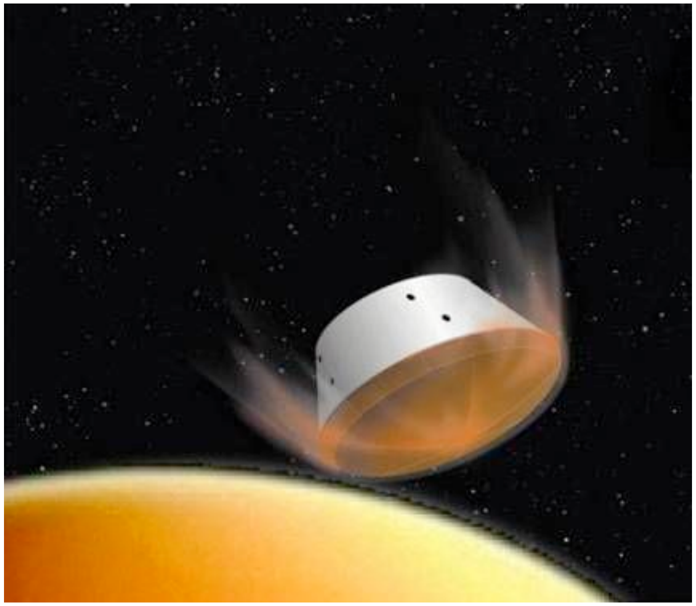
Aerocapture Technology



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Presentation to VEXAG
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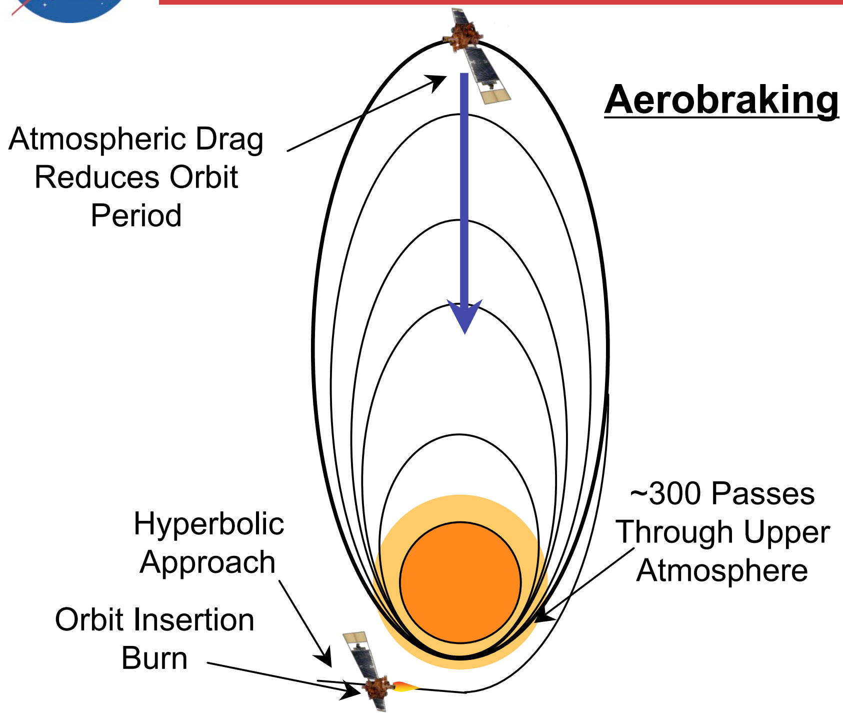
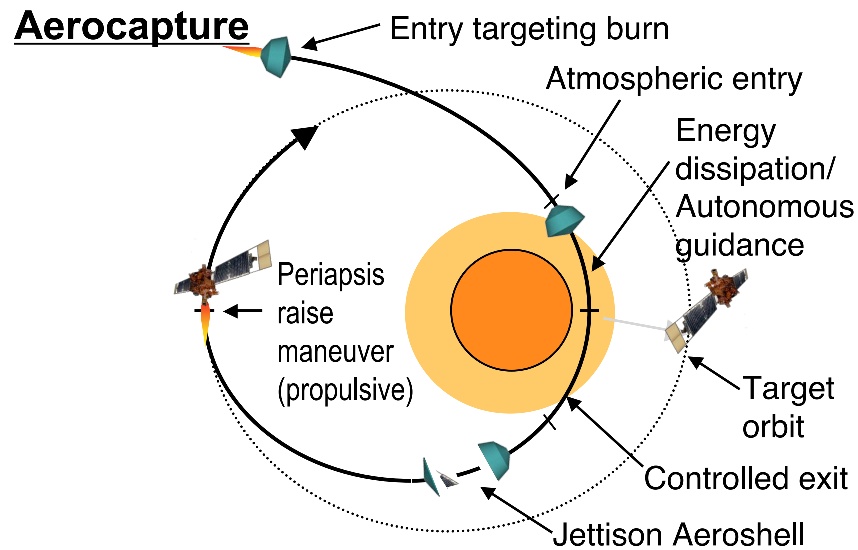
Aerocapture vs Aerobraking



