DISCOS SPACE DATA PUBLICATION AND DOCUMENTATION SYSTEM

F. Pina Caballero [(1)], B. Fernández Montoto [(2)], H. Klinkrad [(3)]

[(1)] GMV S. A., C/ Isaac Newton, 11, P.T.M, Tres Cantos, E-28760 Madrid, Spain, Email: fpina@gmv.es
[(2)] GMV S. A., C/ Isaac Newton, 11, P.T.M, Tres Cantos, E-28760 Madrid, Spain, Email: bbfm@gmv.es
(3) ESOC-TOS/GMA, Robert-Bosch-Str. 5, 64293 Darmstadt, Germany, Email: hklinkra@esa.int

ABSTRACT

ESA's space debris database DISCOS-2 contains a wealth of information on the trackable Space Object Population between LEO and GEO altitudes, together with additional data on launches, launch sites, launchers, etc. These data has been recently made available through a Web Interface.

But even with this new interface, two problems arise for potential users. First, users need to be familiarised with the tools provided by the DISCOS-2 Web Interface, in particular some knowledge of SQL is required in order to access the database contents. This problem is particularly important for occasional users of the database. Second, remote access using the Internet can be a boring, repetitive work, depending on the error frequency and workload of the net. Those two problems can make users to minimise the use of the database.

To solve these problems, a ***DISCOS Space Data Publication and Documentation System*** (***DISPAD***) was created, aimed at easing the access to database data. The generation of periodical publications based on reports on the information in DISCOS-2 facilitates the distribution of such data to a wider range of users and represents a helpful complement to the interactive access to the database provided by the DISCOS-2 Web Interface.

The DISPAD system produces regular situation reports on the DISCOS data contents and its implications with respect to orbit population evolution, development and launch policies, and spatial distribution of objects, on-orbit fragmentation, and effects of mitigation measures, such as GEO reorbiting.

The DISPAD system is being implemented using the tools provided by the Oracle RDBMS, PV-Wave for graphical charts, Perl language for processing of the information extracted from the database, and LaTeX-2ε text processing system for production of the final form of the reports.

Currently, GMV is updating the DISPAD system to adapt it to the new DISCOS-2 System, which includes a number of new tables and new data sources. As part of this update, new tables and graphical charts are being included in the reports, and a critical review of the already existing information is being performed. The newly created tables and charts follow the basic outline of the first release, but adapted to the new database scheme.

Keywords*:* Space debris, DISCOS, LaTeX-2ε

1. INTRODUCTION

The growing importance of the study of space debris, their identification and classification on one side, and the wide number of existing objects and the information related to each of them on the other side, imposes the necessity of the use of a system that facilitates the management of this information in an automated and centralised way.

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. 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 catalogue which became known as DISCOS (Database and Information System Characterising Objects in Space), and which became operational in late 1990. Since then, GMV S.A. has been maintaining the database and since 1997, it has ported DISCOS to a new environment, and it has upgraded both the database contents and the user interface, which is now available through the World Wide Web.

DISCOS-2, 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 worldwide.

The organisation of DISCOS-2 data in a relational database management system (RDBMS) based on Oracle (version 7) allows for multiple correlations between individual data tables and for an intuitive query via SQL (Structured Query Language) by means of compact statements. The information retrieval is supported by statistical and graphical analysis software using Pro*FORTRAN interfaces, and DISSPLA

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utilities. The data can be output numerically or graphically (on screen or as ASCII/PostScript files).

The DISCOS-2 information is stored in thematic tables that can be linked and queried in a relational manner. The scope of data comprises all launch events since Sputnik-1, information on all trackable, unclassified USSpaceCom Catalogue 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.

The data that have been acquired and processed for use within DISCOS-2 under agreements with NASA, RAE/DRA and others provide the most complete information on unclassified space objects available in Europe.

