THE DISCOS SPACE DATA PUBLICATION SYSTEM

H. Klinkrad*, O. Tejedor** and S. Viñals**

* Mission Analysis Section, ESA/ESOC, Robert-Bosch-Str. 5, Darmstadt/Germany
** Grupo de Mecánica del Vuelo, GMV, S.A., Isaac Newton 11, PTM, Tres Cantos, Madrid/Spain

ABSTRACT

ESOC, The Space Operations Centre of ESA, is maintaining a Database and Information System for the Characterisation of Objects in Space (DISCOS). DISCOS is using the ORACLE 7 kernel and toolkits, along with the flexible SQL query language. The scope of data comprises all launch events since Sputnik-1, information on all trackable, unclassified USSpaceCom Catalog objects since 1989, data on 132 on-orbit fragmentation events, launch vehicle and launch site data, and bibliographic references of more than 1000 debris related publications. So far, DISCOS data can only be queried by registered users who meet permission criteria defined by the data providers. In order to make DISCOS information accessible to a wider community, a DISCOS Publication and Documentation System (DISPAD) has been developed which extracts data according to specified criteria, lists them in pre-formatted tables, charts them in various diagrams, and finally merges this information into *LaTeX 2ε* document templates.

1. INTRODUCTION

In 1987 ESA established a Space Debris Working Group, following a recommendation by the ESA Council, with the incentive to improve the understanding of the space debris environment. The final report of this forum of European experts was issued in November 1988[1]. As one of the conclusions of the working group, the necessity to establish a European database on space objects was identified. In June 1989 a one-year contract was awarded to the University of Kent at Canterbury (UK) with the participating Unit for Space Sciences and Computing Laboratory. Its objective was de development of an ESA space object catalog which became known as DISCOS (Database and Information System Characterising Objects in Space), and which became operational in late 1990. DISCOS, which is located at and maintained by the European Space Operation Centre, ESOC (at Darmstadt/Germany), today has 25 space agencies, research institutes and aerospace companies as registered users world-wide

The information which is contained in DISCOS is compiled and maintained under agreements with NASA and DRA (formerly RAE) as major data providers. The RAE Table of Earth Satellites[5] formed the bulk of the launch history information from 1957 to 1989 (when this service was discontinued). Since 1989 data in the same format have been acquired from the Kettering Group and from Molnija Space Consultancy at monthly update intervals. NASA distribute their data via the National Space Data Center (NSDC), where ESOC has access to high rate Two-Line Element sets (TLEs) which provide a snapshot of the USSpaceCom Catalog three times per week, to NASA Satellite Situation Reports which are issued each month, and to SpaceWarn Bulletins. NASA also gave permission to use information from the TBE History of On-Orbit Satellite Fragmentations[2] (produced by Teledyne-Brown Engineering under NASA contract). Several other sources of data are incorporated in DISCOS, for instance launcher and launch site related statistical and technical information. All data are arranged in tables which are embedded in a relational database management system (RDBMS) which is driven by an ORACLE 7 kernel. Registered users can interrogate DISCOS data via a powerful structured query language (SQL), or via menu driven query interfaces. The extracted data can be formatted (e.g. by SQL*ReportWriter or SQL*Forms), written to output files, arranged in new tables, or be subjected to a statistical or graphical analysis. The menu controlled graphic visualisation of data covers a large variety of 2D and 3D charting options, including scatter diagrams, surface plots, pie charts, and bar charts. Details on the implementation of the DISCOS database, and on the scope of its information contents have been summarised in several publications[4,6].

Though the DISCOS user interface was designed to be intuitive, the efficient use of a database as complex as DISCOS requires a certain level of hardware and

information (e.g. the traditional users of the RAE Table or of the COSPAR Bulletin data) may not be prepared to acquire data on such a basis. For this community ESA has devised a DISCOS Publication and Documentation System[7] (DISPAD), which provides a summary of up-to-date DISCOS information in the form of four different reports. Aspects of the implementation of this documentation software, and overviews of the contents of its individual reports will be provided in the following.

