DISCOS SPACE DATA PUBLICATION SYSTEM

DISPAD

EXECUTIVE SUMMARY

GMVSA 2166/96

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1 INTRODUCTION

1.1 Identification and Purpose

This document has been produced by GMV under contract 11183/94/D/IM with ESA/ESOC. It is the *"DISPAD Project Final Report"* produced as output of the DISPAD Project work package WP7000 (Management) (see reference [11]).

DISPAD Project was performed by **GMV** (Madrid), from March 1995 to November 1996. The Agency's technical representative has been Mr. **Heiner Klinkrad** (ESA/ESOC-MOD).

The main objective of this document is to compile the main results obtained from the different activities performed as a part of the DISPAD project, as well as the description of these activities themselves. These results are described in detail. A summary of them can be found in reference [2].

1.2 scope

The present report describes major results of the DISPAD project, along with the activities that produced them, but its scope includes some conclusions about the DISPAD System itself, the benefits of its use, and recommendations for the future.

On the other hand the scope of the project comprises the development of a software system which produces four types of reports on the contents of the DISCOS database maintained by ESOC (chapter 4 provides a brief overview of this Database). These reports are:

1. **EsaROS**: ESA Register of Objects in Space.
2. **EsaLOD**: ESA Log of On-Orbit and Decayed Objects.
3. **EsaLOG**: ESA Log of Objects in or near the Geostationary Orbit.
4. **EsaLOF**: ESA Log of Fragmentation Event.

These reports are discussed in detail in chapter 5.

1.3 Document Layout

This report is structured as follows:

- Chapter 1 (this one) introduces the present Final Report terms of objectives, contents and structure.
- Chapter 2 lists the documents referenced within this summary.
- Chapter 3 summarizes the course of the project describing how the work was organized, the different activities performed, their chronological performance order and major inputs and outputs.
- Chapter 4 provides an overview of the main characteristics and objectives of the DISPAD System, along with an introduction to the DISCOS database.
- Chapter 5 describe in detail the four types of reports that are produced by the DISPAD System. For each report, the data tables and the graphical charts providing information on space population are described.
- Chapter 6 describes the overall architecture of the DISPAD System in terms of functional blocks and relationships among them.
- Chapter 7 describes how relevant information is extracted from the database.
- Chapter 8 summarizes major conclusions that can be extracted from the work done during the course of the project, along with some recommendations for the future.

2 BIBLIOGRAPHY

This chapter provides the list of bibliographic items referenced within this report.

During the course of the DISPAD Project, all the bibliographic references that were found to be potentially useful for the purposes of the Project were collected under a centralized bibliography database, including articles, books, technical reports and documents generated within the scope of the project. This database is supported by BIBTEX, in such a way that bibliographic references can be authomaticaly inserted within LATEX documents of the project.

For each bibliography reference in the database, information such as *title*, *author*, *organization*, *date*, and some *comments* about the reference is included. In this chapter, the documents referenced within this Executive Summary are listed:

[1] Oscar Tejedor. DISPAD: Database Queries Description. GMV S.A., November 1995.

[2] Oscar Tejedor. DISPAD Project Executive Summary. GMV S.A., October 1996.

[3] Oscar Tejedor. DISPAD: Reports Layout Definition. GMV S.A., November 1995.

[4] Oscar Tejedor. DISPAD: Software User Manual. GMV S.A., October 1996.

[5] Oscar Tejedor. DISPAD Technical Note 3: Generation of Graphics and Preformatted Tables. GMV S.A., December 1995.

[6] Oscar Tejedor. DISPAD Technical Note 4: Reports Production. GMV S.A., April 1996.

[7] ESA. ESA Software Engineering Standards. European Space Agency (ESA), February 1991.

[8] I. Wayne-Grisson, Robert P. Guy, and David J. Nauer. History of On-Orbit Satellite Fragmentations. Teledyne Grown Engineering, 1994.

[9] ESOC/OPS/MOD. Invitation To Tender: DISCOS Space Data Publication System. ESA/ESOC, September 1994.

[10] ESOC Mission Analysis Section. Log of Objects Near the Geostationary Ring. ESA/ESOC, 1994.

[11] GMV S.A. Proposal for DISCOS Space Data Publication System. GMV S.A., October 1994.

3 PROJECT HISTORY

This chapter provides a brief overview of the main activities performed during the project, how they were ordered in time, and how they were related to each other, i.e. how outputs of an activity are used as inputs to others.

The project evolved as it was initially proposed in reference [11] (project proposal). In a first approach, two major groups of activities can be identified:

- Definition of the layout of the reports to be produced by the DISPAD System. This part of the project involves the acquisition of knowledge on the database contents, the arrangement of relevant contents in a tabular format and the identification of statistics on the data to be represented graphically.
- Development of the system that will produce the reports. This part involves the identification of technologies that could assist the development, and the development of the parts of the system that implement specific tasks of the system.

In a more detailed inspection, individual tasks are identified by the work breakdown structure described by table 1. It adheres strictly to the one given in the Statement of Work (reference [9]), except for the fact that a *Management* work package was added.

Initially, the different activities involved in the development of the system were planned to run sequentially, but during the course of the project, some *backtracking* took place, as intermediate results of some activities were used as feedback for some activities performed earlier. For instance, review of preliminary versions of the reports, resulted in feedbacks to the definition of reports layouts.

Figure 1 shows how the DISPAD project activities were performed.

WP Name	WP Description
WP 1000	Reports Layout Definition
WP 2000	DISCOS Data Extraction
WP 3000	Generation of Graphics and Pre-formatted Tables
WP 4000	Reports Production
WP 5000	Software User Documentation
WP 6000	Software Upgrade, Installation and Demonstration

Table 1: DISPAD Project: Work Breakdown Structure

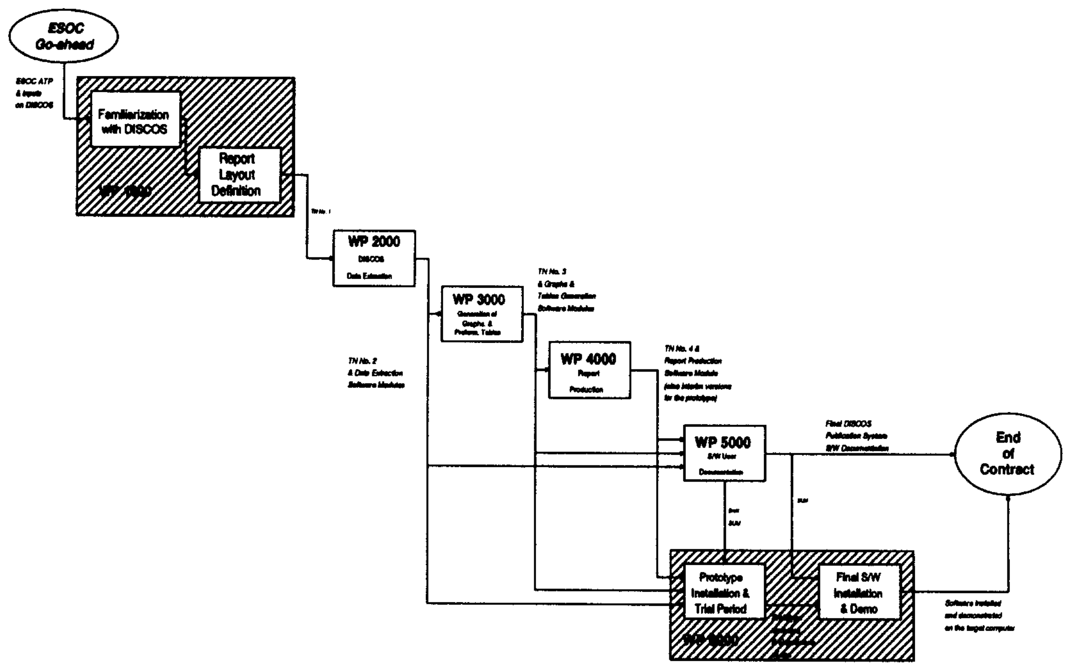

Figure 1: DISPAD Project: Activities Schedule

As the figure shows, the activities performed within WP 1000, which correspond to the first of the groups identified above, were intended to set the basis for the further development. Main activities within this work package involved the study of the DISCOS database and the definition of the layout of the reports.

As a result of these activities, Technical Note 1 describing the reports structures and contents was produced. This technical note corresponds to reference [3], although chapter 5 in this document describes the DISPAD reports as well.

Technical Note 1 was revisited several times as the project evolved to include modifications to both the contents and structure of the documents, specially in the format and contents of the data tables and in the number and appearance of the graphical charts.

Once the reports were fully defined, the extraction of data from the DISCOS database was started. This activity correspond to WP 2000. To start this work package outputs of WP 1000 were necessary, as they define which data were to be extracted.

As a result of these activities, Technical Note 2 summarizing queries developed and format of resulting files (reference [1]), and a set of Pro*Fortran and Pro*C programs were produced.

With the files generated containing the data extracted from the database, the next step was the generation of the software pieces in charge of transforming data in these files into graphical charts. WP 3000 was defined for this purpose.

Main objectives of this work package were initially:

- Derivation of graphical charts from the data extracted from the DISCOS database and written into unformatted tables.
- Give a format to the unformatted data tables generated with the data extracted from DISCOS in such a way that they can be easily integrated into TeX/LaTeX based document templates.

For the first objective, a set of **Perl** scripts and **PV-Wave** programs where written that extract data from the unformatted tables, and generate different types of graphical charts.

No work was invested in pre-formatting data extracted from the database, as the simple format given to the unformatted tables was formal enough to allow the construction of LaTeX tabular material without the need of pre-formatting them, if a powerful tool as **Perl** was used.

Technical Note 3 was produced as output of this work package (reference [5]). This note describes main transformations performed on data in order to produce graphical charts. The Perl scripts used to pre-process unformatted tables, and the PV-Wave programs build to generate graphics are described in detail. It also describes the process used (and implemented later on in the project) to insert data in unformatted tables directly into LaTeX document templates without need for pre-process.

At this point, we were in the position of starting the implementation of the *glue* software necessary to join data extraction programs with graphics generation ones, and of the software pieces that would implement other tasks of the DISPAD System (e.g. integration of extracted data into LaTeX document templates). WP 4000 defines these activities.

The power of Perl was also exploited for this purpose, as it provides mechanisms to activate programs (system calls) and to process text (e.g. regular expressions).

The first task to perform in this work package was the definition of the LaTeX document templates, since the programs that integrates data tables and charts within the templates are strongly influenced by their final format.

At this point, the final structure of how the system would be located at the targe environment was defined in form of a ***directories structure*** and an associated set of ***environment variables*** which allow to easily identify the different software elements of the system and the ***"porting"*** to other environments.

Then the rest of the software pieces composing the system were developed. This development was performed sequentially for the different reports, since DISPAD is made up of four components producing each one of the reports.

