DISCOS – CURRENT STATUS AND FUTURE DEVELOPMENTS

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ABSTRACT

We present ESA's Database and Information System Characterizing Objects in Space (DISCOS). DISCOS not only plays an essential role in the collision avoidance and re-entry prediction services provided by ESA's Space Debris Office, it is also providing input to numerous and very differently scoped engineering activities, within ESA and throughout industry. We introduce the central functionalities of DISCOS, present the available reporting capabilities, and describe selected data modelling features. Finally, we revisit the developments of the recent years and take a sneak preview of the on-going replacement of DISCOS web front-end.

1 INTRODUCTION

In order to support operational and academic activities related to space debris, the European Space Agency ESA is maintaining a Database and Information System Characterising Objects in Space (DISCOS). DISCOS is located at the European Space Operations Centre ESOC, in Darmstadt, Germany. The system is maintained by the Space Debris Office, and it has been in operation since 1990 ([1], [2]).

The first set-up of DISCOS followed the recommendations of an ESA Space Debris Working Group. In a contract with the University of Kent at Canterbury the initial installation was developed in 1989 and became operational in a Vax environment one year later. From that time onwards, DISCOS was operated and maintained by the Mission Analysis Office and later on by the Space Debris Office at ESOC. A major milestone was the addition of DISPAD (DISCOS Space Data Publication and Documentation System) in 1995/96, which allowed the generation of high-quality reports from DISCOS ([3], [4]). Other extensions of DISCOS that became available since the end of the 1990s are

- LASCO (Lifetime Assessment of Catalogued Objects),
- MARWIN (Master Remote Web Interface), and
- SatTrack (external tool).

The porting to Solaris OS finished in 1999, and to Linux in 2009. The web-based front-end is also hosted in a Linux environment, in a demilitarized zone (DMZ), since 2013. This finally allowed the functional split between database back-end and front-end, as it is state-of-the-art today.

We start our discussion by (re)-introducing the central functionalities of DISCOS in section 2. One example of the reporting capabilities is subject of section 3.Current activities focus on the complete overhaul of the front-end and on improving the database model and analysis algorithms at the back-end. These activities are addressed by sections 4 and 5 of this paper.

2 CENTRAL FUNCTIONALITIES OF DISCOS

ESA's DISCOS database assembles launch information, object registration details, launch vehicle descriptions, spacecraft information (e.g. size, mass, shape, mission objectives, owner), as well as orbital data histories for all trackable, unclassified objects which sum up to more than 39000 objects

To maintain these data records DISCOS relies on various sources from which information is automatically retrieved and ingested into the database, such as:

- USSTRATCOM Two Line Elements,
- Satellite Situation Reports,
- ESA/RAE Table of Earth Satellites,
- NASA History of On-Orbit Satellite Fragmentations,
- Launch information provided under ESA contracts,
- Own and contracted research at ESA.

Today, DISCOS is a central tool for supporting the various daily activities at the Space Debris Office, and it is the basis for operational processes in collision avoidance ([5], [6]), re-entry analyses [7], and for contingency support [8].

Currently, about 35 users in agencies, industry, academia and governments worldwide are authorised to access DISCOS via a web front-end. It is due to DISCOS that ESA today serves as the primary supplier on launch data for COSPAR.

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DISCOS-based routine activities also comprise the maintenance of a Re-entry Events Database to support internationally coordinated re-entry prediction campaigns of risk objects.

The current functional architecture comprises a back-end database (Oracle 10), and a front-end server (Apache webserver) located in the DMZ. The organisation of DISCOS data in a relational database management system (RDBMS) combines information sources into a set of related tables with a minimum of duplication. This allows for online multiple complex correlations between individual data tables, structured queries, and for queries via SQL (Structures Query Language) by means of compact statements [4].

