



GUIDED AEROCAPTURE AND ENTRY AT VENUS USING MECHANICALLY DEPLOYED DECELERATORS

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WHY VENUS?

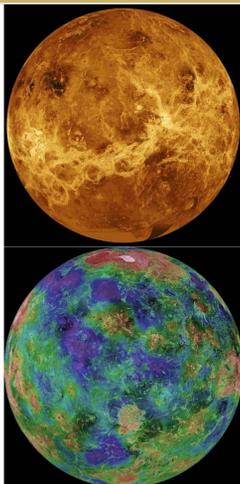
The 2013 Planetary Science Decadal Survey recommends the Venus In Situ Explorer mission as highest-priority within New Frontiers class [1].

Venus In Situ Explorer Science Goals [1]

- Understand chemistry, mineralogy, weathering of the Venus' crust
- Understand history and properties of Venus atmosphere and the role of water
- Understand key drivers of atmospheric dynamics and climate
- Understand planetary-scale evidence of past hydrological cycles

Requirements

- Achieving a majority of the above goals represents a New Frontiers class mission
- Measurements of deep atmospheric gas compositions and surface mineralogy require an *in situ* mission
- Venus Intrepid Tessera Lander (VITaL) concept was evaluated for the 2013 Decadal Survey [2]



CHALLENGES OF ENTRY, DESCENT, AND LANDING IN TO VENUS ATMOSPHERE

- Venera (Russia) and Pioneer-Venus (US): successful missions to survive harsh Venus entry conditions
- Employed traditional rigid aeroshell technology (high ballistic coefficient), Carbon Phenolic (CP) thermal protection system (only with flight heritage)

$$\text{Ballistic Coefficient } (\beta) = \frac{m}{AC_D} \frac{kg}{m^2}$$

- CP: high density and high thermal conductivity
 - Requirement: Increase heat flux, and lower heat load (shorten duration)
- For "ballistic" entry, steep entry flight path angle has to be selected [3]
 - High deceleration loading (150-500 g's)
 - High heat fluxes (3-17 kW/cm²)
- Carbon Phenolic is in short supply!



Venera 7

LOW BALLISTIC COEFFICIENT: MECHANICALLY DEPLOYED DECELERATORS

- Shallower entry flight angles possible using low ballistic coefficient (<30 kg/m²) entry system
- To overcome limits of rigid aeroshells due to launch vehicle fairing diameter: in-space deployment of a decelerator system to increase drag-area
 - Low ballistic coefficient
- Adaptive Deployable Entry and Placement Technology (ADEPT) is a viable mechanically deployed decelerator entry system being developed by NASA



ADEPT [4]

ADEPT FOR VENUS IN SITU MISSIONS

- ADEPT achieves low ballistic coefficient by mechanically deploying a decelerator surface
- Has four primary subsystems: main body, nose cap, ribs, and struts
- Nose cap is a traditional 70° sphere-cone aeroshell with a base diameter of 3 m
- Ribs provide support to the tensioned 3D-woven carbon cloth (thermal protection system) and a pair of struts in turn support each rib: against aerodynamic loads
- Maximum diameter for the ADEPT is 6m and preserves the 70° sphere-cone geometry when fully deployed



BASELINE MISSION CONCEPT [4]

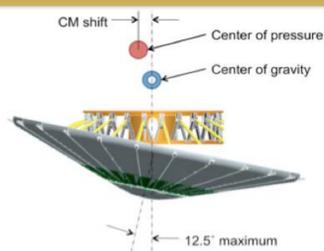
- VITaL repackaged from rigid aeroshell in to ADEPT Decelerator
- Lander mass of 1050 kg, instruments carried inside a pressurized vessel
- Thermal management system supports 3 hours of operation
- Entry mass of 1602 kg: carries the payload from entry interface to subsonic (Mach 0.8) parachute deployment at around ~75 km
- Parachute extracts the lander from ADEPT Decelerator
- Lander lands in a Tessera region (study baseline is Ovda Regio, 3.7° E longitude, and 25.4° S latitude) carries same instruments as VITaL
- Fulfill the same scientific objectives as VITaL



