

Design and Development Status of ETS-7, an RVD and Space Robot Experiment Satellite

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ABSTRACT

ETS-7 (Engineering Test Satellite #7) is an experimental satellite for the in-orbit experiment of the Rendezvous Docking (RVD) and the space robot (RBT) technologies. ETS-7 is a set of two satellites, a chaser satellite and a target satellite. Both satellites will be launched together by NASDA's H-2 rocket into a low earth orbit. Development of ETS-7 started in 1990. Basic design and EM (Engineering Model) development are in progress now in 1994. The satellite will be launched in mid-1997 and the above in-orbit experiments will be conducted for 1.5 years. Design of ETS-7 RBT experiment system and development status are described in this paper.

MISSION OF ETS-7

Mission Objective of ETS-7

Space development activities of our mankind are evolving since its start. Development of geostationary communication, broadcasting and weather observing satellite is nearing its maturity. It is desired by many people to expand our manned presence in the earth orbit and its beyond such as the Lunar and the Mars. It is also desired to deploy robotic spacecraft as a precursor or as an alternative of the manned presence.

The RVD and RBT technologies are the "must technologies" for the future space activities as above whichever it is manned or unmanned. NASDA has a history of RVD and RBT technology research for more than ten years. These technologies are difficult to fully verify their capability on ground. Therefore, NASDA decided to develop and launch an engineering test satellite called ETS-7 (Engineering Test Satellite #7) to perform the in-orbit experiments of the RVD and RBT technologies. The RVD technology will be applied for the future spacecraft development

such as the HOPE space plane. The RBT technology will be applied for the future robotic servicing spacecraft, lunar/planetary exploration, space station utilization and others.

RBT Experiment Plan

Detail of the ETS-7 robot experiment plan is described in reference [1] and [2]. It is summarized as follows:

- Performance evaluation of the onboard robot subsystem and its equipment such as a robot arm, tool, vision system, orbital replacement unit and others in the actual space environment.
- Experiment of the cooperative satellite attitude and robot arm control.
- Teleoperation experiment of the robot arm from a ground control station. It must be noticed that this experiment is a so-called telerobot experiment and the telemanipulation is just part of the experiments.
- Experiment of the in-orbit satellite servicing such as ORU (Orbital Replacement Unit) exchange, fuel supply (dummy fuel is used) and target satellite handling.
- Some optional advanced experiments such as target satellite capture by the robot arm.
- National Lab's robot technology experiments by MITI/ETL (Electrotechnical Lab), NAL (National Aerospace Lab) and CRL (Communication Research Lab).

RVD Experiment Plan

Detail of the RVD experiments is described in reference [3]. It is summarized as follows:

- In-robot performance evaluation of the newly developed RVD subsystem's components such as GPS receiver (GPSR), Rendezvous Radar (RVR), Proximity Sensor (PXS), Docking Mechanism (DM) and Guidance Control Computer (GCC).
- Experiment of autonomous rendezvous

navigation and control of the chaser satellite toward the target satellite.

- Experiment of autonomous docking operation between the chaser satellite and the target satellite.
- Some optional advanced experiments such as remote piloting of the chaser from a ground control station.

SYSTEM DESIGN OF ETS-7 EXPERIMENT SYSTEM

Mission Requirements

In order to perform the above RVD and RBT experiments using NASDA's limited ground and in-orbit infrastructures, the following major mission requirements are identified:

- ETS-7 should consist of two satellites, a chaser satellite and a target satellite. Both satellites should be launched together by NASDA's H-2 rocket.
- NASDA's experimental data relay satellite called COMETS (Communication Engineering Test Satellite, to be launched in 1997) will be used to communicate with ETS-7 from a ground control station which will be located at NASDA's Tsukuba Space Center.
- Since only one data relay satellite can be used, communication coverage area in the orbit is limited. Therefore ETS-7's RVD system should be an autonomous system which is managed by the onboard guidance and control computer and related RVD sensors.
- ETS-7's RBT system should be a telerobot system whose control functions are shared by an onboard controller and a ground control facility and operator.

