Enabling Venus In-Situ Science – Deployable Entry System Technology, Adaptive Deployable Entry and Placement Technology (ADEPT):

A Technology Development Project funded by Game Changing Development Program of the Space Technology Program

What is this talk about?

- Venus is one of the important planetary destinations for scientific exploration, but...
  - The combination of extreme entry environment coupled with extreme surface conditions have made mission planning and proposal efforts very challenging
- We present an alternate, game-changing approach (ADEPT) where a novel entry system architecture enables more benign entry conditions and this allows for greater flexibility and lower risk in mission design

Outline

- Background: The challenge of entry at Venus
- Venus Mission
  - VITaL: Example Venus Lander mission to meet NRC Decadal Survey Science Recommendations
- ADEPT – Mechanically Deployable Aeroshell Integrated Approach and Results of application to VITaL mission design
- Concluding Remarks
ACKNOWLEDGEMENT

- This work is currently supported by the Game Changing Development Program of the Space Technology Program, NASA HQ.
- NASA Ames Research Center is leading this effort and is supported by NASA Langley Research Center, NASA Johnson Flight Center, NASA Goddard Flight Center and Jet Propulsion Laboratory.
- Content of this presentation was previously given at the IPPW-9 (June 2012) in two presentations by (Venkatapathy, Glaze et al)
**High-Speed Atmospheric Entry at Venus:**

The Challenge

- \( \frac{m}{CdA(\beta)} = 208 \, \text{kg/m}^2 \) (3.5m diam, 45° sphere-cone, 2100 kg entry mass)
- \( V_{\text{entry}} = 11.25 \, \text{km/s} \)
- Trajectories terminated at Mach 0.8

---

**Traditional Venus Entry:**
- Rigid 45° sphere-cone, Steep entry (-23.4°)
- Peak g-load 200-300 g’s
- Peak Heat Rate (Total) ~4000 W/cm²
- Peak Stagnation Pressure ~10 atm
- Total Heat Load ~16,000 J/cm²
- Payload Mass Fraction ~0.5

**What happens if we enter at a shallow flight path angle near skip-out (-8.5°) with the same architecture?**
- Peak g-load ~20-30 g’s
- Peak Heat Rate (Total) ~800 W/cm²
- Peak Stagnation Pressure ~1 atm
- Total Heat Load ~28,000 J/cm²
- Payload Mass Fraction ~0.2

---

**Net Effect:**
- Decreasing G-load
- Improved science capability
- Reduced heat shield carrier structure mass
- Increasing Heat Load
- Increased carbon phenolic thickness
- Increasing TPS Mass Fraction!
- Decreasing Payload Mass Fraction!

---

**Decreasing G-load**
- Improved science capability
- Reduced heat shield carrier structure mass

**Increasing Heat Load**
- Increased carbon phenolic thickness

---

**Traditional Venus Entry:**
- Rigid 45° sphere-cone, Steep entry (-23.4°)
- Peak g-load 200-300 g’s
- Peak Heat Rate (Total) ~4000 W/cm²
- Peak Stagnation Pressure ~10 atm
- Total Heat Load ~16,000 J/cm²
- Payload Mass Fraction ~0.5

**What happens if we enter at a shallow flight path angle near skip-out (-8.5°) with the same architecture?**
- Peak g-load ~20-30 g’s
- Peak Heat Rate (Total) ~800 W/cm²
- Peak Stagnation Pressure ~1 atm
- Total Heat Load ~28,000 J/cm²
- Payload Mass Fraction ~0.2

---

**Net Effect:**
- Decreasing G-load
- Improved science capability
- Reduced heat shield carrier structure mass
- Increasing Heat Load
- Increased carbon phenolic thickness
- Increasing TPS Mass Fraction!
- Decreasing Payload Mass Fraction!
High-Speed Atmospheric Entry at Venus: The Challenge

- **For rigid aeroshell entry:**
  - Ballistic coefficient 200-250 kg/m²
  - Size constrained by launch shroud
  - Entry mass constrained by launch vehicle throw capability

