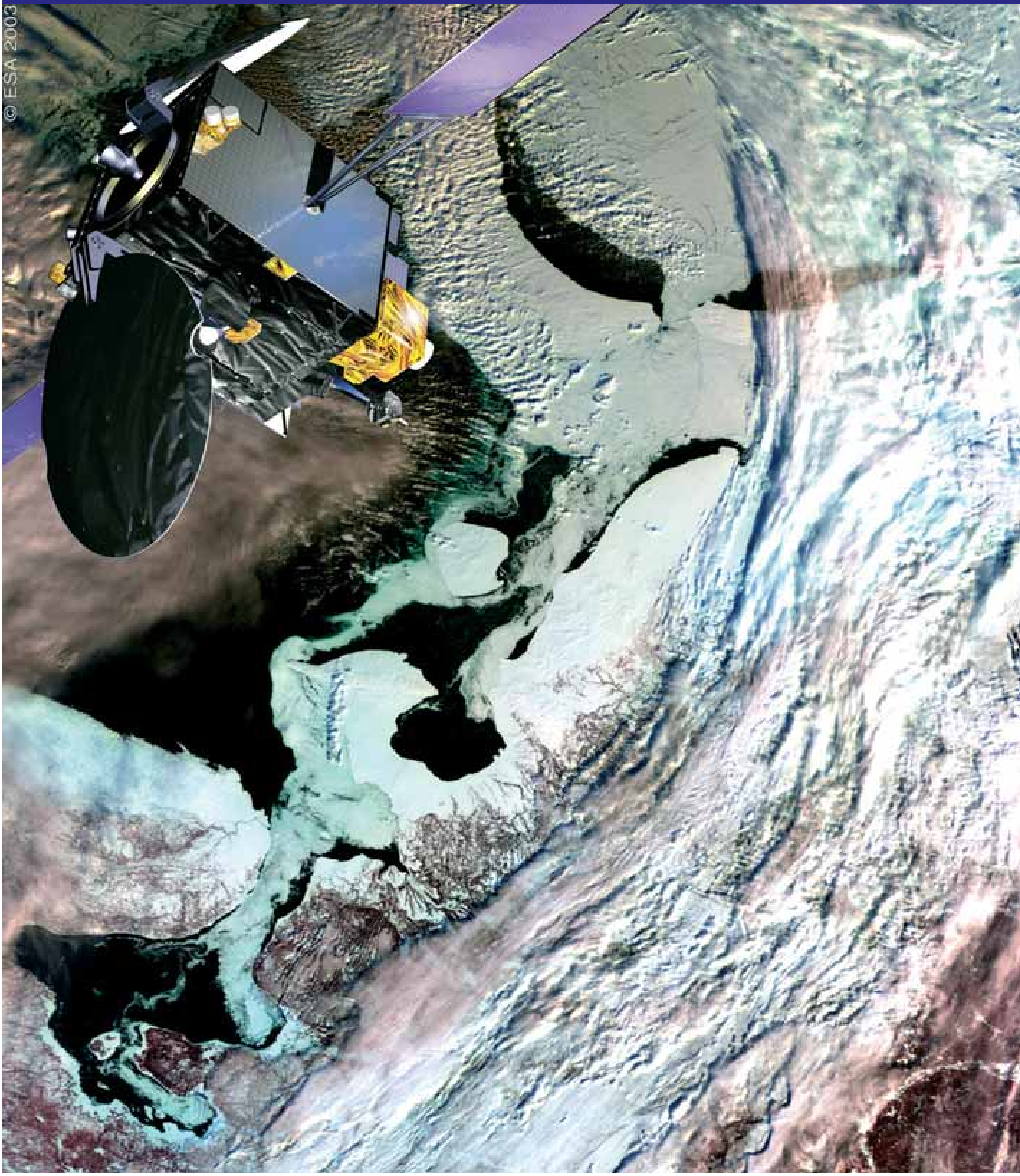
The first Envisat image transmitted by Artemis on 13 March 2003, showing Archangel in Northern Russia



Artemis Finally Gets to Work !

