On-orbit Satellite Servicing

"Status and Strategy of Japan"

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Mitsushige Oda Prof. PhD

- Joined NASDA (now JAXA) in 1977
- Control system engineer
- Involved in R&D of space robotics for more than 25 years.
- Principal Investigator of the ETS-VII and REX-J robot missions
- Received AIAA Automation and Robotics Award in 2011

Contents

What is On-Orbit Satellite Service ?

- On-Orbit Satellite Service will support to accomplish / resume / maintain / finish preplanned mission of customer's satellite(s) such as;
  - Logistics support (refuel, supply coolant / consumables)
  - Rescue from stranded situation (trouble in deploying antenna, solar paddle, etc.)
  - Mitigation of orbital debris (replace from orbit)
  - On-orbit assembly / maintenance of large space platform such as ISS and SSPS

Satellite Servicing and needed technologies

(to healthy satellites)

- Maintenance of satellite
  - Re- fuel, coolant, consumables to extend life of sat.
  - Exchange equipment (limited life equipment)
- Orbit change
  - Re-use a satellite / orbit
  - Salvage from stranded orbit
  - Removing from orbit not to disturb other satellite's operation
- Building and Maintenance of large satellite such as SSPS

< Needed technology>

- Rendezvous docking / berthing
- Re-fuelling
- Exchange Equipment
- Autonomous assembly, maintenance of SSPS

Satellite Servicing and needed technologies

(SS to unhealthy satellites)

Difficult ↓

- Inspection, monitor
- Recovery from trouble (such as loss of attitude stability)
- Remove from mission orbit
  - de-orbit, move to the grave yard orbit
- Repair

(Needed Technology)

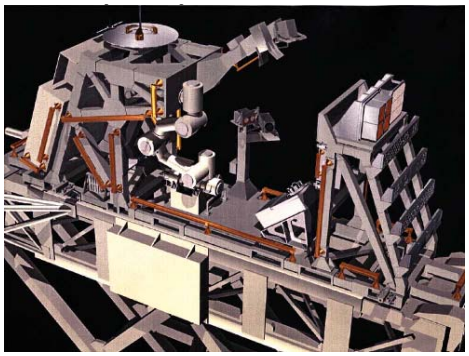
- Rendezvous and Capture non-cooperative satellite
- Dexterous manipulation to Repair

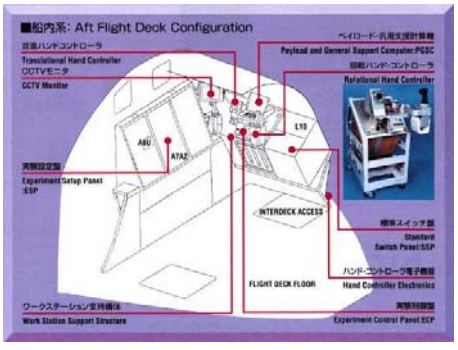
Missions Conducted by JAXA

- JAXA conducted following missions and acquired technologies which can be applied to the on-orbit servicing.
  - MFD (Manipulator Flight Demonstration) in Aug. 1997
  - ETS-VII (Engineering Test satellite 7) in Nov. 1997
  - JEMRMS (RMS of the Japanese Experiment Module, ISS)
  - HTV (ISS logistics support vehicle)in Sept. 2009, Jan. 2011, July 2012

Mission Conducted
MFD (Manipulator Flight Demonstration)

- Mission
  - Verify design of the Japan's first space oriented manipulator (JEM-RMS)
  - Conducted on the space shuttle cargo bay in Aug.1997.
  - Proto-type model of the JEMRMS small fine arm was tested on the cargo bay of the space shuttle. Onboard crew controlled MFD robot arm from the after cockpit of the





ETS-VII (Engineering Test Satellite 7)

- Mission of ETS-VII
  - Demonstrate the automated Rendezvous Docking between the two unmanned satellites.
  - Demonstrate the satellite mounted robot System and its utilization. (Satellite Servicing)
- System
  - Chaser satellite (HIKOBOSHI) 2.5 t
  - Target satellite (ORIHIME) 0.4t
- Launched by H-II in Nov. 1997
  - Orbit 550km alt. incl. 35 deg.