Satellite Platform

(1) Satellite Configuration. From the above mission requirements, ETS-7 is a set of two satellites, a chaser satellite and a target satellite. Both satellites will be launched together by NASDA's H-2 rocket in 1997. Launch date (year) was decided to meet the dual launch opportunity with the TRMM (Tropical Rainfall Measurement Mission) satellite which will be developed jointly by NASDA and NASA.

Capability of the H-2 rocket and mass of the TRMM satellite decide the mass of the ETS-7 chaser and the target satellite. Those are approximately 2.2 ton and 0.4 ton, respectively.

(2) Communication System. Communication between the ETS-7 satellite and the ground operation facility will be established using NASDA's experimental data relay satellite called COMETS and NASDA's tracking control network. The chaser satellite has a dish-type antenna for the intersatellite communication. COMETS will be located at 121 degrees east longitude on the geostationary orbit. Communication with the target satellite will be established through the chaser satellite. Since excess communication capability requirements will make it difficult to plan and design future space missions which use RVD and RBT technologies, requirements for the communication system were set to be minimum. Allocations of communication capacity for RVD or RBT experiments (except satellite platform operation) are as follows:

- Command: 1.3 kbps
- Telemetry: 16 kbps
- Video data: 1.2 Mbps
- Round trip time: approximately 4 to 5 s

(3) Attitude Control. Since much electrical power is necessary for the RVD and RBT experiments, the chaser and the target satellite are three-axis-stabilized satellite with deployed solar panels. During the RVD experiments, attitude and position of the chaser satellite are controlled by the RVD system. During the RBT experiments, satellite attitude is maintained by the attitude control system. Attitude control performance requirements during the RBT experiments come mainly from the intersatellite communication. Since robot arm motion will affect the satellite attitude stability, the cooperative control between the satellite attitude controller and the robot arm controller is necessary and will be tested as one of the RBT experiments.

RVD System

The onboard RVD system consists of GPS receiver (GPSR), Rendezvous Radar (RVR), Proximity Sensor (PXS), Docking Mechanism (DM) and Guidance Control Computer (GCC).

GCC will select a proper sensor from the above three sensors to measure relative location of the chaser and the target satellites. Docking of both satellites is so-called "soft docking". Relative velocity of both spacecraft at the docking is about 10 mm/s. Detail of the RVD system is described in the reference [3].

RBT System

Onboard and Ground Functions. ETS-7 is a kind of a telerobot system which includes the ground control system and the onboard control system. Allocation of robot control related functions to the ground control station and the onboard system is as follows:

Functions	Ground Function	Onboard Function
Teleoperation	<ul style="list-style-type: none"> - Generate Teleoperation Commands from Hand Controller Input - Teleoperation support (Real-time CG simulation) - Generate Robot Language Command 	<ul style="list-style-type: none"> - Interpolate Teleoperation Commands - Automatic Path Generation - Generate Arm Path from the Robot Language Commands - Joint Servo Control
Cooperative Control with S/C Attitude	<ul style="list-style-type: none"> - Arm path planning which does not bother satellite attitude motion - Satellite attitude control status check 	<ul style="list-style-type: none"> - Feedforward Compensation of the RBT motion
Vision Data Processing	<ul style="list-style-type: none"> - On-ground Vision Data processing (On-line) 	<ul style="list-style-type: none"> - Onboard Vision Data Processing (On-Line/Off-Line)
Target Satellite Handling	<ul style="list-style-type: none"> - Experiment Planning - Arm path generation 	<ul style="list-style-type: none"> - Rendezvous Control - Docking Mechanism Control - Robot Arm Control

Onboard Robot Subsystem. The onboard robot subsystem is composed of the following equipment: All robot and vision subsystem equipment except RMOC, ADE and VDP are mounted on the +Z panel (Earth-pointing surface) of the ETS-7 satellite. Size of the +Z panel is 2.28 m * 1.85 m. The Earth sensor and other satellite platform equipment such as omni antenna are also mounted on this panel. ETS-7 satellite and the onboard RBT system are shown in Figure 1 and Figure 2.