The scope of DISCOS data covers orbital information (detailed time histories since launch), orbital lifetime estimates or recorded re-entry dates, data on launch sites and launch vehicles (also cross-related with launch events), common name mission objectives, dimensions, shape, mass and radar cross-section (RCS) for any space object identified by its COSPAR or USSpaceCom identifier. Furthermore information is available on solar and GEO-magnetic activity histories, on activity forecasts, and on debris related literature references. In the new DISCOS-2 system, ESA's Meteoroid and Space-Debris Terrestrial Environment Reference (MASTER) model is also available.

So far, DISCOS-2 data can only be queried by registered users who meet permission criteria defined by the data providers. It is possible to remotely access the DISCOS-2 host machine via public networks (such as Internet). It would be desirable to extent the use of the information of the database within the scientific community, the larger the best.

The access to the information in DISCOS-2 presents two major problems to the potential users:

- Users need to be familiarised with the tools provided by DISCOS-2 for accessing data stored into the database (such as the guided or the direct SQL interfaces found in the DISCOS-2 system). Even using those tools, users must be acquainted with the SQL language and the subjacent DISCOS-2 database structure. This problem is particularly important for occasional users not familiarised with DISCOS-2.

- Remote access using public networks can be a boring, repetitive work depending on the error frequency and work load of the net at each moment, making it necessary to repeat transmissions and to wait for receiving responses in a not efficient way.

In order to make DISCOS-2 information accessible to a wider community, a DISCOS Publication and Documentation System (DISPAD) was developed in 1995. Now, GMV S.A. is adapting the existing DISPAD system to the new DISCOS-2 database contents. The aim of the DISPAD Upgrade project is to use the newly available data in DISCOS-2 and to remove those DISPAD parts that are based in too incomplete data. In particular, the old EsaLOD report has removed from the DISPAD framework.

DISPAD 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. Three major DISPAD documents with extensive indices and explanations are produced:

- ESA Register of Objects in Space (EsaROS)
- ESA Log of Objects In or Near GEO (EsaLOG)
- ESA Log of On-Orbit Fragmentations (EsaLOF)

All documents are generated as PostScript files that can be printed in publication quality on high resolution laser printers.

DISPAD produces regular situation reports on the DISCOS-2 data content and its implications with respect to orbit population evolution, development and launch policies, spatial distribution of objects, on-orbit fragmentations, and effects of mitigation measures (e.g. GEO reorbiting).

2. DISPAD OVERVIEW

The DISPAD System is implemented using the tools provided by the Oracle RDBMS (i.e. pre-compilers), PV-Wave for the production of graphical charts, Perl for processing of the information extracted from the database, and LaTeX-2ε text processing system to produce the final form of the reports.

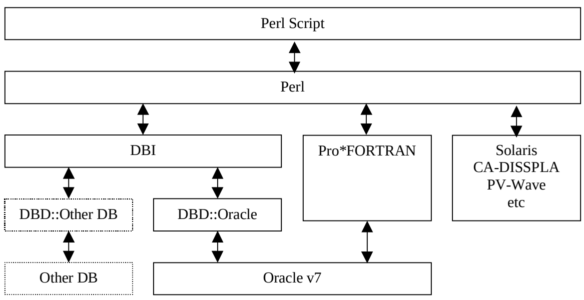

Fig 1: DISPAD architecture

The general structure of the DISPAD System is depicted in fig. 1. As the figure shows, a set of programs written in different programming languages are used to access, process, format and produce the final form of the data stored into the database. These programs are:

Oracle pre-compilers (i.e. Pro*Fortran and Pro*C) programs, used to extract data from the database. These programs write the extracted information into text files. These files are labelled as *"Unformatted Reports"* in the figure, because although they have a predefined format, it would be useless without a subsequent formatting process.

Perl programs which aims at twofold objectives:

- On one side they control the whole execution of the system, by activating the different programs composing the system in the appropriate order.
- On the other side to process the unformatted reports in order to produce two major outputs. *"Pre-formatted Reports"* contain data in a format that can be processed by the PV-Wave programs to produce graphical charts. *"LaTeX-2ε based documents"* are produced by merging data in unformatted reports with predefined LaTeX-2ε document templates. These LaTeX-2ε based documents can be processed by LaTeX-2ε to produce the final form of the documents.