2. THE DISCOS DOCUMENTATION SYSTEM

The DISCOS Publication and Documentation System (DISPAD) has been developed by GMV S.A. Madrid/Spain under ESA contract[7]. The ESA specifications for the DISPAD system called for a software suite which allows to generate a comprehensive overview of consistent and up-to-data information which is extracted from the DISCOS database, and which is then cast into publication quality documents based on the *LaTeX 2ε* typesetting software, with embedded postscript graphics. Using the ORACLE high level language tools Pro*Fortran and Pro*C data extraction routines are coded to query one or several DISCOS data tables. The extracted data are then stored in files which keep this information as un-formatted tables with data separation by custom delimiters. The structure of these files and the contents of the corresponding data extraction routines is determined by the requirements of the document layout (table structures and graphical data representations). The unformatted DISCOS data are retrieved and processed by DISPAD to obtain publication quality tables, and postscript graphics, both of which can be merged into a predefined *LaTeX 2ε* document template. Extensive use is made of Perl scripts to control the data flow, and to control the execution of routines for off-line graphics generation (i.e. by pre-processing at Perl script level), and for in-line table generation (i.e. by direct triggering of Perl scripts via flags inside the *LaTeX 2ε* document templates). The whole DISPAD software has been installed on the DISCOS database server (a SUN SPARC-20) at ESOC. Depending on the kind of document, it needs between 15 and 20 minutes to generate a publication quality report.

Presently, there are four documents which can be produced by the DISPAD system: an ESA Register of Objects in Space (EsaROS), an ESA Log of Objects near GEO (EsaLOG), an ESA Log of On-Orbit and Decayed Objects (EsaLOD), and an ESA Log of On-Orbit Fragmentations (EsaLOF). For each of these reports individual *LaTeX 2ε* templates have been defined with corresponding Perl scripts to control the generation of tables and charts according to the extracted DISCOS data for a given cut-off date. All of these documents have a similar appearance which is controlled via commonalities in the so-called style files, and all documents have extensive indices to allow an efficient localisation of information in the text tables and charts. The DISPAD system generates its outputs by means of the *LaTeX 2ε* document processing software in the form of postscript files. These files can be printed off by high resolution laser printers, or they can be inspected by postscript viewers (e.g. Ghostview). ESA plans to publish the DISPAD products as hard-cover books in A4 format. There is no fixed date yet for the release of these publications.

3. DOCUMENTS GENERATED FROM DISCOS

Each of the four DISPAD publications EsaROS, EsaLOG, EsaLOD and EsaLOF will be issued as a single volume. Together, these documents give a comprehensive overview of the historic launch activities, and of the current state of the trackable on-orbit population of man-made space objects. Each individual DISPAD document adds one specific aspect to the overall characterisation of these objects

3.1. EsaROS

The ESA Register of Objects in Space (EsaROS) maintains a compete record of all USSpaceCom (formerly NORAC) Catalog entries of trackable space objects to date. This document aims at users of the former RAE Table of Earth Satellites[5] which listed all objects launched since Sputnik-1, sorted by their respective COSPAR identifiers, providing initial orbits, launch nation, launch date, expected lifetime, decay date, object name, dimensions, mass, and mission objectives (in some cases augmented by footnotes). The new EsaROS extends these data by adding to the tables information on the USSpaceCom/NORAD Catalog number, on the object type (e.g. manned/unmanned payloads or launch vehicles, and fragments or mission related objects thereof), on the used launch system and on the launch site. Additional comments on some of the objects, sorted by COSPAR international designator, are provided in a separate table. An excerpt of the EsaROS launch register is shown in Tab.1.

The data contained in the EsaROS launch table are processed under different aspects to extract statistically relevant information which is displayed in the form of tables or graphics. The spatial distribution of orbit deployments s illustrated by element-wise histograms which show, for instance, the total number of objects ever launched into a certain inclination band. Similar charts are generated for a, r_{pe}, r_{pa}, e, and ω distributions. The cumulative number of objects launched is depicted in a common chart against the reference year. Another histogram shows the corresponding annual launch rates. The equivalent cumulative and launch statistics are

provided for each spacefaring nation or organisation in a table format. In two more tables the launch activities are discriminated with respect to launch system and launch site with corresponding totals. An extensive index helps to navigate through the vas amount of information contained in the EsaROS.

