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Abstract for NASA

On-orbit Demonstration of Automated Closure and Capture Using ESA-Developed Proximity Operations Technologies and an Existing, Servicable NASA Explorer Platform Spacecraft

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Statement of the Technical Details

The European Space Agency (ESA) has been working to develop an autonomous rendezvous and docking capability since 1984 to enable Hermes to automatically dock with Columbus. As a result, ESA with Matra, MBB, and other Space Companies have developed technologies that are also directly supportive of the current NASA initiative for Automated Rendezvous and Capture. Fairchild and Matra would like to discuss the results of the applicable ESA/Matra rendezvous and capture developments, and suggest how these capabilities could be used, together with an existing NASA Explorer Platform satellite, to minimize new development and accomplish a cost effective automatic closure and capture demonstration program.

Several RV sensors have been developed at breadboard level for the Hermes/Columbus program by Matra, MBB, and SAAB. For example, the Matra laser proximity operation sensor, developed with Matra and CNES funding is based upon a flight qualified CCD sensor working together with a pulsed laser to illuminate retroreflectors mounted on the target docking side. The CCD operates in a Flash-During-Transfer(FDT) mode, enabling operation even with sunlight in the sensor FOV. The sensor has demonstrated good results at ranges out to 1 Km and at proximity operation relative velocities, even with the sun in the FOV. The sensor recently demonstrated the following at 10 m: range accuracy to .35% of range (3 sigma); elevation/azimuth accuracy better than 0.01° (3 sigma); and attitude angles of the target to better that 0.15° (3 sigma) using five optical retroreflectors in a 15 cm wide pattern.

Detailed algorithms for automatic rendezvous, closure, and capture have been developed by ESA and CNES for application with Hermes to Columbus rendezvous and docking, and they currently are being verified with closed-loop software simulation. The algorithms have multiple closed-loop control modes and phases starting at long range using GPS navigation. Differential navigation is used for coast/continuous thrust homing, holdpoint acquisition, V - bar hopping, and station point acquisition. The proximity operation sensor is used for final closure and capture. A subset of these algorithms, comprising the proximity operations algorithms, could easily be extracted and tailored to a limited objective closure and capture flight demonstration.

The software to implement the automatic operations has been written in C, and closed loop performance tests are currently in progress. These tests include the software for final approach operations (100m to a few cm), and testing is to be complete by November 1991.

Potential Cooperative Flight Demonstration

Fairchild and Matra suggest that by combining ESA and NASA resources, a complimentary, cost effective flight demonstration program to demonstrate Automated Closure and Capture could readily be structured. This joint, cooperative program would use the automated guidance and proximity operations system developed by Matra for ESA and the existing Explorer Platform (EP) developed by Fairchild for NASA. These two system elements would be integrated by Fairchild with an EP-mounted docking module receiver and a maneuvering payload module (PLM) to close with and dock to the EP receiver.

The proposed program would have Fairchild build the docking module that would be attached on-orbit to the EP (figure 1); build the Payload Module with a maneuvering capability (figure 2) that performs the docking with the the EP-attached docking module, using the Fairchild developed Resupply Interface Mechanism (RIM, figure 3); complete development of the STS procedures for on-orbit EP payload changeout to remove the current EUVE payload and attach the docking module; and accomplish the overall system integration. ESA/Matra would provide the proximity operations sensor; the guidance software; and verify the satisfactory flight hardware closure and capture on the European Proximity Operations (EPOS) simulator and/or on the CNES 6 degree-of-freedom (DOF) Dynamic Docking Test Facility (DDTF) (figure 4). The EPOS simulator allows simulation of final approach (from 25m) with a realistic lighting environment and with large angular and position errors. The DDTF allows simulation of final approach (from 7m) and the subsequent docking dynamics with full representativity in 6 DOF. The test facility is capable of velocities up to 10 cm/sec and contact forces up to 2000 N. This testing would verify the compatibility between the GNC accuracy and the RIM docking interface, enable final tailoring of the software, and verify in real-time the system performance. Final validation of closure and capture would be done at MSFC.

Once in orbit the Shuttle crew would (1) use the RMS to change out the EP payload, removing the EUVE payload from EP and mounting the docking module to EP; (2) use the RMS to release the PLM, at 1000 ±100 meters in trail from the EP and co-altitude ±100 meters; and then (3) supervise the automatic closure and docking to EP. From 1000 meters the closure and docking is the same whether injected by ELV or carried to orbit by the STS. For subsequent missions following injection, the PLM maneuvers to rendezvous with EP (1000± 100 meters in trail and co-altitude ±100 meters) using GPS positioning (receiver on each of EP and PLM) to provide guidance information to the rendezvous algorithms developed by ESA and Matra.

