On-Orbit Servicing (OOS) & Its Impact On Design, Operations & Efficiency of Future Space Infrastructure

Session 1.2
"Orbital Robotics I - Applications"

by
J. Kreisel
JKIC - Germany

Abstract [Corrected Version vs. Proceedings]

- OOS and its issues gained significant momentum in recent years. Besides technology-oriented projects recently also associated potential economic implications are focus of numerous activities. Various space agencies emphasize on OOS and first commercial endeavors attempt to service satellites. In light of long-term space activities and limited space budgets also on-orbit assembly (OIA) is currently investigated as potential path towards an increased efficiency of space projects. Space automation and robotics, respectively autonomous technical capabilities, as part of an integrated space infrastructure, represent a key element for new approaches in public and private future space projects.

- This paper focuses on selected system engineering and in particular non-technical issues and potential paradigm shifts based on the implementation of on-orbit servicing and associated logistics.

- Background of the findings presented are several studies funded by DLR and other investigations conducted by the author and an international team of partners. Furthermore relevant results of the dedicated workshops "OOS 2002 - Defining A Way Forward" and "OOS 2004 - Developing A Roadmap" are presented.

- The objective is to provide the audience with new perspectives taking into account markets, economics and other factors (e.g. policy, regulations, etc).
On-Orbit Servicing (OOS)

- Fix Problems
- Upgrade Systems
- Increase Mission Flexibility
- Enable for New Missions

- Launch Vehicles
- Service Vehicles (Bus, P/L, …)
- Targets (Sats, Stations…)
- A&R Technology
- Logistics
- Platforms
- Supplies
- …

On-Orbit Assembly (OOA)?

OOS 2002 Workshop Results

52 Participants from 11 Countries

Vision

Sound A&R Base

Immediate Actions!

Teams

0-5
- "OOS Policy & Budget Line"
- Intl. Agency Coordination & Collaboration
- ISS-Related OOS Technology Development Roadmap

3-10
- Paradigm Shift to Infrastructure Availability

10-15
- Large Space Infrastructure Assembly

15-20
- Orbital Supply Platforms

Industry

- Development of Commercial Cases
- OOS Demonstration
- "Maintenance" (US)
- "De-Orbiting" (ORC)

Legal/Reg Bodies

- Frequency Band for OOS

Goverments

- "OOS Policy & Budget Line"
- Intl. Agency Coordination & Collaboration
- ISS-Related OOS Technology Development Roadmap

- Creation of Partnership
- "OOS 6P"
- Sat Mops
- Other Agencies
- 1st Generation OOS Business

- Satellite Disposal & Debris
Space Missions & Systems

Traditional Approach

Space Transportation

Assembly

Basic Functions

Functionality

Ground System

Launchers

On-Ground/-Orbit, Auton./Astr.

Bus/Subsystems/Components

Payload

Operations

Potential Impact of OOS?

Satellite Failures

A. Ellery & JKIC - 2004

“Life Extension & Upgrade”, “Modular Concepts” etc?

GEO Telco Sats = Most Assessable/Mature Class

- Today:
  - MEUR 1,000 Insurance Claims p.a. (50% In-Orbit Failures)
- 1990-1995:
  - 25% In-Orbit Failures (GEO) of MEUR 540 Total Cost (75% Launch)
- 1996-2003:
  - 66% In-Orbit Failures (GEO) of MEUR 5,000 Total Cost (34% Launch)
- Failure Breakdown:
  - App 40% Power, 20% AOCs, 20% P/L, 20% Other

New Design Philosophy Mandatory! (Lifetime & P/L ?)
Failure Detection/Diagnostics Pre-Mature (Route?)
Propagation Not Understood as Part of Design Process Yet
Insurers & Industry: “Most Probable Route Cause” (Gov?)
Some Future Missions Are in Question
More Failures to Come

“Availability” Does Not Necessarily Mean
“Reliability via Redundancy” A. Ellery
### Satellite Servicing Options