Pros	Cons
Little spacecraft design impact	Still need ~1/2 propulsive fuel load
Gradual adjustments; can pause and resume as needed (with fuel)	Hundreds of passes = more chance of failure
Operators make decisions	Months to start science
	Operational distance limited by light time (lag)
	At mercy of highly variable upper atmosphere



Aerocapture: A vehicle uses bank angle control to autonomously guide itself to an atmospheric exit target, establishing a final, low orbit about a body in a single atmospheric pass.

Pros	Cons
Uses very little fuel--significant mass savings for larger vehicles	Needs protective aeroshell
Establishes orbit quickly (single pass)	One-shot maneuver; no turning back, much like a lander
Has high heritage in prior hypersonic entry vehicles	Fully dependent on flight software
Flies in mid-atmosphere where dispersions are lower	
Adaptive guidance adjusts to day-of-entry conditions	
Fully autonomous so not distance-limited	

Aerocapture Benefits for Robotic Missions

Parametric Analysis Results

Mission	Nominal Orbit Insertion ΔV, km/s	Best A/C Mass, kg	Best non-A/C Mass, kg	A/C % Increase	Best non-A/C Option
Venus V1 - 300 km circ	4.6	5078	2834	**79**	All-SEP
Venus V2 - 8500 x 300 km	3.3	5078	3542	**43**	All-SEP
Mars M1 - 300 km circ	2.4	5232	4556	**15**	Aerobraking
Mars M2 - ~1 Sol ellipse	1.2	5232	4983	**5**	Chem370
Jupiter J1 - 2000 km circ	17.0	2262	<0	**Infinite**	N/A
Jupiter J2 - Callisto ellipse	1.4	2262	4628	**-51**	Chem370
Saturn S1 - 120,000 km circ	8.0	494	<0	**Infinite**	N/A
Titan T1 - 1700 km circ	4.4	2630	691	**280**	Chem370
Uranus U1 - Titania ellipse	4.5	1966	618	**218**	Chem370
Neptune N1 - Triton ellipse	6.0	1680	180	**832**	Chem370

Aerocapture offers significant increase in delivered payload:

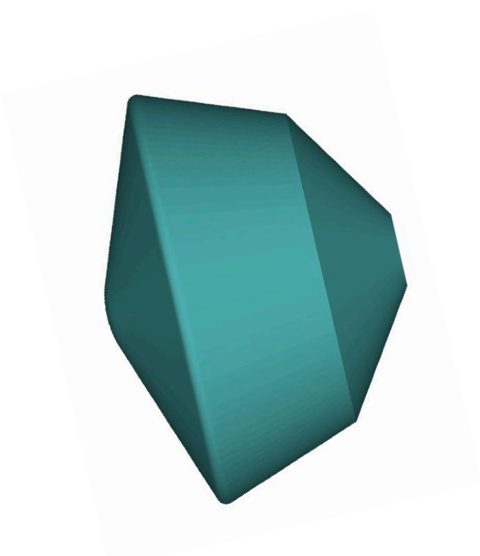
- **ENHANCING** missions to Venus, Mars
- **STRONGLY ENHANCING** to **ENABLING** missions to Titan, and Uranus
- **ENABLING** missions to Jupiter, Saturn, and Neptune

Ref.: Hall, J. L., Noca, M. A., and Bailey, R. W. "Cost-Benefit Analysis of the Aerocapture Mission Set," *Journal of Spacecraft and Rockets*, Vol. 42, No. 2, March-April 2005

Venus Orbiter Spacecraft Design

Top-level spacecraft design, mass, power analysis completed

- Delta 2925H-10 Launch Capability = 1165 kg
  - Cruise stage = 50 kg
  - Orbiter entry allocation = 1090 kg
    - Aerocapture system dry mass allocation = 350 kg (CBE = 243kg)
      - Assumption: Aeroshell Allocation (TPS + aeroshell structure) = 30% of wet launch mass capability
  - Mass margins are 20% or greater
- 1.4 m diameter high gain antennae packages in 2.65m 70deg sphere cone with biconic backshell (similar approach as Titan)

