Technology Overview and Assessment for Small-Scale EDL Systems

Casey R. Heidrich1, Brandon P. Smith2, and Robert. D. Braun3  
1 Georgia Institute of Technology, Space Systems Design Laboratory (cheidrich@gatech.edu), 2 NASA Ames Research Center (brandon.p.smith@nasa.gov), 3 Georgia Institute of Technology (robert.braun@aei.gatech.edu)

Abstract
Motivated by missions to land large rovers and humans at Mars and other bodies, high-mass EDL technologies are a prevalent trend in the research community in contrast. EDL systems for low-mass payloads have attracted less attention. Significant potential in science and discovery exists in small-scale EDL systems. Payloads acting secondary to a flagship mission are a currently under-utilized resource. Before taking advantage of these opportunities, further development of scaled EDL technologies is required. The key limitations identified in this study are compact decelerators and deformable impact systems. Current technologies may enable rough landing of small payloads, with moderate restrictions in packaging volume. Utilization of passive descent and landing stages will greatly increase the applicability of small systems, allowing for vehicles robust to entry environment uncertainties. These architectures will provide an efficient means of achieving science and support objectives while reducing cost and risk margins of a parent mission.

Motivation
The movement toward flying smaller spacecraft emerged out of academia through strict enforcement of mass and volume limitations and by defining standard mechanical and electrical interfaces. In recent years, NASA has begun to actively integrate small spacecraft into its mission portfolio and is reaping the rewards. The value proposition posed by small spacecraft is high due to their dramatically lower cost and more forgiving risk posture compared with large, “traditional” spacecraft with payload-driven requirements. The vision of the current research is to apply the tenets of the small spacecraft movement toward an EDL system for secondary payload missions. An EDL capability for small spacecraft would enable scientists to recover high-quality data from Earth orbit as well as broaden the reach of small spacecraft to landing on other celestial bodies with substantial atmospheres (e.g. Mars, Venus, and Titan).

Small-scale EDL technologies will create novel opportunities for science and exploration objectives. A flagship mission first entering orbit, particularly by aerocapture means, could release small probes to provide day-by-day of atmospheric data before entry of the main vehicle. Data could be processed in-situ or transmitted to Earth as a means of increasing mission success rates. A larger geographical region may be covered with multiple probes released on the approach trajectory. A large variety of missions become feasible with development of compact and passive entry vehicles.

Mission opportunities for small entry vehicle include:
- LEO reentry of long-term science objectives
- ISS rapid return of science or medical material
- Mars sample return missions
- Autonomous EDL environment requirements
- Multiple science probes for redundancy/greater ground coverage

Historical Perspective

Design Space

A novel Mars mission is proposed as an application of small-scale EDL. The mission is to land a static science payload carrying sensitive instruments on the Martian surface. The requirements are:

- The payload is 3U in volume
- Restrictions on the primary vehicle limit capsule height to 0.8 m.
- The payload shall experience less than 12 g’s (sustained).
- The landing temperature shall not exceed 250°C
- The payload shall experience less than a 50 g landing impulse.

Descent system for small EDL architectures. The heritage EDL design paradigm may be ineffective or even irredeemable on small scales. In order to fully take advantage of smaller reentry vehicles, it is advantageous to reexamine typical entry architectures utilizing a separate hypersonic entry system, decelerator, and landing system. From this, two particularly important ideas with respect to the small-scale EDL design process were conceived. First, cross-utilization of systems may be key for achieving small EDL without significantly altering mission requirements such as landing g’s and timeline margins. Second, complete removal of systems may be necessary to achieve feasibility. This may drive mission requirements when small vehicles lack the capacity for controlled flight or soft landing.

Technology Assessment

Concepts suitable for small-scale EDL applications were taken from literature and compared using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). Depressurized Entry, Free Fall, and Stationary Descent

Descent system assessment for small-scale vehicles. Two viable options are the drag ribbon concept and no decelerator concept (typical of a parachute). The drag ribbon concept consists of a long ribbon released behind the vehicle designed to create drag due to its inherent tendency to flay in the oncoming flow. Landing system assessment for small-scale vehicles. Results lack any clear candidate. Soft landing presents a significant challenge on small scales. The crushable structure option is a viable for future research due to its inherent simplicity and passive utility.

Challenges

Packaging in restricted OML geometries. Small-scale EDL systems impose strict volume requirements. Reexamination of the typical “stacked” technique (left) may provide opportunities for volumetric efficiency. For example, the toroidal configuration (right) accommodates the payload length around the parachute canister.

Impact conditions (at Mars) and vehicle properties. Moderate changes in vehicle mass and size properties greatly influence impact conditions absorbed by the landing system. Reducing the MOLA landed altitude reduces the impact velocity of high ballistic coefficient vehicles.

References


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