A Conceptual Saturn Ring Observer Mission Using Standard Radioisotope Power Systems

Robert D. Abelson and Thomas R. Spilker

Missions and Systems Architecture Section, Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Drive, Mail Stop 301-445W
Pasadena, CA 91109-8099
(818)-393-1500, Robert.D.Abelson@jpl.nasa.gov

Abstract. Saturn remains one of the most fascinating planets within the solar system. To better understand the complex ring structure of this planet, a conceptual Saturn Ring Observer (SRO) mission is presented that would spend one year in close proximity to Saturn's A and B rings, and perform detailed observations and measurements of the ring particles and electric and magnetic fields. The primary objective of the mission would be to observe and quantify ring particle properties at multiple key locations within the A and B rings, and to perform ring-particle imaging with an unprecedented resolution of 0.5 cm/pixel. The SRO spacecraft would use a Venus Earth Earth Jupiter Gravity Assist (VEEJGA) and be aerocaptured into Saturn orbit using an advanced aeroshell design to minimize propellant mass. Once in orbit, the SRO would stand off from the ring plane 1 to 1.4 km using chemical thrusters to provide short propulsive maneuvers four times per revolution, effectively causing the SRO vehicle to "hop" above the ring plane. The conceptual SRO spacecraft would be enabled by the use of three multi-mission Radioisotope Power Systems (RPSs) currently being developed by NASA and DOE as the potential next generation of radioisotope power systems. The RPSs would be used to generate all necessary electrical power ($\geq$330 We at beginning of life) during the 10-year cruise and 1-year science mission (~11 years total). The excess RPS heat would be used to maintain the vehicle's operating and survival temperatures, minimizing the need for electrical heaters. Such a mission could potentially launch in the 2015-2020 timeframe, with operations at Saturn commencing in approximately 2030.

INTRODUCTION

A conceptual Saturn Ring Observer mission is described that would spend one year in close proximity to Saturn's A and B rings (Figure 1), performing detailed observations and measurements of the rings and shepherding moons to achieve the science goals defined herein based on the priorities of the Decadal Survey of the National Academies [1]. Co-orbiting operations very close to the ring plane (as little as 1 km separation) would provide a vantage point unprecedented in solar system exploration. Remote sensing and in-situ observations from that point, combined with the large focal-length optics of the SRO spacecraft, would yield a definitive data set that is relevant both to ring systems in general and protoplanetary disks, and would not be obtainable anywhere else in the solar system.

SRO would be a valuable follow-on mission to Cassini-Huygens and would utilize standard RPS technology to enable its 11-year mission duration. The technological cutoff date for this study was assumed to be 2011, with an early launch date of 2015. The SRO spacecraft would be comprised of two stages, a Cruise stage and an Orbiter stage, along with a lifting body aeroshell (Figure 2). To reach the Saturn system, the SRO would use a Venus, Earth, Earth, Jupiter gravity assist (VEEJGA) to minimize fuel usage and associated mass. To enter Saturn orbit, the trajectory of the SRO would be designed to penetrate the upper atmosphere of Saturn (~61,000 km) whereupon the spacecraft would aerocapture into an elliptical orbit (Figure 3). The aeroshell would be jettisoned following aerocapture. Subsequently, the Cruise stage would perform a large propulsive maneuver to circularize the spacecraft orbit within Saturn's B-Ring, slightly inclined to the ring plane. Following circularization, the Cruise stage would be jettisoned and the self-contained Orbiter stage would commence the year-long science mission, performing periodic propulsive maneuvers to maintain the desired proximity to the ring plane and to move the Orbiter radially across the rings for multi-location observations and measurements (Figure 1).