- **For Carbon-Phenolic TPS:**
  - Balance between TPS and Payload mass fraction leads to extreme heat flux, pressure and G’load

- **Alternate option:**
  - Design entry architecture that can operate at shallower entry flight path angle (lower g-loads) and a lower ballistic coefficient (lower heat load)
Game Changing Approach to Venus Direct Entry with a Low Ballistic Aeroshell Concept

- Assume ballistic coefficient can be lowered 10x
- A material that can sustain 250 W/cm² is now feasible
- Corresponding heatload and pressure are considerably lower as well
- Peak deceleration can be reduced by an order of magnitude
ADEPT (Adaptable, Deployable, Entry and Placement Technology) is a low ballistic coefficient entry architecture (m/CdA < 50 kg/m²) that consists of a series of deployable ribs and struts, connected with flexible 3D woven carbon fiber fabric skin, which when deployed, functions as a semi-rigid aeroshell system to perform entry descent landing (EDL) functions.

ADEPT: STP GCD Project (2yr) started in FY12 => Achieve TRL 5 at end of FY13

Project Deliverables

• Characterize thermal and mechanical performance of 3D woven carbon fiber fabric
  • Produce flight like woven fabric skin for ground test article and integrate with breadboard structural/mechanical system
  • Capable to 250W/cm²

• Perform mission feasibility study to understand operational requirements/parameters and sizing calculations

• Design, Fabricate and Test sub-scale ground test article (~2m diameter)
  • Fabricate rib/strut/ring/nose structures using COTS type extruded shapes for breadboard structural support system
  • Design and procure COTS hinge/joint/deployment mechanisms to simulate behavior of ADEPT for ground testing

• Conduct Mission Concept Assessment for potential flight demonstration
Applying ADEPT to a VISE-like Surface Mission: Venus Intrepid Tessera Lander (VITaL)

- **1 hour descent science**
  - Evolution of the atmosphere
  - Interaction of surface and atmosphere
  - Atmospheric dynamics
- **2 hours of surface and near-surface science**
  - Physics and chemistry of the crust
VITaL Strawman Science Instrument Complement

Optimistic with conventional aeroshell: steep entry angle = high g-loads

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Mass (kg)</th>
<th>Power (W)</th>
<th>Volume (meters)</th>
<th>Data Rate/Volume</th>
<th>TRL/Heritage</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral Mass Spectrometer (NMS)</td>
<td>11</td>
<td>50</td>
<td>0.26 x 0.16 x 0.19</td>
<td>2 kbps</td>
<td>High/MSL/SAM</td>
<td>Data rate during descent; reduced to 33 bps on surface</td>
</tr>
<tr>
<td>Tunable Laser Spectrometer (TLS)</td>
<td>4.5</td>
<td>17</td>
<td>0.25 x 0.10 x 0.10</td>
<td>3.4 kbps</td>
<td>High/MSL/SAM</td>
<td>Data rate during descent; reduced to 300 bps on surface</td>
</tr>
<tr>
<td>Raman/Laser Induced Breakdown Spectroscopy (LIBS)</td>
<td>13</td>
<td>50</td>
<td>Per Optical Design</td>
<td>5.2 Mb per sample</td>
<td>Medium</td>
<td>12 bit, 3 measurements per sample – one Raman and 2 LIBS</td>
</tr>
<tr>
<td>Descent Imager</td>
<td>2</td>
<td>12</td>
<td>Per Optical Design</td>
<td>6.3 Mbits per image</td>
<td>High</td>
<td>12 bit, 1024 x 1024</td>
</tr>
<tr>
<td>Magnetometer</td>
<td>1</td>
<td>1</td>
<td>0.20 x 0.10 x 0.10</td>
<td>0.064 kbps</td>
<td>High/Various</td>
<td>Data rate during descent; reduced to 6.4 kbps on surface</td>
</tr>
<tr>
<td>Atmosphere Structure Investigation (ASI)</td>
<td>2</td>
<td>3.2</td>
<td>0.10 x 0.10 x 0.10</td>
<td>2.5 kbps (descent)</td>
<td>High/Flagship</td>
<td>Data rate during descent; reduced to 6.4 kbps on surface</td>
</tr>
<tr>
<td>Panoramic Imager</td>
<td>3</td>
<td>12</td>
<td>Per Optical Design</td>
<td>16.4 Mbits per band</td>
<td>High</td>
<td>12 bit, 2048 x 2048 detector</td>
</tr>
<tr>
<td>Context Imager</td>
<td>2</td>
<td>12</td>
<td>Per Optical Design</td>
<td>25.2 Mbits</td>
<td>High</td>
<td>12 bit, 2048 x 2048 detector</td>
</tr>
</tbody>
</table>

