



# ***THE ROAD TO OOS: ENABLING ARCHITECTURE***

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## **TOPICS**

- Introduction
- Limitations
- History of crew-assisted servicing
- OOS mission architecture
- Challenging architecture
- Logistic need drives
- Technology requirements
- Mission options and operations
- Conclusions



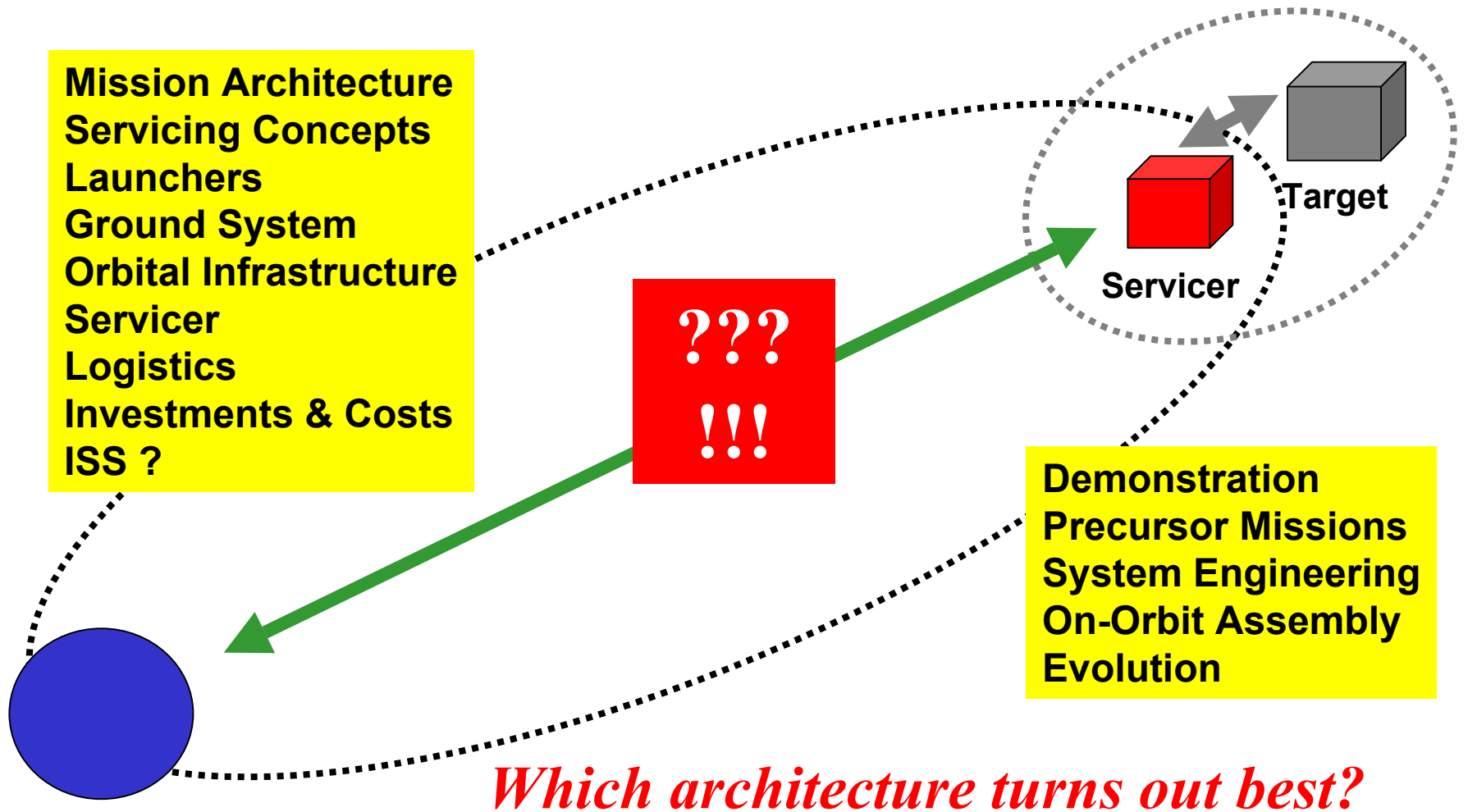
# *Introduction*

- Assumptions
- Current state of activity
  - Examples in U.S.
    - Orbital Recovery Corp. (Private)
    - Orbital Express (DARPA)
    - Space Maneuver Vehicle (USAF)
- Limitations
  - Physical
  - Financial
  - Political
- Government applications
  - Civil
  - Military

