space operations

→ SPACE DEBRIS: THE ESA APPROACH
OVERVIEW OF SPACE DEBRIS

Space debris is defined as all the inactive, manmade objects, including fragments, that are orbiting Earth or reentering the atmosphere. In near-Earth space, this debris is more significant than natural meteoroids, except around millimetre sizes, where meteoroids prevail in some orbital regions.

Routine ground-based radar and optical measurements track and catalogue objects larger than 5–10 cm in low orbits and larger than 0.3–1.0 m at higher altitudes. Some specialised sensors may also detect objects down to sub-cm sizes, but these cannot generally be maintained in catalogues or correlated with specific launch events. The presence of even smaller debris, of typically under 1 mm, can be deduced from impact craters on returned space hardware, or from dedicated in situ impact detectors.

Space debris matters because modern life depends on the uninterrupted availability of space infrastructures.

We need to manage the risk to populations and ground infrastructures from reentering space debris.

At typical collision speeds of 10 km/s in low orbits, impacts by millimetre-sized objects could cause local damage or disable a subsystem of an operating satellite. Collisions with debris larger than 1 cm could disable an operational satellite or could cause the break-up of a satellite or rocket body. And impact by debris larger than about 10 cm can lead to a catastrophic break-up: the complete destruction of a spacecraft and generation of a debris cloud.

The fragments created by a collision can drive a cascading process, the ‘Kessler syndrome’, in which each collision between objects generates more space debris, which increases the likelihood of further collisions.

Large debris objects (such as satellites, spent rocket bodies and large fragments) that reenter the atmosphere in an uncontrolled way can reach the ground and pose a risk to the population. The related risk for an individual is, however, several orders of magnitude smaller than commonly accepted risks in daily life (for example, the risk of serious injury from a motor vehicle accident is about 30 million times higher).

Spacefaring nations are now focusing efforts on controlling the space debris environment. Today, there is a consensus from long-term projections about the onset of a collisional cascading process in low-Earth orbits (LEO). The ultimate goal is to limit this runaway situation, to safeguard future space operations. Mitigation actions have been identified and propagated into international and national standards by various spacefaring nations. Even with strict adherence to these mitigation requirements (which is not yet achieved), it is evident, however, that additional remediation measures will be required in order to limit the number of objects in LEO.

Mitigation: prevention of the creation of space debris and limitation of the long-term presence of objects in protected regions.

Remediation: relocation or removal of a space debris object from the space environment.

The ‘active removal’ of a number of selected objects per year is needed, but this sets a global challenge that can only be achieved by the joint efforts of all spacefaring nations.

Since the mid-1980s, ESA has been active in every area of research, development, technology and operations related to space debris. Since 2006, the Space Debris Office at ESA’s European Space Operations Centre (ESOC) in Darmstadt, Germany, has operated as a standalone entity within the Ground Systems Engineering Department of ESA’s Directorate of Operations. The office coordinates the Agency’s research into space debris, as well as coordinating with national research programmes, and provides operational services to ESA, its Member States and third parties.
SPACE OPERATIONS
SPACE DEBRIS: THE ESA APPROACH

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There have only been human-made objects in space since the start of the Space Age in 1957, and all resulted from the 5253 launches (as of January 2017) since then. The majority (about 58%) of the catalogued objects, however, originate from more than 290 break-ups in orbit, mainly caused by explosions, and from about 10 suspected collisions (of which four are confirmed between catalogued objects).

Major contributions to the population of fragments came from a Chinese anti-satellite test targeting the Feng Yun-1C weather satellite on 11 January 2007, which created more than 3400 tracked fragments, and the approximately 2300 tracked fragments created from the first-ever accidental collision between two satellites, Iridium-33 and Cosmos-2251, on 10 February 2009.

