Terminal Descent and Landing System Architectures for a Mars Precision Lander

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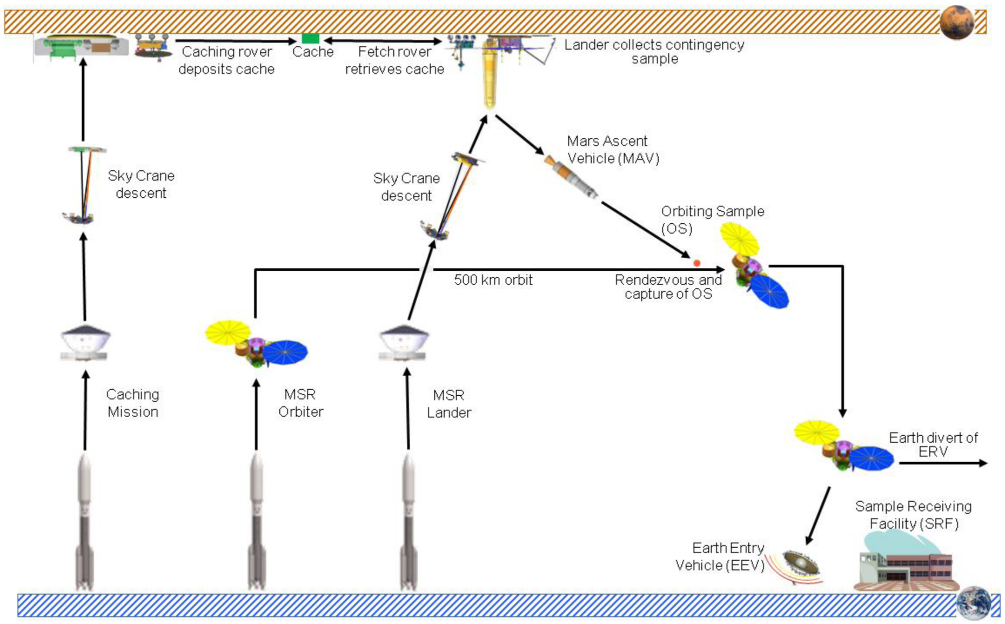
Outline

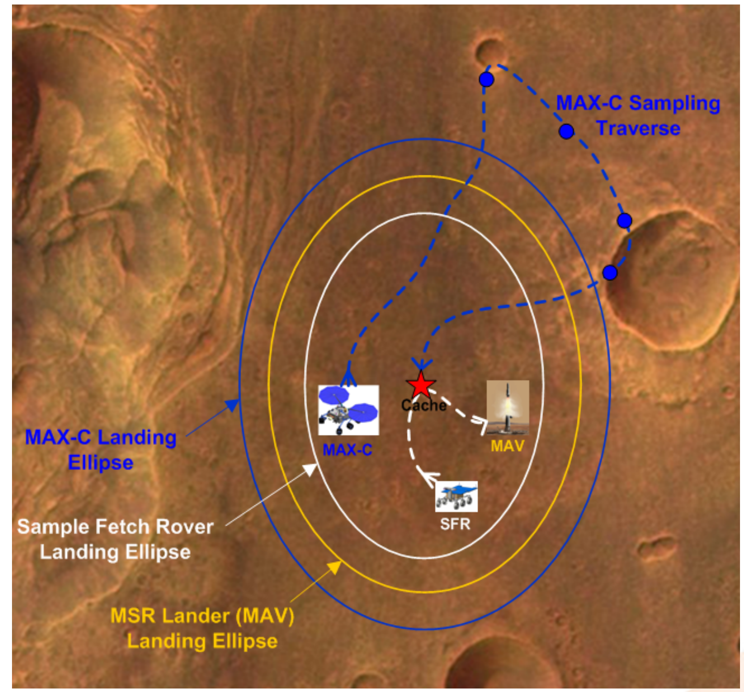
- Background
- Mars Precision Lander Mission
- Terminal Descent Architectures
- Landing/Touchdown Architectures
- Egress Architectures
- Summary and Conclusion

