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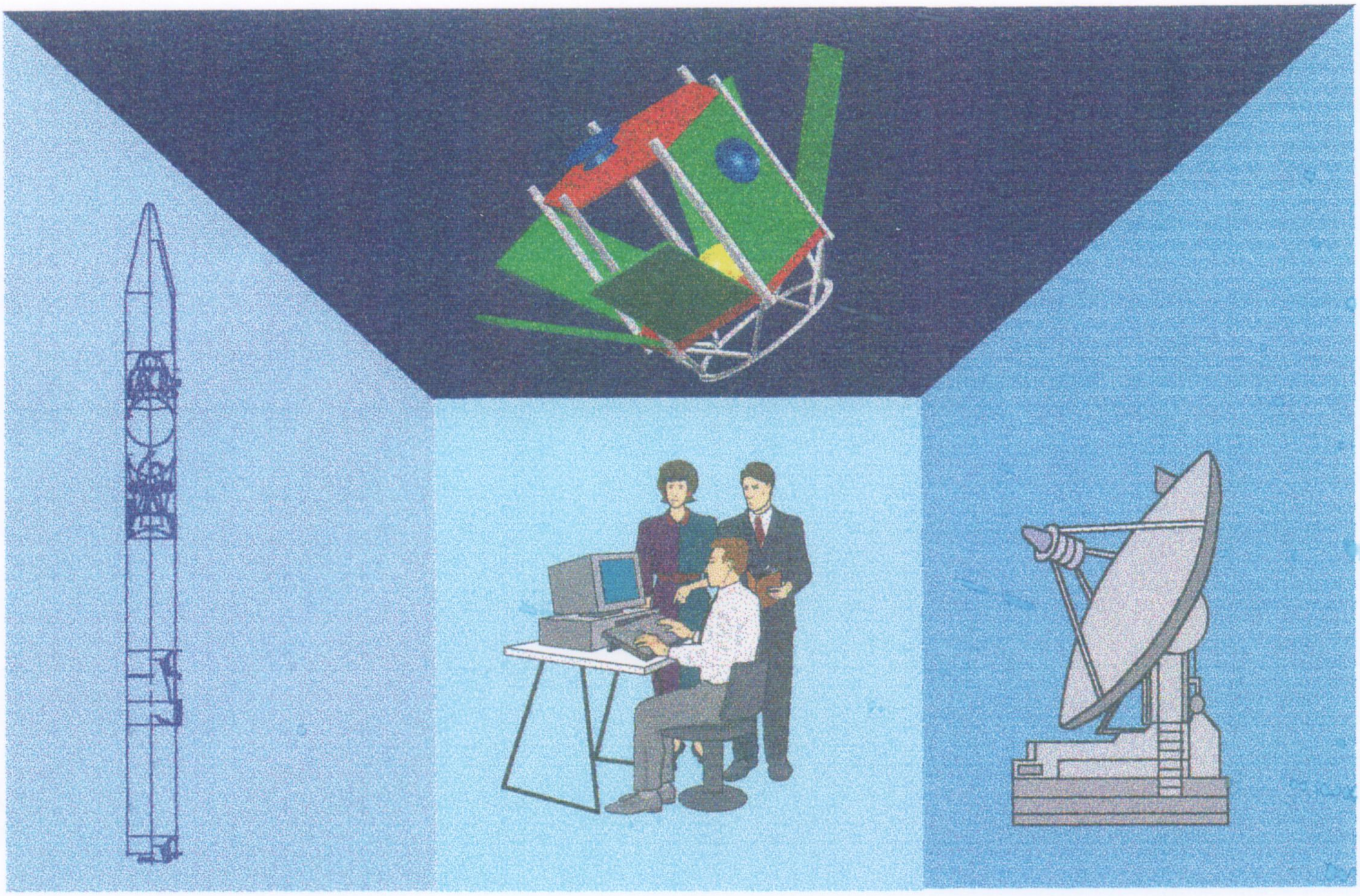
FiatAvio

BPD Space Unit

SMALL MISSION OPPORTUNITIES INITIATIVE STUDY

Executive Summary

Prepared for European Space Agency- Contract n.11469/95/F/TB



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ESA STUDY CONTRACT REPORT

No ESA Study Contract Report will be accepted unless this sheet is inserted at the beginning of each volume of the Report

ESA CONTRACT NO	SUBJECT		NAME OF CONTRACTOR
11469/95/F/TB	SMO Program Executive Summary		FiatAvio - Comprensorio BPD
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ABSTRACT

This document is the Executive Summary report for the feasibility study on Small Mission Opportunities as prepared by the team led by FIAT AVIO, BPD Space Unit. The document:

a. presents the proposed SMO service concept:
"To provide a customer-oriented, cost competitive, technologically up-to-date, European Small Mission Service, which is made up of separate but interrelated launch services, satellite bus services, and payload services, on an 18 month contract-to-launch schedule",

b. shows the results of the missions/payloads market investigation which led to a conservative definition of 2 to 4 missions per year as capturable by a European SMO Service,

c. identifies the proposed baseline for the launch vehicle, satellite platform (bus), and ground control station, and finally,

d. presents a total estimated cost of 311 MECU for the 10 missions requested by ESA along with a breakdown of the non-recurring and recurring costs including a recurring service cost for medium/long-term of 27.7 MECU which is characterized by a solid, 91% European content (based on the adoption of a European small launcher).

An analysis of the significant non-recurring investments required to achieve the high level of European return noted above, relative to the development of a small launcher, led us to define a minimum initial order size of 10 missions to justify an industry decision to finance the pertinant non- recurring costs.

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ACKNOWLEDGMENTS

The study results summarized in this document have been obtained with the help of contributions from many organizations who were not specific members of the FIA AVIO-BPD team:

- the ESA team, for very constructive cooperation, suggestions and information,
- European national delegations, for information and data on potential SMO missions and users,
- CTA Space Systems, for their contributions to the FIAT AVIO-BPD bus team in terms of cost estimating approach and data, and information on Assembly-Integration and Test philosophies,
- potential service segment suppliers, for validation of FIAT AVIO-BPD team cost figures:

Launch Vehicle	Orbital Science
	Eurockot
	Cosmos International GmbH
	Cosmos USA
	EER (Conestoga)
Bus	Aerospatiale Cannes
	Carlo Gavazzi Space
Ground Control Station	Laben
	ATNE-Groupe SFIM
Ground Control Hardware	IN-SNEC
	Vertex Antennentecchnik GmbH
Canary Island Launch range	INTA

- FIAT worldwide organization, for support during the market investigation and information on product standardization and cost reduction techniques when using small serial production techniques.

1. BACKGROUND

1.1 Scope

This document is the Executive Summary Report of the "Feasibility Study on Small Mission Opportunities" as carried out by the FIAT AVIO/BPD-led team under ESA Contract No.11469/95/F/TB. The study kick-off meeting was held on 4 June 95 and the final meeting was held on 24 September 1996.

1.2 Study Objectives

The primary objectives of the Study were to answer the following questions:

- what is the market for a European Small Mission Opportunities Programme?
- what specific missions could be included in the program?
- is it technically feasible and how could be implemented?
- how much will it cost?

After a brief overview of the innovative approach to space utilization which SMOI represents, the answers to the questions listed above are given in a summary of the study results.

1.3 Our team

The study team led by FIAT AVIO-BPD, was made up of several experienced European companies in the roles listed below.

ROLES and RESPONSIBILITIES

FIAT AVIO-BPD :	Study Prime, responsible for the development of the SMO service vision and definion of service element preliminary requirements based on the market survey results; definition of the SMO service baseline; definition of major system level requirements and characteristics; identification of each of the service elements; preparation of bid packages for the service elements; and review of cost feedback from potential suppliers in order to validate the overall SMO cost figures.
ALCATEL TELECOM:	Electrical ground support equipment (EGSE)
INSA:	Ground control segment and operations
TER	Market survey; interface with the science community
SIEMENS:	Study of SMO project management and documentation needs
RAUFOSS:	Analysis of the Andøya launch site option
CRI:	SMO software
OERLIKON CONTRAVES:	Communications scenario and link budgets; structure and mechanisms (within Bus service)
CNES	Study the utilization of the Diamant site in Kourou for launch vehicles of the VEGA family

Moreover, many interchanges occurred with other companies, organizations and European delegations through questionnaires, bid packages and interviews. The scientific/university community in Europe provided inputs through a dedicated workshop held in October 1995 and through follow-up contacts.

1.4 Study timeline

This 12 month study was divided into three phases which as listed:

T1 : SMO Initiative Concept Definition

to analyse the worldwide market and propose an SMO baseline concept.

T2: SMO Initiative Definition and Costing

to define the baseline concept with technical, operational and cost details, and verifying the proposed approach through reference mission analyses; to define and issue bid-packages for binding proposal preparation

T3: SMO Initiative Proposal

to substantiate the SMO concept baseline and costing via negotiations with industry in order to obtain data for a binding proposal

The flow of these 3 phases is illustrated in Fig. 1.4-1

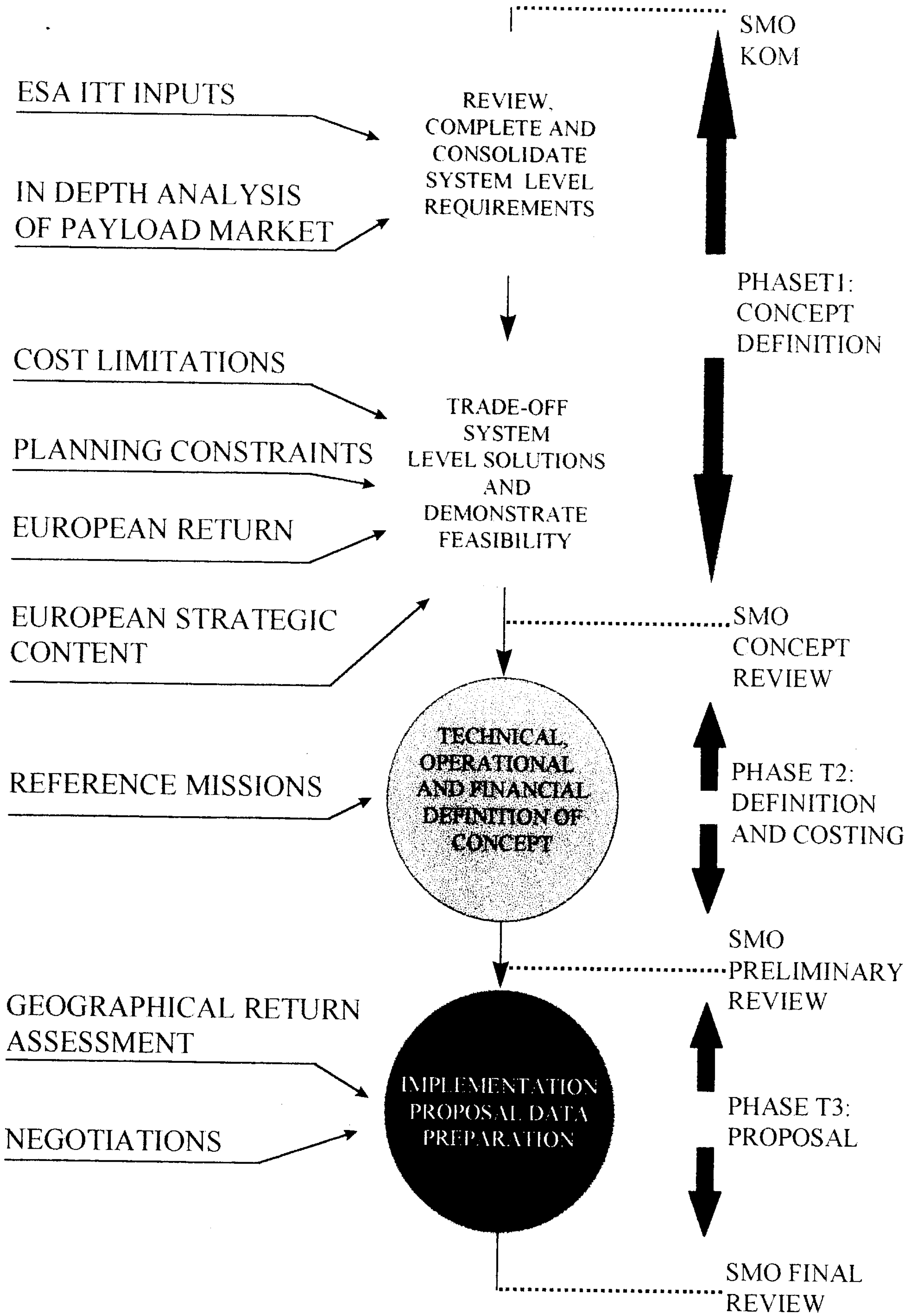


Figure 1.4-1. Study flow.

2. *WHY SMOI: PRESENTATION OF A NEW CONCEPT*

A brief introduction to the history of the SMOI concept is given here due its **innovative** nature as a method for space utilization and to illustrate industry and Agency interest in the concept.

In 1992 the Granada Ministerial Conference asked ESA to "explore with Member States ways in which the development and launching of small satellites could contribute to the fulfilment of the objectives contained in the Long-Term Space Plan with regard to all sectors of space activities".

Starting from the evidence that a growing market for small satellites exists worldwide which includes non-traditional space faring nations such as Israel, Brazil, South Africa and Indonesia, the question was: *why not in Europe?* A realistic analysis of the situation demonstrated that:
- European industry was not competitive, and
- scientific (user) interest was not sufficiently stimulated.

This could be termed a "vicious circle" where potential users showed no interest in something that did not yet exist; whereas, on the other hand, industry had neither the capability to provide a complete "Mission Service", nor the market guarantee to justify the necessary investments.

In May 1994, EUROSPACE published its report "A European initiative to exploit the opportunities offered by small missions" that concluded: *"a vigorous small mission program is necessary to insure that industry is in a position to offer a competitive service"*.

In March 1995, ESA concurred with the EUROSPACE conclusion and proposed an ESA "anchor-tenancy" for developing a "Small Missions Opportunity Initiative."

SMOI was born as a pilot initiative to start a "virtuous circle"; the idea being the formation of a European consortium to provide a turn-key service for small missions with a 2 year preparation phase followed by an “anchor-tenancy” of about 10 missions. This program will place European industry in a globally competitive position while stimulating the European market through the "anchor-tenancy" procurement volume and the existance of low cost, regular launch opportunities. Once a robust small mission program is started, it will be able to continue autonomously.

3. STUDY RESULTS (Our concept for SMOI)

A summary of the results of the Study is reported in the following sections. The study started with a ***market survey*** (section 3.1), which was aimed at quantifying the market. An SMOI scenario was established and the system requirements derived based on the market survey results. Then, a ***service definition*** was developed (section 3.2), including the main service segments (launch, bus and ground) and validated through ***accomodation studies*** (section 3.3).. The programmatics for SMOI, including service implementation (section 4.1) and costs (section 4.2) were developed.

Our approach

The driver of the Study was **customer satisfaction**, obtained mainly by pursuing the following key objectives:

- low mission cost,
- customer oriented management, and
- flexibility of the proposed service and products.

In this area, our company (Fiat group) approach to business was fundamental: the company focus on serial production results in a high level of attention to recurring cost figures, while the dimension of the company provides guarantees for industrial reliability. Furthermore, FIAT AVIO-BPD was more flexible in assessing the space segment since we were not a-priori tied to a solution.

First of all, what is small?

In the context of this study, "small missions" denotes:

- low total cost (design to cost approach),
- short schedule from mission definition through launch (< 18 months),
- simple, direct access to the payload data by the customer,
- focused mission purpose/function,
- small, dedicated team (including the customer) from mission definition - through launch,
- minimum documentation requirements,
- use of standard assemblies and subassemblies,
- use of commercial assemblies and subassemblies,
- use of advanced technologies when needed to solve specific problems, and,
- use of autonomy on the spacecraft to minimize ground operations costs.

and then what is SMOI ?

The FIAT AVIO-BPD vision of the Small Mission Opportunity Initiative service mission is:
to provide a customer-oriented, cost competitive, technologically up-to-date, European Small Missions service, which is made up of separate but interrelated launch services, satellite bus services, and payload services, on a 18 month "contract-to-launch" schedule.

