 42nd AIAA ASME SAE ASEE Joint Propulsion Conference and Exhibit; 9-12 Jul. 2006; Sacramento, CA; United States

References & links

LaFarge, R. A., 1994, A novel CFD/structural analysis of a cross parachute, Aerospace Sciences Meeting and Exhibit, 32nd, Reno, NV, Jan 10-13. AIAA-1994-752
Lepsch, G., 2005, http://www.guilherme.tk/
NASA/JPL, 2006, Water Map, http://mars.jpl.nasa.gov/odyssey/technology/grs.html
McSorley, A., Orbiter forum development thread for NASA DRM 3.0, http://orbit.m6.net/Forum/default.aspx?g=posts&t=11632
Paton, M., Mark Paton's website, http://www.freewebs.com/markpaton/
Paton, M. D., 2005, Penetrometry of NEOs and other Solar System bodies, PhD thesis, the Open University, UK
Portree, D. S. F., Humans to mars - 50 years of mission planning; Nasa Monographs of aerospace history 2001
Raiszadeh, B. and Queen, E. M., 2002, Partial validation of multibody program to optimize simulated trajectories II (POSTII) parachute simulation with interacting forces, Langley Research Center, Hampton, Virginia, NASA/TIM-2002-211634
Ride, S., 1987, A report to the administrator, published online by NASA, contents can be accessed from this link: http://history.nasa.gov/riderep/begin.htm
Rodin, A. V. and Wilson, R. J., 2006, Seasonal cycle of Martian climate: Experimental data and numerical simulation, Cosmic Research, v44, issue 4, pp. 329-333
Sanchez, B. V., Rowlands, D. D. and Haberle, R. M., 2006, Variations of Mars gravitational field based on the NASA/Ames general circulation model, Journal of Geophysical Research, v111
Schweiger, M., "Orbiter: A Free Spacecraft Simulation Tool," *2nd ESA Workshop on Astrodynamics Tools and Techniques*, ESTEC, Noordwijk. 13-15 September 2004 (available at www.orbitersim.com).
Schweiger, M. "Orbiter Space Flight Simulator User Manual: 2006 Edition," web-based publication available from http://orbit.medphys.ucl.ac.uk/manual.html.
SEI, 1989, Document online here: http://history.nasa.gov/sei.htm
Siili, T., Kauhanen, J., Harri, A-M, Schmidt, W., Järvenoja, S., Schmidt, W., Järvenoja, S., Read, P. L., Montabone, L. and **Lewis**, S. R., 2006, Simulations of atmospheric circulations for the Phoenix landing area and season-or-operation with the Mars Area Model (MLAM), Fourth International Conference on Mars Polar Science and Exploration, Octobe 2-6, Davos, Switzerland, LPI Contribution No. 1372, p. 8049
Striepe, S. A., Way, D. W., Dwyer, A. M. and Balaram, 2002, Mars Smart Lander simulations for entry, descent and landing, AIAA Atmospheric Flight Mechanics Conference and Exhibit, 5-8 August 2002, Monterey, California
Stuhlinger, E. "Possibilities of Electrical Space Ship Propulsion," Proceedings of the V International Astronautical Federation Congress, Innsbruck, 5-7 August 1954. 100 - 119.
Vinka, "Spacecraft3.dll full package," 2006 download, http://users.swing.be/vinka/spacecraft3_060302.zip.
Wolf, A. A., Graves, C., Powell, R. and Johnson, W., 2004, Systems for pinpoint landing at Mars, AAS 04-272
Zubrin, R., Baker, D., and Gwynne, O., "Mars Direct: A Simple, Robust, and Cost Effective Architecture for the Space Exploration Initiative", AIAA 91-0326, *29th Aerospace Sciences Conference*, Reno NV., January 1991.
Links