Space Truss Handling Experiment on ETS-VII

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1. Introduction

From the mid of 20th century, manned space mission has been major space activity in the world. Space Shuttle makes space so popular and familiar to human beings overcoming several accidents. Unmanned space missions also took place on orbit and Lunar/Planetary exploration program however, these provide more moderate impressions to the world.

There are so many reasons and motivation to utilize space robots, such as on safety, economy and productivity. But the robots are still on the ground and not so developed as its poor performance when it is compared with human's.

The authors understand there is long way to the actual space robot in space, and pay effort to make the technology advanced step by step approach taking chances. This paper reports one of the activities on space robotics research and development in Japan

2. ETS-7 satellite

1) ETS-7 outline

The purpose of ETS-7 (Engineering Test Satellite No.7) is to acquire the basic technologies of rendevous docking and space robotics that are issues to the future space activities such as retrieval, resupply and exchange of equipment on orbit. ETS-7 consists of two satellites named 'Chaser" and "Target". (Fig 1) Both satellites was launched by NASDA's H-2 Rocket form Tanegashima Space Center in November 1997. After lunched into the low earth orbit (Altitude 550km), the Chaser will release the Target satellite and will conduct rendevous docking experiments with the Target satellite automatically and by remotely piloted form the ground. Chaser satellite will conduct the space experiments by using the robot arm and various experimental test beds prepared by NASDA and national laboratories. (Fig 2) These experiments are conducted via data relay satellite to study integrated on orbit capability. ETS-7 major characteristics are below;

Configuration:
Chaser satellite: 2.6mX2.3mX2m, Box shape
Solar array paddle for Chaser: 1.8mX20m
Target satellite: 0.65X1.7mX1.5m, Box shape
Solar array paddle for Target: 1.15mX6.6m
Weight (Launched):
2860kg (Chaser: 2450kg, Target: 410kg)
Electrical power (EOL, β=35deg):
Chaser: 2360W, Target: 650W
Design life (expected):
2.5 year
Launch site: Yoshinobu launch site in Tanegashima Space Center, NASDA
Orbit: Altitude 550km, Inclination 35deg

2) Space robot Experiment on ETS-7 (Fig 3)

The robotic experiment on ETS-7 was designed to execute space task experiment for the future space robot utilization to the advanced space activities such as tele-science experiment on the International Space Station (ISS, Fig 4), on-orbit satellite service and unmanned lunar/planetary exploration. The robotic arm on Chaser has 6degree-of-freedom and maximum reach is 2m, and is tele-operated form the ground control facilities.

ETS-7 is conducting the following space robotic experiment form early 1998.

1) Coordinated control of spacecraft attitude and robot arm to maintain satellite attitude stability against robot arm's reaction
2) Tele-operation of satellite mounted robotic arm from the ground facilities under space communication system with 5 to 7 seconds time delay environments.
3) On-orbit satellite servicing experiments, such as the visual inspection, handling the ORU (Orbital Replacement Unit), fuel tank transfer, gripping finger and hand operation using special fixture, etc.
4) National laboratories' space robot experiments
   - Advanced robotic hand experiment by MITI/ETL (Ministry of International Trade and Industry / ElectroTechnical Laboratory)
   - Antenna Assembling Mechanism experiment by CRL (Communications Research Laboratory)
   - Truss structure handling experiments by NAL (National Aerospace Laboratory)

3) Robotic arm

The robotic arm on Chaser is the second arm that is actually in space following the first experiment, MFD (Manipulator Flight Demonstration[1]) in 1997, on NASA's Space Shuttle. The arm's performance is designed as below;

Tip position accuracy):
 10mm, 1.0deg (absolute), 5mm, 1.3deg (repetitive)
Tip velocity: 50mm/sec (MAX), 5deg/sec (MAX)
Tip force and torque: 90N, 20Nm
Handling mass: 500kg (MAX)
Weight of the arm: 160kg (including CCD cameras)

The arm is operated by 4Hz command signals from the ground sent in two modes, non-synchronous and synchronous. At the beginning stage for the robotic experiments, non-synchronous mode only was used as space communication problem however, from early 1999 synchronous mode has began to work introducing new on-board arm control software and up-loading it to Chaser. The synchronous mode operation using such as hand controller and joy sticks is now working for supplying us the vital technical data of space tele-operation.
The JEM (Japanese Experiment Module) on the ISS will be facilitated with the same specified tele-robotic arm with ETS-7 and will use the arm for components handling works on the JEM's exposed section supporting astronaut's EVA (Extra-Vehicular Activity) or execute his work instead.