HIKOBOSHI(Boy) is the star "Altair" and ORIHIME(Girl) is the VEGA. These tow stars are high in the night sky in late summer. However these two stars are separated by the Milky way. They are alowed to meet each other once a year on 7th of July.

Rendezvous Docking Experiments on ETS-7

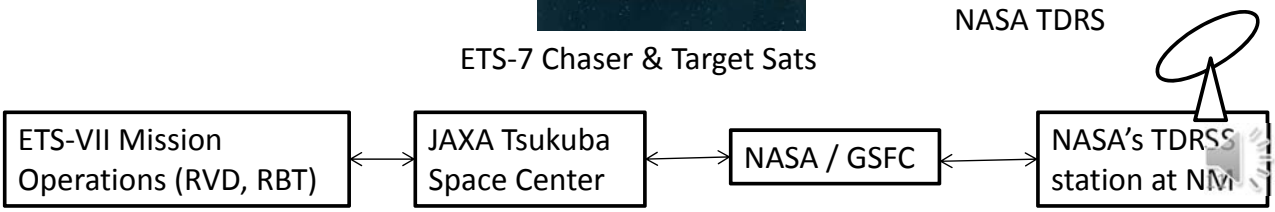
- Automated Rendezvous Docking
  - GPS-R (long distance), Laser Radar (medium range) navigation
  - Proximity (video) sensor based relative position and pose control
  - Low impact docking based on capture berthing mechanism
- These technologies were applied to the HTV, JAXA's logistic support vehicle to the ISS.

ETS-VII's Robot mission

- Demonstration of the Satellite Mounted Space Tele-Robotics System.
  - Tele-operation from the ground station using a data relay satellite in GEO. (NASA's TDRSS was used on contract)
    - Time Delay : 6 to 7 seconds.
  - Coordinated Control of the Satellite Platform and the Satellite Mounted Robot Arm to avoid loss of attitude stability of the satellite platform

