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Automatic Rendezvous to the International Space Station

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Abstract

This paper describes Guidance, Navigation and Control system design of the H-II transfer vehicle (HTV) that transports cargos to the International Space Station. High performance trajectory and attitude control, failure detection capability and operational flexibility are required for the HTV. The onboard software in the GN&C plays an important role to achieve the requirements.

1. Introduction

National Space Development Agency of Japan (NASDA) and Mitsubishi Electric Corporation (MELCO) is developing the Guidance, Navigation and Control (GN&C) system for the H-II transfer vehicle (HTV), which will perform rendezvous approach to the International Space Station (ISS). The HTV is an automatic, unmanned space vehicle transporting cargos to the ISS and disposing of waste from the ISS.

The HTV succeeds to the automatic rendezvous technology developed for the Engineering Testing Satellite VII and it was demonstrated successfully in 1998. The HTV is also expected to be a servicing vehicle on orbit in the future.

This paper describes the role of the GN&C, especially the flight software for Rendezvous flight.

2. GN&C Mission Profile

The HTV will be launched by the H-IIA and injected into the co-orbit of the ISS. Just after separation from the H-IIA, the GN&C starts up its functions and establishes the earth pointing attitude. Some burns are performed to gain altitude and adjust the phase difference between the ISS and the HTV, and the work time of the crews on the ISS. Switching several navigation techniques according to distance to the ISS, the HTV approaches automatically to the ISS with support from ground operators. HTV will be captured and attached to the ISS by a robotics arm on the ISS (Space Station Robotics Manipulation System) that an ISS crew controls.

While the HTV stays at the ISS, the crews take goods out of the HTV cargo carrier and dispose of waste from the ISS to the cargo carrier. After released from the ISS, the HTV goes down to the lower orbit and executes reentry maneuvers. The HTV will be destructed by friction heat due to the atmosphere.

The orbit profile is shown in Figure 2-1.

