Aerocapture Benefits to Future Science Missions

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NASA's In-Space Propulsion Technology (ISPT) Program is investing in technologies to revolutionize the robotic exploration of deep space. One of these technologies is Aerocapture, the most promising of the "aeroassist" techniques used to maneuver a space vehicle within an atmosphere, using aerodynamic forces in lieu of propellant. (Other aeroassist techniques include aeroentry and aerobraking.) Aerocapture relies on drag atmospheric drag to decelerate an incoming spacecraft and capture it into orbit. This technique is very attractive since it permits spacecraft to be launched from Earth at higher velocities, providing shorter trip times and saving mass and overall cost on future missions.

Recent aerocapture systems analysis studies quantify the benefits of aerocapture to future exploration. The 2002 Titan aerocapture study showed that using aerocapture at Titan instead of conventional propulsive capture results in over twice as much payload delivered to Titan. Aerocapture at Venus results in almost twice the payload delivered to Venus as with aerobraking, and over six times more mass delivered into orbit than all-propulsive capture. Aerocapture at Mars shows significant benefits as the payload sizes increase and as missions become more complex. Recent Neptune aerocapture studies show that aerocapture opens up entirely new classes of missions at Neptune.

Current aerocapture technology development is advancing the maturity of each sub-system technology needed for successful implementation of aerocapture on future missions. Recent development has focused on both rigid aeroshell and inflatable aerocapture systems. Rigid aeroshell systems development includes new ablative and non-ablative thermal protection systems, advanced aeroshell performance sensors, lightweight structures and higher temperature adhesives. Inflatable systems such as trailing tethered and clamped "ballutes" and inflatable aeroshells are also under development. Computational tools required to support future aerocapture missions are an integral part of aerocapture development. Tools include engineering reference atmosphere models, guidance and navigation algorithms, aerothermodynamic modeling, and flight simulation.

Aerocapture
Benefits to Future Science Missions
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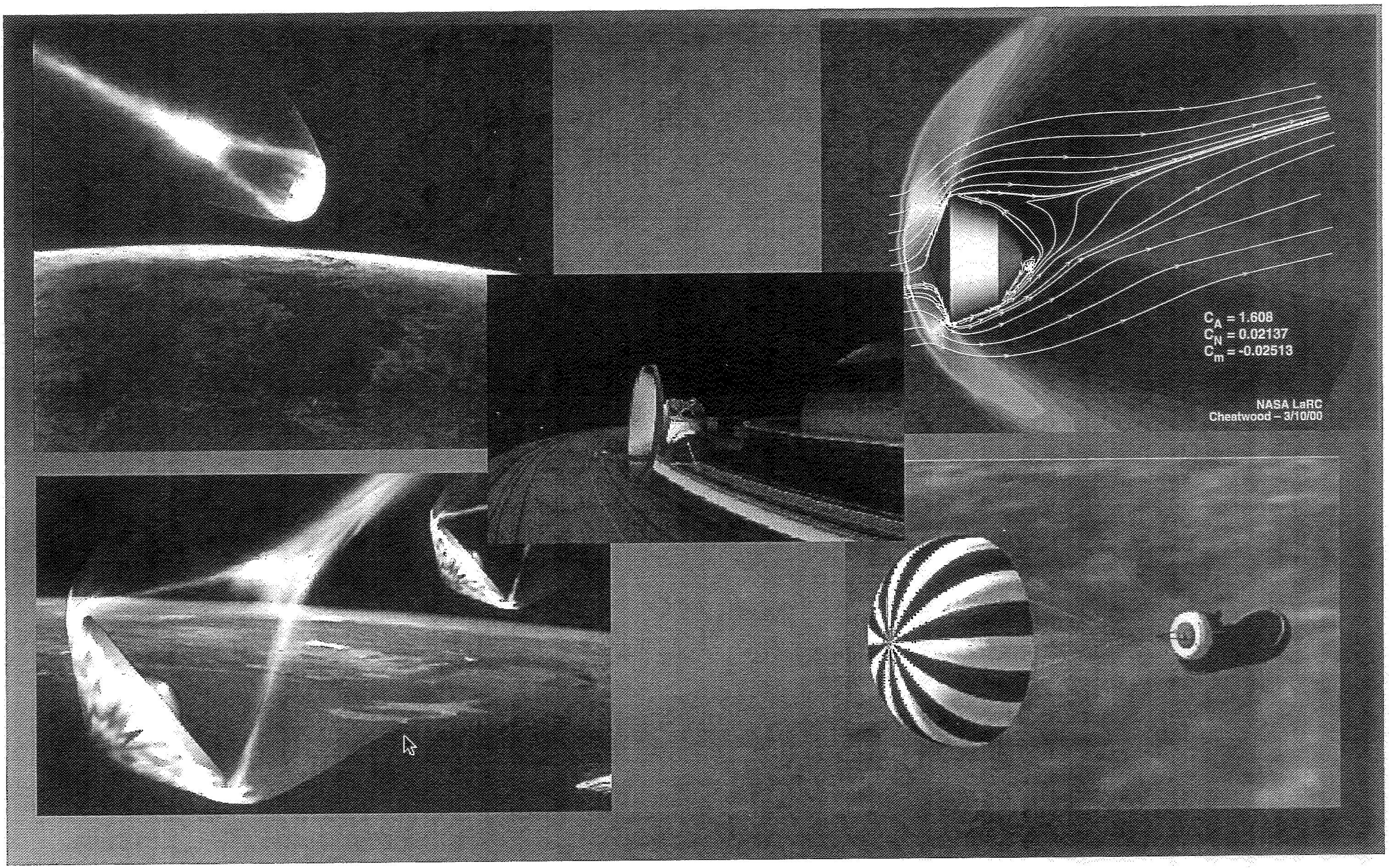
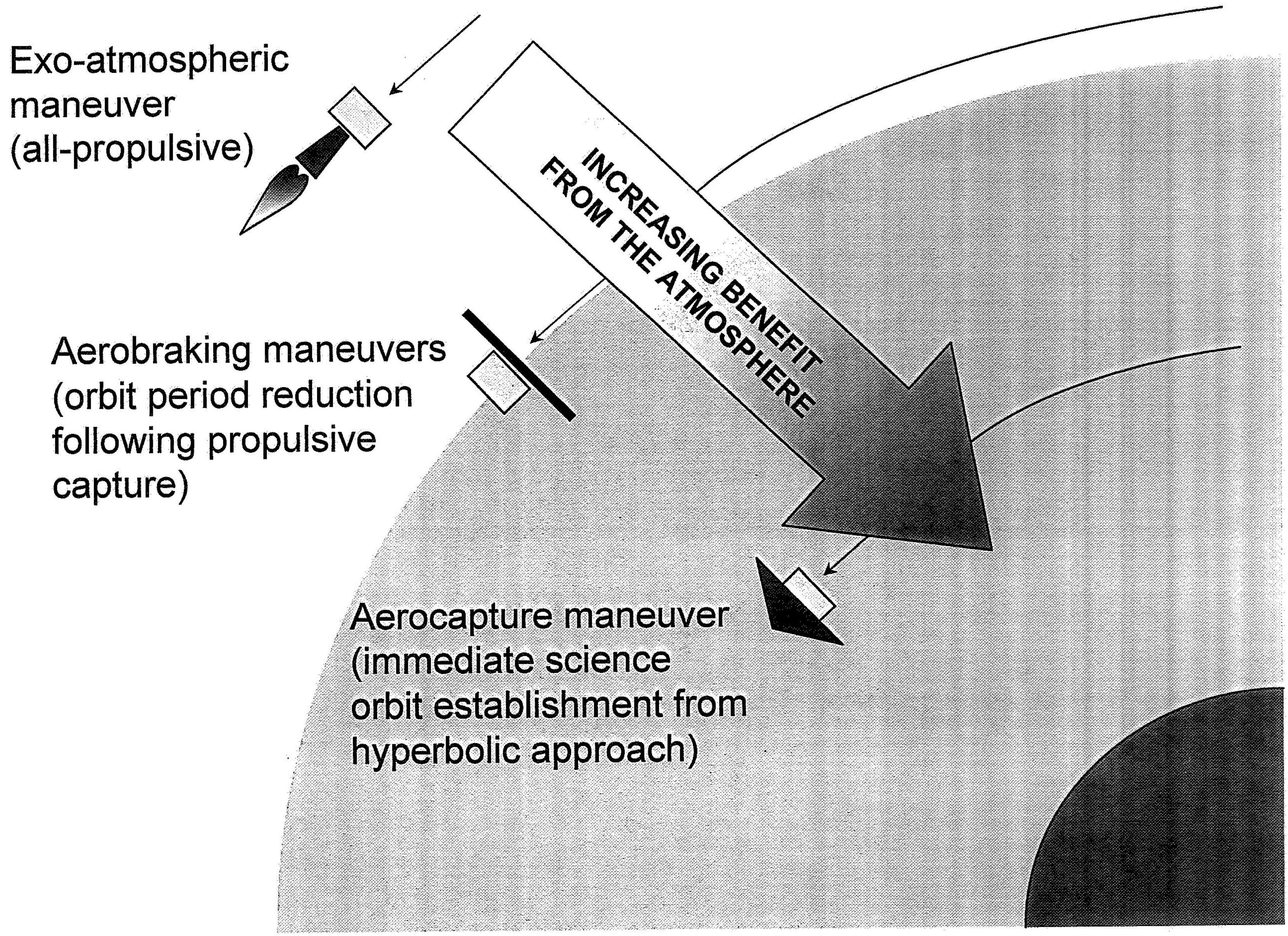
Aeroassist/Aerocapture