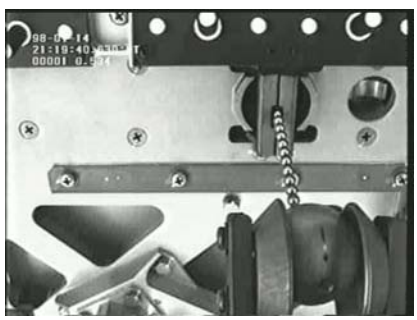
ETS-7 Chaser & Target Sats

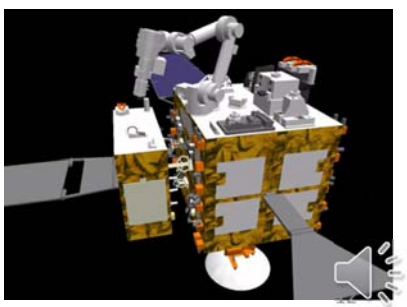
NASA TDRS



ETS-VII's Satellite Servicing Demonstration

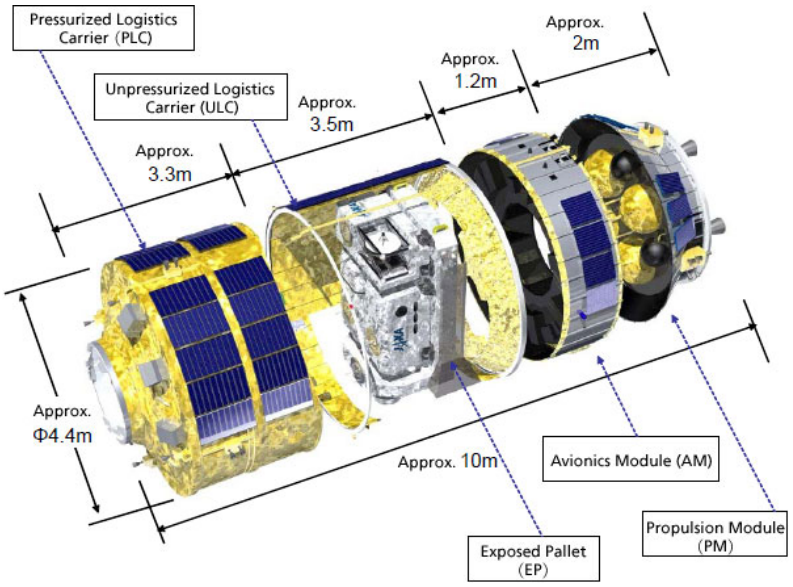
- Tele-operation of the onboard robot arm under the supervised and the tele-manipulation mode.
- Demonstration of Satellite Servicing Tasks.
  - Handling of ORU (Orbital Replacement Unit)
  - Fuel supply experiment
  - Use of add-on tools (for dedicate tasks, for satellite capture) <Left Photo>
  - Handling dedicate equipment (push button switch, slide lever, peg-in, capture a floating ball, truss structure, etc.) (photo Center)
  - Capture the target satellite by the onboard robot arm. (Photo Right)





HTV

(H2 Transfer Vehicle to carry ISS's logistics)



- total payload = 6 ton
- Total mass incl. P/L : 16.5 ton
- Use of CBM (Common Berthing Mechanism) allow carrying large payload into the ISS's cabin
- Can carry large exposed equipment
- Launched by H-IIB rocket
  - HTV-1: 2009.9
  - HTV-2: 2011.1.22
  - HTV-3: 2012.7.21

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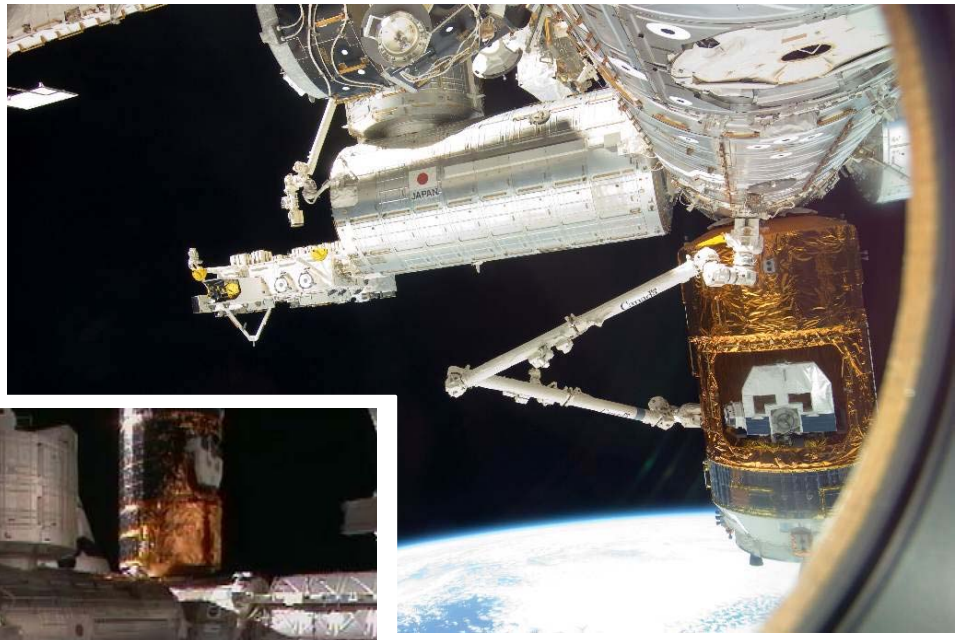

