Manned versus Unmanned Rendezvous and Capture

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Abstract

Rendezvous and capture (docking) operations may be performed either automatically or under manual control. In cases where humans are far from the mission site, or high-bandwidth communications lines are not in place, automation is the only option. Such might be the case with unmanned missions to the moon or Mars that involve orbital docking or cargo transfer. In crewed situations where sensors, computation capabilities, and other necessary instrumentation are unavailable, manual control is the only alternative. Power, mass, cost, or other restrictions may limit the availability of the machinery required for an automated rendezvous and capture. The only occasions for which there is a choice about whether to use automated or manual control are those where the vehicle(s) have both the crew and instrumentation necessary to perform the mission either way.

The following discussion will focus on the final approach or capture (docking) maneuver. The maneuvers required for long-range rendezvous operations are calculated by computers. It is almost irrelevant whether it is an astronaut, watching a count-down timer who pushes the button firing the thruster or whether the computer keeps track of the time and fires with the astronaut monitoring. The actual manual workload associated with a mission that may take as long as hours or days to perform is small. The workload per unit time increases tremendously during the final approach (docking) phase and this is where the issue of manual versus automatic is more important.

The decision over whether a mission will be under automatic or human control will not be made for technological reasons. The Soviets pioneered automatic docking in October 1967 when Kosmos (Cosmos) 186 docked with Kosmos 188 automatically. Clearly current American capabilities in this area, though unproven in space, should be at least as high as Soviet abilities of 24 years ago. However, all Gemini and Apollo docking operations, and all satellite rendezvous and capture maneuvers performed by the space shuttle were performed under manual control. The rationale for using manual control as opposed to automatic control have their origins in the Right Stuff, <u>lack of</u> automatic capability, and human factors. (Incidentally, the common perception that the Soviets use automatic control for all of their docking operations is not correct. When cosmonauts are in the approaching vehicle, they take over from the automatic system when the range is a few hundred meters. The Progress resupply vehicles dock automatically, but the crew are very carefully monitoring the situation and are ready to take control if necessary. (Newkirk, 1990))

NASA commanders and pilots have historically (and most likely will continue to) come from a military pilot background. They have the Right Stuff and they want their hands on the "wheel." They do not want to sit idly by and watch the automatic system perform the maneuver for them. This philosophy is not restricted to future docking operations. The space shuttle and many commercial jet airliners have an automatic landing capability. (Landing an aircraft is roughly analogous to a spacecraft docking operation as they both involve terminal guidance.) In the space shuttle's case, this automatic landing capability has never been used. Commercial airline pilots typically take out the automatic system only periodically, rather than routinely, to make sure it still works. While one might argue that a docking is more deterministic (there are no crosswinds, rain, snow, or other obstacles) and therefore easier to be automated, the fact remains that in more mundane environments than space, human nature prevents the use of automatic pilot systems.

Automatic docking with space station *Freedom* is almost a non issue. Docking could probably be performed with passive reflectors on the station, as Marshall Space Flight Center researchers have been simulating on the air-bearing floor for many years. However, with a target as valuable as the manned station, an active targeting system would most likely be an imperative. Unfortunately, the laser rangefinder for docking was removed from the station design early on its design. Without this device, or something similar, automatic docking will not be performed.

In addition to the Right Stuff justifications, and the lack of essential targeting hardware, there are human performance reasons for using manual control when possible. Humans are good controllers but poor monitors. There is a very real fear, particularly in commercial aviation, of automating pilots out of the loop. The existence of accidents in nuclear power facilities and subway systems serves to support this contention. (Wiener, 1988)

The following extended quotation relating to manual control was taken from (Brody, May 1991, pp. 4-5).

> The importance of manual control aspects of spaceflight operations, such as rendezvous and docking, was recognized early in the United States space program. After only three manned flights in the Mercury Program, the Technical Director of the Behavioral Sciences Laboratory, Aerospace Medical Research Laboratories, Wright-Patterson AFB concluded that "men can contribute greatly to the successful accomplishment of many types of space missions. . . . the Mercury astronauts were able to manually compensate for equipment malfunctions and thereby complete missions which otherwise would have failed or terminated prematurely" (Grether, 1963, p. 79). As Gemini XII and Apollo XI astronaut Buzz Aldrin explains, "Manned orbital rendezvous was a vital field, because any way you cut it, if we were going to assemble large interplanetary spacecraft, we'd have to master the techniques of space rendezvous—bringing two or more separately launched spacecraft together in orbit. With computers we could reduce the blizzard of spherical geometry and calculus equations down to automated rendezvous procedures. But I'd seen enough autopilots malfunction during my flying career to realize that the spacecraft NASA planned to use for Earth orbital lunar spaceflight would need some kind of manual backup" (Aldrin & McConnell, 1989, p. 67). The Soviets also value the flexibility that manual control allows in "the capabilities of man to see three dimensions and to evaluate the situation better than a machine for flight conditions that have not been provided for by the program" (Meshcheryakov & Minaev, p. 804). Gemini X and Apollo XI astronaut Michael Collins advocates manual control as follows: "was this not a noble cause, to build an autonomous capability, to allow a manned spacecraft to roam free of ground control, to compute its own maneuvers? Was not the very name of the game, in manned space flight, to put the pilots in control" (Collins, 1974, p. 169)?