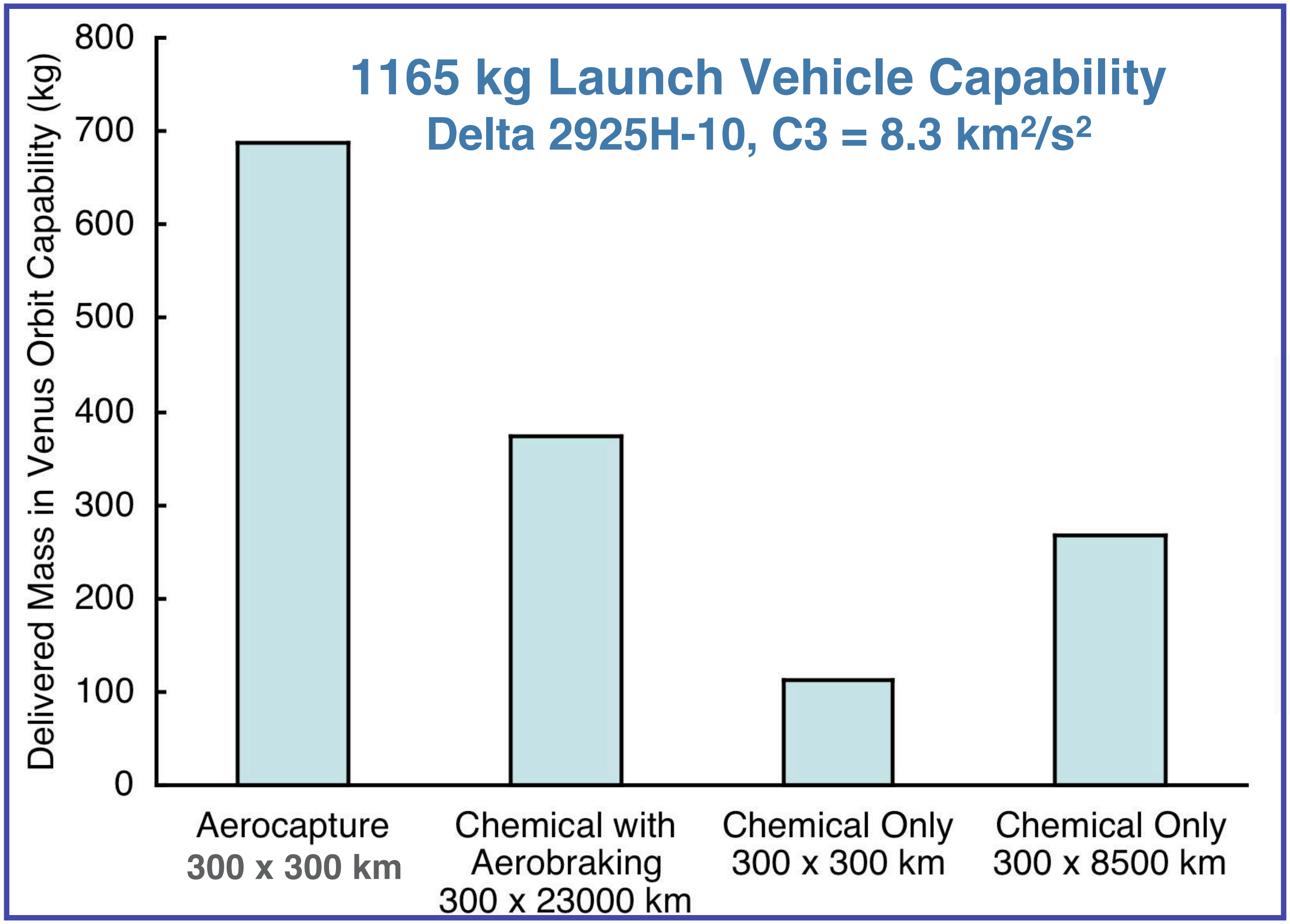


Alloc: Allocation
Cont: Contingency
CBE: Current Best Estimate
MEV: Max Expected Value
Cont = (MEV-CBE)/CBE
Margin = (Alloc-MEV)/MEV