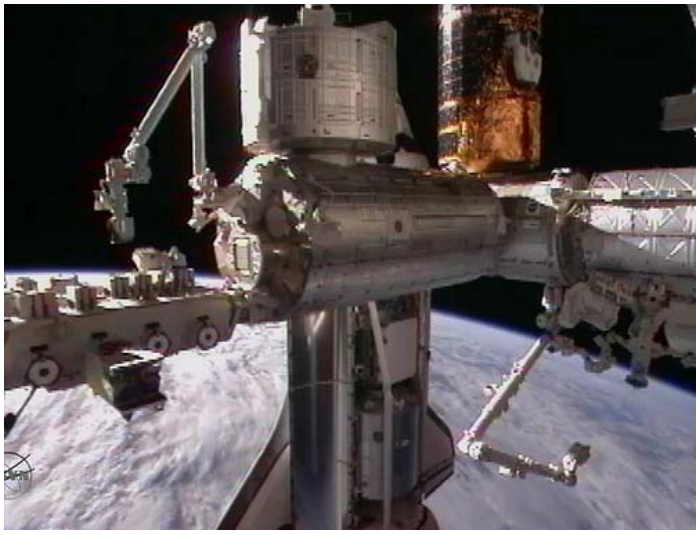

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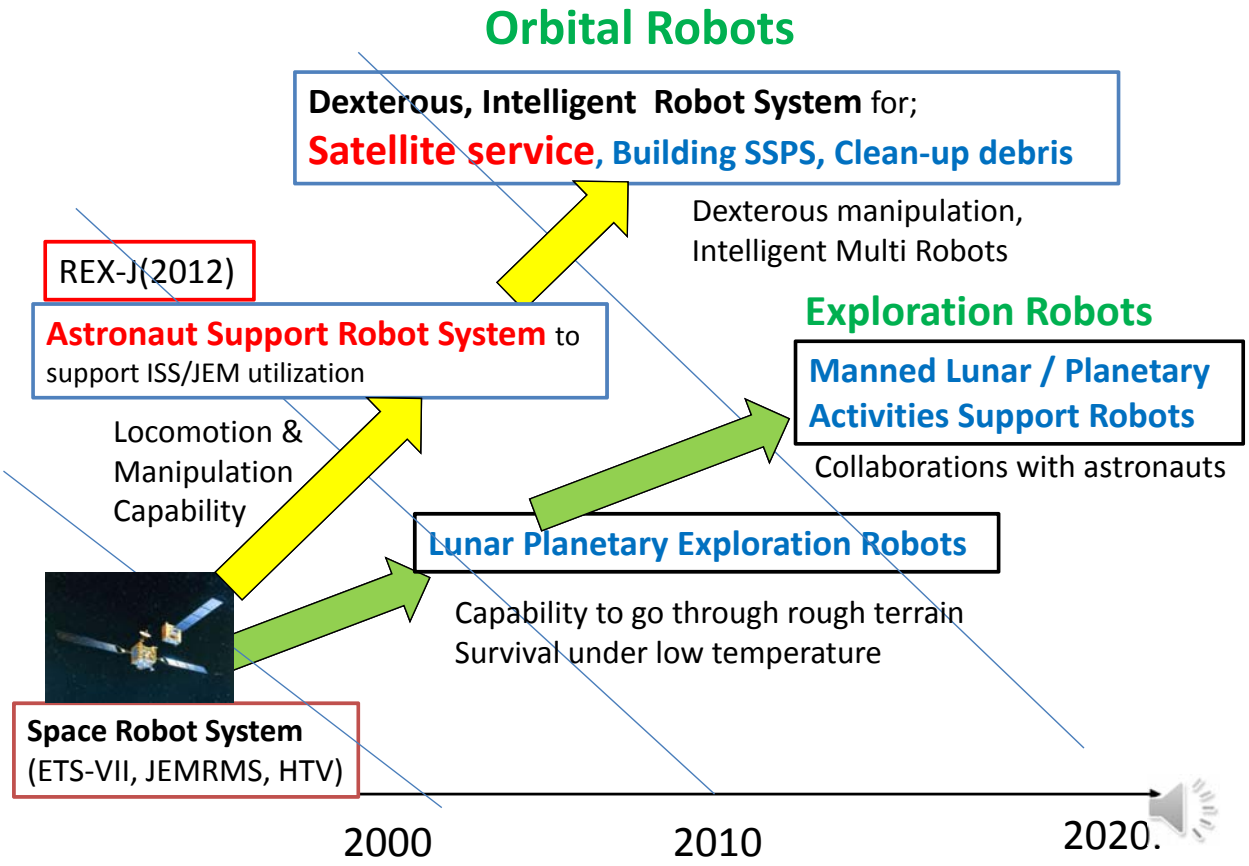
Future Space Robots