PV-Wave programs that are in charge of producing graphical charts representing statistics and relationships between different data. These charts are produced in PostScript format and then inserted into the LaTeX-2ε based documents.

3. ESAROS

The ESA Register of Objects in Space (EsaROS) maintains a complete record of all trackable space objects to date. This document contains several tables, being the main one that which lists all objects launched since Sputnik-1, sorted by their respective COSPAR identifiers. It provides initial orbits, launch nation, launch date, expected lifetime, decay date, object name, dimensions, mass, USSpaceCom catalogue number, cross-section, object type (e.g. manned/unmanned payloads or launch vehicles, and fragments or mission related objects thereof), and mission details. An excerpt of the EsaROS launch register is shown in fig. 2.

Additional subordinate tables have been included in the EsaROS:

- A launch vehicles table, containing launcher configurations, launch capacities to different orbits and the number of successes/failures for each launcher
- A launch site table, showing azimuth constraints, geographical location, mission types, operator, launchers using it and number of launches
- A table summarising the national launch and launch failure statistics
- A table showing both the number of on-orbit and decayed objects classified per country and per orbit/object classes.
- A table containing the mission details for catalogued objects.

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 is illustrated by element-wise histograms which show, for instance, the total number of objects ever launched classified per inclination, semimajor axis, eccentricity, height of apogee and perigee and argument of perigee. The cumulative number of objects launched is depicted in a common chart against the reference year. Another histogram shows the corresponding annual launch rates. A last set of graphs will show the per-year & accumulated, cross-section & mass, on-orbit & decayed number of objects per countries. An extensive index helps to navigate through the vast amount of information contained in EsaROS.

4. ESALOG

The ESA Log of Objects In or Near GEO (EsaLOG) contains GEO related information from the EsaROS, but in adapted tabular formats and diagrams. This document contains several tables, being the main one a list of objects near GEO sorted by COSPAR ID and containing similar information as the EsaROS launch register. It is, however, restricted to near GEO objects which have mean motions between 0.9 and 1.1 revs/d, orbit eccentricities less than 0.1, and inclinations less than 20º. The orbital data in EsaLOG are provided as osculating states in terms of $\Delta a^{(geo)}$, $\Delta r_p^{(geo)}$, $\Delta r_a^{(geo)}$, e and i, where the relative altitudes are referred to $a^{(geo)}$ = 42164 km. The near GEO altitude range defined by n= 1.0 ± 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. An excerpt of the EsaLOG register is shown in fig. 3. The main table of the EsaLOG is also provided as a short list with objects sorted by geographic longitude.

Additional subordinate tables have been included in the EsaLOG:

- A table showing mission details
- A table containing data on super-GEO objects, similar to the main table, but excluding launch, mission and object data and including a drift rate.
- A table summarising data on untracked GEO and super-GEO objects. These list shows all known orbital data for those objects included in DISCOS-2 (and thus in EsaROS), but which are not included in the NASA TLE list.

The current status of in or near GEO objects is visualised in a number of charts, firstly showing the individual longitude positions of all objects (including name tags), grouped by launch date ranges (see fig. 4). Further information is provided on the orbital distribution, with histograms on object numbers versus geographical longitude, semi-major axis, argument of perigee and apogee, eccentricity, inclination, ascending node and argument of perigee. The evolution of the orbit pole positions of drifting objects near GEO is shown in terms of the inclination vector location (see fig. 5). The position of the object in this diagram indicates when orbit maintenance was discontinued. Then, several diagrams are shown detailing near-GEO & super-GEO objects per object type and mission Finally, a histogram summarises the launches of payloads and upper stages into GEO per year and cumulative. Equivalent charts are provided for upper-GEO objects (with perigees at least 50 km above the GEO ring).