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After a remarkable recovery operation lasting 18 months, ESA's latest telecommunications satellite Artemis finally reached its assigned position in geostationary orbit on 31 January. Launched on problematic Ariane-5 flight 142 on 12 July 2001, which experienced a malfunction in its upper stage, the satellite was injected into an abnormal, low-energy orbit with an apogee height only half that of the standard geostationary transfer orbit (GTO). For any conventional communications satellite, this would have resulted in the total loss of the mission. Thanks, however, to the combination of technologies onboard Artemis and the innovative control procedures devised by the spacecraft control team, the satellite has been coaxed into the correct final orbit and is now able to provide the operational data-relay, land-mobile and navigation services for which it was designed.

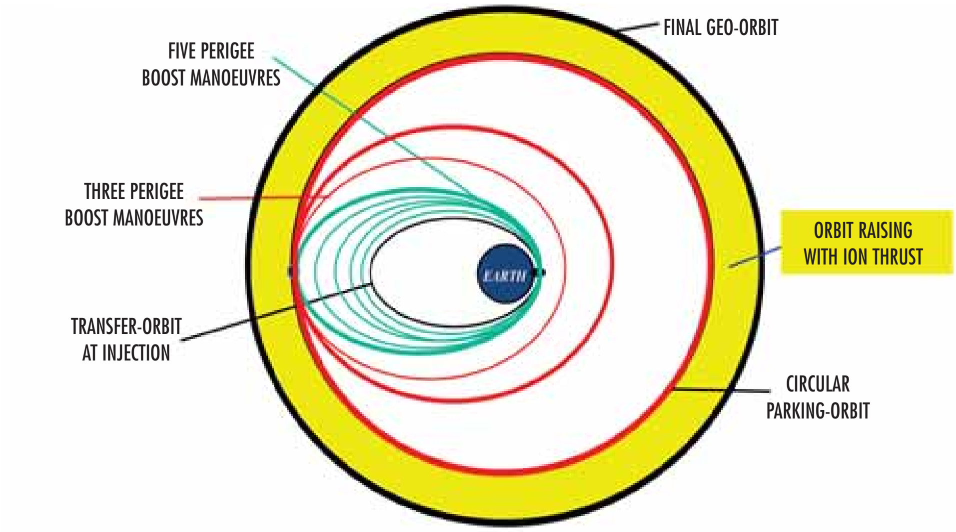
The Recovery Concept

Although Artemis carried a significant mass of chemical propellant, it was judged after the launch mishap that this was insufficient to reach geostationary orbit (GEO) and still have sufficient fuel available to provide a useful station-keeping function. It was therefore decided to use chemical propellant to reach an intermediate parking orbit and then use the satellite's experimental ion-propulsion system, together with a new attitude-control mode, for the transfer to GEO.

A favourable balance was found between the mass of chemical propellant remaining for operations in GEO and the time taken for the final transfer using the ion-propulsion system. The intermediate parking orbit was chosen to be about 5000 km below GEO. This required 200-300 days of ion-propulsion operation but still left sufficient chemical propellant to meet the basic satellite-control requirements in GEO.

The first and most urgent phase of the recovery was to make a series of engine burns at perigee to lift the orbit of Artemis beyond the Earth's destructive radiation belts. It was by no means straightforward to adapt the control modes of the liquid-fuelled engine to operate in eclipse, and in the absence of telecommand contact. Operation of the satellite's infrared earth sensor well below its specified altitude limits was also a critical element in achieving success with these early operations.

The overall manoeuvring strategy for Artemis recovery



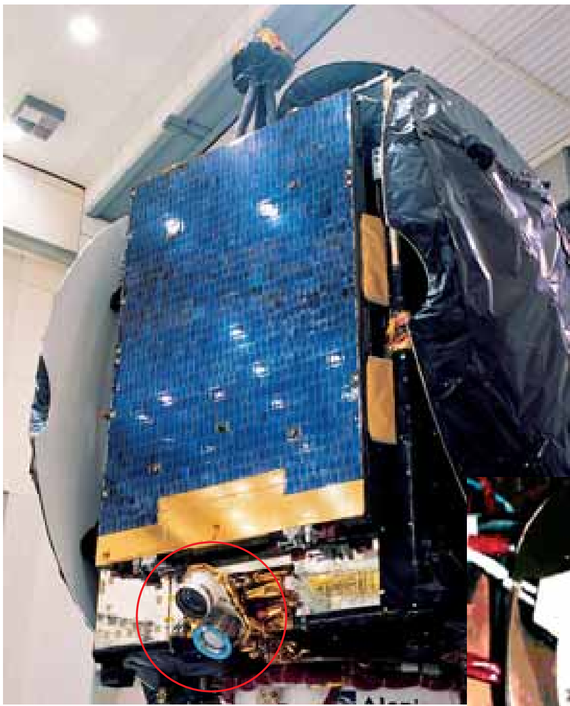
There followed more conventional chemical-engine burns at apogee to raise and circularise the orbit at the chosen parking-orbit altitude and reduce its inclination. All of the manoeuvres executed proved to be successful and were also highly efficient. Within a few days of launch, therefore, Artemis was safely under control in its parking orbit, circling the Earth every 5 days. A new global ground-station network was arranged to monitor and control it.