As a result of these activities, Technical Note 4 was produced (reference [6]) summarizing the results of the work package.

In parallel to these activities, and within the scope of WP 5000, Unix **man** pages were produced describing how the different components of the system are used, and finally a *Software User Manual* (reference [4]) compliant with the ESA Software Engineering Standards (reference [7]) was produced which describes how to use and to install the system.

Finally, the system was transferred to the target environment at ESOC as a part of the activities planned for the work package WP 6000. ESOC exercised the system, produced the reports and provided GMV with feedback about some aspects of the system that could be enhanced, or that needed to be revised.

During all this process some side activities were performed in order to control the evolution of the project, within the frame of WP 7000, Management.

At this point it is also important to spend some words in describing how the architecture of the system evolved during the project due to the changes in the definition of the target environment in which DISPAD System had to run.

This situation is depicted in figure 2:

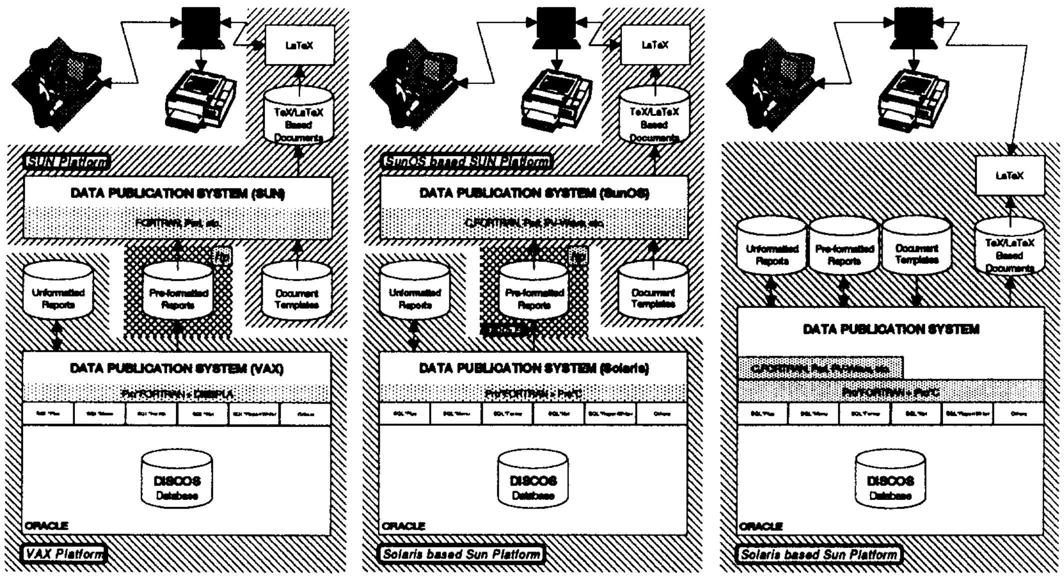

Figure 2: Evolution of the DISPAD System Architecture

1. The leftmost part of the figure shows the initial approach, as it is described in the proposal (reference [11]). In this approach, DISCOS is running on a VAX-VMS machine along with the parts of DISPAD System in charge of the data extraction to unformatted reports, and the preparation of pre-formatted reports. Then these reports were transferred to a Sun-Unix machine in which the rest of the system integrated them into the document templates to produce the LaTeX source files and finally the printable files.

2. In the second approach (the middle of the figure) the VAX machine was replaced by a Sun-Solaris machine, and it was specified that a transfer of data was done through the ESOC firewall to a Sun-SunOS machine. The distribution of tasks was identical to the first approach.

3. Finally, it was decided that the whole DISPAD System will run on a unique Sun workstation with Solaris operating system (right most part of the figure)

4 DISPAD SYSTEM OVERVIEW

ESOC is maintaining a **Database and Information System for the Characterisation of Objects in Space** (DISCOS). The organisation of DISCOS 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 (Structures Query Language) by means of compact statements. The information retrieval is supported by statistical and graphical analysis software using Pro*FORTRAN interfaces, and DISSPLA utilities. The data can be output numerically or graphically (on screen or as ASCII/PostScript files).

The DISCOS information is stored in thematic tables which 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 which have been acquired and processed for use within DISCOS 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 future, also ESA's Meteoroid and Space-Debris Terrestrial Environment Reference (MASTER) model will be available through DISCOS.

So far, DISCOS 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 host machine via public networks (DECNet or InterNet). It would be desirable to extent the use of the information of the database within the scientific community, the larger the best.

In order to make DISCOS information accessible to a wider community, a **DISCOS Publication and Documentation System** (DISPAD) has been developed within the frame of this project. DISPAD extracts data according to specified criteria, lists them in pre-formatted tables, charts them in various diagrams, and finally merges this information into LaTeX2ε document templates. Four major DISPAD documents with extensive indices and explanations are produced, as described in chapter 5.

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

DISPAD produces regular situation reports on the DISCOS 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).

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 text processing system to produce the final form of the reports.

5 REPORTS PRODUCED BY THE DISPAD SYSTEM

This chapter describes the four reports that are produced by the DISPAD System describing for each of them:

- Document layout of the reports.
- Data tables integrated within the reports.
- Graphics (charts) in the reports.

5.1 Common Parts to All Reports

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This section identifies those parts of all the reports produced by the DISPAD system that are common, i.e. those parts that appear in all the reports with equivalent contents.

With respect to the layout of the reports, there are several characteristics that are common to all the reports. These are:

1. Cover page, that includes the elements:
   - Title of the document.
   - Date of issue.
   - Issue number.
   - ESA logo, and a reference to ESOC as the originator of the document.
   - Figures representing satellites population are included in the cover page of all the reports, execpt for the EsaLOG which includes a figure with the updated situation of GEO objects.
2. Disclaimer, Abstract, summarizing purpose and contents of the document, and Foreword are distributed in separate pages.
3. Table of contents.
4. List of tables.
5. List of figures (charts).

6. One chapter of introduction to the report, paying attention to its identification, its objectives and a summary of what can be found in the report, and in which sections.
7. One index identifying each object mentioned in the report. The index is arranged in three columns due to the amount of entries in some of the reports (e.g. more than 23,000 objects are listed in the EsaROS, representing each one entry in the index).
8. An appendix describing main orbital parameters.
9. An appendix compiling main acronyms and abbreviations appearing in the reports.

5.1.1 Major Types of Charts

Along with the standard types of charts presented in this section, other types specific to some of the reports are also produced for specific purposes of the individual types of reports. These more specific types of charts are described in the chapters describing individual types of reports.

The following list describes the types of charts most commonly used in the reports on Space Debris:

- *Bar Chart* that will be mainly used for representing the relationship between two parameters. They are used to represent, for instance the evolution of the number of launches in time.
- *Pie Chart* that will be mainly used for comparing percentages of amounts according to different comparison criteria. The whole circle of these charts represents 100 %, while individual slices (sectors) represent percentage contributions, which are indicated both by the relative size of the slice, and numerically in associated labels.
- *Line Chart* that will be used for similar purposes as the bar charts, but it may be more helpful in specific situations.

5.2 ESA Register Of Objects In Space

ESA Register of Objects in Space (EsaROS) contains information about all catalogued objects in space as a result of satellites launches since 1957 (Sputnik-1).

The EsaROS register is intended to contain different types of information about these objects, including object identification, launch details, spacecraft (S/C) and mission description, lifetime (actual or expected), and orbital information.

5.2.1 EsaROS Layout

The EsaROS will be made up of the common parts described in section 5.1 along with the following specific parts:

1. One chapter about *launches* including both numerical data tables and charts representing the number of launches grouped by different criteria, including:
    - Per country.
    - Per year.
    - Per launcher.
2. One chapter with the list of all the catalogued objects in space both in tabular and graphical formats.

5.2.2 EsaROS Tables

Two types of tables are produced for the EsaROS report:

- Launch statistics.
- Catalogued Objects.

5.2.2.1 Launch Statistics Tables

The purpose of these tables is to provide a general view of the amount of launches and deployments performed since 1957 and how their are grouped according to different criteria. Considered criteria are:

- Per country.
- Per year.
- Per launcher.

Three data tables are produced for the EsaROS with information about launches:

1. **Launch Vehicles**, organized by operators and including the following information per operator:
   - Operator.
   - Launch vehicles, giving for each one:
     - Launcher family.
     - Launcher system.
     - Launcher configuration
     - Launch site abbreviation.
     - Types of missions
   - Number of launches per launcher family, system and configuration.

   Table 2 shows a sample of such a table.

2. **Launch Sites**, organized by nation, giving for each site the following information:
   - Nation.
   - Organization.
   - Site name.
   - Site abbreviation.
   - Launch systems.
   - Azimuth constraints.
   - Geographical coordinates.

   Table 3 shows a sample of such a table.

3. **Number of deployments per year and nation.**

   Table 4 shows a sample of such a table.

EsaROS: Table of Launch Vehicles

Launch Operator	Launcher System	Launcher Family	Launcher Configuration	No.	Launch Site(s)	Mission Types
ESA	ARIANE	ARIANE-4	ARIANE-40	2	KOUR	GEO, GTO
			ARIANE-44P	4	KOUR	LEO, GTO
			ARIANE-44L	2	KOUR	LEO, GEO, GTO
			ARIANE-44LP	10	KOUR	GTO
				18		
		ARIANE-1		3		
		ARIANE-2		6		
				27		
	EUROPA			2		
			⋮			

Table 2: Sample of Table of Launch Vehicles for EsaROS

EsaROS: Table of Launch Sites

Nation	Organization	Launch Site Azimuth Constraints	Site Abbreviation Geogr. Coordinates	Launch Systems
FRANCE	ARIANSPACE	Kourou, French Guiana -10.5 to 93.5	KOUR 52.8W 5.2N	ARIANE
		⋮		

Table 3: Sample of Table of Launch Sites for EsaROS

EsaROS National Launch Statistics

Nation/ Organization	Annual/Cumulative Number of Launches										Year
	+0	+1	+2	+3	+4	+5	+6	+7	+8	+9	
CIS	-/-	-/-	-/-	-/-	-/-	-/-	-/-	1/1	7/8	17/24	1950
	40/64	16/80	29/109	50/159	38/197	55/252	60/312	72/384	53/437	41/488	1960
	../...	../...	../...	../...	../...	../...	../...	../...	../...	../...	1970
	../...	../...	../...	../...	../...	../...	../...	../...	../...	../...	1980
	../...	../...	../...	../...	../...	-/-	-/-	-/-	-/-	-/-	1990
USA	-/-	-/-	-/-	-/-	-/-	-/-	-/-	0/0	../...	../...	1950
	../...	../...	../...	../...	../...	../...	../...	../...	../...	../...	1960
	../...	../...	../...	../...	../...	../...	../...	../...	../...	../...	1970
	../...	../...	../...	../...	../...	../...	../...	../...	../...	../...	1980
	../...	../...	../...	../...	../...	-/-	-/-	-/-	-/-	-/-	1990
⋮			⋮					⋮			⋮
World Total	-/-	-/-	-/-	-/-	-/-	-/-	-/-	0/0	../...	../...	1950
	../...	../...	../...	../...	../...	../...	../...	../...	../...	../...	1960
	../...	../...	../...	../...	../...	../...	../...	../...	../...	../...	1970
	../...	../...	../...	../...	../...	../...	../...	../...	../...	../...	1980
	../...	../...	../...	../...	../...	-/-	-/-	-/-	-/-	-/-	1990

Table 4: Sample of Launches/Deployments per Nation Table for EsaROS

5.2.2.2 Catalogued Objects Tables

The catalogued objects table provides details of all known objects in space launched since 1957. Objects in the table are ordered chronologically.

