Presenter Bio

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Professional Experience:

Paul has been with the NASA Ames Research Center for more than 33 years. He is currently the project manager for the Adaptable, Deployable Entry and Placement Technology (ADEPT) project since 2012. He has been involved in multiple projects, advanced studies, and technology development areas within the Entry, Descent, and Landing (EDL) discipline at NASA over the past several decades. Paul served a 1-year assignment at NASA HQ in the Science Mission Directorate as program executive for the In-Space Propulsion Technology Program (2002-2003). He has served in line management roles at NASA Ames as well as participating in numerous planetary mission studies with an emphasis on EDL.

Education:

B.S. in Aerospace Engineering from the Pennsylvania State University (1987)

M.S in Aero/Astro Engineering from Stanford University (1990)

Nano-ADEPT for SmallSat Missions

Briefing for IPPW-2018 Short Course

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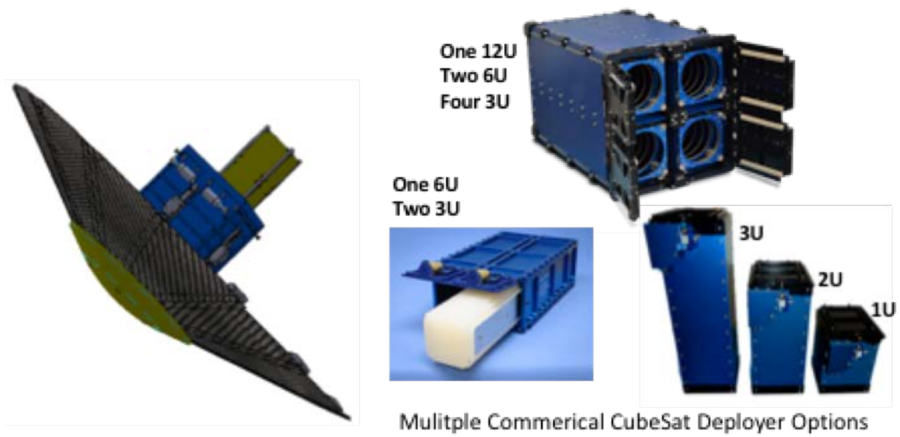
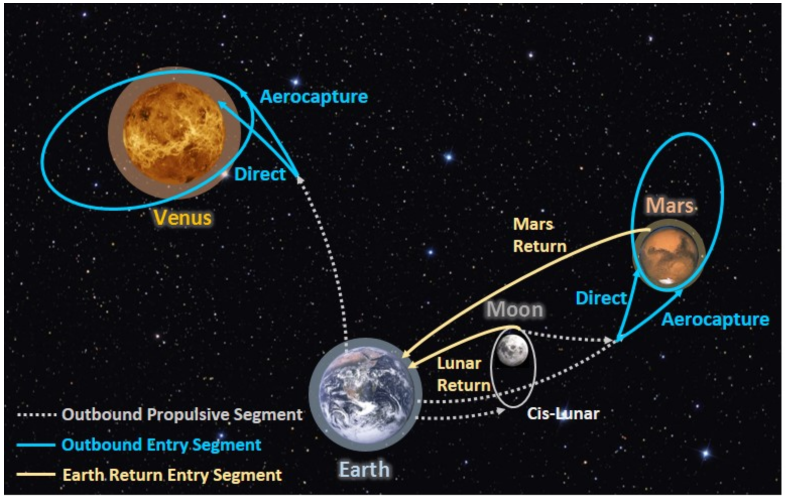
Introduction

- Purpose of this presentation is to highlight key features and design aspects of the Nano-ADEPT entry vehicle for SmallSat scale planetary missions.
- ADEPT is responding to interest in SmallSat missions, especially secondary payloads
  - Deployable entry vehicles offer relatively small stowed volume compared to rigid aeroshells
- Venus SmallSat missions are of particular interest for potential ADEPT applications
  - ADEPT thermal performance is uniquely well suited for relatively high heating Venus conditions