From 1000 m the laser proximity operation sensor acquires EP and provides guidance to the PLM to enable approach to the 100 meter point. From 100 meters in to contact, the proximity sensor provides the continuous positioning required by the payload guidance system to maintain position on target boresight (v-bar) and to control closure velocity to effect a soft (.5 cm/sec) docking.

The program makes maximum use of existing resources within both NASA and ESA, with NASA providing the EP, the docking module and payload module, and the STS launch. ESA would provide the laser sensor, the proximity operating algorithms and software, and support docking system integration on the DDTF.

The benefits of the program would be to (1) validate an automatic rendezvous and capture capability and (2) establish payload module compatibility and use with the existing Explorer Platform (EP) spacecraft. Following the demonstration mission, payload modules would be capable of automatically rendezvousing and docking with the Explorer Platform, following orbit injection by either a Taurus-class ELV or the Shuttle. Spent payload modules would automatically detach from the Explorer Platform and either de-orbit or, if retrieval was desired, adjust their orbit to rendezvous with the Shuttle to be retrieved by the Shuttle RMS.

The docking module (figure 1) is a module, similar to the existing EP Platform Equipment Deck module, that attaches the RIM active interface (docking device, figure 3)) and supporting subsystems to the EP, which becomes the passive, stationary target for the maneuvering payload module.

The payload module (figure 2) is a new development using existing technology to house the laser proximity sensor, power, attitude control, and propulsion subsystems and the RIM passive interface. Subsystems are at Table 1.

Structure **Honeycomb outer shell with internal thrust tube**
Power **NICd Battery** **Body-mounted Solar Array**
Attitude Control **Three axis RIGA** **Fine Sun Sensor** **Magnetometer**
Propulsion **Hydrazine**
Navigation **GPS receiver**
Command & Data **FS386 (NASA RPP derivative**
Communications **5 Kbps transceiver**
Thermal
Harness
RIM - Passive

Table 1 Payload Module Subsystems

Historical Statement on the Origins and Evolution of the Capability

The Explorer Platform spacecraft, built by Fairchild Space, is a derivative of the NASA Multimission Modular Spacecraft. EP has been designed for on-orbit payload changeout, and the first launch is scheduled for December 1991 with the Extreme Ultraviolet Explorer payload. The EUVE Payload, until this summer, was to have been replaced on-orbit in 1994 with the XTE Payload. Historical data from previous MMS flights shows that EP can be expected to last at least nine years with .71 probability. At present, XTE is to fly on a dedicated spacecraft, which permits EP to be used for other missions.

Development of STS on-orbit changeout procedures was accomplished by Fairchild under contract to NASA for the Solar Max repair mission. Fairchild has been under contract to NASA to develop the STS change-out procedures for the current Explorer Platform for the EUVE-XTE changeout mission. These procedures are nearly identical to those that would be required to put a docking module, instead of XTE, onto EP.

The satellite Resupply Interface Mechanism (RIM) (figure 3) was built by Fairchild to provide a means of connecting a satellite tanker to the satellite. It provided for the simultaneous mating of multiple connectors and couplers, and was designed to accept misalignments of up to ±2 inches laterally, and ±10 ° axially. The RIM was demonstrated in 1989 for NASA at JSC to evaluate mating, demating, interface operation and to demonstrate several RMS berthing modes. A small amount of additional development is required to streamline / miniaturize the latching mechanisms.

Source / Sponsorship and current funding estimates

We recommend that NASA and ESA allocate funding to the program as follows

NASA responsibility:
- Explorer Platform
- Docking Module design, development, and test:
- Payload Module design, development, and test:
- Program Management & Systems Engineering
- STS launch and orbit operations

ESA responsibility:
- Laser proximity operations sensor (s)
- Algorithm tailoring for demonstration mission
- Guidance software
- Verification of hardware on EPOS and/or DDTF