The minimal information to be given for each individual object is:

- Object identification.
- Nation.
- Launch information.
- Object type.
- Mission objectives.
- Decay date.
- Orbital lifetime (observed or predicted).
- Object geometry.
- Orbital elements:
  - Determination date.
  - Height of perigee (h_p)
  - Height of apogee (h_a)
  - Eccentricity (e)
  - Inclination (i)
  - Argument of perigee (ω)
  - Period.
- Mission details.

This information will be split up in two tables in order to separate details about the object from the mission details, thus making both tables more readable than a unique table containing all this information.

Table 5 shows a partial example of how the table of general information about catalogued objects will look like, while table 6 shows how the mission details table will present descriptions of mission objectives.

EsaROS Table of Catalogued Objects: General Information

COSPAR Id. Catalog	Nation/Org. Object Type Object Name	Launch Date Launch Site	Lifetime/Decay Launch system	Mission Objectives Obj.Dim.: LxWxH (m) Obj.Mass at BOL (kg)	Orbital Elements Det. Date yyyy-mon-dd	h_p (km)	h_a (km)	e	i (deg)	ω (deg)	T (min)
⋮			⋮					⋮			⋮
1995-004G 23475	USA Fragment ODERACS 2E	1995-Feb-03 ETR, Kennedy SC	1995-Feb-27 (d) Shuttle	Orbital decay studies 0.001 x 0.001 x 0.134 --	11-FEB-95	339	320	0.01	51.6	344.0	91.12
1995-004H 23475	USA Fragment ODERACS 2F	1995-Feb-03 ETR, Kennedy SC	-- Shuttle	Orbital decay studies 0.001 x 0.001 x 0.04 --	--	--	--	--	--	--	--
1995-005A 23477	CIS Spacecraft Progress M-26	1995-Feb-15 Tyuratam	1995-Mar-19 Soyuz	Cargo Freighter 2.72 x 2.72 x 7.9 --	1995-Feb-15 1995-Feb-16 1995-Feb-16 1995-Feb-16	224 294 295 397	188 247 238 391	0.0090 0.0089 0.0091 0.0092	51.6 51.7 51.7 51.7	93.0 128.0 125.0 135.0	88.61 89.62 89.84 92.45
⋮			⋮					⋮			⋮

Table 5: Sample of Catalogued Objects Table: General Information

EsaROS Table of Catalogued Objects: Mission Details

COSPAR Id. Nation/Org. Object Name	Comments
⋮	⋮
1995-004G USA ODERACS 2E	The small satellites are to be used to test the tracking capabilities of ground-based radar and optical sensors, allowing those measurements to be calibrated with small objects of a known size and composition
1995-004H USA ODERACS 2F	The small satellites are to be used to test the tracking capabilities of ground-based radar and optical sensors, allowing those measurements to be calibrated with small objects of a known size and composition
1995-005A CIS Progress M-26	Unmanned cargo freighter, carrying supplies to the MIR cosmonauts as well as 100 kg of equipment to be used by United States astronaut Norman Thagard during his visit to MIR. Spacecraft docked with the rear port on the Kvant1 module at the rear of the MIR Complex 1995 Feb 17.77 (18.22 GMT). Undocked from the MIR Complex 1995 Mar 15.10 (02.27 GMT) and was de-orbited later that day.
⋮	⋮

Table 6: Sample of Catalogued Objects Table: Comments

5.2.3 EsaROS Graphics

The following graphics will represent graphically data in tables describes in section 5.2.2:

- For **launches tables**:
  - Accumulated number of launches per year and nation. A *bar chart* is used to represent the evolution of launches by year for each country and organization.
  - Accumulated number of objects per year: The relationship between total number of objects and objects still on orbit will also be represented (this chart is also included within EsaLOD report).
- For **catalogued objects tables**:
  - Number of objects versus inclination.
  - Number of objects versus semi-major axis.
  - Number of objects versus eccentricity.
  - Number of objects versus argument of perigee.
  - Number of objects versus apogee height.
  - Number of objects versus perigee height.

  Bar charts, are used for representing these relationships.

5.3 ESA Log Of On-Orbit And Decayed Objects

The ESA Log of On-orbit and Decayed objects (EsaLOD) is made up of two differentiated parts:

- The first one provides a situation report of the space objects population on orbit. The level of detail to be given in this report will be similar to that given in the EsaROS register for all catalogued objects (section 5.2.2.2).
- The second one will provide a summary of the objects which have decayed, have been retrieved, or have been lost.

5.3.1 EsaLOD Layout

The EsaLOD is made up of the common parts described in section 5.1 along with some other specific parts:

1. One chapter with the list of all on-orbit trackable objects in a tabular format along with associated statistics represented graphically by means of charts. Section 5.3.2.1 describes layout and contents of the table of on-orbit trackable objects, while section 5.3.3 shows major charts representing statistics about on-orbit trackable objects.
2. One chapter with the list of all decayed objects in a tabular format. Section 5.3.2.2 describes layout and contents of the table of decayed objects.

5.3.2 EsaLOD Tables

As it was described in section 5.3.1, two types of tables will be produced for the EsaLOD report:

- On-orbit trackable objects.
- Decayed objects.

5.3.2.1 On-orbit Trackable Objects Table

The on-orbit trackable objects table lists all known objects in space with identical details as in the table of catalogued objects in EsaROS (see section 5.2.2.2). Objects in the table are ordered chronologically (according to COSPAR ID).

The minimal information to be given for each individual object is:

- Object identification.
- Nation.
- Launch information.
- Object type.
- Mission objectives.
- Decay date.
- Time in orbit.
- Object geometry.
- Orbital elements:
  - Determination date.
  - Height of perigee (h_p)
  - Height of apogee (h_a)
  - Eccentricity (e)
  - Inclination (i)
  - Argument of perigee (ω)
  - Period.
- Mission details.

As in the case of the EsaROS, this information will be split up in two tables in order to separate details about the object from the mission details.

Table 7 shows an abbreviated example of the table of general information about on-orbit objects, while mission details table is very similar to that shown in table 6 for EsaROS.

EsaLOD List of Objects on Orbit

COSPAR Id. Catalog	Nation/Org. Object Name	Launch Date Lifetime	Object Type BOL Mass (kg)	Mission Objectives Obj.Dim.: LxWxH (m)	Orbital Elements						
					Det. Date yyyy-mon-dd	h_p (km)	h_a (km)	e	i (deg)	ω (deg)	T (min)
⋮			⋮					⋮			⋮
1995-004H	USA	1995-Feb-03	Fragment	Orbital decay studies	--	--	--	--	--	--	--
23475	ODERACS 2F	--	--	0.001 x 0.001 x 0.04							
1995-005A	CIS	1995-Feb-15	Spacecraft	Cargo Freighter	1995-Feb-15	224	188	0.0090	51.6	93.0	88.61
23477	Progress M-26	1995-Mar-15	--	2.72 x 2.72 x 7.9	1995-Feb-16	294	247	0.0089	51.7	128.0	89.62
					1995-Feb-16	295	238	0.0091	51.7	125.0	89.84
					1995-Feb-18	397	391	0.0092	51.7	135.0	92.45
⋮			⋮					⋮			⋮

Table 7: Sample of On-orbit Objects Table: General Information

5.3.2.2 Decayed Objects Table

The decayed objects table lists, in chronological order (sorted by COSPAR ID), objects which have decayed, have been retrieved, or have been lost. Less details than provided for the on-orbit objects (described in section 5.3.2.1) will be given for this table.

The minimal information given for each individual object is:

- Spacecraft proper name.
- International COSPAR designator.
- USSpaceCom number.
- Object type.
- Nation or Organization.
- Launch date.
- Decay date.
- Object mass and dimensions

This fields are given for objects (i.e. piece identifier of COSPAR ID from A to C), but in case of fragments, the COSPAR ID field contains the range of on-orbit fragments, the launch date contains the fragmentation event date, the object dimensions contains the detected number of fragments, and the object mass, the currently tracked number of fragments.

Table 8 shows a partial example of how the catalogued objects table will look like.

EsaLOD List of Decayed Objects

COSPAR ID/Cat.No.	Nation/Org.	Object Name	Object Type	Launch Date	Decay Date	BOL Mass (kg)	Obj.Dim.: LxWxH (m)
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
1995-003A/23476	CIS	Progress M-26	Spacecraft	1995-Feb-12	1995-Jul-15	2200	2.72 x 2.72 x 7.9
1995-005C/23480	USA	USA-51 rocket	Upper Stage	1995-Feb-15	1995-May-20	3100	2.4 x 2.4 x 4.2
1995-005D->YG/--	USA	Fragments	Fragments	1995-Feb-23	--	220 max.	110 decayed
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Table 8: Sample of Decayed Objects Table

5.3.3 EsaLOD Graphics

Statistics on the number and distribution of objects on orbit pertaining to different criteria will be included in the EsaLOD report.

Particularly, the following set of statistics will be represented graphically for this report:

- Proportion of on-orbit objects per country.
- Proportion of on-orbit objects per orbital region.
- Proportion of total mass and cross section of objects per country.
- Proportion of total mass and cross section of objects per orbital region.

  Pie charts are used for representing these statistics.
- Number of objects versus inclination.
- Number of objects versus semi-major axis.
- Number of objects versus eccentricity.
- Number of objects versus argument of perigee.
- Number of objects versus apogee height.
- Number of objects versus perigee height.

  Bar charts are used for representing these relationships.
- The relationship between on-orbit objects and decayed objects. For this purpose, a 2 lines diagram is used in such a way that one line would represent the yearly accumulated number of objects on-orbit and the second one the yearly accumulated number of total objects, the difference between both lines being the number of decayed objects.

5.4 ESA Log Of Objects Near Geo

The ESA Log of Objects near GEO (EsaLOG) lists all objects near the geostationary ring, including all objects with low inclination ($< 20\ deg$), near circular orbits (eccentricity < 0.1) of 0.9 to 1.1 sideral revolutions per day.

This document is a successor of (and therefore similar to) the current *"ESA Log of Objects Near GEO"* (reference [10]), with more detailed information on launch, spacecraft (S/C) mass and geometry, mission objectives and spatial distribution of objects.