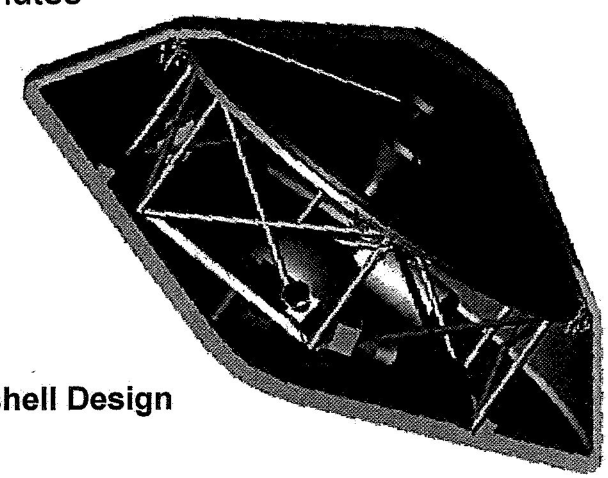


Basics of Orbit Capture

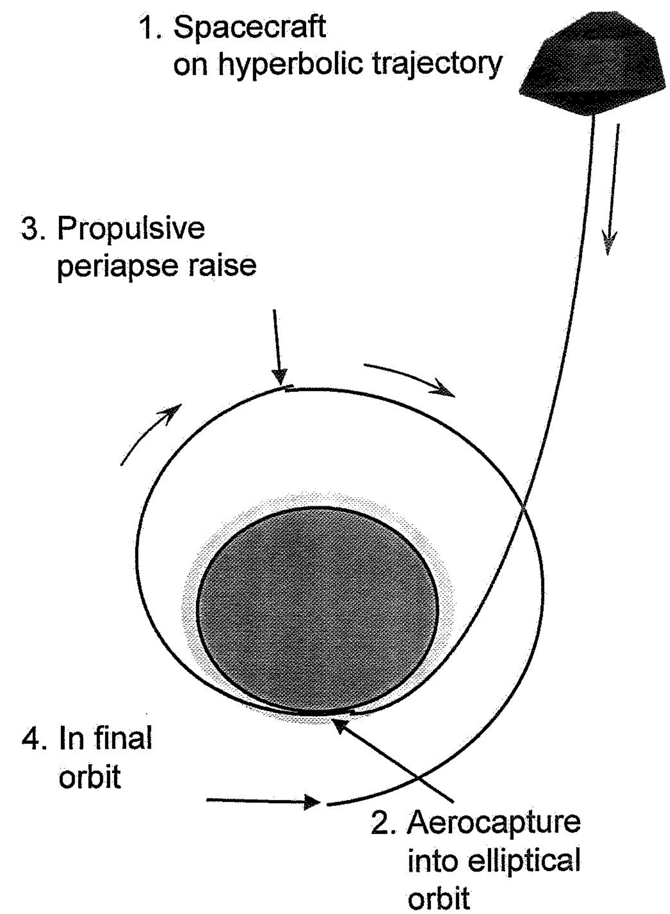


The Aerocapture Flight Maneuver

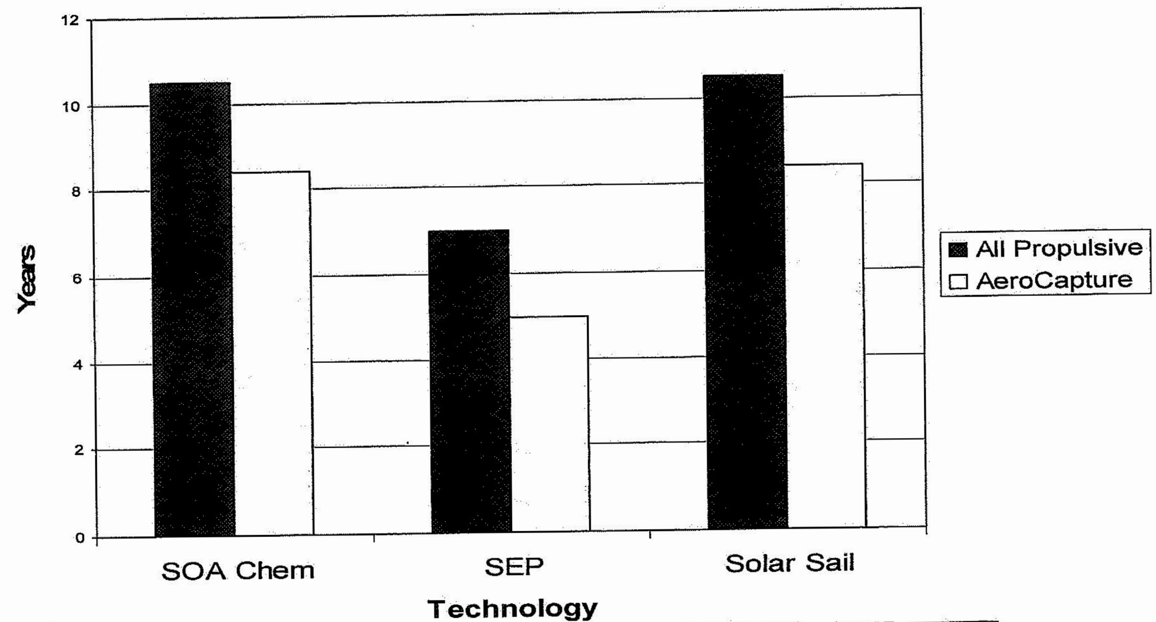
- Aerocapture is executed upon arrival at a body in which atmospheric drag, instead of propulsive fuel, is used to decelerate the spacecraft into a specific orbit
- Aerocapture is a natural extension of other commonly-used, successful flight maneuvers using atmospheres: direct entry and aerobraking
  - Aerobraking uses hundreds of passes over several months to circularize an orbit, requires an extensive ground operations team and a propulsive insertion into a highly-elliptical orbit (e.g., Mars Global Surveyor, Mars Odyssey, Mars Reconnaissance Orbiter)
  - Aerocapture is a single atmospheric pass maneuver that provides delivery of the science payload to final orbit within minutes