Background

- Mars Precision Lander is part of ESA's Mars Robotic Exploration Preparation programme
  - Currently ongoing ESA contract
- Requires landing accuracy better than 10 km with a goal of 7.5 km
  - Significantly more accurate than past Mars missions
  - Technologies to be at TRL5 by 2015
- Potential mission scenario is the safe landing of a Sample Fetch Rover as part of MSR programme
  - 2018 Sample Caching mission: Caching Rover
  - 2022 MSR Orbiter: Comms Relay and Earth Return Vehicle
  - 2024 MSR Lander: Mars Ascent Vehicle and Fetch Rover

Mars Sample Return





- Alternative scenarios could also make use of MPL
  - Larger rover that can sample, cache and return to MAV
  - Element of a network science mission
  - Stand-alone science rover mission for European technology demonstration

Mars Precision Lander Mission

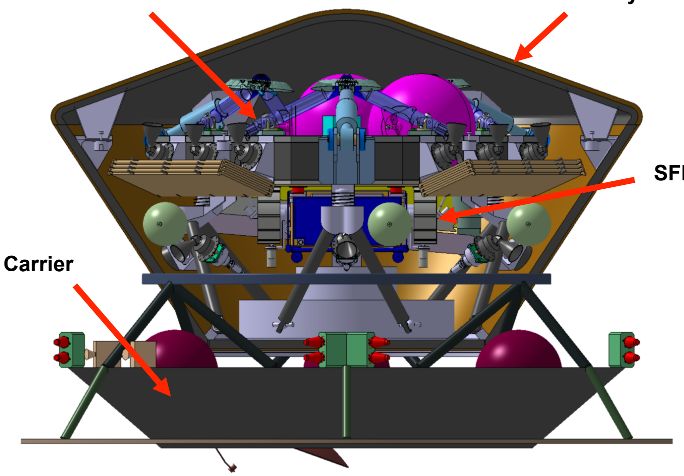
Mission Design

- Launch date will be 2022, 2024 or 2026
- Launch on a Soyuz 2.1b/Fregat M from Kourou
  - Direct transfer preferred for simplicity – 1 year duration
  - Mass constraints mean a launch into GTO or an Earth gravity assist may be necessary – 2.5 year duration

Spacecraft Composite

- Carrier Spacecraft
- Guided Entry Module (GEM)
  - Powered Surface Lander (PSL)
  - Sample Fetch Rover (SFR)

  85 kg SFR must be safely delivered



Mars Precision Lander Mission

- Mars Arrival
  - GEM released from Carrier from hyperbolic arrival trajectory
    - Hyperbolic entry to Mars limited to < 4 km/s
  - GEM mass > 1000 kg must be delivered to EIP
  - Arrival must occur outside main dust storm season and away from solar conjunctions
  - Landing site latitude 5° south to 25° north at any longitude
  - Landing altitude better than -1 km MOLA with a goal of 0 km MOLA goal

- Baseline Guided Entry Module Design
  - Rigid Viking-shape blunt capsule of 2.8 m diameter
  - Lift/drag coefficient expected 0.2-0.25 (heat flux 1600 W/m^2)
  - Ballistic coefficient expected is near 100 kg/m^2
  - Norcoat-Liège is nominal ablative material with ASTERM back-up

Mars Precision Lander Mission

Sequence after Entry Interface Point

- **Hypersonic Entry Phase:** EIP to Mach 2-5
- **Descent Phase:** end of hypersonic phase to start of terminal descent phase, including any parachutes
- **Terminal Descent Phase:** slow-down of lander to just before touchdown, typically starting with parachute release
- **Touchdown Phase:** from first point of touching the surface, including any initialisation or bouncing, to cancellation of all velocities
- **Egress Phase:** from being on the surface with no velocity to the rover being on the surface in a free state ready to start its mission

Entry and Descent

- Direct guided entry with lift modulation
- Single stage supersonic parachute of 14-16 m diameter preferred
- Frontshield separation occurs at Mach 0.4
- Powered Surface Lander separates from backshell when velocity is < 90 m/s relative to ground – expected between 1.2 and 1.7 km