EsaLOG distinguishes between GEO and Super-GEO orbits. In this sense the set of tables of its ancestor, the *"ESA Log of Objects Near GEO"* can be inherited by the EsaLOG report. The tables to be produced for this report are:

1. Objects in or near the geostationary ring.
2. Objects in super-geostationary orbits.
3. Objects in or near the geostationary ring that are not in the first table.

5.4.1 EsaLOG Layout

The EsaLOG is made up of the common parts described in section 5.1 along with some other specific parts:

1. One chapter with the list of all objects in or near the geostationary ring in a tabular format along with associated statistics represented graphically by means of charts. Section 5.4.2.1 describes layout and contents of the table, while section 5.4.3.1 shows major charts that will be included to represent statistics about on-orbit trackable objects.
2. One chapter with the list of all objects in super-geostationary orbit in a tabular format along with associated statistics represented graphically by means of charts. Section 5.4.2.2 describes layout and contents of the table, while section 5.4.3.2 shows major charts that will be included to represent statistics about on-orbit trackable objects.
3. One chapter with the list of all objects in or near the geostationary ring that are not in the first table in a tabular format. Section 5.4.2.3 describes layout and contents of the table.

5.4.2 EsaLOG Tables

Three types of tables are produced for the EsaLOG report:

1. Objects in or near the geostationary ring.
2. Objects in super-geostationary orbits.
3. Objects in or near the geostationary ring that are not in the first table.

5.4.2.1 Objects in or near Geostationary Ring

The table of objects near geostationary ring lists all the objects in or near the geostationary ring, i.e. with:

- Eccentricity < 0.1.
- Mean motion between 0.9 and 1.1 revolution per sideral day (corresponding approximately to a radius of 42164 ± 2800 km).
- Inclination < 20 deg.

Two complementary sets of tables will contain the information about these objects.

The main table of the first set will be similar, but with more detailed information as compare with the second and third table in the "ESA Log of Objects Near the Geostationary Ring" (reference [10]). It will provide for each individual object the following information:

- Object identification.
- Nation/Organization.
- Operator.
- Object type.
- Mission objectives.
- Object mass and dimensions.
- Longitude (λ)

- Drift rate ($\dot{\lambda}$).
- Launch information.
- Orbital elements:
  - Deviation of the semi-major axis (Δ a).
  - Deviation of the height of perigee (Δr_p).
  - Deviation of the height of apogee (Δr_a).
  - Eccentricity (e).
  - Inclination (i).
- Date of orbit determination.

This table is ordered chronologically (according to COSPAR ID). Table 9 shows a sample of this type of table.

This table will be complemented by other three tables: The first one containing comments for the objects in the previous table (as that described for EsaROS in table 6), while the second and third tables contain a reduced set of information fields with respect the main table of the set. Contents of these tables will be identical but ordered according to different criteria: chronologically (COSPAR ID) and geographic longitude. Table 10 shows a sample of these tables.

EsaLOG List of Objects Near GEO

COSPAR ID USSSpaceCom ID Object Name	Nation/Org. Operator Object Type	Launch Date Launch Site Launch Syst.	Mission Objectives Obj.Dim.: LxWxH (m) Obj.Mass at BOL (kg)	Det.Date yyyy-mon-dd	Position		Orbital Elements				
					λ (deg)	λ (deg/d)	Δa (km)	e	i (deg)	Δr_p (km)	Δr_a (km)
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
1995-003A 23476 Ekran	CIS NPO Energija Spacecraft	1995-Feb-12 Tyuratam SL-12	Communication 2.72 x 2.72 x 4.9 4200	1995-Feb-15 1995-Mar-30	123.2E 120.6E	1.2W 0.1E	+24 +2	0.0031 0.0002	5.2 0.6	-5.2 -0.4	+30.4 +1.3
1995-003B 23477 Proton stage#4	CIS NPO Energija Upper Stage	1995-Feb-12 Tyuratam SL-12	Injection into GEO 2.5 x 2.5 x 4.3 2200	1995-Feb-15 1995-Mar-30	123.2E 70.6E	1.2W 2.5E	+24 +50	0.0031 0.0005	5.2 0.8	-5.2 -0.4	+30.4 +1.3
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Table 9: Sample of Table of Objects near GEO (I)

EsaLOG Shortlist of Objects Near GEO

COSPAR ID	Operator/Org.	Object Description	Det.Date yyyy-mon-dd	Position		Orbital Elements				
				λ (deg)	λ (deg/d)	Δa (km)	e	i (deg)	Δr_p (km)	Δr_a (km)
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
1995-003A	NPO Energija	Statsionar Ekran-13	1995-Feb-15	123.2E	1.2W	+24	0.0031	5.2	-5.2	+30.4
	CIS		1995-Mar-30	120.6E	0.1E	+2	0.0002	0.6	-0.4	+1.3
1995-003B	NPO Energija	Proton 4th stage	1995-Feb-15	123.2E	1.2W	+24	0.0031	5.2	-5.2	+30.4
	CIS		1995-Mar-30	70.6E	2.5E	+50	0.0005	0.8	-0.4	+1.3
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Table 10: Sample of short list of Objects near GEO

The main table of the second set lists the same objects as the previous one, but with a different set of information fields ordered by COSPAR Id. Information fields in this table are:

- COSPAR Id.
- Object proper name.
- Longitude (λ).
- Size and mass.
- Frequency and transmitter power.
- Date of beginning of service life (BOL).
- Date of end of service life (EOL).
- S/C owner.
- Mission details.

Table 11 shows a sample of this type of table.

This table is also complemented by a table of comments like that shown in table 6 for EsaROS.

EsaLOG Payload Description of GEO Spacecraft

COSPAR ID USSpaceCom ID Object Name	Launch Nat. Operator S/C Series	Launch Date Begin of Service End of Service	Last Position Det.Date yyyy-mon-dd	Last Position λ (deg)	Last Position λ (deg/d)	Mission Objectives Transponders or Instruments Frequency Bands Used
⋮	⋮	⋮	⋮	⋮	⋮	⋮
1995-003A 23476 Intelsat 5	ESA Intelsat 501	1995-Feb-21 1995-Feb-25 2003-Mar-01 (pred)	1995-Mar-30	120.6E	0.03E	Communications and direct broadcasting 4 transponders with 100 chanels each C-band
⋮	⋮	⋮	⋮	⋮	⋮	⋮
1995-020A 23493 Meteosat	ESA Eumetsat MOP-5	1995-Apr-20 1995-Jun-15 2000-Aug-01 (disp)	1995-May-23	10.6W	0.01E	Meteorology radiometer and data relay S-band telemetry and optical radiometry (IR,Vis)
⋮	⋮	⋮	⋮	⋮	⋮	⋮

Table 11: Sample of Table of Objects near GEO (II)

5.4.2.2 Objects in Super-Geostationary Orbits

The table of objects in super-geostationary orbits lists, in chronological order, those objects in tables described in section 5.4.2.1 (objects in or near the geostationary ring) whose perigee is at least 50 km above the geostationary radius (42164 km).

This table is directly derived from Table 2 of the "ESA Log of Objects Near the Geostationary Ring" (reference [10]). The information given for each individual object is:

- International COSPAR designator.
- Orbit determination date.
- Longitude drift rate ($\dot{\lambda}$).
- Deviation of the semi-major axis (Δa)
- Perigee deviation (Δr_p)
- Apogee deviation (Δr_a)
- Inclination (i).
- Re-orbit date.

Table 12 shows a partial example of the objects in Super-GEO table.

EsaLOG List of Super GEO Objects

COSPAR ID	Launch Nat.	Launch Date	Operator Org.	Det.Date yyyy-mon-dd	Drift	Orbital Elements						EOL orbit raise
					λ (deg/d)	Δa (km)	e	i (deg)	Δr_p (km)	Δr_a (km)		
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮		⋮
1995-003A	CIS	1995-Feb-12	NPO Energija	1995-Feb-15	1.2W	+24	0.0031	5.2	-5.2	+30.4		-
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮		⋮
1995-020A	ESA	1995-Apr-20	Eumetsat	1995-Mar-30	5.1W	+310	0.0050	8.6	+290.5	+331.3		1995-Feb-20
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮		⋮

Table 12: Sample of Super-GEO Objects Table

5.4.2.3 GEO-Objects Not Listed in Tables 11 to 15

This table lists objects in or near the geostationary ring that are not included in tables 9 through 12. These objects are geostationary objects listed in EsaROS, but not included in the **NASA TLE** list.

Information to be given for each object in this table is:

- COSPAR international designator.
- Launch Nation and date.
- Operator.
- Orbit Determination date.
- Orbital information:
  - Deviation of the semi-major axis (Δa).
  - Eccentricity (e).
  - Inclination (i).
  - Height of perigee (h_p).
  - Height of apogee (h_a).

Table 13 shows the header of this table. Each page used by the table includes this header.

EsaLOG List of Untracked GEO and Super GEO Objects

COSPAR ID	Launch Nat.	Launch Date	Operator Org.	Det.Date yyyy-mon-dd	Orbital Elements Δa (km)	e	i (deg)	Δr_p (km)	Δr_a (km)
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
1995-003A	CIS	95-Feb-12	NPO Energija	1995-Feb-12	+24	0.0031	5.2	-5.2	+30.4
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
1995-020A	ESA	1995-Apr-20	Eumetsat	1995-Mar-30	+310	0.0050	8.6	+290.5	+331.3
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Table 13: Sample of GEO-Objects not listed in Tables 9 to 12

5.4.3 EsaLOG Graphics

Different statistics derived from the data in the tables describes in previous section (i.e. section 5.4.2) are included.

5.4.3.1 Graphics of GEO Objects

First of all, a picture showing updated position of S/C in GEO, indicating the name of the different S/C and a pointer to its location, will be included (the same figure without satellite names is included in the cover page –see section 5.4.1–). Depending on the number of objects, it may happen that they need to be distributed in several figures of this type, to make all fo them more readable. In this case the caption of the figure will indicate the range of COSPAR IDs represented in each of the figures.

Then, those charts in the *ESA Log of Objects in or near Geostationary Ring* for the first table will be included. These charts are:

- Bar chart showing the distribution with geographical longitude (figure 1.1 of reference [10]).
- Bar chart showing the distribution of objects with apogee height deviation (Δr_a, figure 2.1 of reference [10]).
- Bar chart showing the distribution of objects with perigee height deviation (Δr_p, figure 2.2 of reference [10]).
- Bar chart showing the distribution with inclination (between 0^0 and 20^0, figure 1.2 of reference [10]).
- Bar chart showing the distribution with right ascension of ascending node (figure 1.3 of reference [10]).
- Bar chart showing the distribution of objects with deviation of semi-major axis (Δa)
- Bar chart showing the distribution of objects with eccentricity.
- Bar chart showing the distribution of objects with the argument of perigee.