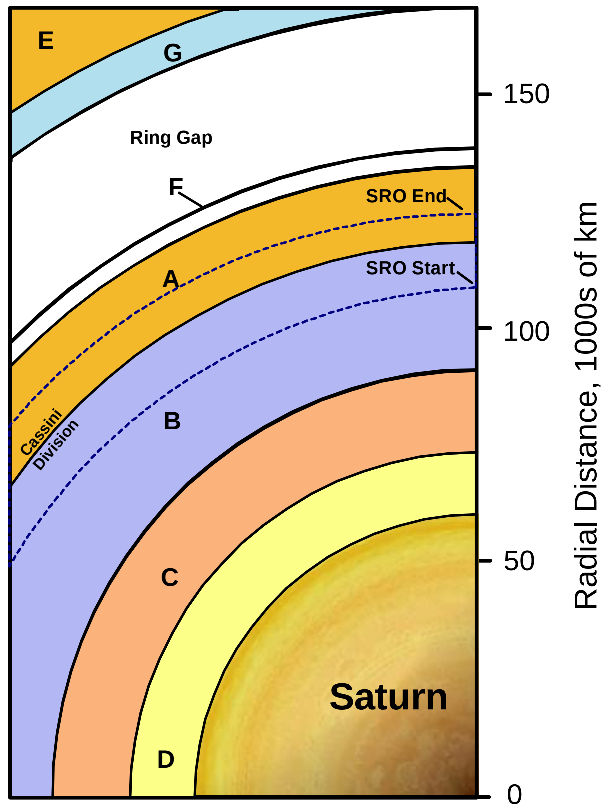

FIGURE 1. Saturn's Ring Structure and SRO Operating Range [43]

The Cruise stage portion of the SRO spacecraft would consist primarily of a large rocket propulsion system with antennas for communication with Earth. It would require a sizable propulsion system sufficient to perform the 3400 m/s orbit circularization burn that follows the aerocapture maneuver. The Cruise stage would interface directly with the Orbiter stage that supplies all necessary electrical and thermal power via three Multi-Mission Radioisotope Thermoelectric Generators (MMRTGs). Following orbit circularization, the Cruise stage would be separated from the Orbiter, having fulfilled its mission. The Orbiter would be a self-contained spacecraft that includes the scientific instrumentation, avionics, power systems, communications electronics and thermal control systems. The Orbiter would possess a high gain and medium gain antenna (HGA and MGA) for communications with Earth, and a propulsion system for trajectory correction maneuvers and attitude control. The Orbiter would be designed to "hop" above the rings using bipropellant engines to maintain a nominal distance of 1 to 1.4 km above the centerline of the ring plane (Figure 4). The Orbiter would nominally carry enough fuel for 1 year's

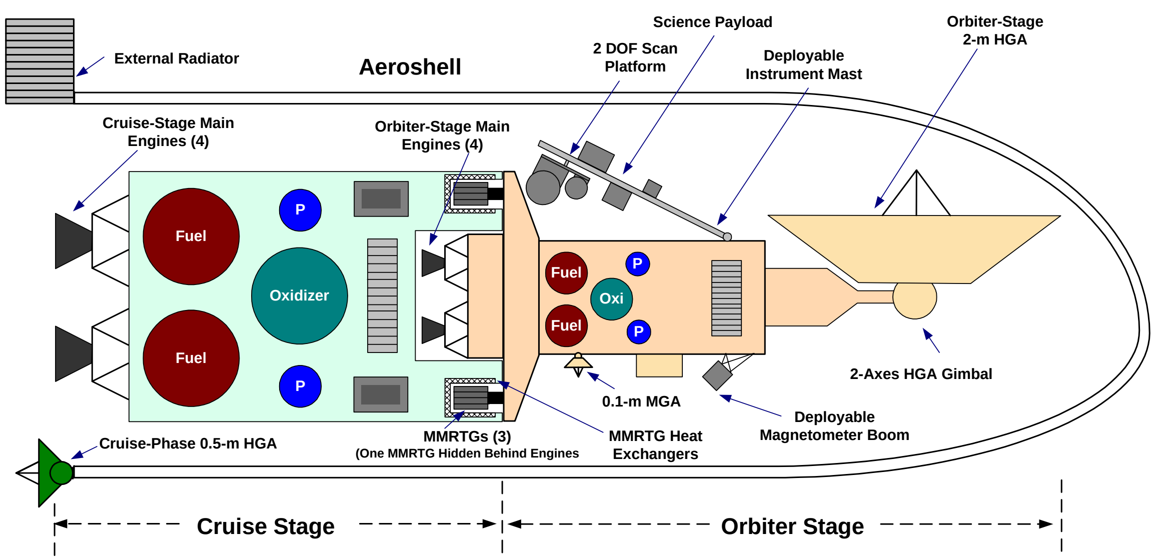

FIGURE 2. Conceptual Illustration of the SRO Spacecraft and Aeroshell

worth of "hopping". Once in orbit, the Orbiter would initiate detailed observations of the Saturn ring system, beginning with the B ring at 110,000 km, and finishing with the A ring at 128,000 km at the end of one year.

