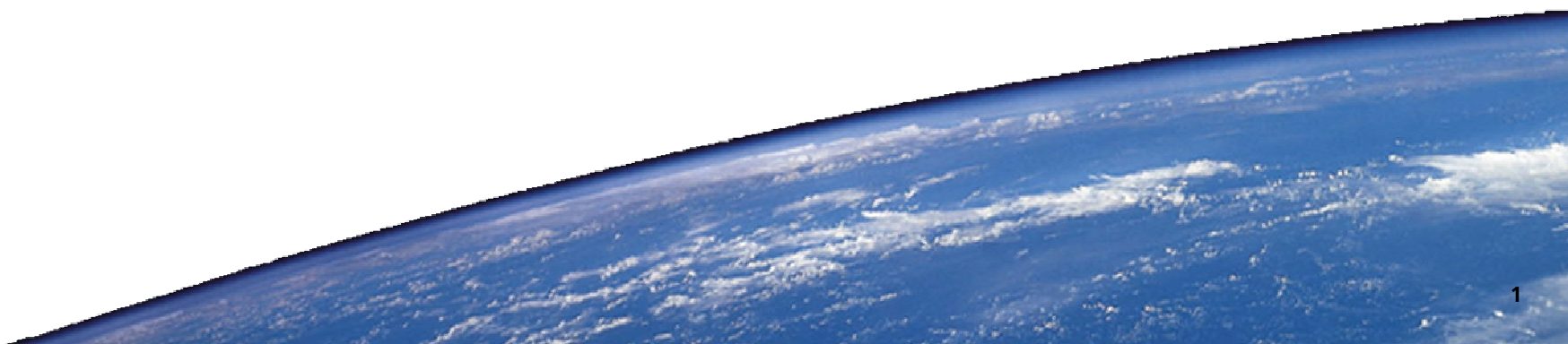
Proceeding of the 7th International Symposium on Artificial Intelligence, Robotics and Automation in Space:
i-SAIRAS 2003, NARA, Japan, May 19-23, 2003

Automation & Robotics (A&R) for Space Applications

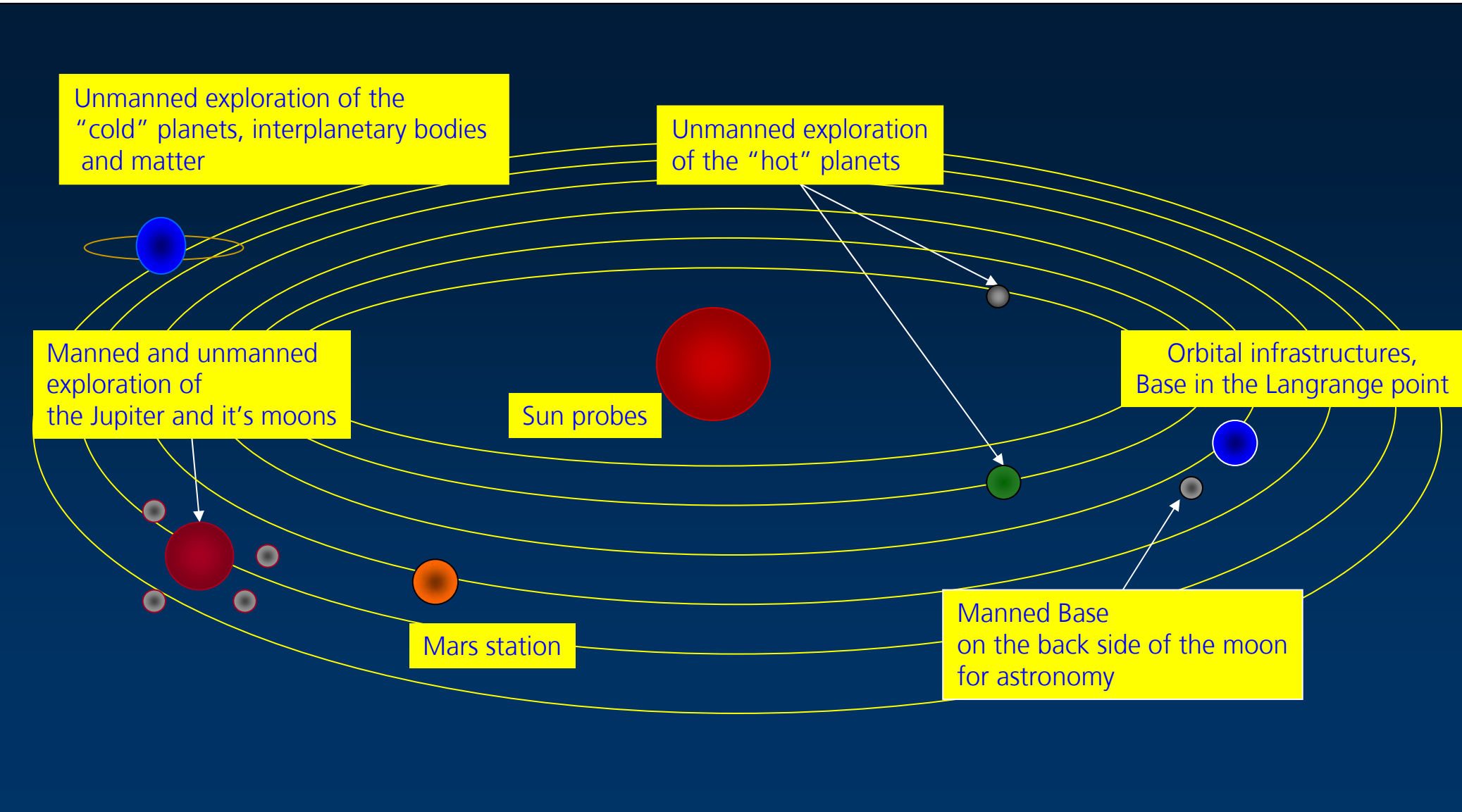
iSAIRAS 2003, Nara, Japan, May 2003

B. Sommer, RD-RR



Automation & Robotics (A&R) for Space Applications

Current and future application areas



Automation & Robotics (A&R) for Space Applications

A changing world - from purely scientific exploration to markets

- The first artificial satellite
- Scientific space probes perambulate the solar system
- Planetary landing missions
- MIR, Skylab, Spacelab, ...
- Disposable satellite infrastructure
- Disposable launchers

etc.