Nano-ADEPT with CubeSat deployers

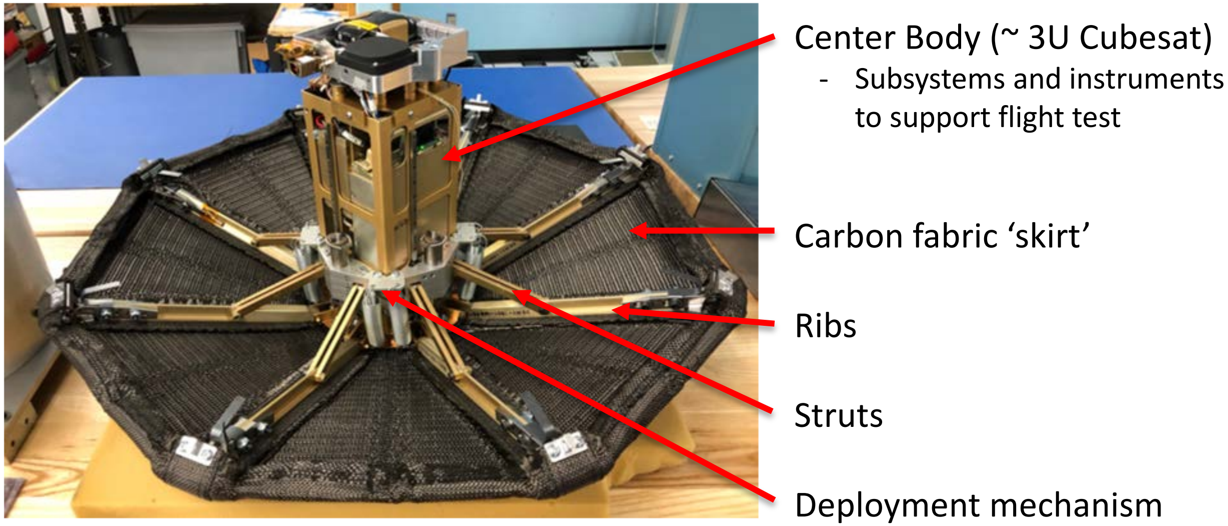


Potential Mission Applications for ADEPT involving atmosphere entry at Earth, Mars, and Venus.

Why Consider Deployables?

- Deployable decelerators can be stowed in relatively small volumes compared to rigid aeroshells.
  - Accommodation of rigid aeroshell may challenge mechanical integration and available volume
- Deployable decelerator's relatively large drag area reduces the entry system ballistic coefficient
  - Vehicle decelerates in the higher, thinner regions of the atmosphere
  - Reduces entry deceleration loads and entry heating
- Deployable decelerators feature open aft bodies without the backshell structures used in rigid aeroshells.
  - The open aft body allows easier access to the payload (pre-launch integration) and would conceivably simplify payload deployment during *insitu* mission phases.
  - The open-back geometry is expected to be aerodynamically stable through the subsonic flight regime.

ADEPT SR-1 stowed (~ 25cm diameter)



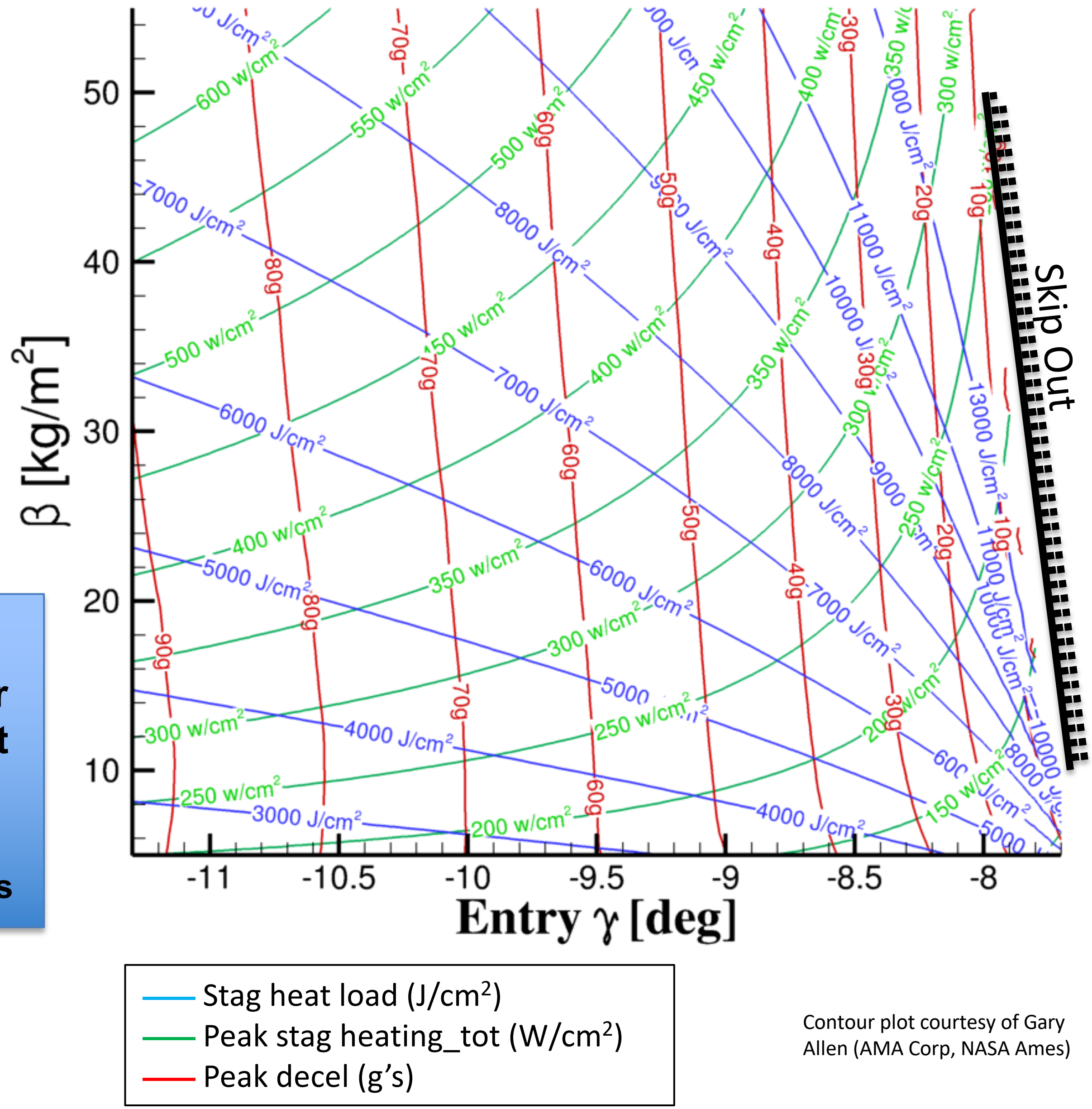
ADEPT SR-1 deployed (~ 70cm diameter)