About 24% of the catalogued objects are satellites (less than a third of which are operational), and about 18% are spent rocket bodies and other mission-related objects. Fragmentation debris dominates the smaller size regimes down to 1 mm. Below 1 mm, slag and dust residues from about 2440 solid-propellant motor firings prevail. Other debris sources can be associated with the release of liquid coolant from 16 Buk nuclear reactors on Russian radar ocean reconnaissance satellites in the 1980s, and with the release of surface materials from old satellites and rocket bodies due to impacts and/or surface degradation.

Debris is generated during normal operations by the injection of stages into orbit, the release of mission-related objects and the eventual retirement of a satellite. Subsequent break-ups and other release events may occur and contribute further debris. These combined debris sources are counteracted by natural cleaning mechanisms, such as perturbations to the orbital motion due to the Sun and Moon, and forces induced by air drag. LEO satellites are continuously exposed to

China’s Feng Yun-1C intercept in January 2007 increased the trackable space object population by 34%. Later, the collision between the intact Iridium-33 and Cosmos-2251 added another 17%.

Debris environment models can be used to estimate total numbers, indicating that there are 29 000 objects larger than 10 cm, 750 000 from 1 to 10 cm, and more than 166 million from 1 mm to 1 cm.
35786 km altitude) and near the orbits of navigation satellite constellations (between 19000 and 23000 km altitude) are smaller by two to three orders of magnitude.

Objects of 5–10 cm in LEO, and 0.3–1 m at higher altitudes, are catalogued by the US SSN.

Models indicate that there may be as many as 750 000 objects larger than 1 cm.

aerodynamic forces from the rarified upper reaches of the atmosphere. Depending on the altitude, after a few weeks, years or even centuries, this drag will decelerate the satellite sufficiently that it reenters Earth’s atmosphere. At higher altitudes, above 700–800 km, the air drag is less and objects generally remain in orbit for at least several decades.

The result of the balancing effects of debris creation and orbital decay leads to maximum debris concentrations at altitudes of 800–1000 km and near to 1400 km. Secondary peaks of spatial densities in geostationary orbit (GEO, at...
SPACE DEBRIS MEASUREMENTS

Existing space object catalogues are typically limited to objects larger than 5–10 cm at low altitudes (LEO) and larger than 0.3–1 m at high altitudes (GEO). In a compromise between system cost and performance, passive optical telescopes are suited mainly to observing high altitudes, whereas radars are advantageous below 2000 km.

Satellite laser-ranging to debris objects is an emerging technology. Several experiments have provided promising results for the detection and follow-up of intact objects and of fragments not carrying laser retro-reflectors, as well as for the determination of their attitude and the attitude motion.

Knowledge of the meteoroid and debris environment at subcatalogue sizes is normally acquired in a statistical manner through experimental sensors with higher sensitivities. ESA collaborates primarily with the Fraunhofer Institute for High Frequency Physics and Radar Techniques, near Bonn, Germany, which operates the Tracking and Imaging Radar (TIRA) system. Apart from dedicated tracking campaigns, TIRA also regularly conducts surveys that detect debris and determine coarse orbit information for objects of diameters down to 2 cm at 1000 km distance.

ESA also gains information on the submillimetre meteoroid and debris environment through analysing retrieved space hardware, and through active in situ impact detectors by analysing impact fluxes (the number of impacts per surface area and time).

ESA concepts for a space-based optical telescope to observe space debris – as a hosted payload (top) or a small demonstrator mission (bottom). The demonstrator mission shown assumes an FLP2 platform.

The knowledge of space debris in the millimetre to centimetre range is poor by comparison, and space debris environment models do not agree well for this class. Such objects are too small for ground-based sensors and rarely impact the sensitive face of the in situ impact detectors. Novel approaches for statistical characterisation, such as through in situ detectors providing a large collecting area or with space-based optical sensors, are being studied.

SPACE DEBRIS MODELLING

ESA maintains a number of software models for characterising the debris environment and its evolution.1

MASTER
The Agency’s preeminent debris and meteoroid risk assessment tool is MASTER: Meteoroid and Space Debris Terrestrial Environment Reference. It was first issued in 1995 and has been continuously improved since then. Impact flux information is provided with high spatial resolution for an object population that is derived from all known historical debris generation events, including the estimation of flux uncertainties.