- ISS design & build up & beginning utilization
- The first space tourist
- Shuttle & Soyuz missions
- Disposable satellite infrastructure
- "New generation systems" studies
- "Back to the Solar System" studies
- Market &business potential studies

etc.

- ISS utilization
- Unmanned maintainable GEO-stations
- On-orbit services infrastructure
- New generation space transportation system & reusable launchers
- Exploration & Exploitation of the Solar System
- Established commercial space markets

etc.

past → **present** → **future**

Exclusively public funded
Science, technology and prestige driven
Basic research
Business or market considerations negligible
Commercialization only in selected areas and outsourcing

Public + private investments
Science, technology **and** market driven
Basic + applied research
First PPP's
Slowly emerging commercial enterprises

Public + private investments
Science, technology **and** market driven
Basic + applied research
PPP's dominate purely publicly financed activities
Profitable commercial enterprises provide a variety of services

Programmatic emphasis

Space activities are more and more evolving from publicly financed to commercial undertakings.

!

It still remains a wide area which needs continuing public financing !

Agency up-front investments for:

-> Scientific space probes
-> Manned space exploration
-> New technologies and other concomitant measures to facilitate commercialization

Automation & Robotics (A&R) for Space Applications

Goals

A&R for Space Applications in Germany

Satellite infrastructure
- Inspection
- Maintenance
- Repair

Space station
- Experiment & Crew Support

Operation of space systems
- O/B autonomy
- Virtual reality

Exploration of the Solar system

Operation of interplanetary infrastructure

Automation & Robotics (A&R) for Space Applications

Infrastructure elements

OSAV	Orbital Unmanned Servicing & Assembly Vehicle
M/U-OTV	Manned/Unmanned Orbital Transfer Vehicle
M/U-PLV	Manned/Unmanned Planetary Landing Vehicle
	Free Flying Robots

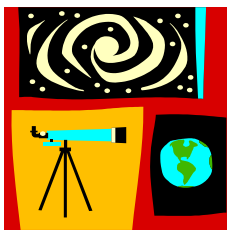
MPSV	Mobile Planetary Surface Vehicle
MAF	Mobile Analyses Facility
MSV	Module Service Vehicle
	Mobile Robots

PHM	Planetary Habitation Module
PMF	Planetary Maintenance Facility
RGHF	Resource Generation and Handling Facility
	Service Facilities

Automation & Robotics (A&R) for Space Applications

Major challenges !

Accurate autonomous navigation
Attitude & orbit control
Ground Control



Scientific applications → **Formation flying**
Exploration of Planets

Commercial/agency unmanned on-orbit servicing missions to space infrastructure elements → **Far & close approach**
Fly around
Capture,Docking
Servicing tasks

Automation & Robotics (A&R) for Space Applications

Capabilities & Technologies

The necessary capabilities :

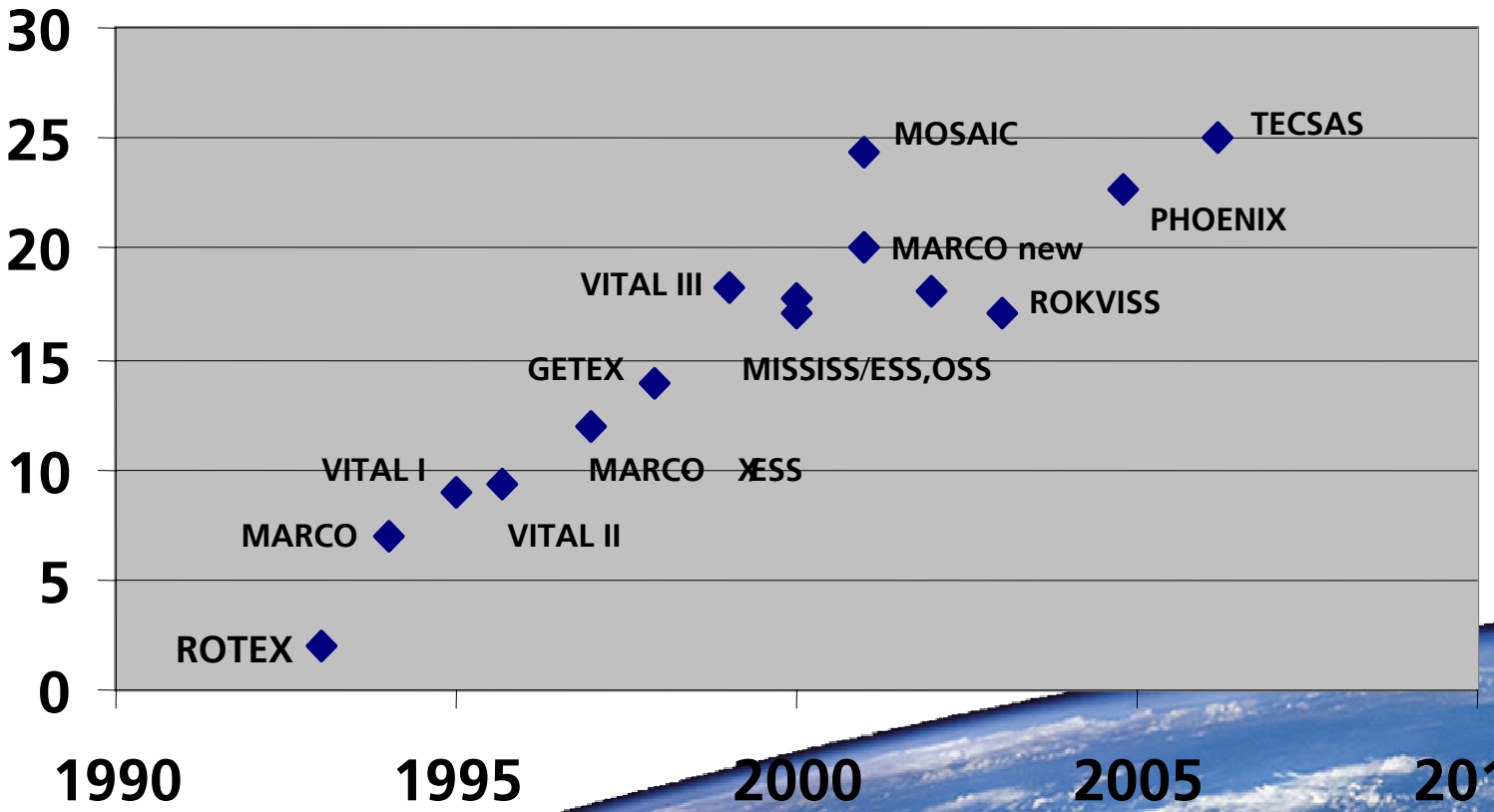
- Interplanetary and planetary navigation
- Rendezvous, Capturing, Docking, Berthing
- Material processing, regeneration, handling and storage
- Fast and reliable high data rate communication
- Environment monitoring and control