Terminal Descent Architectures

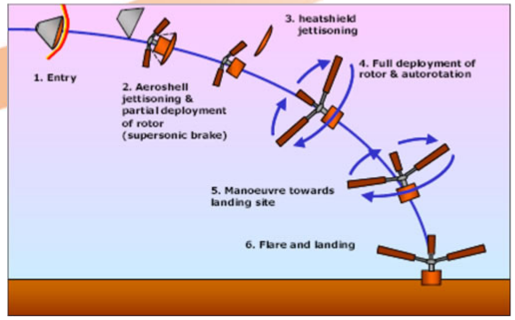
- Six promising terminal descent options identified
  1. Parafoil
  2. Auto-rotor
  3. Balloon/Zeppelin
  4. Rocket Rotor
  5. Retro Propulsion
  6. No Terminal Descent Phase

- Various other less promising concepts ruled out at an early stage as unfeasible
  - E.g. Rotating cylinder, carbon dioxide breathing engines

Terminal Descent Options

X-38

- 1. Parafoil
  - Steerable sub-sonic parachute e.g. X-38
  - Combines functionality of a parachute and a wing with high L/D ratio (> 3)
    - Achieves deceleration and some cross-range corrections
    - Requires high mass winches, ropes, motors to steer
  - Lift generated is proportional to atmospheric density
    - 100 times area required for Mars, very difficult to deploy and control
  - Wind drift is another major issue – not precise
- 2. Auto-rotor
  - Aerodynamic lift achieved by freely rotating rotor blades
    - Auto-rotation studies performed by Astrium
  - Mechanically simple and no cyclic pitch control required
  - After deployment, velocity decreases until steady state descent is achieved
  - Vertical or flare terminal descent manoeuvres possible
  - High mass concept with risky and complex deployment



Terminal Descent Options

- 3. Balloon/Zeppelin
  - After parachute phase, balloon is released during descent
    - Ambient atmospheric gas enters via hole in bottom
    - Rapid heating provides buoyancy (Montgolfieres)
  - More stable than parachutes and can soft-land payloads at <3m/s
  - Limited European work on-going – CNES and Leicester University
  - Requires very large volumes due to thin atmosphere and thus high mass
    - Considered more suitable for a long-duration aerobot

- 4. Rocket Rotor
  - Same principals as auto-rotor but with small rocket motors at the tips of the wings that can spin-up the rotor
  - Provides increased deceleration and more control of the landing
  - Rotary Rocket Inc. were developing this technology for Earth applications
  - TRL is very low for a Mars application
    - Many operational issues

Terminal Descent Options

- 5. Retro Propulsion
  - Traditionally used for Mars EDL missions
    - Viking and Phoenix used monopropellant hydrazine thrusters
    - Pathfinder and MER used solid rocket motors
  - Huge variety of retro propulsion solutions exist
    - Based on propellant and thruster configuration
  - Most advanced technology for a precise and soft landing
  - Issues with plume effects, generation of dust and thermal fluxes and pollution of landing site
  - Mars Precision Lander options:
    - Ariane 5 ECA thrusters and throttleable thrusters considered promising
    - Solids could be used in conjunction with a monopropellant system

- 6. No Terminal Descent Phase
  - Land directly on airbags or hard land
    - Deal with energy during the landing
  - Hard landing would transmit extreme and unendurable shockloads to the rover => not feasible

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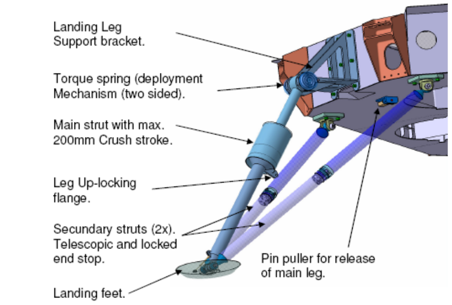
  5. Retro Propulsion
  6. No Terminal Descent Phase