<table>
<thead>
<tr>
<th>Service Class</th>
<th>Kind of Service</th>
<th>Co-Op. Satellite Design</th>
<th>Supplies Logistics</th>
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<tbody>
<tr>
<td>Motion</td>
<td>• Re-Orbiting</td>
<td>?</td>
<td>-</td>
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<tr>
<td></td>
<td>• De-Orbiting</td>
<td>?</td>
<td>-</td>
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<tr>
<td></td>
<td>• Salvage</td>
<td>?</td>
<td>-</td>
</tr>
<tr>
<td>Manipulation</td>
<td>• Maintenance</td>
<td>+</td>
<td>?</td>
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<td></td>
<td>• Repair</td>
<td>+</td>
<td>?</td>
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<tr>
<td></td>
<td>• Retrofit</td>
<td>+</td>
<td>-</td>
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<tr>
<td></td>
<td>• Docked Inspection</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Observation</td>
<td>• Remote Inspection</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Underway!**
- Injection
- Life Extension
- Re-Fueling
- Upgrade

**The Easiest To Do!**

### Characteristics of Services

<table>
<thead>
<tr>
<th>Class</th>
<th>Service</th>
<th>Benefit</th>
<th>Value</th>
<th>Frequency</th>
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<tbody>
<tr>
<td></td>
<td>Observation</td>
<td>Remote inspection</td>
<td>State Information</td>
<td>Low Value, Lower Cost if Multi-Client</td>
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<tr>
<td></td>
<td>Motion</td>
<td>Re-orbit De-orbit Salvage</td>
<td>Operation Liability Orbital Slot Re-Usability</td>
<td>Medium Value</td>
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<td></td>
<td>Manipulation</td>
<td>Maintenance Retro-Fit Repair Docked Inspection</td>
<td>Extended Operation Enhanced Functionality &amp; Performance Information</td>
<td>High Value</td>
</tr>
</tbody>
</table>

**Potential Market, Value & Price?**
Affordability of Satellite Servicing Missions

Drivers
- Service Needs (No.)
- Frequency
- A&R Task (Servicer)
- Orbit & Plane
- Responsiveness
  - Scheduled
  - Emergency
- Logistics (Supplies)

Market Demand?
Economics?
1st Movers?
Demonstration!

Building Block Example: OOS Payloads (Draft)

<table>
<thead>
<tr>
<th>ELEMENTS</th>
<th>SERVICE CLASS / SERVICE</th>
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<tbody>
<tr>
<td></td>
<td>Motion</td>
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<tr>
<td>Docking</td>
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<tr>
<td>Thrusters</td>
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<tr>
<td>Catch</td>
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<td>Storage</td>
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<tr>
<td>ORU</td>
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<td>Throttle</td>
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<tr>
<td>Thr. Device</td>
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<td>Sensors</td>
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<td>Cameras</td>
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<td>X-ray</td>
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<td>Range</td>
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<td>Proximity</td>
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<td>Force</td>
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<td>Torque</td>
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<td>Grip</td>
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<td>Actuators</td>
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<td>Motor</td>
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<tr>
<td>Gear</td>
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<td>Lubricant</td>
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<td>Manipulator</td>
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<td>Links</td>
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<td>Control</td>
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<td>Processors</td>
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<tr>
<td>Algorithms</td>
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<tr>
<td>HW</td>
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<tr>
<td>NRE</td>
<td></td>
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<tr>
<td>Tooling</td>
<td></td>
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<tr>
<td>EndEffector</td>
<td></td>
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<td>PowerTools</td>
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<tr>
<td>OLED</td>
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<tr>
<td>Retrieval</td>
<td></td>
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<tr>
<td>3 Modes</td>
<td></td>
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<tr>
<td>COST</td>
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<table>
<thead>
<tr>
<th>Service</th>
<th>Re-Orbiting</th>
<th>Re-Orbiting</th>
<th>Salvage</th>
<th>Maintenance</th>
<th>Repair</th>
<th>Retro-fit</th>
<th>Docked Inspection</th>
<th>Inspection</th>
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<td>15</td>
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JOERG KREISER
International Consultant

ASTRA 2004 - 2-4 November 2004 - Noordwijk - The Netherlands
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Slide 9
Building Blocks: The Model Drives The Mission!

