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Intercept and Engagement of Asteroid PDC 2021 with Solar Sailcraft

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The EXCALIBUR mission concept provides viable intercept solutions to the PDC 2019 hypothetical comet scenario⁴ (Fig. 2) and PDC 2021 hypothetical asteroid scenario³. The EXCALIBUR mission provides extremely high delta-V (>5 AU/year) low cost, small spacecraft capable of rapidly engaging hazardous objects within months of detection from either direct launch from Earth or prepositioning on an heliocentric holding orbit within the orbit of Mercury. EXCALIBUR's extraordinary velocity is made possible by Xplore's Lightcraft™ advanced solar sail based vehicle² as depicted in Figure 1. The

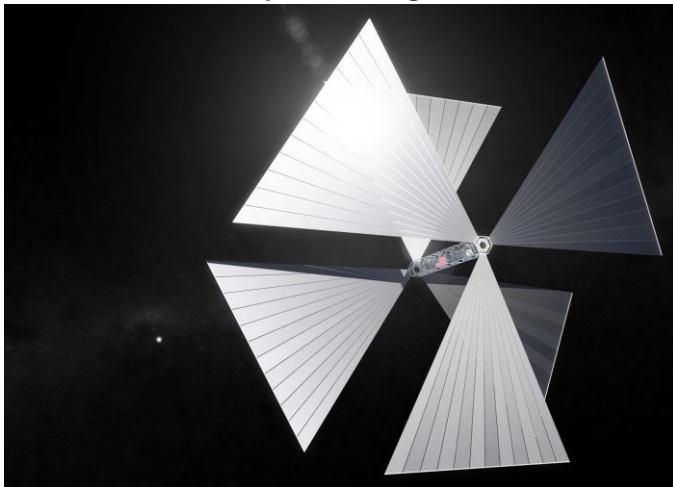


Figure 1: Xplore's Lightcraft Configured for the EXCALIBUR Planetary Defense Mission

Lightcraft is the commercial implementation of LGarde's SunVane revolutionary advanced fractionated solar sail design with a total system area to mass ratio greater than 50 m²/kg. The Lightcraft's acceleration and agility is an order of magnitude greater than any current or proposed

planar sail. With the Lightcraft, the EXCALIBUR mission can fully exploit the immense acceleration potential due to solar radiation pressure at perihelion distances as close as 0.2 AU, while having the control authority capable of rapidly changing its orbit to align with any target outside of the ecliptic. The EXCALIBUR mission concept and Lightcraft design were derived from work supporting the current NIAC Phase 3 Solar Gravity Lens Focus Mission⁵.

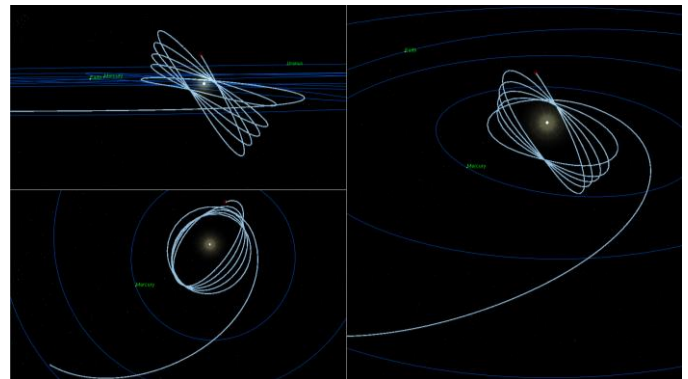


Figure 2: Ingress to Perihelion and 0.2 AU Holding Orbit Alignment with PDC 2019 Comet's Trajectory

The EXCALIBUR baseline mission concept of operations is to employ multiple Lightcraft spacecraft launched from Earth after the detection of a hazardous object or deployed from a prepositioned holding orbit inside the orbit of Mercury. For the direct launch from Earth, once the EXCALIBUR vehicles are in heliocentric space, their articulated solar sail panels or vanes are oriented to dive sunward accelerating to a perihelion distance of 0.2 AU. The transfer time from Earth to perihelion is 60 days. As they approach the Sun, each vehicle

exploits the increasing amount of solar radiation pressure to align its trajectory and inclination to the ecliptic with the hazardous object’s orbit as depicted in Figure 3. At the targeted perihelion point, the EXCALIBUR vehicles reorient their vanes directly toward the Sun to maximize acceleration, intercepting the asteroid in less than 50 days (Table 1).

as the maneuver performed at perihelion by the direct ingress from Earth option. The resulting 49-day trajectory from holding orbit to intercept on 31 July 2021 is depicted in Figure 3.