3.1 Market survey and critical requirements assessment

A detailed market survey was the first task in the study and was based on extensive research (through the FIAT world-wide organization, Arthur D. Little, Euroconsult and the literature) and on direct inquiry with the European scientific community (the "Small Missions Opportunities and the Scientific Community" Workshop, 12-13 October 1995, see R.D.6.2.3). The primary objectives of the market assessment are listed below:

- Examine the literature, on-hand information and the Workshop proceedings to establish a payload-mission characteristics database which itemizes small satellites and small satellite programs which are under discussion, under study, or in development World-wide (independent of project credibility);
- Establish missions and payloads screening/evaluation criteria based on the assumed SMO requirements;
- Screen the database to identify the potential opportunities for SMO;
- Itemize the main payload and mission characteristics, where possible (technical, financial, political, regulatory, business,...);
- Identify potential SMO customers World-wide;
- Evaluate the database to identify the potentially "capturable" portion of the opportunities;
- Analyze these opportunities to identify hidden relationships, where possible, which preclude open competition on price and performance;
- Evaluate and analyze the "capturable" opportunities to define which could be undertaken as part of an ESA SMO Initiative;
- Evaluate and analyze the potential ESA SMO Initiative mission's characteristics to define baseline SMO attributes/requirements;
- Suggest potential missions to ESA for use as test cases during the study.

The details of the analysis and the results are presented below. A payload interface model was developed from this analysis and is presented in Section 3.1.2

3.1.1 MARKET SURVEY ANALYSIS AND RESULTS

Forecasting the potential demand for small satellite services is a difficult task due to the multiple layers of uncertainty in the market. Small satellites can provide communications and remotely sensed data using technologies which are evolving rapidly. Furthermore, scientific missions are taking advantage of new technologies to enable the use of smaller satellites. However, technology is one of the better understood factors affecting the small satellite market. Factors which are more uncertain and volatile include:

- government funding of space activities in the post cold war era,
- the evolution of the worldwide telecommunications and remote sensing markets which are currently the primary end users of satellite-provided services,
- the availability of financing for commercial space ventures,
- individual country and international regulatory constraints which affect the ability to provide satellite services to the market,
- national security and economic development issues in individual countries which affect procurement decisions on satellite services, and
- the web of vertical relationships in the satellite industry which preclude normal competition on price and performance.

At the top level, we can conclude that the factors listed above mean short-term implementation of the SMO Initiative should be pursued vigorously to simulate and test the market for a European SMO-type service.

A global selection of potential small missions is shown in Fig 3.1-1 where a break down by year and mass is given. The satellites shown cover a wide mass range (12 Kg to 1200 Kg) with many capabilities. As should be clear from this chart, there are a very large number of small satellite missions and programs under consideration. The large number being considered means that there will be a substantial market (maybe not fully open) even if only a small fraction of these programs are actually realized. Forecasts for the actual small satellite market based on the large number of programs currently under consideration vary from less than one hundred to more than one thousand over the next 10 years. The high estimates basically assume the launch of most of the programs (excluding Teledesic) while the low estimates have a tendency to consider only programs which are currently funded. In fact, numerous market studies predict that only between 1 and 3 of the proposed LEO constellations are likely to see deployment. We feel that the two extremes misrepresent the potential market which falls somewhere in between. Clearly, not all the satellites listed will be launched; many will turn out to be only "paper satellites." The market assessment discriminated among the technical, financial, political and regulatory needs and constraints of potential customers to establish an accurate profile of the "capturable" market.

The majority of the satellites in Fig. 3.1-1 are from the USA, primarily due to LEO communications satellite constellations. In particular, the large numbers of satellites listed in the period 1998 to 2000 are, primarily, the result of the proposed deployment of these LEO constellations. The total number of foreseen satellites appears to taper down early in the next decade. However, this is not an actual market drop but just an expression that plans are not firm that far in advance. Furthermore, several (possibly many, if history can be used as guide) of the realized missions will suffer delays and slip into the next decade. Generally, the projects which are actually realized over the next five years will, in a large part, determine the scenario during the next decade. It is clear that the potential for small satellite sales opportunities is global and covers a wide mass range.

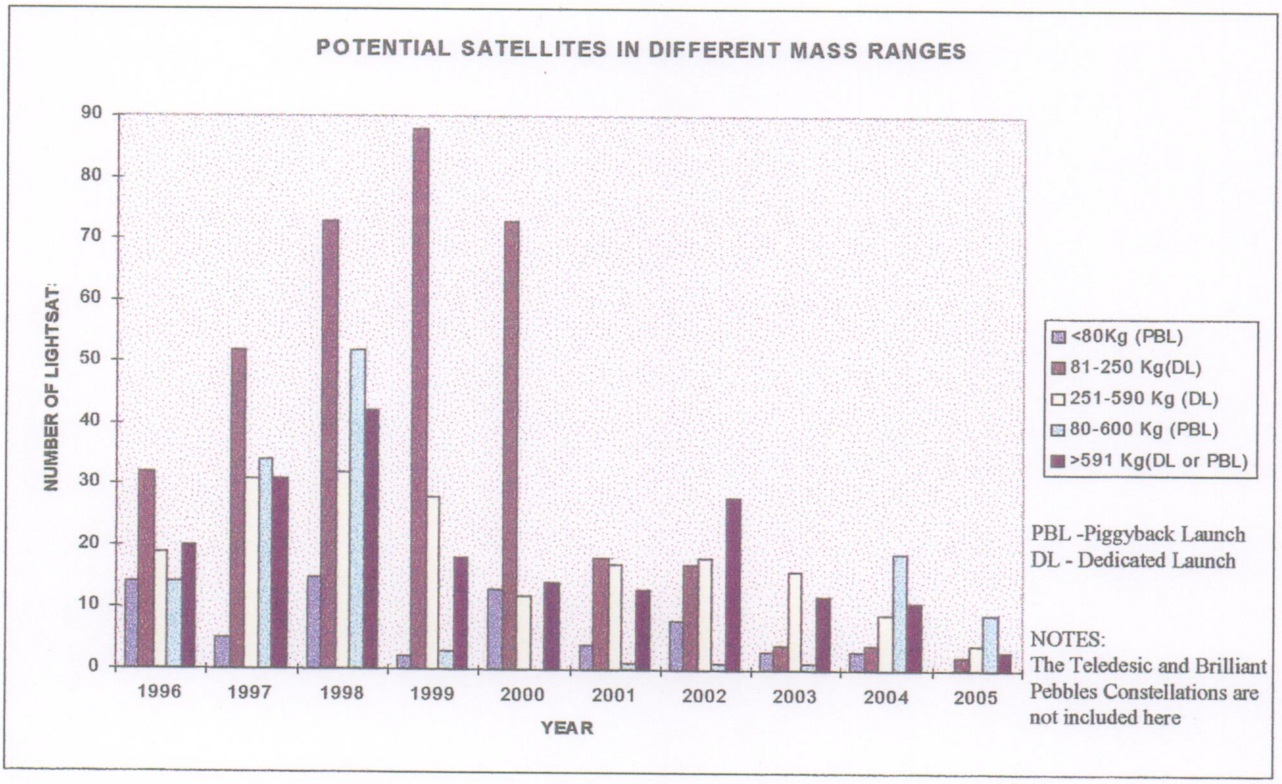


Figure 3.1-1. Number of Small Satellites Distributed by Launch Mass Range and Year (1996 - 2005).

Selection Criteria

The selection and screening criteria used to determine which missions are likely candidates for SMOI utilization are given in Table 3.1-1. These criteria were derived based on the our initial internal analysēs of the key parameters for lightsat mission realization including basic launch requirements (as presented in our program proposal) and programmatic data.

Table 3.1-1. Selection and Screening Criteria.

PARAMETER	VALUE
Payload mass	Up to 400 Kg
Orbital altitudes	250 to 1100 Km
Orbital Inclinations	0° to sun-sync
Program Success Potential	tentative to assured
Availability of Trade-Off Data	minimum main parameters available
Requirements Match	moderate to excellent
Openness for Competition	potential exists
Costs (Development, Payload, Launch, ...)	compatible with SMO guidelines

Capturable SMO Opportunities

An initial screening of the programs illustrated in Fig. 3.1-1 using the criteria of Table 3.1-1 lead to the following points:

- Generally, commercial telecommunications constellations (Teledesic, Iridium, Globalstar, Ellipso, Starsys, Aries/ECCO, Signal, Orbcomm and COSCON) are not expected to be users of the overall SMO Service due to the special relationships which have developed between the service providers and the launcher and/or satellite manufacturers. However, it is possible that SMO launch services could be requested on a competitive basis from time to time. Furthermore, several constellations are still in the definition phases and offer a potential opportunity for an SMO Service Provider to become an equity partner (LEO One, GEMnet, ECCO System and Starnet).

- Programs sponsored by national agencies outside Europe such as NASA (USA), DOD (USA), NASDA (Japan), ISAS (Japan), ISO (India), CSA (Canada) and RKA (Russia) will not be users of an overall SMO-type service. These organizations have vested interests in developing and supporting their national industries similar to ESA's interests in Europe. However, selected SMO services could become part of cooperative projects between ESA and its counterpart in the other country.

- National European programs (from CNES, ASI, DARA, etc) are currently planned around national capabilities and assets, as much as is possible. However, there does appear to be some interest in an SMO service. Clearly, the SMO service will rely on existing and newly developed European hardware, software and services whenever possible.

- SMO will help European industry to become a more active participant in the small satellite field at both the system and equipment level.

- In summary, constellations with developed relationships and missions from national agencies outside Europe are assumed to be excluded from consideration within SMO. Furthermore, missions which have requirements well beyond the baseline SMO envelop are also excluded, regardless of the country of origin.

Potential ESA SMOI Missions

Table 3.1-2 lists a non-exhaustive group of missions which may be "capturable" by a European SMO Service within the framework of an ESA program. The 34 projects listed total approximately 43 satellites. Clearly, it is possible to dispute the likelihood of SMO utilization by any one of these missions. However, in our view, budget constraints and political uncertainties in Europe leave open the possibility of SMO utilization for all of these missions. Clearly, the situation must reviewed periodically to reevaluate the situation.

Table 3.1-2. Potential ESA SMOI Missions.

COUNTRY OF ORIGIN	PROGRAM NAMES
Denmark	Ballerina
Finland	FS-1/SCI and FS-1/EO
France	IBIZA, COROT, SAMBA, IRSUTE, Tropiques, VAGSAT, STEP, Coalas
Germany	ATON, EUVsat, FIRES, Regius, ComRing Demo, HRSC-EO
Italy	SAFIRE, Galileo Galilei, CESAR, JUNO, BPD, PAMELA, GILDA, COSMO-Tech, LOBO, Romolo & Remo, Cobras-SMO, EFAM, Interferometer,
Norway	NISSE
Spain	Minisat FO, Fuego-Tec
Sweden	ODIN.FO
F.O – Follow-on	

The technical and programmatic data for these missions was analyzed to help develop evolved SMOI requirements. Data distributions for payload mass, satellite power, data rate, orbit information, pointing accuracy, stabilization method and satellite life were obtained. According to the mass distribution, 83% of the missions have payloads of less than 120 Kg, see Fig. 3.1-2. Total satellite power has two high points, between 100 and 200 W and above 350 W, but is generally broadly distributed, see Fig. 3.1-3. Furthermore, 62% of the satellites have data rate requirements which fall in the range 1 to 2 Mbps. However, several Earth observation missions (18%) have data transmission needs in access of 15 Mbps. The missions orbit information, shown graphically in Fig. 3.1-4, may be used to estimate potential propellant needs. However, for many of the missions, launcher selection is open. This means that the need for a final orbit transfer is undetermined. Missions with sun-synchronous (SS), polar or equatorial orbits should require little or no on-orbit maneuvering for altitudes above ~550 Km. Missions below 550 Km or in inclined orbits will have some on-orbit maneuvering requirements. The ΔV magnitudes are difficult to estimate. The majority of the satellites require 3-axis stabilization with pointing accuracies between 0.1° and 1°. However, substantial mission applications using spinning satellites (27%) exist while gravity-gradient stabilization also is foreseen (5%) for use. Satellite lifetime needs are about equally split between life needs of 2 years or less (45%) and needs of 2 to 5 years (55%). The science satellites are mostly grouped in the first class while Earth observation satellites generally request lifetimes of greater than 2 years (the longer life need is likely driven by a combination of the higher payload cost for Earth observation satellites, as highlighted during the 12 October 1995 workshop on "Small Mission Opportunities" (R.D.6.2.3) and the need to produce a monetary return on investments).