5. ESALOF

The ESA Log of On-Orbit Fragmentations (EsaLOF) shows all known fragmentation events to date. The main EsaLOF table lists them according to COSPAR ID, indicating also the owner, the object name, type, assessed fragmentation cause, fragmentation date, geographic position of the event, maximal and current fragment count, and pre/post-fragmentation orbital elements. An excerpt of the EsaLOF fragmentations register is shown in fig. 6.

Additional subordinate tables have been included in the EsaLOF:

- A table giving comments for each fragmentation.
- A set of short tables showing fragmentation events ordered by event date, launch date, maximum debris count and current debris count. These tables include only COSPAR ID, name, launch and event dates, maximal and current fragment counts, pre/post event orbital characteristics, and assessed cause.
- A table giving details on fragment cloud characteristics, in particular giving orbital parameters for several datasets: original data, mean data, maximum data and root mean squared data.
- A table summarising information on on-orbit fragments, including the source object, the radar cross-section, assessed lifetime and last orbital characteristics.

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, and for the maximum and current fragment count of the ten major events (see Fig. 7). Several pie charts show number of breakups and total/on-orbit debris according to originator nation, orbit class, object type or break-up cause. Last, scatter plots are used to show the relationship among the fragmentation epoch and the argument and height of perigee, inclination, eccentricity, or launch date (See Fig. 8). Also, for each fragmentation event, several charts are shown:

- The geographic location of break-up is shown as ground tracks over an earth map, based on the last TLE before the event epoch (see Fig. 9).
- Scatter plots of height of perigee and apogee versus orbit period (See Fig. 10), inclination and node are used to illustrate the cloud dispersion.

6. CONCLUSIONS

The DISCOS-2 Publication and Documentation System (DISPAD) was initiated by ESA to make information of the DISCOS-2 database more easily accessible to users who are not computer experts. For a specified information cutoff date, the DISPAD system extracts DISCOS data, formats them into tables, translates them into charts, and merges them into predefined LaTeX-2ε document templates of three individual reports: the ESA Register of Objects in Space (EsaROS), the ESA Log of Objects in or near GEO (EsaLOG) and the ESA Log of On-orbit fragmentations (EsaLOF). All of these reports have been produced with minimum operator intervention in publication quality by means of the LaTeX-2ε typesetting software. Extensive tables of contents and indices enable a quick access to tabulated or charted information. Summarising, DISPAD reports:

- Provide in a comprehensive manner a number of Space Debris related information in tabular form
- Show relationships among data in graphical form
- Users need not to be familiarized with those tools provided by DISCOS-2 system
- Remote access using public networks can be avoided, as DISPAD reports can be printed in high resolution printers

It is foreseen to publish the three updated DISPAD documents in 2001. Inquiries can be submitted to Dr. Klinkrad (e-mail: hklinkra@esoc.esa.de).

7. REFERENCES

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COSPAR ID Catalog ID	Nation/Org. Object Type/Mission Type Object Name	Launch Date Launch Site	Lifetime/Decay Launch vehicle	Obj. Dimensions (m) Obj. Mass at BOL (kg) X_SECT_MIN / X_SECT_MAX	Orbital Elements Det. Date yyyy-mon-dd	 h_p (km)	 h_a (km)	 e (-)	 i (deg)	 ω (deg)	 τ (min)
1057-012A	CIS	1957-Oct-04	1957-Dec-01 (d)	28L 2.58-2.95D	1957-Oct-04	215.0	939.0	0.05200	65.10	58.00	96.20
1	?	TYUR	Vostok SL-1/SL-2 (A)	4000	1957-Nov-04	203.00	738.00	0.03900	65.10	45.00	94.00
	Sputnik 1 rocket			?/?	1957-Nov-24	190.00	458.00	0.2000	65.00	36.00	91.00
1957-001B	CIS	1957-Oct-04	1958-Jan-01 (d)	0.58D	1957-Oct-04	215.00	939.00	0.05200	65.10	58.00	96.20
2	P	TYUR	Vostok SL-1/SL-2 (A)	83.6	1957-Oct-25	213.00	863.00	0.04700	65.10	49.00	95.40
	Sputnik-1			?/?	1957-Dec-25	190.00	458.00	0.02000	65.00	23.00	91.00
1957-002A	CIS	1957-Nov-04	1958-Apr-14 (d)	31.8L 2.58-2.95D	1957-Nov-03	212.00	1660.00	0.09900	65.33	59.00	103.75
3	P	TYUR	Vostok SL-1/SL-2 (A)	508.3	1958-Jan-04	210.00	1356.00	0.08000	65.29	35.00	100.51
	Sputnik-2			?/?	1958-Feb-21	200.00	1040.00	0.06000	65.26	14.00	97.11
					1958-Mar-25	187.00	733.00	0.04000	65.23	359.00	93.79
					1958-Apr-09	166.00	460.00	0.02200	65.21	352.00	90.78
1958-001A	USA	1958-Feb-01	1970-Mar-31 (d)	2.03L 0.15D	1958-freb-01	356.00	2548.00	0.14000	33.24	121.00	114.80
4	P	ETR	Jupiter C (Juno I)	4.8	1960-Dec-05	347.00	1859.00	0.10100	33.21	10.00	107.20
	Explorer-1			?/?	1967-Nov-28	334.00	1281.00	0.06600	33.18	201.00	100.90