Table 1: EXCALIBUR PDC 2021 Asteroid Mission Timeline: Direct Launch from Earth

EXCALIBUR MISSION: DIRECT LAUNCH FROM EARTH			
DATE	EVENT	DAYS FROM DETECTION	DAYS UNTIL IMPACT
19 APR 2021	COMET DETECTED	0	180
19 MAY 2021	LAUNCH FROM EARTH	30	150
20 MAY 2021	BEGIN INGRESS TO SUN	31	149
18 JUL 2021	PERIHELION PASSAGE	91	89
18 JUL 2021	INTERCEPT EGRESS START	91	89
5 SEP 2021	COMET INTERCEPT	140	40

Prepositioning EXCALIBUR-configured Lightcraft in a holding orbit at 0.2 AU results in earlier opportunities to intercept the object without the 60-day ingress of a launch from Earth. At 0.2 AU the heliocentric holding orbital period is 34 days and is aligned with the ecliptic plane. For this conservative simulation, the EXCALIBUR vehicles in their close holding orbit must wait 19 days from initial detection for their orbital geometry to align and their respective intercept windows to open. The intercept window is approximately 2 days in duration and repeats, as detailed in Table 2, every 34 days until asteroid intercept. This staging concept provides additional engagement opportunities over the 180-day threat scenario.

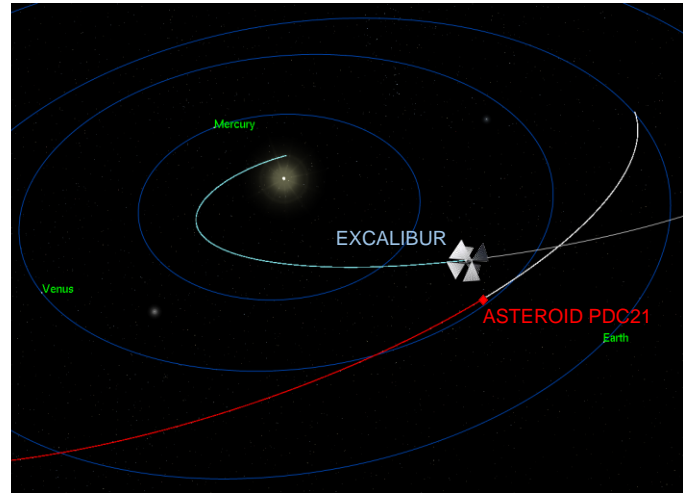


Figure 3: EXCALIBUR Intercept of PDC Asteroid 2021

From planetary defense to rendezvousing with an interstellar object, the EXCALIBUR mission concept provides a high delta-V, low-cost capability to rapidly visit objects across the entire solar system. This concept supports rapid reconnaissance missions for planetary defense against potentially hazardous objects as demonstrated by our realistic solutions to the PDC 2019 and 2021 threat scenarios. EXCALIBUR provides a realistic means of intercepting and neutralizing any threats many months and AU before impact by carrying two 200 kiloton nuclear devices as detailed in the authors’ 2019 Planetary Defense paper¹.

Table 2: EXCALIBUR Mission Timeline: Perihelion to PDC21 Asteroid Intercept Timelines

EXCALIBUR MISSION: 0.2 AU HOLDING ORBIT TO INTERCEPT				
INTERCEPT WINDOW OPEN	TIME OF FLIGHT (DAYS)	INTERCEPT DATE	DAYS FROM DETECTION	DAYS UNTIL IMPACT
9 MAY 2021	57	5 JUL 2021	77	107
12 JUN 2021	49	31 JUL 2021	103	81
16 JUL 2021	49	3 SEP 2021	137	47
19 AUG 2021	48	6 OCT 2021	171	13

The same high delta-V mission profile used by EXCALIBUR for planetary defense can be used to explore any object in the solar system at a high cadence. The Lightcraft can be configured to provide the technical solution for dynamic Grand Tours that combine solar radiation pressure with gravity assists to visit multiple Outer Planets while enabling fast-flyby missions to various high priority objects such as transient interstellar objects, flying through the plumes of Enceladus or analyzing the methane cycle on Titan, all on extremely short mission timelines.

During this waiting period, the EXCALIBUR vehicles are able to change the inclination and right ascension of the holding orbit to match the target object’s orbital plane. Once inside the selected intercept window, the EXCALIBUR vehicles reorient their vanes to generate the needed acceleration vector to the intercept trajectory in the same manner

The integrated Aerospace and Xplore team will continue developing the EXCALIBUR concept and investigating stressing planetary defense missions. In parallel simulations and testing of the required control and intercept navigation will be performed with the Lightcraft hardware in the loop testbed.

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