3.2. EsaLOG

The ESA Log of Objects Near GEO (EsaLOG) will be a replacement and an extension of the former ESA Log of Objects Near the Geostationary Ring[3]. The EsaLOG contains GEO related information from the EsaROS, but in adapted tabular formats and diagrams. The main table, a list of objects near GEO, is sorted by COSPAR ID and contains similar information as the EsaROS launch register. It is, however, restricted to near GEO objects which have mean motions of 0.9 revs/d $\leq n \leq$ 1.1 revs/d, orbit eccentricities of $e < 0.1$, and inclinations of $i < 20^{\circ}$. The orbital data in EsaLOG are provided as osculating states in terms of $\Delta a^{(geo)}$, $\Delta r_{pe}{}^{(geo)}$, $\Delta r_{pa}{}^{(geo)}$, e and i, where the relative altitudes are referred to $a^{(geo)} = 42164$ km. The near GEO altitude range defined by $n = 1.0 \pm 0.1$ revs/d corresponds to $a = a^{(geo)} \pm 2800$ km. Also listed in the orbit information are the geographic longitude λ and its drift rate $d\lambda/dt$ at the epoch of last available orbit determination. The main table of the EsaLOG is also provided as a short list with objects sorted by geographic longitude. The information on many objects is furthermore extended by a table of footnotes, sorted by COSPAR ID. Finally, the last available orbit states are tabulated for objects which are known to be in the GEO vicinity, but which could not be re-acquired by the USSpaceCom tracking network. In a future release of the EsaLOG details on GEO satellite payloads will be include, with due regard to communication aspects

The current status of near GEO objects is visualised in a number of charts, firstly showing the individual longitude positions of all objects (including name tags), with up to 160 entries per diagram, for a certain range of COSPAR identifiers (see Fig. 1). The longitude distribution is also displayed in a frequency plot of objects per 5° longitude bins. Further information is provided on the orbital distribution, with histograms on object numbers versus $\Delta a^{(geo)}$, $\Delta r_{pe}{}^{(geo)}$, $\Delta r_{pa}{}^{(geo)}$, e, i, Ω and ω. The evolution of the orbit pole positions of drifting objects near GEO is shown in terms of the inclination vector location. The position of the object in this diagram indicates when orbit maintenance was discontinued (the early GEO objects have completed about one half of the 54 year inclination cycle which takes them up to $i = 15^{\circ}$ after 27 years). Finally, a histogram summarises the launches per year of payloads and upper stages into GEO. Equivalent charts are provided for upper-GEO objects (with perigees at least 50 km above the GEO ring).

3.3. EsaLOD

The ESA Log of On-Orbit and Decayed Objects (EsaLOD) is another way of looking at the EsaROS information by classifying objects into a current on-orbit population, and into a decayed population. Hence, the EsaLOD is very similar to the NASA Satellite Situation Report which is distributed via the National Space Data Center (NSDC) on a monthly basis. The major EsaLOD tables describing the on-orbit objects have a near identical format and data content as the EsaROS launch table and its corresponding footnotes. The list of decayed objects has a much more compact format with a single line entry per item. Here, only non-orbit data are provided, including object identifiers, launch date, decay date, mass, and physical dimensions.

The EsaLOD graphical representation of data concentrates on the current Catalog population, its origin, its physical properties (mass and cross-section), and its spatial distribution. Pie chart diagrams are used to discriminate the Catalog objects with respect to orbit regime (number, mass, and cross-section in LEO, MEO, GEO and HEO), and with respect to owner (number, mass, and cross-section for USA, CIS/USSR, ESA and others). For the description of the orbit distribution of Catalog objects similar histograms are produced as in the EsaROS (distributions with a, r_{pe}, r_{ap}, e, i, and ω).