  Bar charts will be used for the purpose of representig these statistics.
- Diagram showing the direction of orbital pole (figure 1.4 or reference [10]).
- Line chart showing the increase of GEO and Super-GEO objects and type A objects count (figure 1.5 of reference [10]).

- Bar chart showing the yearly number of payloads and upper stages launched into GEO (figure 1.6 of reference [10]).
- The distribution of objects in or near GEO by countries in percentages are represented in the form of a pie chart.

5.4.3.2 Graphics of Super-GEO Objects

- Bar chart showing the distribution of objects with apogee height deviation (Δr_a, figure 2.1 of reference [10]).
- Bar chart showing the distribution of objects with perigee height deviation (Δr_p, figure 2.2 of reference [10]).
- Bar chart showing the distribution of objects with inclination (between 0^0 and 20^0, figure 2.3 of reference [10]).
- Bar chart showing the distribution of objects with right ascension of ascending node (figure 2.4 of reference [10]).
- Bar chart showing the distribution of objects with deviation of semi-major axis (Δa)
- Bar chart showing the distribution of objects with eccentricity.
- Bar chart showing the distribution of objects with the argument of perigee.

  Bar charts will be used for the purpose of representig these statistics.
- Diagram showing the direction of orbital pole (figure 1.4 or reference [10]).
- Bar chart showing the yearly number of payloads and upper stages launched into Super-GEO (figure 1.6 of reference [10]).
- The distribution of objects in Supper-GEO by countries in percentages are represented in the form of a pie chart.

5.5 ESA Log Of On-Orbit Fragmentations

The ESA Log of On-orbit Fragments (EsaLOF) lists both fragmentation events and corresponding fragments. This report is similar to the *"TBE Table of On Orbit Fragmentations"* (reference [8]) with more detailed orbit and mass/geometry information of the pre-fragmentation object.

The fragmentation events and the corresponding fragments are described in two separate parts of the document.

5.5.1 EsaLOF Layout

The EsaLOF is made up of the common parts described in section 5.1 along with some specific parts:

1. One chapter with the list of fragmentation events occurred since June 1961 (the date of the first serious satellite fragmentation) in a tabular format along with associated statistics represented graphically by means of charts. Section 5.5.2.1 describes layout and contents of the table, while section 5.5.3 shows major charts that will be included to represent statistics about fragmentation events.
2. One chapter with the list of all on-orbit fragments in a tabular format. Section 5.5.2.2 describes layout and contents of the table

5.5.2 EsaLOF Tables

As it was described in the introduction to this chapter, two types of tables are produced for the EsaLOF report:

1. Log of fragmentation events.
2. Log of on-orbit fragments.

5.5.2.1 Log of Fragmentation Events Table

This table lists fragmentation events in ascending order of COSPAR ID.

This table is similar, but with more detailed information, to the table 2.1 in the *"TBE Table of On Orbit Fragmentations"* (reference [8]). The minimal information to be given for each event is:

- Object proper name.
- International COSPAR designator.
- USSpaceCom designator.
- Object size and mass.
- Launch date.
- Pre and post-fragmentation orbit elements
  - Determination date.
  - Height of perigee (h_p)
  - Height of apogee (h_a)
  - Eccentricity (e)
  - Inclination (i)
  - Argument of perigee (ω)
  - Period.
- Mission description.
- Fragmentation date.
- Fragmentation location:
  - Longitude.
  - Latitude.
  - Height.
- Fragmentation cause.
- Fragmentation classification.
- Maximum change in orbital period and inclination (ΔT_{max}, Δi_{max}).
- Highest and current fragment count.

Table 14 shows a partial example of this table.

This table is complemented by a set of tables including the table of comments like that for EsaROS (table 6) to the event list (table 14) and several tables with a reduced subset of the information contained in the event list, containing identical information between them but sorted according to different criteria (event date, launch date, maximum number of fragments and current number of fragments). Table 15 provides a sample of the short lists.

EsaLOF Table of Fragmentation Events

COSPAR Catalog	Nation/Org. Object Name Type	Launch Date Fragm. Date Fragm. Cause	Pos: lon,lan,h (deg,km) ΔT_{max}(min), Δi_{max}(deg) Event Classification	Org.Mass (kg) Max.Obj.Count Cur.Obj.Count	Pre/Post-Fragmentation Elements						
					Det.Date yyyy-mon-dd	h_p (km)	h_a (km)	e	i (deg)	ω (deg)	T (min)
⋮		⋮			⋮				⋮		⋮
1965-020D	CIS	1965-Mar-15.54	162.0E, 51.0S, 1640	2300	1965-Mar-15	224	245	0.012	55.2	162.2	98.5
1270	SL-8	1965-Mar-15.71	10.3, 0.4	148	1965-Mar-16	214	305	0.011	56.2	162.2	98.5
	Upper Stage	Unknown	SL-8 final stage	22							
⋮		⋮			⋮				⋮		⋮
1989-052F	CIS	1989-Jul-05.95	--	56	1989-Jan-12	224	245	0.009	55.2	162.2	98.5
20116	SL-12	1993-Jan-12.00	--	1							
	Upper Stage	Prop.Related	SL-12 aux.motor	1							
⋮		⋮			⋮				⋮		⋮

Table 14: Sample of Fragmentation Events Table

EsaLOF Table of Fragmentation Events: Short List, sorted by event date

Object Name	COSPAR/Cat.No.	Launch Date	Event Date	Catlgd. max/cur	Pre/Post-Event Orbit			Assessed Cause	Event Type
					hp (km)	ha (km)	i (deg)		
⋮		⋮		⋮			⋮		⋮
SL-8	1965-020D/1270	1965-Mar-15.54	1965-Mar-15.71	148 / 22	224	245	55.2	Unkown	SL-8 Final Stage
⋮		⋮		⋮			⋮		⋮
SL-12	1989-052F/20116	i989-Jul-05.95	1993-Jan-12.00	1 / 1	224	245	55.2	Prop.Related	SL-12 aux.motor
⋮		⋮		⋮			⋮		⋮

Table 15: Sample of Fragmentation Events Table: Short List

5.5.2.2 Log of On-orbit Fragments Table

Information related to fragments on orbit are presented in two separate tables containing respectively:

- List of individual fragments on orbit.
- List of fragmentation clouds characteristics.

The first list includes all object fragments resulting from the events listed in log of fragmentation events (section 5.5.2.1). The minimal information given for each fragmentation is:

- COSPAR and USSpaceCom designators of source object.
- COSPAR and USSpaceCom designators of fragment.
- Number of fragment.
- Date when object was created and catalogued.
- Radar cross section (RCS).
- Lifetime.
- Most recent orbital elements:
  - Determination date.
  - Height of perigee.
  - Height of apogee.
  - Inclination.

Table 16 provides a sample of this table.

The second list will contain information about the clouds produced by fragmentations sorted by event date, including:

- Source object name.
- COSPAR and USSpaceCom designators.
- Fragmentation event date.

- Highest and current fragments count.
- Orbital elements of the cloud:
  - Height of perigee.
  - Height of apogee.
  - inclination.
  - Right ascension of ascending node.
  - argument of the perigee

  For all of this elements, it will be given:

  - Mean value over all members of the current debris cloud.
  - Maximum dispersion of a member of the current debris cloud (only for the three first elements).
  - Root-mean-squares dispersion of all members of the current debris cloud with respect to the mean

Table 17 provides a sample of this table.

EsaLOF Table of Fragments on Orbit

COSPAR/Cat.No. of Source Obj.	Source Object or Fragment No.	COSPAR/Cat.No. of Fragment	Date when object was Created	Date when object was Catalogued	RCS (sqm)	Decay (m/d)	Lifetime (d or y)	Most recent elements yyyy-mon-dd	Most recent elements h_p(km)	Most recent elements h_a(km)	Most recent elements i(deg)
				⋮							
1965-020D/1270	SL-8 upper stage	1965-020D/1270	1965-Mar-15	1965-Mar-17	10	-560	120 d	1995-Jul-12	224	245	55.2
	1	1965-020K/2130	1965-Mar-15	1972-Jun-20	1	-430	150 d	14-JUL-95	210	305	56.4
				⋮							
	89	1965-020XA/10230	1965-Mar-15	1986-Jan-10	2	-600	140 d	1995-Jul-13	215	320	54.3
				⋮							

Table 16: Sample of Fragments Table

EsaLOF Table of Fragmentation Cloud Characteristics

Object Name	COSPAR/Cat.No.	Fragmentation Event Date	Catalogued Fragments max./cur	Current Debris Cloud Dispersion				
				mean/d_{max}/d_{rms}			mean/d_{rms}	
				hp (km)	ha (km)	i (deg)	Ω (deg)	ω (deg)
				⋮				
SL-8	1965-020D/1270	1965-Mar-15.54	148/22	1212/-125/55	20239/+1098/167	55.1/-5.2/0.5	-167/100.5	-167/100.5
				⋮				
SL-12	1989-052F/20116	1989-Jul-05.95	1/1	1212/-125/0	20239/+1098/0	55.1/-5.2/0.0	-167/0.0	-167/0.0
				⋮				

Table 17: Sample of Fragmentation Clouds Table

5.5.3 EsaLOF Graphics

In principle, some of the charts in the *TBE table of on-orbit fragmentations* will be included. These charts include:

- Object counts of the largest debris clouds in orbit.
- Number of fragmentations by year. A pie chart is used for this purpose.
- All the pie charts in *"TBE Table of On Orbit Fragmentations"* (reference [8]), except those for which involved data are not available, i.e.:
  - Percentage distribution of causes of known satellite breakups.
  - Percentage distribution of all catalogued satellite breakup debris by breakup cause.
  - Percentage distribution of catalogued satellite breakup debris remaining in orbit by breakup cause.
  - Percentage distribution of sources of satellite breakups by owner.
  - Percentage distribution of on orbit fragments categorized by country of origin.
  - Percentage distribution of sources of satellite breakup debris by satellite type.

  Of course, pie charts are used for this purpose.
- Several diagrams showing the relationship between the *Event Epoch* and the following parameters:
  - Argument of perigee.
  - Perigee altitude.
  - Inclination.
  - Eccentricity ($\log_{10}$).
  - Launch epoch.
- One diagram showing the position of the framenetation events as a function of the latitude and longitude.

For each individual fragmentation event, the following diagrams will be produced:

- Location of the fragmentation.

- Distribution of perigee/apogee altitudes vs. orbital period of a debris cloud. A Gabbard diagram is used for this purpose.
- A rectangular diagram showing the spatial dispersion in altitude and inclination of a debris cloud.
- A rectangular diagram showing the dispersion in altitude and node of a debris cloud.

6 DISPAD SYSTEM ARCHITECTURE

This chapter describes the overall architecture of the DISPAD System. At this aim the overall structure of the system in terms of functional components, and the major processes producing the reports are described.

6.1 Basic Hardware and Software

As it was described in chapter 3, the architecture of the DISPAD System evolved during the course of the project due to the changes in the specification of the target environment in which the system was intended to run.