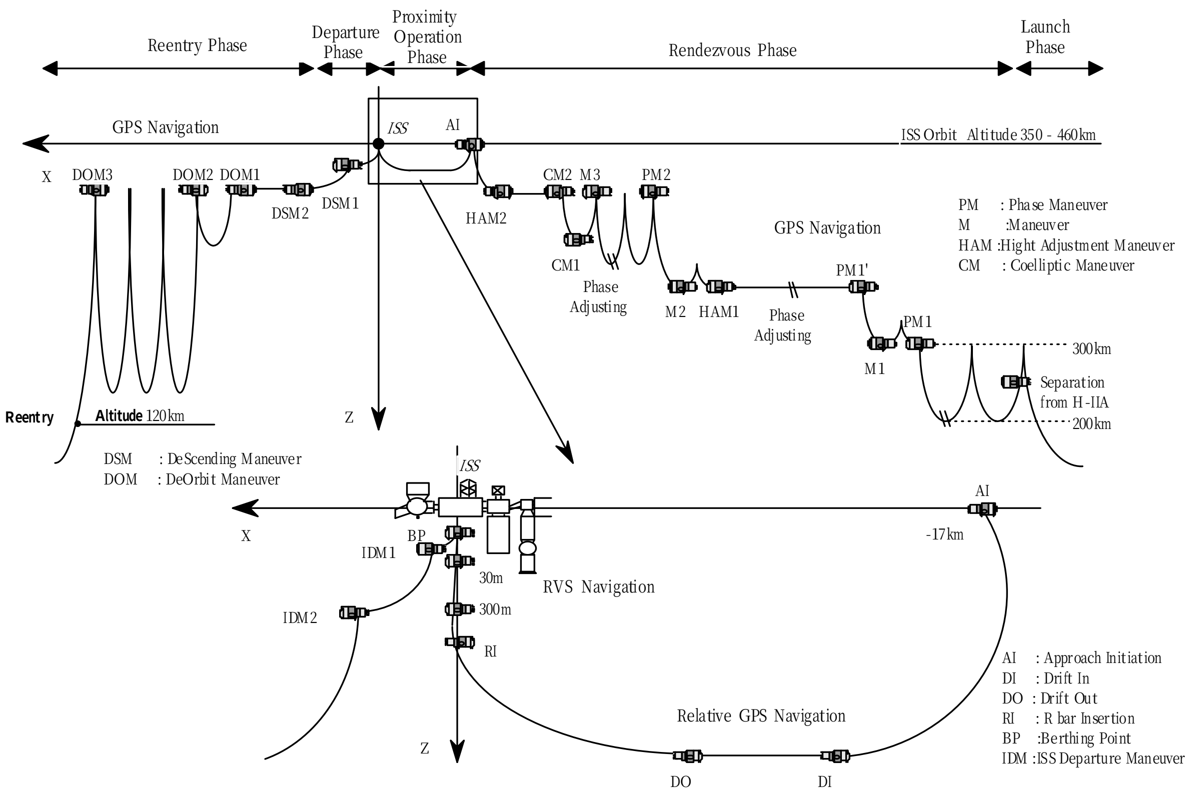

Fig. 2-1 HTV Mission Profile

3. GN&C architecture

The HTV GN&C has Guidance & Control Computer/Abort Control Unit (GCC/ACU) as a controller, three units of Space Integrated GPS/INS (HTV SIGI), two units of Rendezvous Sensor (RVS), two units of Earth Sensor Assembly (ESA) as navigators and three units of Valve Drive Electronics (VDE) as actuators. GCC/ACU is the onboard computer controlling the HTV behavior. SIGI consists of GPS receiver, Gyro and Accelerometer applying the Commercial Off The Shelf components. RVS is the laser range finder under joint development by NASDA and European Space Agency. These components are controlled by RendezVous Flight Software (RVFS) installed in the GCC, which plays an important role for the automatic flight of the HTV.

The Japanese Experiment Module (JEM) on the ISS has two units of SIGI (JEM SIGI) for GPS navigation and the proximity communication (PROX). GPS data on the ISS side is transmitted to GCC via Communication and Data Handling subsystem on both the ISS and the HTV, and RVFS performs two types of GPS navigation: GPS differential and GPS relative navigation. The retro reflectors are attached underneath the JEM and reflect laser beams from RVS on the HTV. Figure 3-1 shows the GN&C architecture.

