IAF'85

36th CONGRESS OF THE
INTERNATIONAL ASTRONAUTICAL FEDERATION
STOCKHOLM, SWEDEN, OCTOBER 7–12, 1985

Peaceful Space and Global Problems of Mankind

PREPRINT

IAF-85-43

SPACE-BASED SERVICING

This Preprint is for distribution at the Congress only

Published for the
International Astronautical Federation
by
Pergamon Press
Oxford · New York · Toronto · Sydney · Frankfurt

$3.00

SPACE-BASED SERVICING

Leslie A. Wickman

Lockheed Missiles & Space Company
0/53-30, B/580
1111 Lockheed Way
Sunnyvale, CA 94086
USA

One of the most viable economic and ideological justifications for a permanent, manned Space Station is the concept of on-orbit servicing of spacecraft and payloads. The capability to extend and enhance operational lifetimes of earth-orbiting experiments at a space-based facility offers tremendous benefit to federal and commercial interests alike, the scope of which is just beginning to be comprehended.

The variety and number of spacecraft and experiments orbiting the earth will increase dramatically over the next decade, according to NASA forecasts.[1] Considering the cost of launch to orbit at approximately 7000 US dollars per kilogram for a Space Shuttle-deployed spacecraft,[2] combined with vehicle fabrication, assembly and verification costs, an orbiting service facility could anticipate a substantial market from otherwise expendable/replaceable spacecraft.

These potential customers of space-based servicing run the gamut from earth-observing satellites used for meteorology, geology, agriculture and other information-gathering endeavors; to astrophysical observatories studying light sources in both visible (e.g., Hubble Space Telescope) and nonvisible (e.g., Gamma Ray Observatory, Advanced X-ray Astrophysics Facility, Space Infrared Telescope Facility) wavelengths; to pharmaceutical, microprocessor, and other high technology materials processing units; to communications satellites; to technology development experiments in such diverse fields as environmental effects on materials performance, fluid management in zero-gravity, and on-orbit assembly techniques; to life sciences laboratories adjoined to the Space Station itself. In the case of each of these types of payloads, numerous servicing operations can be performed on-orbit which would in some way improve the payload's output, increase its useful lifetime, or both.

The concept of on-orbit servicing has come a long way since the first significant demonstration of its utility so dramatically established its necessity on the Skylab mission. The successful repair of the several mission-threatening problems with the solar arrays, thermal control and attitude control systems conslusively proved the value of on-orbit servicing, especially when coupled with man's innovativeness. Today, the potential of on-orbit servicing reaches far beyond limited emergency rescue missions. NASA now has two more successful repair missions to its credit (Solar Maximum Mission, 1984; Hughes LEESAT, 1985), and this overall track record has encouraged the designers of many new satellites to consider servicing to be an integral part of their spacecrafts' operational plans. The Hubble Space Telescope, scheduled for launch in 1986, is the first spacecraft designed for extensive on-orbit servicing to be performed as necessary during planned maintenance missions scheduled at periodic intervals throughout its projected lifetime. As could be expected, many lessons have been learned in designing, building and testing the first of a new generation of spacecraft in terms of making the various parts of the vehicle's subsystems safely accessible and replaceable on-orbit by a pressure-suited astronaut, and many more lessons will be learned during the actual maintenance missions. As a result of these lessons, numerous money-saving design precedents have been established for future serviceable spacecraft.

In the case of Space Telescope, the project's maintenance philosophy is based on the changeout of orbital replaceable units (ORUs). Therefore, every critical appendage, instrument or piece of equipment which could conceivably fail, become obsolete, or outlive its mission during the Telescope's projected lifetime, was made into an ORU: by definition, easily and safely replaceable on-orbit by an extravehicular (suited) astronaut.

The ORU changeout philosophy provides for a number of payload enhancements. The most obvious enhancement, of course, is replacement of failed units to allow continuation of the mission. Additional enhancements include the replacement of existing units with newer, upgraded equipment to improve mission performance, and the replacement of existing mission hardware with hardware that will perform an altogether different mission.