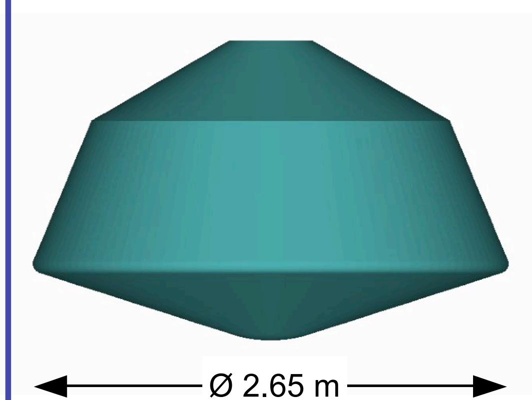
		#	CBE	Cont	MEV	Alloc		
Launch Vehicle Capability						1165		
Propellant and Pressurant					**89.6**			
Hydrazine + Helium					**89.6**			
Cruise					27.3	50	m/s	JPL Margin
Aerocapture					50.9	99.2	m/s	
Orbit					8.8	10	m/s	
Residual & Pressurant	Tank				2.6		**Margin**	
Launch Dry Mass			**680.0**	**22.2%**	**831.2**	**1075.4**	**29.4%**	36.8%
Aerocapture System Dry Mass			**242.7**	**20.0%**	**291.3**	**349.5**	**20.0%**	30.6%
Spacecraft Dry Mass			**437.3**	**23.5%**	**540.0**	**725.9**	**34.4%**	39.8%
Instruments			**50.0**	**30.0%**	**65.0**			
Bus		121	**387.3**	**22.6%**	**475.0**			
Attitude Control		8	19.5	2.2%	19.9			
Command & Data		26	37.3	17.3%	43.8			
Power		5	46.5	17.0%	54.4			
Hydrazine Propulsion System		39	32.4	6.9%	34.6			
Structures & Mechan		1	140.0	30.0%	182.0			
Harness	31.00	1	31.0	30.0%	40.3			
X-Band Telecomm		40	20.6	6.5%	22.0			
Thermal		1	60.0	30.0%	78.0			

s/c dry mass allocation includes 50kg cruise stage

Aerocapture Benefit for a Venus Mission



Venus Orbiter
(OML Design Only)