Landing/Touchdown Architectures

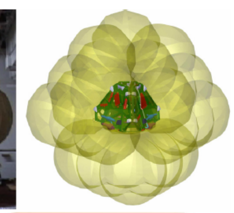
- Eight touchdown options were identified
  1. Legs
  2. Airbags
  3. Crushable Structures
  4. DropShip
  5. Shell Lander
  6. Penetrator
  7. Under-Carriage/Skids
  8. Pre-prepared Landing Structures

- Other concepts where rover had additional elements incorporated on it directly considered
  - Airbags or crushable structures on wheels/body
  - Ruled out due to concerns with separation/fouling

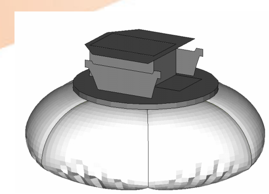


Landing/Touchdown Options

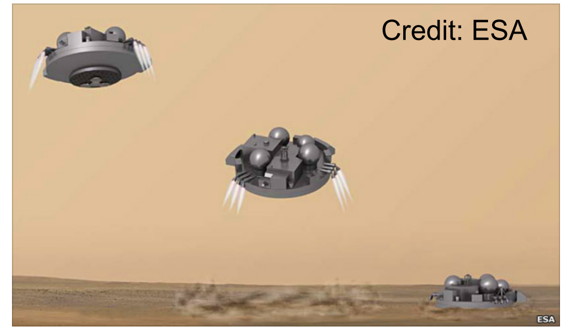
- 1. Legs
  - Commonly used in the past – Surveyor, Apollo, Viking, Phoenix
    - Fixed, flexible, or crushable legs to absorb impact load
    - Cantilever legs: secondary struts attach to outer leg for clearance
    - Inverted tripod legs: secondary struts attach to footpad for strength
  - Deployable legs required to fit within aeroshell => mechanisms
  - Plastically deformable aluminium honeycomb dampers
  - High mass option particularly if hazard avoidance is not used
    - Legs would require levelling capability to survive rocks/slopes



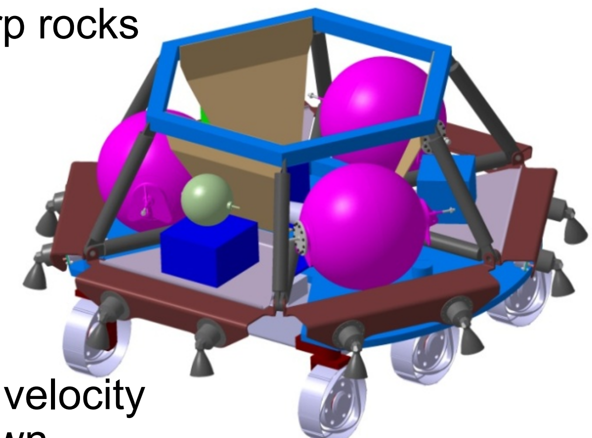
- 2. Airbags
  - Unvented – 'bouncy ball' airbags have Mars heritage
    - Completely surround payload with protective cocoon
    - Not precise, bounce many times before coming to rest
    - Heavy material and substantial lander structure required to self-right
  - Vented – releases airbag gas through a vent on landing
    - Significant risk of toppling if any horizontal velocity present
    - Very sensitive to winds
  - Egress very challenging for both concepts – retraction



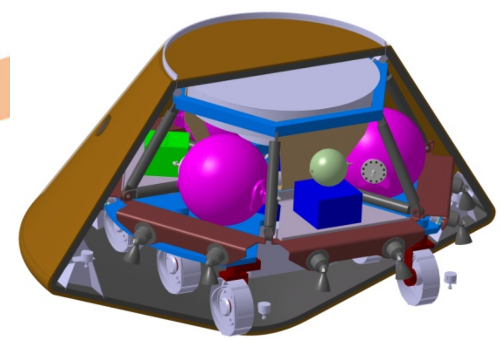
Landing/Touchdown Options



- 3. Crushable Structure
  - Landing platform has crushable structure underneath
  - Layers of aluminium honeycomb appear most suitable
    - Different staggered materials allows tuning of damping
  - Susceptible to rocks/toppling and horizontal velocity
    - Tilted impacts of up to 18° possible with minimal bounce
  - Crushable material sensitive to shear forces and sharp rocks
  - Used on ESA's 2016 EDM mission