A&R technologies to provide :

- Advanced man machine interfaces (virtual presence, tele presence)
- Integrated real time system control
- Actuators, manipulators, sensor systems
- Flexible attitude detection and control
- Sensor data processing and sensor data fusion
- Intelligent assessment of the environment
- Integrated database system

Automation & Robotics (A&R) for space applications

"System intelligence"



Automation & Robotics (A&R) for Space Applications

From program to projects

ROTEX, MARCO, MARCO-X,ESS, GETEX, OSS, MISSIS, VITAL,...

- MISSIS Interim Phase
- NEX Study
- VITAL III
- MARCO new
- Beagle Drill
- Artificial hand
- Ultra light weight arm
- De-orbiting study
- Market analysis servicing
- Requirements analysis for extra terrestrial missions

GroCoS
- Training/control system for on-board facilities

ROKVISS
- A&R Components Qualification

VITAL IV
- COF P/L operation preparation,VR

ISS applications

TECSAS
- Unmanned servicing
- Astronaut assistant/associate/surrogate

Servicing

"Reusable" orbital infrastructure

Advanced Ground Control

Missions to the Solar System !

- E-t-e system engineering & demo-missions
- Market potential analyses and PPP-ventures
- Subsystem and components development.

Ongoing activities → **Next steps** → **Goals**

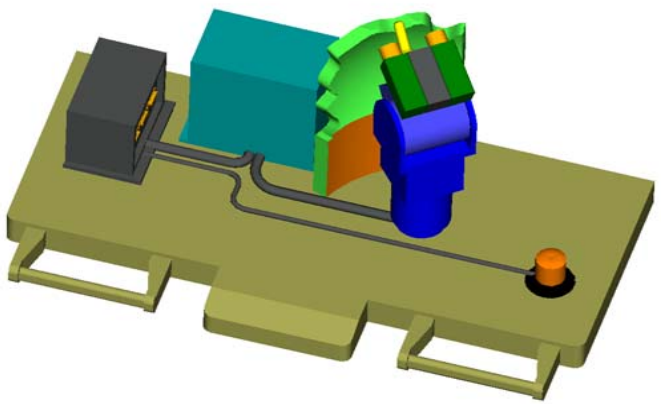
ROKVISS

ROKVISS - Robotik Komponenten Verifikation auf der ISS (Robotic components verification on ISS)

Project statement :

- qualification of robotic components for space applications
- verification of direct link between ROKVISS ground and space segment
- verification of the tele-presence mode (500 ms round trip)

System (flight unit):
- 2 joint units
- electronic box
- antenna
- additional equipment: wide angle camera



External accommodation on the Russian Service Module of ISS

VITAL

VITAL - A virtual reality (VR) system as an advanced tool (MMI) for design, experiment preparation, training and operation of space systems.

Project statement :

VITAL is a 4-step program to:

Proof of the usability and benefit of virtual reality concepts (S/W & H/W) for space applications.

Development of the VR-system on work stations and its demonstration by performing a satellite capture and repair task in the laboratory.

Transformation of the VR-system into a PC version.

Application of the VR-system for astronaut training and experiment preparation (operation?) in COF.

RASAV

RASAV RAdarverfahren zu Satelliten Vermessung
Radar based methods for the measurement of satellite orbits and dynamics.

Mission statement :

- **Investigation of satellite orbit data accuracy and development of a failure compensation model**
- **Implementation of a real time tracking algorithm independent of the availability of orbit parameters**
- **Development of a mathematical method to calculate orbit progression over time**
- **Improvement of existing data processing methods to create radar images and radar movies of orbital objects**

Automation & Robotics (A&R) for Space Applications

Market potential for orbital servicing

Study to investigate the potential markets for servicing, maintenance, repair etc. of orbital infrastructure elements.

Study statement :

Description of potential servicing tasks deduced from public interest/responsibilities (e.g. disposal of space debris)

Description of potential servicing tasks deduced from private/industrial interest (retrieval, repair, inspection, etc. of satellites)

Assessment of the market potential based on non-cooperative as well as on cooperative satellite design

Description of international activities in the field of orbital servicing

Derivation of top level requirements for future satellite design taking into account marketing and business considerations

TECSAS

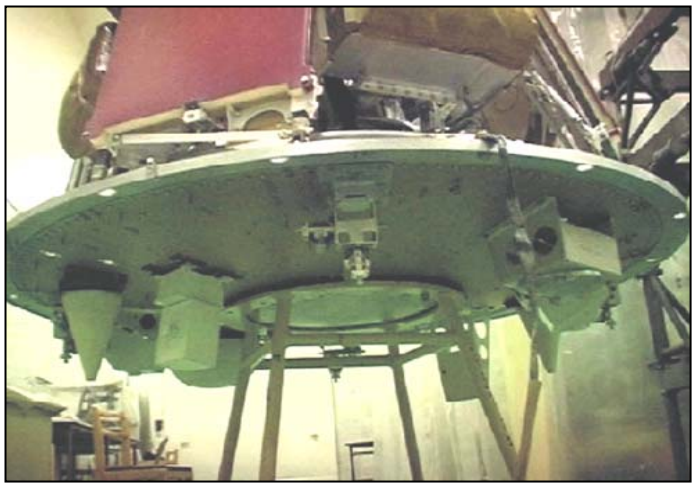
TECSAS TEChnology SAtellite for demonstration and verification of Space systems