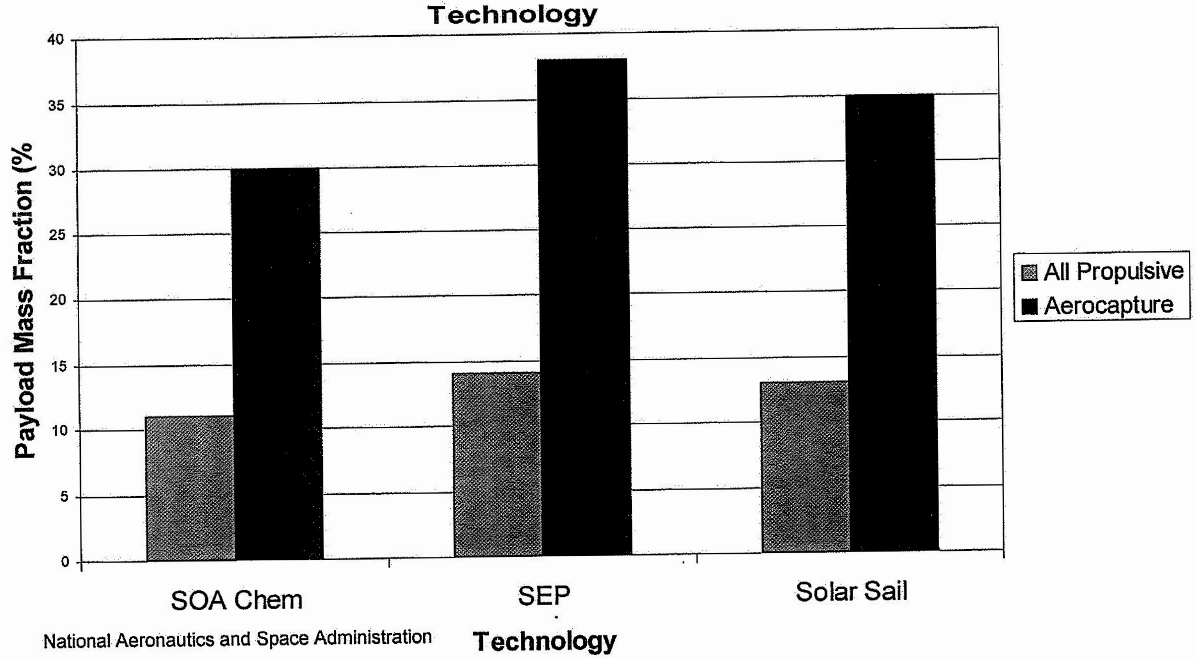


Rigid Aeroshell Design Concept



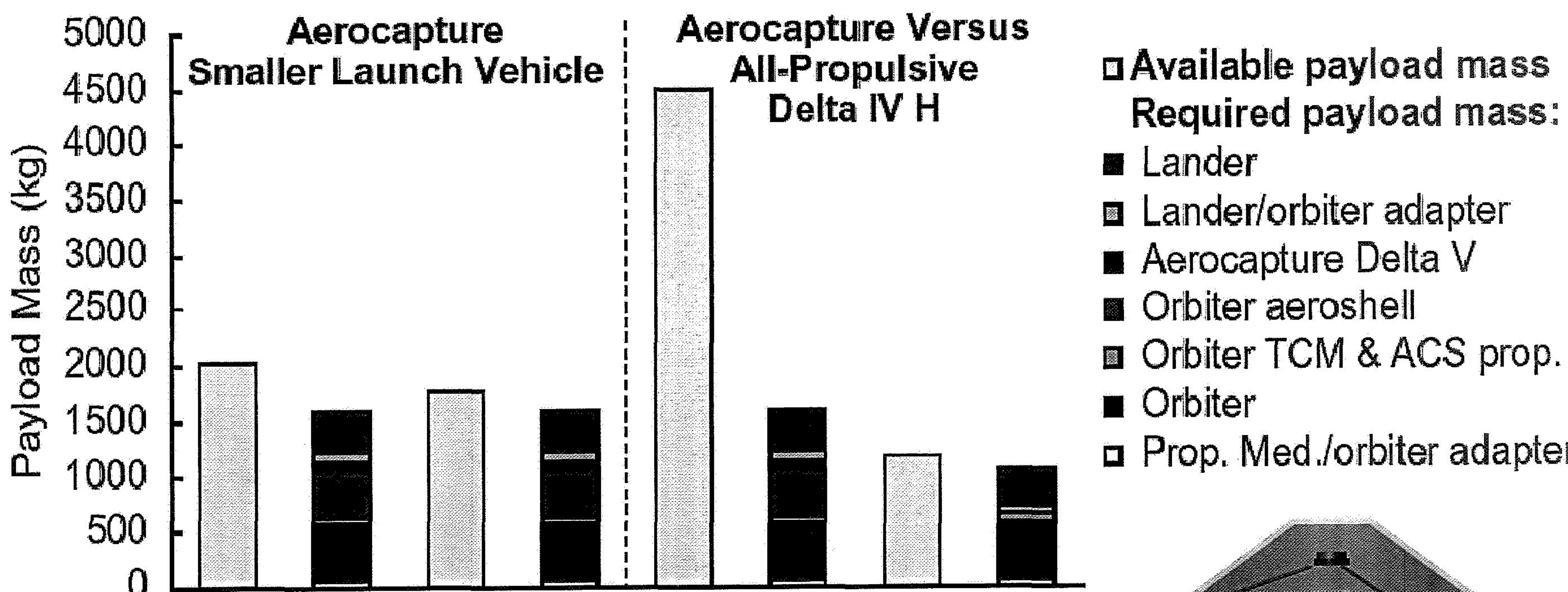
Titan Aerocapture Benefits



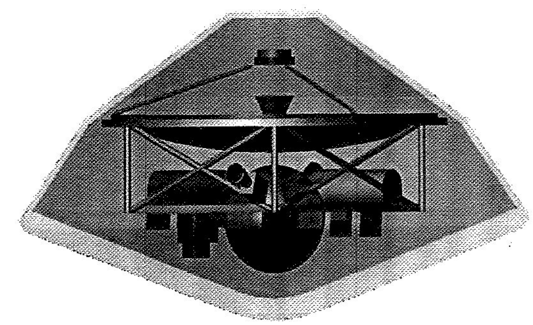


Aerocapture provides significant benefits in <u>Trip Times</u> and <u>Payload Mass Fraction</u> for Titan Exploration

Aerocapture at Titan



Launch Veh:	4450	4450	Delta IV H	Delta IV H
Gravity Assist:	EGA	VGA	EGA	VEEGA
Upper Stage:	SEP	SEP	SEP	Chem
Capture Type:	Aero	Aero	Aero	Chem
Trip Time:	6 yrs	6 yrs	6 yrs	12 yrs*



- Aerocapture is enabling to strongly enhancing, dependent on Titan mission requirements
- Aerocapture results in ~2.4x more payload at Titan compared to all-propulsive mission for same launch vehicle.