The Cruise and Orbiter stages would initially be housed within a protective aeroshell that enables aerocapture. The use of the ablative aeroshell provides a much larger delivered payload mass fraction into orbit at Saturn. As the aeroshell penetrates the atmosphere, the aerodynamic drag rapidly reduces the velocity of the spacecraft to 28 km/s, resulting in the SRO entering an elliptical orbit with a periapse of ~61,000 km and an apoapse of 110,000 km. Following aerocapture, the SRO spacecraft (Cruise and Orbiter stages) would be extracted from the aeroshell. Approximately two hours later, the Cruise stage would begin a two-hour long propulsive maneuver using its four main engines to perform a 2900 m/s burn to circularize the orbit to the desired 110,000 km altitude. Once the SRO orbit had been circularized, the Cruise stage would be jettisoned from the Orbiter stage. The Orbiter would then rely solely upon its own systems to continue the mission. The Orbiter's orbit plane would be very slightly inclined (few degrees) with respect to the ring plane. To prevent ring plane crossings and potential collisions with ring particles, the Orbiter would fire its main engines prior to each nodal crossing such that the spacecraft altitude is nominally maintained between 1 and 1.4 km above the ring plane. The altitude profile of the Orbiter is notionally shown in Figure 4, with the spacecraft appearing to "hop" above the ring plane every 2.5 to 3.25 hours depending on radial position. Four hops would be performed each orbital revolution, with each hop changing the longitude of the ascending node by 90 degrees. The Orbiter would co-orbit with the ring particles at each location, allowing long-term observation and tracking of particle in-

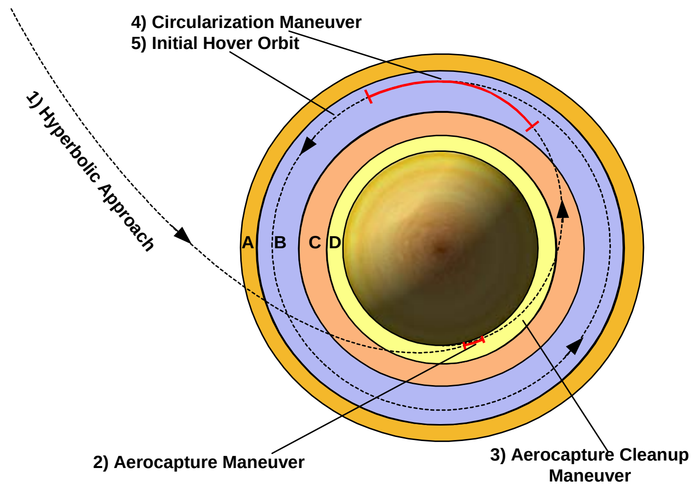

FIGURE 3. Aerocapture Delivery of SRO to Hover Orbit [2]