*Data volumes include 2:1 compression*

Entry flight System

Camera/Raman/LIBS Fields of View

Stable Landing
ADEPT-VITaL Mission Quick-Look

Launch
Atlas V 551
29 May 2023

Mach 0.8: Separation Event Begins
- Mortar-deployed pilot parachute
- Aft cover release
- Pilot-deployed main parachute
- VITaL separation from ADEPT
- Cut main parachute / VITaL release

Peak Deceleration
Entry + 110s
\( q_{\text{total}} = 122 \text{ W/cm}^2 \)
\( P_{\text{stag}} = 0.24 \text{ atm} \)
29.8 G

Peak Total Heating
Entry + 100 sec
\( q_{\text{total}} = 203 \text{ W/cm}^2 \)
\( P_{\text{stag}} = 0.16 \text{ atm} \)
19.2 G

Entry Interface
29 September 2024
\( V = 10.8 \text{ km/s} \)
\( \gamma = -8.25^\circ \)
Ballistic trajectory

Targeting maneuver
Deploy ADEPT
Spin up
Release ADEPT for EDL
Cruise stage divert +1 day

16 Month Trajectory

Mach 2

Alpha Region

Landing Uncertainty

• Mortar-deployed pilot parachute
• Aft cover release
• Pilot-deployed main parachute
• VITaL separation from ADEPT
• Cut main parachute / VITaL release

• Mortar-deployed pilot parachute
• Aft cover release
• Pilot-deployed main parachute
• VITaL separation from ADEPT
• Cut main parachute / VITaL release

Mach 2
ADEPT-VITaL Design Details

- **ADEPT-VITaL Design Results:**
  - Margined mass estimates for ADEPT-VITaL entry configuration are lower than baseline VITaL
• Study Objective: assess the feasibility of the ADEPT concept by quantifying potential benefits for the NRC Decadal Survey’s Venus In-Situ Explorer (VISE) Mission and checking for potential adverse interactions with other mission elements, such as launch and cruise.

• The ADEPT project chose to study the Venus Intrepid Tessera Lander (VITaL) design, a VISE lander developed by NASA GSFC for the Decadal Survey’s Inner Planets Panel. Results are documented in the ADEPT-VITaL Mission Feasibility Report, dated 13 July 2012.

The ADEPT-VITaL Study Addresses:

• Mission Design Elements:
  – Launch vehicle
  – Interplanetary trajectory design / launch date
  – Cruise CONOPS / time of ADEPT deployment
  – Carrier spacecraft mods. / mass and power impacts
  – VITaL lander modifications and mass savings

• ADEPT-VITaL Vehicle Subcomponent Design:
  – Structures
  – Mechanisms
  – Materials

• Payload Separation Event

• Key Trade Studies:
  – Entry shape / trajectory
  – Structures and mechanisms trades

• Operating environments: stowed configuration
  – Launch vibro-acoustic
  – Cruise cold soak

• Operating environments: deployed configuration
  – Aerothermodynamic loads
  – Structural and aerelastic loads
  – Aerodynamic stability and flight dynamics

The ADEPT Team used Venus robotic as most challenging class for low ballistic coefficient decelerator applications
- Fully addressed mission feasibility
- Technology development risks identified
- Close collaboration with Venus Mission Stakeholder (GSFC: Glaze)
ADEPT Project Element Vision and Challenges

The ADEPT concept consists of a series of deployable ribs and struts, connected with flexible 3D woven carbon fabric skin, which when deployed, functions as a semi-rigid aeroshell entry system to perform entry descent landing (EDL) functions.