At submillimetre particle sizes, meteoroids can prevail over space debris in some orbital regions, in particular during intense seasonal meteoroid streams.

MASTER is ESA’s preeminent debris and meteoroid risk assessment tool, covering all debris and meteoroid sizes larger than 1 µm, and giving predictions of the debris environment for up to 50 years into the future.
At the Teide Observatory on Tenerife in the Canary Islands, Spain, ESA operates the Optical Ground Station — dubbed ESA’s Space Debris Telescope. Its 1 m-diameter Zeiss telescope, equipped with highly efficient cameras, is used to survey and characterise objects at high altitudes, often in collaboration with other telescopes, such as those operated by the University of Bern, Switzerland. The ESA telescope can detect and track near-GEO objects up to magnitudes of +19 to +21 (equivalent to down to 15 cm in size). With this performance, the ESA telescope is among the world’s top-ranking sensors.

ESA’s latest data indicate that the number of fragmentation events in GEO is much higher than previously believed. It also appears that objects in GEO tend to release extremely lightweight objects with high area-to-mass ratios, such as pieces of thermal blankets, and with strongly perturbed orbits that require frequent reobservations.

The acquired data on space debris are essential for developing and validating environment models. To validate model predictions and to optimise observation times and sensor sensitivity in the planning of observation campaigns, ESA developed the Program for Radar and Optical Observation Forecasting (PROOF).

Monitoring and model validation of the space debris environment require regular and coordinated radar and optical observation campaigns, as well as development of new sensor technologies.

DISCOS
Consolidation of our knowledge on all known objects in space is a fundamental task of the operational support activities of ESA’s Space Debris Office. This knowledge is maintained and kept up to date through the Database and Information System Characterising Objects in Space (DISCOS)². Today, DISCOS is a recognised, reliable and dependable source of space object data that is regularly used by more than 100 users worldwide, including agencies and companies but also individuals. DISCOS is accessible through a modern web-based front-end.

DELTA
To study the effectiveness of debris mitigation measures on the stability of the debris population, long-term forecasts are required to determine trends as a function of individual mitigation actions. This kind of analysis can be performed with ESA’s Debris Environment Long-Term Analysis (DELTA) tool. DELTA is a time-dependent, dynamic debris model, with detailed traffic model and release event data, and with statistically generated collision events, based on local object concentrations and collision probabilities.

DELTA also provides essential input for addressing technical, regulatory and legal questions raised by the planned implementation of large satellite constellations and the general increase of small satellites in LEO. In support of ESA’s advocacy the sustainable uses of outer space, DELTA provides technical input to discussions on how responsible access to space can be assured as a unique resource common to all spacefarers.

1 https://sdup.esoc.esa.int
2 https://discosweb.esoc.esa.int
space debris: the esa approach

→ MITIGATION

With today’s rate of 70–90 launches a year, an increasing number of launches injecting 30 or more small satellites into orbit at once, and assuming future break-ups will continue at mean historical rates of four to five per year, the number of objects in space is expected to increase steadily. As a consequence of the rising object count, the probability of catastrophic collisions will also grow in a progressive manner.

Collision fragments can trigger further collisions, leading to a self-sustaining cascading process known as the ‘Kessler syndrome’. This is particularly critical for LEO, and may seriously endanger spaceflight within a few decades in certain orbit altitudes.

Estimates (by mass) of the adherence of space missions in LEO to post-mission disposal guidelines at end of life.

‘Business as usual’ space activities will lead to a progressive, uncontrolled increase in debris objects, with collisions becoming the primary debris source.