3.4. EsaLOF

The ESA Log of On-Orbit Fragmentations (EsaLOF) follows the structure of the Teledyne-Brown Table of On-Orbit Satellite Fragmentations[2]. All 132 known fragrnentation events to date are listed according to COSPAR ID in a table which indicates the owner of the source object, the object name, type (e.g. spacecraft or upper stage), assessed fragmentation cause (e.g. deliberate or propulsion related), fragmentation date, and geographic position of the event. The impetus of the event on the debris environment is further illustrated by the mass and dimensions of the source object, by the intensity of the event, and by the maximum and current number of catalogued fragments. For the source object, also the closest available pre- or post-event orbit state vector is provided. For each event, identified by the COSPAR ID of the source object, detailed background information is given in a separate table. The extended fragmentation events list is also provided as condensed short lists (with one line per entry), which are sorted by event date, by maximum number, and by current number of observed fragments. Another table depicts the fragmentation cloud extension. For each event the mean values and rms dispersion statistics of h_{pe}, h_{ap}, i, ω and Ω are listed, indicating the in-plane and out-of-plane spread of fragments as a function of orbit lifetime and fragmentation intensity. As an option, each catalogued fragment orbit can be output, grouped by COSPAR ID

of the source object, and sorted by COSPAR ID of the related fragments.

The fragmentation event history and its impact on the current debris environment is also illustrated by a number of charts. The event history is summarised by one histogram each for the annual rate of fragmentations versus event date, and for the maximum and current fragment count of the ten major events (see Fig.2). Several pie charts assign percentage contributions to the on-orbit debris according to nation of origin, orbit domain (e.g. LEO, GEO, HEO), or break-up cause (e.g. deliberate, propulsion related, etc.). Furthermore, for each fragmentation event, the geographic location of break-up is shown on an earth map with underlying ground tracks, based on the source object state vector which is closest to the event epoch (see Fig.3). For each event also Gabbard plots of h_{pe}, and h_{ap} versus orbit period T, and scatter plots of h_{pe}, and h_{ap} versus Ω and i are shown to illustrate the cloud dispersion.

4. SUMMARY AND CONCLUSIONS

The DISCOS Publication and Documentation System (DISPAD) has been initiated by ESA to make information of the DISCOS database more easily accessible to users who are no computer experts. For a specified information cut-off date the DISPAD system extracts DISCOS data, formats them into tables, translates them into charts, and merges them into pre-defined *LaTeX2ε* document templates of four individual reports: the ESA Register of Objects in Space (EsaROS), the ESA Log of Objects Near GEO (EsaLOG), the ESA Log of On-Orbit and Decayed Objects (EsaLOD), and the ESA Log of On-Orbit Fragmentations (EsaLOF). All of these reports are produced with minimum operator intervention in publication quality by means of the *LaTeX2ε* typesetting software. Extensive tables of contents and indices enable a quick access to tabulated or charted in- formation.

It is foreseen to publish the four DISPAD documents in 1997. Inquiries can be submitted to the first author (e-mail: hklinkra@esoc.esa.de).

5. REFERENCES

1. Flury (editor)
   The report of the ESA Space Debris Working Group
   ESA SP-1109, ESTEC,
   Noordwijk, The Netherlands, 1988

2. I.W. Grissom, G.A. Myers
   History of On-Orbit Satellite Fragmentations
   (9th Edition)
   Teledyne-Brown Eng. Technical Report CS95-KS-024 (under NASA contract NAS9-19215), Colorado Springs, USA, July 1995

3. G. Janin (Editor)
   ESA Log of Objects Near the Geostationary Ring
   Issue 16, ESA/ESOC, Mission Analysis Section, February 1996

4. R. Jehn, S. Viñals-Larruga, H. Klinkrad
   DISCOS - The European Space Debris Database
   IAF-93-742, 44th IAF Congress, Graz, Austria, 16-22 October, 1993

5. D.G. King-Hele, D.M.C. Walker, A.N. Winterbottom, J.A. Piltington, H.Hiller, G.E. Perry
   The RAE Table of Earth Satellites 1957-1989,
   ISBN 0-9516542-0-9, RAE Farnborough, England, 1990

6. H. Klinkrad
   DISCOS - ESA´s Database and Information System Characterising Objects in Space
   Adv. Space Res., Vol.11, No.12, pp.43-52,1991

7. O. Tejedor
   The DISCOS Space Data Publication System Final Report of ESA Contract No. 11183/94/D/IM, Darmstadt, Germany, October 1996.