4. TSE(Truss Structure handling Experiment) mission outline

1) On-board truss experimental structure2)

The structure is facilitated experimental components (Fig 5,6) as follows.

- Deployable truss structure: One segment of Deployable Truss Beam (Fig 7) studied for ISS main truss structure application with 10dof and one GPF (GraPple Fixture, Fig 8,9) was set on the side of the box type main structure
- Assemble truss structure: An original truss joint mechanism3) for space truss was introduced slightly changed for ETS-7 arm operation. The mechanism can be operated one-handed action for connect and disconnect each other.
- Launch lock mechanism: In order to make the truss structure/mechanism survive under severe environments on acoustics and vibration, every components and parts were set in stable to the main box structure. The mechanism is operated to release the lock by the arm on orbit. (Fig 10)
- Targets marks for vision system: CCD cameras for robot vision system measures the arm position and posture relative to the truss structure. (Fig 11)
- Millar: To confirm the arm action visually on the ground, a small miller is attached on the box to see arm finger insertion into GPF.
- Electric sensors and heater: Micro-switches and rotation potentiometers were set to sense the truss mechanism movement status. Small heaters less then few watts were fixed inside the box to make mechanism workable temperature higher than 0deg-C.

2) Missions of experiment

- Launch lock releasing

At TSE experiments started from releasing the launch lock mechanism using the arm. (Fig Launch lock mechanism) GPF on the top of the box must be twisted enough with enough torque. Releasing sequence has several stages and each is composed of links and springs. If the sequence did not work and terminated its action in mid way, there were rescue process using finger device on the satellite. Fortunately the mechanism has worked successfully in a second and NAL experiments started without any problems.

- Deployable truss handling

To deploy the truss, the arm's tip trajectory forms 3 dimensional curve, over notch mechanism for sable truss stow and trough singular point located just before its deployed configuration. Fine-force control applied to the truss is major research issue for the NAL mission, and several force control systems are tested.

- Assembly truss operation

Arm trajectory for the assembly truss is in 2 dimensional and simpler than the deployable however, its process for joining task is more difficult for the arm. (Fig 12) Several arm control modes including human participation from the ground are needed for its operation to complete it. Though the mechanism operation, data that show the necessity of tele-operation mode is vital for reliable space robotic work and an intelligent autonomous robot might not work enough for its limited flexibility and knowledge, were obtained.

5. Ground facilities for operation

Ground facilities for the experiment were set at Tsukuba Space Center, NASDA. Communication between satellite and the ground facilities takes long way from satellite trough NASA's TDRS (Tracking and Data Relay Satellite) location on Hawaii, ground station at New Mexico, and GSFC/NASA (Goddard Space Flight Center). In Tsukuba Japan, NAL's ground facility is used connected with NASDA's robot operation facility. (Fig 13)
NAL's facility is composed from independent functions as below: (Fig14)

1) Communication interface with NASDA's robot operation facility and supervisory control all the components of the facility.
2) Human operator interface for data and status display and creating the command sequence.
3) Vision data processing to find the targets for the system and measure the arm position and posture.
4) Graphic simulator for orbital works and arm action. (Fig 15)
5) Operation managing for SOP (Sequence Of

Procedure) editing and log data recording.

6) Hardware simulator for operation training and safety check for space mission preparation. (Fig 16)

6 Experiments

As ETS-7 fly around the earth in 100 min., 20 to 30 min. is allowed to each robot experiment. "Pass" is the unit for counting experiments. For NAL experiments, 28deys are prepared in total and each day has 2 or 3 passes. Now experiment schedule is at mid of it and experiment window is offered once a month. (Fig 17,18)

7. Conclusions

NAL's TSE mission was outlined. The truss experiment facilities were detailed and experiment operation status was reported. A brief discussion on robotic technology applying to the future space structure construction took place on robot control. More details on the experiment should be reported in the near future to utilize the ISS as the test bed for tele-robotic construction technology development.