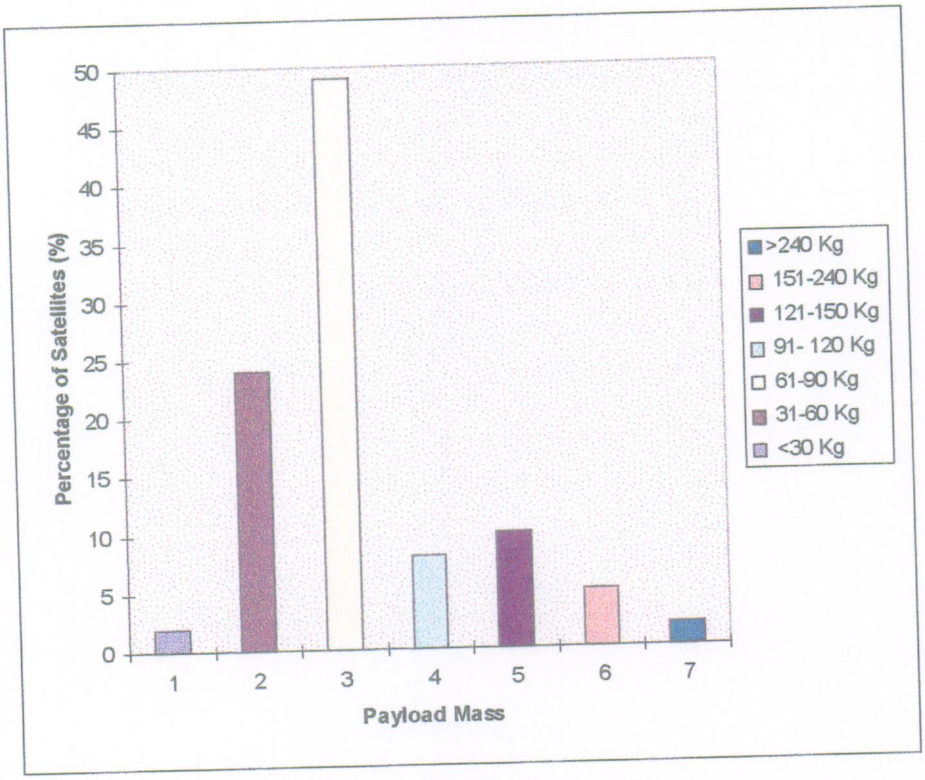


Figure 3.1-2. Potential ESA SMOI Missions Payload Mass Distribution

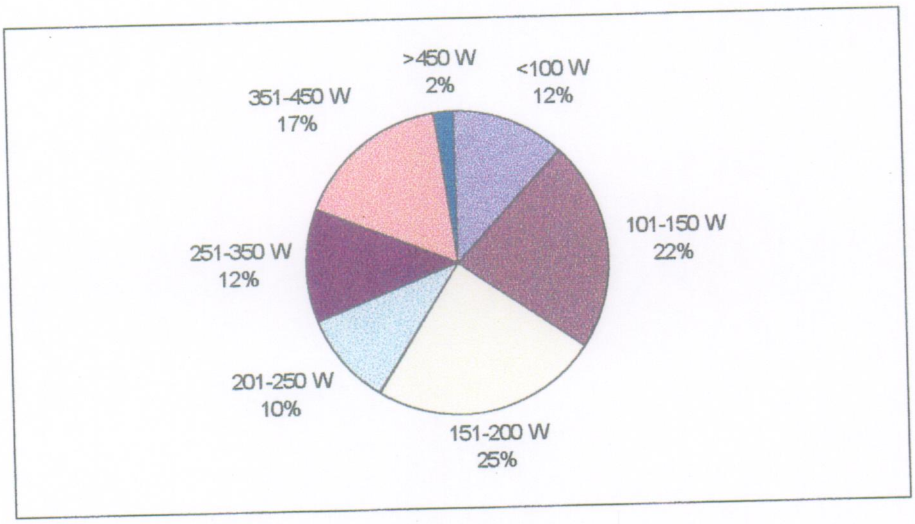


Figure 3.1-3. Potential ESA SMOI Missions Satellite Power Needs Distribution

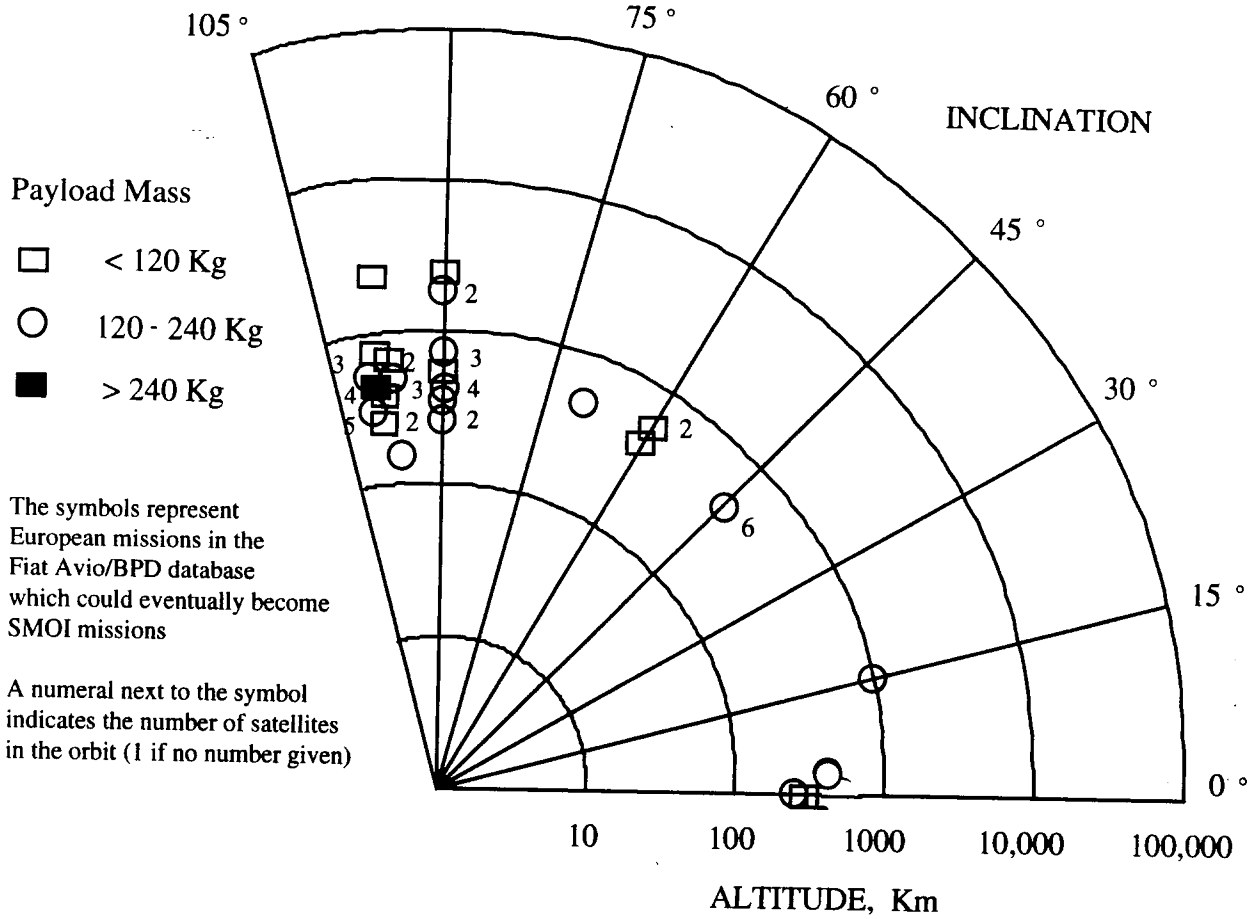


Figure 3.1-4. Potential ESA SMOI Missions Orbit Locations.

SMOI Baseline Attributes

Based on the information presented above, the assumed SMO payload accommodation characteristics which were given in the ITT [A.D. 1] are fairly representative of the focus for an SMO service. The following modifications should be introduced:

- a maximum orbital altitude of 1200 Km should be adopted to cover all missions (alternatively, a lower altitude (ie. 900 Km) could be adopted requiring a Δcost increment for higher altitudes),
- the payload data rate must accommodate higher values than basic S-band capabilities, 1 Mbps should be taken as a 'nominal' value,
- modular payload power levels of up to 350 W are needed (levels above this can be handled as a optional service), and
- a nominal pointing performance of 0.3° can be adopted as long as an upgrade to 0.1° is available.

In addition, we have introduced requirements for satellite on-orbit lifetime, payload data delivery strategy, mission recurring cost (without payload) and mission reliability. The updated SMO characteristics and their evolution are summarized in Table 3.1-3.

Table 3.1-3. Updated SMOI Attributes - Requirements Evolution.

PARAMETER	VALUE		
	ITT Baseline	FIAT AVIO-BPD Proposal Baseline	Evolved Requirements
Payload mass	60 to 240 Kg	Up to 400 Kg	Up to 240 Kg
Orbital altitudes	400 to 900 Km	250 to 1100 Km	400 to 1200 Km
Orbital Inclinations	0° to sun-sync	0° to sun-sync	0° to sun-sync
Continuous electrical power to payload	100 to 250 W	150 to 500 W	up to 350 W
Payload data rate	S band	1 Mbps	nominal 1 Mbps
Attitude and orbit control capabilities	"good"	0 to 225 Kg N_2H_4	0 to 225 Kg N_2H_4
Pointing performance	0.1° to 3.0°	0.1° nominal	0.3° nominal
Schedule (payload selection to launch)	18 months	18 months	18 months
On-Orbit Lifetime	NS	2 years nominal	2 years nominal
Payload Data Delivery	NS	direct user link	preprocessed; direct user link
Mission Recurring Cost	NS	27.4 MAU	28 MAU
Mission Reliability (payload at 0.9)	NS	NS	0.7
NS – Not Specified			

Commercial Market

Table 3.1-4 lists a non-exhaustive group of missions which may be "capturable" by a European SMO Service as commercial programs for either full or partial services. The 16 projects listed total approximately 138 satellites and include projects in Italy, Germany, Spain, the USA, Brazil, South Korea, Mexico, Taiwan, Argentina and Canada. Again, it is clearly possible to dispute the likelihood of SMO utilization by any one of these missions. However, in our view, budget needs, political constraints, and market uncertainties leave open the possibility of SMO utilization for all of these missions. Clearly, the situation must be reviewed periodically to reevaluate the situation. For example, the SMO Operator would likely need to become a partner of some sort to play a major role in the communications constellations listed.

It must be noted that, often, in the global satellite market place, when a "country" purchases a satellite system, they are interested in developing a national capability as well, particularly in developing countries. This means that technology transfer is often important in marketing to new regions, those moving up the technology ladder. Approaches to this issue should be carefully conceived and thought out within the SMO architecture prior to detailed discussions with potential clients who may desire this type of contractual arrangement. Clearly the payload provides the SMO Operator some negotiating room however bus components or subsystems, ground segment equipment or diverse launch arrangements may be requested.

Table 3.1-4. Potential Commercial Users of a European SMO-Type Service.

COUNTRY OF ORIGIN	PROGRAM NAMES
Argentina	SAC Sys
Brazil	SCD FO, ECCO System, SSR
Canada	SCISAT FO
Germany	ComRing (HIRESAT)
Italy	SKYMED
Mexico	LEO One
South Korea	KARISAT
Spain	Fuego
Taiwan	ROCSAT
USA	Starnet, AVSAT, Earthwatch, WorldView, GEROS

The technical and programmatic data on the potential commercial missions was analyzed to assess the effect of potential commercial market needs on SMOI requirements. Again, the data distributions for main mission function, payload mass, satellite power, data rate, orbit information, pointing accuracy, stabilization method and satellite life were developed, where possible. This analysis showed that the majority of satellites are oriented toward communications due to proposed voice and data satellite constellations. The majority of potential commercial satellites (67%) have payloads masses of less than 120 Kg. For competitive reasons, data regarding satellite power, data rates, pointing needs and satellite stabilization are generally difficult to obtain. However, mission applications imply that payload power requirements of up to or greater than 500 W are likely for many satellites. Furthermore, voice communications needs and high resolution imaging requirements imply that data rates substantially in excess of 2 Mbps are likely to be needed in many cases. Pointing accuracy improvements are needed for commercial missions. Specifically, pointing accuracies of better than 0.1° will be required for certain Earth observation missions. Both 3-axis-stabilized and spin-stabilized satellites will be used for these missions. The initial deployments of the large constellations are expected to be conducted using large launchers for multiple satellites. However, as above, the specific ΔV requirements for the satellites are difficult to estimate. Satellite lifetimes of 2 years or less (2%) do not appear to be of much interest for commercial missions. The majority of satellites with known needs have life requirements of 2 to 5 years (69%) and most of these have a life requirement of 5 years. In addition, a new life requirement category must be introduced for commercial missions: satellites lifetimes of greater than 5 years (12%). This information has been used to help develop the optional services to be provided by the SMO Operator.

Missions Recommended For Further Study in SMOI

Table 3.1-5 lists 12 missions which were recommended for further study during the SMOI program. Missions from France and Germany were excluded since the other contractor team (led by MMS) was covering these countries in detail. England and Sweden have no specific missions listed since data for the programs was not readily available or the programs were focused on satellites with a total mass of less than 80 Kg. Generally, satellites below 80 Kg were specifically excluded from the study since they are generally developed for Ariane 5 ASAP launch. Belgium and Austria have no specific missions listed since the programs in these countries focus on cooperative international programs where they provide a contribution at the component and/or subsystem level. Greece, Ireland and Portugal are not listed since they are not currently involved in national satellite programs. Missions 1, 2, 3, 4, 6, 7, 8, and 12 were used in accommodation studies during the program (see Section 3.3) since the available data was relatively complete.

Table 3.1-5. Missions Recommended for Further Study in SMOI.

Number	Mission Name	Country	Type
1	Romolo & Remo	Italy	Science - Magnetosphere
2	Galileo Galilei	Italy	Science - Fundamental Physics
3	FS-1/SCI	Finland	Science - Magnetosphere
4	FS-1/EO	Finland	Earth Observation - Environment
5	FUEGO	Spain	Earth Observation - Fires
6	PAMELA	Italy	Science - Cosmic Rays
7	NISSE	Norway	Science - Ionosphere
8	Gilda	Italy	Science - Gamma rays
9	Ballerina	Denmark	Science - X-ray telescope
10	Cosmo-tech	Italy	Earth Observation - Technology Demonstration
11	Interferometer	Italy	Science
12	Background Prim.Distortion	Italy	Science - Fundamental Physics

3.1.2 GENERAL PAYLOAD IMPLEMENTATION MODEL

During the SMO study, detailed descriptions of the bus, launcher, EGSE and ground systems were developed [R.D.1]. The one element which received very little attention was the payload since no specific payloads were selected. However, many payloads were investigated during the market assessment. Therefore, in order to help establish a full basis for the subsequent discussion on the service segments and software, a physical "payload model" is presented here.

An SMO payload can be considered a black box from the service point-of-view since, in theory, diverse payloads can be considered for SMO implementation using a common set of interfaces. The black-box payload will be made up of the individual payload hardware elements (boxes) and various software elements. The hardware elements will generally consist of a sensor or sensor suite, analog to digital signal conditioning, power conditioning, microprocessor(s), memory, mechanisms and the interface with the satellite bus. A general architecture for these elements is shown in Fig. 3.1-2-1. The specific form of each of these elements will depend very strongly on the type of payload/experiment sensor suite which is selected. The mechanical, electrical, thermal, and signals interfaces for each of the payload elements will need to be matched to the SMO specifications as per the eventual SMO Users Manual.

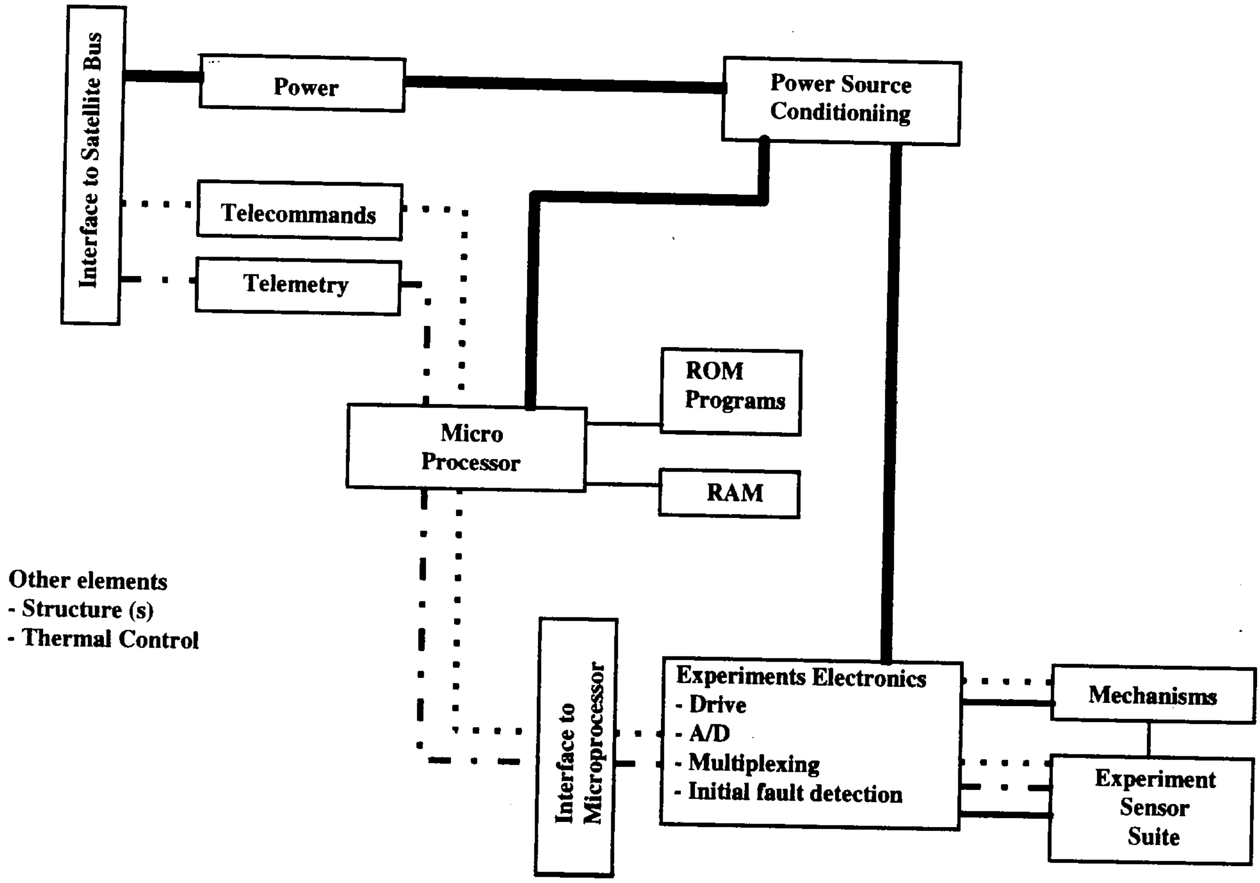


Figure 3.1.2-1. General SMO Payload Model Block Diagram

It is expected that both the payload hardware and payload software elements will have undergone development and validation up through some laboratory level prior to the start of the SMO contract (18 months duration). Clearly, the more focused these efforts are on the ultimate objective of flight within the SMO infrastructure, the higher the probability of success of the mission. This means early availability of SMO simulators and requirements documents are of vital importance to mission success.

3.1.3 MARKET CONCLUSIONS

There is a world-wide market potential for a European SMO Service. In Europe, there are more than 35 satellite projects (excluding ESA programs) in various stages of planning. Internationally, there are many more. Therefore, while 10 specific missions were not identified as the start-up for SMO, a significant market potential has been identified for SMOI utilization in Europe. The European countries with smaller space programs (Norway, Denmark, Finland) seem to have the most interest in an SMOI program at the present time. Interest in Italy and Spain also exists but must be cultivated. Users of an SMOI service from outside Europe are also possible either through bilateral programs with ESA or on a strictly commercial basis (16 potential projects have been identified). A package of modular and flexible services is required to capture and maintain an adequate market. The commercial success of an SMOI program could be contingent upon the development of partnerships or teaming arrangements for participation within one or more of the LEO communications satellite constellations. Service cost and flexibility are likely to be the key drivers in determining market size and the successful implementation of a European small satellite service.

