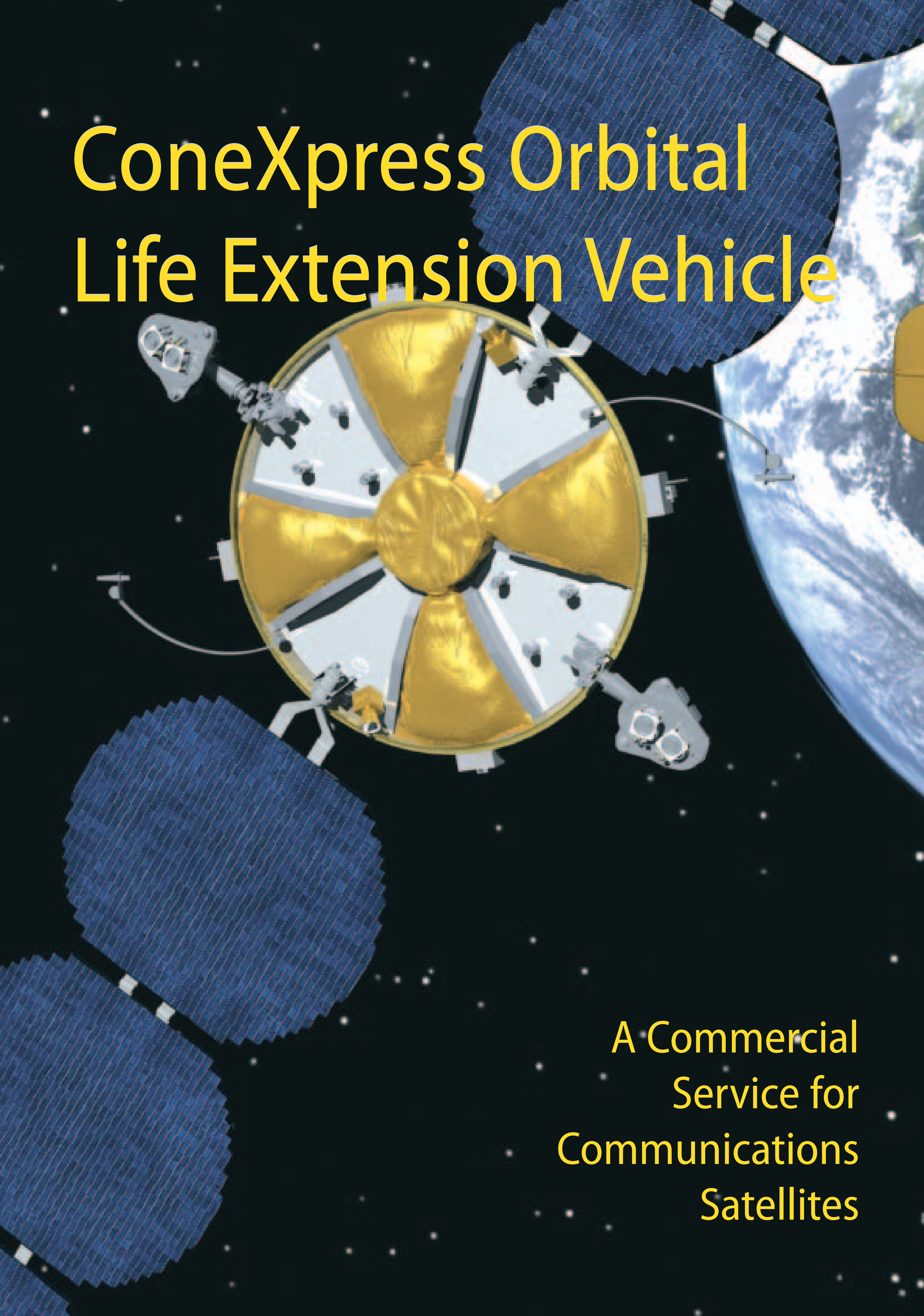
ConeXpress Orbital Life Extension Vehicle