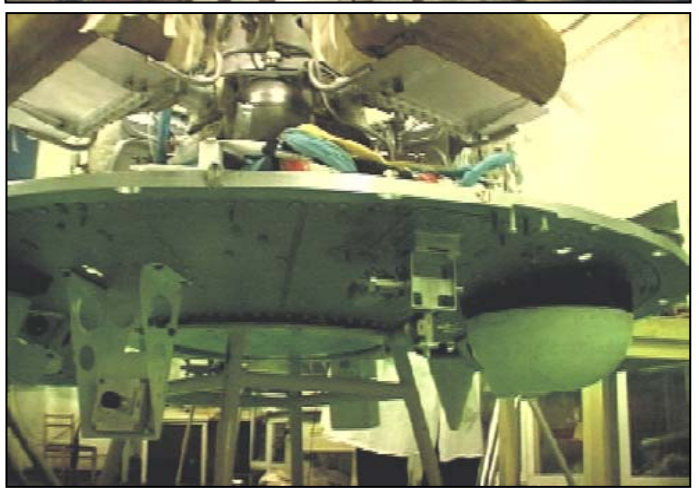
Mission statement :

ESS shall demonstrate the availability and advanced maturity of the technologies necessary for:

- **Approach and rendezvous**
- **Inspection fly around**
- **Formation flight**
- **Capture**
- **Stabilization and calibration of the compound**
- **Compound flight maneuver**
- **Manipulation of the target satellite**
- **Active ground control via tele-presence**
- **Passive ground control during autonomous operations**
- **Thrust control for disposal or de-orbiting**
- **De-coupling of the compound**