Based on the analysis above, we believe that the market potential for a European SMO Service is between 2 and 4 satellites per year. The market is expected to be equally split between European missions (SMO or commercial) and non-European missions (commercial). Realization of a successful program will require strong and focused marketing efforts on the part of the SMO Operator with strong political support from ESA. ESA SMO missions are expected to be primarily science and technology demonstration-oriented with some Earth observation applications. The commercial missions are expected to be mostly remote sensing-oriented with communications applications possible depending on the final SMO Operator arrangements.

Based on the current small satellite programs world-wide, short time to market is vital to realize the success of this initiative. The small satellite market should grow as more countries become interested in access to remotely sensed data, meteorological data, telecommunications and data services, and science programs. The key to this growth will be the availability of cheap, reliable and frequent access to space. The first few service providers on the market will likely control the market.

Based on the scenario described above, we feel that short time to market with minimal non-recurring investments needs is critical to the successful realization of the SMO Initiative while very competitive recurring costs are vital for a mature service offering. Therefore, we have split our picture of SMO into the near-term and medium/long-term time frames. In the near-term, we foresee a competitive service offering which is available very quickly (by the end of 1999) using existing infrastructures as much as possible to minimize non-recurring investments. This near-term phase will enable development and demonstration of the market for a European Small Missions Service. Once the market is validated and the SMO service matures, focused investments can be made to optimize the SMO service by minimizing recurring costs. We believe that the near-term phase should require the execution of at least 5 missions to enable adequate development of the SMO service offering. This number (5 missions) is validated later in the section on SMO Implemetation costs. The first 10 missions listed in Table 3.1-5 are options for this near-term phase of 5 missions. All are sufficiently advanced such that with the proper funding authorizations they could be ready for flight in the period 1999 to 2001.

3.2 Service definition

Introduction

To define the SMO service, bid packages (see R.D.s. 6.2.5, 6.2.6 and 6.2.7) for the three major service elements were developed and sent to space companies worldwide. In the area of the launch service, several solutions are proposed while a "spread" of possible choices is presented for the ground service, in order to comply with different customers requirements and guarantee a competitive price. Bus service proposal information was used to update our baseline solution.

What will a Customer get from the FIAT AVIO/BPD-proposed SMO service?

The baseline SMO service includes:

- Mission design,
- Bus interface simulator for Customer payload design
- Integration of the Customer payload on the satellite bus,
- System level test campaign,
- Launch campaign, and
- In orbit final positioning and spacecraft commissioning (including deliverable ground control terminals).

with Customer contributions in terms of:

- operative mission selection,
- payload selection and development,
- active partner in mission design and implementation team,
- mission management during payload operative life, and
- payload data exploitation.

Optional services have been identified and analysed in the frame of the study in order to support a wide range of mission needs and requirements. The range of options enables support of variety of Customers from those with a high level of space program experience to those just entering the field.

With what performance?

- Maximum 'contract signature' to lift-off schedule: 18 months
- Customer representative fully integrated in the mission management and execution teams
- Nominal orbit lifetime of two years
- Baseline orbit altitudes from 400 to 1200 Km
- Baseline inclinations from equatorial (0°) to sun-synchronous (98°)
- Baseline payload data flow of 4 Mbps
- Payload masses of up to 240 Kg
- Payload power availability of up to 350 W in sunlight
- Baseline bus stabilization: 3 axis (other options available)
- Modular, on-board ΔV spacecraft maneuvering capability
- Payload data storage memory capacity of up to 5 Gbyte

Who will be responsible for the service?

The **SMO operator** will be the responsible for the **service**; its role includes:

management and coordination of SMO exploitation and marketing activities,
procurement and management of the service elements,
integration of the service elements, and
mission operations, if requested.

Why is SMO new ?

The **innovative point** is the "service" concept. The bus and launch vehicles already exist: what is new is a complete, turn- key service which can be "tailored" to each customer.

The **Customer** is at the center of the program and Customer satisfaction is the driver for the technical choices:

- modularity/availability of a spread of options to enable a "tailoring" of the design,
- manufacturing, assembly, integration and test simplified, centrally located and optimized to guarantee cost and time saving, and
- operations optimization to allow simple management of the satellite by the Customer even if he has little or no experience in satellite operations.

The **Customer** will be deeply involved in mission design and implementation from the beginning..

How will the service be implemented ?

The three main elements of SMO service are:

the launch service,
the bus (platform) service, and
the ground control station service

These elements are summarized in the sections below. The proposed management approach for the SMO operator is described in section 3.2.4 and is considered a key factor in achieving the low cost and short time to launch targets.

3.2.1 LAUNCH SERVICE

Analysis logic

This section summarizes the logic used to select the most promising combination(s) of launch vehicle (LV) and launch range (LR) for SMO missions. The guidelines and approach were essentially:

- first to define different classes of small satellites, based on the lift mass and volume of the launcher options. This definition was conducted assuming that dedicated launches would be used in order to enable a "tailoring" of the launch service (LS) to the particular mission/satellite needs,
- to define different LS solutions for dedicated and shared launch missions in order to provide the potential users with a wide choice depending on the particular mission requirements,
- to define a baseline and a back-up (or alternative) solution for the different options in order to guarantee an option for competition between the solutions for both single launch procurements and batch buys, and
- to investigate the various options for the LV and LR to define the most suitable combination for SMO in order to verify if new options could be identified to reduce costs and increase European return.

Listing and discussion of launchers considered

The successful implementation of the SMO Initiative depends very strongly on ready and low cost access to space. As noted in Section 3.1.1, the need for access to space for small satellites is global. The needs are expected to be met using many different launch solutions from multi-satellite launches of large lauchers for constellations through lightsat dedicated launches using small launches to piggyback opportunities for diverse types of missions. In order to understand the potential launch options for utilization within a European SMO, launch vehicles from a wide range of suppliers have been examined in order to define an SMO launch service baseline. Those considered are listed in Table 3.2.1-1 and are grouped by the supplier's country:

Table 3.2.1-1. List of launch vehicles for initial consideration.

USA	***Russia + Ukraine***	***Europe***	***Others***
LMLV1	SS-18 (Ukrayne)	Capricornio (Spain)	Next (Israel)
LMLV2	Rockot (**)	ESL (France)	Shavit (Israel)
Pegasus	Talisman2365S (France+ Ukraine)	Ariane 4	LM2D (Chine)
Taurus	Start (Russia)	Ariane 5	CZ-1D (Chine)
Conestoga 1229, 2379,1620	Start 1 (Russia)	Vega K zero	PSLV (India)
Pacastro	Cosmos USA (*)	Vega K3	
	Cosmos Int (**)		
(*) – commercialized by USA (**) – commercialized by Germany			

In order to define a short list for small launch vehicles, a list of requirements has been identified:

a. low cost: main driver
b. modularity/adaptability to different satellite mass classes
c. achievable orbits:
   - type: circular/elliptical
   - altitude: 400 to 1100 Km
   - inclination: equatorial to sun syncronous
d. orbital accuracy:
   - apogee/perigee altitude: ±20 Km
   - inclination and RAAN:: <0.05°
e. capability to release satellites in both 3-axis and spin stabilized orientations
f. launch campaign duration < 1 month
g. European return for launch service: key driver
h. availability to discuss options to reduce paperwork costs.

All of the suppliers of the launchers listed in Table 3.2.1-1 were contacted to obtain technical and programmatic data regarding their respective launch solutions. This data included mass and available volume. Satellite mass classes were defined based on this data and the satellite mass data from the market survey as shown in Table 3.2.1-2.

Table 3.2.1-2. Launch Classes Used During Study.

Class	Mass	Launch Type
A:	80 - 250 Kg	(dedicated launch)
B:	> 250 Kg	(dedicated launch)
C:	> 80 Kg	(small satellites - multiple launch)
D:	< 80 Kg	(micro satellites - multiple launch)

Selected launchers in each class and discussion

A detailed data base was prepared based on the data from the potential launch service suppliers in order to compare all the information obtained during the survey. After a preliminary analysis of the data, an initial down-selection was performed to reduce the number of LVs on which to focus the detailed trade-off effort. The excluded LVs (Conestoga 1229, Conestoga 2379, Pacastro, Talisman 2365S, Start, Start 1, Capricornio, Next, LM2D, CZ-1D, and PSLV) were dropped due to a lack of information, low potential European return and/or poor performance characteristics. Therefore, the remaining launch vehicles for the detailed trade-off are presented in Table 3.2.1-3 by launch class.

Table 3.2.1-3. Launchers subjected to detailed trade study.

Class A	**Class B**
Pegasus	Rockot
Shavit	Taurus
LMLV1	LMLV2
Vega K0	SS18 K
Ariane	Conestoga 1620
	Vega K3
	Cosmos Int.
	Cosmos USA
	Ariane

The detailed trade-off study and final definition of the SMO launch service baseline was carried out based on the following major drivers:

- launch service cost is one of the major contributions to the mission cost (> 30%), for such a cost, a significant European return must be foreseen in the medium/long-term scenario,
- the need to minimize the time to market for SMO requires a near-term launch solution which is **reliable, available** and **low cost**,
- utilization of Ariane shall be maximized where technically feasible (no adverse technical or schedule impacts),
- the preferred launch strategy is based on individual launches since time-to-orbit and launch vehicle mission optimization (with respect to Customer needs) are considered key values of the SMO service. This makes Ariane utilization difficult.
- competition must be introduced for the procurement of non-European launch services in the near term,

Based on the drivers listed above, the following criteria were identified in order to carry out the trade-off among launch vehicles:

- - recurring costs
- - non recurring costs
- - European return
- - availability / credibility
- - launch campaign adequacy
- - performance
- - reliability / technical risk
- - launch vehicle interface adequacy
- - spacecraft environment
- - payload requirements

The two main concerns were cost and European return. Costs were taken directly from the supplier quotes. European return was examined for each launcher in Table 3.2.1-3. Clearly, the European return for Ariane and the VEGA family is the highest (100%). The Europeanization of the other lauchers was discussed. Of the potential launcher options, the OSC vehicles (Pegasus and Taurus) appear to be the most flexible in this regard. OSC offered up to a 20% return including launcher hardware contributions and launch from a European launch site. However, the ability to recover the Europeanization costs for the US vehicles is not clear. The Russian launchers are the least flexible in this regard. Since these vehicles are based directly on ICBM technology, no Europeanization is possible.

Launch service baseline and back-up

As result of the trade-off, the nominal solutions presnted in Table 3.2.1-4 have been identified. Possible back-up (alternative) launchers include Cosmos, Rockot, LLVs and SS-18K.

Table 3.2.1-4. Nominal SMO launch service selections.

	Class A	*Class B*	*Class C/D*
NEAR TERM	Pegasus	Taurus	Ariane 5
MEDIUM-LONG TERM	Vega K0	Vega K3	Ariane 5

For the near term, a Pegasus/Taurus launch solution has been selected based on its availability and the stability in the supply. Competition will be introduced in near term (for the definition of near- and medium/long-term, see section 3.1.3) between Pegasus/Taurus and alternatives (LMLVs, Rockot, SS18-K, Cosmos) in an effort to minimize costs. These other vehicles are considered to be available and reliable. Therefore, periodic reassessments of their capabilities and programmatics should be made to maintain them as back-up alternatives for the near-term and to VEGA in the medium/long-term.

The VEGA family of launch vehicles (see Fig. 3.2.1-2) has been selected for the medium/long-term. The development of this launch capability has been included in the new Italian Space Agency (ASI) plan and has been proposed to Italian government. For class A missions, VEGA K zero is proposed with a performance of 300 Kg to a 700 Km circular polar orbit from Kourou. This version (see Fig.3.2.1-2) is currently under development based on FIAT AVIO-BPD investment with the first flight scheduled for the end 1999. For class B missions, a VEGA K 3 is considered. Vega K3 is built-up by using many common elements with VEGA K zero. The vehicle payload capabilities are baselined at 600 Kg to a 700 Km circular polar orbit from Kourou, with evolution under study for a 1000 Kg payload capability, namely, the VEGA K. This solution is preferred (for the medium-long term) with respect to alternative launchers from the former Soviet Union which appaer more attractive from cost point of view today. This is due to the strategic importance of the overall European return and political uncertainties in the long term supply of these vehicles.

Table 3.2.1-5. VEGA PERFORMANCE

Parameter	VEGA K0	Vega K3	VEGA K
Satellite mass (700 Km, 90°)	300 Kg	600 Kg	1000 Kg
Launch contract duration	15 months	15 months	15 months
Launch sites	Malindi Kourou Andøya	Kourou Andøya Canary Island	Kourou Andøya Canary Island
Payload max diameter max height	1400 mm 2800 mm	2150 mm 4220	2150 mm 4220
Injection accuracy			
altitude	20 Km	20 Km	20 Km
inclination pointing RAAN	0.05° 1° 0.05°	0.05° 1° 0.05°	0.05° 1° 0.05°

Vega K0, K3, K configuration

The Vega Launch Vehicle family has been defined by taking existing European and US components (mainly motors) into account, with the aim of minimizing development costs and recurring costs. The VEGA family has been designed with the following objectives in mind:

- provide low cost access to Low Earth Orbit (LEO)
- cover a significant portion of the small satellite market needs by offering a modular launch vehicle which can be sized to meet specific mission requirements.

The VEGA family is composed of three launchers:
- the VEGA K0-L for very light small satellites (100 to 300 Kg to 700 Km at 90°)
- the VEGA K3-L for small satellites of 300 to 600 Kg (to 700 Km at 90°)
- and the VEGA K for small satellites of 600 to 1100 Kg (to 700 Km at 90°)

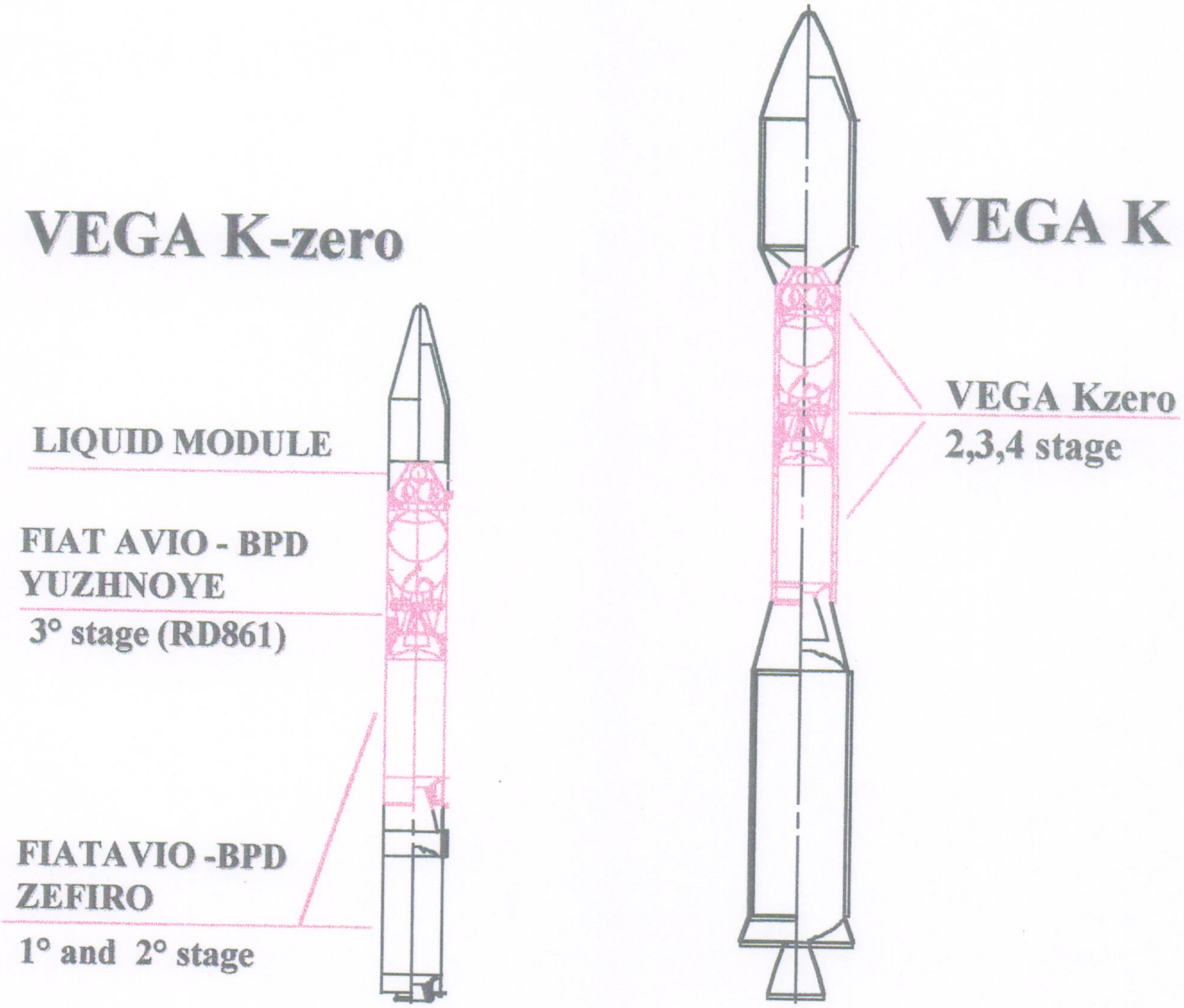


Figure 3.2.1-2. VEGA Family Launch Vehicles.