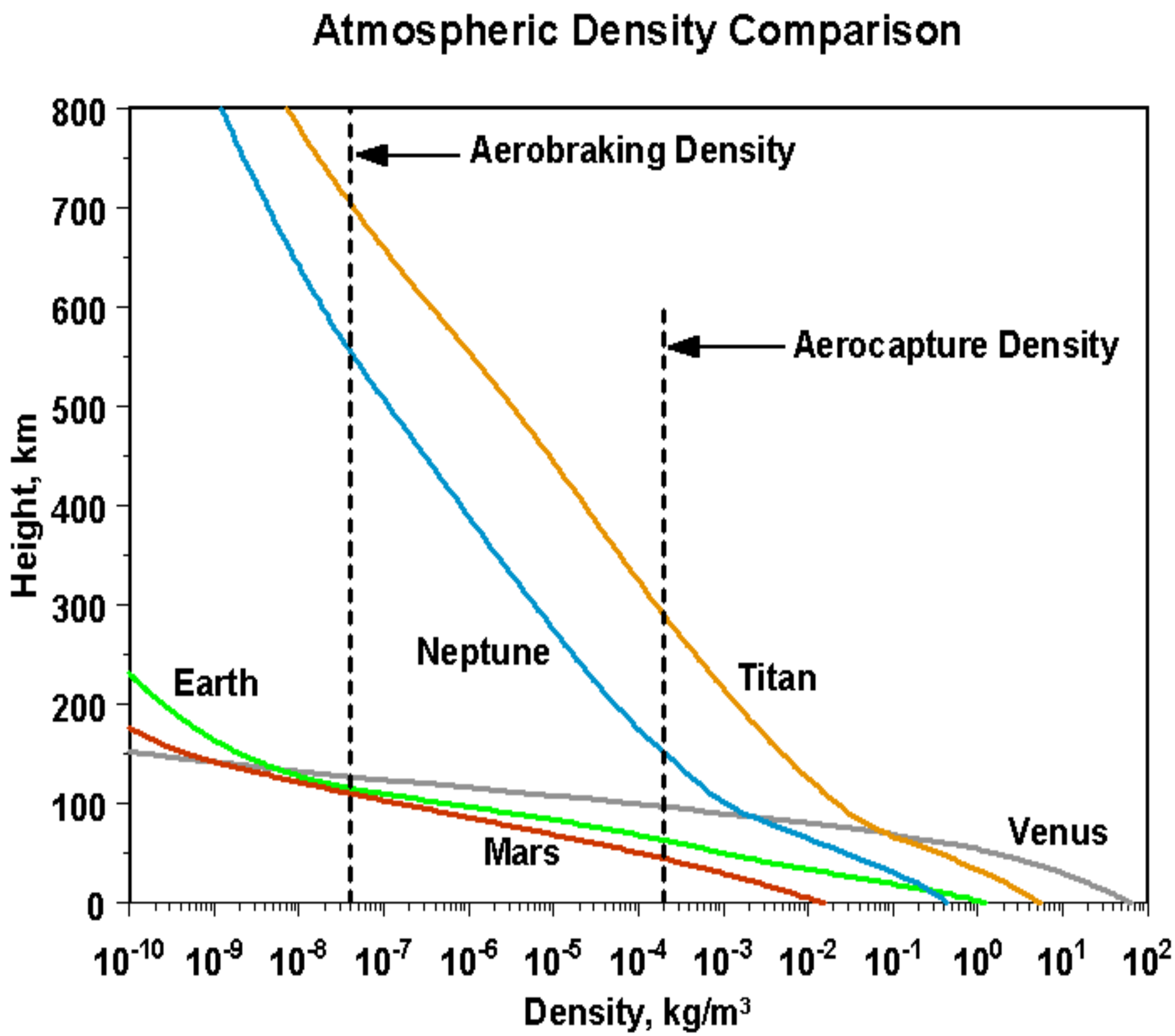


Into 300 x 300 km Venus orbit w/constant launch vehicle, Aerocapture delivers:

- **1.8x more mass** into orbit than aerobraking
- **6.2x more mass** into orbit than all chemical

Reference: Lockwood et al, "Systems Analysis for a Venus Aerocapture Mission", NASA TM 2006-214291, April 2006