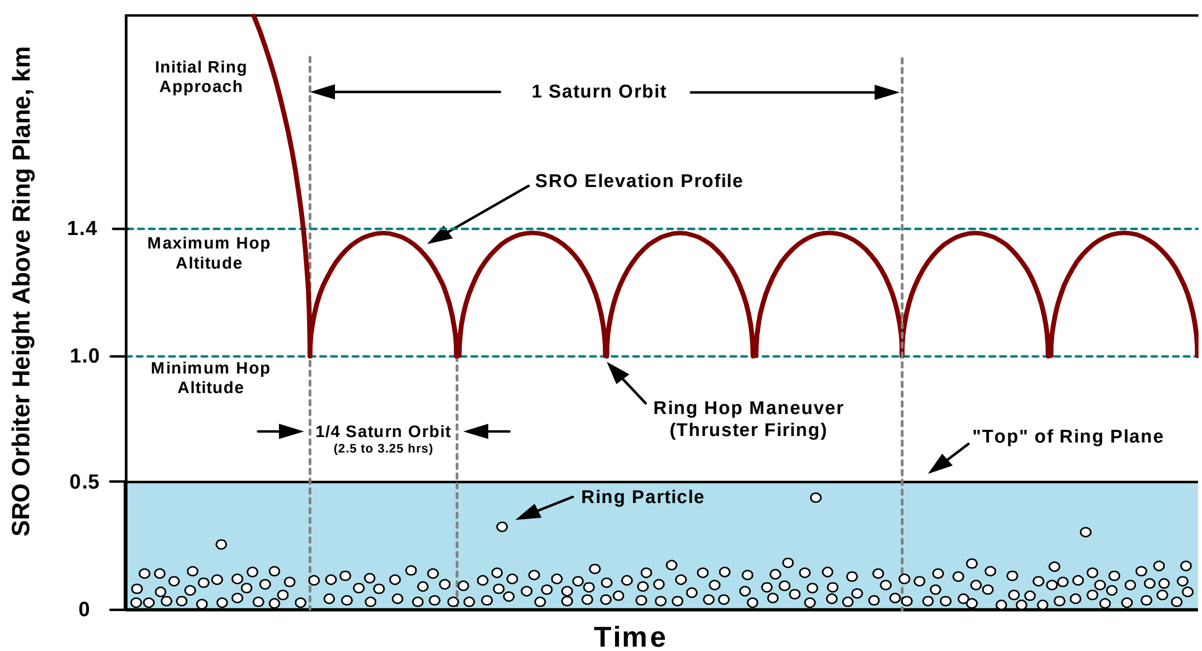

FIGURE 4. SRO Orbiter Elevation Profile Above Ring Plane as a Function of Time

teractions and dynamics. The Orbiter would stay at each selected radial position for an average of one week in order to perform detailed science measurements. At the end of the week, the Orbiter would ignite its main engines to perform a quasi-Hohmann transfer to the next target location (increasing its distance from Saturn each time). A total of ~50 radial translations would be performed over the course of the mission, providing a variety of different locations at which to take measurements. The translation time between radial locations would be between 5 and 6 hours depending on the radial position.

The baseline SRO spacecraft would require a next generation heavy launch vehicle (LV) to perform the mission. Detailed trades were also performed to assess the minimal science payload and mission duration that could be supported by an existing LV; however, it was concluded that a larger LV must be used to launch any scientifically justifiable variant of the SRO spacecraft were a single LV to be used [3]. It is conceivable that the SRO could be launched in multiple sections using existing LVs and then assembled in Earth orbit; however, this option was not explored herein. Instead, this study assumes that a larger boost vehicle would be available in the 2015 timeframe to support the SRO mission, a reasonable assumption considering the identified need for heavier boosters for manned missions to the Moon and Mars. The SRO launch vehicle is assumed to have a lift capability of ~28,000 kg to a C_3 of 15 km^2/s^2, equivalent to those currently being considered using EELV-derived concepts [4].

The SRO Orbiter would use an advanced autonomous collision avoidance system to identify potentially threatening particles that may be on a collision course with the spacecraft and to perform the necessary collision avoidance maneuvers. The velocities of ring particles in the direction out of the ring plane are expected to be slow enough (<15 cm/s) to provide sufficient time for the Orbiter to identify them using its LIDAR, process the data, generate a collision avoidance trajectory, and perform the necessary burn. These burns would generally be perpendicular to the ring plane, effectively initiating a ring-hop ahead of its nominally sequenced time. The size of the ring particles in the A and B rings (where the SRO would operate) are expected to be in the range of 1-cm to 1-m in diameter.