VEGA K0-L:

The VEGA K0-L represents the smaller launcher of the family. It is composed of four stages (2 based on solid rocket motors and 2 based on bipropellant liquid motors). The first and second stages are both powered by the Zefiro Solid Rocket (in order to significantly reduce overall development costs of the project as well as reduce the motor recurring cost), with different nozzles used for the first and second stages. The Zefiro motor, currently under development at FiatAvio-BPD contains approximately 16 ton of propellant.

The VEGA K0-L third stage is derived from the RD 861 motor produced in the Ukraine by Yuzhoye. This motor has been well proven on the Cyclon launch vehicle. The fourth stage is based on a bipropellant liquid module that combines:

- the propulsion function of the fourth stage (by using a fixed main motor),
- the functions of attitude and roll control for the complete flight of the upper stage (during main motor burning, coasting and at satellite deployment),
- the functions of velocity adjustment and orbit inclination control, in order to obtain the required accuracy, and
- the functions the maneuvering needed for satellite separation and final deorbiting of the empty stage.

The new fourth stage liquid module utilizes a high percentage of Eastern components to reduce recurring costs.

VEGA K3-L/K-L

The second and third launch vehicles of the family, the so called VEGA K3-L and VEGA K-L, are composed of, respectively, three and four stages. They are obtained from the VEGA K-zero configuration by substituing the first stage Zefiro motor with a 50 to 85 ton solid rocket motor (the Thiokol Castor 120 or the European P85 solid rocket motor derived from the Araine 5 P230 motor). The difference between the two versions is the presence of the liquid fourth stage on the VEGA KL.

Status of the Program

At present time, development of the VEGA concept is included in the Italian Space Plan proposal, and the schedule critical activities are currently being conducted at FIAT AVIO-BPD using internal company funds. These advance development activities are relevant to VEGA K0-L; the development of the larger versions of the VEGA family are subject to international agreements.

Launch range discussion

A similar approach was used for range selection; that is LR suppliers were contacted and the resulting information was compared and analyzed.
The information obtained from the LR suppliers is summarized in Table 3.2.1-6. The US ranges and CSG/Kourou can clearly support SMO needs now from a technical point-of-view. Furthermore, the Andøya rocket range and the Canary Island launch site appear to be low cost options at the present time. Both sites are already planning upgrades in the near future and present no major constraints for use, (options for both polar and sun-synchronous small missions).

The technical suitability of CSG/Kourou is beyond doubt. From a study performed by FIAT AVIO-BPD and CNES, it was clear that the "Diamant" launch site is the preferred Kourou option since:

- there is a good degree of independance from other Ariane launch sites,
- there is no launch interference with other launch sites, and
- good reuse of existing facilities can be achieved.

Finally, the San Marco Launch Range, located at Malindi in Kenya, must also be considered as a potential solution for equatorial small missions. This site was used successfully a number of times for launches of the Scout vehicle. However, this site requires some modifications for Vega K0. It is intended that "portable" GSE can be carried to any launch site as required. Assuming that the required modifications can be performed independently of SMO, Malindi should be available to SMO with no investments.

In conclusion the investigations perfomed on various LRs have pointed out the following:

- from the technical point of view, the operating ranges such as Cape Canaveral, Vanderberg Launch Complexes 3 and 6, and CSG Kourou are only ranges currently capable of providing full capabilities and facilities for fullfilment of SMO requirements.
- The US ranges are open and available to allow "foreign" LVs to be launched from their premises. However, this must be verified with real cases.

	Spaceport Canada	*California Spaceport by Spaceport Systems International*	*SLC-3W by Lockeed Martin*
Request for info by a questionnaire	10 July 1995	10 July 1995	30 August 1995
Receiving Info	4 September 1995	28 August 1995	8 September 1995
Status of Launch Site	Initial Launch capability , end 98	Launch complex existing. To be improved for small L/V complete end 96	Launch complex existing Modified for small L/V by Nov. 96
Mission Capability	Azimuth 59 °to 61°and 80° to 100° (Pol + He/s)	Azimuth 80° to 120° (Pol + He/s)	Azimuth 80° to 120° (Pol + He/s)
Ground Station Coverage	Full adequate (2 stations)	Full adequate (USAF stations)	Full adequate (USAF stations
L/V and P/L process and support facilities	Full adequate	Full adequate	Full adequate
Specific lift-off facilities	Full adequate (2 launch complexes)	Full adequate	Full adequate
Logistics	Full adequate	Full adequate	Full adequate
Constraints	Seaport not operating December to June	Possible delays due to military priorities	Possible delays due to military priorities
Comments	No weather constraints. No government/military priority. Launch licence March 96	Improvement end of the existing Space Shuttle Complex (never used)	Old Atlas 1-E launch complex to be modifed for small launchers

	Andoya Rocket Range by Norsk Romsenter and Swedish Space Corp	*Kodiak Launch Complex by Alska Serospace Dev. Corp.*	*Canary Islands Spatial Launching Center by INSA*
Request for info by a questionnaire	11 July 1995	11 July 1995	12 July 1995
Receiving Info	4 September 1995	28 August 1995	28 August 1995
Status of Launch Site	Implementation for L/V, predesign completed.Range could be operative within 2 years	Under development Completion by July 97	In the design phase Completed by mid 1997
Mission Capability	Pol + He/s	Azimuth 64° to 116° (Pol + He/s)	Azimuth 84° to 120° 132° to 238° 259° to 273° (Pol + He/s)
Ground Station Coverage	ARR ground control station.Svalbard station as back-up	Commitment to use a Mobile Range System of NASA Wallops. Ground Station foreseen to support TT/C in orbit operations	A complete ground station to assist lift-off will be available Telemetry/tracking/command destruct
L/V and P/L processing and support facilities	Adequate	Full adequate	Full adequate
Specific lift-off facilities	Adequate	Full adequate	Full adequate
Logistics	Adequate	Full adequate	Full adequate
Constraints	Max net weight propellant 60 tons	Outside exposition of L/V prior to launch : max 30 min	None
Comments	Range completion date depends on partners/ alliances availability	Number of partners/alliances shall affect the range completion date	

Table 3.2.1-3 Launch Range Data-base

3.2.2 BUS SERVICE

The main objective of the SMO bus (satellite platform) service consists of providing low cost, routine accommodation of payloads to ensure reliable payload data generation and transmission during the mission. The bus service includes the procurement of the satellite platform (bus) and required GSE, payload acceptance and integration onto the bus, the system AIT campaign, the launch campaign and, satellite on-orbit commissioning. This service shall be provided by the Bus Service Supplier under contract to the SMO Operator. The Bus Service Supplier will assemble an integrated, dedicated team to execute each mission from its start through on-orbit commissioning. This small team will include all of the necessary technical, contractual, and management functions necessary to carry out the implementation of the mission, including the dedicated payload representative(s).

Based on the responses to the bid package requests and information available in the literature (PROTEUS platform, LEOSTAR platforms, Spanish MINISAT platform, SSTL Minisat platform and various European microsat platforms), it is clear that European Industry is capable of offering, starting in the near-term, a technically adequate, bus service. However, detailed technical and cost information on current European products is not readily available due to upcoming competitions. ***Therefore, we have adopted the commercial Standard Bus (STB), a FIAT AVIO-BPD/CTA Space Systems joint lightsat design, as a technical and cost reference for SMO. This solution is called a "reference" since any fully European bus service will need to meet or surpass the technical and cost performance of the STB to be competitive on the world market.***

Main STB Design Features

The STB, based on a FIAT AVIO-BPD/CTA collaboration which started in 1994, is a multi-purpose, low cost, modular, small satellite platform designed to support payloads in LEO orbits. The preliminary design of the STB, including the make or buy analysis, was completed in May 1995 with the successful conclusion of the PDR. The STB design is based on the use of CTA lightsat hardware (electronics) and provides payloads with on-orbit services and, if needed, orbital maneuvering capabilities. The development of certain new elements, such as the qualification of new structural technologies and the solar panel restraint/release mechanism, are ongoing. Mission and configuration analyzes have been performed for various payloads and a dummy, structural prototype has been assembled.

The STB configuration is shown in Fig. 3.2.2-1. It is based on a hexagonal structure which is built from carbon fiber composite structural elements manufactured by FIAT AVIO-BPD. It consists of seven major subsystems: structure and mechanisms; electrical power (EPS); command and data handling (C&DH); attitude and orbit control (AOCS); telemetry, tracking and command radio frequency (TT&C RF); propulsion; and thermal control (TCS). These modular subsystems are distributed within the modules which make up the STB and are listed below:

Propulsion and Interface Module (PIM).
This module contains the launch vehicle interface flange and, if required by the mission, all the propulsion equipment along with one propellant tank (up to 45 Kg of hydrazine).

Additional Tankage Module (ATM).
This is an optional module which can be connected to the PIM for missions requiring more maneuver capability. It can house either 2 or 4 additional propellant tanks (up to 90 or 180 Kg of hydrazine, respectively).

Service Module (SM).

The SM contains most of bus core equipment. A general bus electrical schematic is shown in Fig. 3.2.2-2. The SM also supports the solar array hold-down and release mechanisms (when needed) which are characterized by a newly designed, single (but redundant) actuator for all deployable panels.

Payload Module (PM).

The PM is dedicated to the accommodation of all of the payload hardware and the bus sensors and antennas. It is modular in length to accommodate different payload volumes.

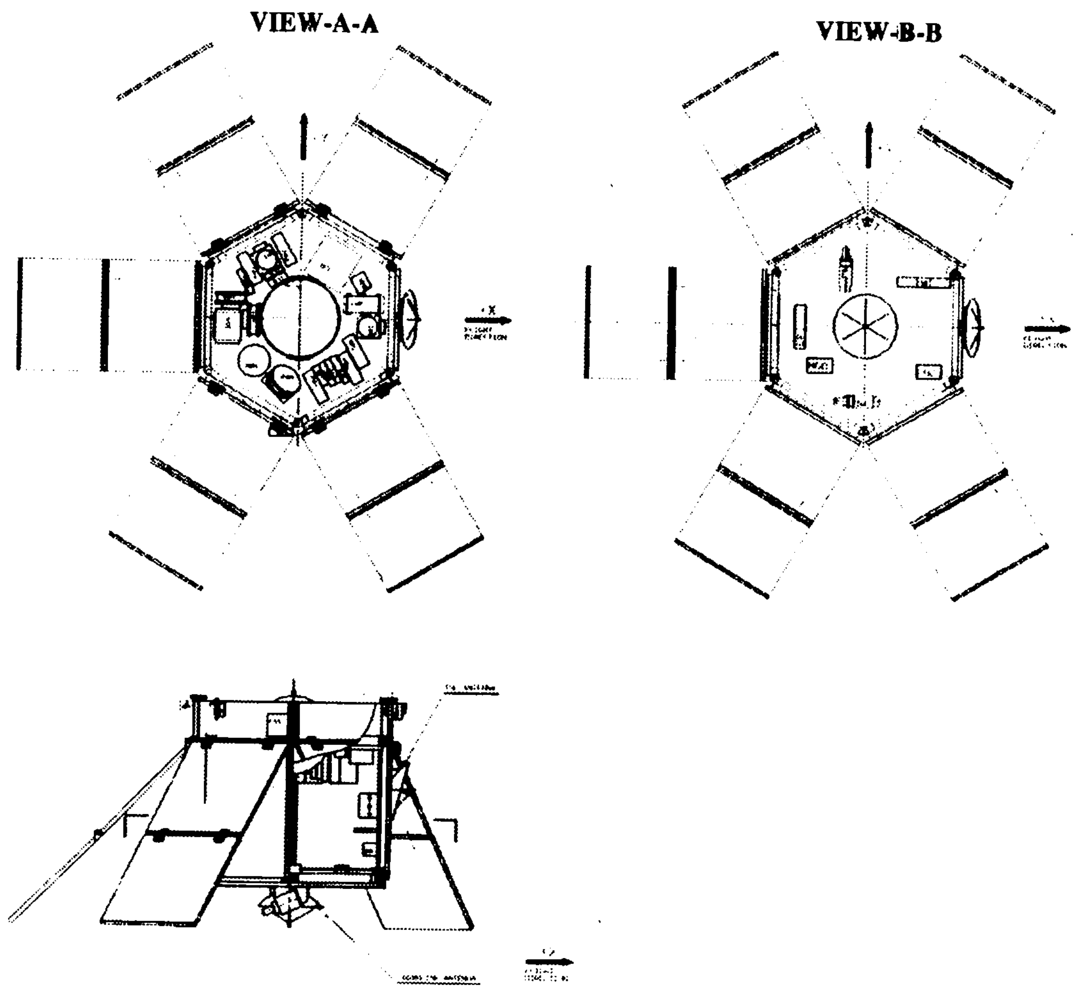
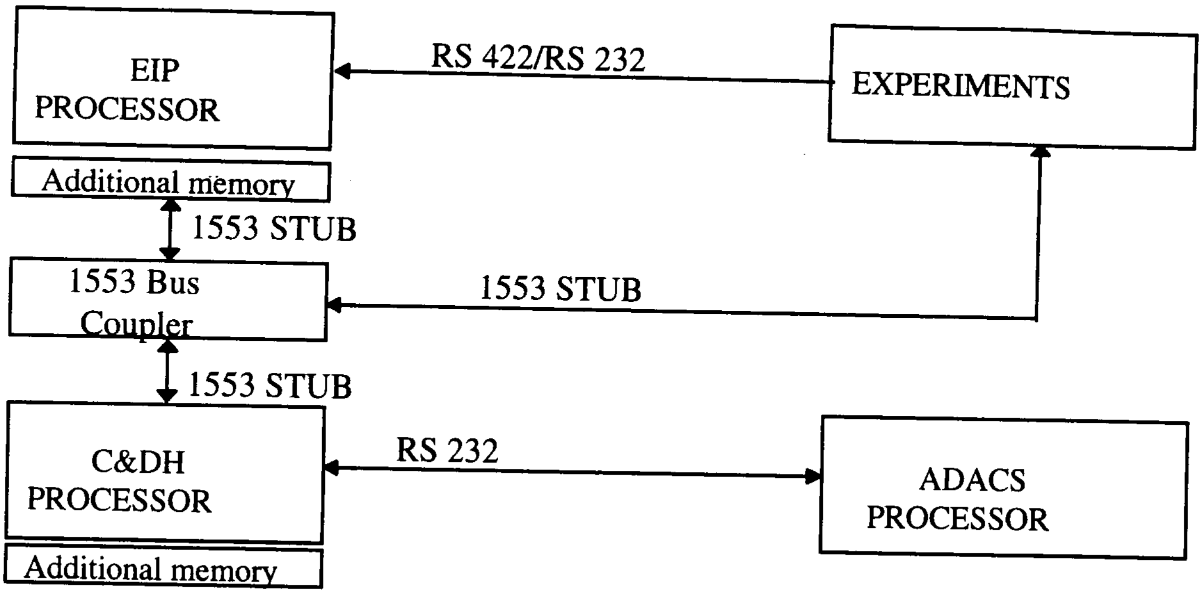


Figure 3.2.2-1. STB Configuration.



Legenda: EIP Experiment Interface Processor
C&DC Command & Data Handling
ADACS Attitude Determination and Control System

Figure 3.2.2-2 STB General Electrical Schematic.