- Manufacture of carbon fabric as system (seams and attachment)
- Carbon fabric material withstands thermal and mechanical loads
- Aero stability of ADEPT entry system
- Fluid structure interaction of fabric at supersonic/subsonic conditions
- Stowage in launch configuration and deployment

- **ADEPT Year 1 – Budget ($3.3 M)**
  - Characterize thermal and mechanical performance of 3D woven carbon fiber fabric
    - Arcjet Testing in relevant environments
  - Develop ADEPT flight system requirements/capabilities
    - Establish end-to-end mission feasibility to support MOT
  - Start design process for Sub-scale demonstration ground test article

- **ADEPT Year 2 – Budget ($3.5M)**
  - Continue 3D woven material of Thermal and Mechanical characteristics development
  - Design, Fabricate and Test sub-scale ground test article (~2m diameter)
  - Initiate Flight Test Planning and Development
ADEPT Year-1 Major Accomplishment: Carbon Fabric Capability Demonstration

- **Bi-axial Loaded Aerothermal Mechanical (BLAM) Test**
  - **Objectives:**
    - Evaluate the carbon fabric’s structural integrity under combined aerothermal and biaxial loading. Intended to be a unit test for the acreage of the ADEPT vehicle (far away from the ribs)
    - Evaluate the rate of layer loss as a function of different combined loads.

- **Test Results:**
  - Data shows that the carbon fabric is able to maintain load at temperature.
  - Biaxial load in the cloth from 188 lbs/in to 750 lbs/in has little to no impact on the rate of layer loss of the carbon fabric.
  - Flipping the warp/weft direction had little effect on the rate of layer loss of the carbon fabric.
  - Fabric tested easily withstood a heat load of 15.7 kJ/cm\(^2\). This is well above the 11 kJ/cm\(^2\) expected for a Venus mission
# ADEPT Year-2 Technical Plan Highlights

<table>
<thead>
<tr>
<th>FY 13</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
</tr>
</thead>
<tbody>
<tr>
<td>GTA</td>
<td></td>
<td>SRR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GTA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PDR CDR C-Cloth Procurement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GTA</td>
<td></td>
<td></td>
<td></td>
<td>CDR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GTA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GTA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GTA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GTA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GTA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GTA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GTA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GTA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* *GTA tests could occur earlier by accelerating procurement of long lead items

---

**Ground Test Article**  
Deployment & Load Tests

**Radiant Testing**  
Thermal Tests

**BLAM-2**  
C-Fabric Seam Tests

**ADEPT/VITaL**  
Flight Test Planning
ADEPT Technology Maturation and Mission Applications Timeline

- **ADEPT Technology Maturation and Mission Applications Timeline**
  - Human/ Heavy Mass Mars Mission and Design Studies (FY’11)
  - ADEPT Project TRL Maturation OCT Project (FY’12 – FY’14)
  - Sounding Rocket Flight Test FY’2015
  - ADEPT Lifting -TRL Maturation Project (FY’14 – FY’17)
  - Lifting Concept Flight Demos (> FY’2022)
  - ADEPT Ballistic for Robotic Mars (~2020)
    - MER/MSL class
    - High altitude access
    - Non-Lifting, Subsonic Parachute
  - Robotic Science Venus, Saturn New Frontier & Flagship Class (~2020)
  - Human Mars (~2035)
Concluding Remarks

• **ADEPT, a Low Ballistic Coefficient, Mechanically Deployable Entry System Architecture is a Game Changer:**
  – Dramatically decreases severity of the entry environment conditions due to high altitude deceleration
  – Enables use of delicate and sensitive instrumentation
  – Use of flight qualified instrumentation for lower g-load at Mars and elsewhere
  – Entry mass and the launch mass are considerably reduced
  – Mission Risk and Cost, once the technology is matured and demonstrated, will be reduced considerably