*Includes 2-yr moon tour used to reduce propellant requirements for all propulsive capture.

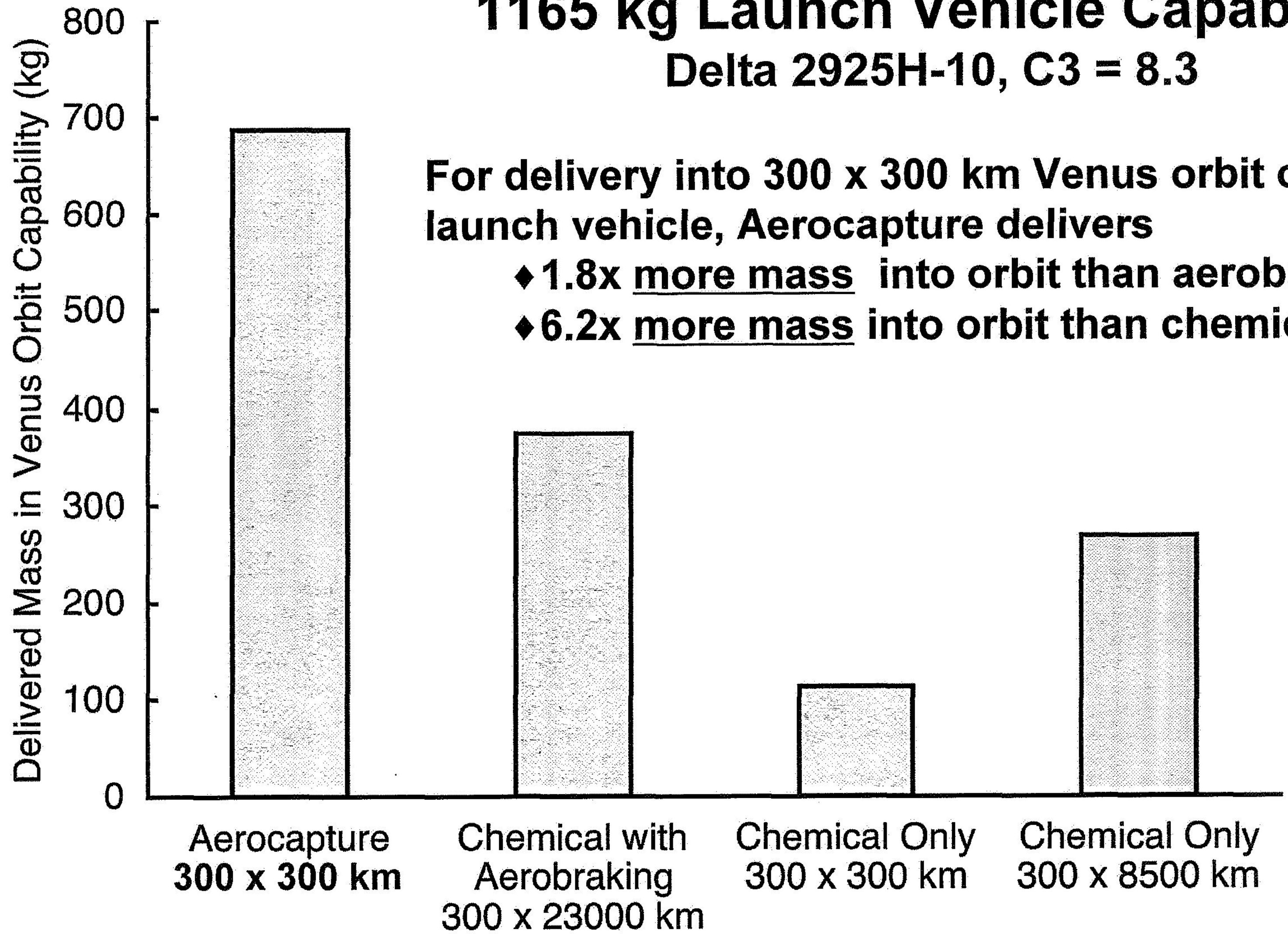
Aerocapture at Venus

1165 kg Launch Vehicle Capability

Delta 2925H-10, C3 = 8.3

For delivery into 300 x 300 km Venus orbit on same launch vehicle, Aerocapture delivers

- ♦ 1.8x <u>more mass</u> into orbit than aerobraking
- ♦ 6.2x <u>more mass</u> into orbit than chemical only



Aerocapture at Neptune

Launch Vehicle	Delta IVH			Atlas 551	
Gravity Assist	VEJGA	VJGA		EJGA	
Earth to Neptune Prop System	Chem	SEP		Chem	SEP
NOI Prop System	Chem	Chem	Aero	Aero	Aero
Cruise Time to Neptune (yrs)	15.0	15.0	[7] 10.3	11.8	10.5
Launch Year	2014	2017	2017	2014	2016
Launch C3 (km2/sec2)	15.6	17.0	18.4	47.3	9.1
SEP Power (kW, EOL)		30	30		30
Inertial Entry Velocity (km/s)			29	29	29
Neptune Cruise Chem dV (km/s)	3429			357	
NOI Chem dV (km/s)[1]	2300	2781			
Launch Capability	[9] 7012	[6] 6130	5964	[6] 2630	4850
Propellant Mass[2,3]	4158	1025	1070	279	713
LV to Prop Module Adapter	70	70	70	70	70
Prop Module Dry Mass	806	1585	1588	243	1559
Chem Prop Mod to Payload Adapter	40			40	40
Pre-NOI Separated Mass[10]	308	308	308	308	308
Pre-NOI Net Delivered Mass	1630	3142	2928	1690	2160
Aerocapture System[4]			1078	1078	1078
NOI Chem Propellant Mass[8]	967	1829			
NOI Chem Dry Mass	272	396			
Payload in Neptune Orbit	605	605	605	605	605
System Margin = LV-Growth	(214)	312	1245	7	477
System Margin % = (LV-Growth)/Growth	-3.0%	5.4%	26.4%	0.3%	10.9%

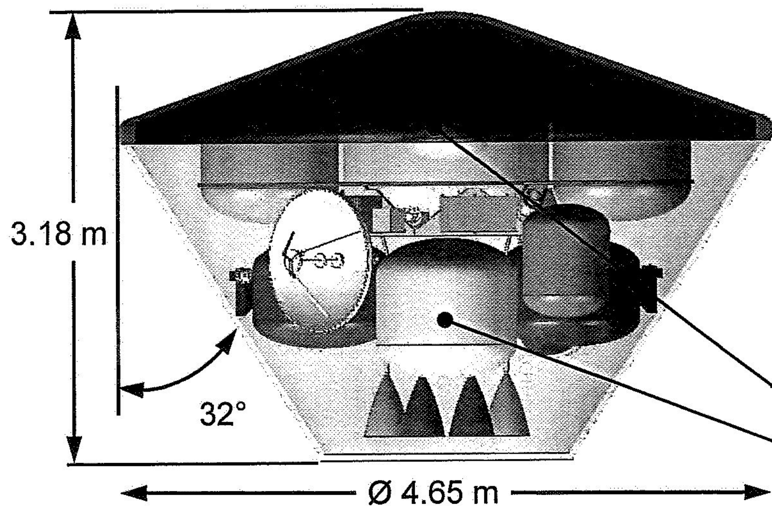
All masses in kg

**

Margin needs to be > 15-20 %

- Aerocapture is feasible and performance is adequate for a Neptune Aerocapture mission.
- Monte Carlo simulation results show 100% successful capture with conservative assumptions on atmosphere and navigation.
- Reference mission orbiter, and two probes can NOT be delivered by all chemical propulsion option .
- Aerocapture can deliver significantly more mass to Neptune orbit than an all-chemical system for the same launch vehicle.
- Aerocapture results in a 3-4 year reduction in trip time compared to an all-chemical propulsion system.