The baseline attributes of the STB are reported in Table 3.2.2-1. The cited value for power, which is provided at 28 ± 4 Vdc, 15 Vdc, and 5 Vdc, assumes a sun-synchronous orbit. The STB has been designed to be compatible with the environments and interfaces of a number of launch vehicles including Pegasus, the VEGA family, Shavit, the LMLV family, Taurus, SS18-K, Rockot, C-1620, Cosmos, and Ariane. Payloads interface to the C&DH processor through an experiment interface processor (EIP), as was shown in Fig. 3.2.2-2, for dedicated payload management. Payloads are also provided with capabilities for command execution and pass-through, code uploading, routine telemetry collection, payload data collection, and position and attitude knowledge.

Table 3.2.2-1. Nominal STB Attributes.

Attribute	Value or Range
Payload Mass	up to 400 Kg
Orbital Altitudes	400 to 1200 Km
Orbital Inclinations	0° to Sun-Synchronous
Electrical Power Availability	up to 500 W (in sunlight)
Payload Data Transmission Rate	1 Mbps, nominal
Altitude and Orbit Control Capabilities	0 to 225 Kg N_2H_4
Pointing Performance	0.1°, nominal
Schedule (payload selection to launch)	18 months
On-Orbit Lifetime	2 years, nominal

STB Modularity Attributes

The STB was designed, from its conception, to be a modular and flexible satellite bus. The design choices were based on the results of a market investigation of potential customers' needs mainly focused on Earth observation and scientific applications. A detailed trade-off analysis was performed on the two extreme boundaries (mission dedicated bus design versus a mission utilizing a highly modular bus). This analysis showed that the modularity needs of diverse small missions can best be met through modularity at the equipment and subsystem-level not at the systems or full bus level. This means that mission needs which require very different bus configurations can be met using the same equipment and subsystems increasing service flexibility. The analysis enabled identification of areas where flexibility is required and lead to the introduction of the following equipment and subsystem-level modularity philosophy:

- The bus structure is built up from carbon fiber, filament wound members and aluminum honeycomb, carbon fiber reinforced panels which can be assembled in the form required to meet the mission needs.
- Electrical power will be provided by body mounted and/or deployable solar panels which will have a nominal width of 700 mm. Different power requirements can be met by varying number and length of the solar panels. Solar cells using Italian GaAs technology will be employed. The baseline energy storage system will utilize modular NiCd battery packs with a nominal capacity of 4 Ah each. Additional energy storage requirements can be met by using additional battery packs.
- Payload data storage capacity can be modified by adding (or deleting) memory cards (4 Mbyte each) in the experiment interface processor of the C&DH subsystem. Very large data storage requirements will be met using a Gbyte-sized dynamic RAM.
- Payload data throughput can be increased by using an X-band transmitter and high gain antenna instead of the baseline equipment (particularly for high bandwidth requirements). Data rates of up to 25 Mbps can be accommodated.
- The available payload volume/dimensions can be increased or decreased by varying the length of the PM.
- Spacecraft ΔV maneuver capability can be increased by using an ATM to pass from the nominal hydrazine propellant load of up to 45 Kg (one tank) to a maximum value of 225 Kg (5 tanks). In addition, FIAT AVIO-BPD hydrazine arcjets can be implemented for improved specific impulse performance for missions with adequate power margins.
- Pointing capabilities include both Earth and inertial concepts, depending on mission specific requirements. Pointing accuracy varies greatly with the selection of the stabilization and attitude determination method. Pointing accuracy can range from 5° using passive stabilization (a low cost gravity gradient method) up to better than 0.1° using full 3-axis stabilization and high precision sensors.

The selected modularity approach enables the definition of a number of STB design complexity levels. The specific payload requirements determine the needed bus complexity level for a given mission. The basic complexity levels are listed below:

1. Low:

   A low complexity mission is characterized by passive stabilization (gravity gradient), low pointing accuracy, no on-board propulsion, low data rate, and low payload power consumption.

2. Intermediate:
An intermediate complexity mission is characterized by a need for three-axis stabilization, intermediate accuracy pointing needs (0.5°), some ΔV maneuvers (1 propellant tank), medium payload data rate, etc.

3. High:
A high complexity mission is characterized by a need for three-axis stabilization, IMU or star tracker attitude determination, high accuracy pointing needs (0.1°), high payload data rate, etc.

These complexity levels allow nominal mass and power budgets to be defined which are presented in Table 3.2.2-2. Values are not presented for the high complexity level case since it is highly mission dependent.

Table 3.2.2-2. Nominal Mass and Power Budgets for the STB.

Complexity Level	Nominal Dry Mass	Nominal Bus Power
Low	126 Kg	51 W
Intermediate	198 Kg	110 W

AIT Campaign

We consider the AIT approach to be a significant schedule and cost driver in the flight segment of the SMO Initiative. Therefore, we have introduced an innovative AIT approach which is based on the use of a small, dedicated team from the start of a mission through spacecraft launch and commissioning. All system elements are comprehensively tested during integration while complete systems tests are conducted before launch. The approach includes techniques which reduce integration time and cost. These techniques include:

- the early availability of a bus simulator for payload development,
- incremental hardware and software integration,
- test of subsystems using PC-based simulators,
- use of a planar spacecraft test bed harness (FLATSAT) for full accessibility to every component during test,
- automated GSE using standard instruments under PC control,
- a design-to-test strategy with ready access to test points and signals, and
- fewer reviews and less documentation.

The major themes of the AIT approach are summarized below:

Centralized, System Test Location -- A centralized, system test location is important to reduce cost and schedule uncertainty since it provides the best management control and enables the full implementation of the integrated project team concept from mission start to launch.

Incremental Hardware and Software Integration -- Incremental hardware and software integration and test uses parallel paths and several progressive integration and test steps in order to detect and solve problems early and allow complete spacecraft testing completion with a low schedule risk. This is accomplished through testing at different levels, see Fig. 3.2.2-3.

Equipment level Equipment level testing is conducted during acceptance to verify equipment operation and functionality,

Subsystem test bed Subsystem test beds are used (for TT&C RF, AOCS, power and the payload) during the first phase of integration to verify proper subsystem workmanship,
FLATSAT The FLATSAT is a planar spacecraft test bed which is laid out such that each piece of equipment and subsystem is directly accessible during testing. It is used immediately prior to final integration on the flight structure to allows all equipment and subsystems to electrically interconnected and operated together as a spacecraft to verify functionality and workmanship,
Spacecraft Overall system level testing of the spacecraft (bus plus payload) is conducted to verify its functionality and overall workmanship.

Modular Test Software -- Modular test software is used in order to lower the adaptation cost for each payload.

Payload Electrical Model Test Before Protoflight Model Integration -- The payload electrical model is tested on the electrical model bus (FLATSAT) prior to allowing payload protoflight model integration on the flight model bus.

Nominal and Back-Up Payloads -- The AIT flow provides for one "nominal" or primary payload passenger and one "back-up" payload (which has similar bus resource needs). This provides an avenue to maintain the overall SMO schedule if a delay occurs with the development of the primary payload due to the high risks associated with new payload development.

In-Flight Anomaly Analysis Back-Up -- The payload electrical model is mounted on an electrical model bus and ready to be utilized following launch to support the launch and commissioning phase as well as act as an aid in analyzing in-flight anomalies.

Fewer Reviews and Reduced Documentation - The only documents which shall be produced are those needed by others to conduct their tasks. The use of a small integrated team enables a paperless methodology to be employed for the day-to-day engineering tasks. Furthermore, the integrated team approach, including payload representatives, allows a continuous review approach to be used during mission implementation. All formal reviews (KOM, PDR, CDR, System Readiness Review, Launch Readiness Review and the Commissioning Review) will be at the system level.

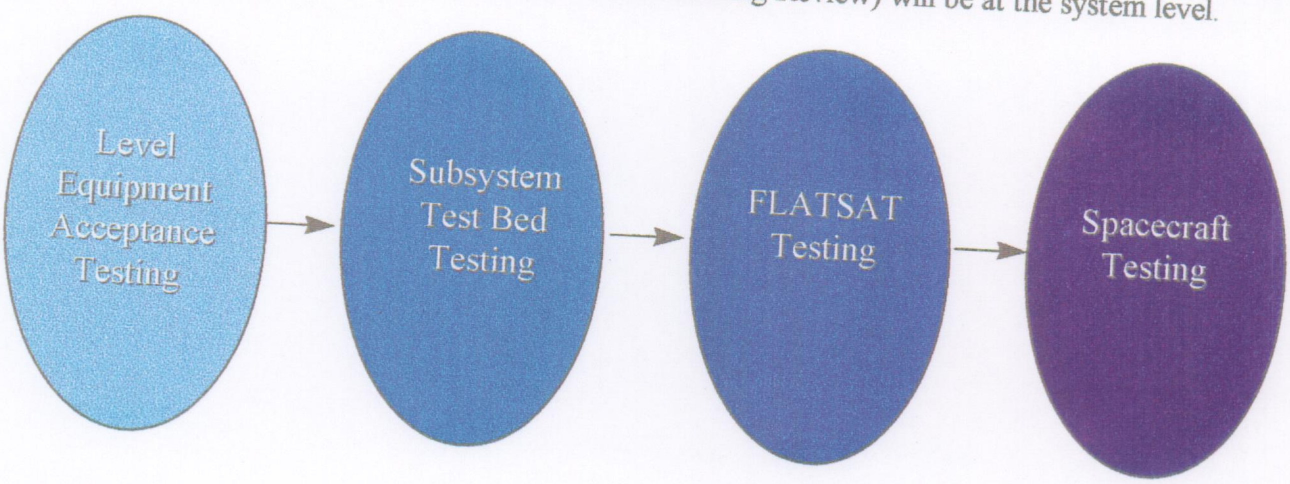


Figure 3.2.2-3. AIT Campaign Testing Levels.

Spacecraft Models and Usage

The proposed AIT approach is based on the use of two electrical model spacecraft (EM1 and EM2) for equipment testing, and a protoflight model (PFM) spacecraft for flight. Both EM1 and EM2 are part of the EGSE and will be available through out the life of the SMO service. The EM1 model is used to verify the electrical compatibility of a payload with the bus electrical design. The flight model payload equipment can be integrated on the flight model bus only after successful testing of the EM payload and the EM1 model spacecraft. The scope of the EM2 model is to support launch and commissioning operations of the protoflight spacecraft. It is possible to use the EM1 and EM2 buses interchangeably to optimize the logistics flow if more than one payload is being processed. The Protoflight Model (PFM) is the flight spacecraft.

Test Flow

Testing is an important and integral part of the assembly process for the bus and its integration with the payload. The PFM spacecraft test flow is shown in Fig. 3.2.2-4. Here, the scheme of the four different test levels of Fig. 3.2.2-3 (equipment, subsystem test bench, FLATSAT and spacecraft) can be identified. Testing starts at the equipment level at the beginning of month six (after the KOM) and concludes with spacecraft system testing and launch preparation testing during month 17 (after the KOM). The total test duration is approximately 12 months.

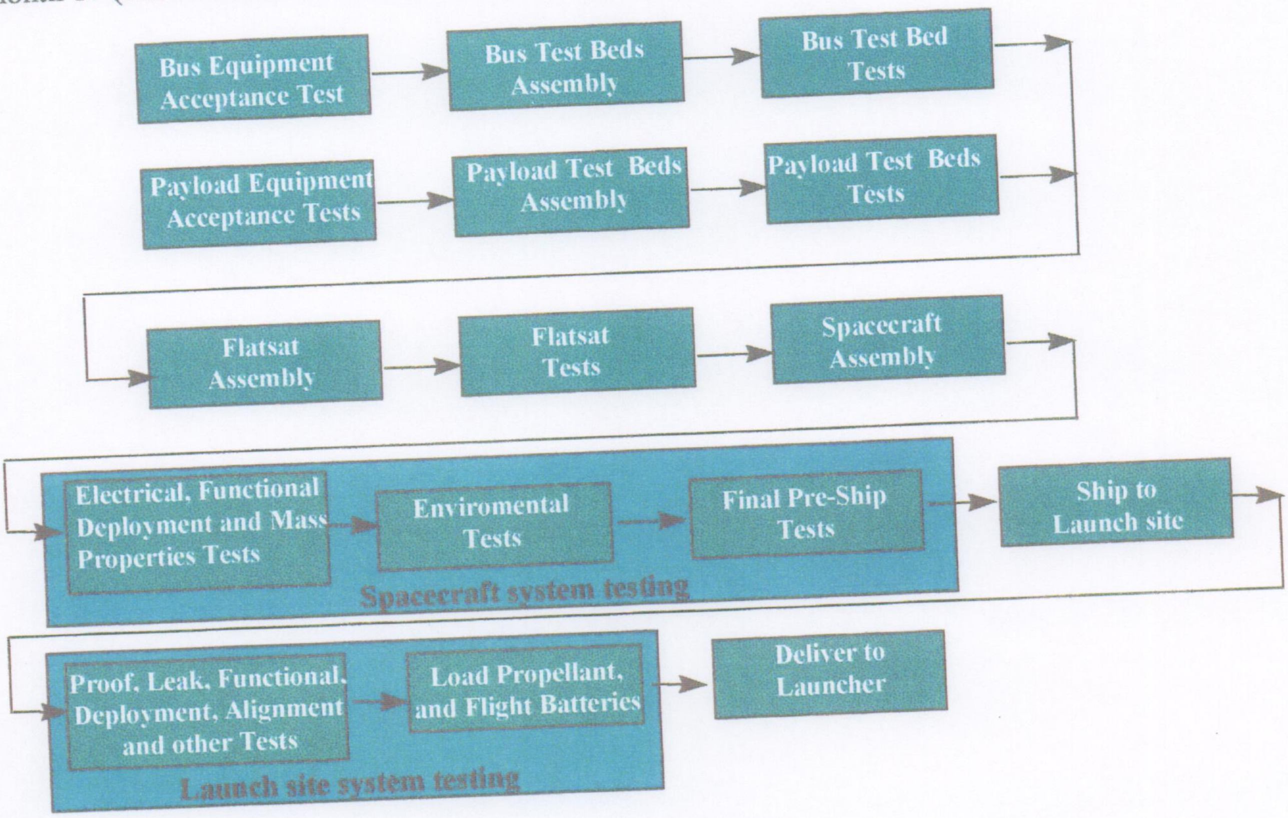


Figure 3.2.2-4. PFM Spacecraft Test Flow.

The overall flow starts with equipment delivery (both bus and payload) and acceptance testing. The equipment is then installed on test beds for testing at the subsystem level. Once subsystem testing is complete, the equipment is integrated onto the FLATSAT spacecraft test bed for initial system level testing. The FLATSAT is effectively an EM model spacecraft. The successful conclusion of FLATSAT testing means that the bus and payload equipment can be integrated on the PFM spacecraft and undergo full spacecraft system testing.

The system level test flow starts with general electrical and mechanical checks, moves through solar array testing and RF tests and into overall spacecraft functional testing. Preparations for environmental testing are made including a spacecraft leak test and mass properties measurement. Environmental tests include sine and random vibration and thermal cycle testing for workmanship. The test system test campaign closes with final leak tests, final RF compatibility tests and final functional tests. Following the completion of PFM spacecraft AIT, the spacecraft is shipped to the launch site, tested, and integrated onto the launcher.

Ground Support Equipment (GSE)

The SMO GSE can be split into both mechanical GSE (MGSE) and electrical GSE (EGSE). MGSE is needed for spacecraft manufacturing and test and spacecraft transportation while EGSE is needed for bus manufacturing and test, payload testing and spacecraft manufacturing and test.

The EGSE must provide support for SMO satellite bus integration, bus and payload integration, environmental testing and launch operations. In order to enable the cost effective implementation of the EGSE, the components must largely be under the umbrella of an automated test system. A classical, workstation-based EGSE architecture, of the sort typically used for large ESA missions, can provide for all SMO EGSE test needs but is fairly costly to implement. These same functions can be implemented in a significantly lower cost manner based on fast (Pentium processor) PCs and an AIT site LAN. Here a simple space segment interface console (SSIC) would be connected to the PCs which in turn monitor and control the various SCOE for the satellite systems. The open architectures of today's PCs mean that many potential suppliers are possible, upgrades are simple and maintenance means the simple change-out of cards. Furthermore, in this architecture, well known and well understood commercial software can be used.