Venus Direct, Non-Lifting Entry (11.5 km/s)
Low Ballistic Coefficient Design Space

ADEPT

Conditions

- Direct Ballistic Entry (L/D = 0)
- Entry velocity, inertial = 11.5 km/s
- Entry altitude = 200 km
- Atmosphere model = VIRA
- Stagnation heating conditions based on Nose radius = 0.425m
- Skip-out defined as return to h=200km



Is there a feasible design space using Deployables for the challenging Venus direct entry?

- **Entry technology limits**
- **Trajectory derived loads**

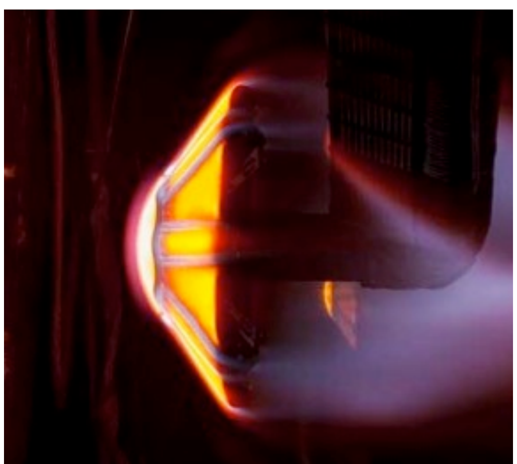
Contour plot courtesy of Gary Allen (AMA Corp, NASA Ames)

Venus Direct, Non-Lifting Entry (11.5 km/s)
Low Ballistic Coefficient Design Space

