GUIDED AEROCAPTURE AND ENTRY AT VENUS USING MECHANICALLY DEPLOYED DECELERATORS

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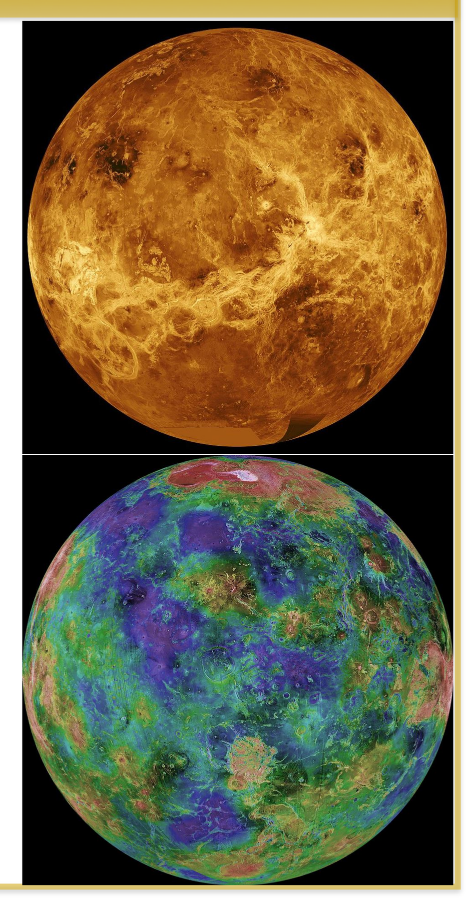
WHY VENUS?

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)

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

- ❑ 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/cm^2)
- ❑ 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/m^2) 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

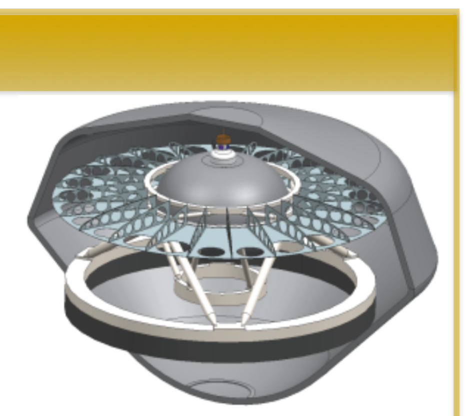
ADEPT [4]

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]

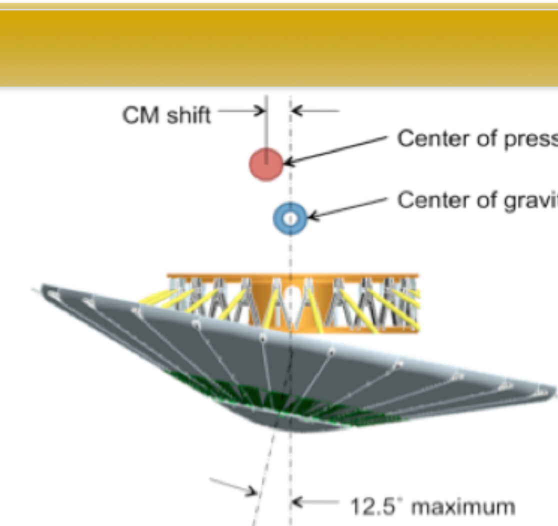
- ❑ VITaL repackaged from rigid aeroshell in to ADEPT Decelerator
- ❑ Lander mass of 1050 kg, instruments carried inside a pressurized vessel
- ❑ Thermal management system supports 3 hours of operation
- ❑ Entry mass of 1602 kg: carries the payload from entry interface to subsonic (Mach 0.8) parachute 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



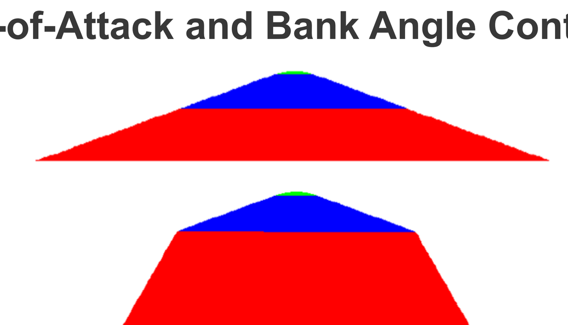
VITal [3]

ADEPT CONTROL STRATEGIES [5]

- ❑ **Bank Angle Control**: The vehicles 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 gimbaled 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.



