

Investigation of Reaction Control System Design on Spacecraft Handling Qualities for Docking

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A program of research, development, test, and evaluation is planned for the development of spacecraft handling qualities guidelines. In this first experiment, the effects of reaction control system design characteristics and rotational control laws were evaluated during simulated proximity operations and docking. Also, the influence of piloting demands resulting from varying closure rates was assessed. The pilot-in-the-loop simulation results showed that significantly different spacecraft handling qualities result from the design of the reaction control system. In particular, cross coupling between translational and rotational motions significantly affected handling qualities as reflected by Cooper–Harper pilot ratings and pilot workload, as reflected by Task Load Index ratings. This influence is masked (but only slightly) by the rotational control system mode. Although rotational control augmentation using rate command/attitude hold can reduce the workload (principally, physical workload) created by cross coupling, the handling qualities are not significantly improved. The attitude and rate deadbands of the rate command/attitude hold introduced significant mental workload and control compensation to evaluate when deadband firings would occur, assess their impact on docking performance, and apply control inputs to mitigate that impact.

I. Introduction

HANDLING qualities embody “those qualities or characteristics of an aircraft that govern the ease and precision with which a pilot is able to perform the tasks required in support of an aircraft role” [1]. These same qualities are as critical, if not more so, in the operation of spacecraft.

Handling qualities includes more than just stability and control characteristics of a spacecraft or aircraft. Handling qualities are affected by all aspects of the pilot–vehicle dynamic system, shown in Fig. 1 [2]. The pilot serves as the system controller, driven by a piloting task or objective, using motion, visual and aural cues of the vehicle response, as well as any feedback from the controller force feel. The pilot’s role is delineated as “the decision maker of what is to be done, the comparator of what’s happening versus what he wants to happen, and the supplier of corrective inputs to the aircraft controls to achieve what he desires” [2].

NASA has initiated a multicentered spacecraft handling qualities project. This project will provide invaluable data and guidelines

for the design, development, test, and evaluation of NASA’s Constellation program platforms as well as all future NASA and other government agency and commercial spacecraft. A research, development, test, and evaluation process is in effect to identify, understand, and interpret the engineering and human factors principles which govern the pilot–vehicle dynamic system as they pertain to space exploration missions and tasks.

In this paper, the results of an initial investigation of reaction control system (RCS) design characteristics on spacecraft handling qualities during Earth orbit docking are described.

A pilot-in-the-loop simulation was conducted for the spacecraft proximity operations and docking task. Experimental variations were used to assess the influence of the following primary variables on spacecraft handling qualities: 1) RCS design characteristics and rotational control law modes, and 2) docking task initial condition and closure rate.

II. Background

The Orion crew exploration vehicle (CEV) is being developed to perform rendezvous, proximity operations, and docking (RPOD) in low Earth as well as in low lunar orbit [3]. The vehicle is being designed for RPOD with the International Space Station (ISS), the lunar landing vehicle, and the Earth departure stage. The RCS design [number of thrusters, their size, location, and orientation, and thruster characteristics (e.g., on–off time, thrust response dynamics, duty cycles)] is a critical element of the utility and acceptability of a spacecraft’s guidance and control system. Numerous challenges are associated with simultaneously providing acceptable RCS designs as well as meeting other critical program and spacecraft design requirements. For instance, as detailed in [4], trade study assessments of various RCS designs were conducted for 1) authority and precision of control, 2) robustness and efficiency, and 3) plume impingement. However, pilot-in-the-loop simulation and handling qualities assessments of the various configurations were not included in this trade study. RCS control authority and precision was assessed analytically. A skewed and canted RCS thruster orientation was downselected (see Fig. 2, extracted from [4]).

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