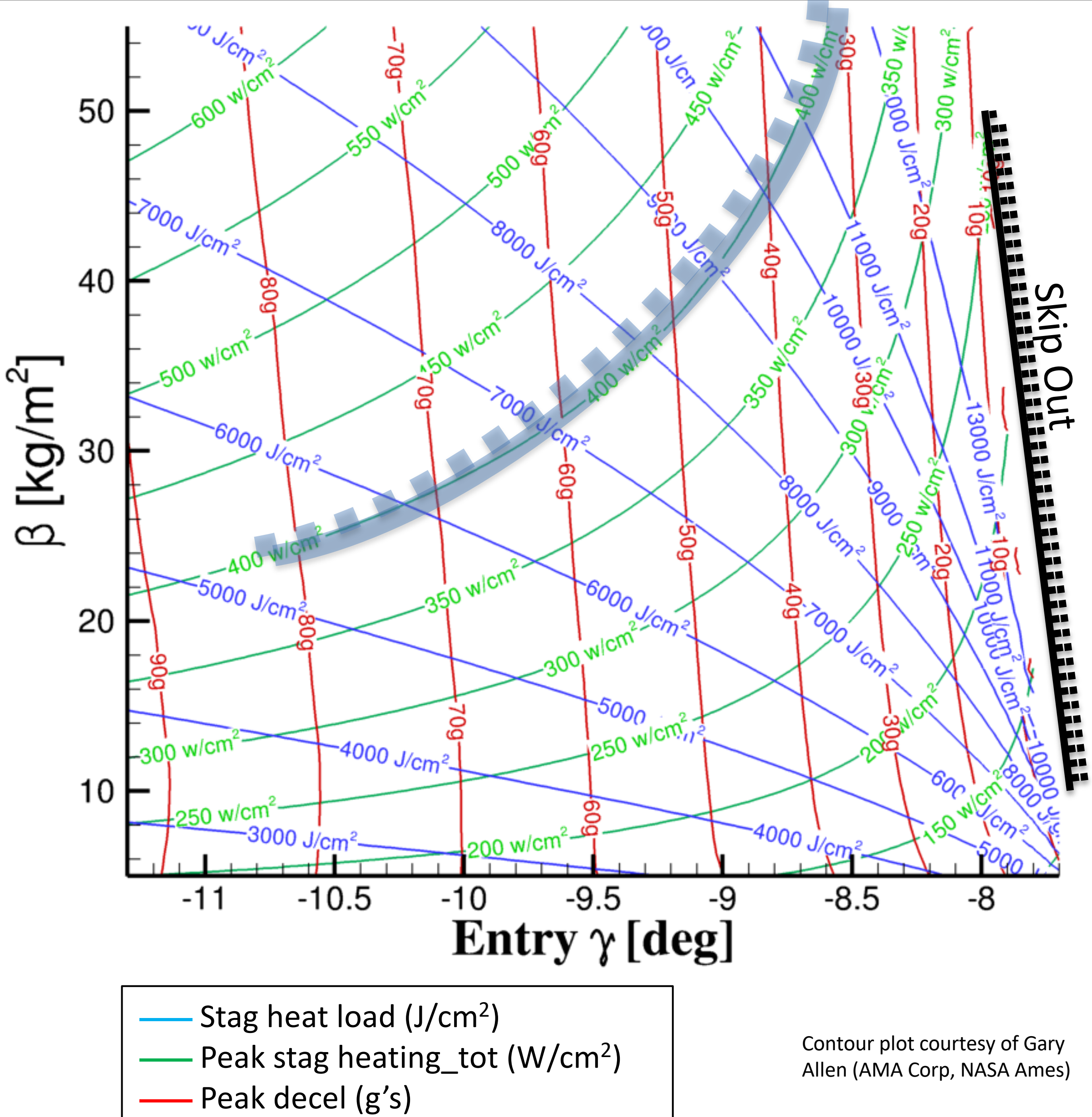
ADEPT

Limit – Maximum Heating Rate

- Assume 400 W/cm^2 stag heat rate
- ADEPT carbon fabric located on entry vehicle conical flank
- Limited arcjet testing on ADEPT carbon fabric up to 240 W/cm^2
  - *Arnold et al, March 2013*
  - Higher limits are possible
- Heating conditions on flank are derived from stagnation conditions
  - Flank cone angle
  - Laminar or turbulent flow on flank?



ADEPT SPRITE-C (35cm)
tested in Ames IHF arcjet



Contour plot courtesy of Gary Allen (AMA Corp, NASA Ames)

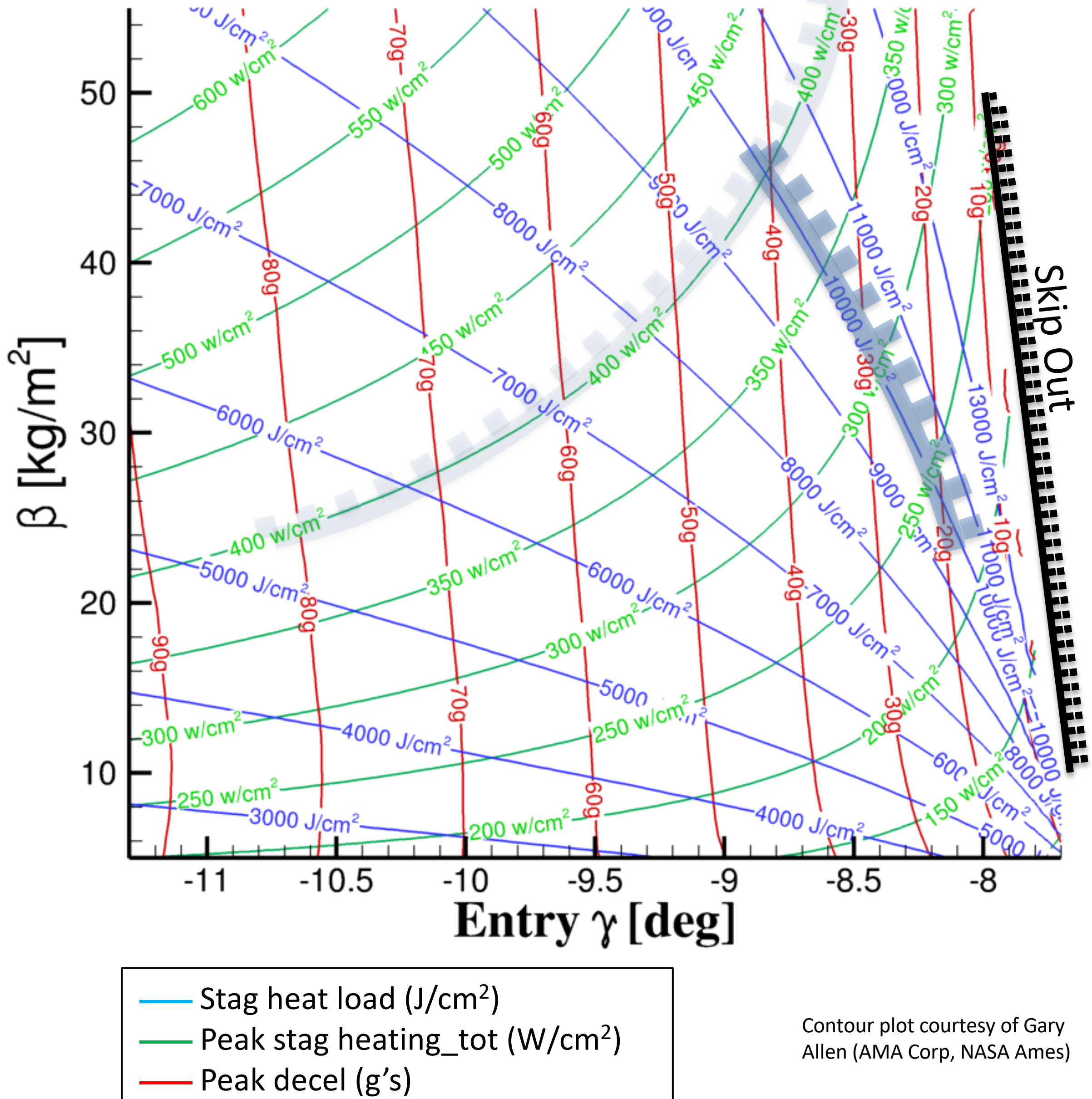
Venus Direct, Non-Lifting Entry (11.5 km/s)
Low Ballistic Coefficient Design Space