3 DISCOS REPORTING CAPABILITIES

Today, DISCOS' reporting capabilities comprise the ESA Log of On-orbit Fragmentations (LOF), the Log of Objects near GEO (LOG), and the ESA Register of Objects in Space (ROS), which are used internally at ESA, and the annually distributed Classification of Geosynchronous Objects. All reports have in common that the underlying data is extracted from DISCOS according to certain selection criteria, is tabulated, plots are generated, and finally text, tables and plots are arranged in high-quality reports using the LaTeX typesetting program. The whole process is highly automated. In this section we describe DISCOS' reporting capabilities using the annual GEO classification as an example.

The most recent issue of the report [9] covers the status of geosynchronous objects at the end of 2012 with an analysis of the re-orbiting during that year. Based on orbital data in ESA's DISCOS database and on additional orbital data provided by the Keldysh Institute for Applied Mathematics, Moscow (KIAM) the situation near the geostationary ring is reported. For this report the GEO is defined as the region where the orbits have a mean motion between 0.9 and 1.1 revolutions per day, eccentricity smaller than 0.2 and inclination below 70 deg. In total there are 1369 known objects. For a subset of 1291 objects, orbital data are available. Of these, 422 objects are controlled inside their longitude slots, 662 are drifting above, below or through GEO, 178 are in a libration orbit, 9 are in highly-inclined orbits, and for 20 the status could not be determined. There are 78 uncontrolled objects without orbital data (of which 73 have not been catalogued).

During 2012, at least fourteen spacecraft reached end-of-life. Nine of them were re-orbited following the IADC recommendations, and their perigee is now at least 250 km above the GEO ring (this is the minimum re-orbiting altitude calculated for typical GEO spacecraft to comply with the IADC guideline). Four objects remained within the GEO protected area of ±200 km, which is required for station acquisition and re-location manoeuvres of GEO satellites.

In addition, we identified one spacecraft that seems to be abandoned or could not make any re-orbiting manoeuvre at all in 2012 and is now librating inside the geostationary ring.

A review of all past 15 issues of the report allows to assess trends in the implementation or re-orbiting practices. Table 1 and the corresponding Figure 1 reveal a clear trend, at least for the last 10 years, towards a better implementation of the space debris mitigation guidelines. On average there are 16 disposals of GEO missions every year, and now on average 2/3 of these are compliant with the IADC recommendations. Furthermore, for nearly all objects at least an attempt to re-orbit is made at the mission end.

Table 1: Summary of GEO re-orbiting practices (too low/IADC: does not comply/complies with IADC re-orbiting guidelines).

Year	libration orbits			disposal orbits		
	L_1	L_2	L_{1+2}	too low	IADC	total
1997	1	3	0	6	6	16
1998	7	3	0	6	6	22
1999	5	1	0	4	5	15
2000	3	1	2	2	3	11
2001	5	2	0	6	2	15
2002	1	1	0	5	4	11
2003	0	1	0	7	8	16
2004	2	1	0	5	5	13
2005	0	1	1	5	11	18
2006	2	1	0	7	11	21
2007	1	0	0	1	11	13
2008	2	1	1	2	7	13
2009	3	0	0	6	12	21
2010	3	0	0	4	11	18
2011	1	0	0	4	13	18
2012	1	0	0	4	9	14
Total	**37**	**16**	**4**	**74**	**124**	**255**

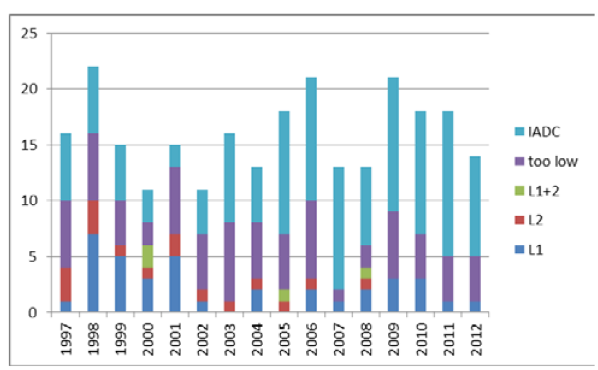

Figure 1. Annual GEO re-orbiting statistics (IADC/too low: complies/does not comply with IADC re-orbiting requirement, Lx: objects left in libration around Lx)