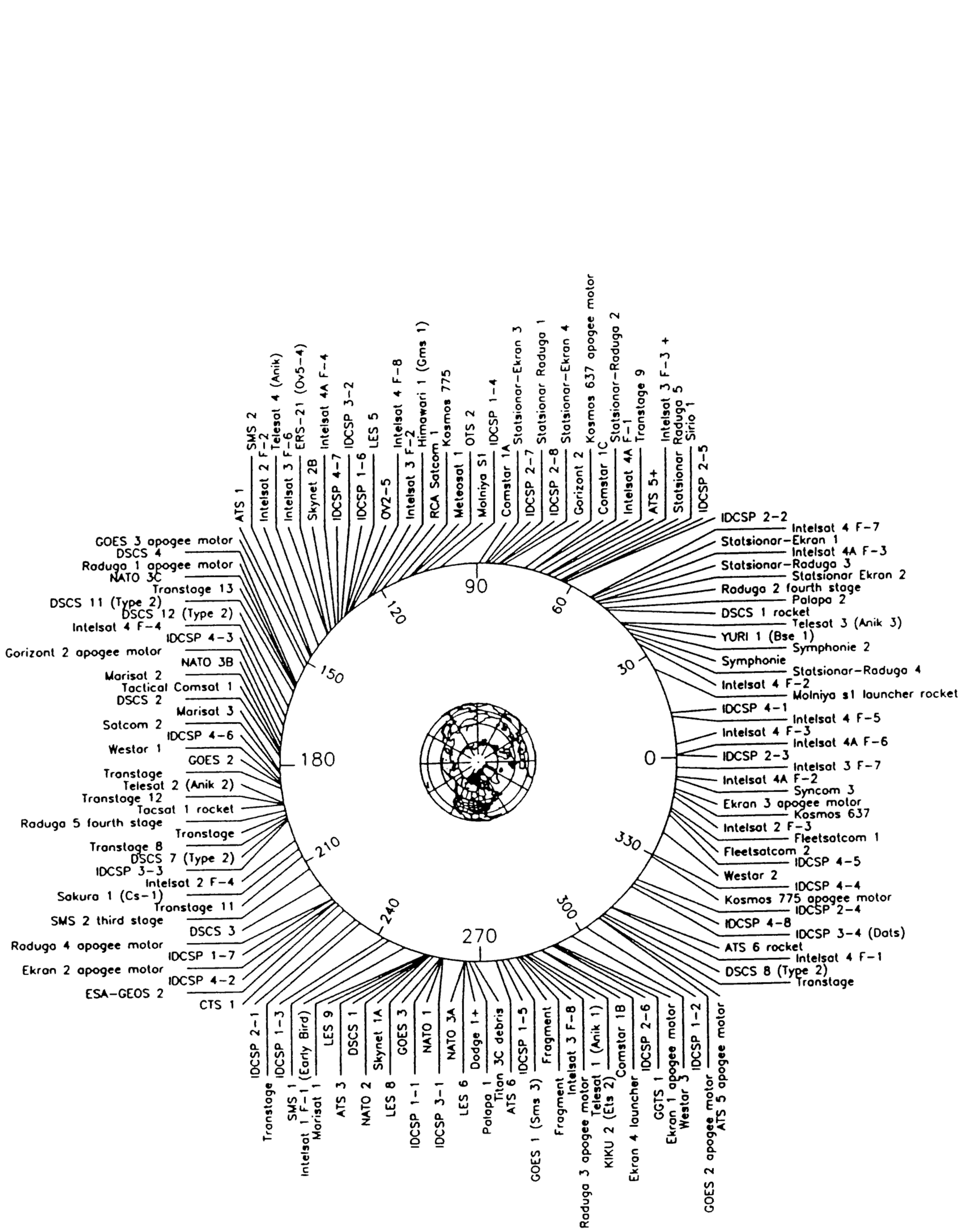

Figure 1: Geographical Longitude of near-GEO objects according to the last available orbit information (COSPAR Ids through 1979-087C)