Qualification Approach

Qualification testing is aimed at demonstrating that the design of hardware and/or software is adequate. Furthermore, qualification testing is used to certify that hardware and/or software works properly. This testing also demonstrates the presence of a minimum design margin with respect to the expected worst case launch/flight loads and environments. Traditionally, qualification testing is done at the piece part level on up to the spacecraft level and each level in between. The traditional qualification approach can not be used for SMO. There are several reasons for this:

- SMO must operate on an 18 month, contract-to-launch schedule.
- Commercially available flight-qualified units will be used in all possible cases (assuming that they are cost effective).
- Initial non-recurring costs must be held to an absolute minimum (dedicated qualification models can not be supported).
- It is not possible to identify "worst case" configurations (envelops) for spacecraft EMC and the thermal loads since they are strongly dependent on the payload configuration characteristics.

Therefore, a protoflight qualification strategy is proposed for SMO. Within SMO, specific qualification activities are foreseen at three different levels; equipment, assembly and system. The specific activities at each of these levels are discussed below.

Equipment level -- The vast majority of the proposed bus equipment has flight experience. Therefore, qualification by similarity is planned (for near-term use). The main exception is the solar array panel which will be subjected to qualification testing. New bus equipment which introduced to replace near-term equipment shall undergo full qualification.

Assembly level -- The only new assembly that requires a qualification effort in the near-term is the solar array hold down and release mechanism. This assembly shall be fully validated through qualification testing including sine vibration, random vibration, shock, thermal cycling and deployment testing.

System level -- Each flight spacecraft will be considered a protoflight unit and undergo protoflight level testing. A qualification model of the spacecraft primary structure will be manufactured and tested since it is not cost critical but can have a significant impact on mission success. These tests will enable validation of the mathematical model simulations on the spacecraft structure. A mathematical thermal model for the spacecraft will be developed but no specific hardware thermal model is foreseen. In cases of thermally critical missions/payloads, dedicated local hardware models will be implemented. In addition, flight data for non-thermally critical missions will provide thermal mathematical model correlation and evolution. No hardware electrical qualification model is foreseen since it is very difficult to identify worst case loadings and configurations. The protoflight spacecraft will undergo electrical testing including over-current and over-voltage testing with automatic monitoring of EMC phenomena-triggered anomalous electrical equipment behavior.

3.2.3 GROUND CONTROL SERVICE

Space-ground communications, mainly consists of :

- Satellite command, control and monitoring, both for the bus and payload, usually known as telemetry, tracking and command (TT & C).
- Receipt and processing of payload data.

The ground station implementation must include similar systems and operating blocks to execute each of the functions listed above.. The operating blocks are the same for most missions and are:

- Tracking Station (TS) , to support Tx/Rx, tracking and ranging, processing and archiving,
- Mission Control Center (MCC), to support performance analysis and space segment health assessment, spacecraft test, command analysis, flight dynamics, and data archiving,
- Payload Control Center (PCC), to support payload health assessments, payload commanding, data processing and archiving; and
- Data Dissemination System (DDS).

Clearly, this ground station philosophy is applicable to a wide range of mission types and therefore diverse satellite platforms.

These operating blocks can be implemented in different ways, depending on :

- type and number of missions to be covered simultaneously;
- the hardware and software lay-out and approach used to fulfill customer requirements;
- the specific agreements (mission by mission) between the Customer and SMO Operator.

For example, the PCC can be an integrated part of the MCC or a decentralized, stand-alone terminal.

Mission requirements examination, together with the comparison of the most promising ground station approaches, will lead to the definition of the proposed ground service.

Ground station reference requirements

The following system level requirements have been considered for the development of the ground control station analysis and trade-off:

- Management of up to 8 missions simultaneously (based on a launch frequency of two to four spacecraft per year, with a nominal lifetime of 2 years each),
- The spread of Customer mission monitoring needs (from fully independant mission control performed by the Customer to a full operational control of the mission and payload by the SMO Operator),
- 400. to 1200. Km orbital altitude, equatorial to polar and sun-synchronous inclinations,
- Need for spacecraft housekeeping data receipt by the SMO Operator (for all operating spacecraft),
- Store and forward concept is utilized frequently,
- Maximization of contact time between the ground station and spacecraft without requiring active pointing by the spacecraft antenna,
- S-band link nominal; X-band for high flow,
- High data rate up to 25. to 50 Mbps,
- Need to use existing hardware, procured under competition,
- Adaptability in the cost of the ground segment to accommodate low performance requirements,
- Transmitted power on board 8 to 10 W (radiated),
- Possibility to delay the non-recurring investments,
- real time interconnection of the ground control station is not required,
- High spacecraft on board autonomy,
- Fixed antenna on board, max 250 mm diameter, and
- The location of ground control station is not specified.

The following ground service approaches were analysed during the study:

- Customer dedicated ground control stations (GCS): in this case the ground station hardware meeting the mission requirements is delivered to the Customer who operates the satellite after spacecraft and GCS commissioning,
- Multimission centralized GCS: this option is based on the use of only one SMO dedicated, centralized GCS that is operated by the SMO operator and supports all operative SMO missions, and
- Intermediate option: one centralized GCS with several customer dedicated GCS and/or terminals; the centralized station is operated by the SMO operator.

After the trade off, the last solution has been selected based on the following considerations:

- the availability of a centralized station allows housekeeping data receiving, postprocessing and storage that is considered essential for the SMO operator (mainly at the beginning of the service) in order to drive the bus design evolution,
- the availability of a centralized station enables the SMO operator to provide the Customer with optional services like full spacecraft management during its operative life and payload data back-up (items which were derived from the market survey as desired for many users),
- the availability of modular Customer-dedicated ground gontrol stations allows the Customer to be partially or fully independent of the SMO operator during the operative life of the satellite, and
- the availability of Customer dedicated ground stations or terminals allows the centralized station to be sized for mainly housekeeping data collection and a reduced level of ground services, resulting in a centralized Ground Station cost reduction.

Therefore the intermediate option has been selected since it does not have a major cost impact (with respect to the other options) and provides increased service (more Customer need oriented).

Ground Service architecture for 8 simultaneous spacecraft is shown in Fig.3.2.3-1, where the centralized GCS (C) receives the housekeeping data for all spacecraft (1-8), manages and operates satellites 1 to 4, and partially operates (payload data downloading is excluded) satellites 7 and 8. The Ground Station is schematically represented in the block diagram of Fig. 3.2.3-2. The station is assumed to be located at the service operator premises (central Italy has been assumed for our analysis).

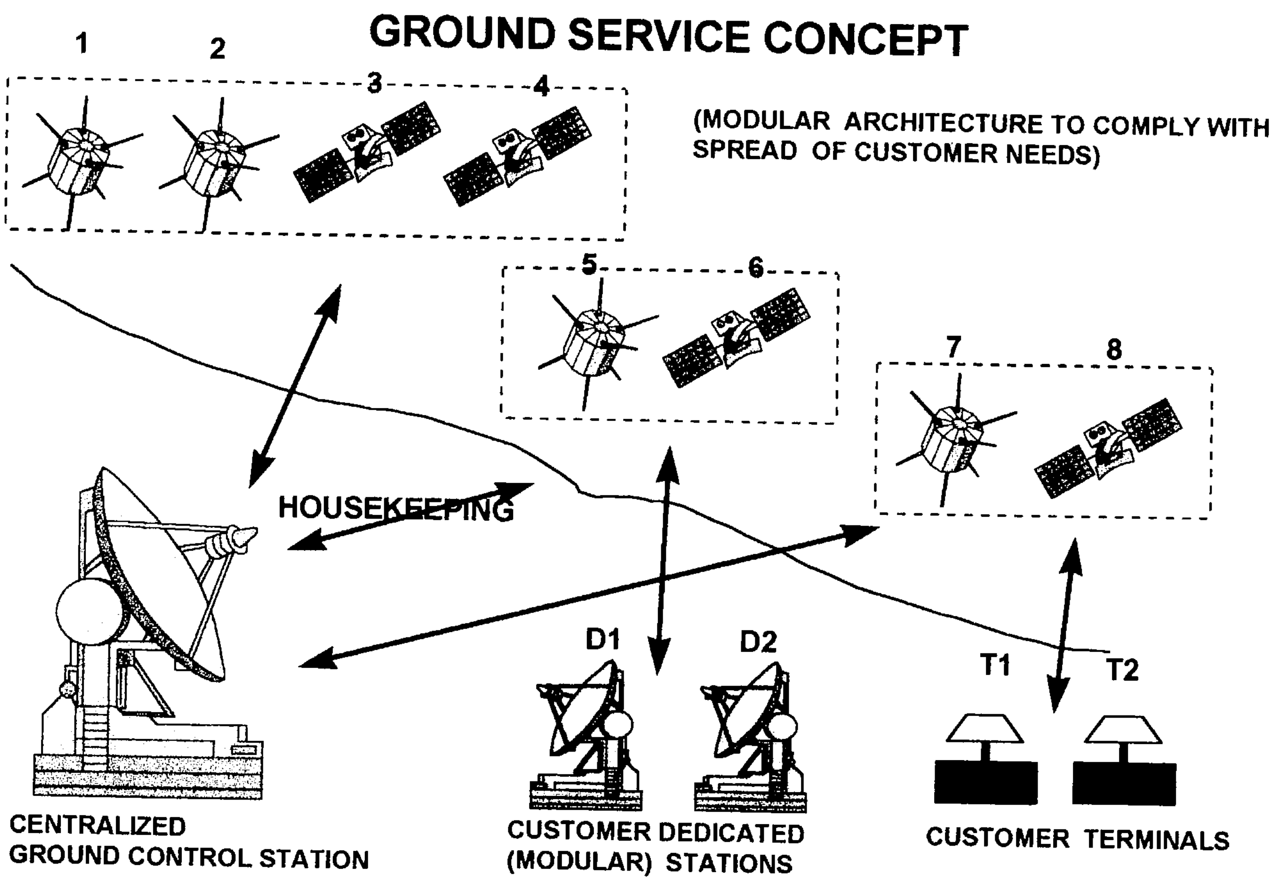


Fig. 3.2.3-1 Ground Service Architecture

FiatAvio

CENTRALIZED GCS

Functions:

- full mission management up to 4 missions
- support up to 4 (other) missions
- housekeeping for 8 missions
- P/L data distribution up to 8 missions
- coordination of 8 satellites access
- ranging
- S-band nominal (up to 4 mbps)
  X-band for high P/L data rate (up 10 Mbps)

Performances

EIRP > 60 dbW
G/T (X) > 27db/°K
G/T (S) > 18 db/°K

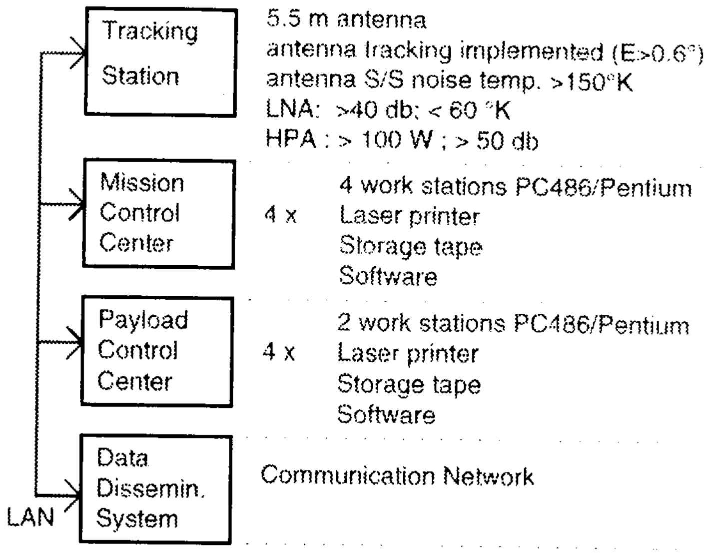


Fig. 3.2.3-2 GCS Block Diagram

The staffing foreseen to operate the station is 4 people working on 3 shifts. These people are made available by the SMO service operator and include the following minimum skill levels: team leader - BS Engineer, > 5 years experience; Subsystems specialist - BS Engineer >2 years experience, Payload Specialist, Senior Technician, > 3 years experience, and a Command Specialist, Senior Technician, > 3 years experience.

The high performance Customer-dedicated ground control stations (DCS), D1 and D2 in Fig. 3.2.3-1, are operating satellites 5 and 6. This ground station is schematically represented in the block diagram of Fig. 3.2.3-3.

DEDICATED GCS

Functions:

- full mission management of 1 mission
- ranging
- S-band nominal (up to 4 mbps)

Performances

EIRP > 46 dbW
G/T (S) > 12 db/°K

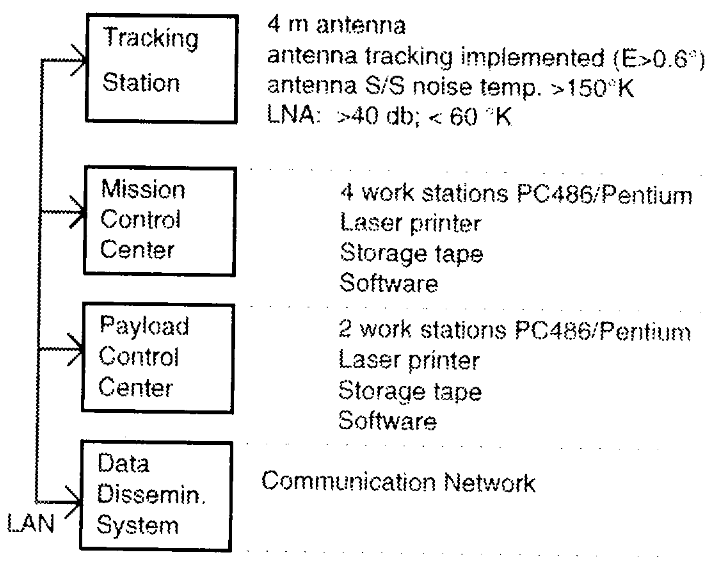


Fig. 3.2.3-3 Dedicated GCS Block Diagram

The staffing foreseen to operate this station is also 4 people but working on 1 shift unless 24 hour monitoring is required. These people are made available by the customer and require the same minimum skills as with the centralized GCS.

The Customer dedicated terminals, T1 and T2 of Fig 3.2.3-1, are utilized to dowload payload data for missions 7 and 8. The terminal is schematically represented in the block diagram of Fig. 3.2.3-4. The terminal consists of a reception chain with the following elements:

- a broad beamwidth S-band antenna,
- an S-band to 70 MHz IF converter,
- a PSK demodulator,
- a PC for P/L data processing,
- a unit for data storage, and
- software.

The S-band broadwidth antenna consists of one receive andazimut tracking "mono-scan" unit working at 70 MHz IF and one compact 16 dBi array antenna which is 70 MHz downconverted. A 70 MHz link between these units is also required. The antenna characteristics are given below:

Type:	12 spiral weighted array
Gain:	16 dBi
Tracking mode:	azimuth monopulse "mono-scan"
Transmit power	10 W

The receiver characteristics include:

Type:	dual frequency conversion with LNA
Nouse figure:	5 dB

The foreseen staffingv is 1 person on 1 shift with a skill leveel of a BS in Engineering Science and > 3 years experience. This person is expected to be part of the Customer organization. The location of the station is at Customer premises (not defined for the study since no specific missions were selected).