. SCIENCE GOALS

The mechanisms of formation and evolution of planetary ring systems are poorly understood. These processes are of considerable scientific interest, as planetary ring systems are thought to share some characteristics with protoplanetary disks [5]. The key unknowns in analyses of protoplanetary disk evolution involve the collisional dynamics of the particles and its effects on the collective behavior of the rings, especially evolution. The goal of the Saturn Ring Observer (SRO) mission would be to obtain close-in observations of centimeter-scale ring particle interactions to better understand these processes. The primary objective of the mission would be to observe and quantify ring particle properties at multiple key locations within the A and B rings. Individual ring particle properties to be investigated include particle sizes, particle shapes, rotation states, compositions, random velocity components, and surface textures. Two-particle investigations would focus on collision dynamics and collision frequency. Bulk and aggregate characteristics to be measured would include gross ring structure, particle density and surface mass density profiles (respectively, the number of particles and the total mass per unit area of ring surface), particle size distributions and spatial variation of size distribution at multiple ring locations, ring and ringlet thickness, layering and banding, wave characteristics, shepherding (e.g., by moons or moonlets) processes, and the neutral and ionized “ring atmosphere” environment. Lastly it would be important to characterize the electromagnetic environment near the rings and its relationship to ring structure and dynamics. Secondary objectives of the mission would include observations of shepherding satellites (such as Pan, Prometheus, etc.), and the characterization of micrometeorite impact rates and dust particle populations in the near-ring environment.

SCIENCE INSTRUMENTS

The baseline payload chosen for this study consists of instruments for characterizing the intrinsic properties (composition, geometry, density, etc.) and dynamics of a population of particles a couple of centimeters and larger in size in a quasi-inertial and electromagnetically active environment. It is understood that the actual instrument complement for the mission would be selected by a team composed of Project and NASA personnel, based upon the recommendations of a science definition team drawn from the planetary and origins science communities. However, the selected payload in this baseline configuration gives the study team a representative set of requirements, including but not limited to such aspects as mass, power, pointing and stability, positioning, etc., that demand a realistic platform and thus provides a higher-fidelity study result. There are three general classes of instruments in this payload: those that measure ring particle geometry and dynamics, those that measure composition, and those that measure the electromagnetic environment. The geometry and dynamics class includes wide-angle and narrow-angle imaging, and LIDAR. A Narrow-Angle Camera (NAC) provides geometry and 2-D dynamics (components perpendicular to the camera pointing vector) of individual particles larger than ~2 cm, with the LIDAR providing particle locations and velocities in the third dimension. The LIDAR also serves the engineering function of measuring the distance from the spacecraft to the ring plane, data that is vital for controlling the thrusters that maintain the standoff distance. Both the NAC and the LIDAR observe a limited area of the rings, and are pointed such that they view the co-orbiting zone directly "beneath" the spacecraft with a field of view (FOV) of 1.2^{o}. A Wide-Angle Camera (WAC) observes a much larger area of the rings with an FOV of 120^{o}, providing context to the NAC images and observing bulk and aggregate structure and behavior.

Two instruments in the composition-measuring class cover both remote sensing and in-situ measurement techniques. A Visual and Infrared Spectrometer (VISIR) measures reflection spectra from the ring particles, providing information about composition, especially for non-volatile components. An Ion and Neutral Mass Spectrometer (INMS) directly measures the composition of the "ring atmosphere", the cloud of molecules and atoms volatilized and sputtered from the ring particles by a variety of processes. Magnetic and electric fields would be measured by separate magnetometer and electric field antenna. Standard techniques for measuring electric fields in space are not appropriate here, since the fields of primary interest might not oscillate at radio or even audio frequencies, but rather are slowly-varying, almost DC fields. Some phenomena, such as meteoroid impacts on ring particles, can generate waves or other rapidly-varying fields, so the instrument would be able to measure those as well.

RPS CHARACTERISICS

Three Multi-Missinon Radioisotope Thermoelectric Generators (MMRTGs) are assumed in this mission study to provide all necessary electrical power for the SRO spacecraft. This corresponds to a minimum of ~330 We at BOM [3], and ~ 275 We at EOM (after 11 years). The RPS system would reside on the SRO Orbiter stage, and power both the Orbiter and Cruise stages during the mission. The ~5230 Wt (EOM) of residual heat would be used to maintain operational and survival temperatures of the Cruise and Orbiter stages using radiatively coupled heat pipes. The Stirling Radioisotope Generator (SRG) [3] is another power system option that could potentially meet the mission requirements assuming that the SRG-induced vibration and EMI environments did not interfere with operation of the narrow angle camera and fields and particles experiments. Were SRGs used for the SRO mission, a total of four units would be required in order to generate the requisite power and to provide one redundant SRG for reliability purposes in accordance with current NASA/DOE guidelines [6]. Fortunately, the lighter unit mass of the SRG (34 kg) means that the overall SRG power system would weigh approximately the same mass as the MMRTG option. Though a detailed thermal analysis was not performed for this mission concept, it is expected that the lower heat generation rate of the SRG would be preferred during the aerocapture maneuver where the excess thermal power would need to be stored for 15 or more minutes until aeroshell separation.