Onboard Robot Components

(1) Robot Arm

ETS-7 robot arm (ERA) is a 6-degrees-of-freedom manipulator whose length is about 2 m. Each joint is driven by a combination of the DC brushless motor and the harmonic drive gear. ERA has following control modes.

- Joint Position/Rate Control mode
- Cartesian Position/Rate Control mode
- Cartesian Compliance Control mode

(2) Robot arm end effector and tools

ERA has an end effector to handle the ORU. Tools which can be attached to the ERA's end

effector are used for some specific tasks. A taskboard handling tool (TBTL) is used to operate experimental elements on the taskboard. A target satellite handling tool (TSTL) is used to grasp the target satellite by its handle. The hand of the Advance Robot Hand (ARH) experiment system is removable from its miniarm and can be attached to the ERA's end effector.

(3) RMOC/ADE

RMOC (Robot Mission Onboard Controller) is a 32-bit onboard computer which manages onboard robot subsystem. RMOC can perform parallel and distributed processing by 3 set of 32-bit processors which run at 20 MHz. Commands from the ground control station come every 250 ms. Interpolation of these commands into the actual robot arm control commands is done by RMOC. Robot arm joint servo control is managed by ADE (arm drive electronics).

(4) ORU

An experimental ORU (Orbital Replacement Unit) is mounted on the robot experiment platform to be handled by the robot arm. The ORU can be grasped, removed and restored by

the robot arm. The ORU houses a fuel supply experiment subsystem which is to demonstrate mate/demate of a liquid QD (Quick Disconnect) connector and fuel (dummy fuel) transfer.

(5) *Taskboard*

The taskboard is used to evaluate the robot arm performance such as robot arm control performance. The taskboard has many experiment elements such as a Force Torque Sensor Calibration Mechanism, a Peg-in-hole experiment mechanism, small Floating Object, a slide handle and others. A tool called taskboard handling tool (TBTL) is used to handle these experiments. TBTL is stored on the taskboard.

(6) *Vision System*

A pair of AHCs (Arm Hand Camera) which are mounted on the ERA's end effector are used to measure relative attitude/distance between the robot arm and the payloads. A pair of AMC (Arm Monitor Camera) which are mounted on the ERA's first joint are used to monitor the robot arm motion. Both pair of cameras can be used as a stereo camera or a single camera with a backup.

For the robot teleoperation, 2-channel video data can be sent simultaneously to the ground control station. A digital video data compression in the JPEG standard is used to reduce data size. For the onboard robot arm motion planning, video data from the robot arm wrist camera (AHC) can be provided to the onboard robot controller (RMOC) for the onboard video data processing. Video data processing of the target maker will take about 500 ms by RMOC.

(7) *National Lab's equipment.*

Beside the above equipment, following equipment from national laboratories (ETL, NAL, CRL) are mounted on ETS-7 to perform their robot experiments:

- ARH (Advanced Robot Hand experiment system: developed by MITI/ETL)
- AAM (Antenna Assembly experiment Mechanism: developed by CRL)
- TSE (Truss Structure handling Experiment system: developed by NAL)

(Note)

- MITI/ETL: Ministry of International Trade and Industry, Electro Technical laboratory

- NAL: National Aerospace Laboratory
- CRL: Communication Research Laboratory

Ground Segment. ETS-7 related ground operation facilities are all located at the NASDA Tsukuba Space Center. Data relay satellite's ground station will also be located at Tsukuba Space Center.

ETS-7 ground segment of the following elements:

- Data relay satellite (COMETS) ground station
- Satellite tracking and control center
- RVD experiment operation facility
- RBT experiment operation facility
- National Lab's ground operation facility

Figure 3 shows overall ETS-7 experiment system.

