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A Study of GN&C Architectures for Robotic and Human-Rated Spacecraft

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Introduction

NASA and private firms are presently planning and building spaceships that will safely transport humans to low earth orbit and beyond. These activities build on decades of human-rated and piloted spacecraft development and lessons learned, as well as establishing the groundwork for NASA's Journey to Mars and human exploration of the solar system. The system-level disciplines of Human System Integration (HSI) and Guidance, Navigation, and Control (GN&C) enable safe, efficient, and successful pilot control of these complex vehicles. Understanding the lessons learned, best practises, and future opportunities and challenges associated with human performance and interaction with guidance and control systems, cockpit technologies, and flight systems of piloted spacecraft from a human factors and performance perspective is a key enabler for ensuring these spacecraft can achieve the exploration objectives. The design and development of this intricate interaction between the human pilot and the GN&C system is a highly integrated process. For all phases of flight, trades between the system architecture, mission design, vehicle design, and human interface with the GN&C system must be carefully considered. Performance, handling qualities, human interactions, and the implications on other systems and subsystems must all be evaluated during the design, development, test, and operating phases.

NASA has a new path for human spaceflight and exploration thanks to the Vision for Space Exploration (VSE) of 2004. To meet the VSE objectives, NASA's CxP will have to acquire and operate several new human-rated systems, including the Orion Crew Exploration Vehicle (CEV), Crew Launch Vehicle (CLV), and Lunar Surface Access Module (LSAM), as well as other elements for crew transportation (e.g., in-space propulsion stages) and lunar habitation and mobility. Robotic lunar landers and robotic lunar orbiter vehicles will also be present. By decreasing both nonrecurring and recurring costs and/or risk, commonality in exploration system hardware and software aspects can considerably improve sustainability. This research was prompted by the remark made by both NESC and MIT that GN&C systems for exploration stand out among all future spacecraft systems as an area where commonality may be most beneficial. This analysis of robotic and human-rated GN&C system architecture methods was carried out as a first step in determining the benefits and drawbacks of GN&C commonality across the CxP flying components. This report presents the findings of this comparison research, which reveal the underlying (historical and objective) differences between robotic and human-rated mission GN&C systems.

The design of a human-rated spacecraft is a complicated and expensive procedure that necessitates the integration of many different criteria. Historically, it has been difficult to reflect the entire influence of the design on the flight operations community in that integrated evaluation. There hasn't been a well-defined set of criteria for measuring operability, nor have the specific "operability" needs been fully recognized. Program managers and flight operations groups are frequently startled when presented with complex and costly

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operations implementations as projects reach their operational stages. To decrease operations phase expenses, a systematic method of anticipating operability difficulties throughout the development phases of a program is required. The problem with addressing flight operability requirements for a new program is threefold: (1) there is no universally accepted definition of flight operability; (2) there is no clear mapping of flight operability needs to program and vehicle requirements; and (3) there is no formal method to assess flight operability characteristics given a spacecraft design and mission definition. The creation of numerous essential components is required to develop a feasible flight operability evaluation technique. Flight operability must be characterized in ways that are understandable to both flight crews and program managers. Specific operability objectives must be established, ideally as official design and performance specifications. To assess compliance with such standards, objective metrics must be devised. Human-rated and robotic spacecraft GN&C systems have a lot in common in terms of design. To appropriately balance mission success (risk), performance, mass, power, and cost, both design procedures need system-level architecture evaluations, trade studies, and fault tolerance and reliability analyses. Both types of spacecraft are created utilizing industry-standard analytical, modeling, and simulation methods. Linear frequency domain stability assessments and time-domain nonlinear performance simulations, for example, are frequently employed. There are a small number of GN&C component vendors due to industry consolidation. As a result, both human-rated and robotic GN&C systems use sensors, computers, and actuators that are comparable.

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Prioritize crew personnel. The European Space Agency (ESA), NASA's Jet Propulsion Laboratory (JPL), and NASA's Lyndon B. Johnson Space Center (JSC) have all released documents aimed at better defining operability requirements. The ESA's Space Segment Operability Standard addresses the safety, efficiency, and cost-effectiveness of robotic spacecraft operations, although it acknowledges the challenge of establishing unambiguous criteria for onboard automation capabilities. For its robotic spacecraft, NASA JPL established a similar set of design requirements. NASA JSC developed its own Space Systems Operational Design Criteria Manual to chronicle comparable lessons learned for human spaceflight. Both human-rated and robotic spacecraft operate under comparable settings in terms of operation. Both must withstand the harsh launch shock and vibration settings. Both must work under extreme space radiation and thermal/vacuum conditions. They share several mission phases, including low Earth orbital cruise, entry, descent, landing, rendezvous, and so on. In addition, both types of spacecraft conduct several mission activities that are identical, such as stellar-inertial navigation, angular rate damping, attitude control, and orbital adjustment propulsive operations.

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