THE NEAR-EARTH OBJECT HUMAN SPACE FLIGHT ACCESSIBLE TARGETS STUDY (NHATS) LIST OF NEAR-EARTH ASTEROIDS: IDENTIFYING POTENTIAL TARGETS FOR FUTURE EXPLORATION.

P. A. Abell[1], B. W. Barbee[2], R. G. Mink[2], D. R. Adamo[3], C. M. Alberding[2], D. D. Mazanek[4], L. N. Johnson[5], D. K. Yeomans[6], P. W. Chodas[6], A. B. Chamberlin[6], L. A. M. Benner[7], B. G. Drake[8], and V. P. Friedensen[9], [1]Astromaterials Research and Exploration Science Directorate, NASA Johnson Space Center, Houston, TX 77058, paul.a.abell@nasa.gov. [2]Navigation and Mission Design Branch, NASA Goddard Space Flight Center, Greenbelt, MD 20771. [3]Aerospace Consultant, Houston, TX 77059. [4]Space Mission Analysis Branch, NASA Langley Research Center, Hampton, VA 23681. [5]Planetary Science Division, NASA Headquarters, Washington, DC 20546. [6]Solar System Dynamics Group, Jet Propulsion Laboratory, Pasadena, CA 91109. [7]Planetary Radar Group, Jet Propulsion Laboratory, Pasadena, CA 91109. [8]NASA Johnson Space Center, Houston, TX 77058. [9]Human Exploration and Operations Mission Directorate, NASA Headquarters, Washington, DC 20546.

Introduction: Over the past several years, much attention has been focused on the human exploration of near-Earth asteroids (NEAs). Two independent NASA studies examined the feasibility of sending piloted missions to NEAs [1, 2], and in 2009, the Augustine Commission identified NEAs as high profile destinations for human exploration missions beyond the Earth-Moon system [3]. More recently the current U.S. presidential administration directed NASA to include NEAs as destinations for future human exploration with the goal of sending astronauts to a NEA in the mid to late 2020s. This directive became part of the official *National Space Policy of the United States of America* as of June 28, 2010 [4].

Detailed planning for such deep space exploration missions and identifying potential NEAs as targets for human spaceflight requires selecting objects from the ever growing list of newly discovered NEAs. Hence NASA developed and implemented the Near-Earth Object (NEO) Human Space Flight (HSF) Accessible Target Study (NHATS), which identifies potential candidate objects on the basis of defined dynamical trajectory performance constraints.

Dynamical Assessment: The current near-term NASA human spaceflight capability is in the process of being defined while the Multi-Purpose Crew Vehicle (MPCV) and Space Launch System (SLS) are still in development. Hence, those NEAs in more accessible heliocentric orbits relative to a minimal interplanetary exploration capability will be considered for the first missions beyond the Earth-Moon system [5]. Note that the NHATS only considered NEAs and not near-Earth comets since the latter have higher eccentricities and longer orbital periods that make them more difficult to rendezvous with and have active surfaces that could present a hazardous environment to both vehicle and crew.

Given that velocity change and mission duration are the most critical factors in any human spaceflight endeavor, the most accessible NEAs are those that have orbits similar to Earth's (i.e., semi-major axis near ~1 AU, low eccentricity, and low ecliptic inclination). If total mission durations for the first voyages to NEAs are to be kept to less than one year, with minimal velocity changes, then NEA rendezvous missions ideally will take place within 0.1 AU of Earth (~15 million km or 37 lunar distances) [6].

Accessibility Criteria: The NHATS algorithm computes all possible direct round-trip trajectory solutions to each NEA and compares the results to a set of intentionally inclusive dynamical trajectory performance constraints. In order to "pass the NHATS filter," a NEA must offer at least one round-trip trajectory solution that satisfies these constraints, which are total mission change in velocity $\leq$ 12 km/s, mission duration $\leq$ 450 days (of which at least 8 days must be spent at the NEA), Earth departure date between Jan 1, 2015 and Dec 31, 2040 (inclusive), Earth departure $C_3 \leq 60\ km^2/s^2$, and atmospheric entry speed upon Earth return $\leq$ 12 km/s. The total change in velocity (Δv) includes the impulse required to depart a reference circular Earth parking orbit at 400 km altitude, the impulse required to match the NEA's orbit upon arrival, the impulse required to depart from the NEA's orbit at a later time, and the impulse required, if any, to limit the atmospheric entry speed at Earth return to no more than 12 km/s. These extremely inclusive performance constraints were purposely selected for the NHATS filter in order to provide a very broad view of the relative accessibility landscape for NEAs [7].

Monitoring and Updates: The NHATS list of potentially accessible targets is continuously updated as new NEO discoveries are made. Data from the International Astronomical Union (IAU) Minor Planet Center (MPC) is fed into the Small Body Data Base maintained by NASA's NEO Program Office at JPL, which keeps the catalogued list of NEOs and their orbits up-to-date. New discoveries and existing objects with updated orbital parameters are then analyzed against the NHATS criteria on a daily basis. Any object that offers at least one viable trajectory for human spaceflight is added to the accessible target list. E-mail updates summarizing the latest processing results are also transmitted daily [7]. For reference, the current top 25

NHATS-compliant NEAs are listed in Table 1. NHATS-compliant NEAs are currently ranked according to the number of viable trajectory solutions offered, denoted as *n*. This parameter has been found to be useful for comparing NEAs when assessing relative accessibility.

Table 1: Brief Summary Data for the Current Top 25 NHATS-Compliant NEAs

Designation	*n*	Estimated Diameter (m)
2000 SG_{344}	3302638	27 - 85
1991 VG	2737751	5 - 16
2006 BZ_{147}	1674416	20 - 63
2001 FR_{85}	1618888	30 - 96
2008 EA_{9}	1597844	7 - 22
2010 VQ_{98}	1580174	6 - 18
2007 UN_{12}	1443703	4 - 14
2006 RH_{120}	1283817	3 - 10
2010 UE_{51}	1242487	5 - 17
2008 HU_{4}	1227757	6 - 17
2007 VU_{6}	1186902	12 - 38
2008 UA_{202}	1114827	3 - 10
2010 UJ	1082350	14 - 45
2011 BQ_{50}	1010896	5 - 16
2004 QA_{22}	1008597	6 - 20
2001 GP_{2}	980724	10 - 32
2009 HE_{60}	970582	18 - 56
2010 JR_{34}	960736	7 - 22
2009 BD	936904	5 - 16
2011 MD	936324	6 - 18
2010 TE_{55}	920319	6 - 20
2008 JL_{24}	904774	3 - 9
2011 BL_{45}	865199	9 - 28
2007 YF	791134	27 - 85
2010 JK_{1}	773964	32 - 100

Future Website Development: The most current list of accessible NEAs that have been identified as potentially viable for future human exploration under the NHATS criteria will be made available to the international community via a website. A beta version of the website is already under design and development at NASA. It is expected that the full version of the website will be available by mid-2012 and will be maintained by NASA's Near-Earth Object Program Office (http://neo.jpl.nasa.gov/) under the auspices of the Science Mission Directorate (SMD) and the Human Exploration and Operations Mission Directorate (HEOMD).

This promising list of NEAs will be useful for analyzing opportunities for robotic missions, identifying optimum round trip trajectories for human spaceflight targets, and highlighting potentially attractive objects of interest that may have future ground-based optical and radar observation opportunities for further characterization and/or orbit refinement. As such, the information contained on this website will be beneficial to planetary scientists, aerospace engineers, mission planners, astronauts, decision makers, and the general public as NASA and its international partners consider the possibilities for human exploration beyond the Earth-Moon system.

References:

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