Atmospheric Density Variation with Height

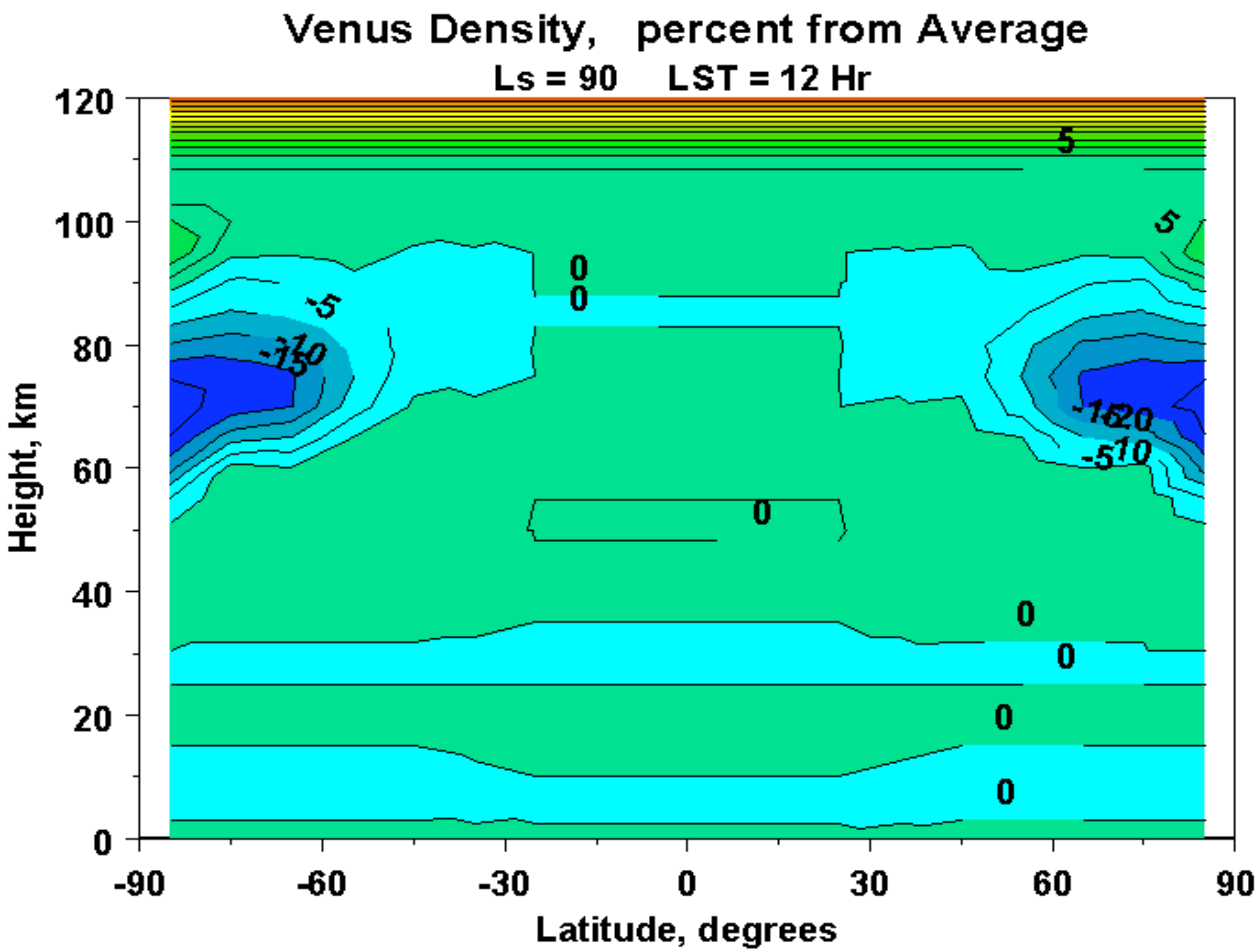


Venus at Aerocapture Altitude (~100 km)

- Rapid Height Variation of Density
- Low Density Scale Height
- Other Things Being Equal, This Leads To Smaller Entry Corridor Width

Venus Atmospheric Density 0-100 km vs Latitude

1-sigma variations at 100 km = ~8%; 3σ = ~24%



Example Monte Carlo Simulation Results:
Venus Aerocapture

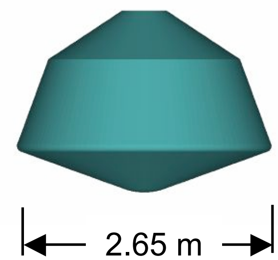
<u>Venus Aerocapture Systems Analysis Study, 2004</u>