However, a full-blown on-orbit maintenance and refurbishment capability would offer many services in addition to the changeout of ORUs. The ability to replenish consumables, for example, is one service that would greatly extend the operational lifetimes of many earth observation and communications satellites which become useless simply because they run out of propellants for attitude control and altitude maintenance. In addition to refuelling, the replenishment of consumables refers to the resupply of other fluids such as cryogens and pressurants, as well as to the resupply of raw materials for materials processing units, and even to the resupply of food and water to the life sciences experiments.

Another category of services offered by a fully-equipped orbital servicing facility would be general maintenance. This would include refurbishment of degraded components (such as cleaning of optical surfaces), optical realignment, instrument recalibration, purging of scientific instruments, mechanical adjustments, and other operations of this nature.

The next category of services that should be mentioned is that involving on-orbit assembly. On-orbit assembly has a variety of applicaitons, several of which are identified here: construction of spacecraft which are too large to fit inside the Space Shuttle's payload bay and/or too fragile once assembled to sustain the loads imparted by an earth-based launch; on-orbit mating of payloads with orbital transfer vehicles (OTVs) or upper stages; structural modifications or additions required to reconfigure spacecraft for the performance of alternate missions.

The final group of services that a mature orbital servicing facility must be capable of providing is repair of failures. Excluding repairs accomplished by way of ORU changeout, this category covers unplanned servicing and servicing to a lower level than the ORU. This might include structural patching or welding to repair damage caused by collision with another orbiting object, or the replacement or intricate repair of a component or piece part inside an ORU. Unplanned servicing involves responding to the same types of emergencies as were encountered on the Skylab mission. However, with an extensive space-based servicing facility, many, if not most, of the emergencies could be reduced to contingencies, having been either experienced before or anticipated in advance, and provided for accordingly with appropriate materials and equipment. Planned maintenance enables a more efficient response, but emergencies and surprises will always arise, and for that reason man's presence and innovativeness on-orbit is especially valuable.

There are numerous economic and operational advantages which derive from on-orbit servicing, some of which have been implied in the preceding paragraphs. These and others will be explored in more detail here.

The most readily apparent of these orbital servicing advantages is the ability to achieve a longer spacecraft operational lifetime through on-orbit replacement, replenishment and repair, rather than having to either return the spacecraft to earth, service it, and relaunch it, or simply expend the spacecraft in its entirety. With regard to cost effectivity, ground-based servicing offers substantial savings to spacecraft in low earth and sun-synchronous orbits ($420,000 per tonne spacecraft mass per operational year for spacecraft in low earth orbits, $770,000 per tonne per year for sun-synchronous spacecraft)[3] over purely throwaway spacecraft, but on-orbit servicing offers significantly greater savings ($1,060,000 per tonne spacecraft mass per operational year for spacecraft in low earth orbits, $1,960,000 per tonne per year for sun-synchronous spacecraft, and $4,140,000 to $4,830,000 per tonne per year for geosynchronous spacecraft, depending on whether the service was performed at the Shuttle or a permanent Space Station, with Space Station-based servicing being the biggest cost saver)[3] over expendable spacecraft to satellites in a wider range of orbits, primarily because the cost of relaunching the serviced satellite from earth is avoided.

Another economic advantage of orbital servicing is lower acquisition cost of satellites. This is because a vehicle that can be routinely serviced requires fewer costly redundant systems, and can tolerate greater risk in design and developmental stages. Along these same lines, higher satellite reliability can be realized via test and checkout of all vehicle systems in proximity to the servicing base prior to deployment.

Additional economic and operational benefits of on-orbit service include the achievement of improved spacecraft performance and optimized science through instrument/equipment upgrades, and the concept of the reusable spacecraft, which can be repeatedly reconfigured to perform mission after mission consecutively.

Conversely, there are some significant disadvantages to ground-based servicing which make the case for on-orbit servicing all the stronger: a spacecraft being returned to earth risks structural damage and severe contamination during the return trip and ground handling operations, and the time required to requalify a spacecraft for flight may be unacceptable in terms of the mission schedule and objectives.

Now that the advantages of on-orbit servicing have been expounded, let us take a look at Space Station- versus Shuttle-based service.