A Commercial Service for Communications Satellites

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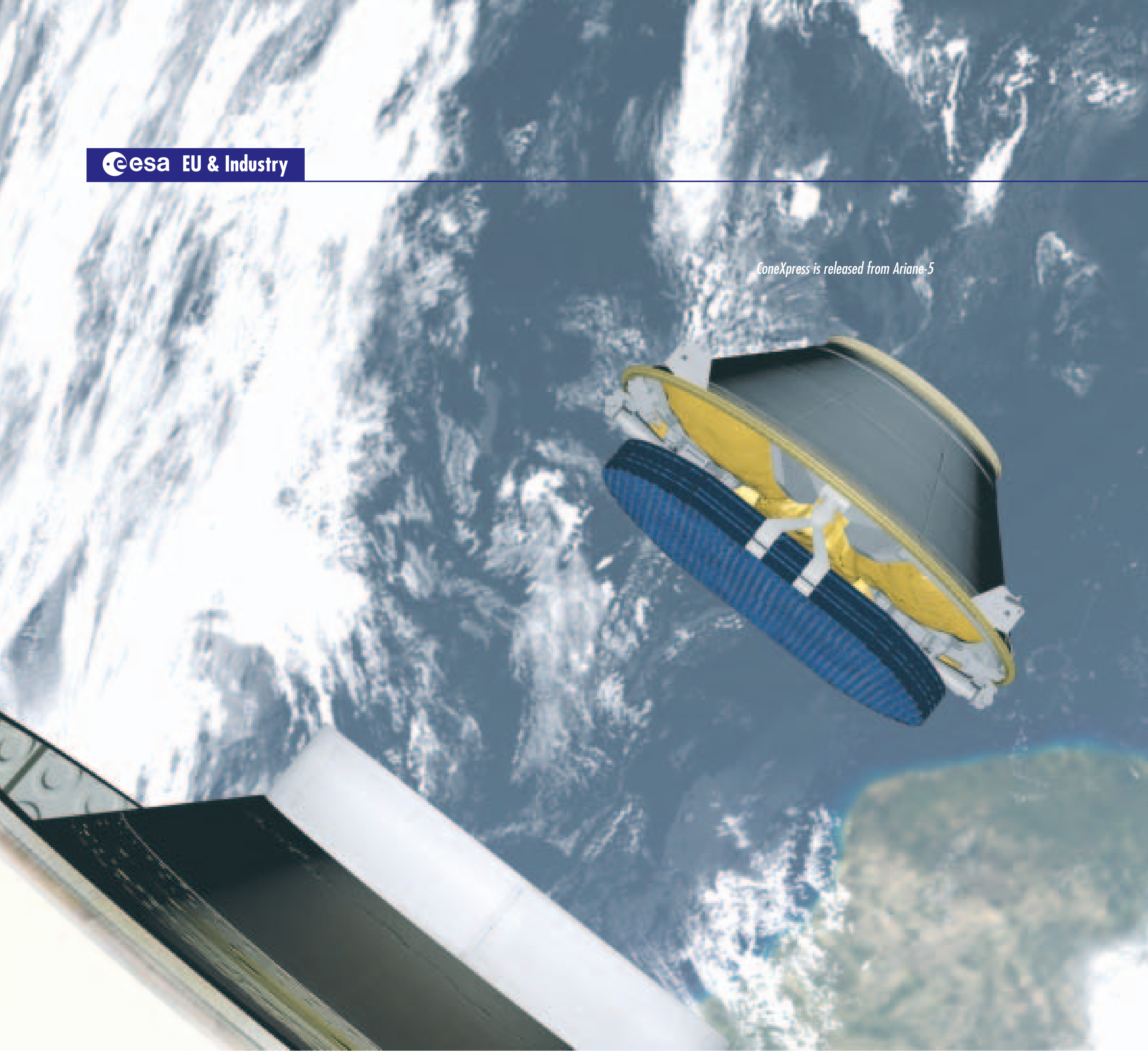
Telecommunications satellites are designed for useful lives of 10–15 years before they are 'junked' when their propellant runs out. This is a waste of huge capital investments, because all or most of the satellites' revenue-generating communications payloads is still functional. The ConeXpress Orbital Life Extension Vehicle is a novel spacecraft that will significantly prolong the operating lives of these valuable satellites. Launched aboard Ariane-5, it is designed to dock with a satellite and operate as an orbital 'tugboat', supplying the propulsion, navigation and guidance to keep its host in the proper orbital slot for many more years of revenue-earning service.

Introduction

The ConeXpress Orbital Life Extension Vehicle (CX-OLEV) can extend the lives of large geostationary satellites for up to 12 years beyond their original productive lives. It can also recover satellites launched into incorrect orbits, move them along the orbital arc, or manoeuvre them into to a disposal orbit. ConeXpress is a wholly European initiative and it is the only commercial on-orbit servicing project in advanced development. This on-orbit service market is being pursued by Orbital Recovery Limited (ORL) of the UK.