• **GCD investment in ADEPT, mechanically deployable aeroshell technology, has broad payoff for Solar System Exploration and Science including Venus**

• **Continued Technology Maturation of ADEPT concept by 2015/2016 will**
  – Enable Venus Missions with more comprehensive science to be a top contenders for the next round of New Frontier AO
  – Continue Deployable Entry Concept development for Mars robotic and eventual human exploration missions
Backup
Design/Analysis Accomplishments
Flight Aerodynamics

Key Points:
• Static aerodynamics and dynamic stability of open-back configurations
• Flow-structure interaction and determination of “flutter” boundary (if any) at supersonic speeds

Accomplishments:
• Static aerodynamic database completed up to Mach 2 using 3D CFD code DPLR
• Wake and vehicle dynamics computations with 3D CFD code Us3D (pitch damping characteristics)
• Model developed for flow-structure interaction and incorporated into 3D CFD code Us3D
• Assume ballistic coefficient can be lowered 10 x

• A material that can sustain 250 W/cm² is now feasible

• Corresponding heatload and pressure are considerably lower as well

• Peak deceleration can be reduced by an order of magnitude
### ADEPT-VITaL Design Details and MEL

<table>
<thead>
<tr>
<th>Item</th>
<th>ADEPT-VITaL CBE (kg)</th>
<th>ADEPT-VITaL Margined (kg)</th>
<th>VITaL Baseline Margined (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probe</td>
<td>1,621**</td>
<td>2,100**</td>
<td>2,758</td>
</tr>
<tr>
<td>Spacecraft</td>
<td>797</td>
<td>970</td>
<td>846</td>
</tr>
<tr>
<td>Satellite Dry Mass (Probe + Spacecraft)</td>
<td>2,418</td>
<td>3,070</td>
<td>3,858</td>
</tr>
<tr>
<td>Propellant Mass</td>
<td>1,111</td>
<td>1,122***</td>
<td>356</td>
</tr>
<tr>
<td>Satellite Wet Mass</td>
<td>3,529</td>
<td>4,192</td>
<td>4,214</td>
</tr>
<tr>
<td>Atlas V 551 Throw Mass Available to Lift Wet</td>
<td></td>
<td></td>
<td>5,140 kg</td>
</tr>
</tbody>
</table>
A DEPT

Deployable (Low-β), Shallow-γ Sweet Spot

- Low-β entry, results in high altitude deceleration where the resulting entry aerothermal environment is benign
  - Well within the capability of carbon cloth
- Furthermore, the low-β architecture allows entry with a very shallow flight path angle, dramatically reducing entry G-load

ADEPT key benefits:
1. No need for carbon phenolic
2. Benign entry G-load
   - Simplifies qualification of scientific instruments
   - Reduced structural mass of payload
   - Opens doors for improved science return using more delicate instruments
# ADEPT-VITaL Master Equipment List and Comparison with VITaL