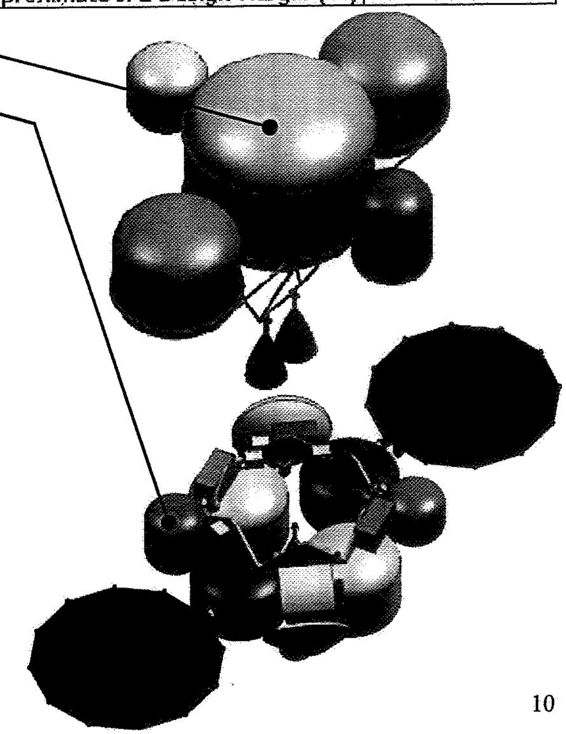
Aerocapture at Mars



Notional Configuration, Launch Orientation
No primary structure shown

Element	Dry Mass CBE (kg)	Dry Mass w/Contingency (kg)	Propellant Mass (kg)	Total Wet Mass w/Contingency (kg)
Earth Return Vehicle, Total	677	881	2120	3001
ERV, Earth Entry Vehicle		*56*		
ERV, Jettisoned Sample Capture Hardware		*79*		
ERV, Bus+Retained Sample Capture Hardware		*746*		
Propulsion Stage	653	848	2920	3768
Mid-Truss Stage	191	248		248
Aeroshell/Backshell	721			937
Cruise Stage	376	489	255	744
Total Launch Mass				**8698**

Launch Vehicle	Delta 4050H-19
C3 (km^2/s^2)	10.3
Launch Vehicle Capability	**7760**
Launch Vehicle Margin (kg)	-938
Launch Vehicle Margin (%)	**-12.1%**
Approximate JPL Design Margin (%)	-1.97%



- The primary objective was to perform a high fidelity Aerocapture systems definition study for a large Mars robotic mission; to drive out technology gaps
- Case selected: "Fast Case" - MSR, 2013 launch, opposition class, 20 month total trip time (vs. conjunction class (traditional approach) at 33 - 39 months)
- Fast round trip requires deep space maneuver of over 1 km/s and Venus gravity assist
- Aerocapture enables this mission; three times less mass than all-propulsive case; stay time at Mars too short to utilize aerobraking
- Results indicate that a substantial mass savings could be realized for conjunction class sample return as well as for any large delivered mass to Mars by utilizing Aerocapture
- However, for this specific "Fast Case", incorporating all constraints given by JPL, launch mass exceeded largest vehicle available by 12%; more analyses required

Titan Aerocapture Systems Definition Study
Independent Assessment Panel

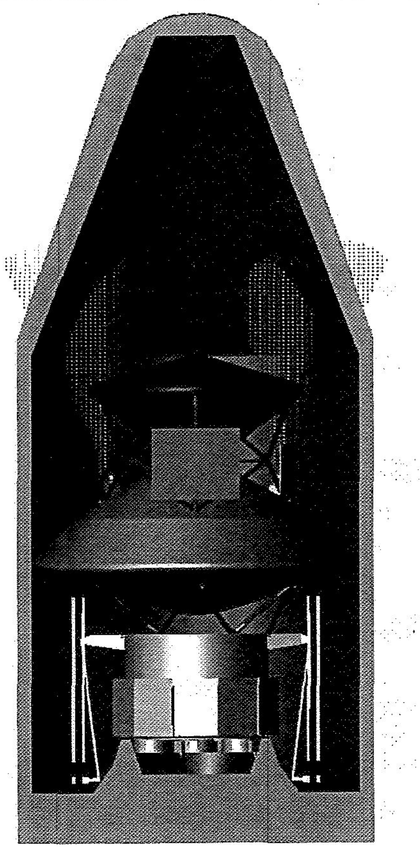
Study Concluded with an Independent Panel Review at JPL on August, 2002:

13 Panelists – Academia, NASA Centers, Industry

50 Reviewer Recommendation Forms Collected and Resolved/ Final TM Report in work

Common Programmatic Issues:

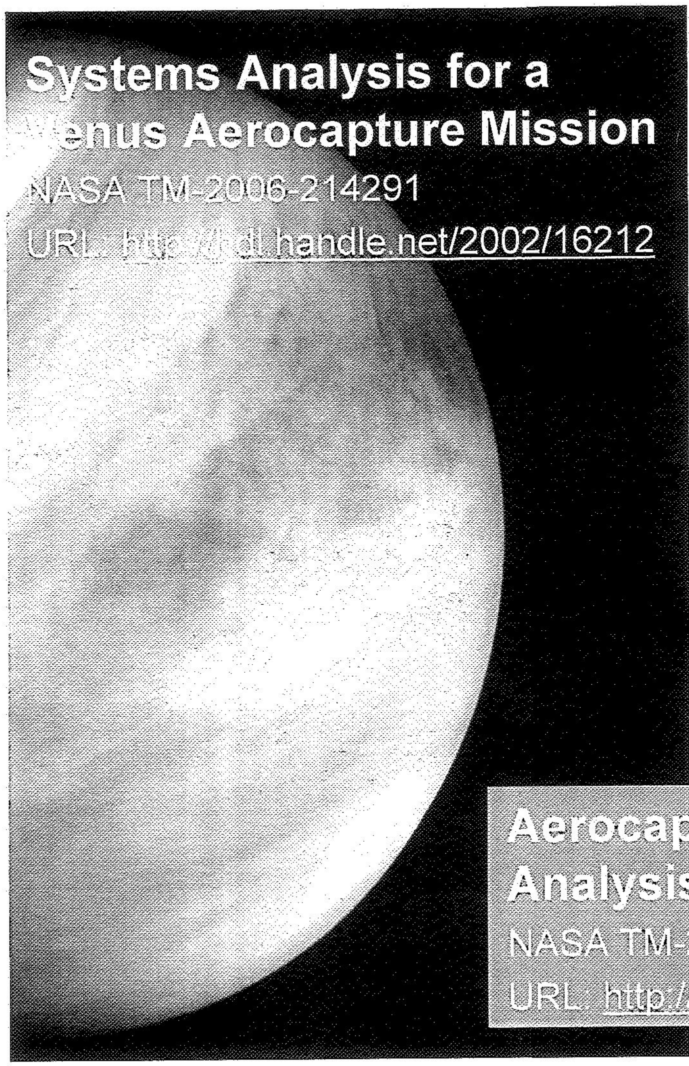
- Timely access to Cassini/Huygens data
- Need for flight demonstration of aerocapture system