DATA AND COMMUNICATIONS

The SRO mission would be divided into separate cruise and science phases. During the cruise phase, data would be limited to health and status information of key subsystems, and the resultant data volume would be relatively small. During the science phase, however, the data volume would be significant, as the eight scientific instruments would be operated in parallel. The data volume obtained during the science phase is estimated at 1380 Mbits/day (24 hours), and represents the stressing case in terms of sizing the transmitters and antennas for the SRO mission. The SRO science instruments sampling rates would range from just two measurements per hour for wide-angle camera images, up to 3600 measurements per hour (1 Hz) for the electric field/plasma wave instrument and magnetometer during entry and exit of the Orbiter from Saturn's shadow. The key data volume drivers would be the narrow angle camera and LIDAR, each employing a 4096x4096x8 bit CCD with high performance compression. These two systems would operate in unison to generate detailed spatial and temporal maps of the ring particles that are used to fulfill the science requirements and for collision avoidance. These systems would operate at a rate of six frames per hour, each yielding 3.95 Mbits/frame or ~570 Mbits/day. The data produced by these two instruments would account for 83% of the total data volume. The wide angle camera would use the same resolution CCD and compression system as the NAC and LIDAR, but would require less frequent imaging (2 frames/hour) due to the larger field of view. The resultant data volume of the WAC would be 187 Mbits/day or 13.5% of the total. The remaining 3.5% of the data volume would be consumed by engineering data and the six remaining instruments, comprised of the VISIR, Electric Field/Plasma Probe, Magnetometer, INMS, Dust Detector, and VISIR.

Communications with the spacecraft during the Cruise phase would be via a gimbaled 0.5-m Ka/X-band HGA. The HGA would nominally transmit at X-band with a minimum download data rate of ~170 bits/s (assessed at 10.5 AU) for engineering data sent to Earth. During the Science phase, a gimbaled 2-meter Ka/X-band HGA would be used for nominal data downlink, with a fixed Ka/X-band MGA serving as backup. The maximum HGA downlink date rate is estimated at 80 kbits/s using Ka-band. The SRO Orbiter would have a baseline communications window of 8 hours per day, spread throughout the 24-hour interval (i.e., not contiguous), which would be necessary to satisfy the required science measurement schedule. This communications window corresponds to a total data volume capability of 2.3 Gbits per day. This window could be expanded were additional science data requested (especially high-rate imaging) or following a solar conjunction. During this later event, the longer communications window would be needed to download the week (or more) of buffered science data back to Earth.

THERMAL

The SRO design would use a combination of passive and active thermal control systems to maintain operating and survival temperatures during the mission. During the cruise phase, the Orbiter would be stored within a protective aeroshell (Fig. 2), which would thermally insulate the Orbiter stage by preventing the spacecraft from directly radiating to the cold of deep space (T_{amb}~4K). Supplemental electric heaters would be used on the Orbiter to regulate the temperature of the instruments, sensitive subsystems, and the fuel, oxidizer and pressurant. The Cruise stage, also located within the aeroshell during the cruise phase, would maintain system temperatures via a loop heat pipe system radiatively coupled to the RPSs on the Orbiter. The three MMRTGs would jointly produce a total of ~5670 Wt (BOM) of excess heat that would be absorbed by the heat exchanger and circulated through the Cruise stage, primarily to warm the fuel, oxidizer and pressurant tanks. The RPS heat would then be rejected to deep space by radiators mounted externally to the aeroshell. The radiators would use thermal control louvers or polychromatic surfaces to actively control the heat rejection rate, and would be jettisoned just prior to the aerocapture maneuver to prevent them from being uncontrollably burned off during aerocapture (possibly affecting spacecraft attitude control) and to prevent heat flow into the Cruise and Orbiter stages..

