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Virtual prototyping of human Mars missions with the Orbiter space flight simulator

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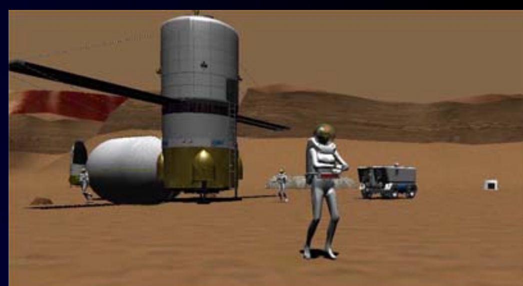

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Presentation outline

- Background
- Orbiter space flight simulator
- Modeling space systems in Orbiter
- *Mars for Less* – mission profile summary
- Spacecraft modeling for MFL
- Propulsion system modeling and TMI simulation
- Tether system simulation – LEO assembly and pseudo-G
- EDL simulation and test flight results
- Summary and questions

- Credits
- Resources

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Background

- Virtual prototyping of human Mars missions in a suitable space flight simulator can be a powerful supplement to conventional mission planning methods
- Orbiter is an excellent platform for this application – it has been used to model many historical, current, and proposed space systems, some in great detail
- Virtual prototyping can be done even at the preliminary analysis stage of mission planning, providing useful data from virtual "test flights" as well as excellent static and dynamic visualization of mission elements
- A *Mars for Less* add-on was developed and tested as an example of virtual prototyping possibilities of Orbiter
- This presentation and associated paper will demonstrate the approach and show the quality of visualization and the level of technical detail that can be achieved

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Orbiter space flight simulator

- Orbiter is a real-time space flight simulator – it features:
  - Modeling of atmospheric flight (launch and re-entry), sub-orbital, orbital and interplanetary missions (rendezvous, docking, transfer, swing-by etc.).
  - 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 recreational Windows application for space flight simulation.
  - 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, autopilots, etc. can be defined and flown.
  - Orbiter 2006 is freeware, courtesy of its author, Dr. Martin Schweiger of University College London.

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Orbiter example graphics

- Orbiter operates from a first-person (pilot's) perspective
- Both 3D external and internal "cockpit" views are available

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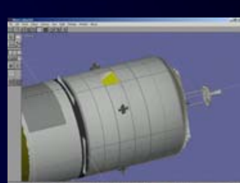
Modeling space systems in Orbiter

- Orbiter's open architecture allows easy addition of new spacecraft, launch vehicles, instruments, and planetary terrain.
- Starts with 3D graphical models of vehicle components.
- Stages and modules can be attached or docked.
- Masses, fuel, propulsion, PMI, RCS, aerodynamics, etc. can be defined in several ways including custom DLL programming.



3D modeling
(anim8or freeware)

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Mars for Less: Mission profile summary

- *Mars for Less** is a modular plan adapted from *Mars Direct*
- Modules sized for launch with existing MLLV's (~25 t per launch)

- Modules to be designed for LEO assembly with minimal EVA (i.e., use of semi-autonomous propulsion modules)
- Six MLLV launches (two spacecraft modules, four propulsion modules) needed for ERV and MTSV, for a total of 12 launches.
- ERV launches with no crew ~2 years before MTSV, landing on Mars to establish remote/robotically controlled ISRU operations to produce propellants (CH_4/O_2) for crew's future return to Earth

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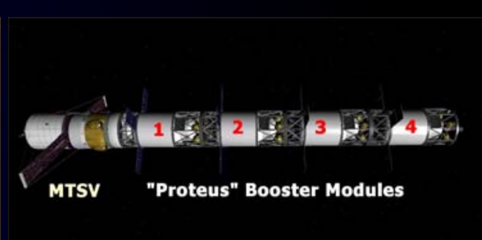
* G. Bonin, "Reaching Mars for Less: The Reference Mission Design of the MarsDrive Consortium" (ISDC 2006, May 2006)