MULTI-PURPOSE ORBITAL BOOST PLATFORM



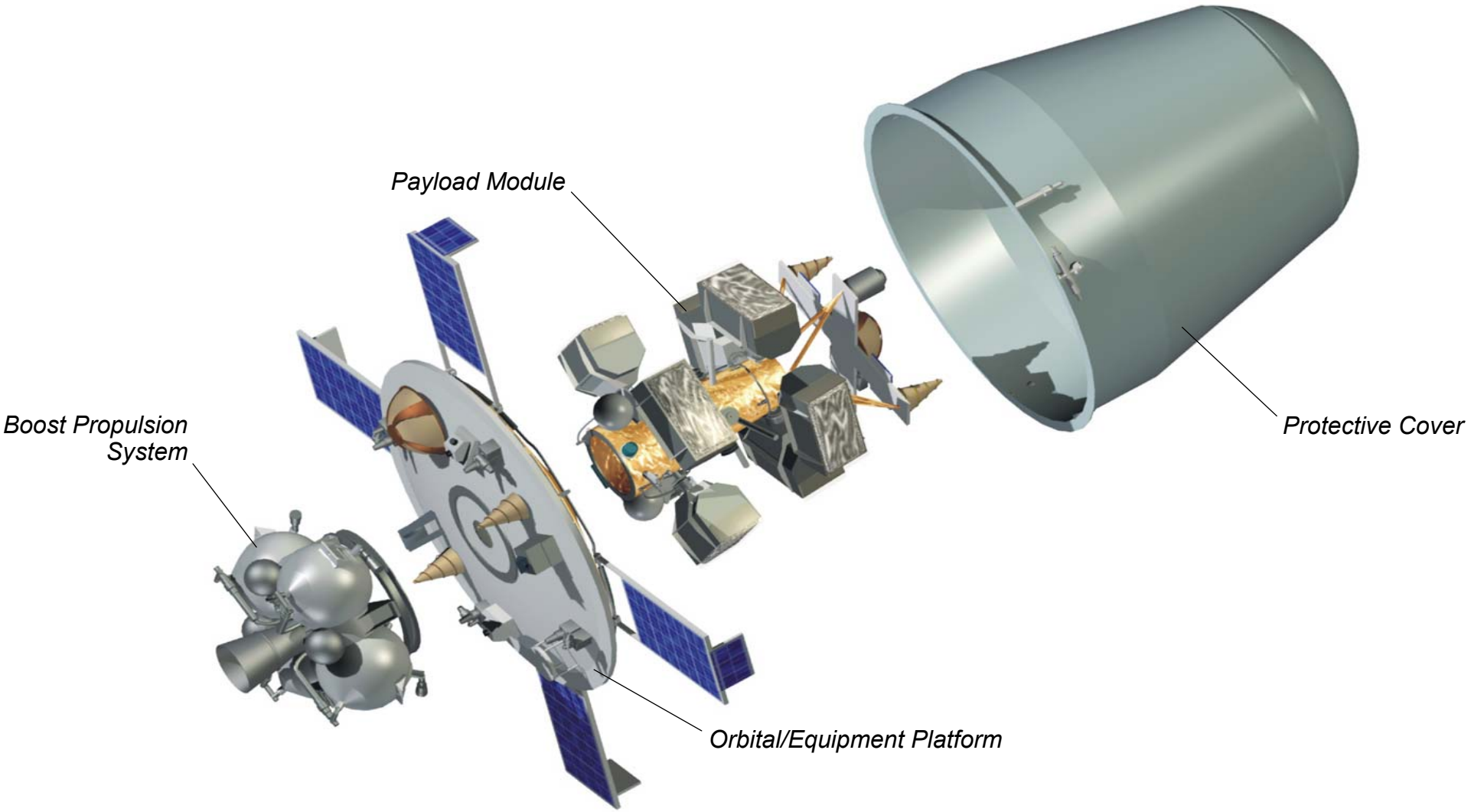


2002

BABAKIN SPACE CENTER

MULTI-PURPOSE ORBITAL BOOST PLATFORM

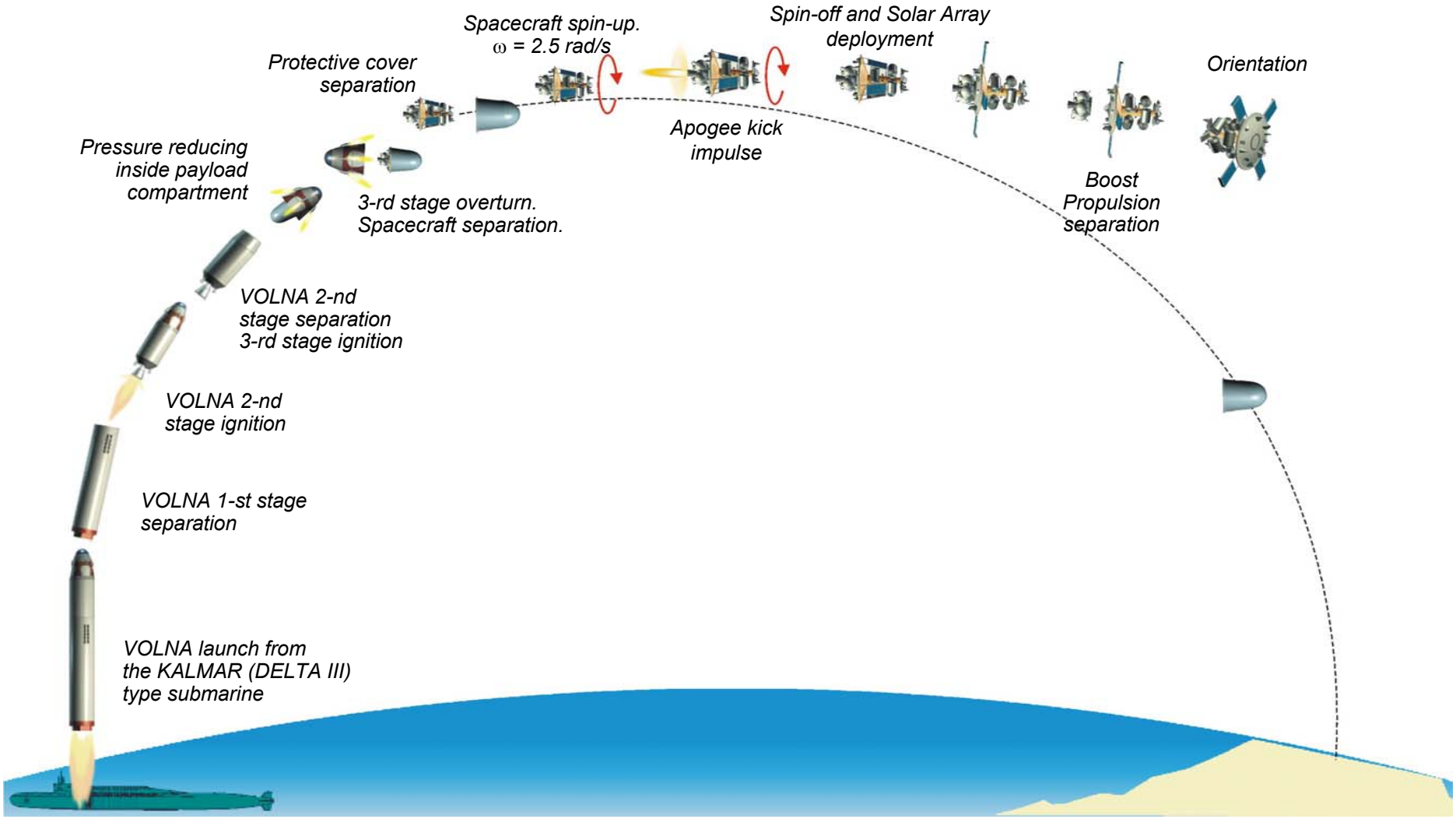
SPACECRAFT COMPOSITION



BABAKIN SPACE CENTER

MULTI-PURPOSE ORBITAL BOOST PLATFORM

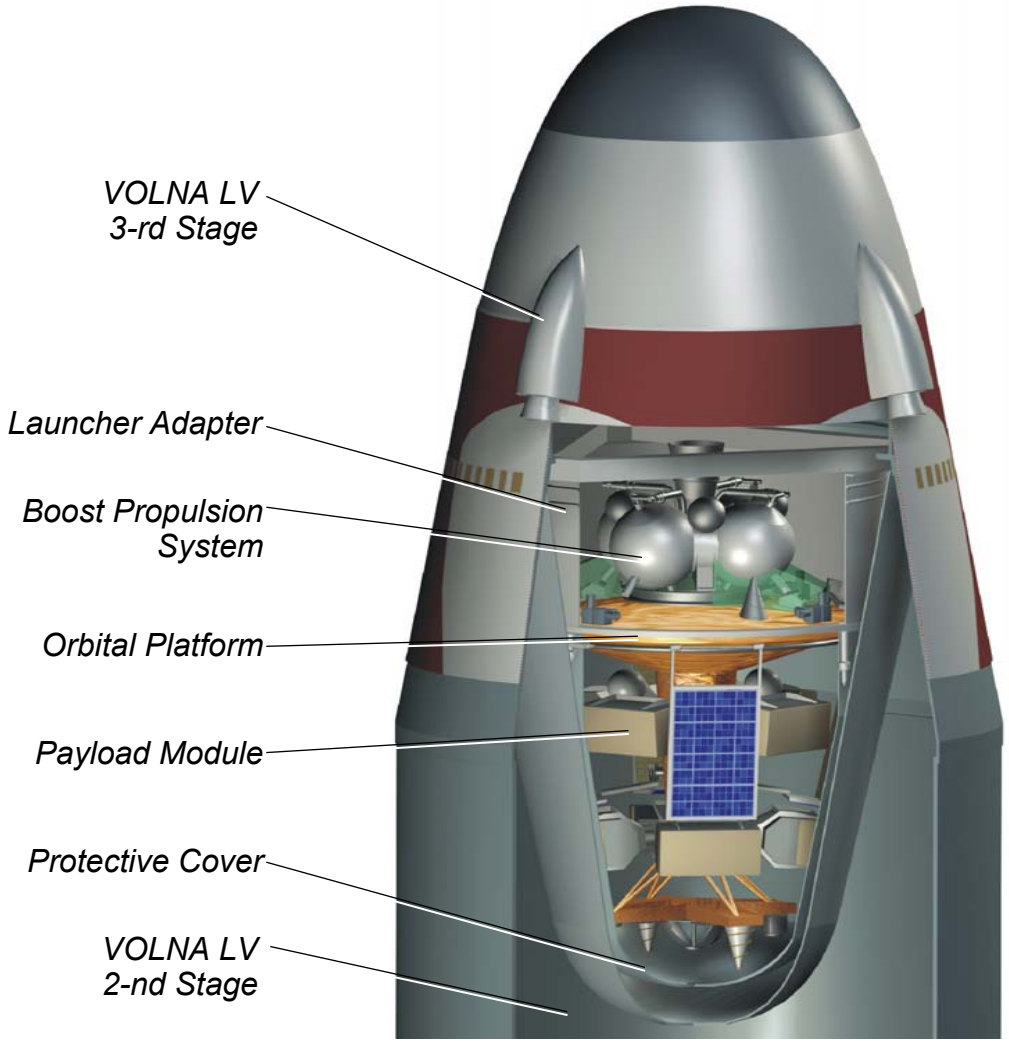
TYPICAL INSERTION PROFILE



BABAKIN SPACE CENTER

MULTI-PURPOSE ORBITAL BOOST PLATFORM

SPACECRAFT ARRANGEMENT ON LAUNCH VEHICLE



Upper composite mass budget

Protective cover	***21 kg***
Boost Propulsion System	***87 kg***
Separation system	***4 kg***
Orbital spacecraft:	***98 kg***
❑ Orbital platform	*44 kg*
❑ Payload module	*54 kg*
Upper composite	***210 kg***

Status and perspective of Automation & Robotics (A&R) for Space Applications

Status:

Autonomous and automated systems are used in a broad spectrum of applications in production, manufacturing and fabrication.

In spite of some spectacular successes the utilization of "intelligent" systems in space missions is still in an initial state.

Perspective:

The combination of new information technologies, highly integrated mechatronics and advanced actuators and sensors together with powerful simulation tools will open up a large array of space applications in the future.

Areas of special interest within DLR Space Management

DLR Space Management pursues the development of systems for space applications in the areas of :

- **Tasks inside and outside of the International Space Station**
- **Maintenance and repair of satellites**
- **Exploration of the solar system and other celestial bodies**

