SmallSat Spinning Landers for Ocean Worlds Exploration Missions – Future ESPA-class Hitchhikers.

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Introduction: The spinning lander concept is a novel adaption of a classic dual-spin spacecraft architecture. A spinning module provides robust gyroscopic attitude stability, a relatively benign thermal environment (by evenly distributing heat loads) and centripetal acceleration (for effective propellant settling and flow control); it is connected to a despun module *via* a rotor/bearing assembly, and this despun module also accommodates a landing leg system. Most subsystems for a spinning lander—power, telemetry and command, RF telecommunications, attitude control, despun rotor control, propulsion, etc.—are nearly identical functionally to those included on over a hundred successful dual-spin spacecraft missions in the past [1-3]. What converts this proven, robust, scalable spacecraft architecture into an effective small lander [4, 5] is the addition of landing legs to the despun section, a landing radar and dedicated science instrument payloads that are commensurate with CubeSat volumes, *e.g.,* spatial heterodyne Raman spectrometer [6, 7]. It is envisaged that a constellation of spinning landers (each spinning lander carring a dedicated payload) would be ejected and deployed from an Evolved Expendable Launch Vehicle Secondary Payload Adapter (ESPA). Fig. 1 shows an ESPA-class spinning lander concept with a 1U CubeSat avionics enclosure volume.

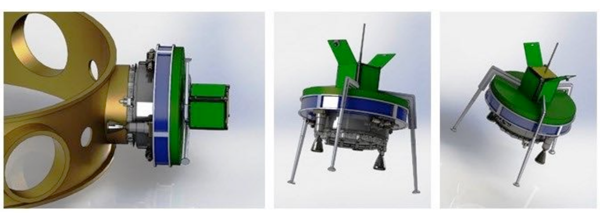

Figure 1. ESPA-class spinning lander concept (only one spinning lander shown). There is an 8" Lightband interface with the ESPA ring port and ~1U CubeSat-sized avionics electronics enclosure on the despun side.

Fig. 2 shows a notional spinning lander mission concept. Control of spacecraft velocity, spin rate and attitude is accomplished *via* relatively simple and independent sets of thrusters: axial (parallel to spin axis), radial (normal to spin axis) and tangential (to spinning section rim). In free space, bulk spin rate of the spacecraft is controlled with the tangential thrusters, while relative spin rate and azimuth phase control between the despun and spun sections is accomplished with the rotor/bearing assembly, which also passes power and signals across the interface *via* a series of slip rings. Telecom antennas, scaled to meet mission objectives, can be mounted to both sections, though the higher gain antenna(s) are almost always on the despun section.

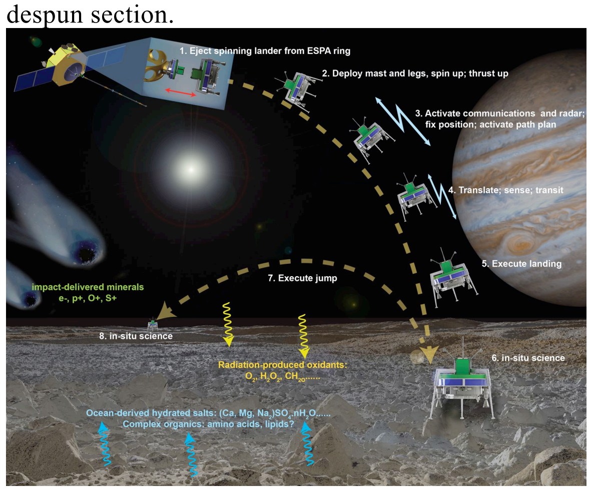

Figure 2. Cartoon of stowed spinning lander in an ESPA ring and subsequent ejection and concept of operations. For example a dedicated Raman spectrometer science payload on a Europa Mission will provide surface and near-surface spectroscopy while the lander is stationary or hovering. Europa's surface composition is derived from a mixture of processes, which must be unraveled to understand the ocean below.