ADEPT

Limit – Maximum Heat Load

- Carbon fabric thickness directly correlates to heat load requirement
- Need sufficient layers (thickness) to survive heating with adequate margin for structural integrity
- 'Simple' design rule is approximately 1 layer = 2kJ/cm^2
  - *Smith et al, March 2015*
- 8 layer (~4mm thick) design should be conservative for 10 kJ/cm^2 limit
- Fabric foldability needs to be considered for feasible stowing geometries

ADEPT SR-1 (4-layer) shown in stowed configuration

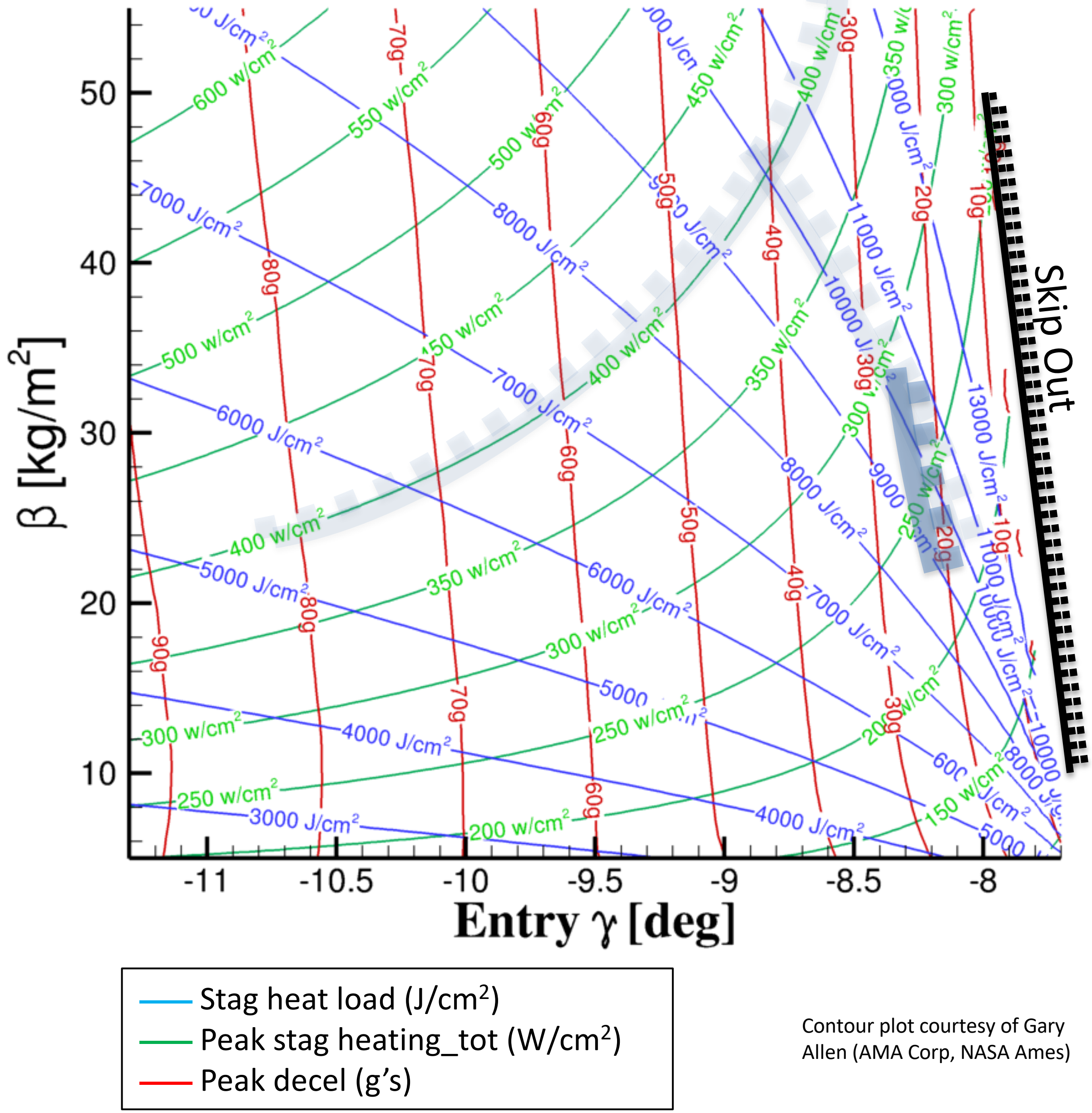


Contour plot courtesy of Gary Allen (AMA Corp, NASA Ames)