Fig. 2: EsaROS – Object description table

COSPAR Id Catalog Id Object name	Nation/Org Object type	Launch date Launch site Launch vehicle	Mission Type Obj. Dimensions (m) Obj. Mass al BOL (kg)	Latest orbit Det.Date yyyy-mon-dd	Latest Position λ (deg)	 $d\lambda$ /dt (deg/d)	Orbital Elements Δa (km)	 e (-)	 i (deg)	 Δr_a (km)	 Δr_p (Km)
1964-047A	USA	1964-Aug-19	Technology mission	1974-Dec-06	6.06W	0.19W	+14.92	0.00136	8.55	+72.12	42.27
85B	payload	ETR, Kennedy SC	0.39 L 0.71 D								
Syncom 3			39								
1965-028A	ITSO	1965-Apr-06	?/?	1997-Sep-29	47.38W	0.02E	-1.64	0.00008	14.11	+1.85	-5.13
1317	payload	ETR Kennedy SC	0.59 L 0.72 D								
Intelsat 1 F-1			39								
1966-053A	GGTS 1	1966-Jun-16	Technology mission	1995-Jun-08	67.71W	27.64E	-2024.06	0.00331	11.40	-1891.39	-2156.72
2207	Not Implemented	ETR, Kennedy SC	0.8 L 0.9D								
USA	payload	Titan IIIC	47								
1966-052B	IDCSP 1-1	1966-Jun-16	Telecommunications	1997-Aug-06	140.40E	27.49E	-2013.38	0.00280	10.93	-1900.81	-2125.95
2215	Not implemented	ETR, Kennedy SC	0.8L 0.9D								
USA	payload	Titan IIIC	45								
1966-110A	ATS-1	1966-dec-07	Technology mission	1998-Mar-02	148.56W	.033E	-26.01	0.0046	14.35	-6.62	-45.40
2608	Not Implemented	ETR, Kennedy SC	1.45L 1.42D								
USA	payload	Altas SLV3	352								

