MISSION CONCEPTS ENABLED BY SOLAR ELECTRIC PROPULSION AND ADVANCED MODULAR POWER SYSTEMS.
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Introduction: Over the last several years we have introduced a number of planetary mission concepts enabled by Solar Electric Propulsion and Advanced Modular Power systems. Most, if not all of these concepts can be made to fit within a $500 million Discovery Mission Cost cap. In addition, we have proposed further reducing spacecraft cost by using a common bus for deep space missions. With the recently announced, commercially produced, all electric Boeing 702 SP and the delay of both Discovery and New Frontiers competed missions, we felt that there is value in a review of these concepts.

The Boeing 702 SP: Using a common spacecraft for multiple missions reduces costs. Solar electric propulsion (SEP) provides the flexibility required for multiple mission objectives. SEP provides the greatest payload advantage albeit at the sacrifice of mission time.[1]

Boeing introduced the powerful 702 spacecraft family in 1995. Today, more than two dozen are flying, with over a dozen more currently in production. The scalable 702 product line design uses economies of scale to cost-effectively support payloads with a range of power requirements. This advantage allows Boeing to meet the needs of a wide range of government and commercial customers.

The newest addition is the 702 SP, a smaller platform satellite in the 702 production line capable of providing 8 KW of power at 1 AU using standard solar arrays. It is designed to be able to perform a wide variety of commercial and government missions, including mobile telephony, wideband communications, navigation, weather and environmental observation, situational awareness, and digital television and radio. The spacecraft is compatible with a range of launch vehicles, including Delta IV, Atlas V, Ariane 5, Proton, Soyuz, Sea Launch, and Falcon 9. Furthermore, it is designed to accommodate additional payloads, commonly referred to as hosted payloads, without interfering with the primary mission. Hosted payloads allow launch and operations costs to be shared. There are many near-term hosting opportunities on contracted commercial spacecraft and the same model could be used for science missions.

Advanced Modular Power System (AMPS): The 702 SP for deep space is designed to be able to use the Advanced Modular Power System (AMPS) solar array, producing high (multi Kw) power levels with significantly lower system mass (specific power densities of ~130 watts/kg) than current solar power system technologies. This power can be used to operate the SEP system out past Mars orbit and provide power with margin for science experiments and spacecraft operations at Jupiter, and even as far out as Saturn. AMPS is based on previous DARPA and AFRL solar power and propulsion system technology development.

Mission Concepts: We have studied a number of science and exploration mission concepts for Outer Planets, Small Body, and Mars.

Outer Planets. 1) Europa Explorer - Our studies demonstrate that New Frontiers-class science missions to the Jupiter and Saturn systems are possible with commercial solar powered space craft. These spacecraft would be equipped with highly efficient solar arrays capable of up to 25kW at 1 AU. Such a vehicle could generate nearly 1kW in the Jovian System. Our analysis shows substantially greater power at the end of mission with this solar array system than the system that was planned for use in the Europa Jupiter System Flagship mission study.[2]

2) Trojan Tour - The mission design features a direct injection by an Atlas 401 with a C3 energy of 17.2 Km^2/Sec^2. The mission objective is 1143 Odysseus, a Trojan within the Trojan cloud, consistent with the Decadal Survey REP (Radioisotope Electric Propulsion) mission objective. The launch date is November 11, 2016; the probe reaches Odysseus May 13th, 2022. There are 3 NEXT thrusters, 2 are operated during the first 420 days, throttling down a single thruster the remainder of the approximately 6 year cruise. In comparison, the REP mission concept flight time was 8 years. The thrusters are duty cycled at 95 percent to allow at least one contact per week with the spacecraft during the cruise. For the purposes of this study, the science payload instruments, data rates, mass and power requirements are identical to the Trojan Decadal study.[3]

Small Body. 1) NEO Precursor Mission - NEO missions benefit greatly by using high ISP (Specific Impulse) Solar Electric Propulsion (SEP) coupled with high power generation systems. Our NEO mission concept closes significantly below the current Discovery Mission Cost cap of $425 million and includes the Minotaur IV launch vehicle. Our parametric cost estimates also include a 30% margin on top of the standard reserve assumptions for mass and LV contingencies. This concept further sets the stage for human exploration by doing the type of science exploration needed as a precursor to a human visit to a NEO and flight demonstrating enabling technology advances (high power generation, SEP) for human missions. Many possible targets exist for future NEO exploration; since very few NEOs have been explored by spacecraft, many exploration opportunities exist. This asteroid was a possible target for the Hayabusa -2 mission. The same SEP system can also do a July 2021 launch to 1993 JU3.[4]

2) Multiple NEO Rendezvous, Reconnaissance and In Situ Exploration - We propose a two spacecraft mission (Mother Ship and Small Body Lander) rendezvous with multiple Near Earth Objects (NEO). This two spacecraft mission mimics the likely architecture approach that human explorers will use: a “mother ship” (MS) designed to get from Earth to the NEO and a “Small Body Lander” (SBL) that performs in situ investigation on or close to the NEO’s surface. The MS carries the SBL to the target NEO. Once at the target NEO, the MS conducts an initial reconnaissance in order to produce a high resolution map of the surface. This map is used to identify coordinates of interest which are sent to the SBL. The SBL un-docks from the MS to rendezvous with the NEO and collect data. Landings are possible, though the challenges of anchoring to the NEO surface are significant. The SBL design is flexible and adaptable, enabling science data collection on or near the surface. After surface investigations are completed on the first NEO, the SBL will return and autonomously rendezvous and dock with the MS. The MS then goes to the next NEO target. During transit to the next NEO, the SBL could be refueled by the MS, a TRL8 capability demonstrated on the DARPA/NASA Orbital Express mission in 2007, or alternately sized to operate without requiring refueling depending on the mission profile. The mission goals are to identify surface hazards; quantify engineering boundary conditions for future human visits, and identify resources for future exploitation.[5]

Mars. Our concept involved using the Boeing 702SP with a highly capable SAR imager that also conducts autonomous rendezvous and docking experiments accomplished from Mars orbit. Our concept of operations is to launch on May 5, 2018 using a launch vehicle with 2000kg launch capacity with a C3 of 7.4. The Heliocentric phase of the mission is 273 days that includes 135 days of coasting. For this mission design, a 100 kg payload is assumed and our launch mass is 1769 kg. We will only consume 243 kg of propellant out of 450 kg that is available on the spacecraft. Removing a propellant tank can give us up to an additional 100 kg of payload with sufficient launch margin. After reaching Mars it takes 145 days to spiral down to a 250 km orbit above the surface of Mars when Mars SAR operations begin. A small payload is dropped off during the spiral operations to be later retrieved using technology demonstrated by Orbital Express: a Lightweight, low-cost concept for vehicle-to-vehicle detection and orbit determination of objects in Mars orbit (in support of rendezvous and docking/capture).[6]

Conclusion: Using advanced in-space power and propulsion technologies like High Power Solar Electric Propulsion provides enormous mission flexibility to execute baseline science missions and conduct Technology Demonstrations in deep space on the same missions. An observation spacecraft platform like the Boeing 702SP enables the use of high powered instruments to reveal new insights and understanding for both science and future manned exploration and utilization missions. Leveraging investments would provide the ability to greatly expand the scientific scope and return of both Discovery and New Frontiers missions while demonstrating beneficial synergy between the NASA Human and Robotic exploration program investments. We advocate FAST/AMPS enabled SEP as a key component to an exploration architecture that will take us beyond LEO and enable both Robotic and Human deep space missions

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