Spacefaring nations are focusing their efforts on controlling the debris environment. The ultimate goal is to limit the collisional cascading process in the Earth environment. Initial steps aim at reducing the generation of hazardous debris by avoiding in-orbit explosions or collisions with operational satellites, and by removing satellites from densely populated altitudes at the end of their missions. To this end, the Inter-Agency Space Debris Coordination Committee (IADC), recognised internationally as the technical authority on space debris, released a set of space debris mitigation guidelines in 2002. These guidelines have been used as the model for national legislation and international standardisation. ESA is taking a leading role in monitoring adherence to these guidelines, and reports its findings annually to the international community, including the United Nations.

ESA missions that were designed during the previous century can only implement best practices for space debris mitigation. For example, in 2011, ESA implemented dedicated end-of-mission operations for its European Remote Sensing (ERS-2) satellite, which at that time had been operational for over 16 years. During these operations, the remaining orbital lifetime was significantly reduced, to well below 15 years, and all residual fuel was consumed. This effectively reduced the risks of collision and accidental break-up by orders of magnitude. In 2013, ESAs astronomy satellites Planck and Herschel were injected into orbits around the Sun after their missions were completed, in order to avoid creating a collision threat or reentry hazard. In 2015, two large orbit-change manoeuvres were implemented for ESA’s Integral and Cluster-1 satellites. These manoeuvres ensured that both satellites will reenter Earth’s atmosphere during the next decade in a safe way, and avoid long-term interference with the protected LEO and GEO regions.

All new ESA missions now include space debris mitigation as part of the standard mission design. To facilitate analyses by mission planners, spacecraft engineers and space system manufacturers, ESA has developed the Debris Risk Assessment and Mitigation Analysis (DRAMA) software tool. DRAMA allows the estimation of delta-V budgets for collision avoidance, optimisation of disposal strategies along with estimation of orbital lifetimes, and analysis of ground casualty expectations. DRAMA is available for use by industry and academia worldwide and is distributed free of charge by ESA.
PROTECTION

The impact of a small projectile on an aluminium cube, showing the (often counter-intuitive) dynamics during such impacts. The time-series shows ejecta upon impact (first image), the projectile exiting (second image), and the shock wave causing rupture of the structure (last two images). This illustrates the huge amount of energy released by small debris objects involved in a hypervelocity collision.

ISS is equipped with debris shields around the inhabited modules, known as ‘stuffed Whipple shields’. These shields are composed of two metal sheets, separated by about 10 cm. Between the walls, fabric with the same purpose as in bulletproof vests is used. This design enables the shield to defeat debris objects of up to 1 cm. At more than 7 km/s, depending on the materials, an impact on the bumper wall will lead to a clear-hole penetration with a complete break-up and melting of the projectile, such that the dispersed fragment cloud can be withstood by the back wall.

Protection of an unmanned satellite can be improved efficiently by moving sensitive equipment away from the most probable impact direction, and/or by covering sensitive parts with protective fabric layers. Such measures can significantly increase the survival chances of a satellite against debris of up to 1 mm.

Recent research focuses on the vulnerability of membranes used for solar sails and drag augmentation devices. These thin foils need to survive micrometeoroid and debris impacts without losing too much of their effective area.

Furthermore, with the number of in-orbit collisions rising, a better understanding of the structural destruction and fragment generation is required as input to environment modelling. Modern methods of computational physics are applied for this purpose.

On 18 February 2008, DEBIE-2 (the second Debris In-orbit Evaluator) was launched to ISS on Columbus. This in situ impact detector has three 10 x 10 cm sensors looking in different directions, which measure the submillimetre-size populations of meteoroids and space debris particles in space. They are attached as external payloads to the Columbus module.

Smaller, uncatalogued objects can only be defended against by passive protection techniques, such as those as used by the International Space Station (ISS).
COLLISION AND REENTRY RISK MITIGATION

The first accidental collision between two intact satellites occurred at 16:56 GMT on 10 February 2009. An operational US commercial communications satellite, Iridium-33, and a retired Russian military satellite, Cosmos-2251, collided 776 km above Siberia at a relative speed of 11.7 km/s. Both were destroyed and more than 2300 trackable fragments were generated, some of which have since reentered.