- Carol Carroll (NASA Ames) Chair
- Leon Allen (Orbital Sciences; AFE Proj Mgr) *participated remotely*
- Rita Beebe (NMSU; scientist) *participated remotely*
- Joe Gamble (JSC, retired; guidance and control)
- Howard Goldstein (ARC, retired; thermal protection systems)
- Torrence Johnson (JPL; SSE scientist)
- Eric Nilsen (JPL; mission planner)
- John Rogers (LaRC; project manager) *participated remotely*
- Robert Sackheim (MSFC; Asst. Director and Chief Engineer for Space Propulsion)
- David Stephenson (MSFC; propulsion)
- Darrell Stroebel (Johns Hopkins University; atmospheric scientist)
- Mike Tauber (ARC, retired; radiative heating) *participated remotely*
- Sam Thurman (JPL; project manager, entry systems)
- Ellis Whiting (ELORET; radiative heating)

Aerocapture Systems Analysis

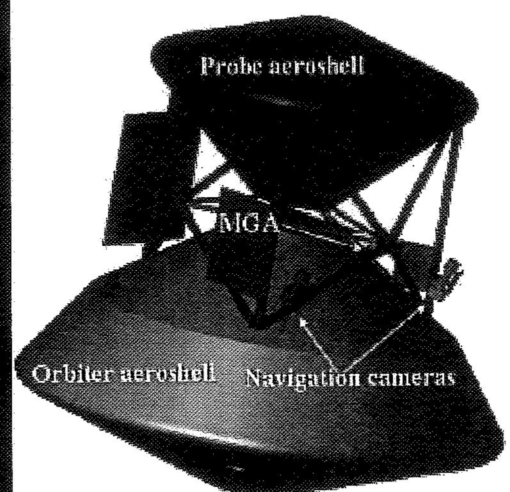
ISPT systems analysis studies play a key role in defining technology development drivers for Aerocapture:



Systems Analysis for a Venus Aerocapture Mission

NASA TM-2006-214291

URL: http://hdl.handle.net/2002/16212



Aerocapture Systems Analysis for a Titan Mission

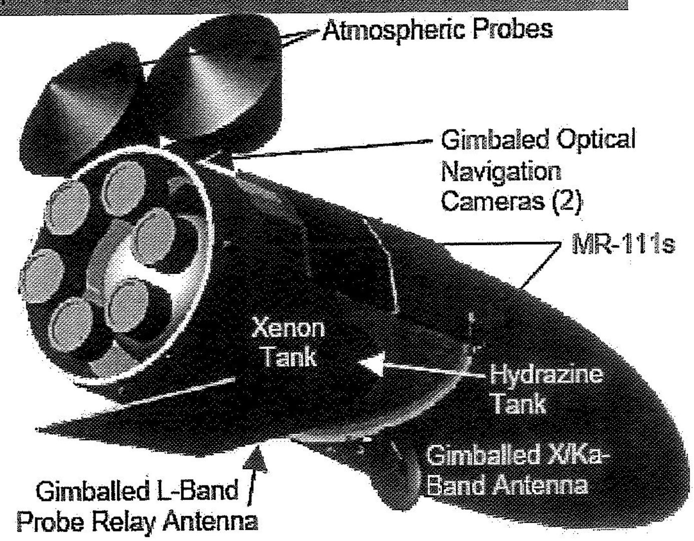
NASA TM-2006-214273

URL: http://hdl.handle.net/2002/16166

Aerocapture Systems Analysis for a Neptune Mission

NASA TM-2006-214300

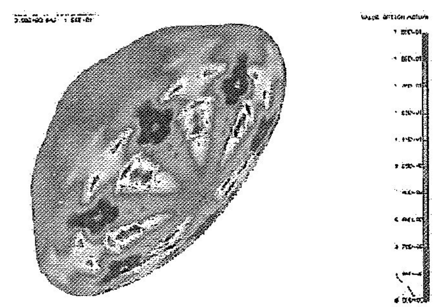
URL: http://hdl.handle.net/2002/16221



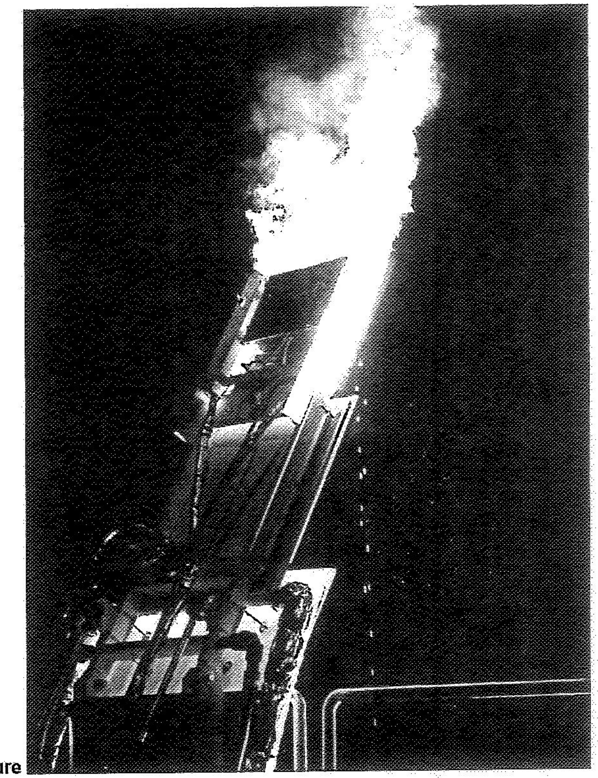
Aerocapture - Approach

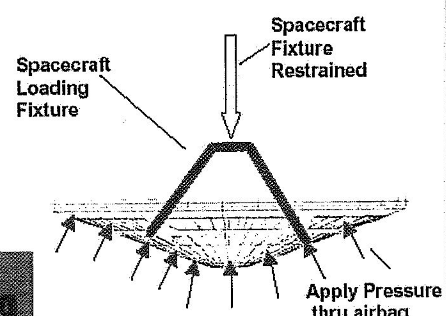
- Raise Aerocapture propulsion to TRL 6 through the development of subsystems, operations tools, and system level validation and verification in relevant environments.