Fig. 3: EsaLOG – Object description table

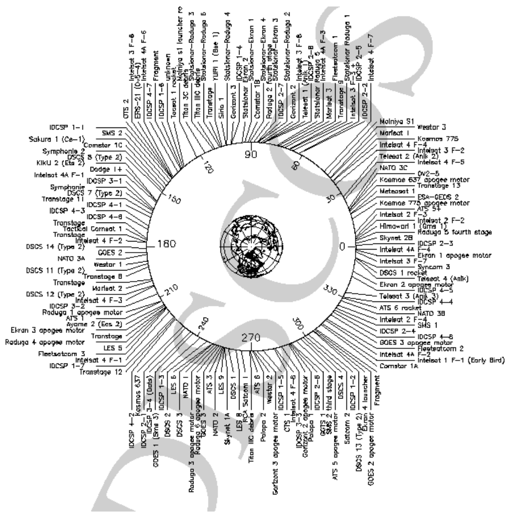

Fig. 4: EsaLOG – Geographical longitude of in or near GEO objects

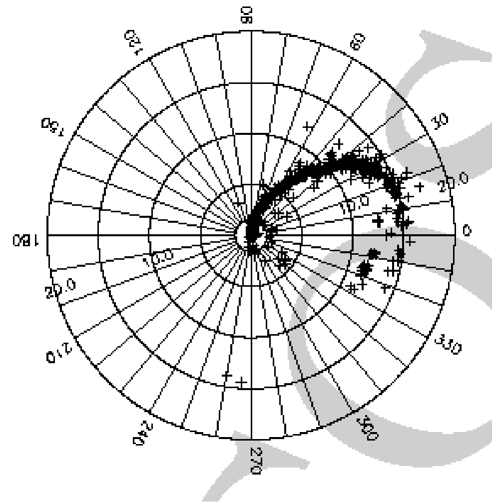

Fig. 5: EsaLOG – Node position and inclination of GEO objects

COSPAR ID Catalog No. Nation/Org.	Object name Object type Fragmentation cause	Launch Date (UT) Event Date (UT)	Position ΔT_{max} (min), Δi_{max} (deg)	Org. Mass (kg) Max.Obj.Count Cur.Obj.Count	Pre/Post Fragmentation Elems Det. Date yyyy-mon-dd	h_p (km)	h_a (km)	e (-)	i (deg)	ω (deg)	τ (min)
1961-015C	TRANSIT 4A R/B	1961-Jun-29	990.0, 28.0N, 196.0W	625	1961-Jun-06	883.38	997.81	0.00782	66.82	288.24	103.84
118	Ablestar Stage	1961-Jun-29 06:08	15.5 min, 1.3 deg	298							
USA	Propulsion-related		Not implemented	201							
1962-057A	SPUTNIK 29	1962-Oct-24	?,?,?	3900-6200	1962-Oct-24	203.04	261.90	0.00445	65.11	92.27	89.15
443	Payload and R/B(s) (?)	1062-Oct-29 ??:??	?,0.6 deg	24							
USSR	Propulsion-related		Not implemented	0							
1963-047A	ATLAS CENTAUR 2	1963-Nov-27	?,?,?	4600	1963-Dec-02	476.55	1781.73	0.08693	30.34	151.82	107.89
694	Centaur Stage	1963-Nov-27 ??:??	0.9 min, 0.4 deg	19							
USA	Propulsion-related		Not Implemented	9							
1964-070A	KOSMOS 50	1964-Oct-28	?, ?, ?	4700 (aprox.)	1964-Oct-29	187.69	233.13	0.00345	51.23	312.96	88.70
919	Payload	1965-Nov-05 ??:??	?, ?	96							
USSR	Deliberate Detonation		Not Implemented	0							
1965-012A	KOSMOS 57	1965-Feb-22	380.0, 64.0S, 76.0W	5500 (aprox.)	1965-feb-25	171.61	414.76	0.01822	64.74	68.73	90.38
1093	Payload	1965-feb-22 09:57	4.4 min, 0.9 deg	167							
USSR	Accidental Detonation		Not Implemented	0							
1965-020D	KOSMOS 61-63 R/B	1965-Mar-15	1640.0, 51.0S,162.0S	1500(aprox.)	1965-Mar-15	263.16	1831.61	0.10561	56.05	106.16	106.13
1270	SL-8 Final Stage	1965-Mar-15 17:14	10.3 min, 0.4 deg	148							
USSR	?		Not Implemented	22							
1965-022B	OV2-1/LCS 2 R/B	1965-Oct-15	740.0, 22.08, 108.0E	1500 (?)	1965-Dec-27	659.22	762.95	0.00727	32.17	123.61	99.01
1640	Titan 3C-4 Transtage	1965-Oct-15 18:20	4.1 min, 1.4 deg	470							

