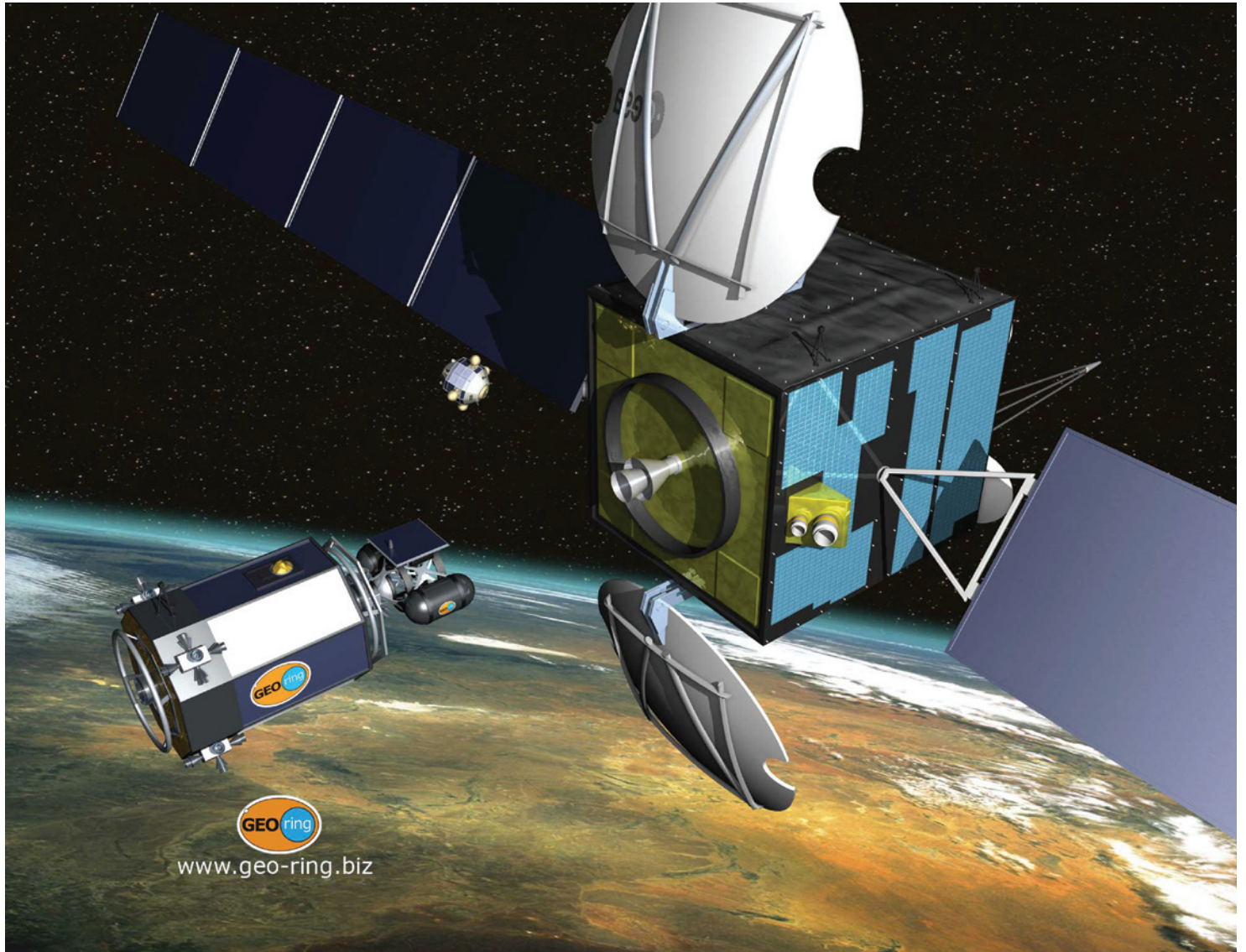




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On-Orbit-Servicing by

HERMES On-Orbit-Servicing System

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Certain timely “in-situ” help for satellites (on-Orbit Servicing or OOS) is more than desirable when problems arise. HERMES OOS defines a new and patented architecture based on a symbiotic philosophy with the client base and has established a policy robust planning. It starts on ground with a minimalistic approach for enabling refueling services on-orbit, since refueling is seen as the most promising OOS service. The necessary hardware for enabling the service is now available. It consists of a specially designed quick disconnect (QD) accessory, the HERMES QD. This QD can be fixed on top of any fill & drain valve, rendering the carrying satellites repeatedly refuelable without the need for any other modification. Such application of the HERMES QD on satellites will open a host of new opportunities that in aggregate we call the “HERMES Fuel-Trading System” (HFTS). The small (20 gram) HERMES QD can effectively eliminate the need for a dedicated tanker spacecraft since any spacecraft carrying the HERMES QD can also perform the function of the tanker spacecraft. Given the high initial costs for developing the infrastructure needed for OOS such simplification is currently considered indispensable.

A. The mission scenarios:

Certain fuel transfer scenarios on-orbit are envisaged that make the deployment of the coupling a priority:

1. Extracting fuel from a damaged satellite

Total-loss-failure events in the last decade include at least 15 satellites that have had a type of failure that renders the satellites commercially a total loss, but still in a condition that would enable defueling to take place (temperature under control, attitude under control, one transponder functioning). These are the ideal candidates for initial low risk defueling operations.

2. Extracting fuel from overfed satellite