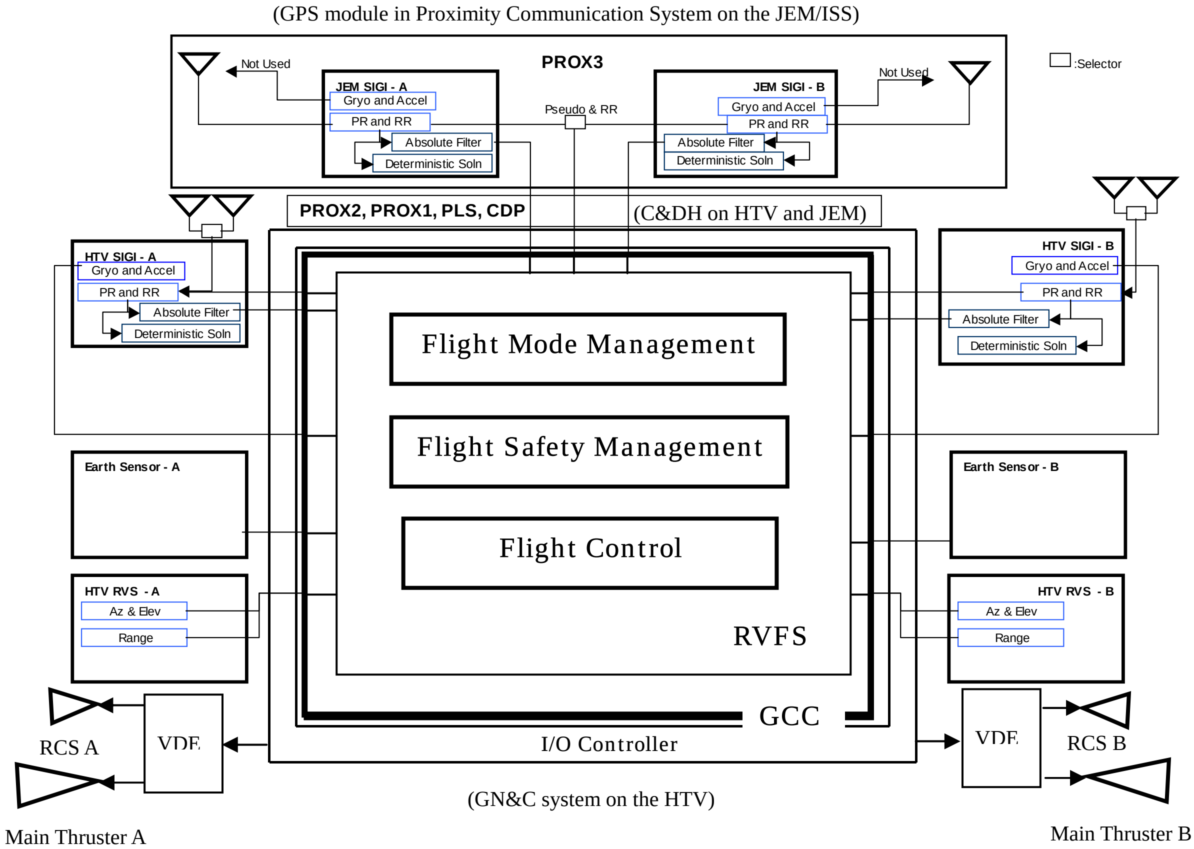

Fig. 3-1 HTV GN&C architecture

4. Flight software

RVFS is the key component for the HTV automatic rendezvous flight. The figure 4-1 shows the functions/modules structure of the RVFS. It mainly consists of the flight control function, the flight safety management function and the flight management function. This section describes details of those important functions.

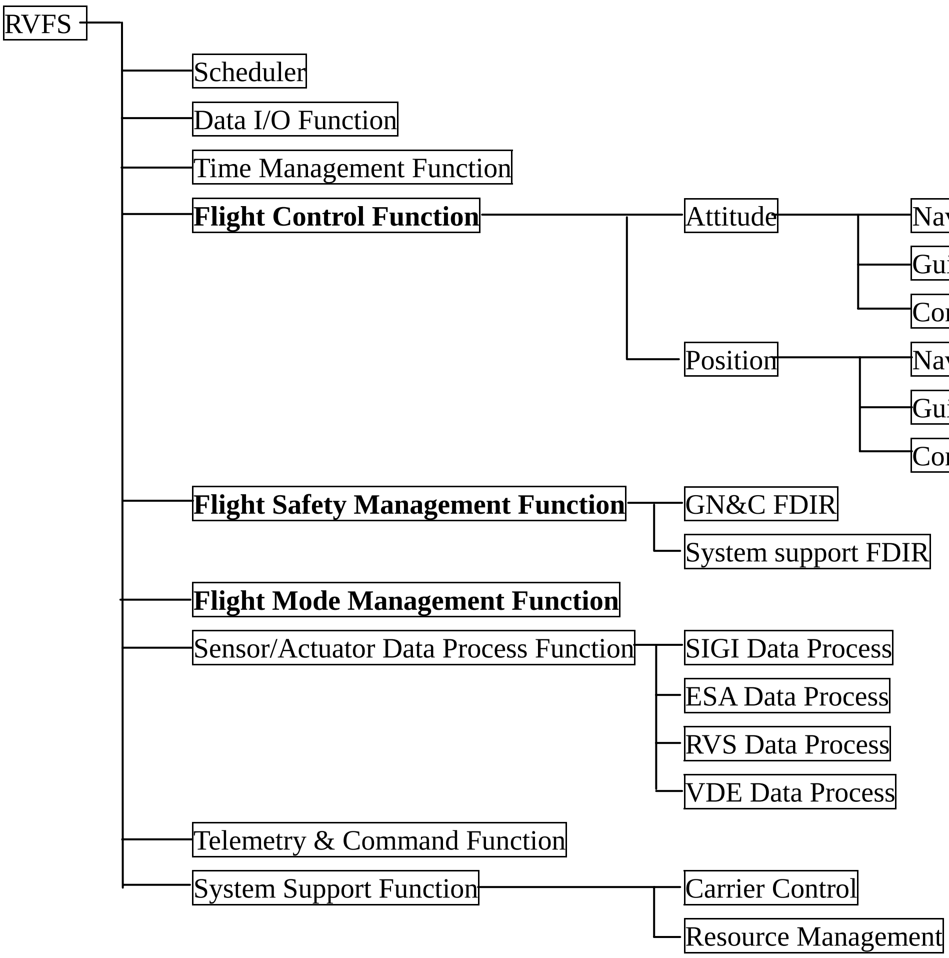

Fig. 4-1 RVFS software Function Tree

4.1 Flight Control Function

The Flight Control Function is composed of the attitude flight control and position flight control. Each flight control has the navigation function, the guidance function and the control function. Furthermore, the position part is divided into INS (initialized by GPS), differential GPS, relative GPS and RVS flight controls according to the distance from the ISS.