DEVELOPMENT STATUS AND FUTURE DEVELOPMENT SCHEDULE

Development Schedule

Development of ETS-7 started in 1990. The conceptual study was done in 1990 and 1991. The preliminary design and BBM development were done in 1992 and 1993. The basic design and EM development are in progress in 1994. Series of PDR (preliminary design review) meetings of ETS-7 Components, subsystem and satellite system are held between June 1994 and October 1994.

Budget for the flight hardware (PFM) production is approved this spring by the Diet and the launch of the satellite is planned in mid-(August/September) 1997. Mission life of the satellite is 1.5 years.

CONCLUSION

This paper summarized design and the current development status of ETS-7. Detail of the ETS-7 mission is described in reference [1] and [3]. Feasibility study result of optional experiments will be presented in other paper of this conference. Development of the ETS-7 satellite is now in the phase C and the satellite will be launched in 1997 by NASDA's H-2 rocket.

REFERENCE

[1] M. Oda et al. "ETS-7, the world first telerobotic satellite (Mission and its design concept)", Proc. of i-SAIRAS'92, Sept. 30-Oct. 2, 1992, Toulouse, France.

[2] M. Oda, "Preliminary design result of ETS-7, a RVD and space robot experiment

satellite", Proc. of ICAR (Intl' conf. of Advanced Robotics), Nov. 1-2, 1993, Tokyo, Japan.

[3] S. Ichikawa, et al. "ETS-7 RVD experiment system, Proc. of EIOOTS (ESA-NPP-059), June 22-24, 1993, ESTEC, the Netherlands.

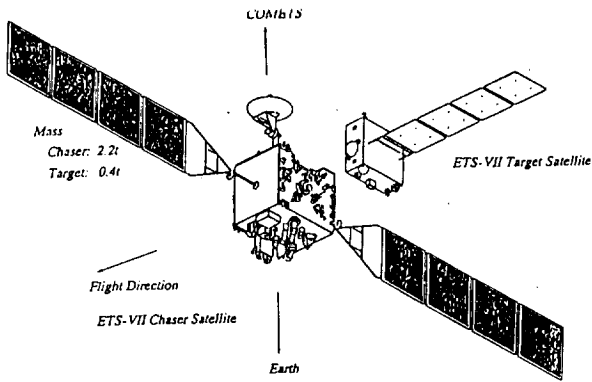


Figure-1 In-orbit Configuration of ETS-7 Chaser and Target Satellite

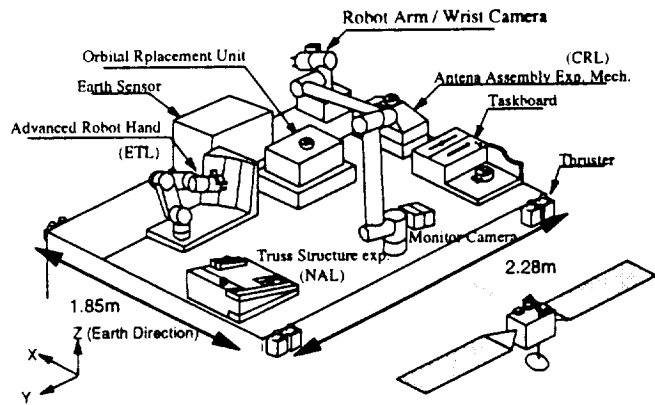


Figure-2 ETS-7 Onboard Robot System

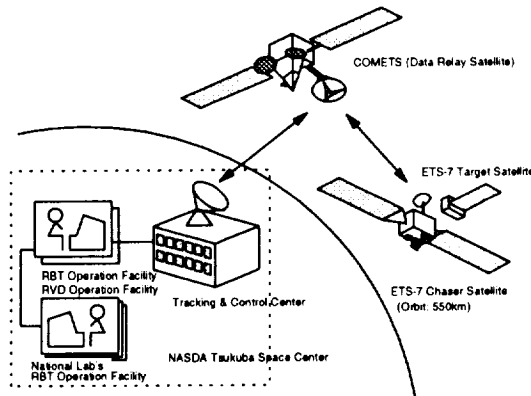


Figure-3 ETS-7 RVD & RBT Experiment System