Satellites that are launched directly to GEO could be overfed wrt propellants & pressurant gas they carry with them. Satellites that are launched in this way they normally carry only the amount of propellant that is required for station keeping which is 20% of the useful volume of the propellant tanks. Topping up a single satellite that goes directly to GEO would mean it would carry a surplus propellant load equivalent to the propellant budget of 4 satellites of the same size.

3. Extracting fuel from Upper stages.

Due to potential concerns wrt approaching new assets of high value on orbit (scenario A.2) an alternative way would be to get the propellant from the upper stage that is anyhow a disposable item.

4. Extracting safety margin fuel.

Launch injection at GTO/GEO, is always very hard to predict accurately. This uncertainty means technically that a fuel margin could be the right mitigation solution. However, financially, such a solution would entail a sizeable cost. Recovery of this cost would be on a very distant point in time (after 12 years) on the condition that the satellite would still be operational and that it would still have a market. Such a distant eventuality deters operators to opt for a sizeable margin wrt propellants. However if they would also have the choice to sell the excess fuel on-orbit, they could opt for such a margin.

Certainly this proposition will not find many advocates before we record significant evidence of successful defueling/refueling operations. However, as many other options exist for performing such demonstrations we believe this milestone will arrive soon.

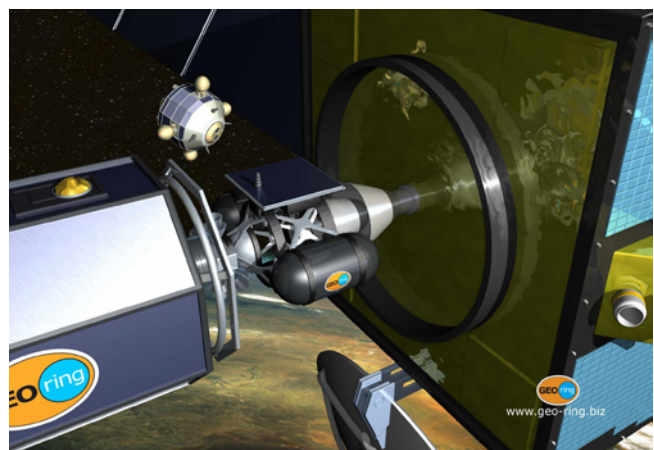
5. Passivation of spacecraft

The recommended practice to passivate spacecraft could be modified for becoming a resource transfer action and especially for pressurant gas.

Likewise, empty S/Cs can serve as temporary storage vessels in case the primary propellant holding vessels would need to be emptied fast (degradation of power subsystem, risk or losing also the spare processor, ...).