4 DEVELOPMENTS OF THE RECENT YEARS AND SELECTED DATA MODELLING FEATURES

During the last years a number of improvements and new functionalities were introduced into DISCOS. We will outline here the three most significant cases in dedicated subsections: the improved estimation of orbital lifetimes with LASCO, the changes made to the modelling of object shapes, and a new model for the owner/operator information stored in DISCOS.

4.1 LIFETIME ESTIMATES WITH LASCO

LASCO is a software suite dedicated to the analysis of the orbital lifetime of catalogued objects. The suite became operational in 1999 [10] and, since then, has undergone significant improvements in its configuration but also in accuracy due to an update of the propagation methods. LASCO is connected to DISCOS database by means of a caller script. A full run makes use of the two parts of the suite:

1. BaPIT (Ballistic Parameter Iteration Tool) calculates the ballistic parameters of catalogued objects contained in DISCOS.
2. SOLAT (Simple Orbital Lifetime Assessment Tool) performs the actual propagation along with the ballistic parameters found.

BaPIT makes use of a so-called “shooting method”, which is applied to a number of TLE sets as available from DISCOS. The shooting method is an iterative process of estimating the ballistic parameter of a given object by evaluating its orbital evolution. Starting with an initial assumption of the ballistic parameter, orbit propagation tools are used to propagate from one set of orbital elements for a certain time span.

The selection of this time span is a viable issue, since significant orbit changes are required for the method to work. Selecting time steps below the sensitivity threshold of the method, will lead to noisy results. Time steps which are too long will not be able to capture the more rapidly changing dynamics in the last days before the re-entry. A dynamic adaptation of the selected time-step as a function of the perigee height and eccentricity has been implemented.

After the propagation is done, the ballistic parameter is changed in an iterative process until a user-specified minimum difference between the propagated and measured (TLE) orbit at the propagation target epoch, i.e. after the time step, is reached (see Figure 2). This process is repeated several times over all available TLE sets in the analysis period and always the same time step is applied. The mean value of the ballistic parameters found is used for further analyses. The standard deviation provides additional information on the accuracy of the shooting results.

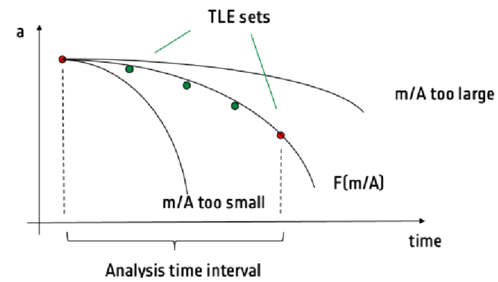

Figure 2. Schema of iterative ballistic parameter estimation (shooting method) applied in LASCO/BaPIT, based on the orbital decay over a dynamically selected analysis time interval.

The actual orbital lifetime is then determined by means of orbit propagation tools. With the obtained ballistic coefficient, the initial lifetime estimate is performed by straight forward application of King Hele`s formulations. Based on this initial estimate, a refined analysis is performed with different fidelity (and computing power) according to the outcome. If the initial estimate leads to lifetimes of less than 100 years, King Hele’s formulations are applied iteratively. Semi-analytical propagation is applied if the initial estimate results into less than 1 year. Semi-analytical propagation is also applied when the orbit eccentricity is larger than 0.2 in case of which luni-solar perturbations can have significant influence on the decay, which is not considered in King Hele’s formulations. To save computation time, the semi-analytical propagation is interrupted as soon as 1 year of simulated time is elapsed in this case. Since 2012, a semi-analytical propagator is used with access to modern atmosphere density models and Gauss-Legendre quadrature of the drag equations of motion. A full run (on all objects of the USSTRATCOM catalogue) is realised within a few hours and therefore performed once a day.