***OOS - a new and exciting industry!***



# The Road to OOS?





# *Limitations*

## Physical Limitations

- Energy to orbit:
  - GEO – 13,580 m/s
  - MEO – 10,000 + m/s
  - LEO – 9,650 m/s
  - SSO - 10,000 + m/s
- Energy to maneuver – 100 to 5,000 m/s
- Space environment – Vacuum & temperature

Financial Limitations – Costs vs market

Political Limitations – Utility missions

Security Issues – Military applications

***OOS had many constraints!***



## *History of Crew-Assisted Servicing*

<u>Vehicle</u>	<u>Year(s)</u>	<u>Activities and Accomplishments</u>
Voskhod	1965	First EVA
Gemini	1965-66	Ten EVAs
Soyuz	1969	Crew transfer
Apollo	1969-72	Crew transfer, repairs on lunar surface
Skylab	1973-74	Deployed sunshades and solar array, repaired and serviced science experiments
Space Shuttle	1983	Demonstrated MMU and hydrazine transfer
Mir	1987-00	Repaired various hardware
Space Shuttle	1992	Retrieved Intelsat VI, installed new PKM
Space Shuttle	1993-99	Serviced HST
ISS	1998-02	In orbit construction

***OOS – very expensive manned missions only, so far!***



# *OOS Mission Architecture*

- Required Elements
  - Launch vehicles
  - Payload (servicer & supplies)
  - On-orbit servicers
  - On-orbit logistics platforms and supply depots
  - ISS?
- Required logic
  - Mission scenarios
  - Protocols
  - Operational procedures
- Market Needs

*Three legs of the chair!*



# *Challenging Architecture*

- Physical limitations
  - Orbit
  - Maneuvers
  - Services required
- Mission objectives
  - Service Kind & Orbit
  - Responsiveness: Emergency vs. Scheduled
- Mission value versus costs
  - Minimum cost is about \$50 mm
  - Cost vs benefit

***A balance of physics and finance!***



# *Logistic Need Drives*

SERVICE CLASS	KIND OF SERVICE	LOGISTICAL SUPPORT + SERVICER	DRIVER
Motion	Re-Orbiting	Fuel, Station Keeping	Orbit, Delta V
	De-Orbiting	Fuel	Orbit, Re-entry or Graveyard
	Salvage	Salvage (On-Orbit), Reentry Vehicle	Target Size & Mass
Manipulation	Maintenance	Fuel, Liquids	Supply Need/Mass, Orbit
	Repair	Tools, Parts	Task & Parts, Storage, Orbit
	Retrofit	Tools, ORUs	Number & Storage, Orbit
	Docked inspection	Inspection Device, Communication	Data transfer, "Visibility", Orbit
Observation	Remote inspection	Special Sensors, Communication	Maneuver (Around & Neighborhood)

Eight kinds of service needed today.

Responsiveness: emergency vs scheduled service

***A large variety of mission issues for the virgin market!***



# *Technology Requirements*

## Launch and transport

- Multi-mission launch vehicle and servicer design
- Software for maneuvering
- Propulsion and maneuvering strategies

## Servicing

- Inspection and interrogation techniques and devices
- Repair and replacement strategies

## Orbit infrastructure

- Continuous orbital-to-Earth communications links via TDRS relay
- Service stations and supply depots

***Three categories of technology needed!***



# *Mission Options and Operations*

- Launch on demand, e.g., Space Shuttle approach
- On-orbit tender vs service station
- On-orbit supply depots
- Maneuvering multi-function servicing machines
- De-orbit/re-orbit approach
- Other operations

*For full OOS, the infrastructure must be complete.*



# Conclusions

- On-Orbit Servicing implies a large variety of complex missions and hardware.
- Economics of servicing effectively limits its applications.
- Permanent presence in space makes servicing common.
- Increasing On-orbit servicing capability requires “design-for-servicing.” (& Co-Operative Design of Satellites)
- On-orbit repair is limited to assembly/disassembly of modules for the next one or two generations
- On-orbit servicing is a necessary step toward on-orbit manufacturing.
- The major technological elements for on-orbit servicing are available, but a good deal of engineering, design and innovation are still required.

***We are at the beginning of an exciting new space activity!***