B. The Elements :

The elements of the complete HERMES OOS system at full deployment are five (Utility Base, Utility Agent, Escort Agent, Kinitron® and Orbit Raising Module). However, only a UA is necessary for starting up the operation. The remaining 4 elements enhance functionality and efficiency of operations. They are designed so that more difficult cases of servicing can be realized, such as serving satellites of current design that do not have the HERMES QD coupling, or future satellites that would be designed in a modular fashion consisting of an orbit raising module and the rest being a satellite with ion based station-keeping thrusters.



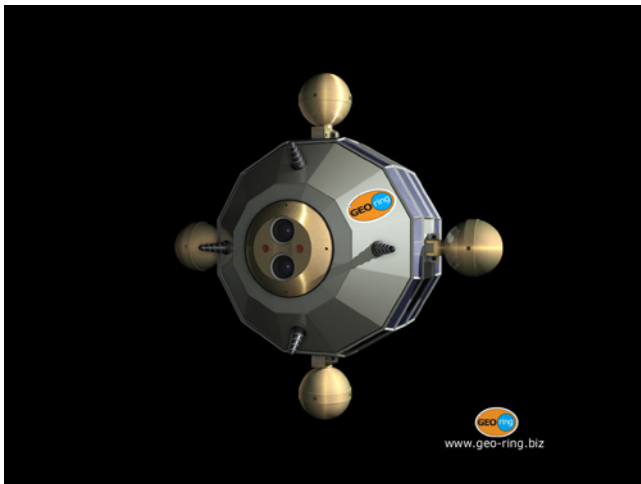
1. The Utility Agent

Is a small (250-300 kg) autonomous space vehicle equipped with a single robotic arm for connecting an “Agent-half coupling” to the F&D valves of propellant donating or receiving spacecraft, for further performing extraction or delivery of propellant. A version without the robotic arm would be capable to deliver Kinitrons® to client satellites. It will have capability to carry one or more Kinitrons® when they will become available. Several versions are envisaged with variations in the carried accessories and propellant capacity.

2. The Utility Base

Is a large spacecraft designed for second-tier maintenance operations equipped with robotic manipulators. It is stationary at a convenient place at GEO and functions as a store place of resources and spares for UAs, EAs and Kinitrons® and as their parking place. Its exact configuration will be dictated by market forces.

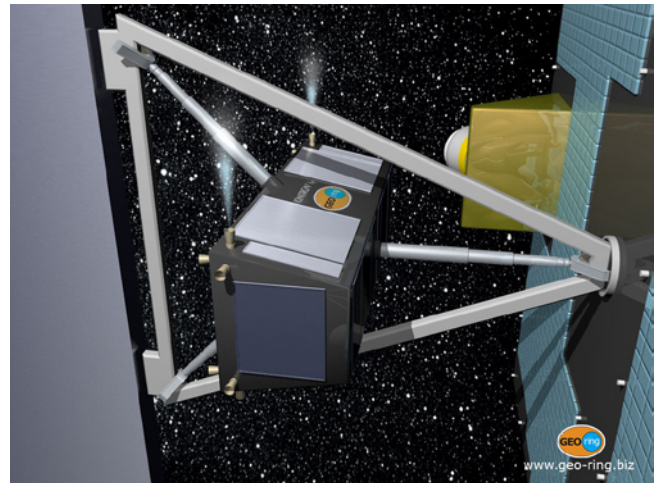
3. The Escort Agent



Is a miniature (7-15 kg) highly compact free-floating inspector. It is usually carried by a UA for long trips and is deployed close to the inspection target. It can perform risk free close-up inspection and relays video feed with wireless technology to the UA. Its propulsion is based on heated-gas MEMS-technology based microthrusters.

