On-orbit Service System Based on Orbital Servicing Vehicle

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Abstract. On-orbit service (OOS) system based on Orbital Servicing Vehicle (OSV) is a complex giant system which needs an overall planning according to the analysis of its components and demands. Accordingly in this article, the target spacecrafts of the OOS system and their demands are firstly analyzed based on their function design and orbital location. Then the servicing mission is divided into 3 aspects including service, maintenance and assembly. The mission types and effectiveness are clarified as well. Finally, the components and their mutual relationship of OSV-cored OOS system are elaborated considering the future development. The plan proposed in this paper will make a good reference for the overall design of OOS system.

1 Introduction

On-orbit service (OOS) is a kind of space operation including on-orbit assembly, maintenance and service in order to extend the lifetime, expand and upgrade the performance of on-orbit system [1~3]. As core of OOS system, Orbital Servicing Vehicle (OSV) is a type of new concept intelligent spacecraft specially assigned for the on-orbit service mission [4].

OOS system is a complex giant system which needs an overall planning based on the analysis of its components and demands. The system analysis and overall design are the precondition and primary task for the study of service stragety and key technology. Accordingly in this paper, the analysis about system demands, mission classification and components relationship are carried out.

2 Servicing targets and their demands

The spacecraft which needs and is capable of acceptting OOS is called servicing object or target. Theoretically, the targets include any kind of on-orbit system. The demands of them are diverse with their different function, location and design characteristics [5-7].

1) Demands of different types of spacecraft

As is known, satellites are the main service targets, which are unmaned on-orbit system composed of mission sensors and satellite platform. The mission sensors provide original data for the ground station, and the platform makes a carrier for the sensors and provides power, heat control and communication for them. Without any maintenance or supply, the lifetime of the satellites may be 5~15 years, but contrarily, it will hopefully be doubled. The demands of the satellites are described as follows:

(1) Satellites orbit adjusting: the satellites apart from the destination orbit or out of gesture control need timely adjusting and maintaining in order to cut the loss.
(2) The liquid and the consumable supply: the supply of engine fuel, gas, refrigeration, lubrication, power medium and so on.
(3) Satellites hardware maintenance and replacement: the maintenance and upgrade of imaging camera, solar battery pannel, storage battery, gyroscope and other orbital replaceable unit etc.

The space telescopes such as HUBBLE are kind of special satellites system. Different from other reconnaissance satellites, the space telescopes investigate not into the earth but into the deep space. Staying in the outer space, the telescopes need as long time as possible running on orbit. Thus,

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besides the general demands of regular satellites, the more important ones of space telescopes are equipment maintenance and upgrade.

The space station is a kind of manned spacecraft which is long term running in LEO for space investigation and experimentation. Consequently, the long time running of the space station makes the demands of OOS become more frequent. The same as general satellites, the space station needs liquid supply and equipment maintenance and upgrade. In addition, it needs life maintenance as well, including oxygen and food supply for astronauts and maintenance of waste and carbon dioxide disposal system. Besides, in the early construction procedure, the demand for on-orbit assembly is more significant.

The reuseable manned spacecraft such as space shuttle and X-37B fulfills the tasks like spacecraft launching and on-orbit servicing. These spacecrafts also need on-orbit service, which contains emergency inspecting and repairing, e.g. heat insulation replacing, body crack mending and space salvation for accident.

2) Demands of different orbital location of spacecraft

The shape of spacecraft's orbit may be circular or ellipse and the inclination angle may vary between 0 and 180 degree. Furthermore, the height may be LEO (hundreds of kilometres~ 2000km), MEO (2000～20000km) or HEO (above 20000km) etc. Naturally, according to different parameter of the orbit, the demands are different:

Some general communication and reconnaissance satellites with simpler function and lower cost stay in LEO or MEO. These satellites' demands are limited, because the cost of executing on-orbit service is equivalent to that of launching new satellites. Nevertheless, the other highly cost spacecrafts in these orbits such as space station, space telescopes, scientific experiment cabin and navigation satellites etc. need more frequent OOS.