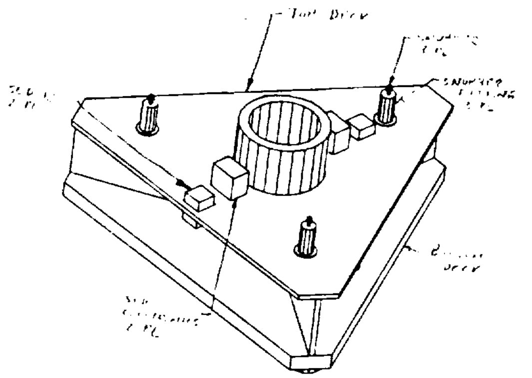

Figure 1 EP-attached Docking Module with RIM Active Interface

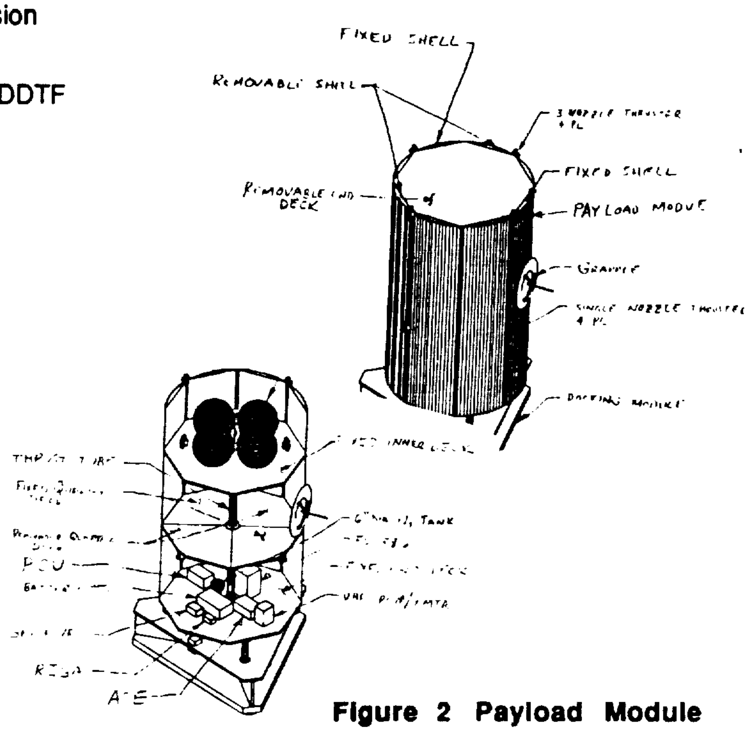

Figure 2 Payload Module

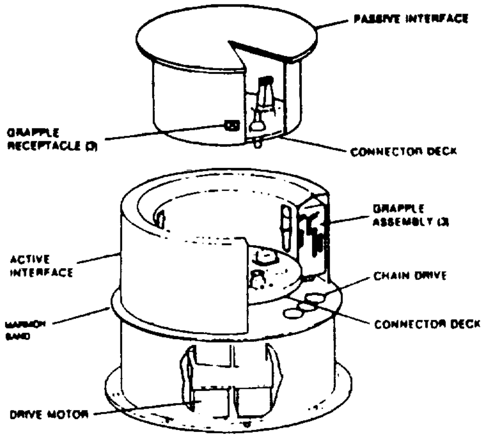

Figure 3 Resupply Interface Mechanism (RIM)

DYNAMIC DOCKING TEST FACILITY

- SIMULATION OF DOCKING OPERATIONS (WITH PROTOTYPE DOCKING MECHANISM)
- EXTENSION FOR SIMULATION OF LAST METERS (WITH PROTOTYPE RV SENSOR)
- MAY BE USED FOR ASSESSMENT OF MANUAL CONTROL DURING LAST METERS.

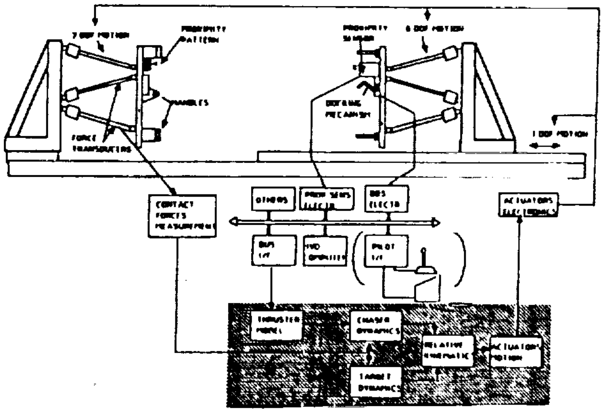

Figure 4 CNES Dynamic Docking Test Facility