AEROCAPTURE STUDY

Jet Propulsion Laboratory
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Client
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JPL Innovation Foundry
A-Team Study

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INTRODUCTION

- Aerocapture technologies have the potential for enabling orbital missions to the outer planets and their satellites with shorter trip times than is practical when achieving orbit capture using conventional chemical propulsion.
- Aerocapture centers on the judicious use of aerodynamic forces in a planetary atmosphere to guide the spacecraft to a desired captured trajectory.
- NASA's STMD is investing in aeroassist technologies in response to the needs of human Mars exploration.
- The purpose of this study is to determine both the applicability of the STMD-developed technologies to robotic exploration and what other aeroassist technology and risk reduction investments would benefit robotic exploration, and assess the readiness of aerocapture technology for potential robotic missions.

STUDY GOALS & OBJECTIVES

Study Goals

Identify what technologies are needed for a future orbital mission using aerocapture

Determine if a technology demonstration mission is required prior to its first use for a science mission

Study Objectives

1. Characterize the current status of aerocapture technologies for SMD missions
2. Determine NASA actions needed to ensure that proposed missions can use these technologies
   a. Determine if near- or far-term aerocapture missions need technology developments
   b. Determine these technology gaps, if any
   c. Determine the potential impacts of technologies using deployables or inflatables
3. Provide a technology roadmap to the PSD and STMD if developments are required
4. Identify the recommended path forward for NASA HQ
5. Determine if an aerocapture demonstration is required before using it for an actual science mission
6. Determine if we need more modeling and/or simulations, such as improved CFD to support aerodynamic and aerothermal databases, or Monte Carlo simulations addressing system performance at Neptune.

For Objective 5: If the study's conclusion is that a demo is not required, is that conclusion a universally accepted consensus? Is the evidence for not requiring a demonstration convincing?

PARTICIPANTS IN JPL A-TEAM AEROCAPTURE STUDY

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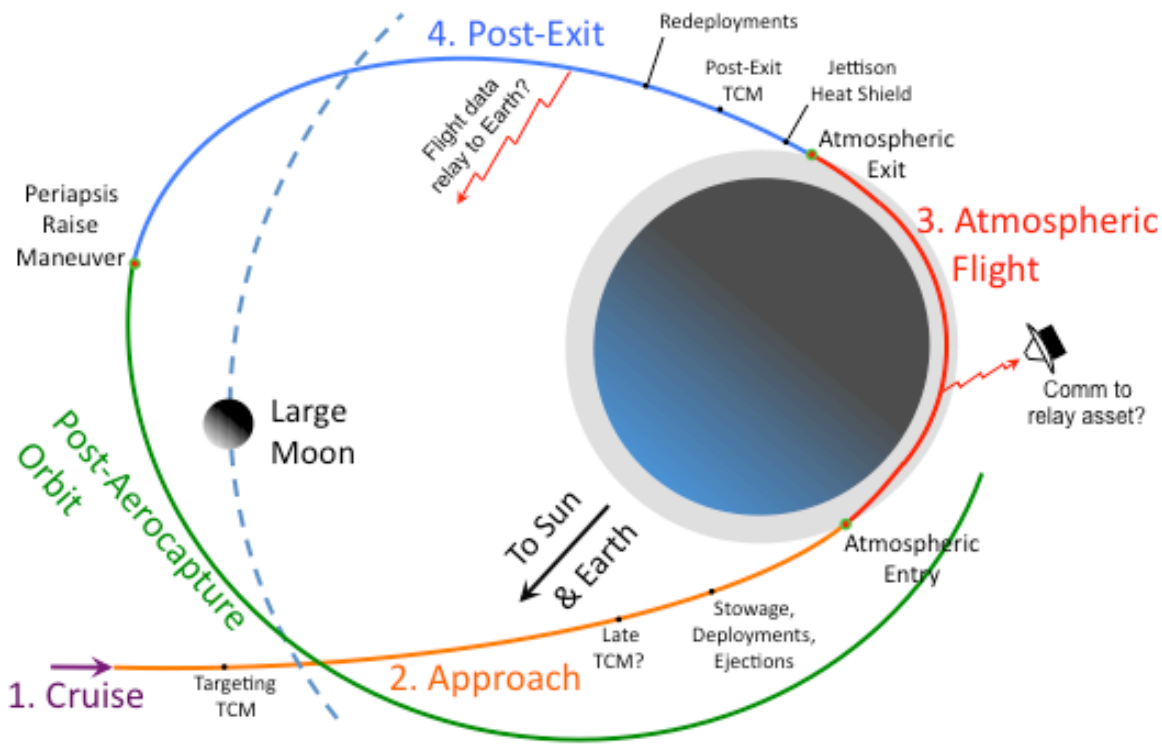
AEROCAPTURE MANEUVER SEQUENCE