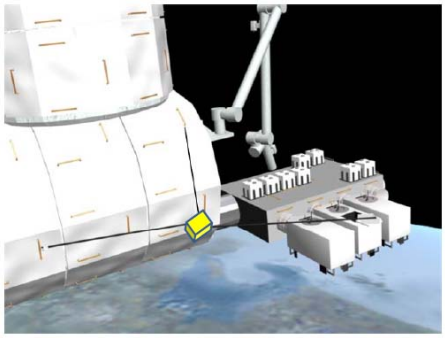
- Several types of space robots are needed.
  - Orbital robots for SS
  - Astronaut support robot to be used with astronauts / instead of astronauts on ISS
  - Exploration robots for moon / planet exploration
- Astronaut Support Robots will be highly needed to utilize ISS.
  - Number of astronauts is limited.
  - Lowering the operation cost of ISS is required
  - Use of robots to save astronauts work hours will be welcomed.
  - NASA's Robonaut is one of the Astronaut Support Robot
- Space robot road map of JAXA

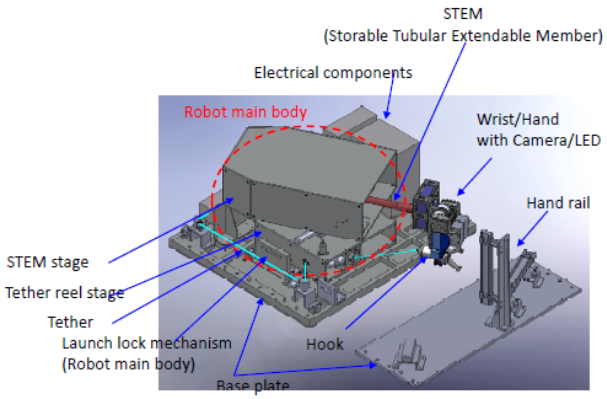
JAXA's Space Robotics Road Map



REX-J (Robot Experiment on JEM)

- Mission
  - Develop and demonstrate the tether based space robot's locomotion capability
    - Locomotion capability to move along surface of the ISS is important to conduct such as inspection of damages caused by space debris, building ultra large space facility such as SSPS
    - Manipulation capability to handle some mechanism like an astronaut
  - Experiments
    - To be launched by HTV-3 in July, 2012 and will be attached to the Exposed Platform.