**ADEPT Aeroshell**

<table>
<thead>
<tr>
<th>Item</th>
<th>CBE [kg]</th>
<th>Composite Mass Growth Allow. [%]</th>
<th>ADEPT MEV [kg]</th>
<th>VITaL MEV [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Shield</td>
<td>484</td>
<td>30%</td>
<td>629</td>
<td></td>
</tr>
<tr>
<td>Main Body</td>
<td>233</td>
<td>30%</td>
<td>303</td>
<td></td>
</tr>
<tr>
<td>Nose cap &amp; Lock Ring</td>
<td>61</td>
<td>30%</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>Ribs &amp; Bearings</td>
<td>46</td>
<td>30%</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Struts &amp; End Fit</td>
<td>42</td>
<td>30%</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>Joint Hardware</td>
<td>10</td>
<td>30%</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Carbon cloth</td>
<td>92</td>
<td>30%</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>Rigid Nose TPS</td>
<td>71</td>
<td>20%</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>-Nose tps</td>
<td>50</td>
<td>20%</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>-Ribs tps</td>
<td>12</td>
<td>20%</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>-Aft cover TPS</td>
<td>9</td>
<td>20%</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Backshell</td>
<td>30</td>
<td></td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>&quot;Payload&quot; backshell</td>
<td>30</td>
<td>30%</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>Mechanisms &amp; Separation</td>
<td>205</td>
<td></td>
<td>267</td>
<td></td>
</tr>
<tr>
<td>Overall Deployment System</td>
<td>54</td>
<td>30%</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Stowed/Deployed Latches</td>
<td>19</td>
<td>30%</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>-aeroshell separation ring</td>
<td>30</td>
<td>30%</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>-separation guide rails</td>
<td>45</td>
<td>30%</td>
<td>59</td>
<td></td>
</tr>
<tr>
<td>-backshell sep</td>
<td>7</td>
<td>30%</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>-parachute system</td>
<td>50</td>
<td>30%</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>Avionics &amp; Power</td>
<td>17</td>
<td></td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>-avionics unit</td>
<td>4</td>
<td>30%</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>-harness</td>
<td>5</td>
<td>30%</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>-power unit</td>
<td>8</td>
<td>30%</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

## ADEPT/VITaL Mass

<table>
<thead>
<tr>
<th>Item</th>
<th>CBE [kg]</th>
<th>Composite Mass Growth Allow. [%]</th>
<th>ADEPT MEV [kg]</th>
<th>VITaL MEV [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probe (Lander + Aeroshell)</td>
<td>1620.5</td>
<td>30%</td>
<td>2100</td>
<td>2758</td>
</tr>
<tr>
<td>VITaL Lander</td>
<td>813.5</td>
<td>30%</td>
<td>1058</td>
<td>1379</td>
</tr>
<tr>
<td>Lander Science Payload</td>
<td>36.9</td>
<td>30%</td>
<td>48</td>
<td>63</td>
</tr>
<tr>
<td>Mass Spec</td>
<td>8.3</td>
<td>30%</td>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td>TLS</td>
<td>3.4</td>
<td>30%</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Atmospheric Package</td>
<td>1.5</td>
<td>30%</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Magnetometer</td>
<td>0.9</td>
<td>30%</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Descent Camera</td>
<td>1.6</td>
<td>30%</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>LIBS / Raman Context Camera</td>
<td>1.8</td>
<td>30%</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>LIBS / Raman</td>
<td>9.8</td>
<td>30%</td>
<td>13</td>
<td>17</td>
</tr>
<tr>
<td>Panoramic Camera</td>
<td>2.3</td>
<td>30%</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Science Payload</td>
<td>7.5</td>
<td>30%</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>Accommodation (Including Mechanisms)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lander Subsystems</td>
<td>776.6</td>
<td>30%</td>
<td>1010</td>
<td>1316</td>
</tr>
<tr>
<td>Mechanical/ Structure</td>
<td>212.3</td>
<td>30%</td>
<td>276</td>
<td>368</td>
</tr>
<tr>
<td>Landing System</td>
<td>452.3</td>
<td>30%</td>
<td>568</td>
<td>784</td>
</tr>
<tr>
<td>Thermal</td>
<td>65.5</td>
<td>30%</td>
<td>85</td>
<td>100</td>
</tr>
<tr>
<td>Power</td>
<td>12.3</td>
<td>30%</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Harness</td>
<td>10.0</td>
<td>30%</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Avionics</td>
<td>6.8</td>
<td>30%</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Mechanism Control Electronics</td>
<td>8.5</td>
<td>30%</td>
<td>11</td>
<td>13</td>
</tr>
<tr>
<td>RF Comm</td>
<td>9.0</td>
<td>30%</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>ADEPT Aeroshell</td>
<td>807</td>
<td>30%</td>
<td>1042</td>
<td>1379</td>
</tr>
</tbody>
</table>