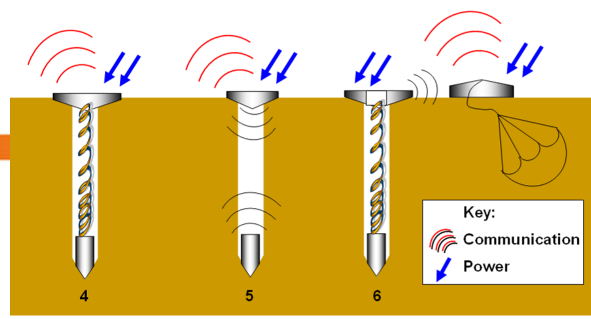
- 4. DropShip
  - Based on NASA's Skycrane approach
    - Powered descent stage with retropropulsion
    - Rover touches down on its wheels or pallet, lowered by a cable system
    - Soft touchdown possible with minimal horizontal velocity
    - Cable system cut immediately following touchdown
    - DropShip pitches and throttles to crash-land
  - Removes mass of touchdown and egress systems
  - Requires more capable rover with larger footprint
  - Flexible to different payloads and missions



Landing/Touchdown Options

- 5. Shell Lander
  - Payload totally encapsulated by protective shell
  - Lands on surface after an extended parachute phase
    - Difficult to control landing ellipse precision
  - Crushable (honeycomb or metallic foam), airbag, or combination absorbs impact loads – inside or outside shell
  - Hard shell poses egress difficulties (although self-righting)
  - Loads induced to rover are very challenging requiring significant redesign
    - More suited to static landers

- 6. Penetrator
  - No attempt at soft landing – impact energy absorbed in Martian surface
  - Forebody absorbs impact loads, aftbody contains rover on surface
  - Very high impact loads – hits surface at > 400 km/h
    - Would shatter shell and protective devices
    - Extremely complex/impossible to build such a shock-resistant rover



Landing/Touchdown Options

- 7. Under-carriage/Skids
  - Landing on skids is only useful with high horizontal velocity
    - i.e. parafoil or balloon terminal descent
  - Terrain must be flat and rock free – not common on Mars
  - High risk concept with significant likelihood of catching/toppling
  - Eliminated for Mars Precision Lander

- 8. Pre-prepared Landing Structures
  - Novel concept - a suitable landing surface is ejected ahead of the lander or laid down on a previous mission
    - Airbags, nets, crushable structure, foams
  - Any addition of a previous mission is outside the MPL scope
    - Landing accuracy on order of metres required – very stringent
  - Eliminated for Mars Precision Lander

Landing/Touchdown Architectures

- Eight touchdown options were identified
  1. Legs
  2. Airbags
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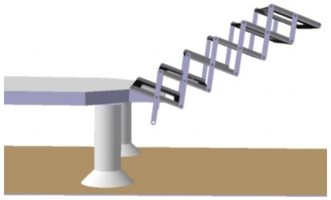
Egress Architectures

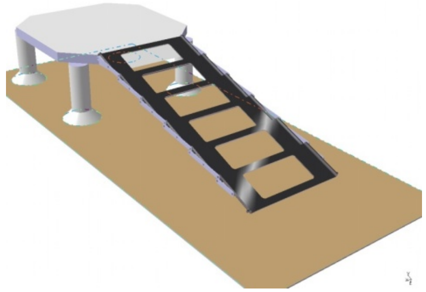
- Safe egress of rover is highly interlinked with terminal descent and landing architecture

- Six egress options considered
  1. Mechanical Ramps (folded, inflatable, rolled)
  2. Cables and Winch
  3. Crane
  4. Folding Legs
  5. Drop onto Surface
  6. Flip Rover