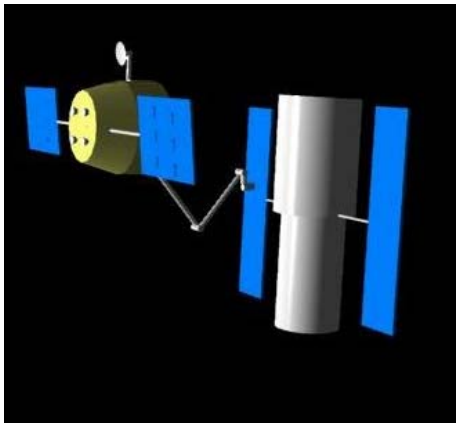


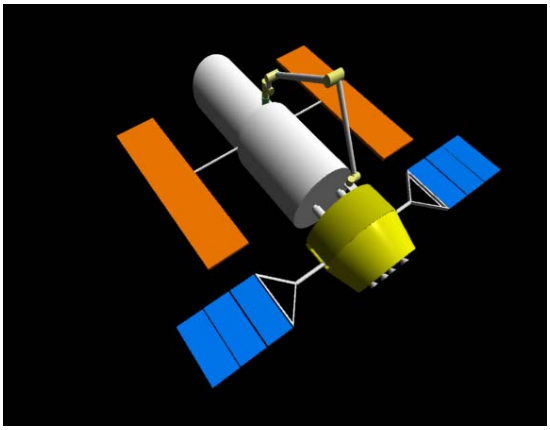
Study of Satellite Servicing Robot

- Mission
  - Inspecting the target satellite
  - Rendezvous and capture target satellite
  - **Resume / start functioning** of abandoned satellite.
    - Help deploying antenna, solar cell panels
    - Replace malfunctioned equipment
  - **Remove from useful orbit** such as LEO, GEO, PEO
    - Rendezvous with the TS, attach **Electrodynamic Tether** (EDT) and Lower the altitude of the TS.
- Challenge (Technical)
  - Rendezvous and Capture of non-cooperative target
- Challenge (Cost, Economy, Obligation)

HST Service Vehicle

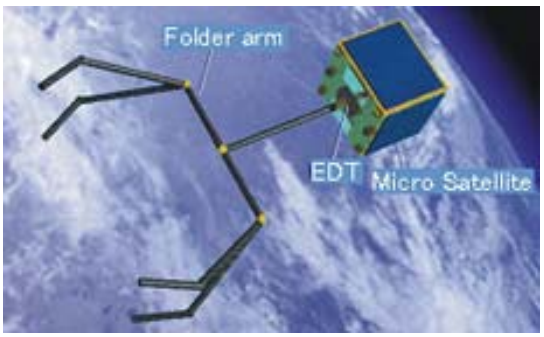
- Based on AO issued by NASA, HST service vehicle to capture and de-orbit HST was studied.
- Based on HTV to rendezvous with HST and de-orbit HST, JEMRMS to capture HST, and ETS-VII to berth HTV.
- I believe this solution would be possible if the HST is functioning. However, if HST lost control, mission would be very difficult.



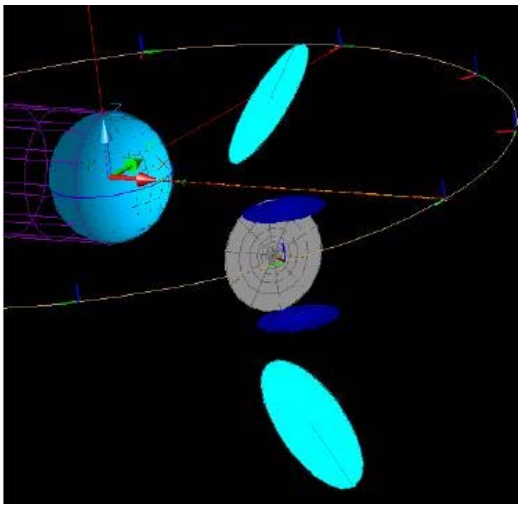


Mitigation of Space Debris

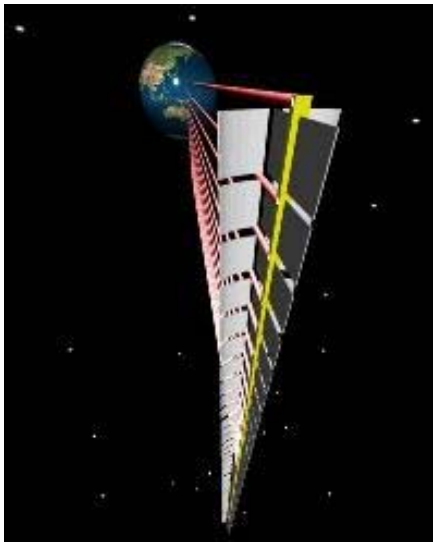
- Mission
  - Capture and remove from orbit
- Method
  - Attach Electro Dynamic Tether and decrease altitude using Lorentz force