Fig. 6: EsaLOF – Fragmentation description table

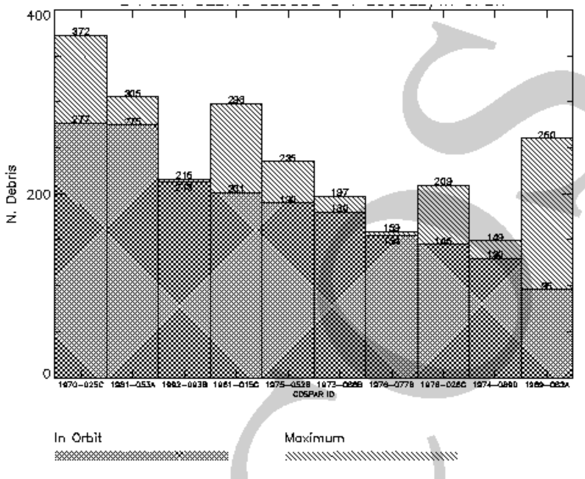

Fig. 7: EsaLOF – Largest debris clouds catalogued / on-orbit

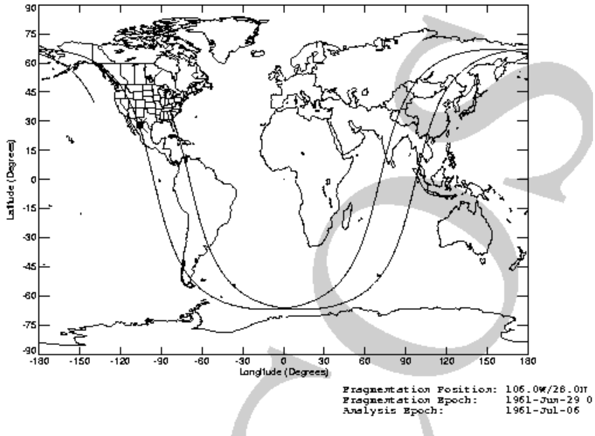

Fig. 9: EsaLOF – Fragmentation location

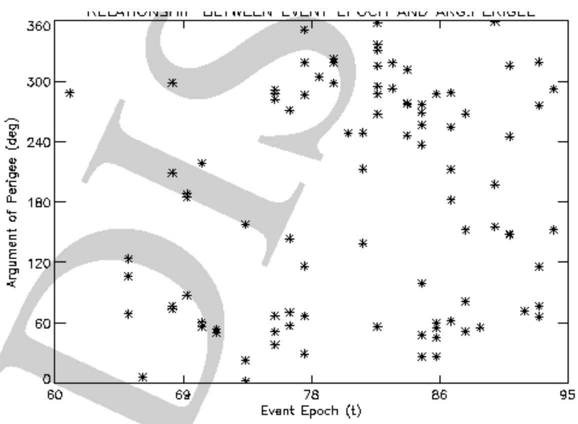

Fig. 8: EsaLOF – Relationship between the fragmentation epoch and the argument of perigee

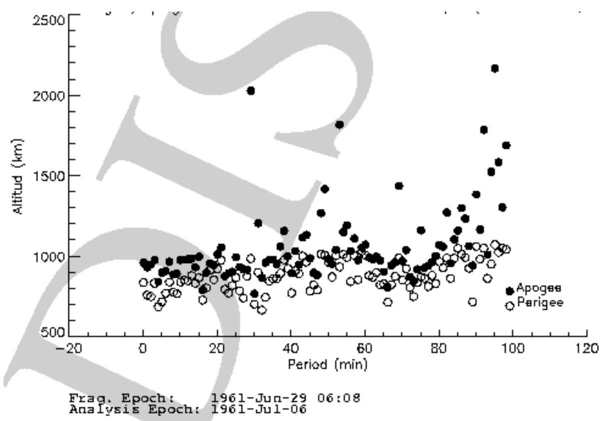

Fig. 10: EsaLOF – Fragment Altitude vs. period