NOVEL ARCHITECTURES AND TECHNOLOGIES FOR A LOWER SWAP-C ENCELADUS ORBILANDER FLAGSHIP. A. E. Nash, M. A. Chodas, E. S. Bailey, D. Balentine, P. D. Burkhart, A. B. Davis, A. Ferrer, A. Freeman, A. K. Ho, R. R. Karimi, A. Kolanjian, M. E. Larson, S. S. Lisman, L. E. Newlin, J. Rapinchuk, M. Saing, S. Sposato, E. T Sunada, A. R. Sundberg, I. A. Trettel, G. A. Welz, and P. R. Woodmansee. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA.

Introduction: The second-highest priority new Flagship mission in Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032 is the Enceladus Orbilander [1].

The committee also included the Enceladus Multiple Flyby (EMF) mission theme in the New Frontiers target list, "should budgetary constraints not permit initiation of Orbilander", as an alternative pathway "for progress this decade on the crucial question of ocean world habitability", "albeit with greatly reduced sample volume, higher velocity of sample acquisition and associated degradation, and a smaller instrument component to support life-detection."

Because Enceladus is roughly between 9 and 10 AU away from the Sun, Radioisotope Thermoelectric Generators (RTGs) are an attractive power source. However, based on current best estimates, the inventory of RTGs is likely to be limited in the future, driving a desire to reduce power demand and the number of RTGs required while maintaining flagship-worthy science and the earliest possible launch date that budget profiles will allow.

Therefore, to maximize science return within the decade, study of lower Size, Weight, and Power (SWaP) and Cost (SWaP-C) concepts than the Decadal Enceladus Orbilander concept is warranted.

Method: The study targeted science goals commensurate with those recommended in the 2022 Planetary Science Decadal Survey with comparable or better science than considered previously.

The study employed mission architecture choices and advanced technologies (~5 years or fewer to reach TRL 6) to (1) minimize flight system dry mass as much as possible, and (2) enable the mission to technically close using only one Next Gen Mod 1 Radioisotope Power System.

A key insight that enabled these reductions was the technical resource demand network within spacecraft [2]. Because architecture and design choices that result in power reductions are also often accompanied by mass reductions, but the converse does not occur as often, a "power reduction first" design rule was employed throughout.

The study was conducted by JPL's Team-X [3] using its standard tools and validated Institutional Cost Models [4], but incorporated technologies that can be developed to flight readiness within 5 years. Grass roots estimates for the development time and cost to bring any new technologies to flight readiness were added to the modeled cost estimate.

Results: The resulting mission architecture is comprised of a launch in November of 2038 on Falcon Heavy Expendable and Star 48 kick-stage, with a single Earth flyby, followed by a 7.5 year interplanetary cruise phase. This phase is followed by a 1.0 year Saturn approach and transfer to Enceladus phase. Saturn Orbit Insertion (SOI) and Periapsis Raise Maneuver (PRM) uses Titan gravity assists to transfer into Saturn/Enceladus elliptical orbit. This is followed by 0.5 years of Enceladus fast flybys. During this phase the plumes can be sampled 12 times at 50 km and 5-9 km/s. This is followed by a 2.6 year Saturn Tour and Enceladus Orbit Insertion (EOI) phase where the spacecraft uses moon gravity assists to pump down speed with respect to Enceladus. This is followed by a 0.3 year Enceladus flyby phase where the plume can be sampled 8 times at 30 km and 500-900 m/s. 1.0 years of landing reconnaissance follows at 200 to 50 km orbit, 120 deg inclination permitting imagine of landing sites at ~60S latitude. Deorbit, Descent, and Landing (DDL) is followed by 2.0 years of surface operations where material is collected and analyzed with a stationary lander.

This is enabled by a two element, staged architecture comprised of a Lander and a Saturn Orbit Insertion (SOI) stage. Given the challenge of fitting within the available launch mass, a staged architecture was chosen to reduce wet mass. The SOI stage was assumed to be jettisoned after SOI and before PRM, enabling an easy disposal of the SOI Stage into Saturn. A delta V of 2923 m/s was assumed. This is ~500 m/s higher than the Decadal Survey Orbilander study delta V of 2402 m/s. The Total Integrated Dose (TID) for this mission is 885 krad behind 100 mil of Aluminum including an RDF of 2. This dose exceeds the qualification level of typical parts. A parts qualification of level of 100 krad was chosen for this study. The dose received by the parts was reduced by implementing an aluminum vault with walls that are 100 mil thick. The vault was assumed to be 1 m x 1 m x 1 m in size.

For the attitude control system, an architecture without reaction wheels was chosen because it significantly reduces mass and power needs, especially in safe mode. Three-axis control is managed by biprop system during cruise and by cold gas system when in Saturn or Enceladus orbit. An all-stellar safe mode and recharge mode architecture was chosen because allows the IMU to be turned off in safe mode and recharge mode, enabling a power positive state with only one RTG at End of Mission (EoM).

For the command and data system, the High Performance Space Computer (HPSC) was chosen because it reduces system mass and power.

For DDL, an Intelligent Landing System Lite was chosen because it enables pinpoint landing and hazard avoidance. Simplification of ILS instrumentation requirements reduces power and mass as well as reducing computation resources needed.

The payload consisted of instruments of half the mass and power of today's instruments based on ongoing NASA investment in this area.

The power subsystem is comprised of a Distributed Power Architecture which reduces cabling mass by 33% and a Peak Power Tracker which allows the RTG to run at 30V from beginning to end of mission, increasing the power available from the RTG.

The propulsion system included a Low Temperature Cold Gas System. Improvements to cold gas thrusters allows -40°C storage and usage. This reduces heater power requirements. It also included a Low Temperature Biprop System. Improvements to Biprop thrusters and mixture that allows -40°C storage and usage. This also reduces heater power requirements. Composite overwrap tanks were chosen for reduced tank mass.

The telecom system included a 10° half-angle X band MGA for safe mode and tones. This relaxed pointing requirement on the MGA in safe mode saves ACS propellant by allowing a large dead band during cruise. It also included a 50% safe mode transmit duty cycle which enables a power positive state with only one RTG at EoM. A Patch Array High Gain Antenna (HGA) reduces HGA size and enables easier packaging.

The thermal system uses Advanced Variable RHUs which reduces the number of RHUs needed to heat a complex propulsion system by using a more optimized design.

These architectural and technological design choices resulted in a system that had an 846 kg lighter launch mass, did not require an SLS launch system, and was about $900 M cheaper than the TRACE estimate of the Decadal Survey concept while simultaneously delivering an additional 9 kg of instrumentation to the surface of Enceladus.

Conclusions: The mission concept presented here offers a compelling, cost-effective alternative to the Decadal Survey's Enceladus Orbilander while achieving comparable science objectives and addressing critical constraints on RTG availability and budgetary limitations. By leveraging advanced technologies and a "power reduction first" design philosophy, this study demonstrates significant reductions in mass, cost, and complexity, resulting in a mission architecture that delivers enhanced science capabilities, including increased payload mass delivered to the surface of Enceladus. This approach not only reduces launch vehicle requirements and overall mission cost but also ensures technical feasibility within the timeline constraints of the decade. These results underscore the viability of a lower SWaP-C approach as a pathway for accelerated progress this decade on the crucial question of ocean world habitability, providing an important step forward in advancing the scientific priorities outlined in the Decadal Survey.

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