Besides the enhancement of space system autonomy and the level of automation DLR Space Management puts major emphasis on the development of advanced ground control methods

Input to
I-Sairas 2003
Presentation B.Sommer/DLR

Joerg Kreisel

Automation & Robotics (A&R) for Space Applications

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Activities wrt On-Orbit Servicing (OOS)

Potential "OOS" Market (2001:High-Level Study I)

- JOERG KREISEL International Consultant

Implementation of Study Recommendations:

- **Creation of OOS Community**
  - **Logo & Website (www.on-orbit-servicing.com)**
- **Focused Follow-On Activities, e.g.**
  - **SpaceTech: CCP 2003 on OOS**

    DelftTopTech
  - **High-Level Study II: "Roadmap Context"**
- **International Workshop on OOS (Nov 2002)**

Services Types & (E) vs (S)
Orbits: GEO, MEO, LEO, SSO
Satellite Types: T; N; EO; SC
Customers: Civil/Commercial
Service Types
Policy, Legal, Regulatory ...

A&R & Maneuvers

Target Sat

Servicer Sat

Servicing A&R
Servicer
Co-Op Design Target
Logistics => Target

Mission Architecture

Mission Design
Servicing Concepts
Orbital Infrastucuture
Servicer
Logistics => Servicer
Costs

G/S

Satellite Failures
Servicing Needs
Customer Benefits
Stakeholders
Market Drivers

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OOS Challenge: System & Business Engineering Solution?

Services: Definition

Service Class	Kind of Service
“Motion”	Re-Orbiting De-Orbiting Salvage
“Manipulation”	Maintenance Repair Retrofit Docked Inspection
“Observation”	Remote Inspection