Aerocapture activities & risks by flight phase

Mission Phase, Characteristics, & Risks	Risk Mitigation Activities	Feasibility & Trade Studies	Risk Reduction prior to Project Start	Project Development Effort
CRUISE				
Heat rejection	Investigate the complexity, reliability, & lifetime of heat rejection systems			
APPROACH				
• Navigation errors • Need OPNAV(s)? • Late maneuvers? • Equipment failures	Determine whether OPNAV or a late autonomous maneuver is needed			
	Quantify flight path angle errors			
Deployments, stowage, & ejections				
• Mechanism failures • Environmental issues • Warming up electronics	Develop redeployables, including solar panels, if needed			
Attitude determination & control	Aerocapture introduces no additional risk			
Atmosphere & gravity field knowledge & uncertainty				
• Temperature, density, & pressure profiles • Composition	Increase atmosphere & rings modeling efforts			
	Advocate opportunistic stellar occultations			
	Take spacecraft-based measurements on approach			
	Send an advance scout probe			
	Improve knowledge with Earth- & space-based observations			
• Gravity field	Aerocapture introduces no additional risk			

Aerocapture activities & risks by flight phase (cont'd)

Mission Phase, Characteristics, & Risks	Risk Mitigation Activities	Feasibility & Trade Studies	Risk Reduction prior to Project Start	Project Development Effort
ATMOSPHERIC FLIGHT				
Survival				
• Heating • Pressure • Shear • Turbulence (including "pot holes" and buoyancy waves) • Acceleration	Establish a peak acceleration requirement			
	Determine CFD aerothermal model quality			
	Understand uncertainty on radiative heating component			
	Work on high-velocity physics development			
	Expand/build aerothermal & hypersonic turbulent flow test facilities			
	Develop heat shields: flexible TPS, carbon phenolic, woven TPS, deployable carbon fabric			
	Investigate long-term storage & protection of heat shields			
	Analyze & test roughness effects			
	Identify cold & micrometeoroid survival means			

Aerocapture activities & risks by flight phase (Atmospheric Flight Phase, cont'd)

Mission Phase, Characteristics, & Risks	Risk Mitigation Activities	Feasibility & Trade Studies	Risk Reduction prior to Project Start	Project Development Effort
Flight control—knowledge & algorithms				
Vehicle aerodynamics database	Improve/expand hypersonic wind tunnel capability			
• Knowledge (attitude & initial deceleration) • In-flight guidance algorithms	Aerocapture introduces no additional risk			
Flight control—actuators				
Actuators	Determine whether anything beyond heritage hypersonic control is needed			
Flaps or other shape change	Analyze & wind-tunnel test			
CG change	Analyze & wind-tunnel test or low-cost flight test			
Deployable drag modulation through release or adjustment	Research, analyze, & wind-tunnel test for different drag conditions			
• Thrusters • Mass modulation	Aerocapture introduces no additional risk			

Aerocapture activities & risks by flight phase (cont'd)