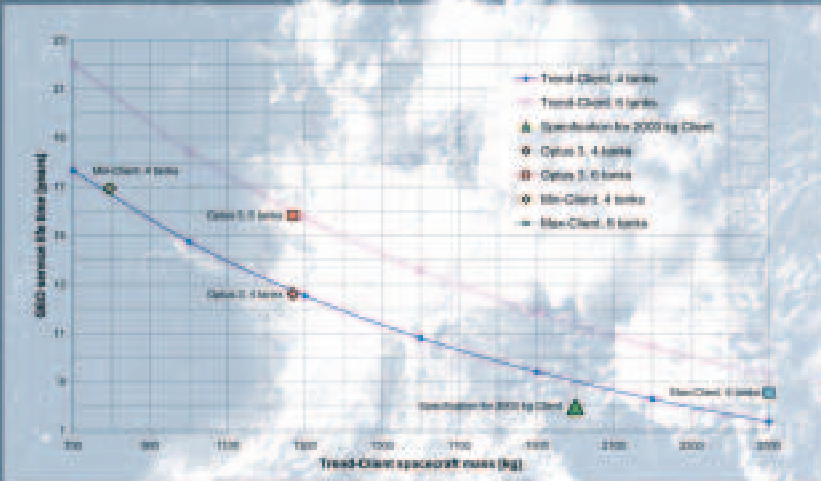


ConeXpress is released from Ariane-5

ConeXpress is an innovative concept tailored around Ariane-5 to enable affordable missions to high orbits such as geostationary (GEO) or even deep space using a lunar flyby. ConeXpress exploits the spare capacity of Ariane-5 under the primary satellites. It uses the standard Ariane-5 conical payload adapter as its main structure. This creates a uniquely versatile satellite with ample capacity for high-orbit missions at exceptionally low prices – about €35 million in orbit (plus the cost of building the payload). The enabling technology is electric propulsion, which has been successfully demonstrated by ESA's SMART-1 mission to the Moon. Indeed, ConeXpress has significant heritage from SMART-1, including the propulsion system, computer, databus and thruster-pointing mechanism.

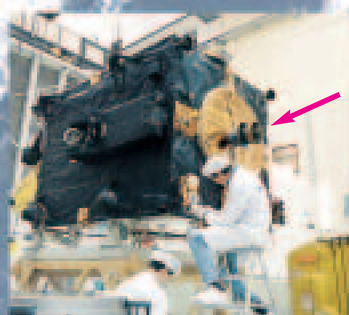
The idea of servicing and extending the lives of ailing satellites is as old as the space industry itself: NASA performed extensive studies in the 1960s and 1970s; ESA studied a Geostationary Service Vehicle in the 1990s; The German-Japanese Getex/ETS-VII docking experiment was successful in 1999; and ESA's Robotic GEO Orbit Restorer (ROGER) studies were performed in 2002–2003.

NASA and the US Air Force have conducted demonstration missions of rendezvous and docking in recent years: DART and XSS11. Further orbital servicing efforts are under way at the US Department of Defence, notably the Orbital Express project. However, all of the above efforts are restricted to research and development. The commercial servicing envisaged by ORL is unprecedented, and several years ahead of any competitors. ConeXpress is also unique in that it can dock with 'uncooperative targets' – satellites that are not designed for docking. To do this, it exploits a feature common to almost all GEO satellites: the apogee engine, using the inert nozzle as a docking port. ConeXpress captures the satellite by inserting and locking a probe in the nozzle's throat and then retracting the probe until the two craft are firmly lodged against each other.