Venus Direct, Non-Lifting Entry (11.5 km/s)
Low Ballistic Coefficient Design Space

Limit – Atmosphere skip out

- Assume 0.75 deg targeting margin offset from actual skip out



Contour plot courtesy of Gary Allen (AMA Corp, NASA Ames)

Venus Direct, Non-Lifting Entry (11.5 km/s)
Low Ballistic Coefficient Design Space

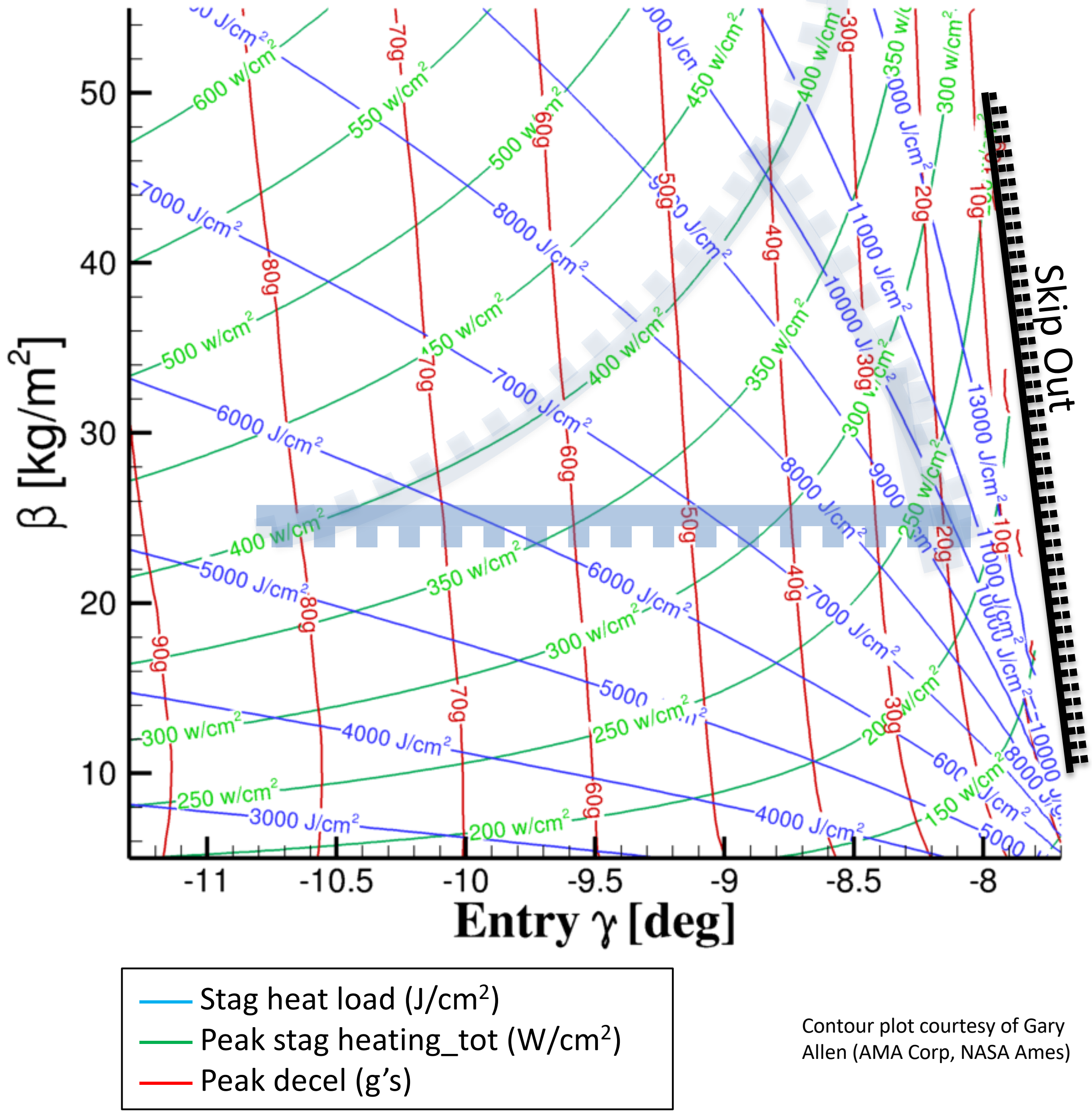
ADEPT

Limit – Minimum Ballistic Coefficient, β (M/CdA)