The satellites (mainly considering the communication satellites and tracking and data relay satellites (TDRS)) staying in GEO cost much higher than the ones staying in any other orbits, but the application is restricted by their limited lifetime which may be around 10 to 15 years. The length of lifespan is affected by the following aspects: the designed lifetime of payload equipment, the tough space environment and the limited fuel for orbit keeping. With the more application of highly reliable avionics, the influence of the former two aspects becomes less, but in contrary the one of the latter becomes more, which is the disability of fuel supplement. A well functional GEO satellite often has to retire due to the lack of fuel, and consequently the re-producing and re-launching of new ones has to carry out, which causes unnecessary waste. The problem could just be solved by on-orbit fuel supply which is one of the OOS function. Furthermore, because of the limited position of GEO, the abandoned satellites which can not recover or depart from the orbit independently need compellent deviating service. The deviating service is the special demand of the GEO spacecraft, which could be pulling the satellites into the higher abandon orbit or pushing them reentry to burn off.

3) Demands of different stage of lifetime (the spacecraft is already running, about to launch or designed for the future)

Without considering OOS, Some spacecraft already running on orbit has not been designed for OOS, e.g. there is not docking device on board, not facility to open the shell and not ORU etc. These spacecraft can only accept the service like orbit adjusting, keeping or deviating, which is the same as some satellites did with the help of CX-OLEV.

The demands of some spacecraft which has been produced and is about to launch is unpredictable and emergency. Once the injection is missed or the failure accurs, the OOS system with swift reaction will do adjusting or repairing work for the spacecraft in time.

In order to accept more OOS, the future spacecraft need more enable design including the zip-designed shell, the plug & play module, the orbital replacement unit (ORU), the docking device, the refuelable propelling system etc. The enable design enables the spacecraft to accept more OOS, and makes full use of OOS system to keep the long time running and unfailing for the targets.

3 Servicing mission analysis

1 Mission types

The service modes of executing the OOS include the following:

1) Motion: the target is moved through a prearranged path by the OSV for a certain reason. E.g. the orbit adjusting for mis-injected target and the deviating for the abandoned one.
2) Manipulation: the OSV does some operation on the target with physically connecting. E.g. the fuel supplement and the module replacement after docking.
3) Observation: the OSV acquires information from the target with a close range (without physically connecting). E.g. close observation and examination for the target.

The service mission types are constituted by the combination of the above modes (as table1).

Table1 Service types and their missions

Types		Missions
Service	Orbit keeping, adjusting or changing	Sending the target to the destination or changing its orbit according to need
	Orbit deviating	Dragging the failed and unrecoverable target off the orbit (to abandoned orbit or reentry)
	Space rescuing	Sending the target to the orbital service station or back to ground
	Life extension	Supplying the target with the fuel and the expendable
Maintenance	Checking with connecting	Checking and diagnosing the target scheduled or nonscheduled with physical connecting
	Checking without connecting	Checking and diagnosing the target in a close range without connecting
	On-orbit repairing	Diagnosing, adjusting or repairing the failed unit of the target
Assembly	On-orbit upgrading	Upgrading, updating or replacing of the ORU
	On-orbit assembling	Assembling the components of the target on orbit

2 Characteristics of different missions

The different effectiveness of different missions:

1) Life extension: including the service to extend the lifetime of on orbit system, e.g. fuel supplement, on-orbit repairing etc.
2) System upgrading: including the service to upgrade the performance of on orbit system via the importion of new technology, e.g. addition of new module and replacement of better performance module etc.
3) System adjusting: including the service to modify the system to meet the needs and to achieve new function, e.g. orbit changing, addition of payload.

According to the happening time, the OOS can be devided into two types: the scheduled and the emergency. Some service is scheduled because the demand accurs in a certain term according to which the service can be prearranged, e.g. the life extension service in the last stage of lifetime. The other is the emergency in order to serve the target in time whenever the random or sudden failure breaks out. Of course, some service may have different characteristc at different time it accurs. E.g. the ORU replacing service, in the beginning of the target lifetime may be the emergency, but in the end becomes scheduled. Table 2 shows the demands characteristic of different services [8-10].