8. Acknowledgements

The authors would like to acknowledge Dr. Minoru Oda, ETS-7 project leader of NASDA, and his team members for their effort on cooperative space experiment development and operation from 1993. For the software development of NAL's ground facilities, engineers from Mitsubishi Electric Company Ltd. could offer fine technical support.

The truss development and experiment operation support for NAL's experiments are carried out by Shimizu Corporation under contract with NAL.

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2) K. Matsumoto et al., "Development of Truss Structure Teleoperation Experiment by ETS-7 Robot", Proc.of International Symposium on Artificial Intelligence, Robotics and Automation in Space, 1997
3) W. Wendel, T. Yoshida et al., "Truss Joint System for Space Structures", Proc. Of 16th International Symposium on Space Technology and Science, Sapporo Japan, 1988

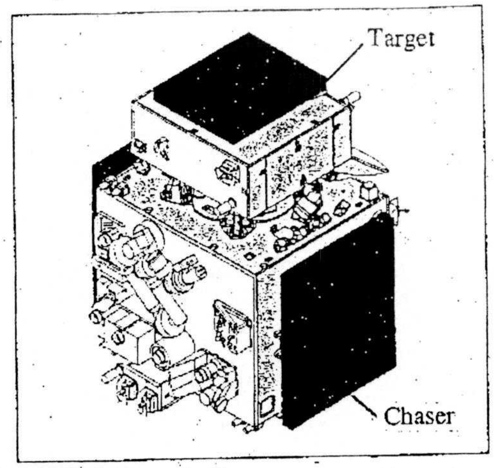

Fig 1 ETS-7 (Launched)

Fig 2 ETS-7, Robot arm & Experiment Equipment

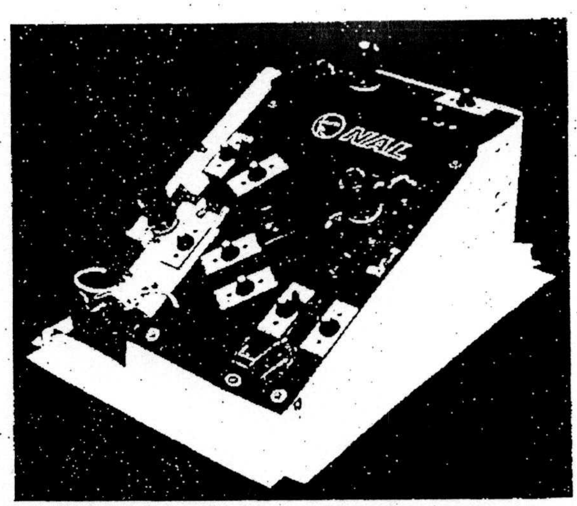

Fig 5 Truss structure (Stowed)