- Entry mass
- Cd -> Cone angle
  - 45 deg, Cd ~ 1.05
  - 70 deg, Cd ~ 1.7
- Deployed Diameter

• **Assume β limit = 25 kg/m²**

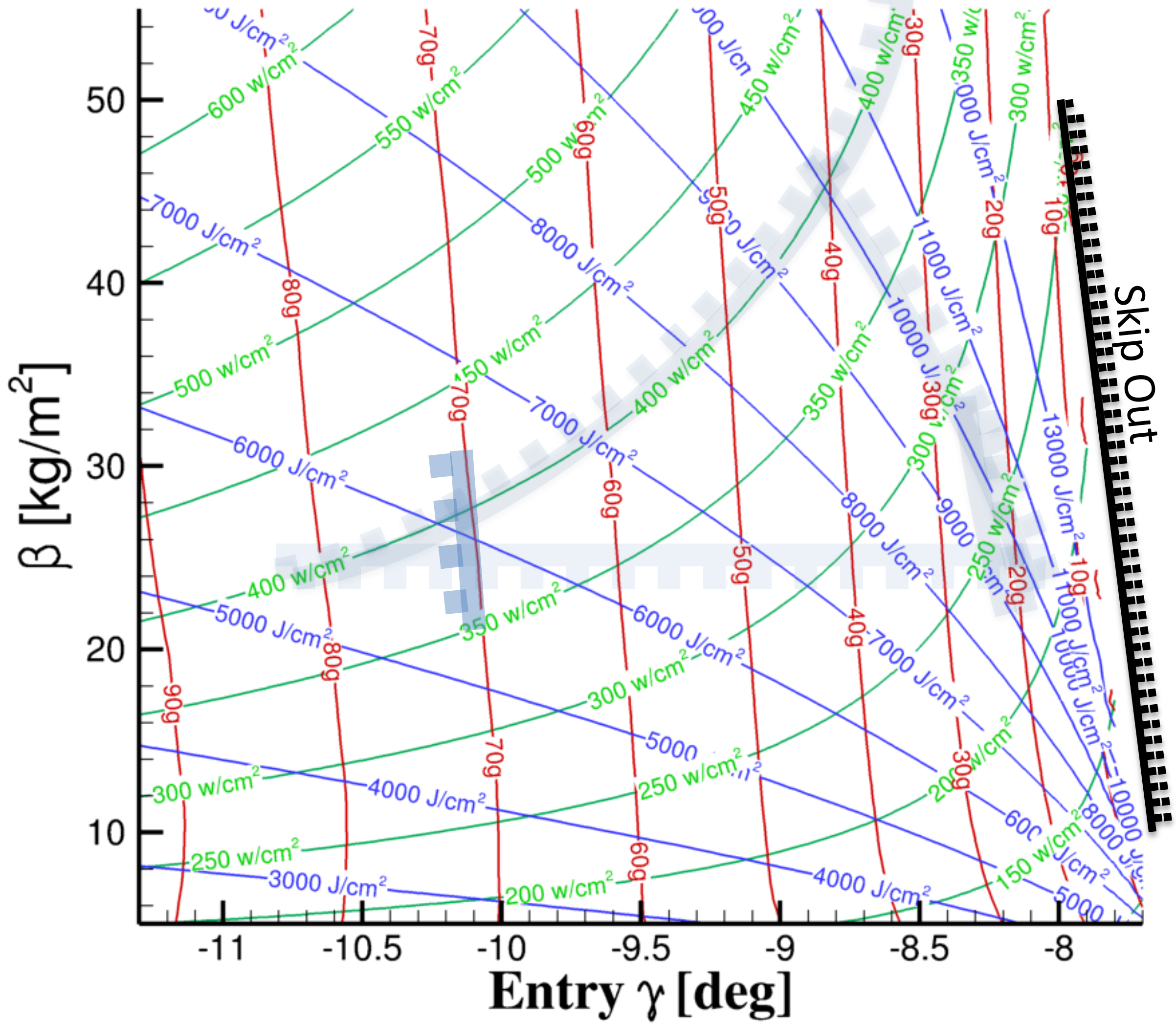
- ADEPT SR-1 (M/CdA = 19kg/m²)
  - Mass = 10.9 kg
  - Ref. Area = 0.34 m²
  - Cd (hyp) ~ 1.65
- Pioneer Venus Large Probe
  - M/CdA ~ 190 kg/m²
- Stardust
  - M/CdA ~ 60 kg/m²



Contour plot courtesy of Gary Allen (AMA Corp, NASA Ames)

Venus Direct, Non-Lifting Entry (11.5 km/s)
Low Ballistic Coefficient Design Space