Further justification for manual control may be found in the airline industry where "pilots still manually fly even the most highly automated aircraft, if only to maintain their flying skills in the case that they are called on if the automatics fail" (Nagel, 1988, pp. 293-4). Also, the adaptive capability that humans bring to control tasks adds further weight to the decision to use manual control instead of automation.

While automation is and will continue to be an important aspect of manned space flight,

> It is unlikely that the pilot will be eliminated, any more than will the operator of a nuclear power plant. Our society believes that humans should have ultimate responsibility for control of complex systems even if inserting the human degrades overall system performance most of the time. The human is still the ultimate back-up system. While machines that are overloaded fail abruptly, people degrade gracefully under excessive levels of workload. Thus it seems prudent to include human operators, even if only as the sub-system of last resort that can "pull the plug." Furthermore, there are also strong political forces to keep humans employed. (Kantowitz & Casper, 1988, p. 183)

A number of studies have been performed recently to quantify the human performance envelope involved with piloting a spacecraft docking maneuver. (Brody, 1987, 1989ab, 1990ab, 1991; Brody and Ellis, 1990, 1991ab, in press) Many factors affect the ability of a crewperson to perform such a maneuver including: thruster magnitude, braking gates, control mode, impact velocity, docking port location. With a better understanding of how these factors affect performance, mission and hardware designers will be able to take action to increase safety, performance, reliability, and productivity while reducing cost. Benefits from this work, such as reduced operational costs, will greatly enhance the United States space program.

References

Aldrin, B. & M. McConnell. (1989). Men From Earth. New York, Bantam Books.

Brody, A. R. (1987). Spacecraft Flight Simulation: A Human Factors Investigation into the Man-Machine Interface Between an Astronaut and a Spacecraft Performing Docking Maneuvers and Other Proximity Operations. Unpublished Master's thesis, Massachusetts Institute of Technology, Cambridge, MA. see also NASA CR-177502, Sept. 1988.

Brody, A. R. (1989a). The Effect of Initial Velocity on Manually Controlled Remote Docking of an Orbital Maneuvering Vehicle to a Space Station. American Institute of Aeronautics and Astronautics, Paper 89-0400, Washington, DC:

Brody, A. R. (1989b). Remote Operation of an Orbital Maneuvering Vehicle in Simulated Docking Maneuvers. Third Annual Workshop on Space Operations Applications and Research (SOAR '89). Washington, DC: National Aeronautics and Space Administration, NASA CP-3059.

Brody, A. R. (1990a). "Evaluation of the "0.1% rule" for Docking Maneuvers." Journal of Spacecraft and Rockets. 27(1): pp. 7-8.

Brody, A. R. (1990b). Recovery from an Anomalous Thruster Input During a Simulated Docking Maneuver. Fourth Annual Workshop on Space Operations Applications and Research (SOAR '90). Washington, DC: National Aeronautics and Space Administration, NASA CP-3103.

Brody, A. R. (1991). Quantitative and Qualitative Comparison Between Acceleration Control and Pulse Control in Spacecraft Docking. Unpublished Master's thesis, San Jose State University, San Jose, CA.

Brody, A. R. & S. R. Ellis. (1990). "Effect of an Anomalous Thruster Input During a Simulated Docking Maneuver." Journal of Spacecraft and Rockets. 27(6): pp. 630-633.

Brody, A. R. & S. R Ellis. (1991a). A Comparison of Acceleration Control and Pulse Control in Simulated Spacecraft Docking Maneuvers. Washington, DC: American Institute of Aeronautics and Astronautics, 91-0787.

Brody, A. R. & S. R. Ellis. (1991b). Logistics and Operations Implications of Manual Control of Spacecraft. Washington, DC: American Institute of Aeronautics and Astronautics, 91-4094.

Brody, A. R. & S. R. Ellis. (in press). "A Comparison of Acceleration Control and Pulse Control in Simulated Spacecraft Docking Maneuvers." Journal of Spacecraft and Rockets.

Collins, M. (1974). Carrying the Fire An Astronaut's Journeys. New York: Bantam Books.

Grether, W. F. (1963). Human Performance Capabilities for Military Operations in Space. In Lectures in Aerospace Medicine. Brooks Air Force Base, TX: USAF School of Aerospace Medicine, Aerospace Medical Division.

Kantowitz, B. H. & P. A. Casper. (1988). Human Workload in Aviation. Human Factors in Aviation. San Diego: Academic Press, Inc.

Meshcheryakov, I. P. & Minaev, S. A. (1976). "Construction and Investigation of an Information Model of the Process of Approach of Piloted Spacecraft." 15: 804-807.

Nagel, D. C. (1988). Human Error in Aviation Operations. Human Factors in Aviation. San Diego: Academic Press, Inc.

Wiener, E. L. (1988). Cockpit Automation. Human Factors in Aviation. San Diego: Academic Press, Inc.