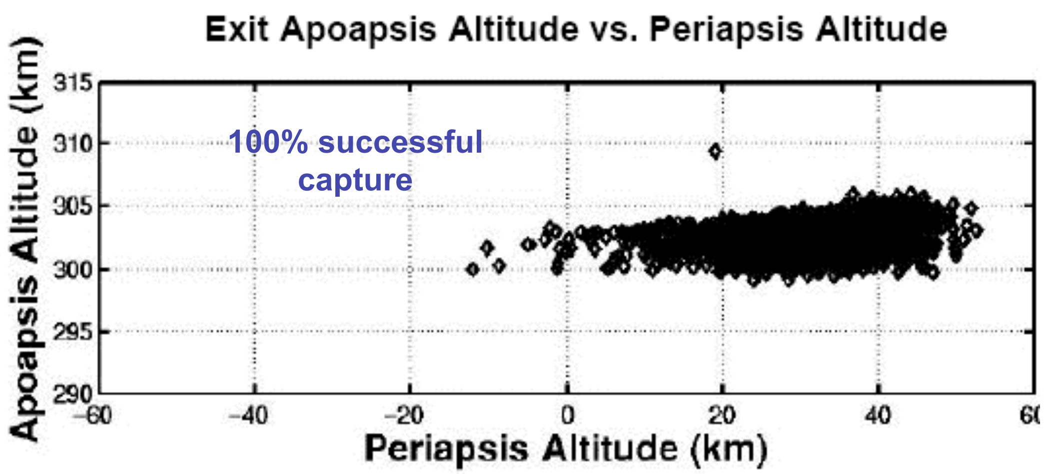
Vehicle L/D = 0.25, m/C_DA = 114 kg/m^2

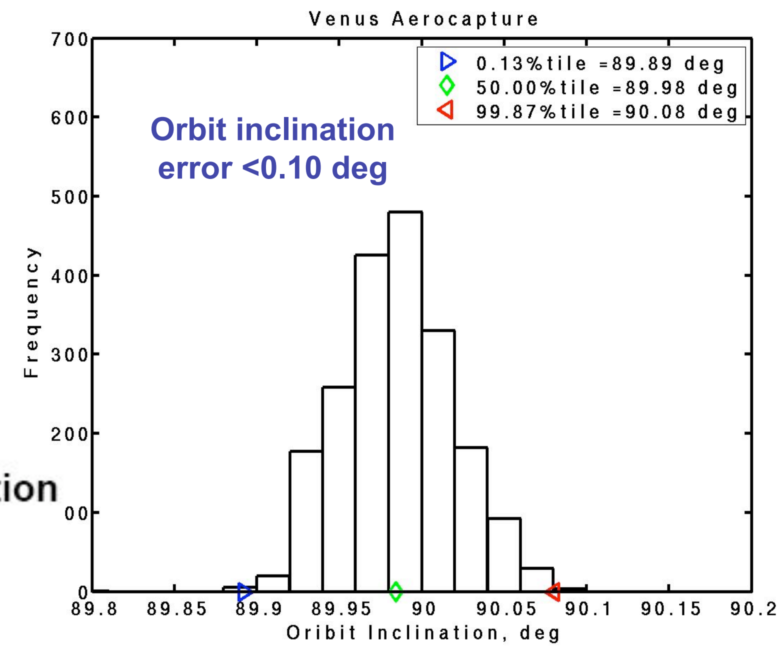
Target orbit: 300 km circ., polar

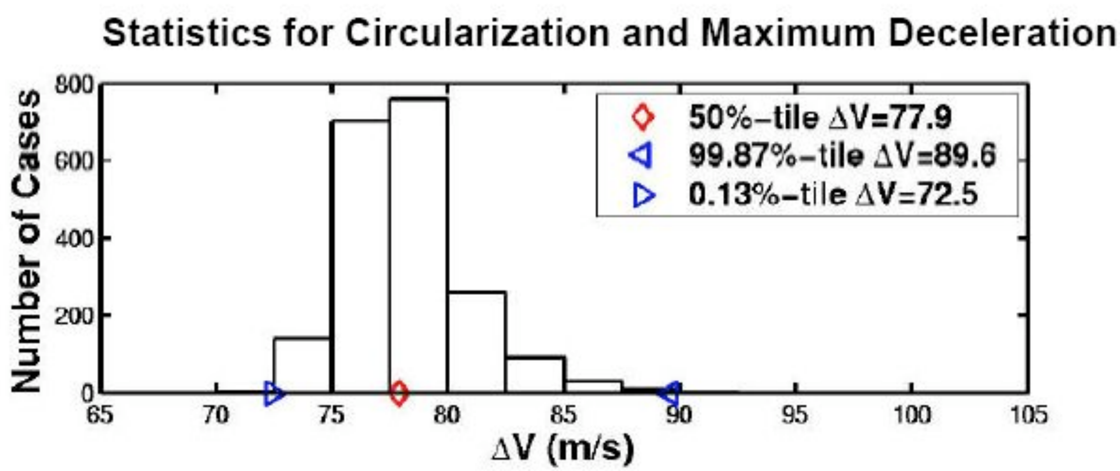
All-propulsive ΔV required for orbit insertion: 3975 m/s

ΔV provided by aerocapture: 3885 m/s (97.7% of total)









30 deg/sec bank rate

5 deg/sec2 bank acceleration

Aerocapture Summary

Aerocapture has Heritage

- Aerocapture can be accomplished at Mars, Titan, Venus and Earth with a high-heritage blunt cone shape like that of existing planetary entry vehicles
- Aerocapture guidance is fully analytic, less than 400 lines of code, derived from Apollo and Shuttle entry guidance (and works at every destination)
- Hypersonic guided entry has been accomplished many times; the only part of aerocapture that has **not** been proven is the atmospheric exit, but skip entry is similar
  - Apollo human-rated a skip entry mode for weather divert but it was never executed
  - Orion will fly skip entry for anytime Lunar return to the US Pacific coast (flight test scheduled for ~2015)--using a numerical guidance of 1000's of lines

Aerocapture is Robust

- An aerocapture system is designed with performance margin to handle worst-case nav, aero, and atmospheric uncertainties. Conservative estimates of variations are used in Monte Carlos.
- Thousands of simulations are run with validated tools to verify performance; *guidance works even with worst-on-worst uncertainties*.
- Guidance allows vehicle to "fly out" density dispersions, which are modeled based on all available data for each planet/moon
- **Aerocapture is much simpler (and easier) than a planetary lander (single flight regime)**

Aerocapture is Not High Risk

- PRA Conducted by SAIC in 2005
- Compared propulsive capture, aerobraking, and aerocapture at Mars
- Results* showed that if the system reliability is normalized so that the reliability of propulsive capture = 1.0, then
  - Aerobraking reliability = 0.9841
  - Aerocapture reliability = 0.9941
- **Aerocapture has HIGHER RELIABILITY than aerobraking, to which we routinely entrust high-dollar missions.**