During the ~15 minute aerocapture event, the aeroshell would protect the Cruise and Orbiter stages from the intense external heat generated during their deceleration through Saturn's upper atmosphere via a combination of ablation of the aeroshell material (using a carbon-based material) and radiative heat exchange - the aeroshell would be designed to emulate a black body to maximize radiative heat loss. The heat generated by the MMRTGs during aerocapture would either be stored in the thermal mass of the system until aeroshell separation, or if determined to be too great (via detailed analysis), could be managed using a phase change material such as water that would be vented out the rear of the spacecraft. Upon completing the aerocapture maneuver, the clamshell-designed aeroshell would separate, freeing the Cruise and Orbiter-stage spacecraft. The Cruise stage flow control valves would then be reconfigured to reject the MMRTG heat via body-mounted radiators during the course of the subsequent circularization burn. The Orbiter stage would stay warm using blankets of multilayer insulation (MLI) augmented with electrical heaters. Following the circularization burn, the spent Cruise stage would be jettisoned, exposing the Orbiter-stage MMRTGs to the ambient background temperature where their integrated fins would passively maintain their operating temperatures. The Orbiter itself would continue to rely upon a combination of MLI blankets, self-heating of powered instrumentation and subsystems, supplemental electric heaters, and polychromatic radiators or thermal control louvers to regulate the temperatures of the instruments, propulsion system, and other thermally sensitive subsystems.

PROPULSION

The delta V requirement of the cruise stage is estimated to be 3650 m/s, with 3400 m/s allocated to circularization and subsequent cleanup maneuvers at Saturn (Table 1). The total mass of the cruise-stage propellant (fuel, oxidizer and pressurant) would be ~10,470 kg. The delta V requirement of the Orbiter stage would be ~2280 m/s, with ring translations requiring ~1510 m/s (66% of total) and ring hops requiring ~770 m/s (34% of total).

The cruise stage propulsion system would consist of four gimbaled 890 N bipropellant main engines used for deep space maneuvers and orbit circularization at Saturn, and twelve 0.7 N monoprop thrusters. The Orbiter stage would include four 45 N bipropellant main engines used for ring hops, four 4.5 N monoprop thrusters used for roll control, desaturation of the reaction wheels, small TCMs, and coarse attitude control, and twelve 0.7 N monoprop thrusters for fine attitude control (e.g., for instrument pointing, etc.)

TABLE 1. Delta V Estimates for the SRO Cruise and Orbiter Stages

Activity	Delta V (m/s)
Cruise Stage	**3650**
Cruise Phase in Deep Space	250
Periapse Raise	2900
Circularization Burn	500
Orbiter Stage	**2275**
Ring Hops	768
Ring Translations	1507
Total Delta V	**5925**

The nominal mission profile would include 4 ring hops per orbit, corresponding to one hop every 2.5 to 3.25 hours (depending on radial distance from Saturn). The duration of each ring hop burn would be ~2 seconds, and impart an average delta V of approximately 0.3 m/s per hop. Additional hops could be employed were the collision avoidance system to detect the Orbiter approaching a thicker section of the ring plane (e.g., spokes or waves) or if incoming particles were detected on a collision course with the spacecraft.

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POWER

The baseline SRO spacecraft would employ three MMRTGs and secondary batteries to supply all electrical power during the mission. The electrical output of the three MMRTGs is ~330 We at BOM, corresponding to ~275 We at EOM (11 years after launch). The power system (RPSs, batteries, and power distribution subsystem) would be located on the Orbiter stage; the Cruise stage would rely on the Orbiter stage to supply all its power needs for propulsion, etc. The maximum power draw during the cruise phase is estimated at 293 We, driven primarily by the Cruise stage propulsion system used during the orbit circularization maneuver. The peak power draw of this mode exceeds the available RPS power, and thus redundant 400 W-hr batteries would be used to carry the peak energy demand of the ~2 hour circularization burn and subsequent clean-up activities. Batteries are the preferred solution rather than additional RPSs, as the circularization burn is a one-time occurrence and adding batteries is lighter (8 kg) than adding an additional MMRTG (45 kg). The peak power draw during the science phase of the mission is ~287 We, and driven by propulsion system valves operated during ring hops, and the need to keep all instruments fully powered to maintain operating temperatures and keep them in a hot-standby configuration (i.e., to prevent having to endure potentially lengthy startup times). Secondary batteries are used to cover the peak power demand during this mission phase as it exceeds the steady state power output of the RPSs.