Mars for Less: MTSV and ERV

ERV (Earth return vehicle) & MTSV (Mars transfer & surface vehicle)



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Mars for Less: Orbital assembly

- MTSV and ERV will each launch in two modules with relatively complex LEO assembly, probably requiring astronaut EVA and "tug" support by CEV or similar spacecraft as shown here:

- "Proteus" booster module linkage is simpler (e.g., no life support systems) and could be designed for remote control, semi-autonomous docking-type assembly in LEO

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Spacecraft modeling for MFL

- MTSV and ERV are both multi-module (LEO assembled) vehicles with multiple mission phase configurations and various deployable systems, modeled for Orbiter in 3D with animated components
  - Supports LEO assembly and docking simulations
  - ERV spacecraft is also multi-stage, with lander and two-stage Earth return propulsion
  - Deployables include solar arrays, antennas, aeroshields, parachutes, and more
- The spacecraft.dll module (variants 1, 2, and 3) was used to support modeling and animation of complex interacting systems without custom programming
  - It allows easy access to Orbiter's internal capabilities including aerodynamics, propulsion, staging, animation, etc.
  - Dozens of spacecraft properties are defined via text files

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Spacecraft modeling example: ERV

- The ERV evolved from a simple cylinder to a two-stage Mars ascent vehicle with a biconic Earth entry module
- These modeling and Orbiter screens suggest the intricacy of the 3D model (in addition to animations and modeling of operational details needed for physical simulations)

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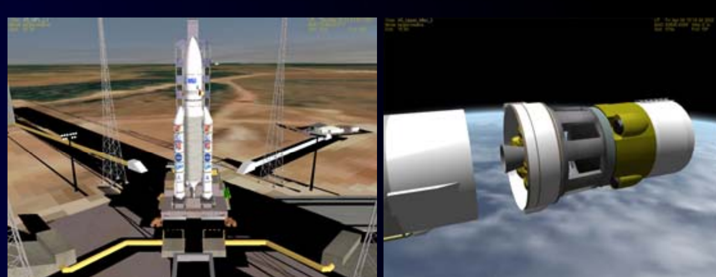
Propulsion system modeling for MFL

- Existing model of Ariane-5 with an advanced upper stage was used as the MLLV for this simulation though others would also be feasible
- New 25 t modular booster design called “Proteus” was modeled for this project
- Four of these propulsion modules would be assembled in LEO to later perform staged TMI over four orbits



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Ariane-5 modeling ("typical" MLLV)

- We used a freely modifiable Ariane-5 model, enhancing its main engine (Vulcain-3) per announced ESA plans
- Also designed expanded fairing for larger-diameter (~6m) MTSV / ERV but decided to stay with 4.5 m size for now

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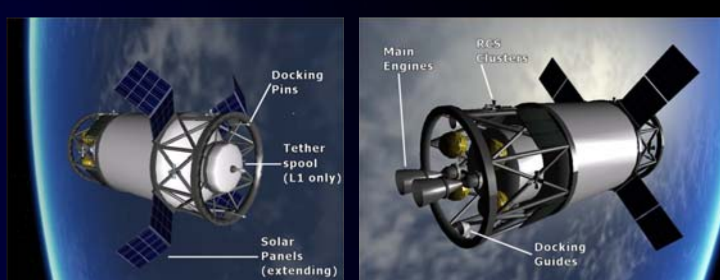
"Proteus" modular stage

- A modular TMI stage was modeled for this Orbiter project
  - Two Vinci LH2/LOX engines (ISP 465 s, total thrust 360 kN)
  - 25 t mass (22 t propellants, 2 t structure, 1 t insulation/RCS)
  - Solar panels, guidance, docking, and com systems
- MLLV upper stage would deliver each Proteus close to the assembly point where semi-autonomous/remote control systems, RCS, and possibly tethers would allow alignment/docking



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Staged TMI (trans-Mars injection)