DISPAD System software was developed in an environment that differs in some points from the target environment in which it will finally run. This is imposed by the limited availability of resources at the development site (GMV), and by the change of the architecture of the target system (both hardware and software) since the beginning of the development. Therefore, the simplest solution was to use the resources available at the development site, which have not been affected by changes in the specification, but bearing in mind on which target environment the system was intended to run.

This target environment is made up of the following hardware and software items:

Hardware Platform	→	Sun Work Station (Sparc-20)
Operating System	→	Solaris 2.4
Window System	→	OpenWindows 3.4
DBMS	→	Oracle server 7.1.6
DBMS Tools pre-compilers:	→	SQL*Plus 3.1.3.4.1 Pro*Fortran 1.6.4.1.0 Pro*C 2.0
Compilers	→	SPARCompiler Fortran 3.0 (f77) SPARCompiler C 3.0 (cc)
Perl	→	Perl 5
Graphics Tools	→	PV-Wave 5.0

Text Processing → LaTeX2$_\varepsilon$

Some of these items are not necessary to run the DISPAD system, but they are required for maintenance activities (e.g. compilers)

The development environment was made up of two separate work stations each running a subset of the software tools available at the development site. This environment consists of:

- Sun work station with Solaris 2.3 operating system:
  - DBMS and associated tools:
    - Oracle 7.1.3.0.0.
    - SQL*Plus 3.1.3.4.1.
    - Pro*Fortran 1.6.4.1.0.
    - Pro*C 1.6.4.1.0.
  - Compilers:
    - SPARCompiler Fortran 3.0 (f77).
    - SPARCompiler C 3.0 (cc).
- Sun work station with SunOS 4.1 operating system:
  - Perl 4.0.1.8.
  - PV-Wave 4.20.
  - LaTeX 2.09 and LaTeX2$_\varepsilon$

Additionally, both workstation are connected through a LAN and implement **NFS**, so files managed by tools in any of the workstations are always available to both of them.

6.2 Producing the Reports

This section describes the overall process of producing a report starting with the data extracted from the DISCOS database.

6.2.1 Information Processing

Figure 3 depicts the general process of producing reports on the DISCOS database contents. From left to right, data are extracted from the DISCOS database, and are written to text files in form of *Unformatted Tables.* This task is performed by the data extraction programs generated by the compilation of Fortran/C programs containing embedded SQL statements (for instance `$DORA_BIN/EsaLOG_1` is the program which extracts data for table 1 of the EsaLOG report). In spite of being called *"unformatted"*, these tables present a very simple format which allows high level tools (e.g. Perl) to identify different information fields easily.

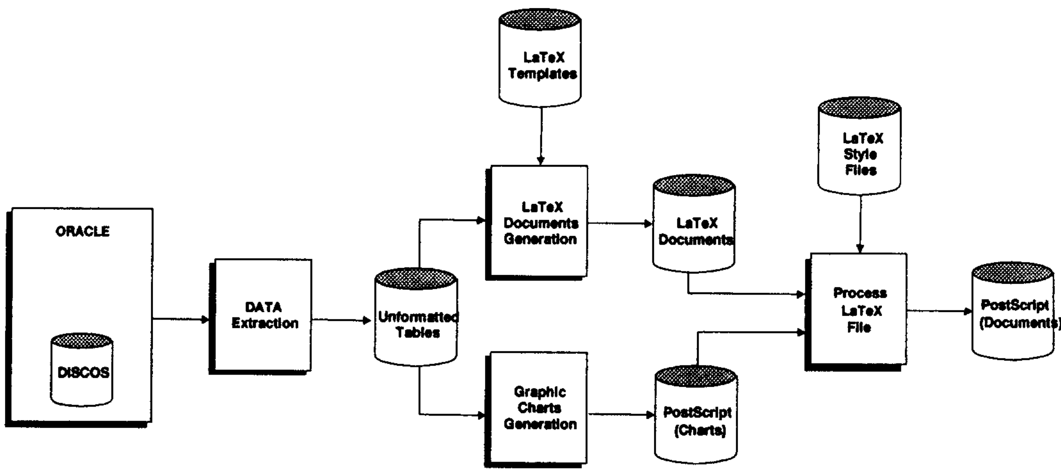

Figure 3: Producing Reports from DISCOS Information

These unformatted tables are used by the LaTeX document generation component of the system to produce *LaTeX Documents* by integrating data extracted from the *Unformatted Tables* into the *LaTeX Templates.* This component is a Perl script (for instance `$DISPADHOME/Perl/include/ROS_TEX.perl` is the script generating the file `$DTEX_SRC/EsaROS.tex`, i.e. the LaTeX source file for the EsaROS document).

Unformatted Tables are also used by the component in charge of generating graphical charts. This component, which is made up of a set of Perl scripts generating PV-

Wave scripts which in turn use PV-Wave programs. This component generates graphics in form of encapsulated *PostScript (Charts)* files.

Finally, there is a DISPAD component which controls the execution of LaTeX processes, *LaTeX Documents*, and encapsulated *PostScript (Charts)* files, along with the *LaTeX Style Files*, in order to generate the printable version of the document, i.e. the *PostScript Document*[1].

All the DISPAD components described in this section are controlled by a Perl script which activates them in a predefined sequence, and according to user preferences specified as options at the operating system command prompt.

6.2.2 Control Module

There exists one Perl script each for the control of the process of generating each of the DISPAD reports on the DISCOS contents. These scripts have the following basic structure:

1. Function `Options` reads user input from the command line and checks the correctness of the options specified. With these options the user can determine:
   - Whether the data are to be extracted from the database or not (the user may prefer to use data extracted in a previous execution of the system). If data are to be extracted and DISCOS `user name` and `password` are not specified in the command line, the user is asked to input them.
   - Whether the graphical charts are to be generated or already existing postscript files are to be used.
   - Whether the LaTeX source files are to be generated or already generated ones are to be used.
   - Whether LaTeX is to be run or not.
   - Whether a PostScript version of the document is to be produced or not.
   - Some other parameters for the generation of the document, including document issue, reference, date, orientation of some tables (landscape or portrait), relative size of figures with respect to the text width, etc.

   If this specification is not correct, then function `Usage` displays how the command can be specified correctly (indicating possible values for the different options) and aborts execution.

[1]Other format documents can also be generated, such as ASCII (plain text)

2. Depending on the user preferences different components of the system are activated:

   (a) Invokes `$DORA_BIN/EsaXXX_Y` with the user name and password given by the user.

   (b) Invokes `$DISPADHOME/XXXG_Y.perl` scripts to generate involved graphics.

   (c) Invokes `$DISPADHOME/include/XXX_TEX.perl` to generate the LaTeX source file of the document.

   (d) Invokes `$DISPADHOME/include/RunTeX.perl` to process the source file with LaTeX.

   `XXX` represents the denomination of the report being produced (names of the executable and script files share the same construction rules), i.e. `ROS`, `LOD`, `LOG` or `LOF`, while `Y` represents a sequential number.

   At each of these steps permissions of the generated files are changed to read only, so they cannot be damaged accidentally. If the step needs to write any file, first set write permissions for the file, and after modifying it restore permissions to read only again.

6.2.3 Extracting Data from DISCOS

Files in `$DORA_BIN` are executable files which extract data relevant for the different reports from the DISCOS database. Figure 4 shows the process of generating the executable files: Source files written in Fortran/C with embedded SQL statements are processed by the ORACLE pre-compilers to generate pure Fortran/C source code files which are compiled/linked by the corresponding compiler/linker to generate the executable file, which writes unformatted tables with data extracted from the database.

As an example, the file:

```
$DISPADHOME/Oracle/sources/ProFortran/EsaLOG_2.pfo
```

is a Fortran source code file with embedded SQL statements. The Oracle Pro*Fortran pre-compiler generates the file:

```
$DISPADHOME/Oracle/sources/ProFortran/EsaLOG_2.f
```

i.e. the Fortran source code file, which is compiled and linked to generate the binary file:

$DORA_BIN/EsaLOG_2

which, when executed, generates data file

$DORA_UTAB/EsaLOG_2.utab

i.e. the unformatted table for table number 2 of the ESA Log of Objects in or near GEO (EsaLOG).

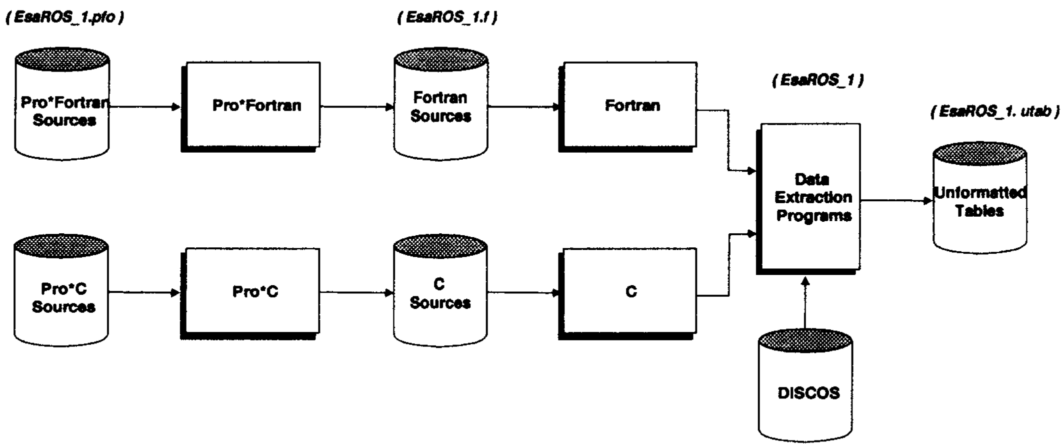

Figure 4: DISCOS Data Extraction

This process describes function **Extract DB Contents** in diagram 2 of SADT model.

6.2.3.1 Deriving Graphics from Data

Figure 5 shows this overall process: For each graphic or set of graphics with common characteristics to be generated for a report, the corresponding control module sequentially activates the different Perl scripts which are controlling this task.

These scripts are represented by the *"Format Data"* box in the figure. This submodule reads unformatted tables to extract the data relevant for the graphic and writes them to new text files with a predefined format (this format is imposed by the PV-Wave programs which will use them).

Then one or more PV-Wave scripts are written and executed.