Avoiding collisions is an important mitigation measure but this requires that the orbits of the approaching objects (‘chasers’) are known with sufficient accuracy. Benefiting from a data-sharing agreement with US Strategic Command, ESA uses Conjunction Data Messages provided by the US Joint Space Operations Center together with ESA’s own orbit data to analyse all close approaches (‘potential conjunctions’) of a given satellite (‘target’) with any of the catalogued objects. The collision risk is determined as a function of the object sizes, the predicted miss distance, the flyby geometry, the orbit uncertainties and the time to conjunction. Today, ESA has a highly automated process in place to process several hundred messages every day, and to screen autonomously planned routine orbital manoeuvres. A modern, web-based front-end with visualisation capabilities supports communication with the flight control teams, flight dynamics teams, and mission managers.

ESA executes on average 12 collision avoidance manoeuvres per year, in cases where the estimated collision risk is above the mission-defined ‘tolerable probability threshold’.

ESA’s Space Debris Office provides conjunction predictions and collision risk estimation as an operational service to ESA and third-party missions.

ESA’s web-based Spacecraft Conjunction Assessment and Risk Front-end (SCARF) supports close approach analysis and communication with the flight control teams, flight dynamics and mission management.
Only a few very large objects, such as heavy scientific satellites, reenter Earth’s atmosphere in a year. In total, about 75% of all the larger objects ever launched have already reentered. Objects of moderate size, 1 m or above, reenter about once a week, while on average two small tracked debris objects reenter per day.

In general, reentering objects pose only a marginal risk to people or infrastructure on the ground or to aviation. From an altitude of 110 km, during the last 10 minutes before an object reaches the ground, the atmosphere is dense enough that the object heats up due to air resistance and decelerates, leading in the majority of cases to its demise. In the case of a large or a very compact and dense satellite, and especially when a large amount of high-melting-point material such as stainless steel or titanium is involved, fragments of the object may reach the ground. As these are rare events, and as about 75% of Earth’s surface is covered by water and large portions of the land mass are uninhabited, the risk for any single individual is several orders of magnitude smaller than commonly accepted risks faced in daily life. Even being struck by lightning is 60 000 times more likely. In fact, to date there have been no known injuries resulting from reentering space debris. However, it is important to monitor the risk to the global population.

Skylab (74 tonnes, July 1979) and Salyut-7/Kosmos-1686 (40 tonnes, February 1991) are well-known examples of large-scale uncontrolled reentries. In such cases, 20–40% of the spacecraft mass may impact the ground. Examples of recent uncontrolled reentries that generated a lot of public interest were the Russian Phobos–Grunt Mars mission in 2012 and ESA’s Gravity field and steady-state Ocean Circulation Explorer (GOCE) in 2013.

To assess the risks associated with reentries, ESA has developed finite-element and simplified models that allow simulation of the break-up of a spacecraft in Earth’s atmosphere. The models take into account the aerothermal, aerodynamic, atmospheric chemistry and thermomechanical effects, and are coupled with population forecast models. ESA’s Space Debris Office provides information on upcoming and past reentries to a wide target audience, including national protection agencies, researchers and the general public, via a web-based portal. ESA participates in and hosts a reentry data exchange platform for the IADC.

A 1 in 10 000 probability threshold for the casualty risk of a single uncontrolled reentry is commonly accepted by space agencies and nation states. It is mandatory for ESA missions to meet this threshold. ESA can provide the required analysis of both controlled and uncontrolled reentries.

1 reentry.esoc.esa.int
Space debris is a problem to which all spacefaring nations have contributed. Likewise, debris poses a risk to the missions of all spacefaring nations.

Since analysts first became aware of an emerging space debris problem in the early 1970s, the understanding of debris sources, the resulting debris environment and the associated risks have improved significantly. Today, the global dimension of the problem is internationally recognised, and space system designers, operators and policymakers share the view that active control of the space debris environment is necessary to sustain safe space activities in the future.