- Mission starts with LEO assembly of ERV or MTSV "stack"
    - 200 km, 28.5° assembly orbit (OK for Kourou and KSC)
    - Rendezvous/docking simulation with standard Orbiter tools
- Use of 4 TMI booster modules needs special flight planning
    - Basic idea is four boosts at successive periapses
    - Interplanetary MFD (IMFD) add-on allows this trajectory planning and even auto-burn support within Orbiter itself

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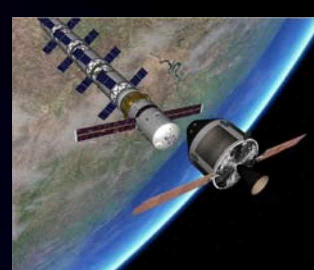
Crew transfer simulation

- After assembly in LEO (possibly assisted by assembly and checkout crews), the four-member Mars crew would launch for transfer to the MTSV
- In our simulation, we assumed development of the NASA CEV and CLV (Ares I), using existing Orbiter add-ons
- Other crew transfer options may be possible in real life and in Orbiter (e.g., t/Space CXV add-on model now available)



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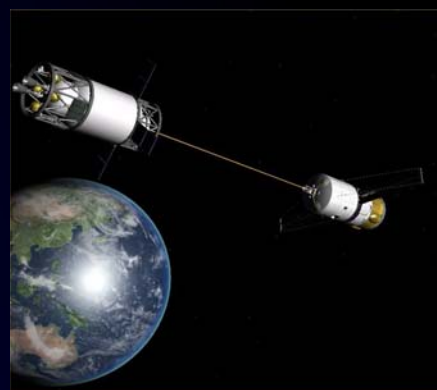
Tether system simulation

- Tethers have a number of potential uses in space systems
  - Assist in remote-control or EVA-assisted orbital assembly
  - Long tether can be used to rotate spacecraft with spent final stage to generate 0.4g artificial gravity
- Tether MFD add-on used in Orbiter to experiment with these uses in the MFL mission



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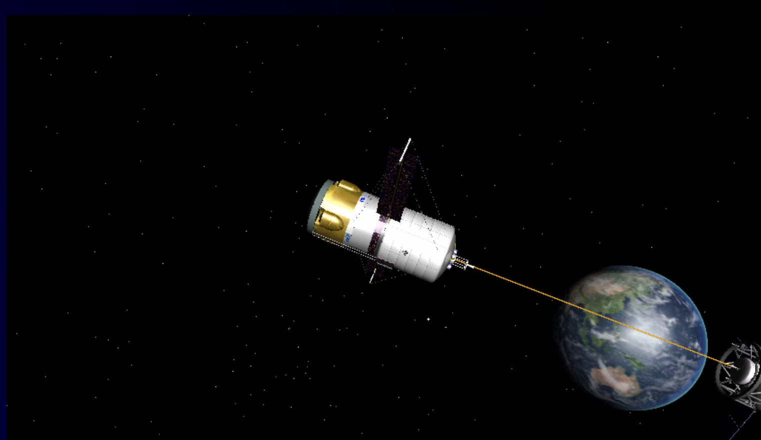
Tether rotational gravity test video

- Short tether and fast spin used here for illustrative purposes
- For 0.4g, ~1500 m tether would be used at ~2 RPM



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Entry/Descent/Landing (1): Overview

- Inflatable aeroshield was assumed for two mission phases
  - Aerocapture into Mars parking orbit
  - Precision EDL from Mars orbit to planned site using aeroshield, chutes, and descent engines for landing
- Model includes guidance to entry corridor, auto or manual chute deployment, and automated rocket powered final approach and landing (manual override is possible)