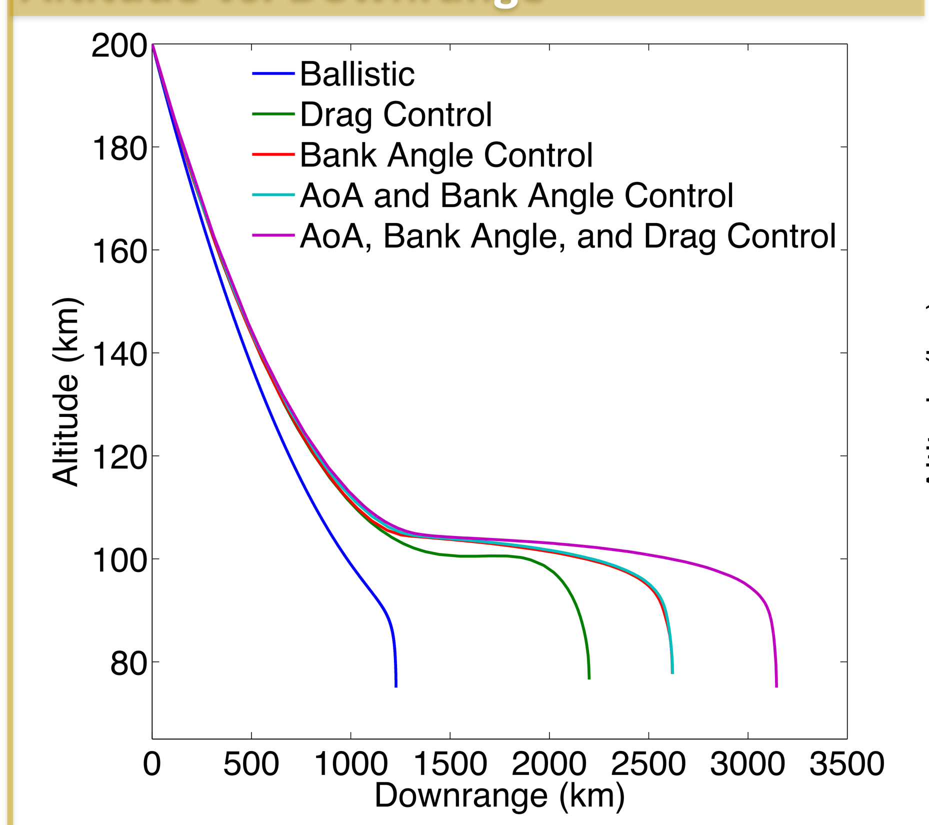
Angle-of-Attack and Bank Angle Control [5]