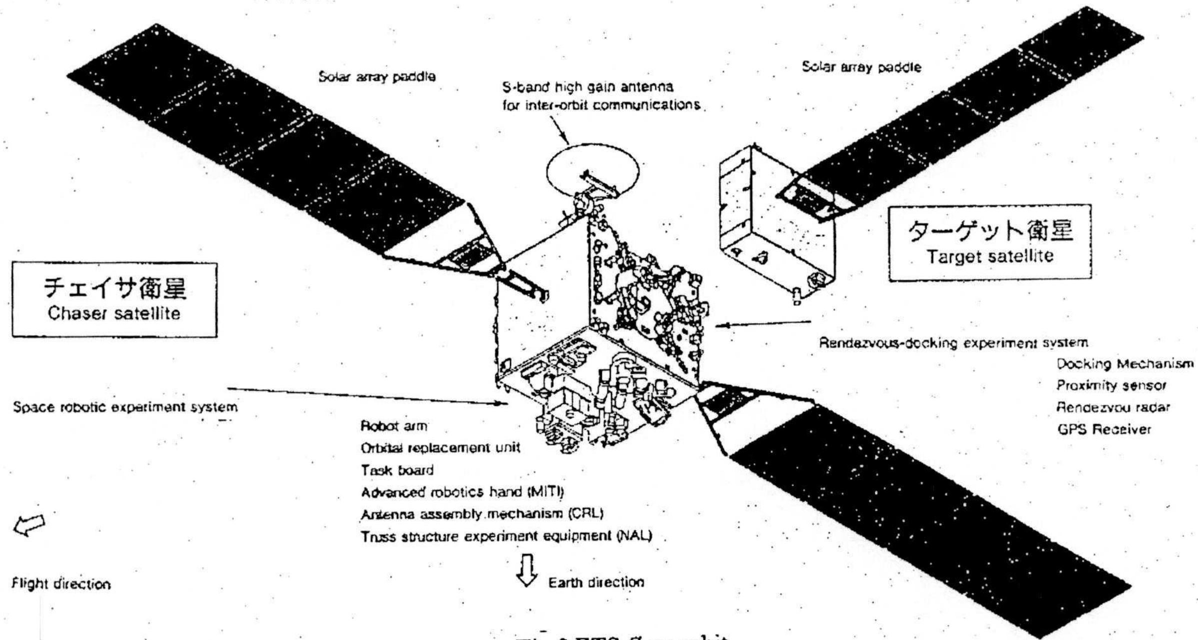

Fig 3 ETS-7 on orbit

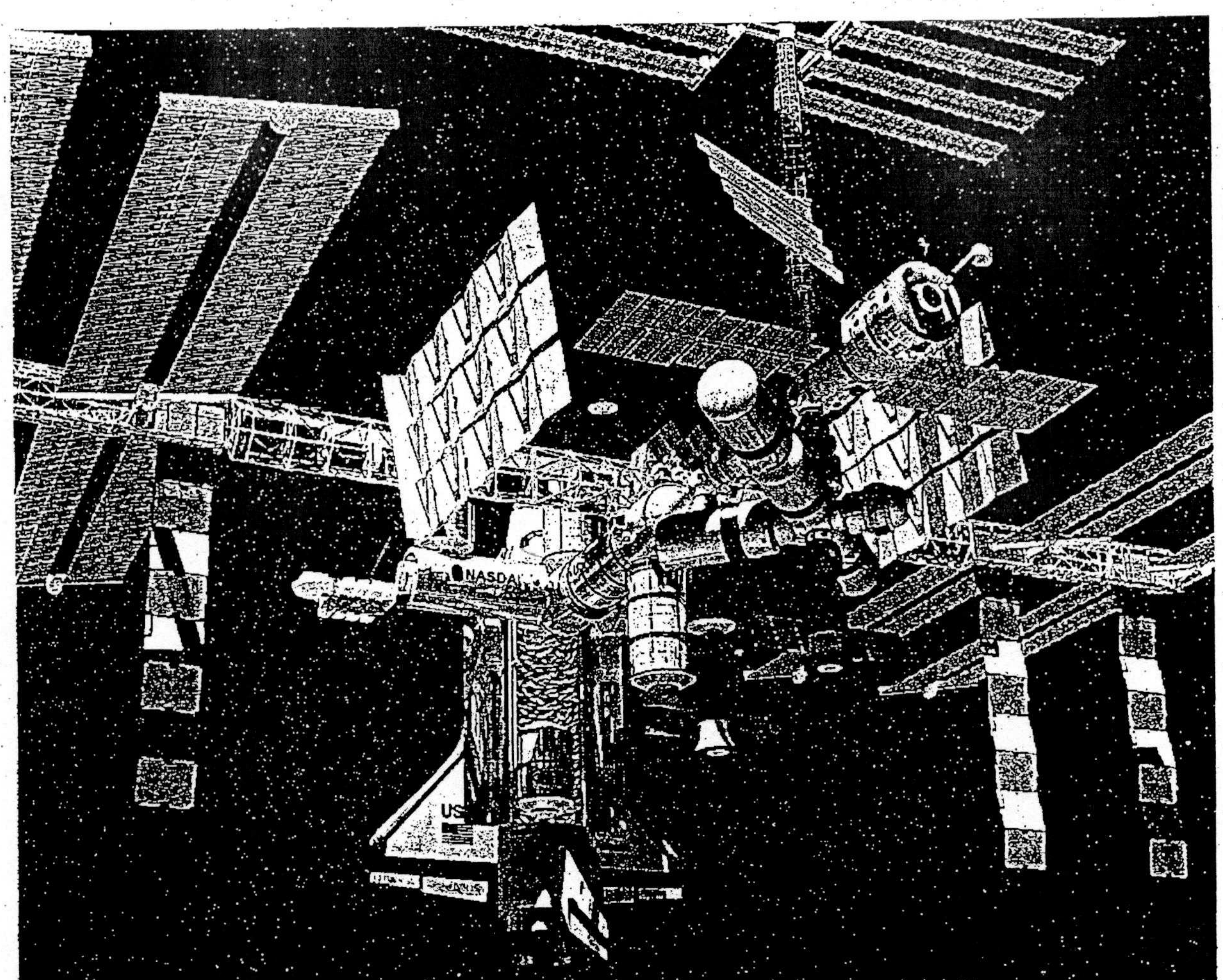

Fig 4 International Space Station

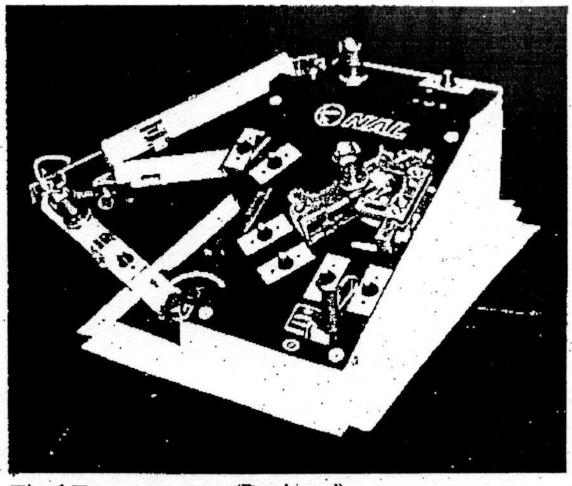

Fig 6 Truss structure (Deployed)