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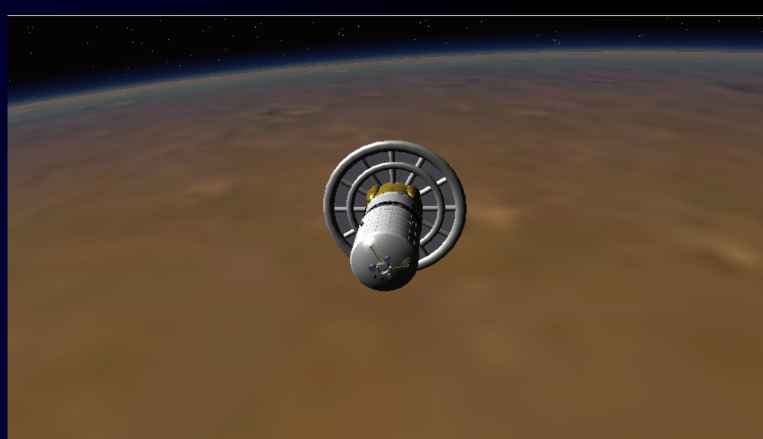
EDL (2): Simulation video

- This 1:54 video has clips from each EDL phase
- Actual total time from 100 km entry interface ~11 minutes



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EDL (3): Iterative design process

Heat shield issues

1. **Obstruction of solar panels**
2. **Integration onto Proteus stack**
3. **Thermal environment during entry**
4. **Safe g levels for crew**
5. **Positive separation after entry**

Iterative design process

Parachute issues

1. **Mach number deployment**
2. **Size**
3. **Safe g level**

Propulsive deceleration and landing issues

1. **Engine thrust**
2. **Cross-range**

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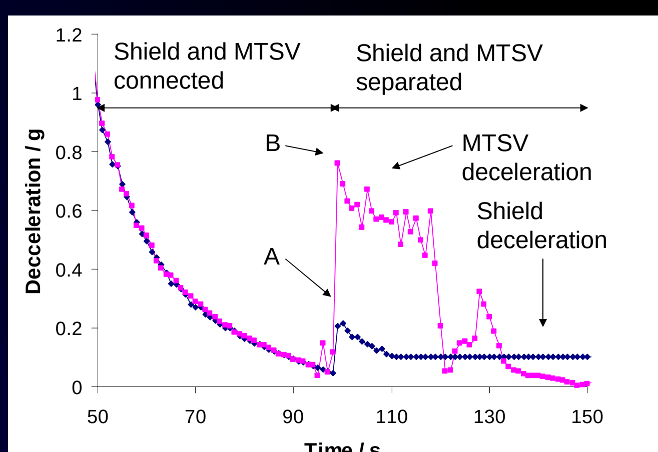
EDL (4): Early test flights

- One of the first problems was that the heat shield stuck to the MTSV.
- A brief pulse of main engine thrust gives adequate deceleration for heat shield separation (B>A required) and the subsequent soft landing.