Table2 the demands characteristic of different services

Service types		Characteristic	
		Emergency	Scheduled
Service	Orbit keeping, adjusting or changing	√	
	Orbit deviating	√	√
	Space rescuing	√	√
	Life extension		√
Maintenance	Checking with connecting	√	√
	Checking without connecting	√	√
	On-orbit repairing	√	√
Assembly	On-orbit upgrading		√
	On-orbit assembling		√

4 The Constitution of OOS System

The same as general space system, the OOS system is composed of ground system and on-orbit system. The former includes the launch vehicles, the launching system, the ground facility, command & control system and the ground part of communication system (e.g. ground observe and control system). The latter includes OSV, service targets and the orbital part of communication system (e.g. TDRS and navigation satellites etc.).

With the development of space technology, the new concept on-orbit system which goes together with the OSV will come into being such as on-orbit service station and on-orbit depot etc. with all of them, a more prompt space-based OOS system will be constituted such as orbital transportation system refered in literatures [11~12]. Considering the future development, the constitution of OOS system based on OSV is as the follow graph:

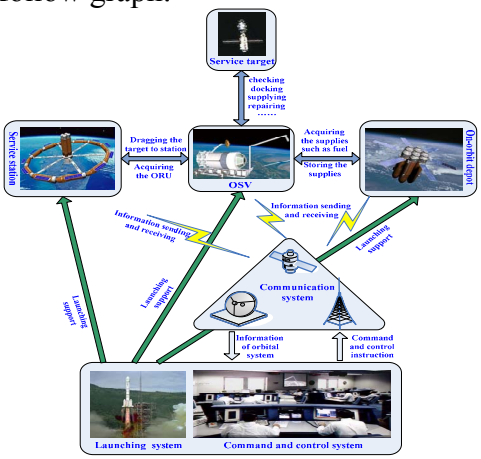

Fig. 1 the constitution of OOS system

The components's explanation is as follows:

1） The service target: the spacecraft or satellite enabled to accept OOS.

2） The on-orbit depot: a new concept spacecraft used for storing the supplies including the fuel, lubrication or other liquid consumable for both the OSV and the target. The depot must meet the need of the liquid supplies' storage requirement. Multiple depots can be located in different parking orbits.

3） The on-orbit service station: a spacecraft used for storing the ORUs & maintenance facilities and providing servicing sites. When necessary, the OSV can drag the target to the station for more complicated service or space salvation.

4） The communication system: it includes ground observe & control sites and centre and the space information network, taking charge of the transmission of the command instruction and the on-orbit status messages.

5） The command and control system: with various technologies and facilities based on computers, the system is used for mission control including the information collecting, transmiting, processing and the decision-making.

6） The launching system: it contains the launching site and the launching vehicle. The former is used for the spacecraft assemblying, storing, testing and launching, the flight trajectory testing, the control command transmiting and telemetry information receiving & processing. The latter generally means the launching vehicle which takes charge of the transportation from ground to space, including not only the launching of the target or OSV but also the supplement for the depots and service station.

7） OSV: as the main executor of the unmanned OOS mission, the OSV (the illustration in graph 2) performs the transportation between different orbits in space. According to different mission demands, the OSV can observe and check the targets remotely or dock with them for further operation. It can also drag the targets for orbit adjusting, changing, or deviating. Furthermore, it can drag them to the space service station for maintaining or to the depots for liquid supplement. Besides, it can acquire the supplies and ORU from the

depots, and take them together to the targets in order to implement automatic maintenance.

Fig.2 Illustration of OSV

5 Conclusion

In this paper, the service targets of OOS and their demands are analyzed, the different types and characteristics of the service mission are clarified, and the constitution and mutual relationship of the OOS system based on OSV are programmed. Considering the follow-up tasks, the program should be more detailed and optimized through the analysis of cost and effectiveness in order to construct a practicable system with high performance and low cost.

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