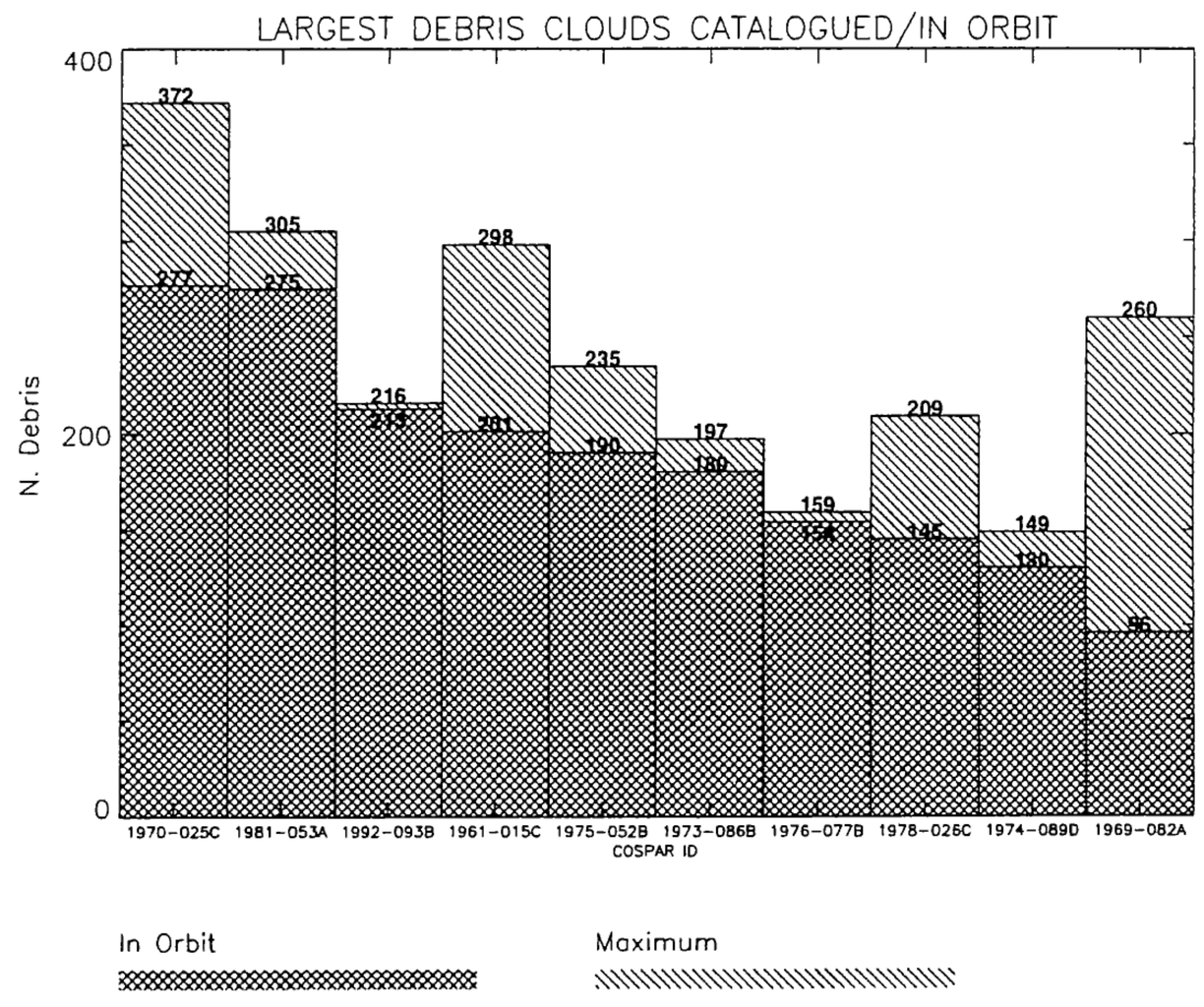

Figure 2: Maximum and current number of catalogued debris of 10 most severe fragmentations events.