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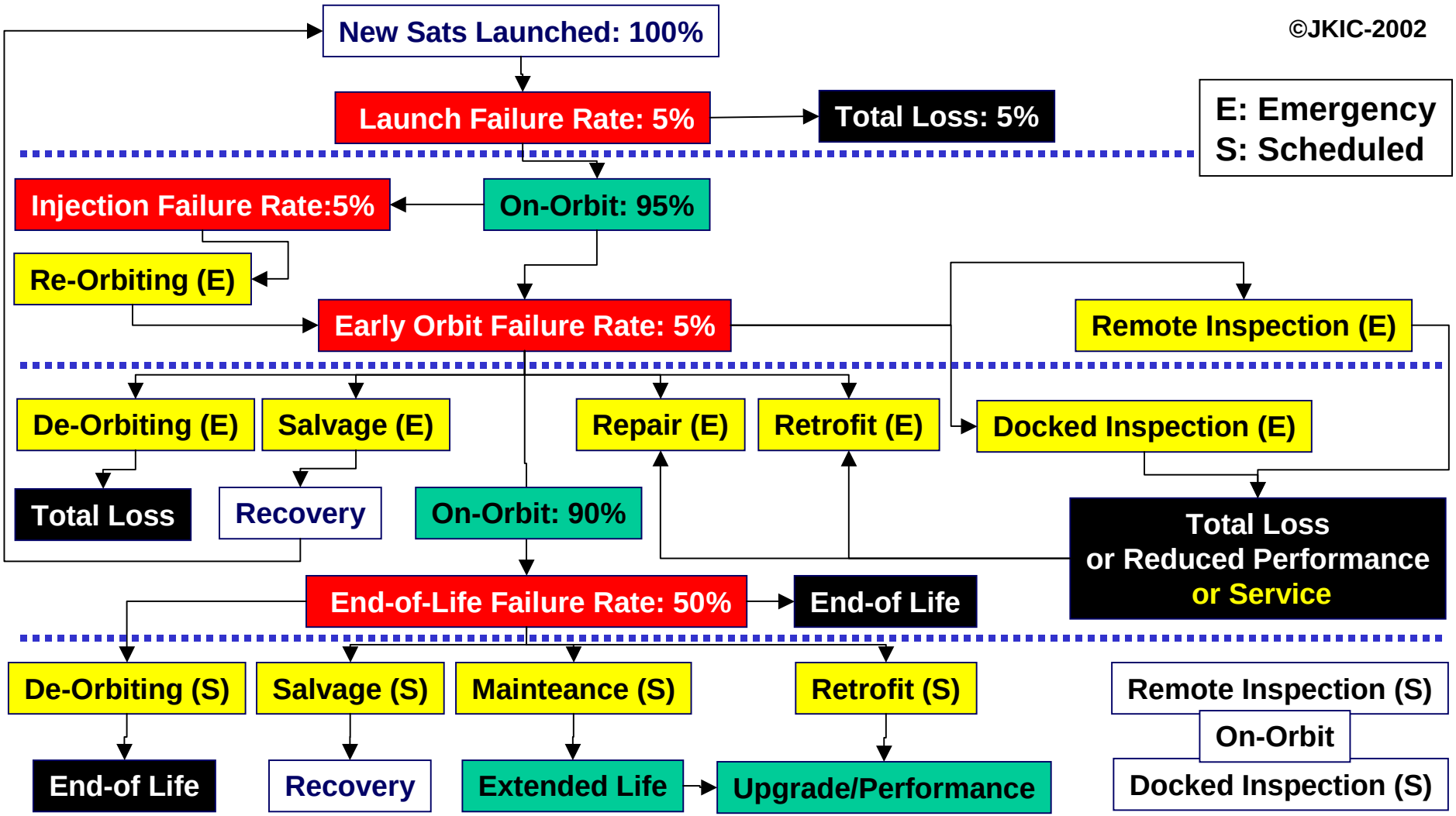
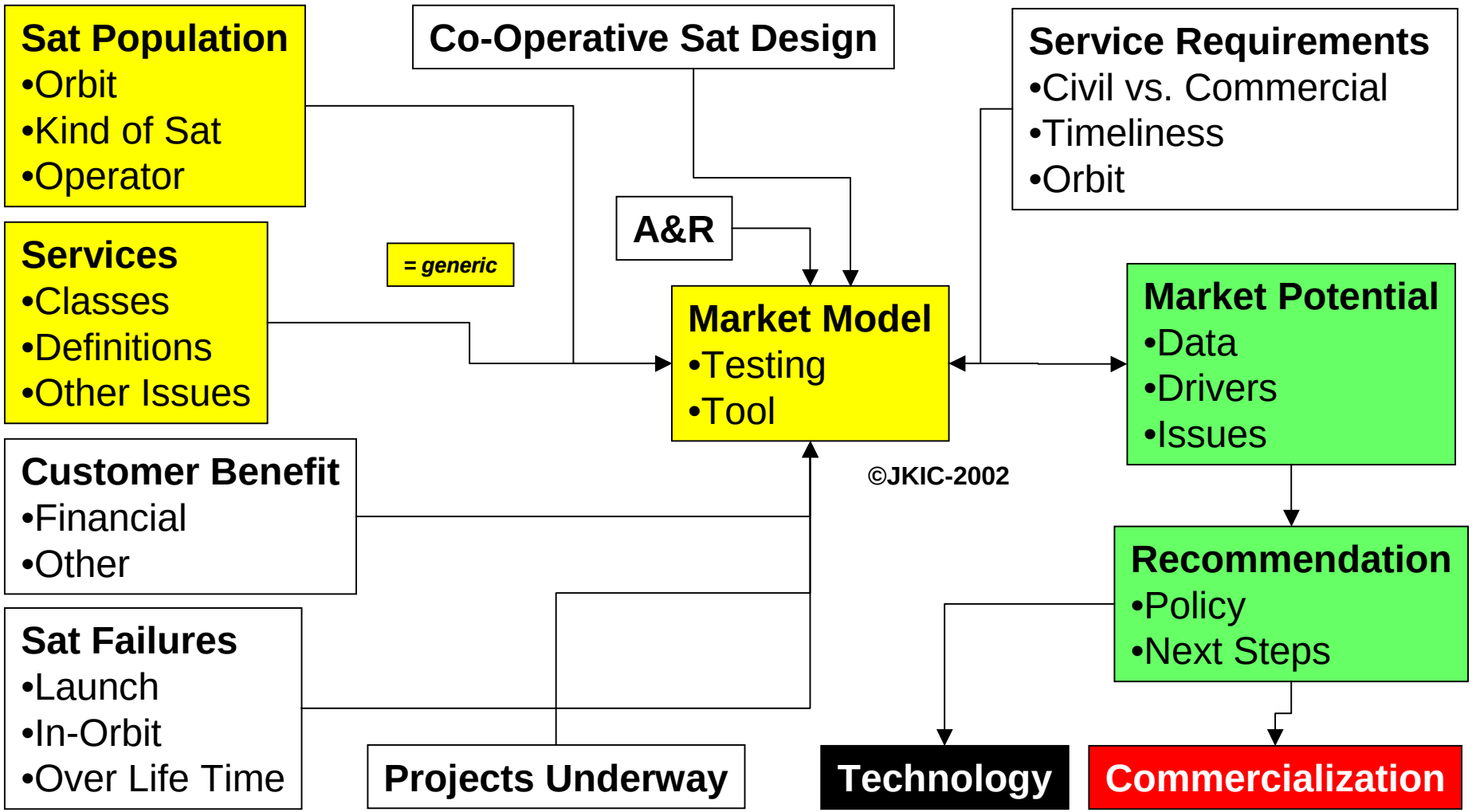
The Young OOS Domain Needs Clear Definitions!