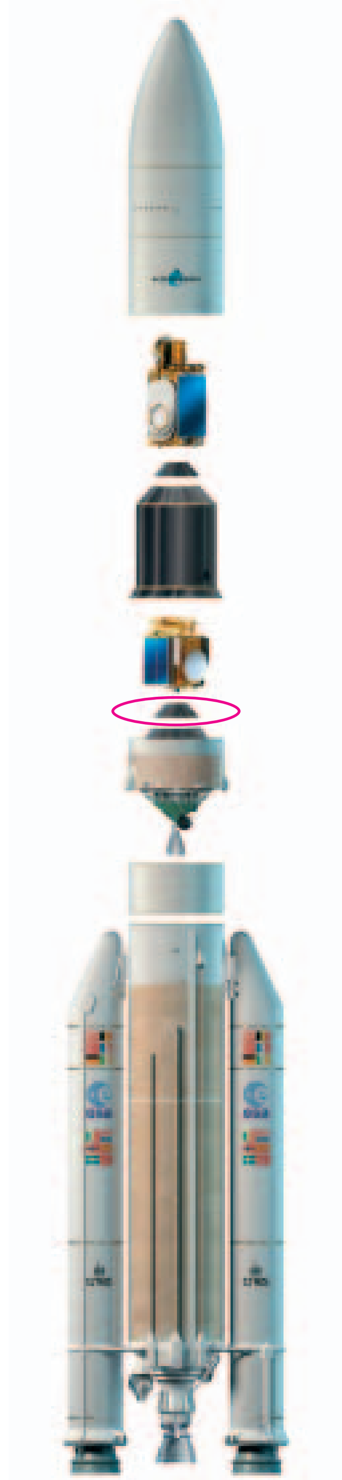


Achievable orbital lifetime extension as a function of the client satellite's mass at the time of docking. The design specification shows that the life of a 2 tonne satellite is extended by about 8 years. The diagram assumes routine N-S and E-W stationkeeping only, without GEO relocation or major inclination manoeuvres. Optus is an Australian communications satellite that may be an early customer of the service. The '4 tanks' and '6 tanks' refer to the number of xenon propellant tanks carried by ConeXpress

Ariane's payload adapter outfitted as the ConeXpress free-flying spacecraft



ConeXpress docks with the satellite's nozzle (arrowed)