Mass

The total wet mass of the SRO spacecraft, inclusive of the Cruise and Orbiter stages and aeroshell, is estimated at ~18,700 kg including 30% margin (Table 2). The bulk of the SRO spacecraft is comprised of propellant for the orbiter and cruise stages (~11,500 kg, 61% of the total spacecraft mass) and the aeroshell used for aerocapture (~4650 kg, 25%). Together, the propellant and aeroshell comprise 86% of the total launch mass.

The SRO instrument mass would be ~130 kg, corresponding to less than 1% of the total launch mass. The instrument mass is dominated by the large aperture NAC (65 kg) that is needed to obtain the requisite 0.5 cm/pixel resolution images. The total mass of the Orbiter stage is ~1820 kg (wet) and is comprised of an 840 kg (dry) spacecraft and nearly 1,000 kg of propellant and pressurant used for performing ring hops and translations during the science mission.

The mass of the Cruise stage is estimated as ~12,200 kg (wet), and comprised of a ~1760 kg (dry) spacecraft, and ~10,500 kg of propellant and pressurant. The bulk of this propellant is used to correct and circularize the SRO orbit following aero-capture (delta V of 3400 m/s), with the remaining amount used for trajectory correction maneuvers during the VEEJGA flybys and during Saturn approach. The aeroshell mass is estimated at approximately 4650 kg [7]. Though the mass of the aeroshell appears relatively high, it is lower than other credible near-term orbit insertion alternatives including the use of chemical rockets engines.

TABLE 2. Mass Estimates for the SRO Spacecraft

Subsystem	**Mass w/ Margin, kg**
Orbiter Stage (Dry)	**842**
Orbiter Stage (Wet)	**1823**
Instruments	129
Subsystems and Contingency	714
Propellant and Pressurant	981
Cruise Stage (Dry)	**1757**
Cruise Stage (Wet)	**12227**
Subsystems and Contingency	1757
Propellant and Pressurant	10470
Aeroshell	**4648**
Total Launch Mass (Dry)	**7246**
Total Launch Mass (Wet)	**18698**

SUMMARY AND CONCLUSIONS

Saturn remains one of the most fascinating planets within the solar system. To better understand the complex ring structure of this planet, the conceptual SRO mission would spend one year in close proximity to Saturn's A and B rings and perform detailed observations and measurements of the ring particles and electric and magnetic fields. The SRO Orbiter would co-orbit close to the ring plane (1 to 1.4 km above the ring plane centerline), providing an unprecedented vantage point for making ring particle observations. These data would be used to enhance our understanding of the mechanisms of formation and evolution of planetary ring systems. Due to the long mission duration (11 years), low solar insolation at Saturn, and stringent spacecraft stability requirements, radioisotope power would be the only viable option for this mission. Three MMRTGs would be employed to provide 275 We (EOM) to power all instruments and subsystems, and would be augmented by lithium-ion batteries to provide load leveling during peak power usage. A natural follow-on to the Cassini-Huygens mission, SRO would be a challenging mission of significant scientific value.

NOMENCLATURE

BOM	Beginning of Mission
CCD	Carge Coupled Device
DOE	Department of Energy
DOF	Degree of Freedom
DSN	Deep Space Network
EELV	Evolved Expendable Launch Vehicle
EOM	End of Mission
FOV	Field of View
HGA	High Gain Antenna
INMS	Ion and Neutral Mass Spectrometer
IR	Infrared
LGA	Low Gain Antenna
LIDAR	Light Detection and Ranging
LV	Launch Vehicle
MGA	Medium Gain Antenna
MMRTG	Multi-Mission Radioisotope Thermoelectric Generator

NAC	Narrow Angle Camera
NASA	National Aeronautical and Space Administration
PCM	Phase Change Material
RF	Radio Frequency
RPS	Radioisotope Power System
SAR	Synthetic Aperture Radar
SRG	Stirling Radioisotope Generator
SRO	Saturn Ring Observer
SSR	Solid State Recorder
VEEJGA	Venus Earth Earth Jupiter Gravity Assist
VISIR	Visual and Infrared Spectrometer
WAC	Wide Angle Camera
We	Watts (Electric)

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