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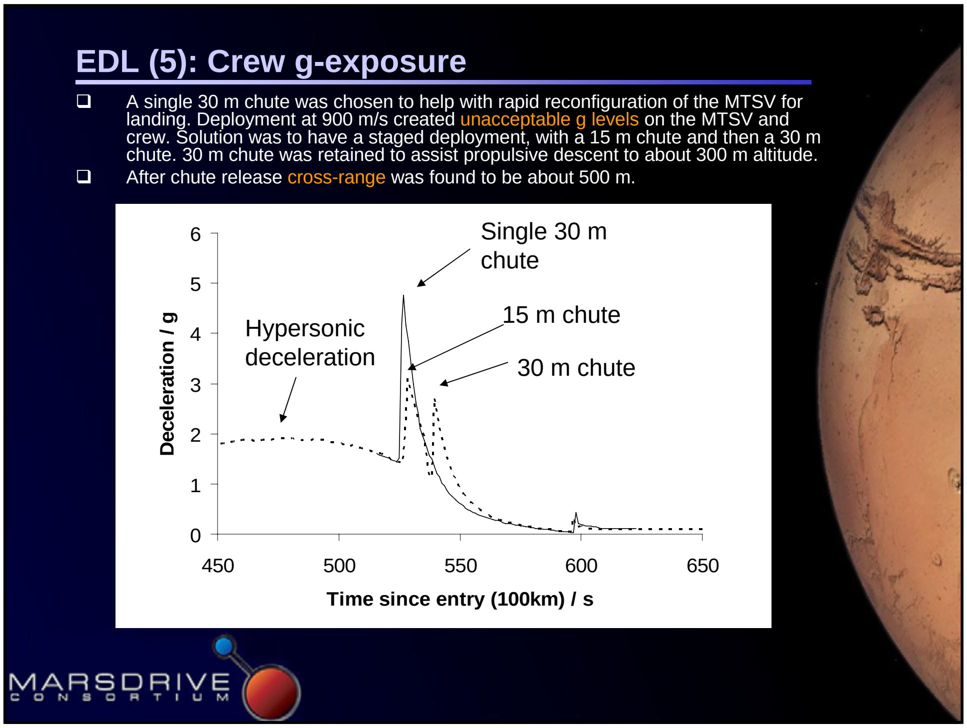
EDL (5): Crew g-exposure
A single 30 m chute was chosen to help with rapid reconfiguration of the MTSV for landing. Deployment at 900 m/s created unacceptable g levels on the MTSV and crew. Solution was to have a staged deployment, with a 15 m chute and then a 30 m chute. 30 m chute was retained to assist propulsive descent to about 300 m altitude.
After chute release cross-range was found to be about 500 m.
Single 30 m chute
15 m chute
30 m chute
Hypersonic deceleration
Deceleration / g
0
1
2
3
4
5
6
450
500
550
600
650
Time since entry (100km) / s
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Going Home: ERV from Mars to Earth
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Summary and questions

- The Orbiter space flight simulator provides an accurate, robust, and versatile environment for virtual prototyping of certain phases of space missions
  - Data capture from virtual test flights is possible
  - Excellent visualization and educational tool
- Because it is based on simple 3D models and directly-specified system data, one can prototype and even perform trade-off studies for aspects of space missions including propulsion, aerodynamics, trajectory planning, docking/assembly, and even Mars EDL
- The *Mars for Less* reference mission provides a challenging test for Orbiter in this application, since it includes a variety of spacecraft and modules and a substantial number of mission operations and phases
- Questions?

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Credits

- Thanks most of all to Dr. Martin Schweiger for creating Orbiter, and to the Orbiter community and members of MarsDrive Consortium for inspiration and help
- Add-ons used (see www.virtualspaceflight.com for links)
  - Orbiter Sound 3.0 by Daniel Polli
  - Spacecraft.dll modules by Vinka
  - NASA CLV (custom concept) by António "Simcosmos" Maia*
  - Interplanetary MFD by Jarmo Nikkanen
  - Ariane-5 original model by Thomas Ruth
  - Vallis Dao 3D Mars terrain by “jtiberius”
  - Tether MFD by “MattW”
  - Kourou base by “Papyref” and “Mustard”
  - NASA CEV (ESAS) by Franz “francisdrake” Berner
  - 3D models of astronauts and base objects by Greg Burch
  - Autopilot v1.7 for Orbiter by R. Bumm
  - Flight Data Recorder MFD by Matt Weidner

*Thanks to António Maia for providing customized *Mars for Less* versions of his in-work launchers for this project.

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Resources

- Orbiter resources
  - Orbiter main web site (many links): www.orbitersim.com
  - Main Orbiter add-on site: www.orbithangar.com
  - Orbiter Discussion Forum: http://orbit.m6.net/v2/boardtalk.asp
  - Introductory tutorial (*Go Play In Space*) www.aovi93.dsl.pipex.com/play_in_space.htm
  - Anim8or 3D modeling program (freeware) http://www.anim8or.com
- *Mars for Less* resources
  - MarsDrive Consortium www.marsdrive.com
  - Virtual Spaceflight www.aovi93.dsl.pipex.com/mars_for_less.htm

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