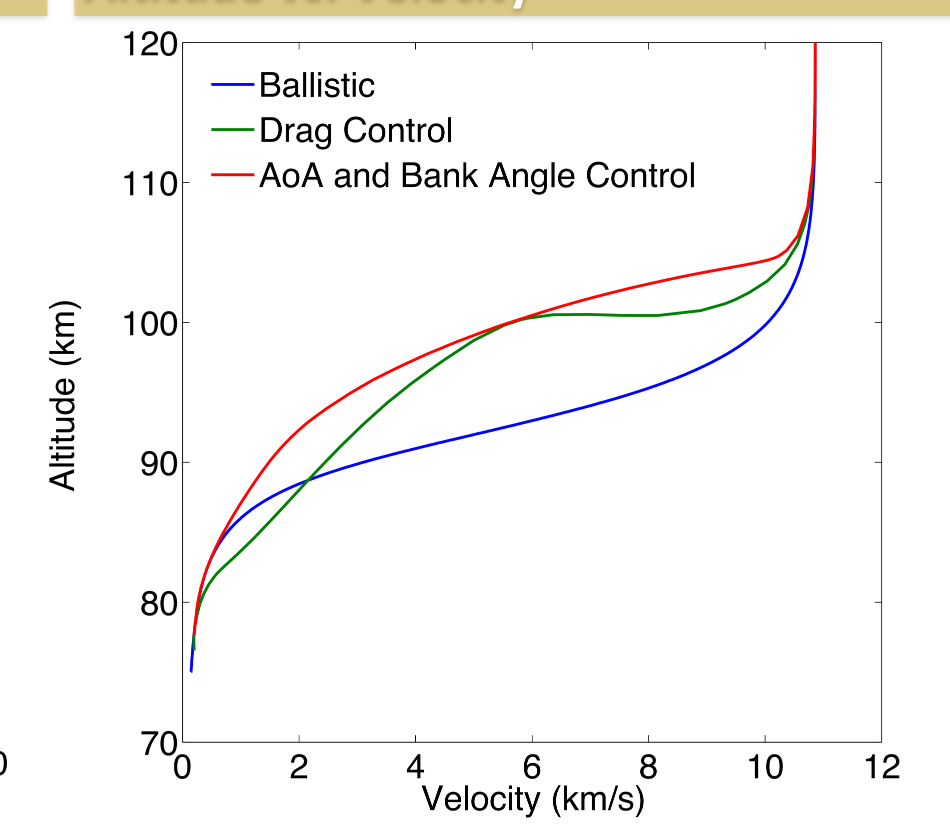
Drag Control

RESULTS

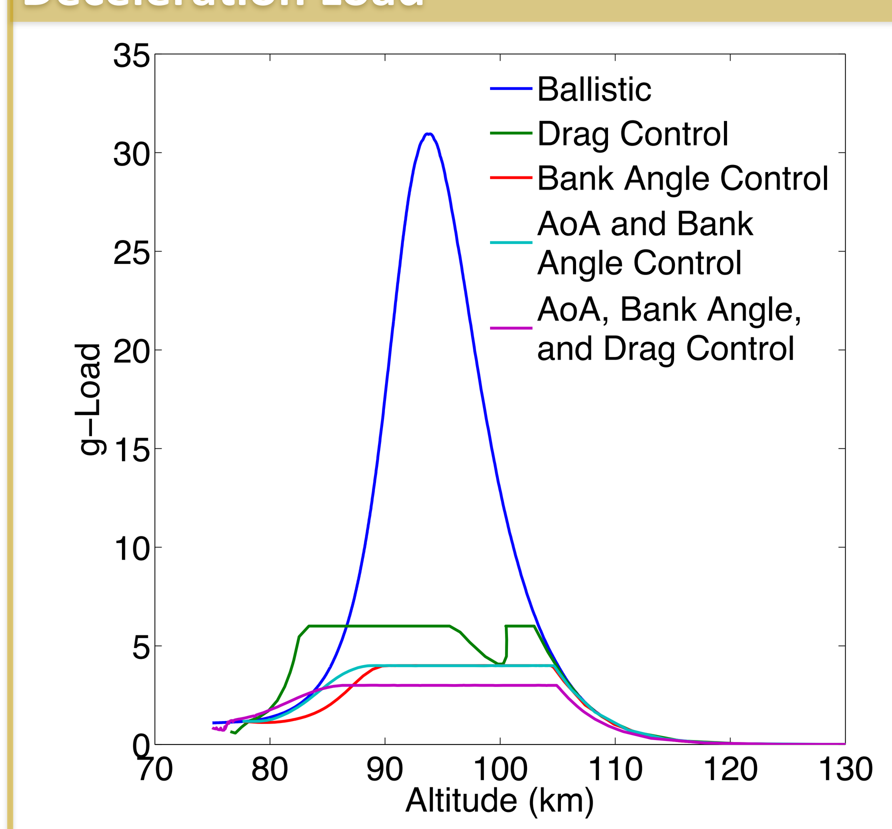
Altitude vs. Downrange



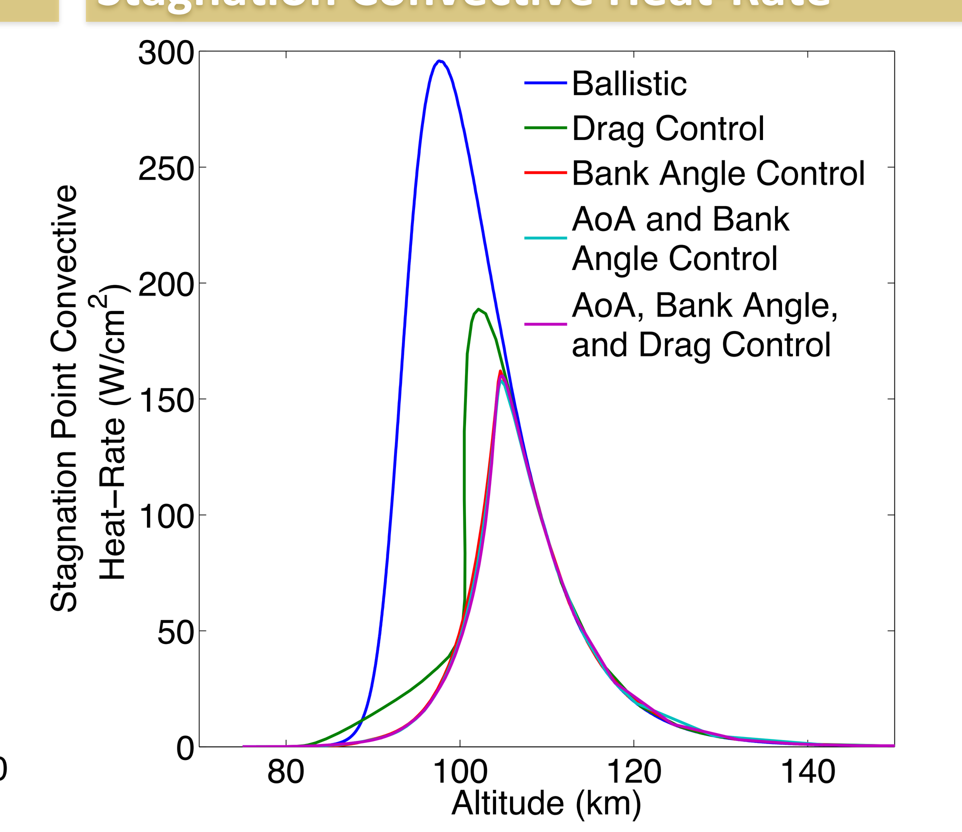
Altitude vs. Velocity



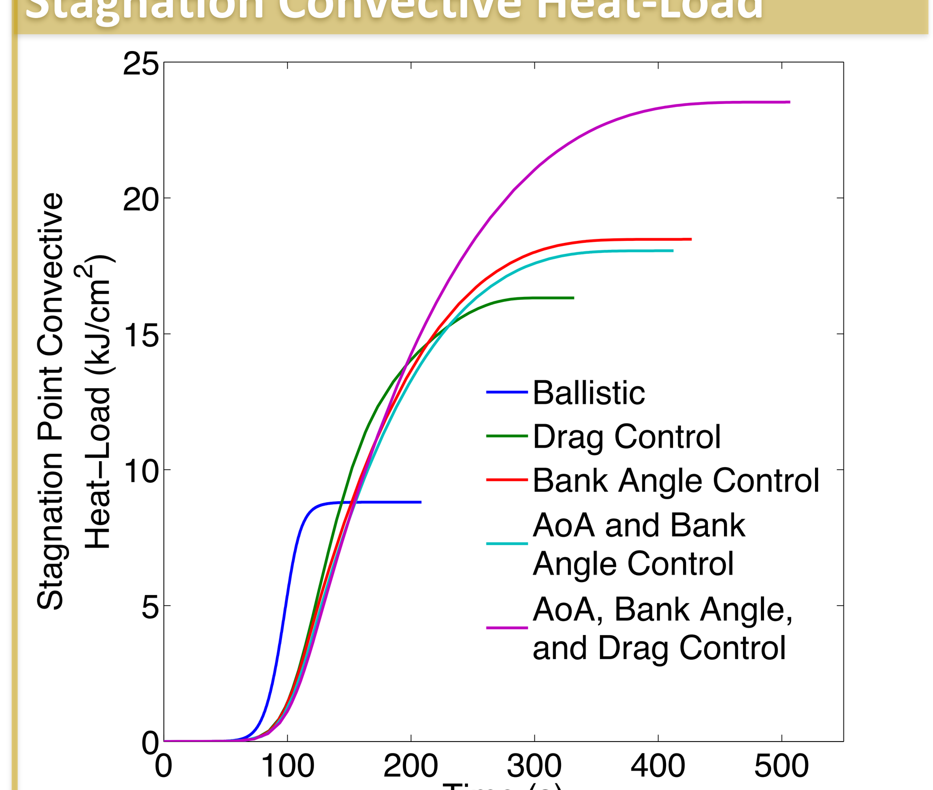