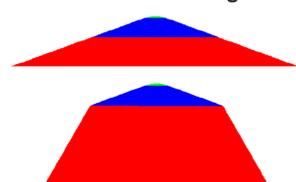
VITaL [3]

ADEPT CONTROL STRATEGIES [5]

- Bank Angle Control:** The vehicle is trimmed at 12.5°. Vertical component of the lift vector is controlled by varying bank angle.
- Drag Control:** The ADEPT vehicle is trimmed at 0 deg. Angle-of-attack. The drag coefficient is varied by controlling the level of deployment of the decelerator system.
- Angle-of-Attack and Bank Angle Control:** The aero-surface is suitably gimballed to orient the lift vector in the desired direction. This translates to a unique combination of angle-of-attack and bank angle.
- Angle-of-Attack, Drag, and Bank Angle Control:** In addition to gimbaling the aero-surface, the drag skirt deployment angle is also controlled.



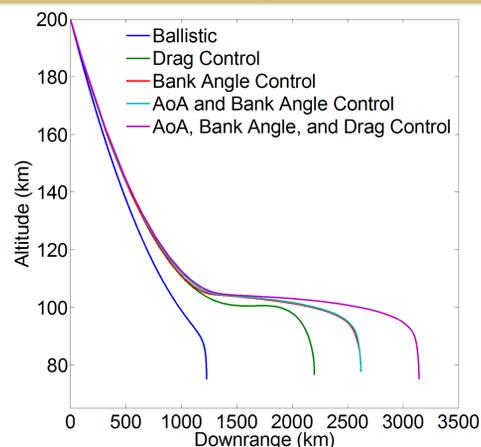
Angle-of-Attack and Bank Angle Control [5]