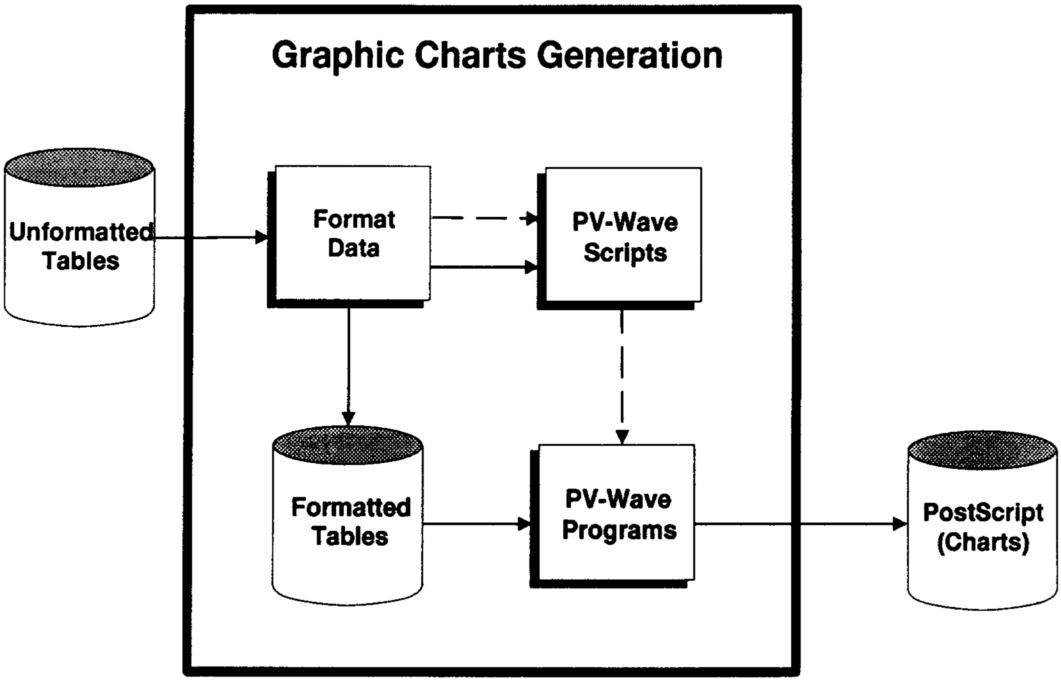

Figure 5: Graphic Charts Generation

These PV-Wave scripts activate PV-Wave, load the adequate PV-Wave programs, specify encapsulated PostScript files as output device, and run loaded programs with specified parameters.

The result of this process are one or more encapsulated PostScript files each containing a separate chart.

6.2.4 Producing LaTeX Source Files

The LaTeX source files for the different documents are generated by merging data extracted from the database into the unformatted tables with the LaTeX document templates.

There is one document template for each of the reports generated by the DISPAD System. These templates are in `$DTEX_TMPLT` and their names are build with the name of the report, followed by the suffix "_tmplt" and the extension ".tex". Therefore the document template files are defined as follows:

1. `$DTEX_TMPLT/EsaROS_tmplt.tex` is the template for the ESA Register of

Objects in Space (EsaROS).

2. `$DTEX_TMPLT/EsaLOD_tmplt.tex` is the template for the ESA Log of On-Orbit and Decayed objects (EsaLOD).
3. `$DTEX_TMPLT/EsaLOG_tmplt.tex` is the template for the ESA Log of Objects near GEO (EsaLOG).
4. `$DTEX_TMPLT/EsaLOF_tmplt.tex` is the template for the ESA Log of On-orbit Fragments (EsaLOF).

All these templates share the same structure: They are composed of some **static parts** which never change, and some **marks** to be replaced when the LaTeX document is being generated. These marks can be directly replaced by an actual value, or they can produce a function which is invoked to process an unformatted table in order to generate the corresponding LaTeX tabular material.

Perl script also exists for the generation of each of the reports mentioned above. Their names are built from the name of the report followed by the suffix "_TEX" and by the extension ".perl". For instance the Perl script:

```
$DISPADHOME/Perl/include/ROS_TEX.perl
```

contains the functions to generate the LaTeX source file:

```
$DTEX_SRC/EsaROS.tex
```

The "_TEX" scripts share a common structure, and their behaviour is illustrated by figure 6. The scripts read lines sequentially from the document template. While these lines are simple LaTeX commands, they are directly written to the output file (the LaTeX document source file), but when a mark is reached, the scripts execute the appropriate action. These actions can be the replacement of the mark by its actual value (as in the case of the document date) or the invocation of a function which generates the LaTeX tabular material in the document using data from the unformatted tables.

The process of producing a table involves the opening of the input file (unformatted table) and a loop of reading lines until end-of-file is reached. Within this loop, read lines are scanned to identify individual information fields. When all the information for an entry in a table is completed it is written to the LaTeX document source file in the proper format. Furthermore, index entries are created with object names when they are written.

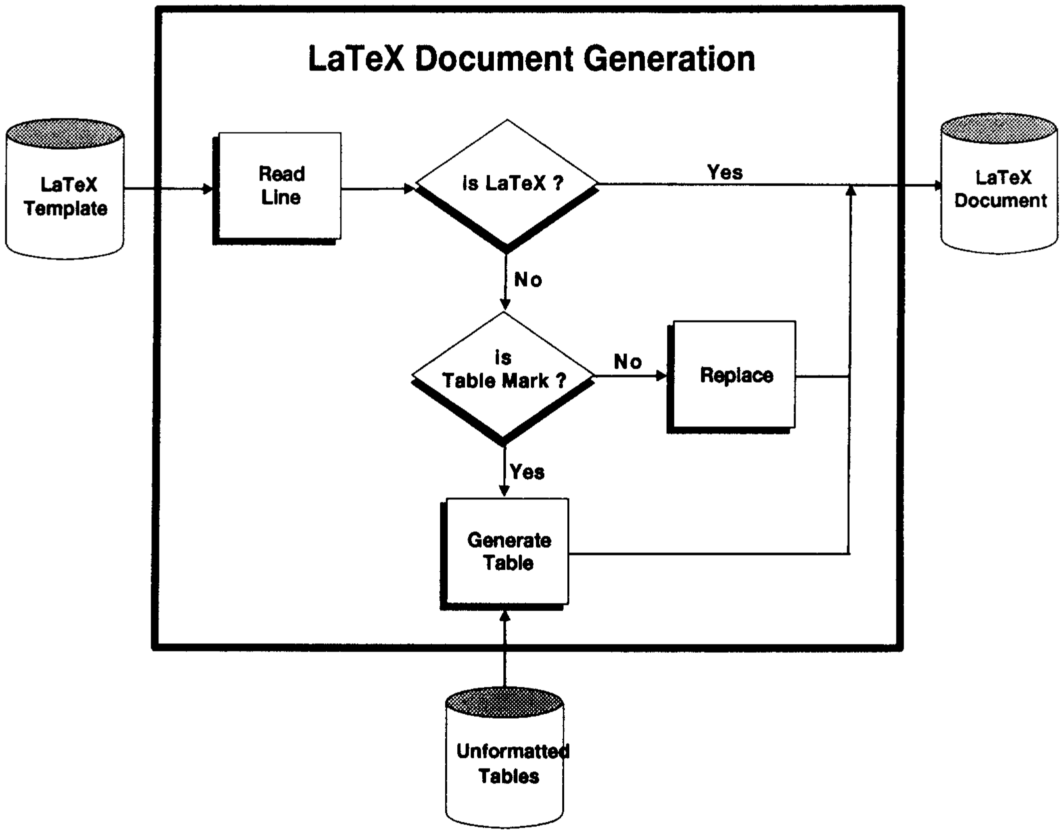

Figure 6: Generation of LaTeX Source Files

For instance, file `$DISPADHOME/Perl/include/ROS_TEX.perl` contains the function `ROS_TEX` and associated functions to generate tables of ESA Register of Objects in Space. Function `ROS_TEX` is invoked from control module script `$DISPADHOME/Perl/EsaROS.perl` to generate the `$DTEX_SRC/EsaROS.tex` source file. Then this function calls functions to generate tables when necessary. For instance, when the mark of table 1 of EsaROS is reached, the function `EsaROS_Table1` is called. This function reads data from the appropriate input file and writes these data to the LaTeX source file with the LaTeX syntax to compose the tabular material. Similarly, functions `EsaROS_Table2`, `EsaROS_Table3` and `EsaROS_Table4` which generate the other tables to be included in EsaROS, have also been developed.

At the end of the process an error free LaTeX document source file should have been created.

The major marks in template files are the following:

TABLEiMARK This marks (i=1,2,3,...) are to be replaced by the corresponding table of the report. For instance when mark **TABLE1MARK** is reached the function which generates the first table of the document will be invoked, while when mark **TABLE3MARK** is reached the function which generates the third table of the document will be invoked.

DOCREFMARK This mark is replaced by the value of the document reference which may have been specified by the user or can be a default value (i.e. "ESAXXX-ESOC-00", with XXX=(ROS, LOD, LOG or LOF)).

ISSUEMARK This mark is replaced by the value of the document issue which may can have been specified by the user or can be a default value.

STATUSMARK This mark is replaced by the value of the document status which may have been specified by the user or can be a default value.

DATEMARK This mark is replaced by the value of the document status which may have been specified by the user or can be a default value (i.e. current date).

FIG_PROPORTION This mark is replaced by the value of a variable which contains the proportion of the figures with respect to the width of the text, 0.7 being the default.

OPTIONAL_LANDSCAPE_BEGIN This mark is replaced by the **\begin{landscape}** LaTeX command if the subsequent table is to be arranged in landscape. The mark is suppressed otherwise. This applies to the ***Mission Details*** tables in all the reports which can be arranged with both orientations.

OPTIONAL_LANDSCAPE_END This mark is replaced by the **\end{landscape}** LaTeX command if the last table was arranged in landscape. The mark is suppressed otherwise. This applies to the ***Mission Details*** tables in all the reports which can be arranged with both orientations.

OPTIONAL_LONGTABLE_DEFINITION This mark is replaced by the corresponding definition of the tables of ***Mission Details***. The definition of the table differs significantly depending on the orientation of the table.

Environment Variables Some environment variables are specified in the template files. Since LaTeX does not manage this type of variables, they are replaced by their actual values. This is the case for the encapsulated PostScript files of charts which names include the value of the `$DPVW_PS` environment variable.

6.2.5 Running LaTeX

This section explains how LaTeX is run on a document source file to produce its final results, i.e. a printable version of the document.

Figure 7 illustrates how the script which is in charge of processing the document source file works. This script is shared by the programs generating the different reports (i.e. it is invoked by the control modules of all these programs), since the process is identical for all of the reports.