Deceleration Load



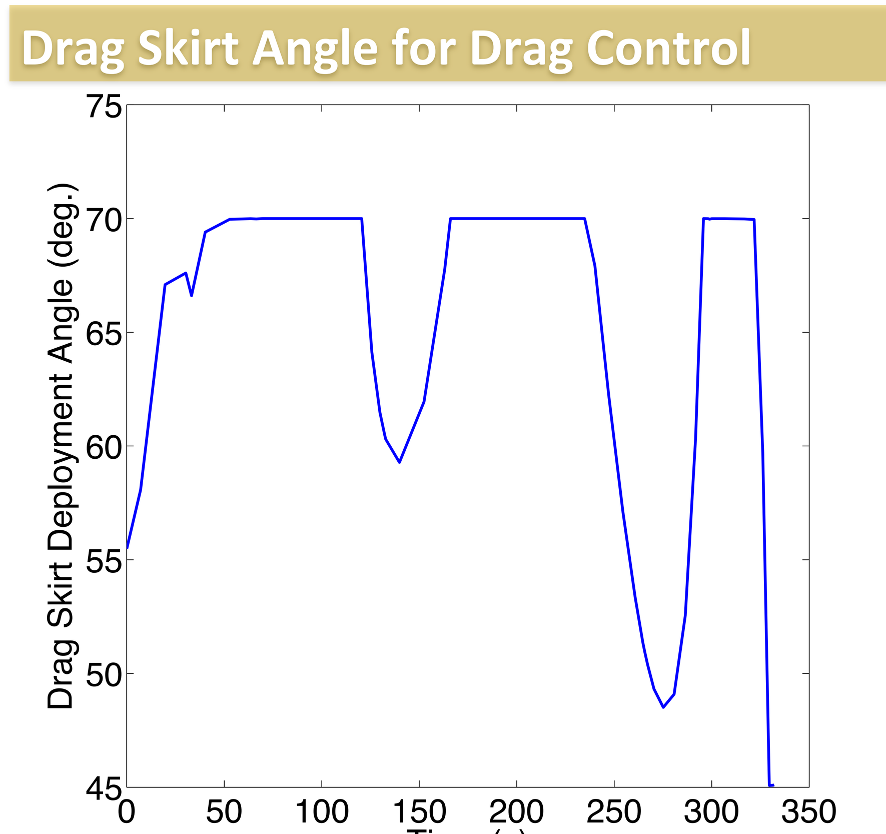
Stagnation Convective Heat-Rate



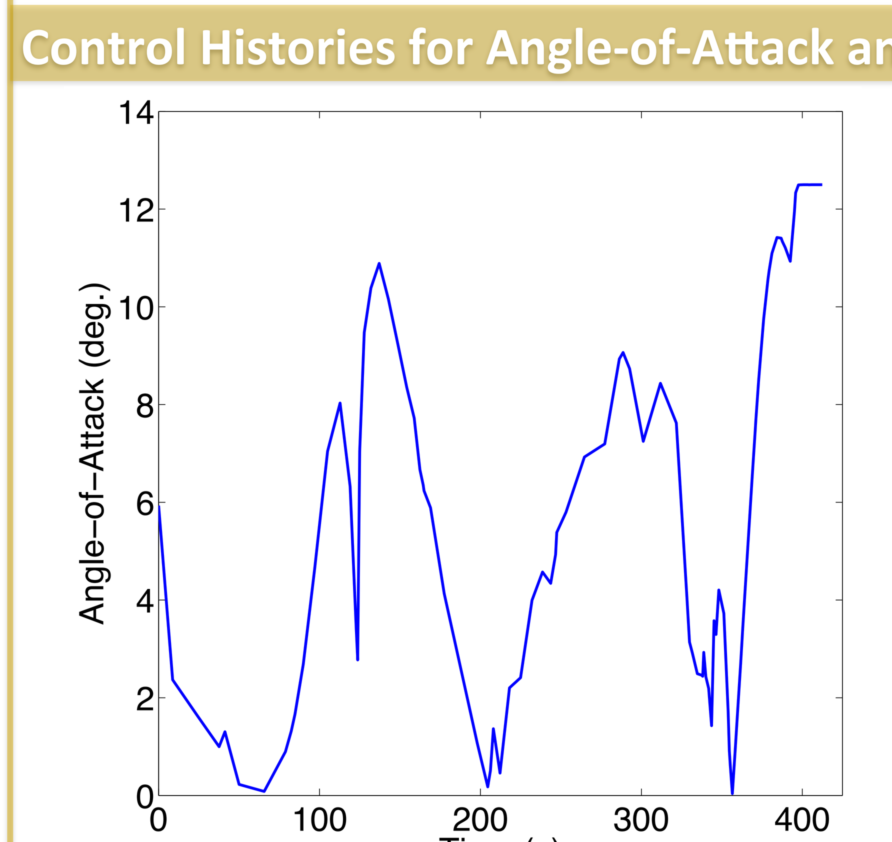
Stagnation Convective Heat-Load

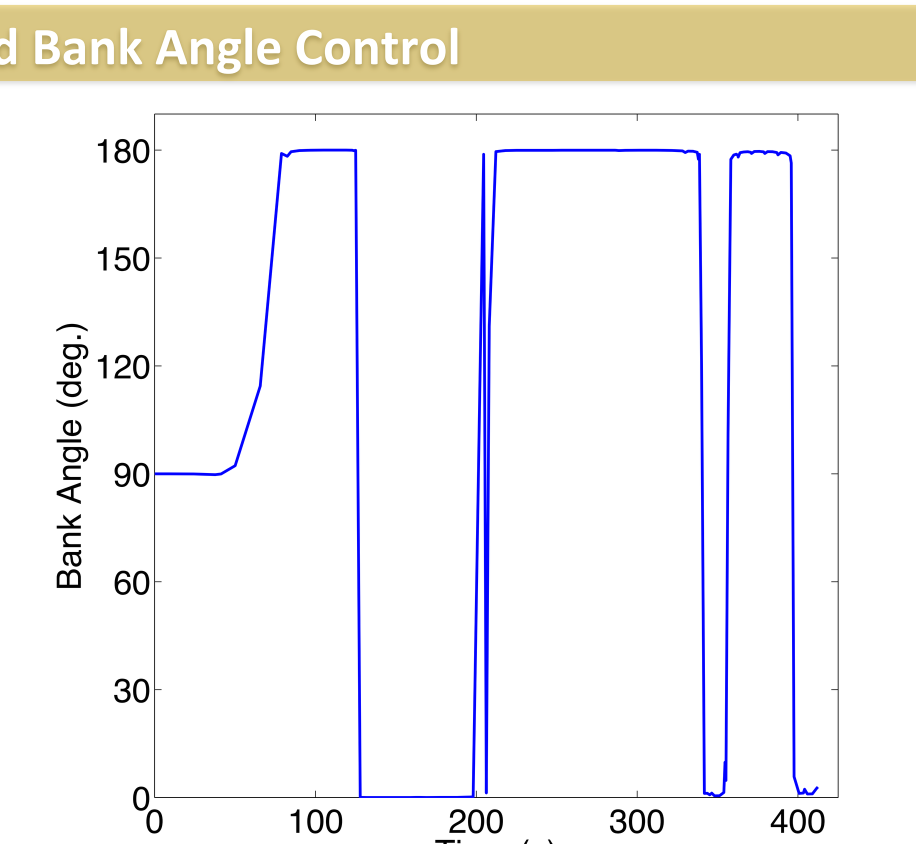


Drag Skirt Angle for Drag Control



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





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/cm^2) Vs. ~300 W/cm^2 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)

REFERENCES: [1] Squyres, S., et al. (2011), NAP Press, pp. 111-132. [2] Gilmore M. S. et al. (2010) NASA [3] Dutta S. et al. (2012) IEEE AC, 10.1109 [4] Smith B. et al. (2013) IEEE 978-1-4673 [5] Venkatapathy E. (2011) AIAA 2011-2608.