Figure 3 gives predicted re-entry epochs as function of the forecast epoch, where we assume that the most recent data is always used for predictions. We selected the recent (January 2013) Cosmos 1484 re-entry as example. The figure makes it possible to compare LASCO to other sources of lifetime estimation for the last phase before a re-entry event. The usual +/-20% uncertainty window is also given in the figure. We read from the figure that LASCO predictions are mostly within this uncertainty window, and that they are consistent over time. For the time being, the LASCO predictions only provide a limited output resolution based on the unit of days. This explains the non-continuous behaviour of the curve in Figure 3.

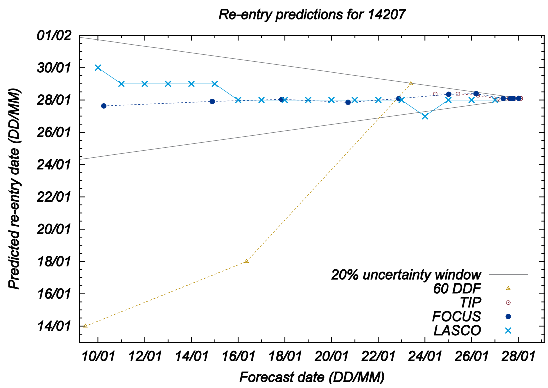

Figure 3. Daily automated LASCO predictions for the re-entry of Cosmos 1484 in January 2013, compared to manual predictions using a semi-analytical propagator (FOCUS), and av ailable 60 day decay forecasts (60 DDF) and T rajectory Impact Predictions (TIP) form USSTRATCOM

The comparison of LASCO to FOCUS (which is the reference tool for the Space Debris Office, a tool that must be precisely configured and operated by a specialist), as well as to the US TIP messages reveals a very good agreement.

LASCO predictions are updated daily and are comparably precise. It is, however, clear that for the last phase of a re-entry, specialist tools should be used for making predictions of the impact window and impact epoch more accurately.

4.2 SHAPE MODELLING IN DISCOS

Based on interpretation of an expert all objects are associated with geometric dimensions, if they can be positively identified as an intact piece with a known origin. This data is deliberately kept simple and includes the height, length and maximum span of an object. These three numbers are sufficient to describe most of the known intact objects. Whenever an object stored in the DISCOS database has these dimensions, it is also attributed with a structured text describing the shape based on predefined keywords, which adds more context to the dimensions.

First of all, the overall shape of the object is described by one or more geometric forms. These forms include a box, sphere, cylinder, torus, cone, ellipsoid and polyhedron. These shapes can be accompanied by one or more adjectives, such as ‘half’ or ‘truncated’, in order to increase the accuracy of the description. This description of the overall shape, together with the bounding dimensions of the object, are used to compute the minimum, maximum and average geometric cross-section of an object. When only one shape, with or without adjectives, is used to describe an object, the calculation of these cross-sections can be done exactly by applying Chaucy’s theorem on the projected area of convex bodies and Pappus’ geometric centroid theorem. If more than one geometric form is present, an approximation is made to determine which basic form is best suitable as an overall approximation.

Of course, more geometric shapes are not sufficient when we want to take into account large structures attached to a spacecraft’s main body, e.g. solar panels or a tether, which significantly influence the stored span dimension. A large amount of keywords, including panel, antenna, cable, nozzle, etc., are foreseen to functionally describe the object with more detail. Frequently used extensions, impacting the span dimension, are taken into account when estimating the cross-section values for the object. As this process is intended to be fully generic, it is tuned to fit the most average condition in which these extra objects appear.