- Concept with highly capable robot arm on rover lifts itself down from platform was briefly considered and ruled out as out of scope

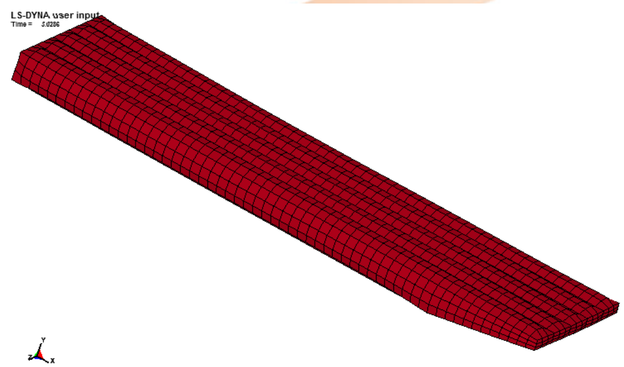
Egress Architectures



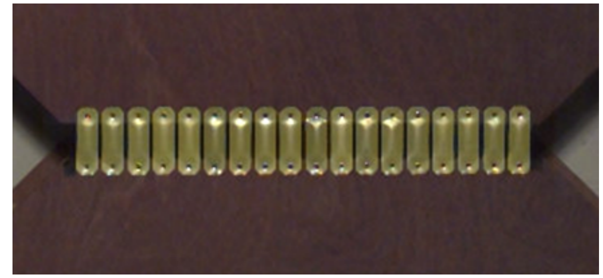


▪ 1. Mechanical Ramps

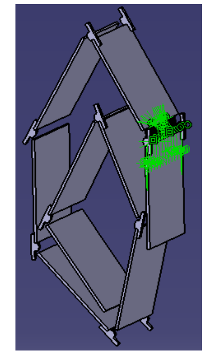
- Folded Ramps
  - Fan folded or scissor ramps deploy a number of sections that lock into place to provide rigid structure
  - Number of sections driven by volume available inside entry module
  - Deployment driven by springs or motors
  - Locking mechanisms required for fan folded ramps
  - CFRP slats give mass of ~6 kg per ramp
- Inflatable Ramps
  - Material filled with nitrogen by gas inflation system
  - Reduced stowed volume
  - Complex system with high pressure gas and number of mechanisms
  - Silicon-coated Vectran used for aircraft-escape slide like ramp
  - 5 longitudinally connected beams
  - Inflation pressure of 6 kPa sufficient
  - Mass of ~10 kg per ramp



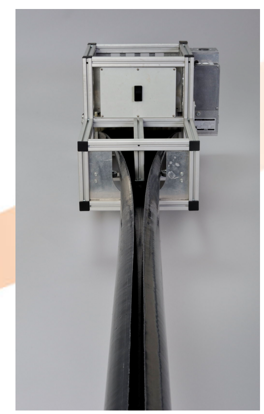
Egress Architectures

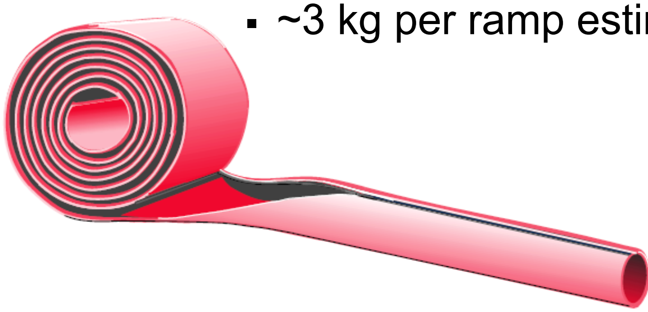


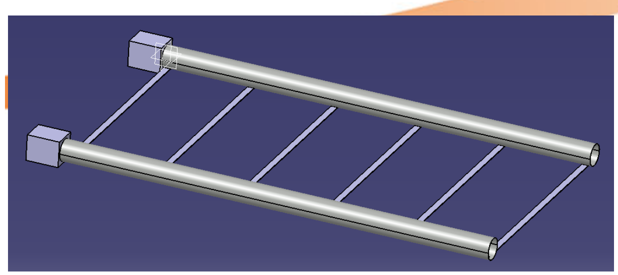
▪ 1. Mechanical Ramps cont.