Building and Maintenance of SSPS



Microwave based SSPS
(M-SSPS)



Laser based SSPS
(L-SSPS)

Hurdle before realizing SS

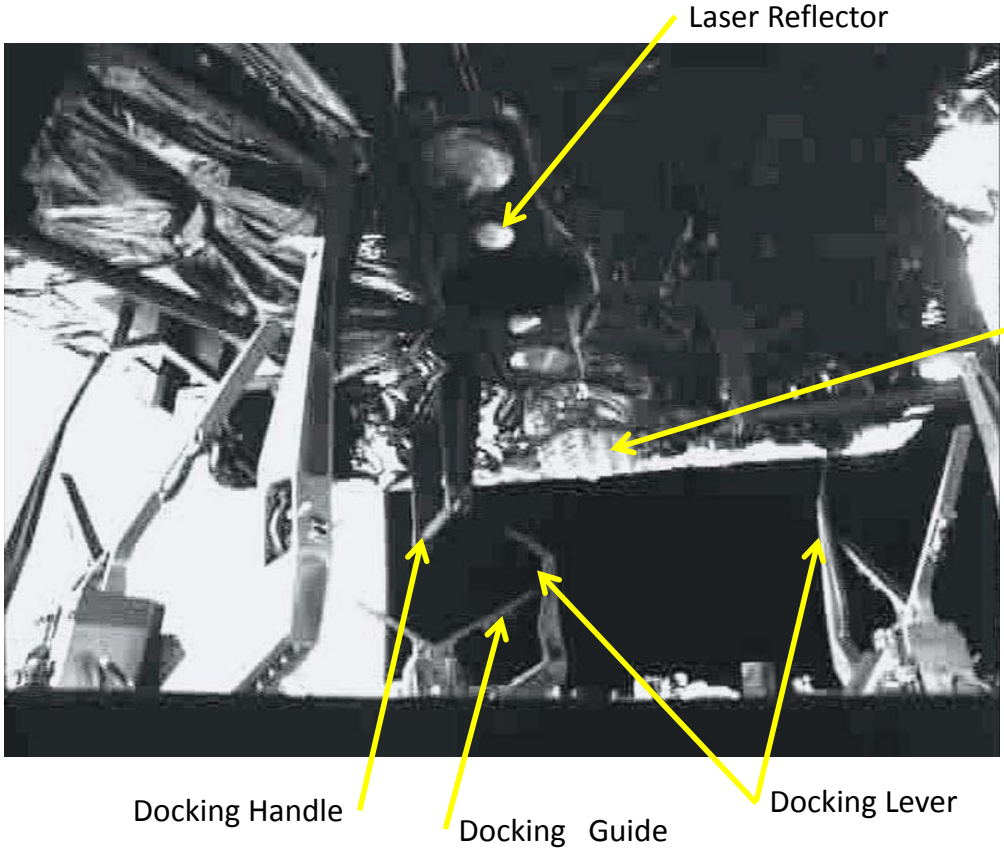
- Technical hurdle - - - - Medium
  - Technically Possible to define a solution
- Economical hurdle - - - High
  - Servicing a single satellite by a single servicer demands full cost to be paid by a single customer
  - Servicing many customer by a single servicer might be economically feasible.

Conclusions

- Technologies needed to realize the Satellite Servicing are maturing.
- Economical feasibility is also progressing.
  - Logistic support of ISS is maturing
  - Relocating used satellite from GEO
  - In-orbit maintenance (Inspection, refuel, orbit change
  - Assembling large space facility using robots

BACK UP

ETS-VII's Capture Berthing



- REX-J experiment system consists of ;
  - robot main body suspended by three tethers
  - One extendable STEM based extendable robot arm (Two fingered hand is attached at the end of the robot arm
  - The extendable root arm can manipulate a tether hook attached to the 4th tethers.
  - Robot supported 4th tether will modify the robot's locomotion area.