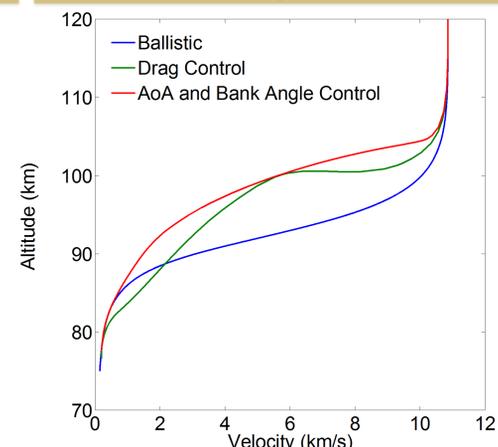
Drag Control

RESULTS

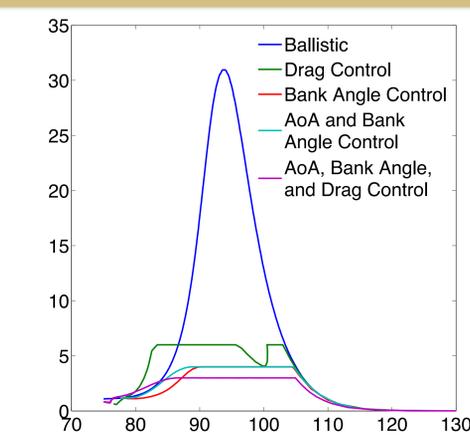
Altitude vs. Downrange



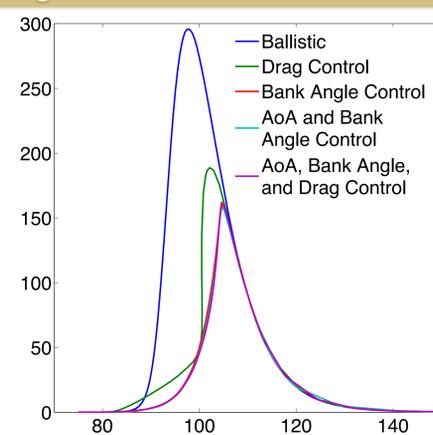
Altitude vs. Velocity



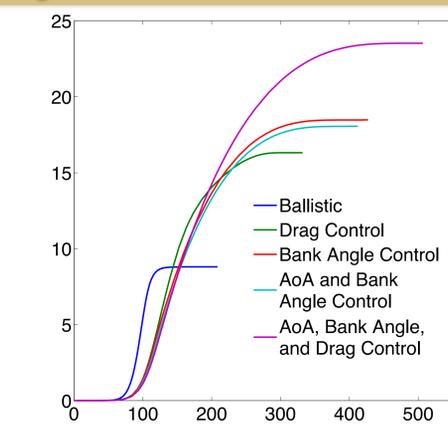
Deceleration Load



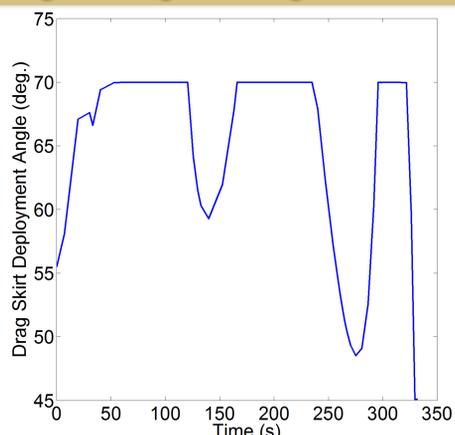
Stagnation Convective Heat-Rate



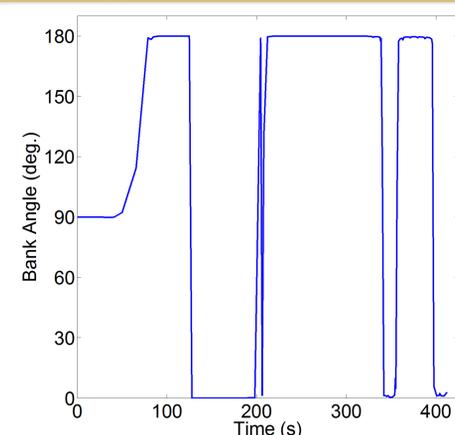
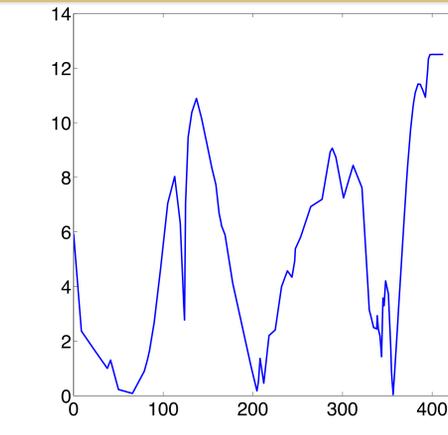
Stagnation Convective Heat-Load



Drag Skirt Angle for Drag Control



Control Histories for Angle-of-Attack and Bank Angle Control



SUMMARY AND CONCLUSIONS

- Low-β ADEPT lifting and guided entry (in contrast to ballistic entry) leads to
 - further reduction in peak deceleration loads (3-6 g) Vs. 30 g for ADEPT ballistic entry
 - reduction in convective heat-flux (<190 W/cm²) Vs. ~300 W/cm² for ADEPT ballistic entry
- Integrated stagnation-point heat-load increases because of increase in time of flight
- Drag control (β), angle-of-attack (α), and bank angle (σ) and combination thereof used as control strategies. β-α-σ control strategy results in least peak g-load
- Mechanism for gimbaling the decelerator system involves minimal additional structural elements
- Introduction of β-control will require additional control elements (increase in mass)
- Precision delivery of scientific payloads
- Low peak deceleration: significant mass savings