- Regulatory
- Market
- Insurance
- Partnership
- Finance
- OOS Business Model
- Risk Mgmt
- OOS System/Mission Architecture
- Servicer
- Launch
- Ground Segment
- Logistic Platform
- Design (Technology)
- OOS Payload
- Bus

Space Business System

- Environment
- In-Orbit Infrastructure
- Other
- Satellites
- Business & Economics
- Mission Architecture & Logistics
- Transportation
- Supply
- Assembly
- G/S

System & Business Engineering Solution?
Example 1: Remote Inspection (Observation)

State Information
- Visual Imaging
- Thermal Imaging
- Electromagnetic Imaging
- X-Ray ...

Scheduled (& Emergency)
- Periodic Check-Up
- Failure Analysis
- Decision Making Support
- Design Feedback
- ...

Reduction of
- Complexity
- On-Board Sensors
- Cost
- Risk

Low Price & High Volume

Example 2: Co-Operative Satellites (“Shorter Lifetime”)

Periodic Overhaul
- Maintenance: Re-Fueling
- Retro-Fit: ORU Exchange
- Repair?
- ...

Co-Operative Design
- Shorter Lifetime
- Modularized Concepts
- Standardized Interfaces
- Logistics
- Launches
- ...

Reduction of
- Complexity
- Cost
- Weight
- Size
- Risk

High Price & Low-Medium Volume

Technology Advance
Economy of Scale
Example 3: Alternative Operational Concept

Provision of Service Availability
- Large Platform in Busy GEO Slot
- E.g. Transponder Capacity
- Continuous Overhaul & Upgrade
- Operation of System
- ...

- Co-Operative Design
- ORUs
- Modularized Concept
- Standardized Interfaces
- Logistics/Traffic
- Vehicles
- Launches
- ...

Focus on System Availability
Technology Advance
New Customer Relationship
Operations vs. System Supply
Core Business
New Business Model

OOS as Enabler: Large Space Structures etc.

OOS 2004 Workshop Vancouver
- 70 Participants
- 11 Countries

3 Sectors for Roadmaps
- Technology
  - Large Space Structures
  - Satellite Servicing

OOS & On-Orbit Assembly (OOA) Are Key to New Missions
### Large Space Structures: Characteristics

<table>
<thead>
<tr>
<th>LARGE SPACEC STRUCTURE</th>
<th>Where</th>
<th>When</th>
<th>Needs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Orbit</td>
<td>Base</td>
<td>Short</td>
</tr>
<tr>
<td>Large Aperture</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Solar Power Satellite</td>
<td></td>
<td></td>
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<tr>
<td>Space Hotel</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Warehouse</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Lunar/Mars Exploration Vehicle</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Lunar/Mars Base</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Jupiter Icy Moon</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Space Mirror</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Orbiting Lab</td>
<td></td>
<td></td>
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<tr>
<td>Commercial Platform (Condo Sat)</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Artificial Moon</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Space Colony</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Space Factory</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Space Elevator</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Mag Lift</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Solar Sail</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

**OOS Needs:**
- L: Low
- M: Medium
- H: High

### Large Space Structures: Evolution Based on OOS

<table>
<thead>
<tr>
<th>LARGE SPACEC STRUCTURE</th>
<th>0-5 yrs Short-Term</th>
<th>5-10 yrs Mid-Term</th>
<th>10-20 yrs Long-Term</th>
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</thead>
<tbody>
<tr>
<td>Technology Demonstration</td>
<td>Large Aperture</td>
<td>Solar Power Satellite</td>
<td>Space Elevator Mag Lift</td>
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<tr>
<td>Low Servicing (OOS)</td>
<td>Space Mirror</td>
<td>JIMO</td>
<td>Lunar/Mars Exploration</td>
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<tr>
<td>Medium Servicing (OOS)</td>
<td>Orbital Labs</td>
<td>Solar Elevator Mag Lift</td>
<td>Commercial Platform (Condo Sat)</td>
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</table>