The most prominent body for information exchange on space debris is the 13-member IADC.

Research results are regularly discussed at the quadrennial series of ESA-organised European Conferences on Space Debris, and at dedicated sessions of the International Astronautical Congress and COSPAR (COnmittee on SPAce Research) Scientific Assemblies and other conferences. The IADC, the most-recognised international entity on space debris, has produced a set of mitigation guidelines, which also served as input to a set of space debris mitigation guidelines adopted by the UN Committee on the Peaceful Uses of Outer Space (UN COPUOS). The key recommendations are:

- limit debris release during normal operations;
- minimise the potential for break-ups during operational phases;
- limit the probability of accidental collisions;
- refrain from intentional destruction and other harmful activities;
- minimise the potential for post-mission break-ups resulting from stored energy;
- limit the long-term presence of spacecraft and launch vehicle orbital stages in protected regions after the end of their missions.

Since its foundation in 1993, IADC has conducted annual meetings to discuss research results in debris measurements, modelling, protection and mitigation.

IADC is internationally recognised as a centre of competence for space debris and it also influences mitigation activities at the UN COPUOS Scientific and Technical Subcommittee and at the Subcommittee for Space Systems and Operations (ISO-TC20/SC14) of the International Organization for Standardization. In order to guarantee an effective and balanced implementation of debris mitigation practices, identified control measures need to be based on an international consensus. As an example, the 2011 ISO standard 24113 defines primary debris mitigation requirements. This standard was adopted by the European Cooperation for Space Standardization, whose standards, via a formal ESA ADMIN/IPOL instruction, are applicable to all ESA projects. Verification of compliance with the ISO standard can be supported by using ESA’s DRAMA tool.

The next step after technical definition and international standardisation is the transfer of guidelines into actual regulations. While some countries have already taken this step and reflected space debris mitigation in their national regulations, worldwide implementation is still pending. In this context, the Scientific and Technical Subcommittee of UN COPUOS recently achieved consensus on a set of guidelines that address this important implementation of regulations in the UN’s Member States.
ACTIVE DEBRIS REMOVAL

Mitigation measures proposed by IADC to control the growth in the number of space objects have been adopted by various countries and organisations. Over the past 15 years, between half and two thirds of all satellites initially operating in the GEO region have been reoribited to a graveyard disposal orbit, in line with IADC recommendations – an improving trend. For LEO, which is most sensitive to an onset of collisional cascading, the first comprehensive statistics on compliance show poor results regarding the clearing of the region within 25 years of mission completion. Only 25% of the rocket upper stages and 10% of the satellites in LEO perform an active manoeuvre in order to comply with the IADC recommendations. Fortunately, many satellites are inserted into orbits where they comply naturally.

Studies performed with long-term evolution models like DELTA have shown that a ‘business as usual’ scenario will lead to a progressive, uncontrolled increase of object numbers in LEO, with collisions becoming the primary debris source. The IADC mitigation measures will reduce the growth, but long-term proliferation is still expected, even with full mitigation compliance, and even if all launch activities are halted. This is an indication that the population of large and massive objects has reached a critical concentration in LEO.

Mitigation alone is therefore not sufficient, and it is necessary to introduce a programme of remediation measures as well, namely active debris removal (ADR).

Studies at NASA and ESA show that, with a removal strategy focusing on large target masses, the environment can be stabilised if about five to ten objects are removed from LEO per year with the following priorities:

- objects with a high mass (largest environmental impact in terms of critical-size fragments);
- objects with a high collision probability (orbiting in densely populated regions);
- objects at high altitudes (long orbital lifetime of the object and of fragments in the event of a collision).

High-ranking hotspot regions have been identified at around 1000 km altitude and 82° inclination, at 800 km and 98°, and at 850 km and 71°. The concentration of critical-size objects in these narrow orbital bands could allow multi-target removal missions.