The rigid use of a keyword scheme opens new analysis options. For example, it is now a simple SQL query to estimate that 14 objects were launched in the first two months of 2013, which have solar panels attached to the main spacecraft bus. Moreover, from the same query one can deduce that a total of 29 related solar panels add an estimated average area of $11.23\ m^2$ each.

The accuracy of the cross-section estimation based on the simple model set out earlier, can be verified by comparing it with a by-product of LASCO’s as described in the previous section. For the lifetime estimations, the mass to area ratio of an object is calculated with the shooting method from a subset of recent TLE data. Combining the average computed cross-section with the researched mass of the object as stored in DISCOS, we obtain another mass to area ratio. In Figure 4, the two values are compared for payloads launched after the year 2000, which are still, as on March 2013, residing on a circular orbit with an altitude below 1000km. The objects known to have been manoeuvring during the time required for convergence of the shooting method are removed, leaving a total of 65 objects for analysis.

A linear trend with a slope around the unity is clearly visible in the data, indicating a rather good match between both independent mass to area estimation methods. The bias towards higher mass for the DISCOS data estimate can partially be explained by the use of a wet-mass estimated at mission start for the overall mass estimate. An off axis group of about 10 spacecraft having a higher LASCO estimate are thought to might have manoeuvred within the analysis period.

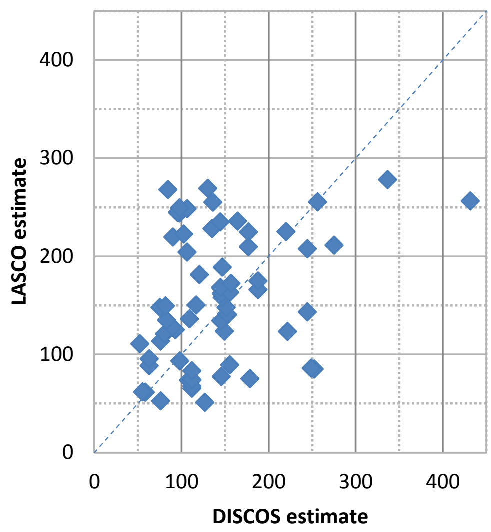

Figure 4 Estimated mass to area ratio [kg/m^2] for recently launched payloads; LASCO – derived from TLE data, DISCOS – derived from research and shape modelling.

4.3 NEW OWNER/OPERATOR MODEL

In the first years of space exploration, it was clear that only national authorities had the capabilities to launch and operate space assets. However, as space activities have evolved to a more commercial endeavour, it is clear that keeping only a country classification (the "launching state") in the DISCOS database is not always sufficient. Exemplary cases, which could lead to possible errors, ambiguities, or misinterpretation are highlighted in the following.

- Some commercial organisations were initially located in one particular country, but have been bought by a company in another country, making unclear to which country ownership and operations of new satellites should be assigned, or if in fact a reassignment of the old objects is required for a complete picture.
- Some international organisations have been founded or ceased to exist, have added or changed members, making it difficult to keep track of the countries related to them and their evolution.
- Some new countries have appeared, others disappeared, or changed their name.

All of these problems are now handled with a new owner/operator model, extending the storage of the "launching state" information. The new model keeps track of the operator organisations in addition of just storing countries, and also stores the related transitions over time. Organisations can now be countries, international organisations, commercial companies, universities, etc.

Technically, new tables have been added to DISCOS:

- ALL_ORGANISATIONS contains a numerical identifier and a short code for each organisation, plus the organisation information (host country, type of organisation, begin and end epoch and complete name).
- ALL_ORG_RELATIONS is a table providing the relations between different organisations and the epochs of validity. For example, ESA is an international organisation, and it is possible to recover each of its member states and the date when they joined from this table.

This new schema opens new analysis capabilities, e.g., to identify which objects have been built by research institutions or universities and in which countries they are based. As an example, a simple query returns that there are in total 105 cubesats payloads which weight less than 200kg, and that were launched by universities. Eight of them were launched as a cooperation between two organisations. The other ones originate from 27 different countries, with US and Japan (with 24 and 15 objects, respectively) being the leading nations in small university missions.