Mission Phase, Characteristics, & Risks	Risk Mitigation Activities	Feasibility & Trade Studies	Risk Reduction prior to Project Start	Project Development Effort
POST-EXIT				
• Attitude control • Critical reconfigurations & maneuvers (escape avoidance cleanup, periapsis raise) • Non-critical reconfigurations & maneuvers (additional cleanup)	Aerocapture introduces no additional risk			
Aerocapture communications (any flight phase)				
• Occultation issues • Relay asset? • Direct-to-Earth semaphores/low data rates/Doppler • Engineering performance & instrumentation data	Aerocapture introduces potential mission constraints but no additional risk			

AEROCAPTURE STUDY - KEY FINDINGS

1. **An aerocapture demonstration is not needed to reduce risk prior to flight implementation.**

- This conclusion is the overwhelming consensus of the study participants. Multiple successful demonstrations of aeroassist techniques that are more demanding than aerocapture, by multiple nations' space agencies, support it. Any flight demonstrations required would test specific subsystems; an end-to-end aerocapture demonstration would have limited utility.

2. **Within the time frame considered, aerocapture at the destinations of interest is feasible with no or modest developments.**

- No developments are needed for aerocapture at Titan, Venus, or Mars. For other destinations, continued heat shield development is needed. Depending upon the destination this would involve TPS material development or higher-L/D aeroshell development (Uranus and Neptune). With the possible exception of Neptune, heritage hypersonic guidance and control technologies may be sufficient.

3. **Aerocapture can be used at Uranus and Neptune to reduce the time of flight, bring additional science payload to the destination, and/or reduce overall mass.**

- Of all potential solar system destinations, the ice giant planets, with their large heliocentric distances, stand to benefit the most from using aerocapture. The benefit for other destinations, though somewhat smaller, is nonetheless significant.

AEROCAPTURE STUDY - KEY FINDINGS

4. **Trade studies and Design Reference Mission (DRM) developments are needed to determine any developments required in advance of a project.**

- In the light of the range of potential flight control techniques and aeroshell configuration options, these studies would better define technology requirements such as the required control authority. This might allow use of higher-heritage, lower-L/D aeroshell geometries (blunt bodies). For the widest range of applicability continued focus on low L/D blunt body shapes is appropriate, with the caveat that Uranus and Neptune might require higher performance, depending upon the outcome of DRM-based studies. Improved models of the mass requirements for aerocapture systems would increase the fidelity of these trade studies.

AEROCAPTURE STUDY - KEY FINDINGS

5. The following would be beneficial risk mitigation activities:

- Update and improve atmosphere and ring models
  - Most important for Uranus and Neptune; improvements at Venus, Mars, and Titan might be enhancing but are not enabling
  - Identify opportunistic stellar occultations of Uranus and Neptune, especially using the *Kepler* spacecraft's extended mission, for improving atmosphere models
- Quantify and constrain the complexity, reliability, and lifetime of heat rejection systems
- Develop redeployable solar panels, if needed
- Determine whether any techniques beyond heritage hypersonic guidance and control are needed
- Identify potential mission constraints arising from aerocapture data capture requirements, if any
- Determine whether late autonomous maneuvers would be needed (destination-dependent)
- Quantify achievable flight path angle errors at Uranus and Neptune from practical approach navigation accuracies and planetary ephemeris uncertainties

Supporting Materials

- Michelle Munk (LaRC) – Aerocapture Overview
- John Elliott (JPL) – Mission Needs / Systems Engineering
- Dick Powell (LaRC) – Vehicle Capabilities
- Ron Sostaric (JSC) – Orion skip guidance
- Parul Agrawal (ARC) – Uranus Study
- Helen Hwang (AMES) – TPS Capabilities
- Neil Cheatwood (LaRC) – HIAD for Titan Aerocapture
- Paul Wercinski (ARC) – ADEPT for Titan, Uranus and Neptune Aerocapture