Actions to counter the exponential growth of space debris, such as mitigation and active removal, are most effective when they are applied early. The further the number of critical-size, intact objects in the debris environment deviates from a sustainable level, the more objects will have to be removed to suppress the additional growth and the multiplying effects. ESA’s internal studies show that continuous removal actions starting in 2060 would be 25% less effective in comparison to an immediate start.

ESA, as a space technology and operations agency, has identified active removal technologies as a strategic goal. ADR is necessary to stabilise the growth of space debris, but even more important is that any newly launched objects comply with post-mission disposal guidelines (namely orbital decay in less than 25 years). If this is not the case, most of the required ADR effort would go to compensate for the non-compliance of new objects.

Legal constraints associated with the ownership of space debris and related liability issues cannot be neglected and the responsibility for a coupled remover/target is shared between the object owners.

ESA’s CleanSpace Initiative is looking at the required technology developments, including advanced image processing, complex guidance, navigation and control (GNC) and innovative robotics to capture debris. Technologies for a wide range of removal targets will be studied, including real applications. ‘e-Deorbit’, to be launched in 2023, will be the first ADR mission conducted by ESA, with the objective of removing a large ESA-owned object from its current orbit and performing a controlled reentry into the atmosphere.
The Copernicus mission Sentinel-1A, operated by ESA on behalf of the European Commission, experienced a sudden and permanent power reduction in a solar array on 23 August 2016, an anomaly suspected to be caused by a hypervelocity impact. Unusually, the satellite carries a small ‘webcam’, intended for checking deployment of the large array and never to be used again. Happily, the flight control team remembered this exceptional capability and was able to photograph the affected array.

The observed attitude and orbit changes, the damage visible in the photograph, the estimated direction of the impactor and the latitude of the spacecraft at the time, point to an impact by a small (maximum 1 cm) manmade debris object, most likely a fragment from an explosion or collision. Tracking by US-SSN indicates that a total of six fragments seem to have been released into the direction of approach of the impactor. Fortunately and somewhat surprisingly, the satellite survived with little damage and the mission is continuing nominally.

This event highlights the existing space debris threat to missions, and that more efforts are required to better understand the small-sized space debris population.
ESA’s Space Debris Office provides operational services in support of planned and current missions, both within ESA and to third parties. The Office operates a Space Debris Facility where it maintains a 24-hour alert team for its collision avoidance and reentry prediction customers. The service portfolio has recently been expanded to offer ad hoc in-orbit risk assessment support after severe in-orbit fragmentation events.

As of January 2017, about 20 European spacecraft are making use of ESA’s collision avoidance service. The alert centres of several European countries regularly obtain reentry alerts concerning their countries. Further information can be obtained by contacting:

space.debris.support@esa.int

The ESA team has developed and maintains several engineering tools for debris analyses, which are available as ready-to-use software packages or web front-ends. They include the MASTER model for predicting debris and meteoroid particle fluxes, the DRAMA software for verifying compliance, ORIUNDO for on-ground safety analyses, the reentry and fragmentation front-ends that give access to the Facility’s reentry predictions and risk assessments after on-orbit fragmentations, and the DISCOS database that holds information on the properties of more than 40,000 human-made space objects. The Facility also issues regular reports reviewing global performance in adhering to mitigation guidelines and publishes key figures on the space debris environment.

Direct access to these tools and reports is available by registering online on the ESA Space Debris User Portal:

https://sdup.esoc.esa.int

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The Space Debris Office at ESOC coordinates ESA’s research activities into space debris. Academic and scientific outreach is organised through the quadrennial series of European Conferences on Space Debris. This worldwide gathering of experts, academia, engineers and professionals on space debris will have its 7th event in April 2017: conference.sdo.esoc.esa.int

Sentinel-1A’s solar array before and after the impact of a millimetre-sized particle on the second panel. The photograph reveals a very large damage area: an almost circular feature of about 40 cm in diameter. This clear indication of an impact location, together with a clear recording of the impact momentum and epoch, allows the impact to be modelled – a great opportunity for space debris research.
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