The Ion-Thrusting Solution

Up to that point, the possibility of using the ion-propulsion system with a new attitude-control mode had been only the germ of an idea. The four ion engines are mounted in pairs (for redundancy) on the corners of the satellite, providing thrust both perpendicular to and in the orbital plane. As originally designed for control of the satellite's orbital inclination, the in-plane component was unused. However, this was the very component needed for the rescue operation, which required thrust to be generated in the orbital plane to increase the radius of the orbit. Harnessing this in-plane thrust in the direction of motion required rotation of the satellite in the orbital plane by 90 degrees.

Thus just a few weeks after launch, the serious design work was started to devise, test and program the new attitude-control laws, data-handling modes and new flight-control procedures. In all, about 20% of the original spacecraft control software had to be modified. Thanks to the re-programmable onboard control concept used on Artemis, these modifications could be uplinked to the satellite as ‘software patches’, amounting in total to 15 000 words – the largest reprogramming of flight software ever implemented on a telecommunications satellite.

By the end of December 2001, work on the new software had been completed and it was subsequently validated using the spacecraft simulator. Once the new flight-control procedures had also been validated, all preparatory activities were complete, and on 19 February 2002 the orbit-raising manoeuvres were commenced. The ion engines started to expand the orbit with their almost imperceptible thrust, but with good efficiency, and more than 20 km/day could be achieved by using two thrusters simultaneously.



Two ion thrusters on the south face of Artemis

The RITA ion-propulsion thruster

The first few months, however, brought many new problems to be resolved, related to the daily passages through eclipse, tuning of engine performance, and experimentation with different attitude-control techniques to orientate the satellite for optimum propulsion from the engines. These activities took time and sometimes resulted in an interruption in effective thrusting, slowing progress. The greatest concern was the failure by July 2002 of three of the four ion-propulsion units. At that time Artemis was barely half way on its 5000 km route to GEO. The ensuing months were a very tense period, but the one remaining thruster unit continued to perform well, providing an average rate of climb of 15 km/day.

In evaluating the performance of the ion-propulsion system, we have to remember that two different, experimental technologies were being flown and tested in-orbit for the first time, and used in operational modes for which they had not been intended. In practice, all four ion thrusters worked successfully for periods ranging from a few hundred to several thousand hours, during which they exhibited a robust, stable performance and high efficiency. The three engines that failed did so for reasons unrelated to the fundamental ion-propulsion process or the design of the thruster assemblies (possible breakdown of high-tension insulation; sticking of a thruster flow-control valve). These anomalies are still under investigation, and those three thruster units may yet be reactivated. Still, the ion-propulsion subsystem has already operated for the equivalent of 4 years of geostationing lifetime, and the remaining operable thruster has so far logged no less than 6000 hours of in-orbit operation.

The Artemis experience therefore represents a major step forward for ion-propulsion technology, by dramatically demonstrating not only its impressive performance, but also the practicality of low-thrust orbital transfer. The feasibility of many of today’s planned missions relies on ion propulsion and they have been eagerly awaiting the Artemis demonstration, albeit not in such a spectacular fashion!

The Commissioning Phase

When Artemis at last reached its assigned slot in geostationary orbit on 31 January 2003, there was hardly time for congratulations, let alone a well-deserved rest for the operations teams. Within hours of its arrival, the spacecraft had to be reconfigured for geostationary operations using new attitude-control laws and new operational procedures.

