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ABSTRACT

AN AUTOMATED RENDEZVOUS & CAPTURE SYSTEM DESIGN CONCEPT FOR THE CARGO TRANSFER VEHICLE AND SPACE STATION FREEDOM

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A rendezvous sensor system concept was developed for the CTV to autonomously rendezvous with and be captured by SSF. This paper describes the development of requirements, the design of a unique Lockheed developed sensor concept to meet these requirements and the system design to place this sensor on the CTV and rendezvous with the SSF.

The system design is based upon the CTV mission scenario guidelines which are currently being defined by Marshall Space Flight Center. The guidelines are a product of study contracts let by MSFC to establish specifications for the National Launch System,NLS. The system design concept also meets the preliminary Avionics System Requirements which are a product of the same MSFC study contracts. These requirements include the safety aspects of man-rating (for operation near and while attached to the SSF).

These evolving scenarios under the development direction of MSFC for rendezvous of the CTV with SSF include six modes: 1. rendezvous phasing of the CTV to catch up with SSF; 2. injection to a stable orbit point at 20nm from the SSF; 3. transfer to a stable orbit point 1nm from the SSF; 4.transfer to a stable orbit point at 1000 ft from the SSF; 5. proximity operations, approach from 1000ft to a capture area; and 6. manual grappling with the SSF ARM to capture and berth (attach) the CTV to the SSF.

The classic system design process was applied: flow down of the mission scenario guidelines and NLS requirements to establish the rendezvous sensor requirements. These sensor requirements were derived by taking advantage of measurements that are available from other sources, such as prelaunch SSF position data provided to the CTV, and guidance and navigation instruments planned for the CTV to meet other requirements. This reduced the range requirement on the rendezvous sensor from acquiring at the initial orbit injection point which is 20,000 km away from SSF. The CTV has Global Positioning System, GPS, for navigation. The baseline SSF does not have GPS. However, since GPS may be added to SSF, a second set of requirements were developed for this possibility.These two sets of assumptions produced two very different sets of requirements for the automated rendezvous and capture,AR&C, sensor. The baseline set requires a sensor that has a range of 56 nm, whereas the second assumption (GPS on SSF) only requires that the sensor have a range of 1nm. This large difference is due to the large uncertainty in the SSF position,36nm, without GPS, compared to 30 meters with GPS. In both cases the sensor must provide measurements to the capture area, near 0 distance. In addition to range other measurements are required: range rate,and bearing angle. Relative attitude measurement is not required for capture as it is for

docking. The accuracy of all measurements was established by analysis and confirmed by simulation.

Previous approaches have met the large operating range requirement with the use of two or more devices, e.g. microwave radar for long range and visual imaging for close in. However, this requires that the long range sensor hand over to the close in sensor at a possibly dangerous point in the mission scenario. To avoid this problem we were interested in determining if a single sensor concept could be used over the entire range(s) for safety and simplicity. Sensor concepts that are applicable are described in references 1. and 2., but none appeared to meet our single sensor requirement over the large dynamic range with a simple design. The solution was found in a Lockheed developed measurement device that is based on laser interferometry and employs modulated optical phase. This device was built and tested under contract to SDIO for an application that is different than rendezvous (measurement of mirror flatness). When we applied the concept to designs to meet the sensor specifications we found that they could be met with reasonable design parameters. We had to invent techniques for obtaining range, bearing, and range rate and relative attitude. From these techniques the design parameters of the sensor were defined such as: laser power, laser broadcast solid angle, detector performance (NEP) to meet the two sets of system requirements. The electronic filtering and processing were similar to the original SDIO developed sensor, but with fewer channels. The processing power for this application was determined. It proved to be quite small, ~ 2 k flops which is less than 1% of a typical space computer capacity. In summary the sensor was found to have the following advantages: simple mechanical design(no moving parts) ,simple electronic design ,high accuracy(not effected by signal amplitude), large dynamic range(operates from acquisition to capture), low processing power, high noise rejection, and low laser power.

The technical risk of this concept is very low. The concept we selected exploits technology developed under SDIO and requires no additional technology innovations. It employs a relatively straight forward projection and detection of a modulated interferometry pattern to accuracies well within the SOA.

Three implementation architectures were defined. The first places the lasers on the CTV and a passive target board with retroreflectors on the SSF that send the signals back to the CTV where they are detected and processed. The second architecture places the laser on the SSF and the detectors and processing on the CTV. The third has the laser on the CTV and the detectors on the SSF. The SSF processes the signal and sends control commands to the CTV. The latter two concepts provide a built in passive collision avoidance capability. Lack or loss of commands or laser signals would abort the rendezvous.

The integration of the sensor with the CTV was defined and analyzed. Integration analysis performed was with structure (physical location and boresight direction for the signal laser and FOV's of the detectors), attitude control system,and the reaction control system. The CTV attitude reference was switched from local horizontal to SSF oriented at the 1nm point. A comparison was made for three different "final" approaches, V-bar, R-bar and Constant Bearing. The variation of propellant usage with approach angle is quantified.The inherent safety of each approach is compared in the event of need to abort. The optimum CTV /Payload carrier vehicle orientation during the final approach is also determined for several sets of RCS thruster configurations.

The system design, analysis and simulation of the described system was developed initially by Lockheed using discretionary funds ,and is currently partially funded as part of MSFC 's National Launch System system definition study contract . The development of optical phase measurement was performed under contract to SDIO. The application of modulated optical phase to the specific designs to meet CTV/ SSF rendezvous requirements, and CTV integration was accomplished entirely with LMSC discretionary funds.

1.Rendezvous and Capture of Station Keeping Platform, JPL , IOM 343-89-030, R. Van Bezooijen

2.Sensor Trade Study,Vol 1: Autonomous Rendezvous and Docking, JSC, 216900-8-F1