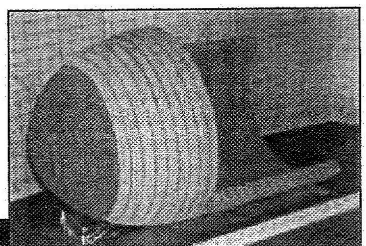
- Uncover all risk factors for Aerocapture infusion into science missions and mitigate each risk factor

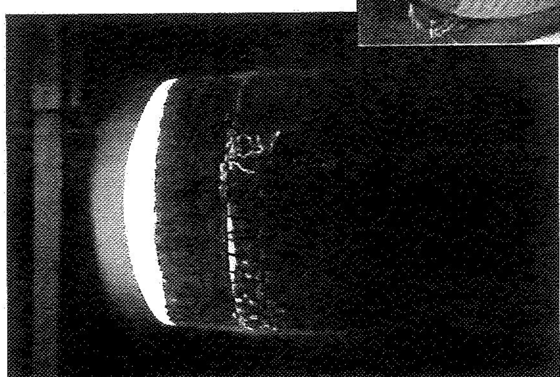


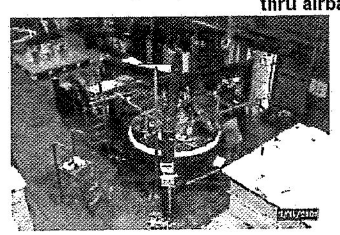
Aeroshell Displacements (Limit)

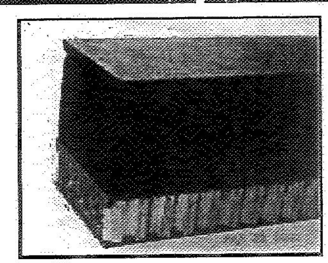






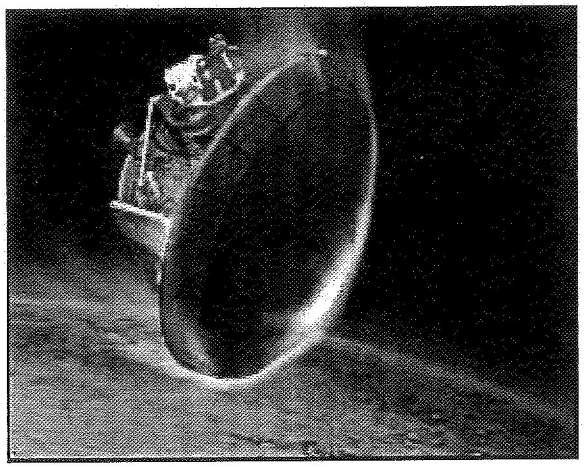






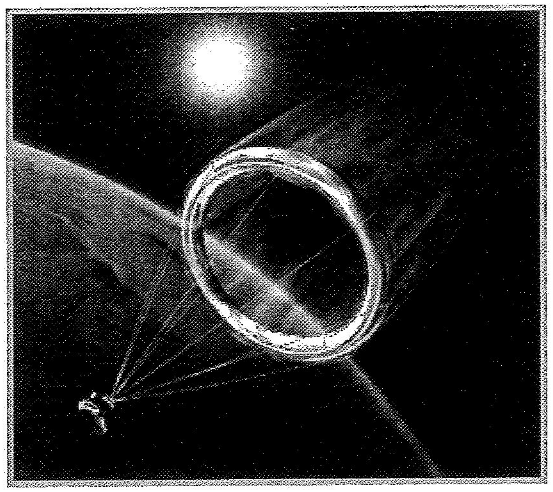
Aerocapture Flight Hardware System Alternatives

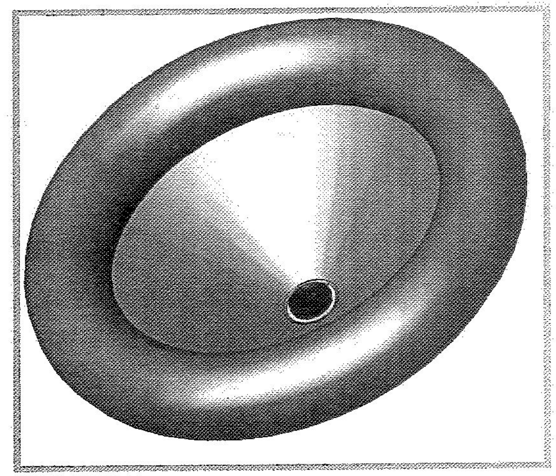
Higher TRL
Rigid Aeroshells



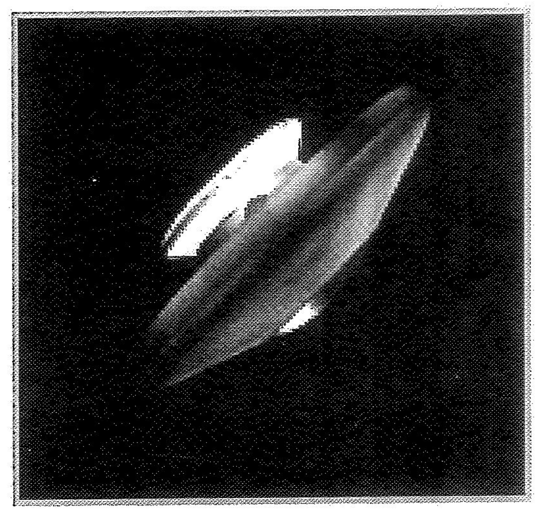
- Moderate to high maturity
- Rigid aeroshells widely used in direct entry systems: Mars Rovers, Genesis, Stardust...
- Provides modest tolerance for nav and atmospheric uncertainties

Lower TRL
Inflatable Deceleration Systems/Ballutes ("Balloon Parachutes")