- Rolled Slat Ramp
  - CFRP slats deployed by tape springs – developed by Astrium for deployable space structures
  - Significant energy stored when a tape spring pair is folded
  - High mass concept and requires large volume
  - ~9 kg per ramp estimated
- Rolled Tube Ramp
  - Bi-stable Reeled Composites (BRCs) similar to STEM members
  - Stored in a squat coiled form, deploy to long thin tube
  - Very light and stiff and stable at any point in deployment
    Glass/propylene, carbon-fibre/cyano-ester, other materials possible
  - Deployment mechanism light and simple – rollers and motor
  - BRCs form the two outer struts for a deployed ramp
  - ~3 kg per ramp estimated – very lightweight

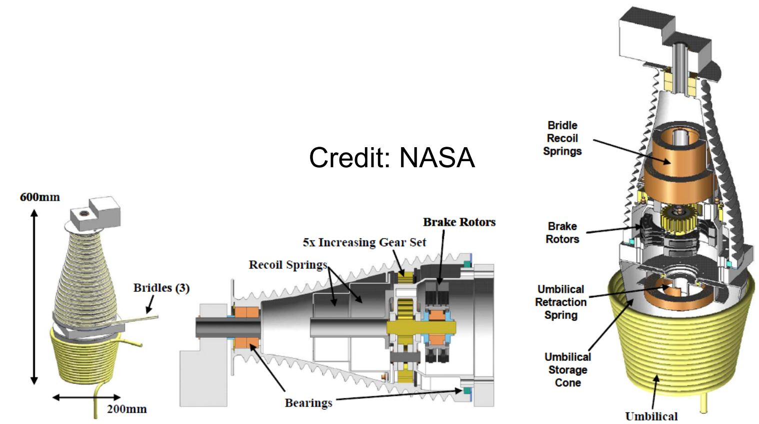






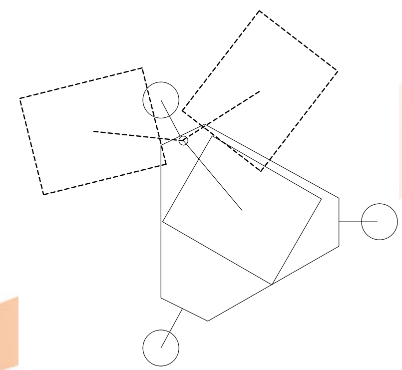
Egress Architectures

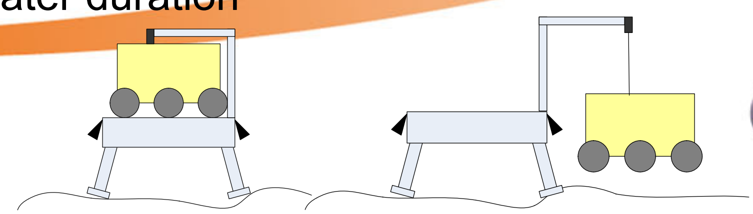
Credit: NASA



- 2. Cable and Winch
  - Applicable for the DropShip design
  - Lowers rover using a set of cables (Vectran fibres)
  - Rotating spool with brakes and gears to give a continuous feed
  - Umbilical provides electrical link to the rover
  - Pyro guillotine cutters cut the cables then umbilical after touchdown
  - Low mass egress solution of ~6 kg total

- 3. Crane
  - Rover lifted by a crane via a hard latching point
  - Rotates 180° and lowered to surface with cable/pulley system
  - Crane must be pre-attached to rover – fairing volume
  - Difficult to provide multiple egress paths
    - Extendible top bar or two cranes – each complex
  - Separate camera system needed on lander
  - Power required for greater duration
  - ~8 kg per crane