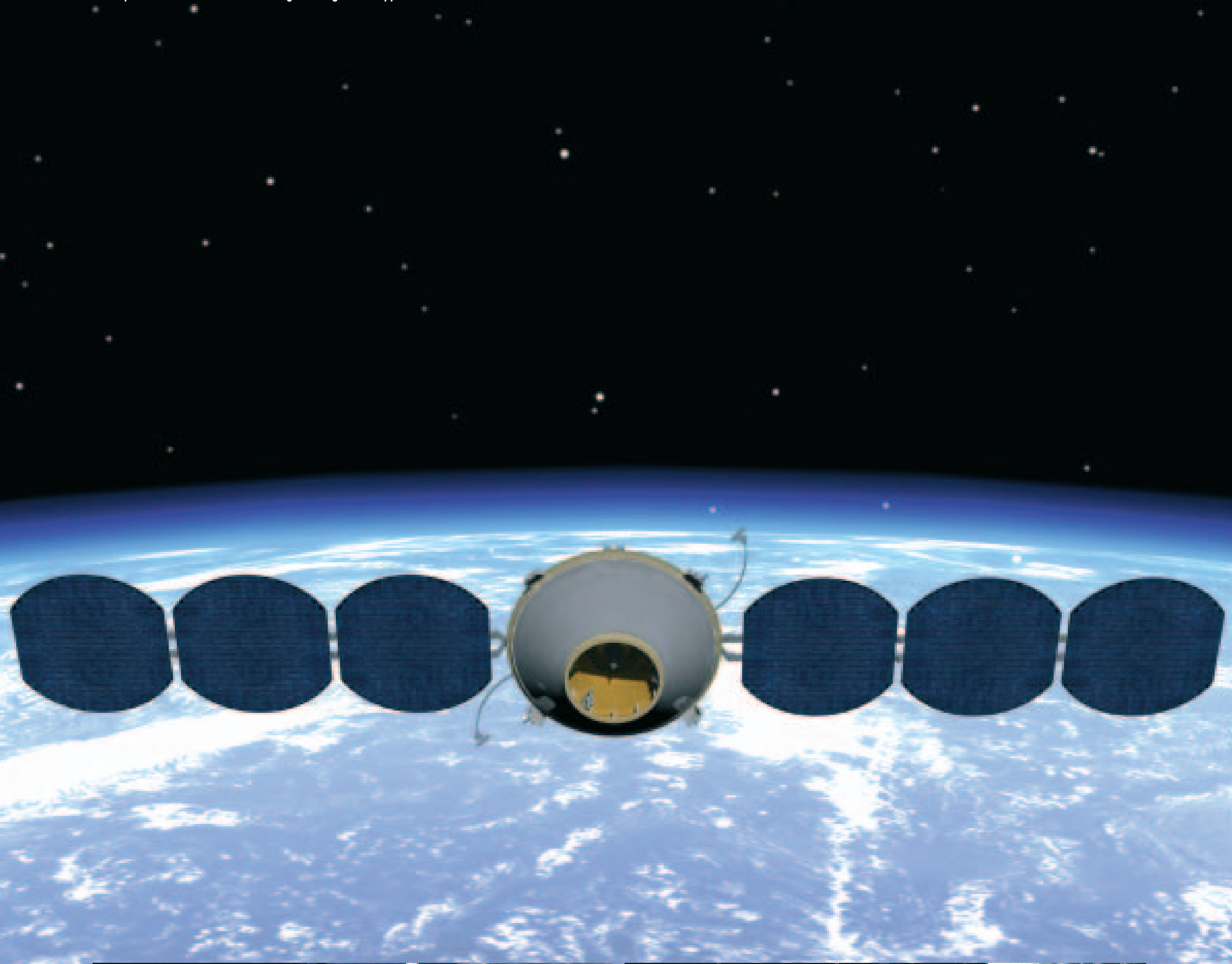


Market Aspects

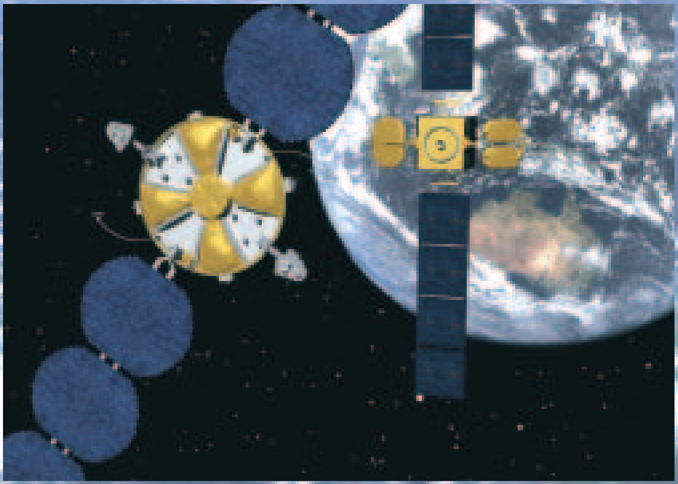
Orbital Recovery Ltd has established a preliminary business plan for CX-OLEV. It considers only commercial communications satellite clients of high value, because these are a tangible and well-defined set with much information publicly available. The addressable market for CX-OLEV is larger and includes institutional programmes for science, Earth observation and military applications. More than 60 commercial telecommunications satellites will reach their ends of life through lack of propellant before 2009, representing a value of around €13 billion. Another market potential is the less predictable early failures of propulsion and attitude-control subsystems. Statistically, one geostationary satellite suffers such a failure every 18 months. ConeXpress offers a way to rescue these satellites and extend their useful lives by several years.

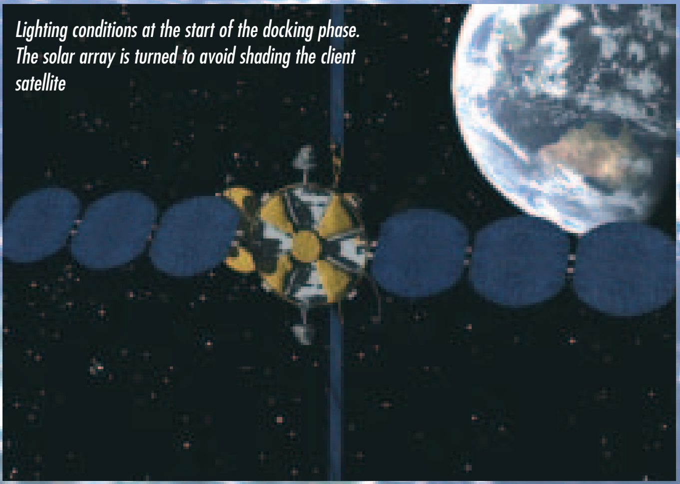
Lengthening the lives of satellites running out of fuel is of interest to their owners, while rescuing satellites suffering early failures is frequently an issue for satellite insurers, making both operators and insurers potential customers. ORL projects that 10% of the initial total addressable market may be captured, and assumes an average of two missions per year. Market limitations result from the expected initial slow take-up rate.