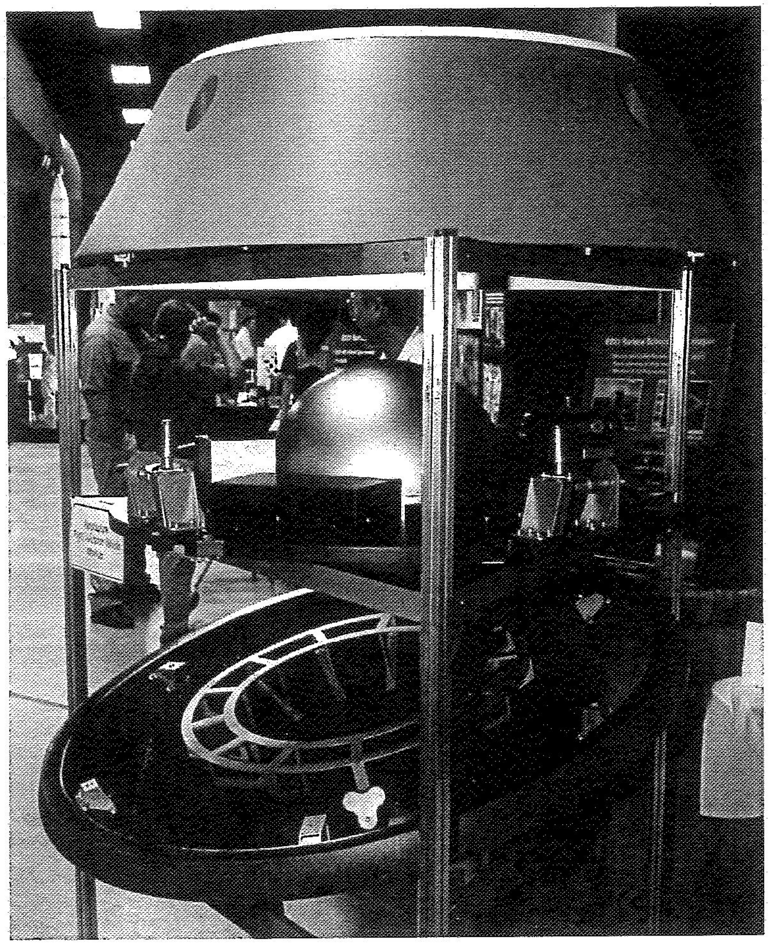


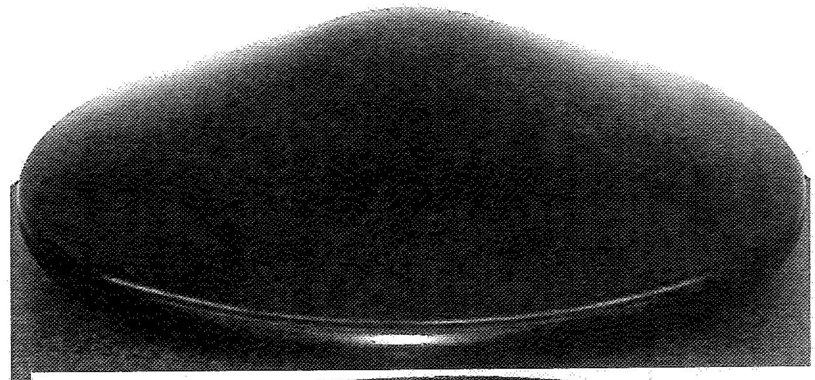


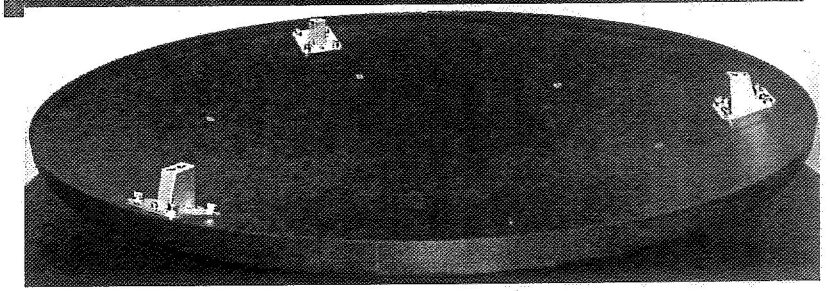
- Lower maturity
- Applicable to all size and shape payloads
- Payload not enclosed during interplanetary cruise as with rigid aeroshell system
- Reduced heating conditions
- Packaging efficiencies

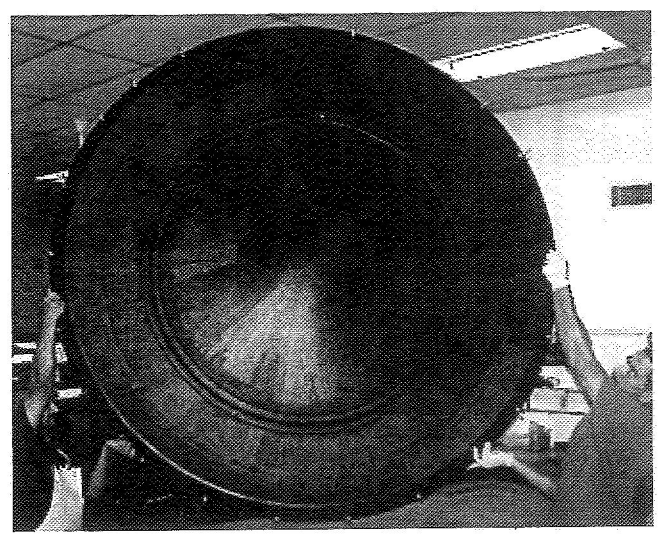


Aerocapture Rigid Aeroshell Development

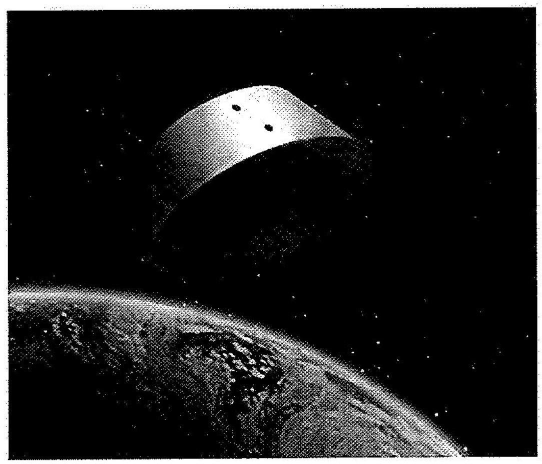








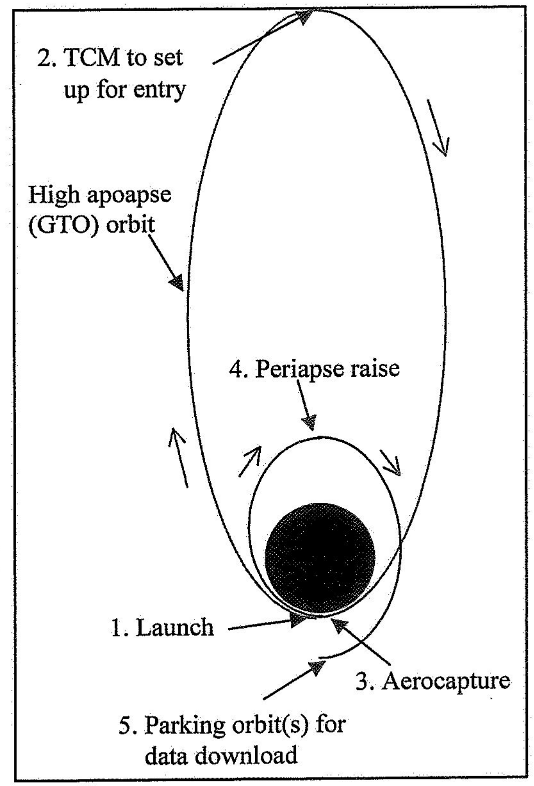
Spaceflight Demonstration of Aerocapture



Mission Parameters

Vehicle Type	60° sphere-cone
Vehicle Mass (CBE)	185 kg
Access to space	Piggyback to GTO
Mission Duration	16 hours
Atmospheric Entry Speed	10.3 km/s
Atmospheric ΔV	2.4 km/s
Nominal Launch	Spring 2010
NMP ST-9 Funding	$86 M

Mission Sequence



Flight Test Objectives:

1. Validate the performance of the autonomous aerocapture guidance system based on bank angle control.
2. Improve the validation of computational modeling tools used for aero/ aerothermodynamic design and trajectory performance.
3. Develop and validate systems engineering processes for doing aerocapture missions.
4. Obtain flight performance data on components of interest for future aeroentry and aerocapture missions.

New Millennium Program Space Technology - 9

Summary

- Utilizing Aerocapture for orbit capture at the destination can significantly increase payload capacity, decrease trip times, and decrease overall mission costs.
- Aerocapture can enable completely new types of missions that were just not feasible before; landers + orbiters + probes…
- Aerocapture utilizes heritage hardware/software and has seen significant technology development in the last four years.
- Aerocapture is one of five technologies proposing spaceflight demonstration on the New Millennium Program's Space Technology – 9 mission, scheduled to launch in 2010.
- It's now time to begin preparations for Discovery, Scout, New Frontiers, Flagship proposals that incorporate Aerocapture!