4. The KINITRON®

Is a spacecraft having the role of an orbital replaceable unit (ORU) with propulsion function and can be carried by a UA for placement on a client satellite. Its function is to provide externally induced thrust. It is useful in cases where we cannot perform refueling. It comes in two versions as regards placement interfaces. One is designed for mounting on Apogee Engine nozzles and the other for mounting on a solar panel bracket. In both cases the composite thrust vector needs to



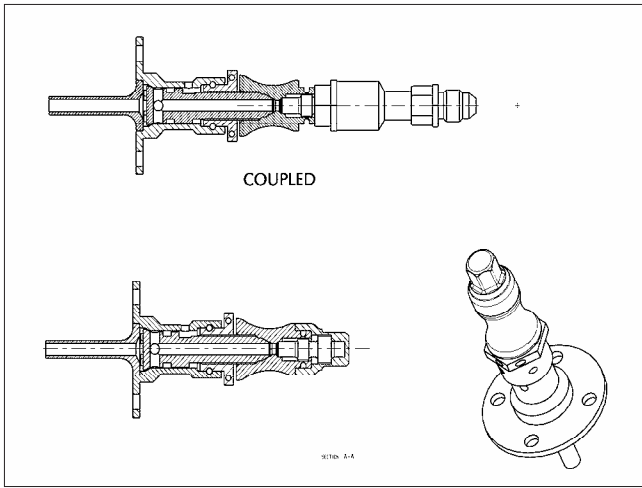
be driven through the CoG of the client satellite. The Kinitron® is sized for performing station-keeping duties for about 8-10 Months and has 60-70 kg total mass. After the 10 months it is being refueled

5. The Orbit Raising module (ORM)

In the assumption that the future satellites will have two separate propulsion subsystems, one for Orbit Raising (chemical propellant based) and one for station keeping (ion engine based) there is high probability that future satellites will be constructed in a modular way. The ORMs will be specially designed to cater for docking of UAs and separation at GEO for further towing to a disposal place. This modular design and the availability of the towing service or ORM will result in timely elimination of the nonfunctional mass of a satellite (30%) when on orbit, without the risk of creation of debris.

C. The coupling

The need for a special coupling stems from the fact that each connection-disconnection cycle, as currently being performed on ground with the current type of available valves, entails a minimal but important leakage of propellant that is isolated in the closure between the recipient valve and the delivery hose valve. This leakage is in the range of 2 sq. cm. and necessitates the purge & decontamination-



passivation process that is performed with the help of the apparatus of the filling-cart. However, in space such filling-cart would be impractical and any purging operation would be impossible if one considers the lack of separation walls and lack of decontamination-passivation equipment. Consequently any leaking during the disconnection process would constitute a highly harmful event dangerous both to the client satellite and to the servicing vehicle, given the need for presence of optics on UA (deposition contamination sensitive) and presence of gears (corrosion sensitive) for the mechanisms of the robotic arm and of the “Agent-half coupling” manipulator.

The coupling consists of two halves, the “Client-half coupling” that is mounted on the client satellite, ideally before launch, and the “Agent-half coupling” that is to be carried by the UA.

D. The Symbiotic nature

The core characteristic of the HERMES-OOS system is the design of each of the 5 constituting spacecraft elements under the objective of maximizing the reuse of materials and/or functionality of the satellites at GEO. Therefore drastic reduction is achieved on the

absolute minimum of the functionality needed by the servicing vehicle(s).

Given the abundance of bandwidth on a telecom satellite, virtual presence of many tele-operators is possible with the mere introduction of video-capture apparatus on the servicing vehicle. The latter in some cases needs nothing but a feeder connection out of the star-tracker-camera-read-out electronics of the UA.

The captured video stream is then transmitted at low power (1-3 Watt) to the client satellite in proximity, and then, after being amplified there, is retransmitted to ground based operators. This indirect transmission mode is catalytic. Given the virtually unlimited bandwidth of a telecom satellite, virtual-presence of operators will establish a new norm in designing service operations.

E. The Patents

The enabling technologies of the above architecture are innovative and have been patented by a series of patents and further pending patent applications.

The concepts that have been patented include: the use of the client satellite to relay signals, use of client satellite to relay telecommands through the telemetry. Further patent pending concepts include: use of the client satellite to relay telecommands through manifestation of execution of standard commands, a modular GEO spacecraft comprising an orbit raising module and an actuator arm for use on a spacecraft for capturing and fetching operations.

The breadth of the patented concepts covers the entire mission life of satellites. Some concepts are directly applicable to existing satellites requiring no modification, while others are applicable only to future satellites and they require radical redesign. However, one needs to retain that HERMES offers solutions both for the current satellites and to the future ones.

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