At the end of the 1990s, there was a surge of GEO communication satellite launches and these craft will reach the



ConeXpress manoeuvres behind its target to begin final approach





Lighting conditions at the start of the docking phase. The solar array is turned to avoid shading the client satellite ends of their fuel-limited lives from 2010 onwards at a rate of about 20 a year. ConeXpress is planned to be ready to harvest this rich market. Various operators have declared their interest in using ConeXpress to develop new businesses by exploiting cheap, second-hand satellites. This could be more efficient than the current practice of using small satellites to develop the market and large satellites to exploit the mature market or to continue inclined-orbit operations. Operators are also interested in risk-mitigation in unclear market situations and in using ConeXpress as a new tool for their fleet management. Discussions with potential clients have revealed some added-value for ConeXpress users, over and above life extension, such as:

– orbital slot protection using ConeXpress in free-flying mode;
– repositioning along the GEO arc;
– restoration of orbital inclination and orbit-node position;
– creation of a second-hand satellite market by using old satellites for services to developing regions.

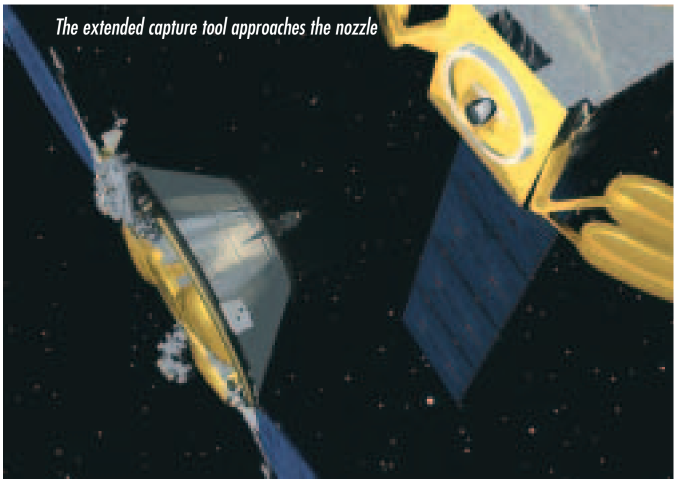
Today, there is no competitor on the market to ConeXpress, and there is none under development. It is a pioneer in commercial orbital servicing. In the future, there will be an even larger market following the introduction of satellites designed for refuelling or equipment exchange.

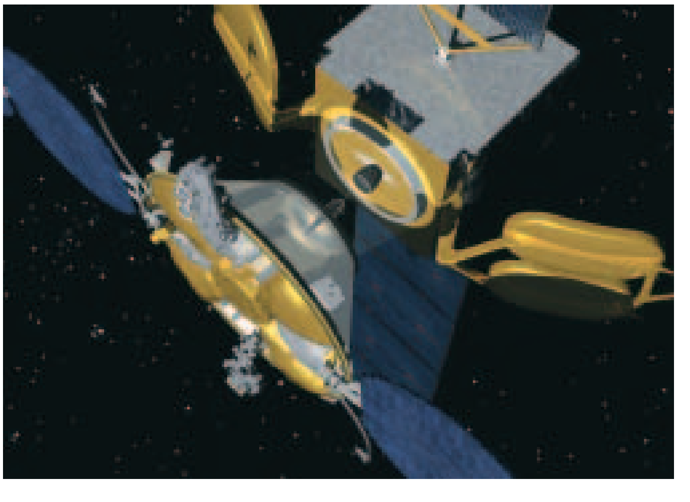
Mission Description

ConeXpress will be launched as a standard payload adapter in the bottom position of the Ariane-5 payload stack, filling the vehicle's spare capacity after accommodation of its primary satellite payloads for launch into geostationary transfer orbit (GTO). Using the payload adapter creates a uniquely powerful auxiliary satellite with ample capacity for high-orbit missions at a very low cost. ConeXpress then uses electric propulsion to raise the orbit from GTO to GEO. Electric propulsion is compact and lightweight in comparison to traditional chemical thrusters. The transfer lasts about 6 months and is optimised for minimum duration by using continuous thrust from two parallel electric thrusters burning simultaneously. ConeXpress carries four of the same PPS-1350 80 mN thrusters as SMART-1. Swung out from 'under' the bus on orientation mechanisms, they are paired for redundancy.