The new organisation identifier is a property of each object in DISCOS, as well as of all launch vehicles and launch sites. This improvement is transparent to the users as only extra information was added to the database with no changes in tables names or resulting in removed content.

5 ON-GOING REPLACEMENT OF DISCOS WEB FRONT-END

The current DISCOS Web Interface becomes obsolete due to the technological improvements of the last 15 years. A replacement is designed, implemented and tested currently. The new interface will provide a modern look and feel supported by the most common web browsers and which is in line with ESA corporate branding based in the latest state-of-the-art technologies for web applications.

The developed solution is modular and flexible enough to support an advanced interface for user and contents management and for the addition of new features, such as new data analysis, inspection and visualization improvements, and is fully compliant with changes to the hosting architecture. This capability is easy enough to be used by a non-software skills person.

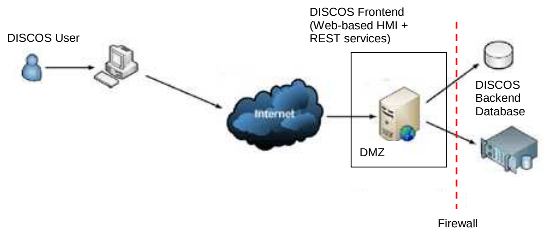

Figure 5 Architecture of the new web-based front-end to DISCOS.

Figure 5 shows the context diagram of the implementation. The rationale behind this diagram is the following:

- End-users or administrators of DISCOS web interface access the DISCOS front-end from their own computers using a web browser.
- DISCOS web interface and DISCOS url-based API backend services are installed in separated servers but within the same secured zone.
- The DISCOS backend services perform the necessary SQL queries to DISCOS database retrieve their data and return that information to the user.

DISCOS front-end user interface and back-end services are designed as a distributed system composed by independent modules, which can be installed in different locations. The interaction between both uses well-defined interfaces. All these interfaces are implemented as RESTful web services to allow remote access to the components and to provide user authentication and secure protocols to guarantee the confidentiality of private data.

The following capabilities are accessible through the interface:

- Authentication and authorization mechanisms that allow managing different users and their associated metadata and roles
- Simple wizards allowing users to build and store for future re-use their own queries considering applicable access levels and quotas
- Pre-built queries (i.e. analysis paths) that users can apply to retrieve information from different related tables in an easy way
- Provision of DISCOS information (visualisation via selected plots, tables/lists, statistics) together with basic searching capabilities
- Content Management System managed by the database administrator

Figure 6 Mock-up of the new DISCOS web front-end currently under development.

The following technologies are used in the implementation of the new solution:

- Web-interface based on Liferay 6.1 framework together with a set of HTML5/AJAX libraries
- Business layer composed by a set of RESTful web services based on JAX-RS 2.0 and a persistence layer based in Hibernate 3.0
- Deployment using Glassfish 3.1 engine

Figure 6 gives a pre-view of the new front-end based on the current development status.

6 CONCLUSIONS

DISCOS is a workhorse in the daily activities of ESA's Space Debris Office. The systems is essential for supporting operational activities, such as collision avoidance and re-entry prediction services, as well as in supporting various research activities, such as for assessments of the stability of the space debris environment and the development and validation of space debris environment models. DISCOS is available to support academia and European industry in their projects.

Annual reports based on DISCOS data show (as example for DISCOS' reporting capabilities) that the implementation of mitigation guidelines for GEO end-of-life operations is a clear success. The vast majority of providers attempt re-orbiting and in 2/3 of all cases IADC-compliance is achieved.

DISCOS is regularly maintained. Updates to the lifetime estimates based on TLE data (LASCO), to the shape modelling, as well as a new owner/operator model were introduced recently.

The hosting infrastructure also undergoes changes and a new web-based front-end is currently under development.

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