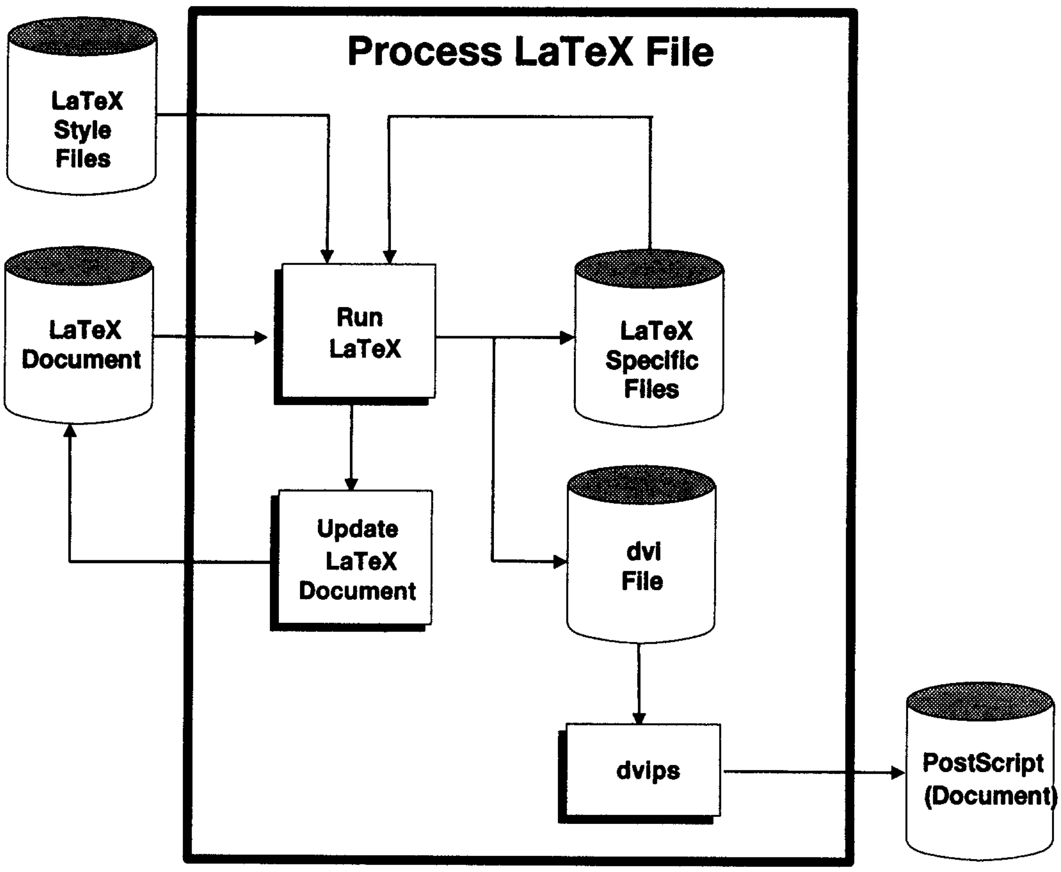

Figure 7: Running LaTeX

This script is `$DISPADHOME/Perl/include/RunLaTeX.perl` and performs the following steps:

1. Runs LaTeX on the source file of the report being processed. It executes an `xterm` with the -e option which opens a terminal and executes the command

following the -e option. This command is the LaTeX one.

2. Runs **makeindex** on the .idx file, thus generating the corresponding .ind file.

3. Scans the source file to find a comment line with the command \setlongtables and removes the comment mark (%).

4. Runs LaTeX two more times on the same source file just modified (also by executing a xterm). Now the device independent file is available to generate the printable version or to be directly sent to the printer.

5. If the user has requested it, **dvips** is run on the .dvi file and puts its output in the corresponding PostScript file (e.g. $DTEX_PS/EsaROS.ps in the case of the ESA Register of Objects in Space).

7 DATABASE QUERIES DESCRIPTION

7.1 Queries Production

This section describes both the environment used to produce and test the SQL queries to extract from the DISCOS database the information relevant to the different DISPAD reports (section 7.1.1), and the process of producing such queries (section 7.1.2). It also describes some general aspects present in the different data extraction programs implemented (section 7.2).

7.1.1 Queries Production Environment

As it was described in chapter 3, the target environment in which DISPAD was planned to be installed was composed by two separate machines:

- VAX-VMS, where the actual DISCOS database resides will support the extraction of data from the database and the creation of unformatted data tables.
- Sun-Unix, will support, after transferring unformatted tables from VAX, the integration of data extracted into the LaTeXdocument templates, the generation of formated data files to feed plotting application in order to produce charts, and the processing of LaTeX document to generate printable formats.

However, due to hardware/software configuration of GMV, data extraction was performed and tested on a Sun workstation with Solaris:

- Operating system: Solaris 2.3 (Unix System V)
- Oracle server 7.1.3.0.0
- SQL*Plus 3.1.3.4.1
- Pro*Fortran 1.6.4.1.0
- Fortran: SPARCompiler FORTRAN 3.0 (f77)

This fact entailed some migration effort from this environment to the target one in VAX-VMS.

However, as DISCOS database was moved to a Sun environment, there was no need for this migration. This also implied that C language and Pro*C Oracle pre-compiler could also be used for the data extraction programs. This enlarged the development environment described above to add the following items:

- Pro*C 1.6.4.1.0
- C: SPARCompiler C 3.0 (cc)

Therefore some of the programs are written in Pro*Fortran (those produced before the decision of moving DISCOS to a Sun based environment) while other are written in Pro*C.

7.1.2 Queries Production Process

For testing purposes, partial copies of the DISCOS database were brought to be used at GMV. This process involved the following steps:

1. ESOC provided GMV with an account at **NSP** host in ESOC.
2. ESOC also provided GMV with an account in the DISCOS database.
3. GMV created its own tables as (total or partial) copies of the existing one and exported them, using the **exp** utility of Oracle, to dump files (*.DMP).
4. These files were transferred to GMV's machines via ftp and imported, using the **imp** utility of Oracle.

Then Pro*Fortran and Pro*C programs were produced and tested against these copies of the database tables.

7.2 Generalities of the Programs

The queries to the DISCOS database for extracting information are embedded in either Fortran or C programs in form of Pro*Fortran or Pro*C pre-compilers primitives respectively. The integration of source code with these primitives produce pre-compilers source code.

These pre-compilers have been organized individually, existing one source code file, which corresponds to one program (it gives raise to an executable unit), for each table of the reports. Furthermore a Fortran source code file containing a set of routines that are shared by the other (Fortran) programs was produced.

These source files have been named using the name of the report to which the table for which it extracts data belongs, followed by the number of the table within that report[2], and the extensions ".pfo" or "pc" depending on whether it is a Pro*Fortran or a Pro*C Program respectively. In this way, the names of the source files are of the form "EsaROS_2.pfo", "EsaLOD_2.pc", etc[3]. while the executable files generated from them have the same name without extension.

These programs share a common structure, that in its simplest form is made up of a declaration section, the definition of the SQL query, and a loop in which data extracted by that query are analised, processed and saved to the unformatted table file. But in some cases, this structure is enhanced by defining more than one selection query. This becomes necessary when all the entries in a database table have not a correspondence in other table with which it is related. For instance, for the table of all catalogued objects, the table **ALL_CATALOGUE** contains most of the information about all the catalogued objects, but the orbital information about the objects is searched in the table **ALL_ORBITS**. These tables are related through the key fields **IDYR**, **IDLNO** and **IDPNO** (that all together form the International COSPAR Identifier). If we select all the entries in ALL_CATALOGUE table and all the entries in ALL_ORBITS where the fields IDYR, IDLNO and IDPNO are equal in both tables, only those objects in ALL_CATALOGUE that have orbital information associated are selected. For this reason it is necessary to consult both tables separately.

In all these programs an Oracle function is used: **NVL()** that in case of a null value for a field a default valued specified as its second parameter is returned, avoiding execution errors when a null value is detected. For instance `NVL(SITE_NAME,'unknown')` retrieves the value of the field SITE_NAME from the database whenever it exists

[2]Some exceptions exist to this rule as some programs produce more than one table. For instance EsaROS_1 produces tables 1 and 2 of the EsaROS

[3]Since the development environment is a Sun with Solaris OS (i.e. Unix) the case of the characters in the files names is significant.

(its value is not null), but it returns the value "unknown" if a null value is detected for that field.

The files generated by these programs contain the data extracted from the database with a raw format: all the information fields are separated by a character "|" and the correspondence between an item and its actual value in those files are calculated by other programs using the unformatted tables by its relative position within the file. For these reason, all items must be written to the output file, event those which value is unknown. Unknown values of the items are represented by the word "unknown" in the output file.

These output files are given the same name as the programs that originate them but with the extension ".utab" (unformatted table), thus EsaROS_2 will produce a file called "EsaROS_2.utab"[4].

[4] **Some exceptions exist to this rule as some programs produce more than one table. For instance EsaROS_1 produces unformatted tables EsaROS_11.utab and EsaROS_12.utab**

8 CONCLUSIONS AND RECOMENDATIONS

The objectives of the DISPAD project, i.e. the production of a software tools which allows the production of situation reports on the contents of the ESOC's DISCOS database with minimum human intervention, in such a way that information in the DISCOS database becomes more accessible to users who are not computer experts, avoiding also the inconveniences provoked by the access to the database through computer networks.

DISPAD System extract DISCOS data, building data tables and graphical charts that are automatically merged into LaTeX based document templates to produce the documents:

- **EsaROS**: ESA Register of Objects in Space.
- **EsaLOD**: ESA Log of On-Orbit and Decayed Objects.
- **EsaLOG**: ESA Log of Objects in or near the Geostationary Orbit.
- **EsaLOF**: ESA Log of Fragmentation Event.

The production of the DISPAD system involved a great complexity due to several reasons:

- The amount of information managed (DISCOS contains information about more than 23,000 objects).
- The different technologies and tools that were used for its development, which include:
  - ORACLE, the server and both Pro*Fortran and Pro*C pre-compilers, for accessing and extracting the database contents.
  - Perl, for text files processing and controlling the system execution
  - PV-Wave for producing graphical charts.
  - TeX/LaTeX to prepare document templates and formatting files and for processing resulting documents.
- Some inconsistencies and incompleteness of the information in the DISCOS database. These inconsistencies were detected as a consecuence of the work performed during the project; they were reported in due time and corrected by ESOC. This corrections included both modification of tables contents, modification of tables structure and creation of new tables.

Documents produced by the DISPAD System and enumerated above are available upon request to ESOC, which can be submitted to the first author, **Dr. Heiner Klinkrad** (e-mail: hklinkra@esoc.esa.de).

These documents provide alltogether a complete information on all objects on-orbit and decayed, launches and fragmentation events occurred since 1957. Their size range from the near 1,200 pages of the EsaROS to the near 400 of the EsaLOF.

APPENDIX A: ACRONYMS

List of acronyms used within the scope of this document:

BOL	Begin Of service Life
COSPAR	International COmmittee on SPAce Research
EOL	End Of service Life
EsaLOD	ESA Log of On-orbit and Decayed objects
EsaLOF	ESA Log of On-orbit Fragments
EsaLOG	ESA Log of Objects near GEO
EsaROS	ESA Register of Objects in Space
GEO	GEostationary Orbit
GTO	Geostationary Transfer Orbit
LEO	Low-Earth Orbit
S/C	SpaceCraft
S/T	Satellite
SSR	NASA's Satellite Situation Report
TBD	To Be Defined
TBE	Teledyne Brown Engineering
TLE	Two Line Elements (NASA List)