The navigation detects the attitude of the HTV itself and the relative position between the ISS and the HTV using the sensors’ output. The guidance calculates references to get the desired point. Comparing the outputs of the navigation and the guidance, the control generates force and torque commands, which are executed by the thrusters.

Figure 4.1-1 shows the block diagram for the attitude flight control. ESA reference updates the gyro oriented navigation filter for attitude and attitude rate estimation. Guidance provides the commands to achieve the earth pointing attitude. Difference between the navigation and command are fed into PD controller. Torque command from the PD controller is modulated for thruster drive pulse. This attitude flight control is used commonly for each position flight control.

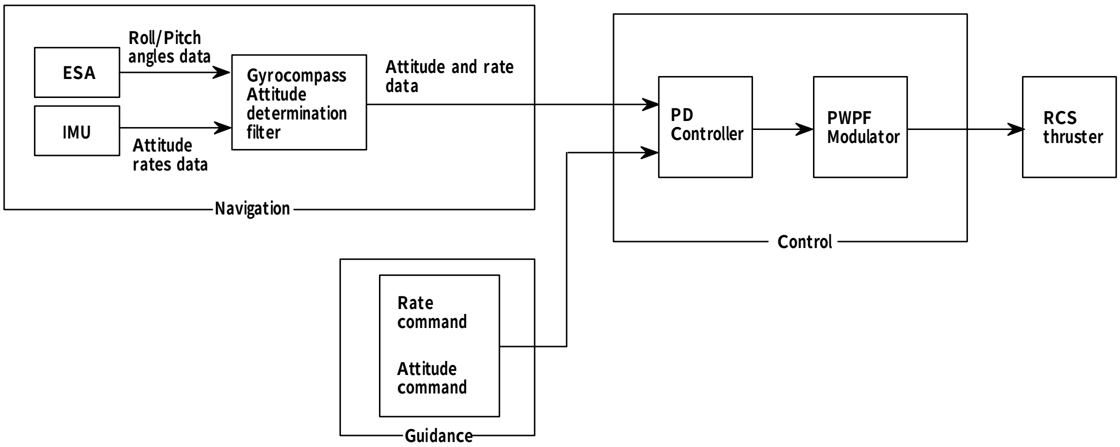

Fig. 4.1-1 Attitude Flight Control Block Diagram

Figure 4.1-2 shows the block diagram of the position flight control using the relative GPS navigation, as a sample of the position flight control.