Limit – Maximum g's on Payload
- Assume 70 g's limit



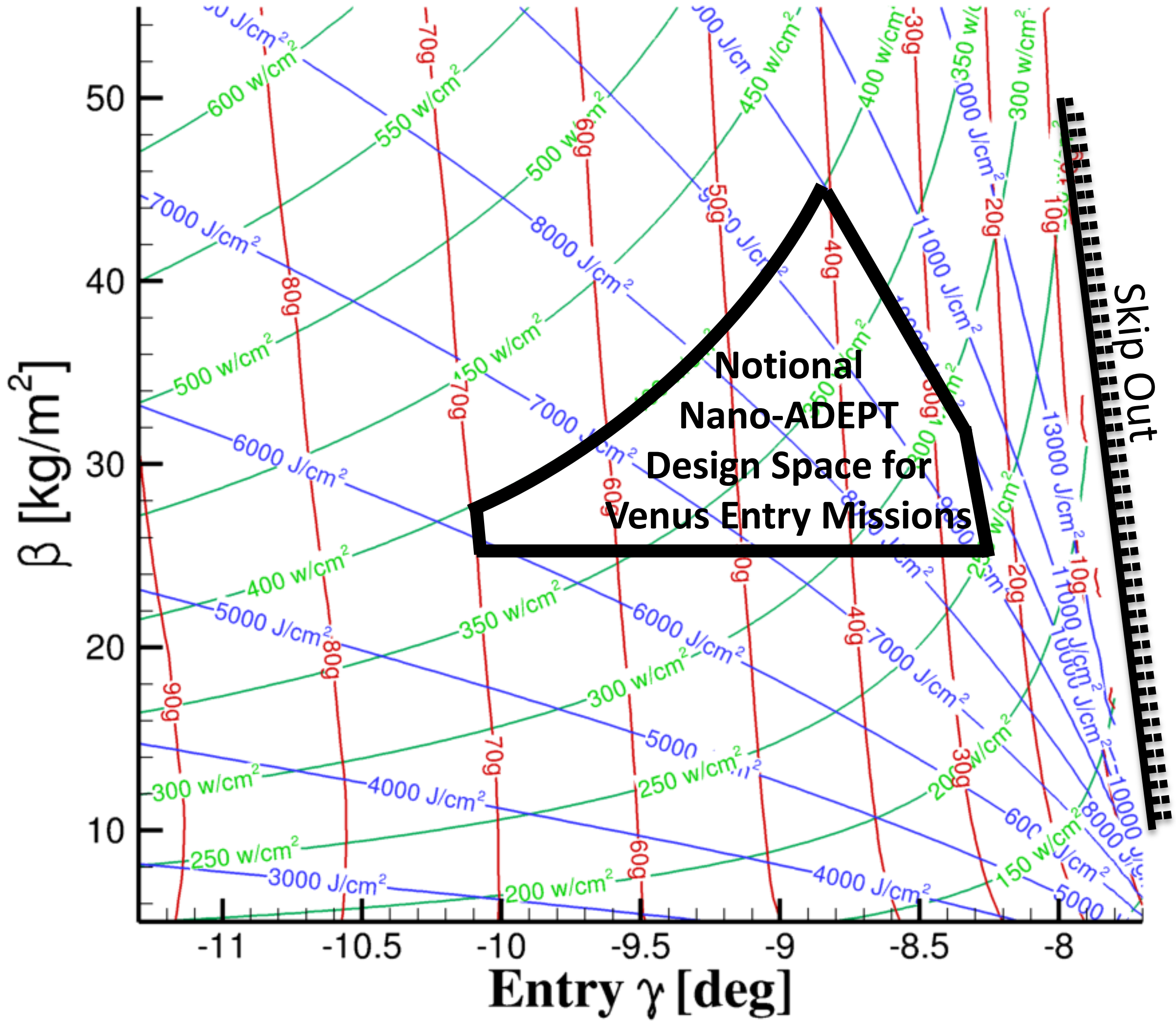
Stag heat load (J/cm²)
Peak stag heating_tot (W/cm²)
Peak decel (g's)

Contour plot courtesy of Gary Allen (AMA Corp, NASA Ames)

ADEPT

Venus Direct, Non-Lifting Entry (11.5 km/s)
Low Ballistic Coefficient Design Space

ADEPT



- ADEPT deployable is uniquely suited for challenging Venus heating environment
- Even larger 'Design Space' as Venus entry velocities get lower, such as 10.5 km/s

Summary
Applicability of Nano-ADEPT for SmallSat Missions

- Secondary Payloads and Volume Constraints:
  - Missions with a secondary payload as an entry system may be manifested within tight volumetric constraints, such as those imposed by ESPA rings. In these cases, the ability to package deployable decelerators in small volumes may make them enablers for such missions.
- Load Limits:
  - If the science payload is sensitive to deceleration loads, a shallow entry angle will reduce the loads to allowable levels.
- Science Platform Deployment Conditions:
  - Lower ballistic coefficient of deployable decelerators allows deceleration higher in the atmosphere.
  - Open back (no backshell) should permit stable, subsonic flight without a parachute and support science payload deployment at altitudes of interest
- Entry System Design:
  - Does the entry system design close with respect to adequate margins against trajectory dispersions, mass and volume growth, and thermal management?

- ADEPT deployable decelerator may be the best solution for SmallSat atmosphere entry missions…especially the challenging Venus entry environments.

ADEPT Technical Paper Bibliography

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