As mentioned parenthetically in the preceding text, considerable economic savings can be realized by servicing geosynchronous satellites using a permanent Space Station rather than the Shuttle. This cost savings accrues due to the fact that Station-based servicing does not require a half- to a wholly-dedicated Shuttle flight. The savings also applies to the service of all other earth-orbiting spacecraft in nearby inclinations to the Space Station when they are in nodal coincidence with the Station. If a significant plane change has to be made to rendezvous with a satellite and again to retrieve it to the Station, any potential savings over direct insertion of the Shuttle gets eaten up in OTV propellant.

Another major benefit of Station- over Shuttle-based service is time availability. The Shuttle's present baseline capability allows it to stay on-orbit for an outside maximum of thirty days with the average stay being seven, and for the typical mission it carries enough extravehicular mobility unit (EMU, or spacesuit) expendables for just two two-person six-hour extravehicular activity (EVA) sessions. In contrast, the Station will be on-orbit continuously and provide the capability to perform multiple consecutive EVAs. These factors will lead to less criticality of Space Station servicing timelines, which translates into fewer resources being spent on verification of procedures and training.

One more time-related benefit of Station-based servicing is the ability to provide a fast response to contingency or emergency servicing needs of attached and co-orbiting payloads. In some situations, this could make the difference between salvaging or expending an entire payload.

Because of the respective missions of each of the two space systems, Space Station will boast a much larger resource base to draw on for servicing operations than the Shuttle was designed for in terms of power (initial Station is planned to have 75 kW available versus the Shuttle's maximum of 8.5 kW), thermal control, data management, long duration attitude/altitude maintenance, an orbital maneuvering vehicle (OMV)/OTV depot, and large and diverse stores of consumables and spares which will be accumulated on-orbit via regularly scheduled Shuttle resupply flights.

Likewise, the Station will have dedicated servicing facilities far more extensive than what the Shuttle is capable of carrying to orbit for a servicing mission (let alone considerations of practicality). These extensive servicing facilities (the capabilities of which were discussed previously in this paper) should be built up at the Station over a period of about ten years and will initially consist of: a servicing berthing port with tilt and rotate capability and a standard electrical umbilical interface; a spacecraft storage port for vehicles awaiting service or launch; fluid storage tanks and a refuelling system at a berthing port away from the servicing and storage ports to avoid contamination of payload instruments and optics; a contamination monitoring system; OMVs, docks, and special function kits; storage lockers for ORUs, instruments, and tools; a mobile remote manipulator system; manned maneuvering units; zero-prebreathe spacesuits (for quick-response EVA); crew mobility and restraint equipment: spacecraft diagnostic and test equipment; closed circuit television monitoring system; work area lighting; EVA terminals with access to the data management system; adjustable spacecraft sunshades; heaters; and a pressurized workbench in one of the laboratory modules for more intricate and complex servicing tasks which can be performed on items small enough to be brought inside through an airlock.

The Station's facilities will continue to grow as the market develops to include the addition of: fully-outfitted, thermally controlled hangars at the servicing, refuelling, and storage/coincidental service ports housing the large collections of servicing equipment for convenient accessibility; increasingly automated and robotic servicing systems to relieve the crew of hazardous and tedious tasks; a contaminant/spill cleanup system; OTV and hangar; a large space structures assembly/service platform; and ultimately perhaps a pressurized hangar providing astronauts a shirtsleeve environment to work on entire spacecraft.

It can be seen from the lengthy description of proposed Space Station servicing facilities and capabilities that the Station will be far better equipped to handle a larger volume and variety of servicing jobs than the Shuttle was ever intended to handle. However, the Shuttle will retain its essential roles as logistics vehicle to the Station, contingency servicer of low earth orbit satellites in nearby inclinations to the Station at non-optimum times for Space Station access, and servicer of low earth orbit satellites not in nearby inclinations to the Space Station.

Space-based servicing offers spacecraft owners and users a valuable resource for improving the return (both economic and operational) on their investments. But in order to optimize that return, spacecraft designers and servicing technology developers must work together now to encourage the standardization and modularity of spacecraft designs, and the adaptability of servicing technology to accommodate the wide variety of potential customers. Only then can the full potential of space-based servicing be realized.

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