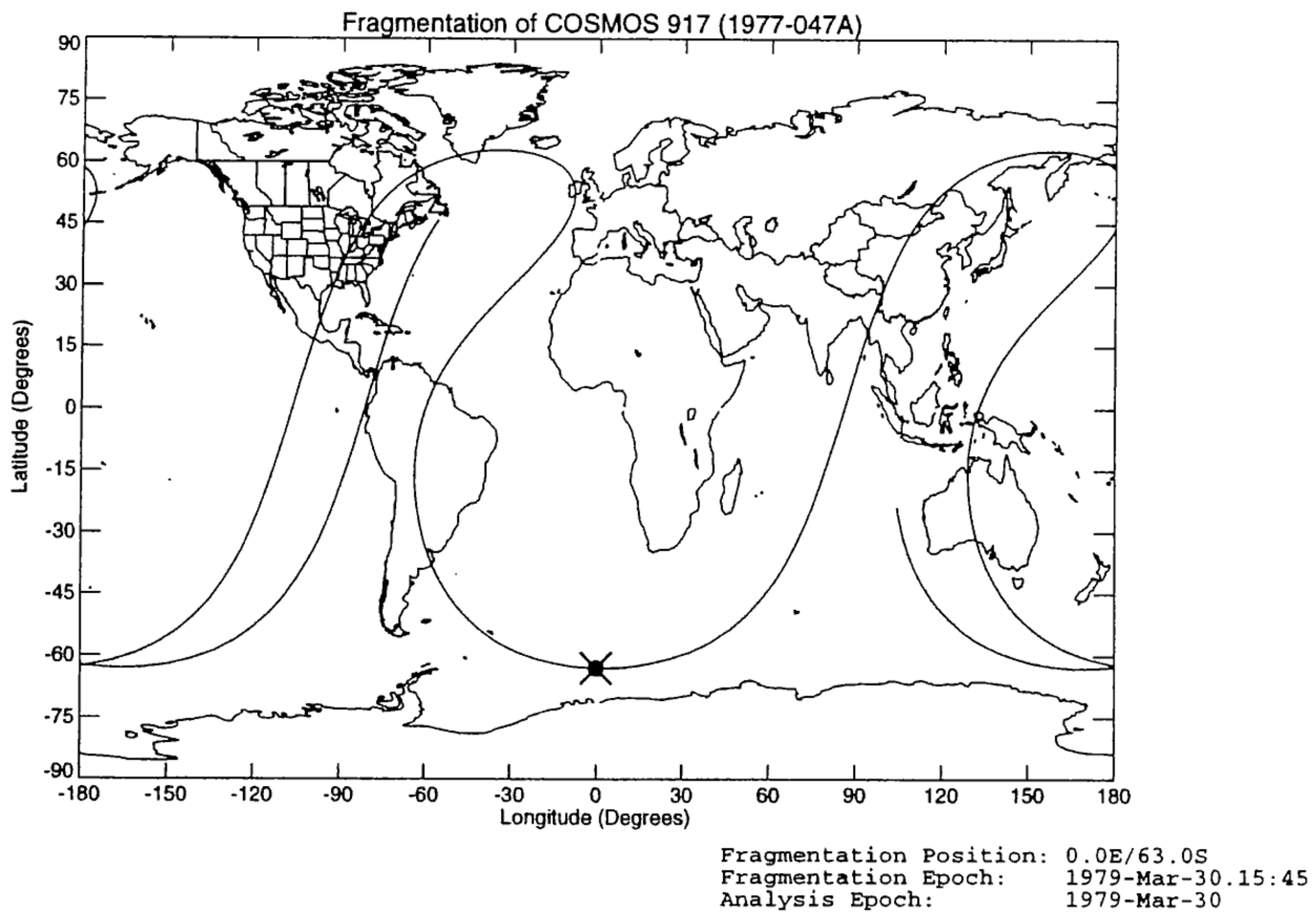

Figure 3: Pre-event and fragmentation location (×) of Kosmos 917 (1977-047A)