Rendezvous and docking is divided into three separate phases: final transfer, rendezvous and docking. The final transfer relies on conventional ground-based ranging for independent position determinations of ConeXpress and the client satellite. During rendezvous, ConeXpress cameras relay images of the target to the ground for highly accurate relative position determination. ConeXpress attaches itself to the satellite's zenith side (the anti-Earth face), allowing the client to continue uninterrupted service. The solar arrays of ConeXpress point east-west to minimise any shadowing of the target's north-south arrays. Two docking cameras create a stereo image to assist the ground operator in steering ConeXpress. Closer in, a xenon cold-gas system orientates it. A capture tool on a deployable and retractable boom is inserted into the target's inert nozzle and locked. The boom is then retracted to pull the client onto the ConeXpress support mechanisms to create a rigid mated structure. Rendezvous and docking require typically 36 hours, timed to ensure ideal illumination conditions for safe docking. Closing in, ConeXpress moves from in front of the satellite along an elliptic trajectory to a zenith position. At this point, it rotates 90º to orientate its solar wings east-west, eclipsing the target's array by less than 2%. After docking, ConeXpress commands and telemetry are routed via a dedicated S-band station at the client's command centre.

ConeXpress is designed for up to 12 years of operations in or near geostationary orbit. The service life for a particular mission depends on the mass of the client satellite and the type of operations required. The mission concept avoids the risky aspects envisaged in more advanced future automated servicing scenarios. For example, docking is under manual control until the capture tool is in the cone, when it is automatically centred


The extended capture tool approaches the nozzle



using internal lasers. Nor are their any robotic arms or manipulators.

ConeXpress is designed for docking and undocking to allow multiple missions. Once it has transported the satellite to a graveyard orbit some 300 km above GEO, it can undock and return to GEO to work with another target. The process is repeated until ConeXpress and its last customer reach the graveyard orbit and retire there.

ConeXpress Platform

The ConeXpress platform is being developed by Dutch Space in Leiden, The Netherlands. Ariane-5 offers 3–4 opportunities per year to make use of its otherwise-unused capacity. The ConeXpress stack comprises the payload adapter and an extension cylinder incorporating a separation mechanism and mountings for the inner structure. The inner structure accommodates equipment such as avionics and the rendezvous and docking payload. Immediately after separation from Ariane-5, ConeXpress deploys its antennas, solar wings, thruster-steering mechanisms and client-support mechanisms, in that order. It is now ready for its 6-month journey to GEO. During this transfer, and while preparing for rendezvous and docking, ConeXpress resembles a conventional geostationary communication satellite with its solar panels pointing north-south.

The mass and lifetime requirements for the coupled spacecraft define the ConeXpress propulsion system. The velocity increment and the mass range of the target rule out chemical propulsion. With current technology, the only choice is electric propulsion. The required amount of xenon gas, in turn, drives the design and mass budget. During orbit transfer, the two electric thrusters operate simultaneously, while only one is required for stationkeeping in GEO. The Hall-effect thrusters are suitable for prolonged operation, mounted on deployed steering mechanisms. The direction of the required stationkeeping velocity increment dictates the thruster orientation. Additionally, the thrust vector has to point through the combined centre of mass of the mated spacecraft for stability. North-south and east-west stationkeeping manoeuvres are combined in order to minimise perturbations on the target's antenna pointing. For north-south stationkeeping, 50 cm-long arms place the thrusters as far out of plane as possible. The thrusters are gimballed to align with the mated vehicle's centre of gravity to allow north-south thrusting through the centre of gravity in order to maintain the target spacecraft nadir pointing. Reaction wheels assist in nulling any residual thrust misalignment. The manoeuvres are limited to about an hour each day, around the orbital nodes. ConeXpress needs only a fraction of the power from the solar arrays when docked to its client. ConeXpress will not thrust during periods of eclipse, when there will be almost a kilowatt-hour of battery power to preserve ConeXpress. Eclipses will last no longer than 72 minutes, during equinox.

The platform offers a range of applications beyond these servicing missions. Under investigation are optical data-relay missions and the DuneXpress deep-space science mission for stellar dust research (Max Planck Institute Heidelberg, D), and Earth observation and meteorology missions from GEO.

Docking Payload

Docking with GEO satellites is not a simple task because they are not designed for such operations and do not offer standard provisions for capture and docking. Even worse, although all GEO satellites have similar functions, they vary greatly, depending on their manufacturer and production family. Luckily, every potential client satellite is equipped with an Apogee Kick Motor (AKM). This boosts the satellite from its initial parking orbit into GEO, but then typically is never used again.