Although many spacecraft modes had been exercised during the recovery process, and although payloads had also been checked out, the most remarkable being the first optical data-relay link in November 2001 with SPOT-4 (reported in ESA Bulletin No. 108), Artemis had finally arrived in orbit just when a significant community of users was waiting for it. It was therefore imperative to complete formal commissioning and performance assessment as quickly as possible. An intensive measurement campaign was conducted using the test facilities at ESA's Redu station in Belgium, followed by interface tests with Artemis users. This campaign thankfully demonstrated that the spacecraft and its payload were both performing according to specification.

The 50 Mbps optical data-relay link with SPOT-4 was again established with the same high quality achieved in November 2001. The particularly exacting 100 Mbps Ka-band data-relay link with Envisat was also acquired at the first attempt and image transmissions and subsequent tests have shown this link to be of very high quality. The first Ka-band and S-band links between Artemis and NASDA's ADEOS-II satellite were also realised first time without a problem, and the whole test plan with ADEOS was completed within three days.

Upon completion of these commissioning tests, formal reviews have been held and Artemis has been declared fully operational and cleared for routine service operations starting in April 2003.

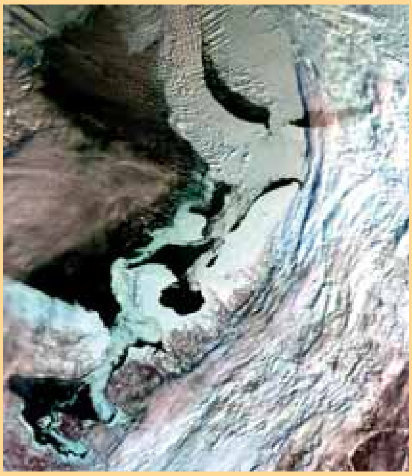
The Services Provided by Artemis

Data-Relay Services

Routine use of the data-relay links by SPOT-4 and Envisat started in April.

SPOT-4 will make operational use of the SILEX payload to transmit high-resolution image data via Artemis to the SPOT Image data-processing centre in Toulouse (F). Several optical passes per day will be used. Occasional use will also be made of the S-band data-relay link for SPOT-4 telemetry reception at the SPOT-4 Control Centre.

Envisat will use up to two Ka-band channels with one link every orbit. Its global, background, ASAR and MERIS instrument data will be transmitted via Artemis to the Envisat data-processing centre at ESRIN in Frascati (I).



Space-based data relay offers a number of benefits to Earth-observation missions: longer contact times, real-time transmissions, higher volume of data, improved reliability, and greater flexibility of data selection. When the first real-time images are received in Europe following an environmental incident, the full potential of data relay will be apparent. Data-relay users need extensive in-orbit experience with this new form of data collection to adapt their control and operations philosophy, and the future of European data relay will very much depend on the Artemis experience.

Other users planning to the Artemis data-relay services are the Automated Transfer Vehicle (ATV) and Columbus element of the International Space Station (ISS).

Land-Mobile Services

From April until the end of the year, the L-band payload of Artemis will carry the European Mobile System (EMS) service provided by Telespazio/Eutelsat. This provides low-data-rate and voice services to small mobile users (trucks, boats). It is expected that under future contracts the volume of the service will steadily increase to take advantage of the greater capacity of the Artemis payload.

Navigation Service

The European Geostationary Navigation Overlay Service (EGNOS) is currently in prototype operation using navigation transponders on Inmarsat satellites. The navigation payload on Artemis will be integrated into the EGNOS system in the course of 2003 without interruption of current service. When EGNOS goes live around April 2004, the Artemis transponder will form an invaluable element of the operational system, providing the additional coverage, precision and reliability needed to meet the system performance requirements.

Conclusion

The Artemis mission has encountered many programmatic and practical problems during its development, culminating with the unfortunate launch failure. Thanks, however, to the satellite's novel ion-propulsion and re-programmable onboard control technologies, and the ingenuity of its engineers, a unique recovery operation has been possible. As a result, the satellite is safely in orbit, having already fulfilled its technology demonstration mission admirably. Despite the long and arduous recovery action, Artemis is now ready, on time, to provide the services it was designed for, both demonstration and operational, with the potential to promote and stimulate further space-enabled data-relay activities in Europe.