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Use of Automated Rendezvous Trajectory Planning to Improve Spacecraft Operations Efficiency

by

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Abstract

The current planning process for space shuttle rendezvous with a second Earth-orbiting vehicle is time consuming and costly. It is a labor-intensive, manual process performed pre-mission with the aid of specialized maneuver processing tools. Real-time execution of a rendezvous plan must closely follow a predicted trajectory, and targeted solutions leading up to the terminal phase are computed on the ground. Despite over 25 years of Gemini, Apollo, Skylab, and shuttle vehicle-to-vehicle rendezvous missions flown to date, rendezvous in Earth orbit still requires careful monitoring and cannot be taken for granted. For example, a significant trajectory offset was experienced during terminal phase rendezvous of the STS-32 Long Duration Exposure Facility retrieval mission.

Rendezvous of an unmanned spacecraft with Space Station Freedom (SSF) during permanently-manned operations will become a routine activity, occurring with greater frequency than rendezvous flights currently performed by the space shuttle. The current shuttle rendezvous process from conceptual mission design to real-time target vehicle grapple carries too high a price for repetition over the lifetime of the SSF. The bulk of this bill is paid during many months of preflight rendezvous trajectory analysis before the shuttle ever leaves the ground. Several improvements can be introduced to the present rendezvous planning process to reduce these costs, produce more fuel-efficient profiles, and increase the probability of mission success.

Realization of the above benefits requires incorporation of an automated or autonomous rendezvous and docking capability. Several organizations are presently developing sensors, mechanisms, and algorithms to aid in the execution of pre-computed rendezvous plans. However, a sometimes-overlooked effort is needed for reduction of the manpower necessary to generate the optimum maneuver plans –especially real-time trajectory replanning based on unforeseen problems and dispersions.

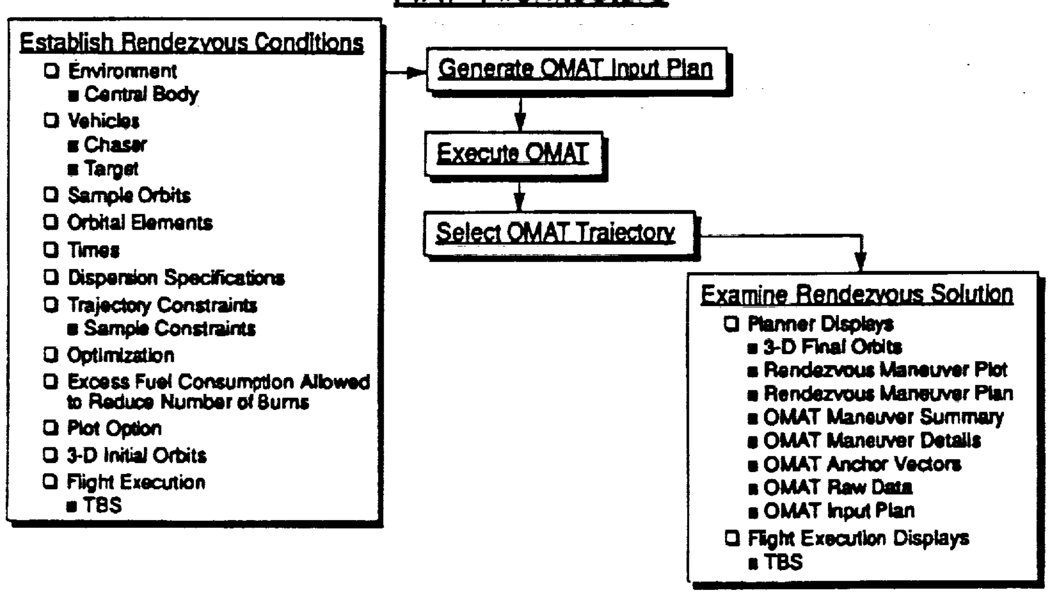
The Rendezvous/Proximity Operations Trajectory Control Expert System (RENEX), the Expert First Guess component of the Expert Flight Analysis System (XFAS), and the rendezvous planning segment of the Autonomous Operations (AUTOPS) project were NASA/JSC attempts at reducing the flight design effort through use of expert systems. These concepts engaged predefined rules that applied to orbital situations for "catching up" or "falling back" to the target vehicle. The Autonomous Rendezvous Planner (ARP), under development at McDonnell Douglas for the Navigation, Control, and Aeronautics Division of the Engineering Directorate at NASA/JSC, however, steps beyond this approach by producing a mathematically-optimum

rendezvous trajectory that meets flight-specific constraints which are determined pre-mission. A first guess from which to converge need not be provided and rule bases are unnecessary. Prior to ARP, application of mathematical trajectory optimization techniques to flight design tools and approaches for vehicle-to-vehicle rendezvous has, for the most part, been neglected.

Key to the trajectory optimization for ARP is the McDonnell Douglas-developed Optimal Maneuver Analysis of Trajectories (OMAT) program. Under development since 1985, OMAT uses Primer Vector Theory in minimizing spacecraft Δv or fuel for n maneuvers, where n can be pre-defined, and either impulsive or finite burns can be selected. OMAT has been used for orbit transfer problems at LaRC, the Aerospace Corp., and for the National Aerospace Plane. Recent improvements have made OMAT a better tool for addressing real-world rendezvous applications. However, the code is still under development while a comprehensive set of 165 new rendezvous constraints is being mathematically defined and incorporated. These constraints will allow the user to optimize a spacecraft's trajectory within controlled points along its path. Currently, for example, a trajectory can be optimized within the constraints of not dropping below a defined minimum altitude while meeting a specified phase angle, at a certain time, relative to a target vehicle. The latest results show that a small savings in propellant can be obtained for near-circular, near-coplanar orbits, and a significant savings can be obtained for orbits that are non-circular and non-coplanar, when compared against current rendezvous planning tools.

ARP has the potential to significantly streamline both the preflight and real-time ground planning processes. The architecture of ARP is being designed to facilitate integration into a spacecraft's onboard software to expand the spacecraft's level of autonomy; thus, reducing its reliance on ground assistance solely to the uplink of navigation data.

ARP Architecture



ARP incorporates chaser and target vehicle characteristics, state vector data, and pre-defined orbital constraints. It takes these inputs and generates a maneuver plan that is executed by other parts of the GN&C system. This process repeats itself after each rendezvous maneuver or navigation update until proximity operations begins.

The flexibility to quickly react to minor or even major real-time adjustments to complex schedules and vehicle states significantly enhances the probability of carrying out a successful mission. This need is a realistic one, given the large number of rendezvous missions expected of a generic resupply spacecraft. ARP's approach differs considerably from OMV targeting software, which consisted of pre-defined co-elliptic orbits with a limited ability to respond to orbital trajectory perturbations.