During the terminal landing phase, with despun section and legs set at zero spin, the spinning portion of the lander continues to spin until touchdown, providing significant gyroscopic stability to the entire landed system. Importantly, this system essentially can't tip over during landing, but will rather 'bounce' or 'stick' depending on the leg system design. Depending on mission goals, once on the surface the spacecraft's spinning section can either be stopped or left to spin at any desired rate *via* rotor/bearing control. In the spinning mode, the entire lander becomes an excellent hopper as well, providing extended range/coverage options, onboard propellant permitting. Selected instruments on the despun section can be controlled independently in azimuth and elevation during all mission phases using typical pan-tilt assemblies. Instruments and components on the spun side can be positioned in azimuth by rotation of the entire spun module.

The mass-efficient, cost-effective spinning lander system designs can, for relatively low total mission costs, address mission objectives for planetary exploration, resource utilization and commercialization at various solar system destinations. Solar system mission capability is enabled primarily by how much onboard Δv capability is incorporated (*via* some combination of liquid monopropellant and/or bipropellant and/or solid kick motor systems) and available power (*via* spun- and despun-mounted solar arrays, batteries).

Issues to address by 2050: Apart from issues of landing leg design, spun-despun bearing design, lander dynamics and control system design and analyses, propulsion subsystem design, *etc.*, adapting the small spinning lander concept to Ocean World exploration missions brings into play some additional challenges not yet addressed:

- Lander Δv requirements will be different for specific missions. These differences will likely drive propulsion subsystem sizing and technologies in significant ways, and perhaps other subsystems.
- Communication relay operations will be much more challenging.
- Landing targeting will inherently come with significant uncertainties.
- Solar arrays will not be a practical option for lander power generation. Miniaturized RTG's and primary batteries are anticipated to be far superior in 2050 leading to longer mission duration. However focused science objectives must be accomplished in hours to days.
- Outer planet and moon surface environments are extremely cold, and subject to extreme radiation so temperature-control and radiation hard subsystem designs need to be addressed..
- Two-way light times from Earth to target and back combined with a short mission duration will likely lead to the requirement that all lander operations be conducted in a fully autonomous mode.

The lander mission will be architected to reduce the total radiation dose incurred on critical flight elements while maintaining reasonable mass margin on the lander element. The unknown surface terrain on the planetary target at lander scales will drive the architecture to deploy all means feasibly available to ensure a precision landing and hopping on safe terrain. Studies have to be performed for obtaining pre-deployment orbital reconnaissance, precision deorbit maneuver execution, altimetry-guided soft landing, and estimate the performance of the high-stability landing system with energy attenuation. Most of these technologies exist but need to be matured and tested, and all of these techniques will be required to ensure a safe landing and completion of the primary science objectives in a single mission. In scouting missions we assume that there is no precursor reconnaissance mission.

It is recommended that concept studies should proceed in the next few years so that the necessary technologies can be matured and demonstrated by 2050. To do this we will first baseline some assumptions about battery technology, propellant type, radio frequency, class of onboard avionics and spinning lander-to-primary spacecraft mechanical interface. Next, the Δv requirements for descent and initial landing will be estimated based on likely initial flyby or orbiting conditions. Mission scenarios involving a primary lander which carries one or more spinning landers to the surface of a solar system body would also be considered. These Δv will drive sizing of the thrusters and propulsion tank, and to some extent the spun-despun bearing interface sizing. Post-landing hopping (whether after direct descent from an orbiter or flyby spacecraft or from a primary lander) will increase tank sizing from their baseline sizes and thus may also drive the sizing of other subsystems.

Assessing the thermal environment during lander descent, initial landing, surface operations and hopping combined with one or more notional operations scenarios will inform heat-balance analyses, which will drive battery sizing.

All of these analyses should lead to some good estimates of overall lander size, with which assessment of science instrument accommodation and landing leg design can proceed.

Some workable lander system configuration options should derive from this process, with which various mission and system design trades can be conducted, especially lander system initialization, guidance and control details, and related thruster sizing and placement details.

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