Continued from previous page

COSPAR ID Catalog	Nation/Org. Object Type Object Name	Launch Date Launch Site	Lifetime/Decay Launch system	Mission Objectives Obj.Dim. (m) Obj.Mass at BOL (kg)	Orbital Elements Dat. Date yyyy-mon-dd	hp (km)	ha (km)	e (-)	i (deg)	ω (deg)	T (min)
1993-064A 22867	CIS Payload Progress-M 20	1993-Oct-11 TYUR	1993-Nov-21 (d) Soyuz SL-4 (A-2)	Freighter 7.9 L? 2.3 D? 7020	1993-Oct-12 1993-Oct-13	260.00 264.00	311.00 309.00	0.00400 0.00300	51.62 51.62	115.00 118.00	90.16 90.19
1993-064B 22868	CIS Rocket Progress-M 20 rocket	1993-Oct-11 TYUR	1993-Oct-13 (d) Soyuz SL-4 (A-2)	Not Available 7.5 L? 2.6 D? 2500	1993-Oct-12	186.00	221.00	0.00300	51.65	82.00	88.50
1993-065A 22869	USA Payload STS 58 (Columbia F15)	1993-Oct-18 ETR	1993-Nov-01 (d) Columbia (OV-102)	Manned 37.1 L 17.4 H 23.8 S 103237	1993-Oct-18	283.00	292.00	0.00100	39.02	288.00	90.13
1993-066A 22871	ITSO Payload Intelsat 7 F1	1993-Oct-22 KOUR	? (d) Ariane 44LP	Geosync Comms 2.45 x 2.20 x 2.70 21.8 S 1495	1993-Oct-23 1993-Oct-24 1993-Oct-31	180.00 333.00 35664.00	35785.00 35781.00 35916.00	0.73100 0.72500 0.00300	6.97 6.82 0.07	178.00 180.00 79.00	630.03 632.95 1436.16
1993-066B 22906	AS/ESA Rocket Ariane 44LP V60 third stage	1993-Oct-22 KOUR	1994-Apr-17 (d) Ariane 44LP	Not Available 11.4 L 2.6 D 1274	1993-Nov-07	156.00	36451.00	0.73500	6.89	193.00	642.51
1993-067A 22875	CIS Payload Kosmos 2265	1993-Oct-26 PLES	? (d) Cosmos SL-8 (C-1)	Military 2.0 D 550	1993-Oct-27	291.00	1574.00	0.08800	82.94	111.00	103.74
1993-067B 22876	CIS Rocket Kosmos 2265 rocket	1993-Oct-26 PLES	? (d) Cosmos SL-8 (C-1)	Not Available 7.4 L 2.4 D 2200	1993-Oct-26	290.00	1566.00	0.08700	82.94	112.00	103.64
1993-068A 22877	USA Payload Navstar 2A-14 (USA 96)	1993-Oct-26 ETR	? (d) Delta 7925	Navigation 5.3 S? 2.4 L? 1.8 D? 930	1993-Dec-01 1993-Oct-31	20104.00 19829.00	20261.00 20065.00	0.00300 0.00400	55.08 55.07	280.00 177.00	717.97 708.42
1993-068B 22878	USA Rocket Delta 2 second stage	1993-Oct-26 ETR	? (d) Delta 7925	Not Available 5.88 L 2.44 D 919	1993-Oct-27	451.00	533.00	0.00600	35.15	174.00	94.30
1993-068C 22879	USA Rocket Navstar 2A-14 rocket (PAM-D)	1993-Oct-26 ETR	? (d) Delta 7925	Not Available 2.29 L 1.5 D 2154	1993-Oct-30	176.00	20282.00	0.60500	34.94	197.00	354.73
1993-069A 22880	CIS Payload Gorizont 28	1993-Oct-28 TYUR	? (d) Proton SL-13 (D-1)	Geosync Comms 2000	1993-Oct-30 1993-Nov-02	35759.00 35780.00	35793.00 35866.00	0.00040 0.00100	1.53 1.45	268.00 3.00	1435.45 1437.84
1993-069B 22881	CIS Rocket Gorizont 28 third stage	1993-Oct-28 TYUR	1993-Oct-31 (d) Proton SL-13 (D-1)	Not Available 6.5 L? 4 D ?	1993-Oct-28	180.00	199.00	0.00100	51.66	330.00	88.22
1993-069C	CIS	1993-Oct-28	1993-Oct-29 (d)	Not Available	1993-Oct-28	187.00	199.00	0.00100	51.65	46.00	88.29

Continued on next page

Tab.1: Excerpt of the launch history table of the ESA Register of Objects in Space (EsaROS).