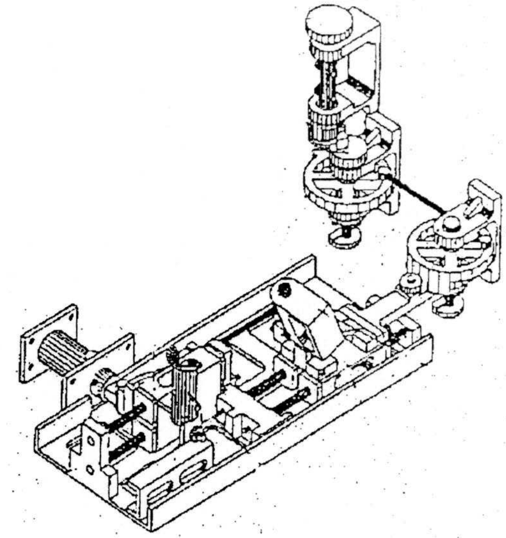

Fig 10 Launch lock mechanism

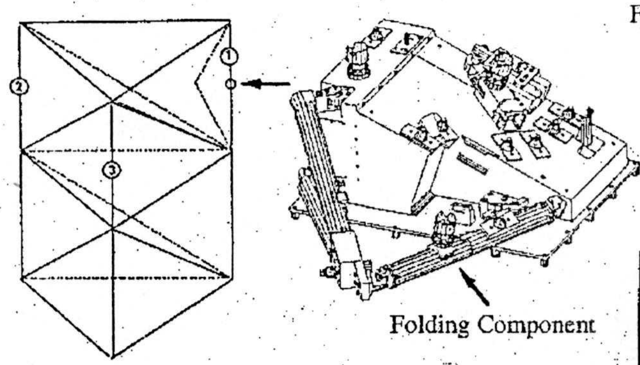

Fig 7 Deployable truss beam

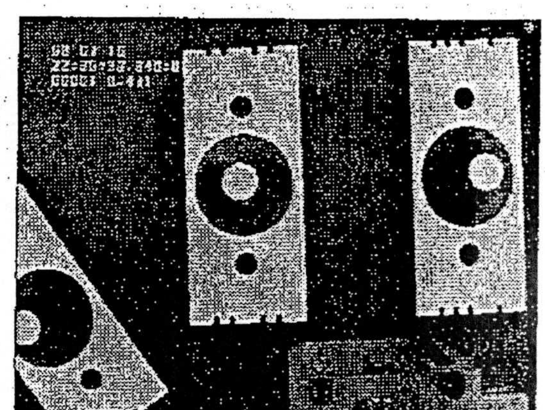

Fig 11 CCD camera views target mark

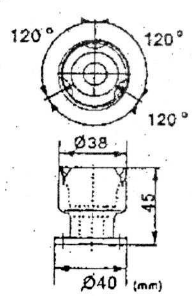

Fig 8 GPF for NAL mission

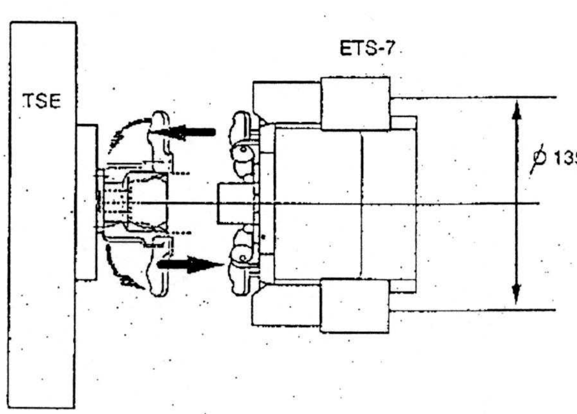

Fig 9 Robot arm gripping GPF

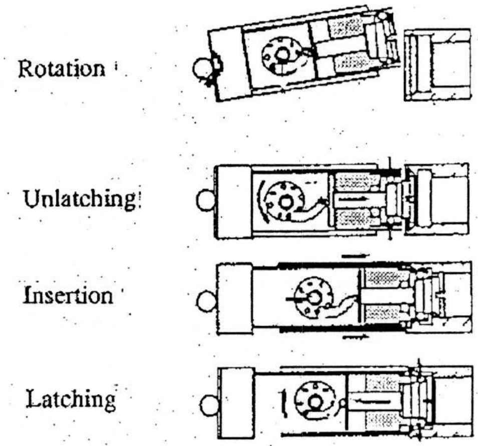

Fig 12 Assembly truss operation