All the space you need

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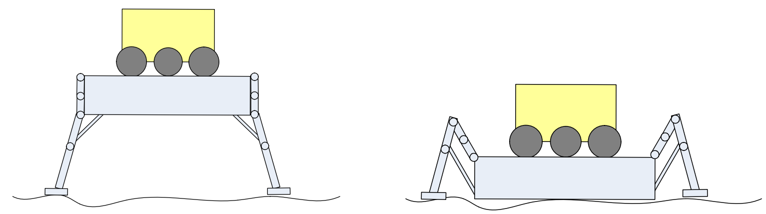
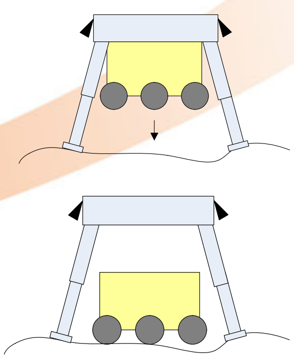
Egress Architectures



4. Folding Leg

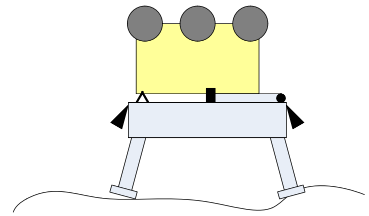
- Additional joints added to a folding leg design to allow legs to ‘fold’ and lower to the surface – extension of past Astrium research activities into levelling
- 3 rotating joints at top locked to surface platform for landing to survive impact
- Released and folding/lowering process performed
  - If surface platform height is small enough, rover could drive straight off
- Large and robust joints necessary to carry surface platform mass: ~2 kg each
- Highly complex with numerous sensors and mechanisms required
- Preliminary mass estimate of 23 kg – very heavy concept
  - Interesting only if no hazard avoidance – enables rock/slope landings

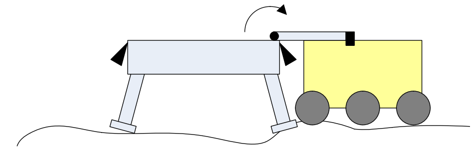
5. Drop onto Surface



- Simple concept only applicable if rover is suspended below platform
- No egress apart from a mechanical release via HDRMs
  - Rover initialised prior to release
  - Impact velocity of up to 2.28 m/s
- Prevents solar array deployment during initialisation

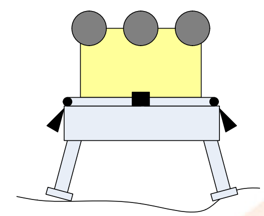
Egress Architectures





6. Flip Rover

- Rover stowed in an inverted position
- Flipped 180° by a simple robot arm and placed on the surface
  - Bipod support struts and HDRMs support rover when inverted
  - Arm attached to rover at hard latching point
  - Rotational joint at base of arm must be robust and likely heavy
- Frame could be used instead of arm for better support
- Same major issue with egress as crane – single egress path only
  - Two arms could be used, both pre-latched and one released
  - Complex with potential for failure
- Limits height of surface platform – inflexible to changes
- Entry module COG – higher due to locomotion system being at back
- Preliminary sizing gives mass of ~8 kg per flipping arm



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Summary

- Large number of terminal descent, touchdown and egress architectures are possible
  - Certain level of technology readiness needed for Mars Precision Lander
- Terminal Descent
  - Retro propulsion powered descent is most promising for precision – heritage and reliability
- Touchdown
  - Four concepts promising: legs, airbags, crushable structures and DropShip
  - Further work being performed on these currently
- Egress
  - Highly dependent on touchdown design selected
  - Legged lander, airbags and crushable structure: rolled tube ramp is very promising – low mass
  - DropShip: cables and winch mechanism necessary

Conclusion

- Selection of preferred options via trade-off analysis is forthcoming
  - In conjunction with ESA
- Second phase of Mars Precision Lander contract will focus on detailed design of selected mission architecture
  - Next IPPW we will be able to show the full design in more detail
- Prove the feasibility of a precise and safe landing system for Mars

Questions

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