The concept of capturing satellites view their AKM nozzles is not new: it was explored by ESA in the Geostationary Servicing Vehicle study (*Bulletin* 78, May 1994).

ConeXpress Characteristics

Launch mass: 1400 kg
Docked mass: ~1200 kg
Size: 2.6 m diameter, 1.35 m height, 14 m solar array span
Solar cells: 4704 GaAs RWE 3G cells
Solar panels: 6 panels max. 1.74 m across (18 m^2); output 4.03/3.62 kW beginning/end of life (12 years)
Batteries: Li-ion SAFT VES 180S, 6480 kWh (50 % depth-of-discharge)
Main engines: 4 PPS-1350G 80 mN Snecma Hall-effect plasma thrusters (from SMART-1)
Propellant: 165 kg xenon, delta-V 2370 m/s, total capacity 3220 m/s
Attitude control thrusters: 4 clusters of 5 Xe cold-gas thrusters (same supply as main engines)
Reaction wheels: 4 skewed wheels
Rendezvous: under manual control until capture tool in cone then automatically centred using internal lasers

For ConeXpress, the Capture tool Deployment Mechanism (CDM) inserts the tool into the nozzle and locks it into place. The CDM is basically an extending boom made of three stems, enabling out/in movement of the tool. After capture, the CDM retracts the target satellite onto ConeXpress interface points to create a rigid mechanical link. The docking payload is at the heart of the spacecraft. The other main elements of the Docking Payload are:

– the Camera and Lighting Unit, to measure the satellite's position with respect to ConeXpress, and to provide visual aid to ground operators during docking;
– the mechanism to hold the satellite against ConeXpress;
– the Docking Payload Control Unit, with Camera Control Electronics.

DLR, the German space agency, is providing the Docking Payload. It has developed the capture tool and the sophisticated telepresence software for the servicing missions. Kayser-Threde is responsible for industrialising this capture technology and its integration into the docking payload. The rendezvous and docking system is controlled by the Marco telepresence system developed by DLR. Marco is currently in use in space by the ROKVISS robot on the International Space Station. This use of proven and operational software is reducing the risk for ConeXpress.

Operation and Ground Segment

ConeXpress is controlled after launch and during the initial free-flight phase by Orbital Recovery Ltd. Docking and checkout of ConeXpress with its satellite client is a joint effort between ORL and the telecom satellite operator. Once the docking and checkout are completed, long-term control is handed over to the satellite operator or its designated contractor, with technical support provided by ORL throughout the operating lifetime.

The design of the ground segment is dictated by three factors:

- the need to provide global telemetry, tracking and command during the launch and early orbit phase;
- the need to receive low-speed (<10 kbit/s) housekeeping telemetry data and high-speed memory dump and video data (<500 kbit/s) during rendezvous and docking;
- the desire to maintain operational autonomy and cost-effectiveness during the operational phase.

The ground segment is provided by the global PrioraNet ground station network, which may be extended by partnership with national and international networks. The stations are connected to the primary ConeXpress control centre under the authority of the Swedish Space Corporation at Esrange in Kiruna (S). The ground stations operate at S-band using 13 m-diameter antennas. A dedicated and transportable ground control facility provides command uplink, tracking and low-speed housekeeping telemetry reception at S-band using a 3.5 m dish. This facility will be located at a suitable position during orbit transfer, and collocated with the client operator's control centre during the rendezvous, docking and routine phases.

Status

The Phase-A/B studies for ConeXpress and its OLEV application were conducted under the industrial lead of Dutch Space within ESA's ARTES (Advanced Research in Telecommunications Systems) programme. Other major contractors include Sener, GMV, Casa, Snecma, Contraves and MDA. The System Preliminary Design Review was completed in February 2006. ORL is now preparing for full development (Phase-C/D), which they want to begin this year under an ESA ARTES Public/Private Partnership framework (ARTES 4), provided they can meet the conditions imposed by ESA, in particular the consolidated business case and financing scheme. The Phase-C/D cost is about €150 million, with ESA responsible for €75 million. A customer would pay about the same as the cost of the rocket to launch a replacement satellite; the saving comes from not having to build and commission a new satellite.

The goal is for an initial servicing mission in 2010. If successful, the market for 'used' satellites would then be open for business.