(Service Definitions Can be Combined, e.g. ORC = Re-Orbiting + Maintenance)

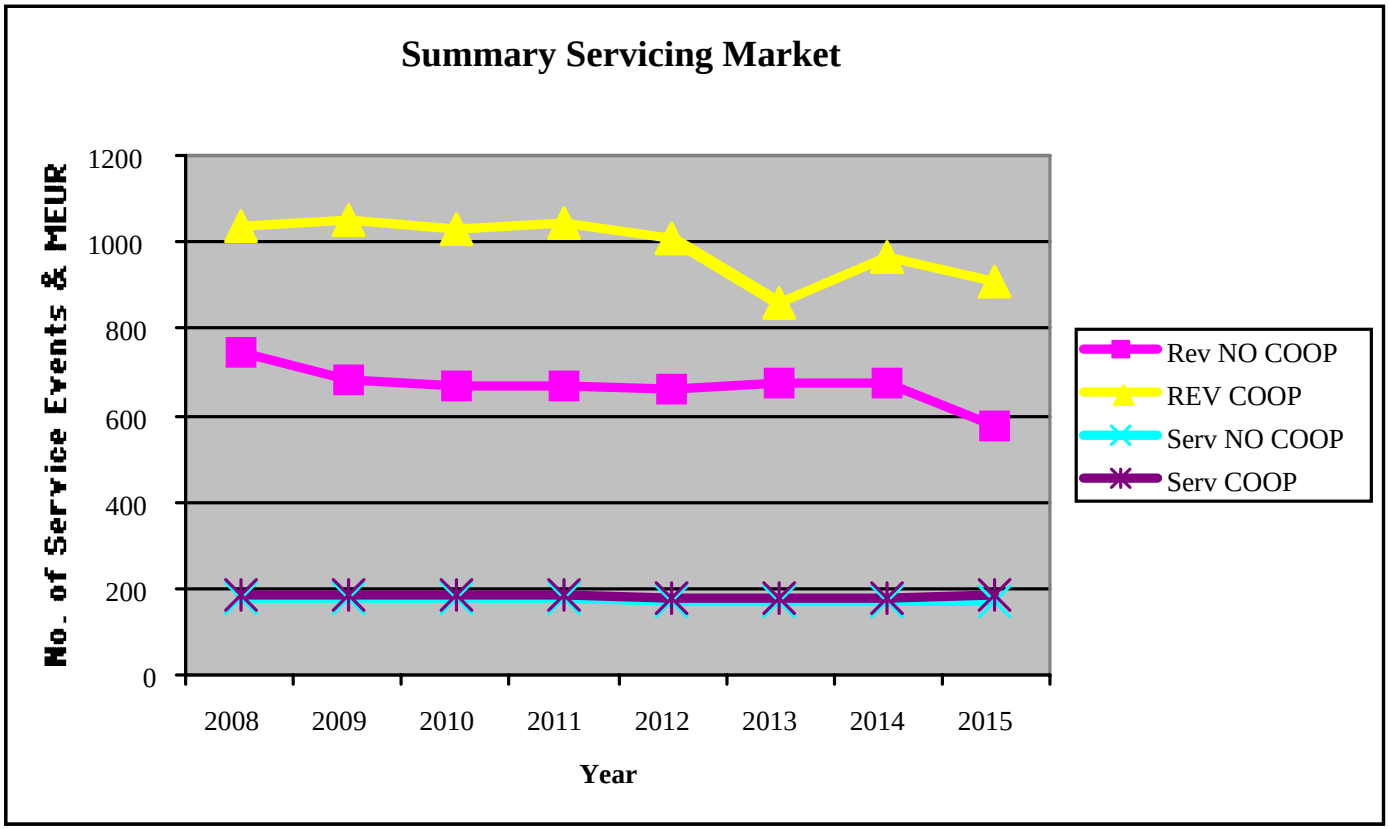
Model: Servicing Baseline



JKIC OOS Study I Approach



Overall Potential OOS Market



Playing in the Same Class with Infoterra or Galileo

Potential Market of app 100 Service Events & 0.5-1 bill EUR p.a.

Questions

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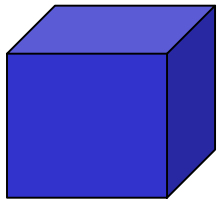


Target

Sat Failures

Technical

Probability & Timing

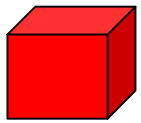
Impact on Sat Mission

Impact on Operator

Value of Service

Service Need ?

- How to Match these 2 Major Streams?
- Co-Operative Satellite Design?
- High-Value Civil vs ComSat Servicing?
- Servicing Concept?



Servicer & Supply

Service Need

Time. A&R, Design, Orbit, Target ...

Mission Design

Cost

Service

Feasibility ?

Workshop Vision

Years	Governments Agencies	Industry	Leg&Reg Bodies
0-5	▪ "OOS Policy & Budget Line" ▪ Intl. Agency Coordination & Collaboration ▪ ISS-Related OOS ▪ Technology Development Roadmap	▪ Development of Commercial Cases ▪ OOS Demontration ▪ "Maintenance" (US) ▪ "De-Orbiting" ▪ "Re-Orbiting" (ORC)	▪ Frequency Band for OOS

5-10	▪ Paradigm Shift to Infrastructure Avaialbility	▪ Creation of Partnership
		  ▪ OOS-SP's
		  ▪ Sat Mans
		  ▪ Gov'ts/Agencies
		▪ 1st Generation OOS Business
			▪ Satellite Disposal & Debris

10-15	▪ Large Space Infrastructure Assembly	▪ 2nd Generation OOS Business	
15-20		▪ Orbital Supply Platforms	

Start Today!

Workshop A&R Map

Missions	Observation	Docking PDFS	Re-/De-Orbiting PDFS	Maintenance PDFS	Retrofit FDFS
Inspector	√				
Aercam	√				
Canadarm 2	√	√			√
ETS VII	√	√		√	√
Orbital Express	√	√		√	√
Orbital Recovery	√	√	√	√	√
TECSAS	√	√	√		?
SPDM	?	?	?		
Robonaut		√			√

Sound A&R Base