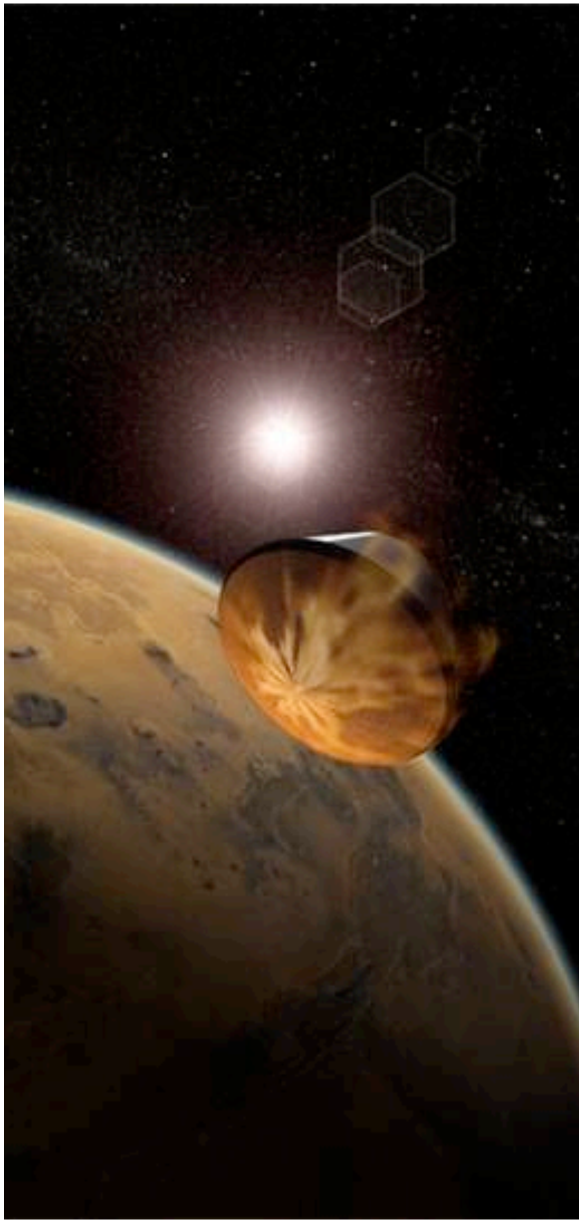
* Reference: T. Percy, E. Bright, A. Torres, "Assessing the Relative Risk of Aerocapture Using Probabilistic Risk Assessment," AIAA-2005-4107

Aerocapture Status/Next Steps

- ISPT will complete ground-based development to TRL6 by end of 2009
- Technically, a flight test of Aerocapture is not necessary before use at Titan, Mars, or Venus
- However, a flight validation would mitigate risk perception and immediately prove Aerocapture for multiple mission customers, for a relatively small up-front investment
- Continue to seek a near-term mission infusion or flight validation opportunity.
- Seek to infuse ISPT-developed thermal protection systems to fill gaps in current Agency choices.
- Advocate that heatshield sensors, some developed by ISPT to fly on MSL, be used on every entry vehicle to improve tools and future performance

Concluding Remarks

- ISPT Venus systems study showed benefit, feasibility of Aerocapture in terms of mass and performance
  - **TPS investments** may be applicable
  - **Aerothermal modeling** improvements can reduce design margins
- Aerocapture is **not** a high-risk maneuver:
  - Aerocapture is made of flight system elements that have **Strong Heritage** and firm computational basis
  - Aerocapture guidance is **simple and robust**
- Use on a **Venus** mission could enable more scientifically-rich architectures (like an orbiter and a probe, in one launch) -- suggest **detailed study**
- **Aeroshell sensors**, developed by ISPT and proven on MSL, can be applied to Venus probe or aerocapture vehicle to **increase scientific/engineering return**



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Backup

Venus Systems Study: Science

- **Science and corresponding mission is scoped for NASA's Discovery Program**
- **Multiple Sources of Information on Science Priorities**
  - SSE Decadal Survey
  - PIs of Discovery Program proposals for Venus missions
- **2 year science mission**
  - near polar orbit
  - planetary rotation provides full longitudinal coverage
- **Strawman Instrument Complement**
  - IR imaging spectrometer (200 m resolution)
  - Microwave radiometer
  - Low-energy neutral and charged particle detectors

Venus Systems Analysis Conclusions

- Aerocapture performance is feasible and robust at Venus with high heritage low L/D configuration
  - 100% of Monte Carlo cases capture successfully
- Top level analysis indicates that launch on a Delta 2925H results in large mass margins, opportunity for Delta 2925
- Performance sensitivity to ballistic coefficient provided
- TPS investments could enable more mass-efficient ablative, insulating TPS; accompanying aerothermal analysis investments would enable prediction of ablation, potential shape change
- Some additional guidance work would increase robustness for small scale height of Venus atmosphere
- For delivery into 300 x 300 km Venus orbit on same launch vehicle (Delta 2925H), aerocapture delivers
  - 1.8x more mass into orbit than aerobraking
  - 6.2x more mass into orbit than chemical only