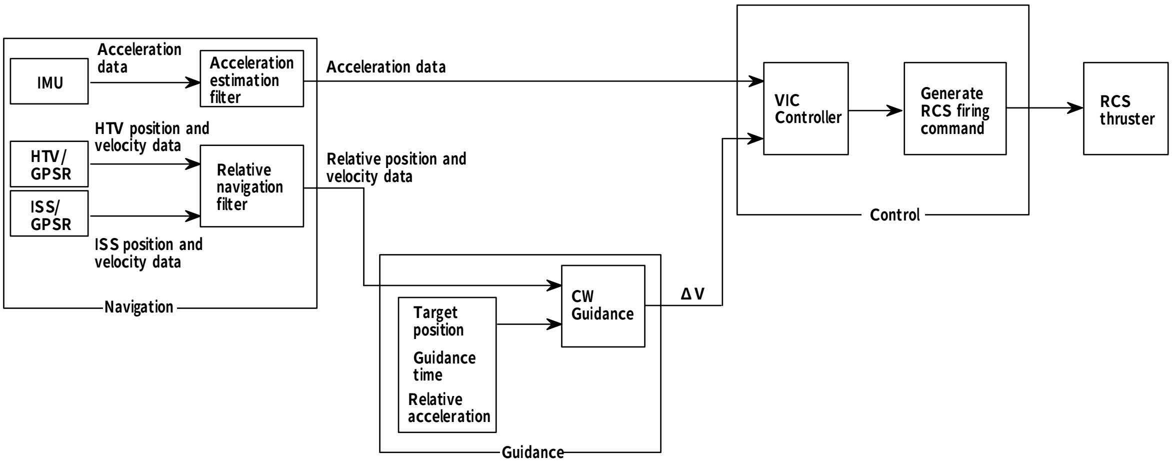

Fig. 4.1-2 Position Flight Control (Relative GPS) Block Diagram

In the range of PROX communication (23km from the ISS), the HTV knows its relative position and velocity between the ISS and the HTV using the relative GPS navigation technique. GPS pseudo range and delta range measurement from both HTV and JEM SIGI are processed at Kalman filter in RVFS. Since GCC CPU has heavy load due to the Kalman filtering using eight states (three axes position & velocity, clock bias and clock drift), the major filter process cycle at 1 Hertz is divided into a minor cycle of calculation at 8 Hertz. The guidance part generates the start time of thruster burn and the desired velocity increment at the next maneuver using CW equation. While the HTV performs a maneuver burn, the increment velocity is detected by accelerometer in the SIGI. At the moment the velocity reaches the desired one, the control part stop the thruster firing.

Figure 4.1-3 shows another sample of the position flight control. When the HTV arrives at 500m point below the ISS, the relative GPS navigation is switched to the RVS navigation. RVS provides the range between the ISS and HTV, the azimuth and elevation angle from the line of sight direction of RVS. The relative position is obtained from combination of RVS information above and attitude information. The relative velocity comes from differentiation of the position. Position, velocity and acceleration commands in order to guide the HTV along R bar, which is the radius direction line from the ISS to the center of the earth. Difference between the position and velocity navigation and command are fed into PD controller. Acceleration information is feed forward command. Force command from the PD controller is modulated for thruster drive pulse. Upon the crew request command, the position flight control performs maneuvers on the R bar for “Hold (stop and stay at that position)”, “Retreat (go back to the safe point)” and “Resume (approach restart)”

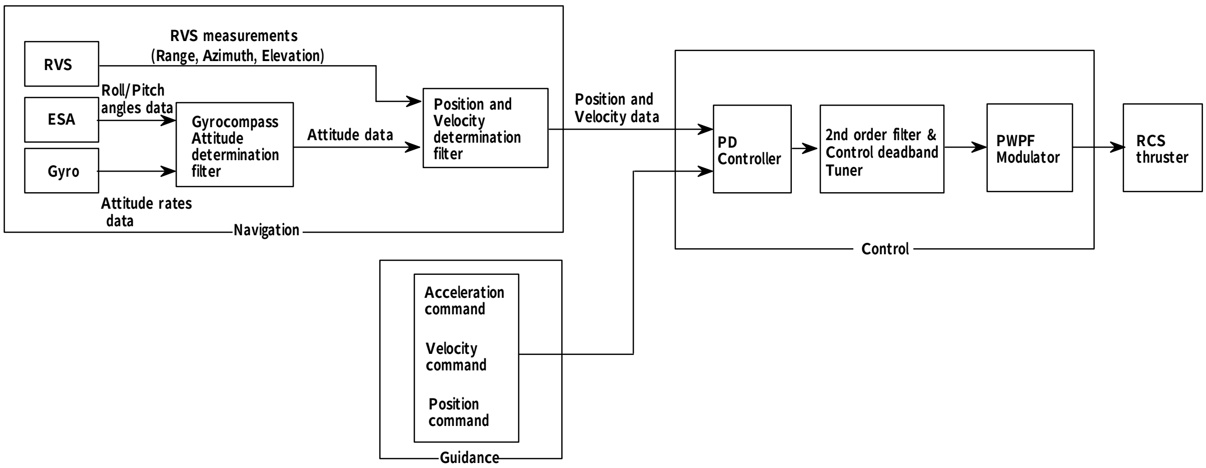

Fig. 4.1-3 Position Flight Control (Relative RVS) Block Diagram

4.2 Flight Safety Management Function

Two fails safe against collision with the ISS is strictly required to the HTV. One fail operation is also required for higher level mission success. When a failure occurs in a sensor or an actuator, RVFS changes the string from the primary one to the redundant one. When two failures occur in sensors or actuators, RVFS executes a mission abort maneuver. The failures are detected, isolated and recovered (FDIR) automatically.