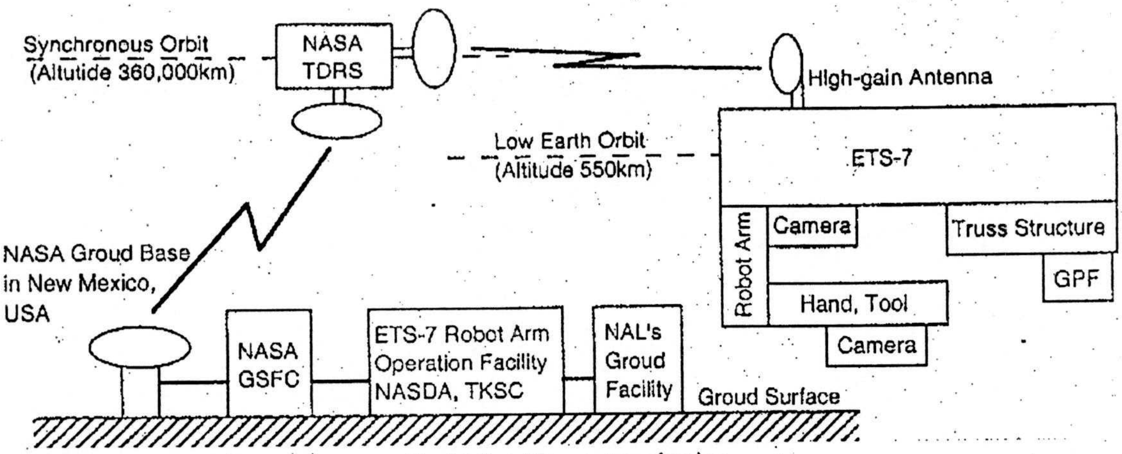

Fig 13 Satellite communication

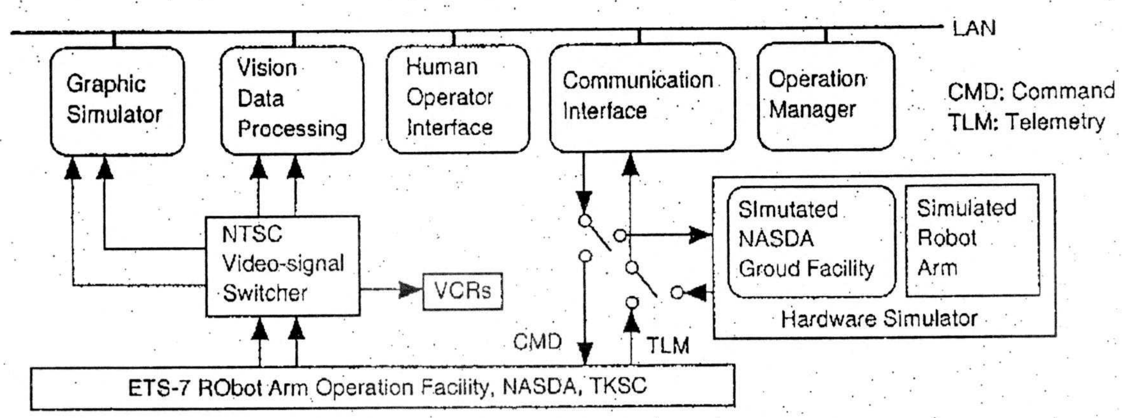

Fig 14 NAL's ground facility

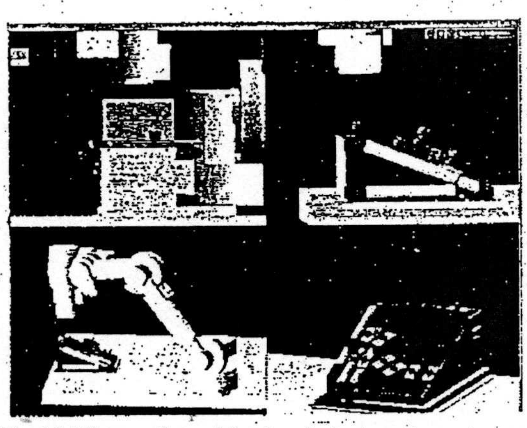

Fig 15 Views of graphic simulation

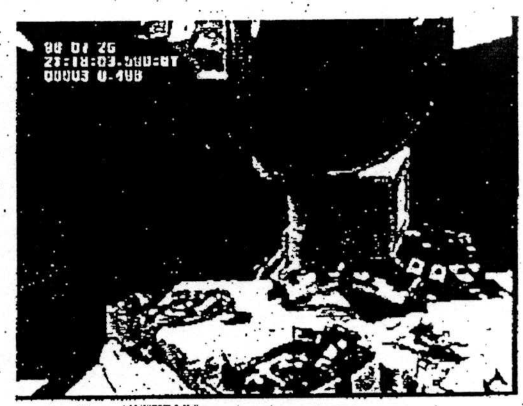

Fig 17 Monitor camera view on orbit

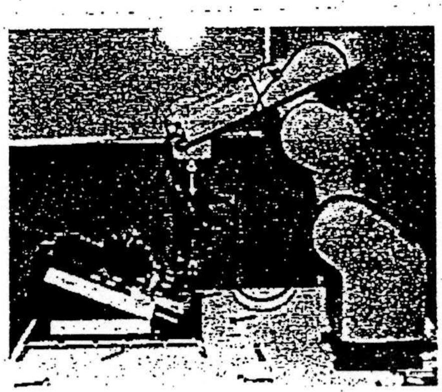

Fig 16 Hardware simulator

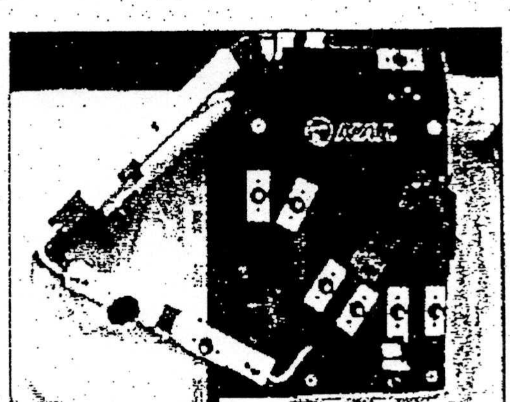

Fig 18 Hand eye camera view for NAL truss