OOS To Prepare for “OOA” & To Enable Future Space Missions
Summary

- **OOS**
  - Is “Not Of An End Itself”!
  - Helps Understand Other Issues in Space
  - Drivers and Associated Implications 2B Understood
  - Fits Space Policies Ideally: Public Support!
- **Co-Operative Design for Entire Missions**
  - Modularized Concepts, Standardization
  - Building Blocks Will Help!
  - OOA (On-Orbit Assembly)
  - Evolutionary Cross Roads
- **Mandatory**: Demonstration & 1st Commercial Success
- **Need For Long-Term Visions Involving New Concepts**
  - E.g. Staging Orbits, Satellite Swarms, Formation Flying, ...
- **Focus Way Beyond Technology & Space Systems**
  - Legal&Regulatory, Insurance, Finance, Business Models
- **Analogies & Lessons Learned from Other Sectors**
  - Automotive, IT, Infrastructure, ...

### This Presentation & Further Information on OOS

**Via Website:**

[www.on-orbit-servicing.com](http://www.on-orbit-servicing.com)
General Issues

- Although not all future space projects will have a commercial background, all activities involve space industry, which provides major elements to such projects and is based on commercial principles.
- Space missions consist of mission architectures and operations of systems, whereby all system elements are based on certain design principles.
- Due to the complexity of space missions in general and based on traditional planning methods, projects are typically planned in advance and are characterized by long-term scenarios, which are typically set way in advance, too.
- Sophisticated design, system engineering and cost estimation methods have evolved over decades driven by technical and schedule requirements trying to minimize costs.
- Alternative approaches focused on overall efficiency based on system availability, mission flexibility, financing and stakeholder benefits, etc. of future space missions are not yet mainstream in the sector.

General Issues (cont’d)

- Many of the currently discussed future space missions and long-term scenarios will have to involve OOS and On-Orbit Assembly (OOA) to become a reality. This will require modular concepts as for realizing technical elements of such missions.
- Drivers other than technology, reliability and cost have a stronger impact than commonly believed in the sector. Finance, insurance, legal/contractual issues and overall models for future space missions are key elements to deal with and to be understood.
- There are obvious lessons learned and analogies in other, terrestrial sectors as e.g. automotive, IT and infrastructure, etc.
- Availability of service x,y,... (e.g. satellite services, ISS supply, exploration, science, etc) and mission flexibility are major challenges for future space. Therefore approaches best meeting those requirements are sought. However, this does not necessarily imply most cost-efficient systems. Solutions most suitable to all stakeholders involved will be best based on more commercial approaches, even if initial mission goals are not of commercial nature, since the space industry produces the systems and other commercially-oriented players are involved.
- New models are needed and will have to combine more drivers than used to be considered so far to enable for a new generation of space missions following a “faster, better, value-balanced” principle, and thereby increasing their efficiency (and chance for realization).
- This requires paradigm shifts at various levels - primarily in culture and mindset -, which represents a major challenge itself.
The Content of this Presentation Is Based on:

- Own Research, Experiences & Perspective on Status & Trends in Space, and on
- Results of OOS-Related Activities Funded by DLR - See Box Below
  (With Means of the German Federal Ministry of Education and Research BMBF - No. 50JR0166 and 50JR0268)

### Study Team

- Independent
- International (D, UK, USA)
- Multi-Level Background
- Broad Experience & Global Connectivity

<table>
<thead>
<tr>
<th>Name</th>
<th>Background</th>
<th>Role</th>
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<tbody>
<tr>
<td>JKIC</td>
<td>Space Commercialization</td>
<td>Study Lead</td>
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<tr>
<td></td>
<td>Business &amp; Finance (VC)</td>
<td>Approaches &amp; Models, Synopses</td>
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<td>Subcontractor</td>
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<td>R&amp;D</td>
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<tr>
<td>Joerg Kreisel</td>
<td>(Tom Grigovschi)</td>
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<td>Andy Shaw</td>
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