FDIR watches the status and data value from the sensors, controllers and actuators. In addition to the FDIR for each component, there are some combination FDIR: comparison of primary and redundant sensor’s output, comparison of different sensors’ output, actuator failure estimation by sensor’s output, and so on. Figure 4.2-1 shows the block diagram for RVS failures as an example of FDIR.

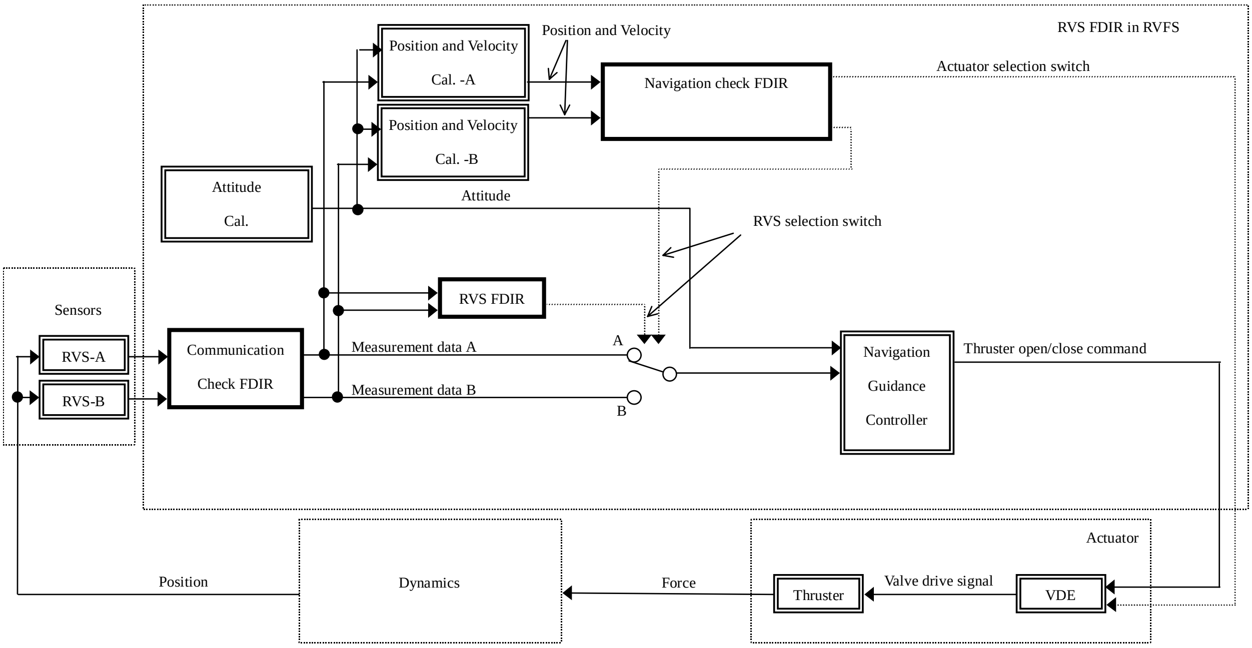

Fig. 4.2-1 FDIR Block Diagram for RVS

4.3 Flight Mode Management Function

The flight mode management is an automatic mode sequencer to approach the ISS step by step. It chooses the navigation, guidance and control properly for each flight phase. Also it sets the proper parameters and switches for the GN&C and FDIR functions. Automatic decision by the flight management function or commands from the ISS crew / the ground operator triggers mode transition.

5. Summary

The HTV flies automatically with these functions above, getting the minimum support from the ISS crews or the ground operators such as Go/No Go decisions at the predetermined checkpoints and are captured/released by the robotic manipulator of the ISS. The HTV also has the maximum operational flexibility such as Abort of mission, Hold on the spot, Retreat backward, Resume of approach when the crews or the operators desire.

Preliminary design review for RVFS was successfully done at MELCO in August 2002. The software verification is performed in 2003. GN&C subsystem verification will start after the completion of the software verification and is planned in 2004. Closed loop tests will be used on GN&C subsystem with the actual hardware, RVFS and 6 degrees of freedom motion table.

6. Reference

(1) Tsukui, J., et al., April 1999, “H-II Transfer Vehicle’s Guidance, Navigation & Control And Trajectory design of Proximity Operation”, AIAA ISS Service Vehicle Conference, Houston, TX