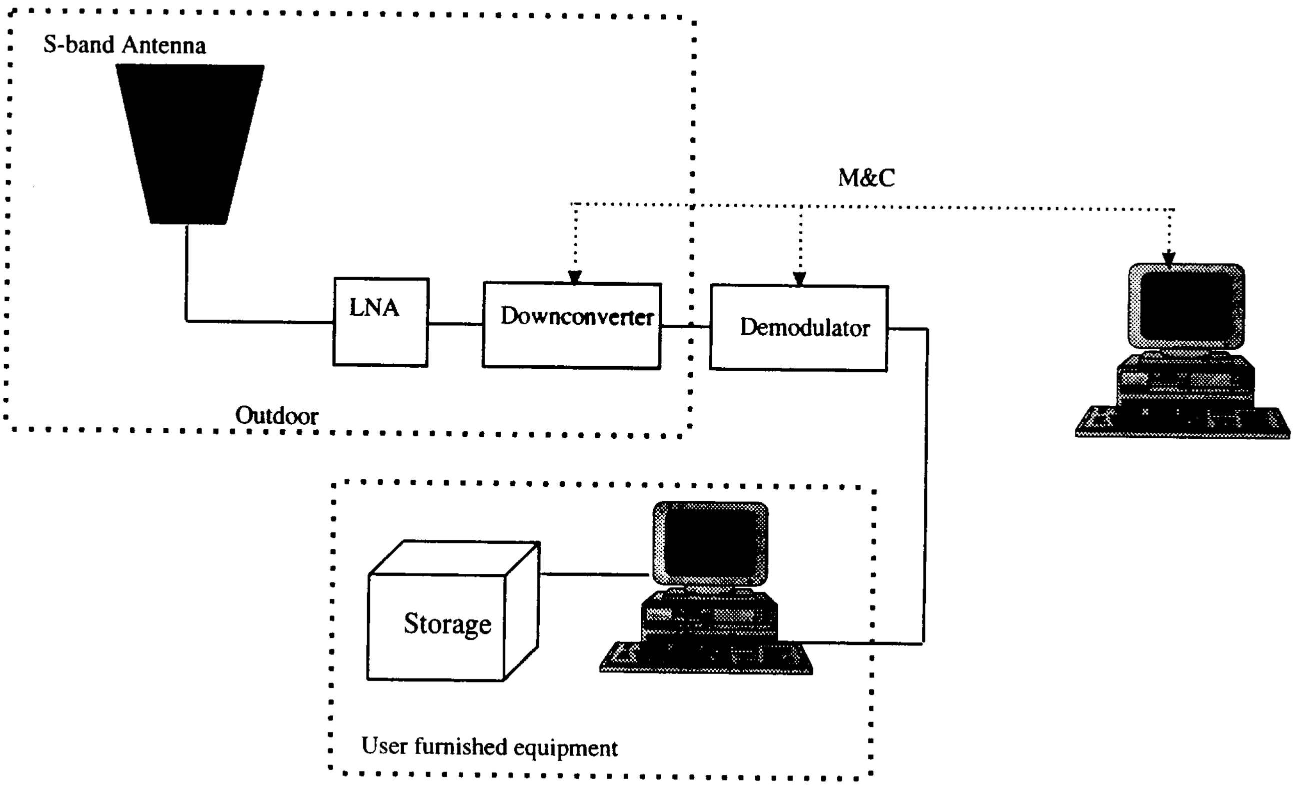


Fig. 3.2.3-4 Customer Dedicated Terminal

The 8 accommodation analyses carried out in the frame of the SMO study have demonstrated full compatibility with the ground service scenario as described in this section. For each of the ground station options described above, complete Bid packages were issued. The responses validated the ground segment cost figures presented in section 4.2.

3.2.4 SOFTWARE

Each of the main service segments (launch, bus, and ground) and the payload includes needs for software development. The software elements for each of the service segments and payload will need to operate together to permit execution of the test campaigns, communications, and operation the satellite. This means that the software approach will strongly influence both the cost and reliability of the missions. Therefore, software must be considered a key element in the implementation of the overall SMO Initiative.

The scenario is a key consideration in the development of overall SMO software requirements. In the near-term, SMO software definition and development must be conducted in an environment where minization of non-recurring costs is of prime importance. Minimum non-recurring costs should translate into the use existing software elements for a large part of the overall SMO software package. This initial package will not necessarily be optimized for SMO but will enable the basic SMO services to be delivered in a cost and schedule effective way. As the SMO service matures, investments can be made to optimize the overall SMO software package. These investments will likely lead to the development of specific, dedicated software elements for SMO within an "SMO-optimized" architecture according to SMO-focused specifications and guidelines.

The development of the SMO software package is expected to involve diverse sources. Therefore, its development and transition from the near-term implementation to an SMO-optimized architecture, is a primary issue in the success of the SMO Initiative. The software intensive elements include the payload, bus, EGSE (including SCOE), ground system (both the centralized ground control station and customer dedicated terminals) and launcher. The software interactions between the first four elements are considered the most important since the launcher software can largely stand alone. As should be clear, software from diverse systems and, most likely, diverse suppliers must be able to interact correctly in order to deliver SMOI services. This has to be done in an environment where the bus, EGSE and ground software can be very similar (minor modifications) for each mission but where the payload itself and its software will likely be completely different. Proper management of the SMO software package will depend on the adoption and establishment of a standard, or group of compatible standards, for the software interfaces. Any standards which are adopted or established must be compatible with existing standards to enable portability or simple translation. This can help maximize the capturable payloads.

The software development schedule for each mission will have to be compatible with the overall mission schedule. Major software deliveries are needed at 12 months ("electrical model" software) and 15 months (final flight software) in order to meet the overall, recurring schedule requirement of 18 months. A non-recurring phase of 18 to 24 months is foreseen prior to the first mission in order to develop, build and qualify the hardware and software for the spacecraft bus, ground system and EGSE.

Software Development Approach

Based on the considerations above, the following software development approach is proposed for SMO:

- Design the definitive SMO software architecture and develop the relevant requirements. The software architecture must define the responsibilities and task partitioning between different software segments of the spacecraft (including the payload) and between the different layers of software.
- Examine the non-recurring cost items and tasks and try to delete them by identifying alternative approaches with acceptable risks from the recurring cost and reliability points-of-view,
- Conduct a detailed reuse analysis of existing software packages for all service segments. Assemble the near-term SMO software package based on the use of existing software elements and newly generated elements where needed,
- Define the transition strategy between the near-term solution (low non-recurring costs) and the definitive solution (low recurring costs) while maintaining production, and
- Develop and implement SMO-optimized software modules and packages as investments allow, while focusing on decreasing operating costs and increasing mission reliability.

This approach enables near-term implementation of SMO software using critically reviewed, existing software packages and modules while allowing evolution to an SMO-optimized software architecture.

Software Standards

The ESA PSS-05 software standards were examined in an effort to define an outline for an SMO software standard. While the general philosophy is good, direct application of the current PSS-05 standards to SMO is too burdensome from both the cost and time points-of-view. We recommend that the software development process for SMO adopt a limited incremental development approach for each mission while using an evolutionary development approach to upgrade the generic SMO software. In the limited incremental delivery approach, the user requirements, software requirements and architectural design phases are completed sequentially and then the detailed design, transfer and operations/maintenance phases are split up to allow multiple releases of the software. Each release has increased functionality and capabilities. This allows the most critical items to be developed and tested first. This method is suitable for use by small-team-oriented, long-term projects such as SMO. The evolutionary development approach provides for planned multiple releases of the software where all of the software development phases are repeated (reduced in scope) for each release. This process is also suitable for implementation in the SMO environment.

Software Reliability

Reliability is a measure of the duration of proper operation of the software uninterrupted by failures/anomalies from internal faults. Quantitative methods can be used to predict the probability of future failures but rely on statistical methods and are therefore not applicable to the SMO service in the near-term. Once several SMO missions have been flown, a database will exist which can be used to help assess future missions quantitatively. Therefore, qualitative methods will have to be applied for near-term SMO missions. Qualitative methods are used to identify system failure modes and event combinations leading to those modes. The methods which should implemented are SFMECA at the software requirements level and SFTA during the entire software lifecycle. This methodology enables the implementation of the needed fault tolerance and safety barriers.

The development of the general SMO software reliability budget is based on the approach summarized in the following guidelines:

- Launch vehicle software reliability shall be included in the overall launcher reliability figure and be verifiable (previous use).
- Ground station and EGSE software are expected to be based largely on existing packages (previous use). Since EGSE and GCS malfunctions shall not cause loss of a mission, the reliability of EGSE and GCS software can be taken as 1.0.
- Bus software can be used for critical and non-critical functions. Critical bus software is expected to be based largely on existing packages (previous use). New software elements shall be generated using traceable design and development practices. Non-critical bus software elements can be ignored in software reliability calculations.
- Payload software can also be used for critical and non-critical functions. Critical payload software elements must be defined by the payload provider. The SMO system software authority shall verify that the critical payload software is complete and that no other mission criticalities can be generated when the payload is placed on-board the spacecraft. Non-critical payload software elements can be ignored in software reliability calculations.

As a final note, unlike hardware, software can be "repaired" on-orbit. Significant software modifications are possible by feeding new or updated software to the satellite via the commands/communications channels. This feature makes software life cycle prediction difficult but adds a large amount of flexibility.

Software Design Guidelines and Development Environment

Based on the considerations above, software design guidelines have been assembled to help focus SMO software development, where necessary, and are listed in Table 3.2.4-1.

Table 3.2.4-1. List Of SMO Software Design Guidelines.

Software Design Guidelines
Simple, modular design
Approach development from a system perspective
Design for satellite autonomy from the start
Maintain all design margins at system level
Mission software package built from standard/independent modules
Each module should be independently testable and debugged
No error propagation between modules (I/O data checking)
Specific, independently testable, user written routines tie modules together
Hardware/software interfaces should be tested together early and often
PC-based on-board computer/data bus simulators needed early
Flight software is not considered delivered until fully tested on satellite

The software development environment for SMO should be an integrated set of tools that supports the entire software development process. This means that the tools must be available to support all of the software lifecycle phases (user requirements, software requirements, architectural design, detailed design, code generation, testing, debugging, operations and maintenance). The use of this type of integrated tool provides direct support for software reuse in subsequent missions. The specific attributes of the desired software development environment are listed in Table 3.2.4-2. Several commercially-available, integrated software development tools are listed in Table 3.2.4-3.

Table 3.2.4-2. SMO Software Development Environment Attributes.

ATTRIBUTE
The compilers and linkers should be commercially available and well proven.
The development environment should be thoroughly tested by other projects → problems should be well-known and documented.
Rapid service and support must be available (< 1 week).
All tools at various levels must be replaceable (modularity).
Built-in debugging facilities should be available.
Built-in configuration management facilities should be available.

Table 3.2.4-3. Commercially Available, Integrated Software Development Tools.

Product Name	Supplier	Summary of Attributes
EPOCH 2000/OASYS	Integral Systems	Extensive past space experience; workstation-based distributed architecture with LAN interfaces; integrated, open, graphically-oriented environment for satellite command and control; data base-driven; full satellite fleet control capabilities
SCOSII	CRI	Under development (ESA/ESOC), workstation-based distributed architecture with LAN interfaces; integrated and open environment for satellite command and control; full satellite fleet control capabilities; C++ programming language, built-in analysis and database capabilities
LabWindows/CVI LabView	National Instruments	Used extensively in many industries including space applications; integrated, open, graphically-oriented programming environment for building instrumentation systems; C programming language; PC and workstation compatible; LAN communications; control libraries for GPIB, VXI, serial and plug-in DAQ instruments; extensive built-in analysis and database capabilities

Possible Pre-Project Software Activities

The initial development of the software needed in the SMO Initiative for the launcher, bus, GCSs and EGSE can be handled in the non-recurring phase. These software items will then largely be reused for subsequent missions. After the first mission, a fixed, 18 month schedule is adopted. In order for a payload provider to commit to such a schedule, some level of payload instrument laboratory development and testing (including software) will need to have been completed. Therefore, it is reasonable to expect that the payload provider is, first of all, considering the use of SMO and, secondly, has already begun software development using their own methodology and, therefore, has laboratory prototype software working.

In order to maximize the probability that the laboratory software is useable for the mission or can be upgraded to mission-usable condition, the SMO user's manual must include the basic software development standards for SMO. These standards must be compatible with other existing standards (such as PSS-05) in to allow portability of software from other programs to SMO (and vise-versa). In addition, PC-based, SMO spacecraft bus simulators will be available prior to contract signature so that principal investigators can begin instrument and software development which is compatible with the SMO software. In other words, they will be able to transfer their "laboratory environment" software to an "SMO simulator environment" early. This will enable development of transportable code from the start. Existing, non-portable modules can be located and rewritten early and, with the simulator, early testing can be done to ensure payload/SMO compatibility.

3.2.5 MANAGEMENT

Main purpose of the SMO management approach is to define and create an effective and efficient organization which is able to understand and implement Customer needs and provide a complete small missions service at low cost and within the contract schedule (see Fig 3.2.5-1).

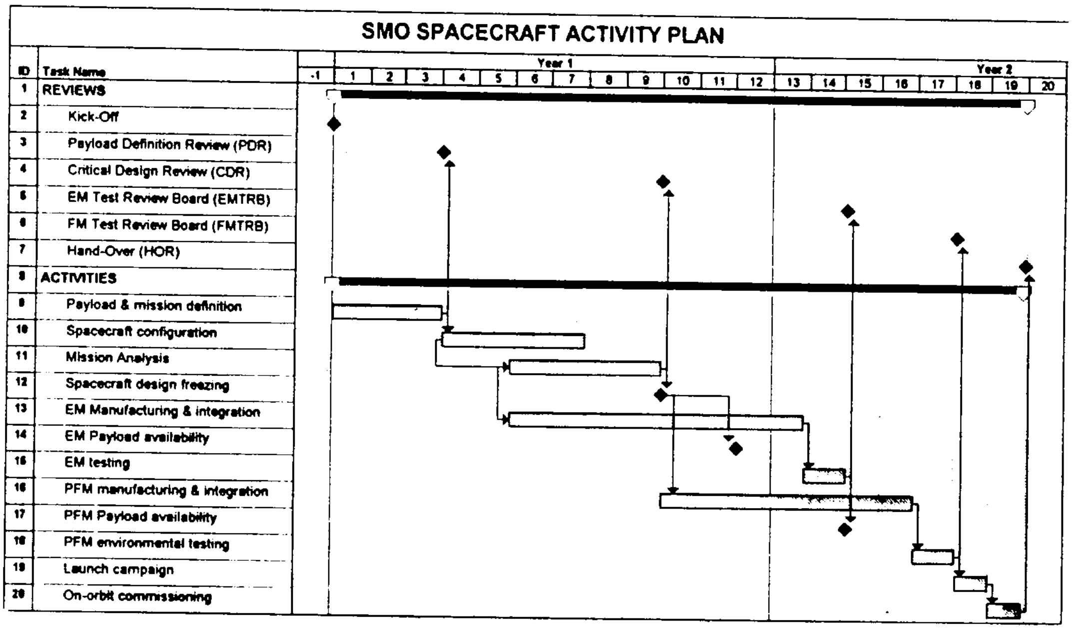


Fig. 3.2.5-1 Contract schedule

In order to have a close working relationship between the SMO Operator and Customer organizations, the following integrated teams are foreseen:

- Mission Definition Team -
- Mission Implementation Team including the Spacecraft Team

Mission Definition Team (see Fig. 3.2.5-2) is a dedicated and integrated team, with the following participants:

- Mission manager, that coordinates the work of
- Payload responsible(s)
- Spacecraft buyer
- Launch buyer
- Ground segment buyer

All these people belong to Service Operator organization, with the exception of payload responsible, who is designated by the Customer. The Team is coordinated by the Mission Manager (Service Operator organization). The payload responsible (Customer organization), in conjunction with the Mission Manager, represents the Customer interests to all of the buyers. The tasks of Mission Definition Team include:

- carry out the mission preliminary design,
- define the procurement specifications for each element (launch vehicle, bus, ground segment),

- issue requests for quotations, (only for the delta/adaptation to a specific mission, while the nominal services solutions are "batch" negotiated),
- identify the supplier for each element,
- negotiate contracts,
- issue orders for the service elements,
- mission planning, and
- cost budgets and planning functions.

The activity of the Mission Definition Team is terminated with the issue of service elements contracts and lasts about 3 months.

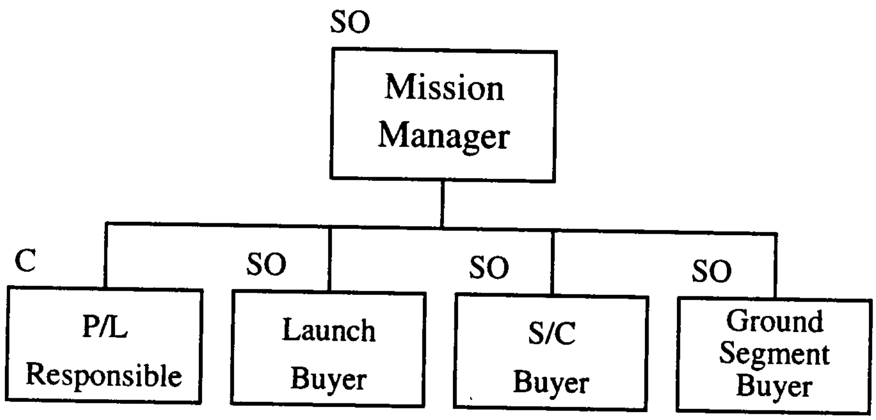


Fig. 3.2.5-2 Mission definition team

After service elements contracts definition and issue, the **Mission Implementation Team**, whose structure is shown in Fig. 3.2.5-3, begins work. The Mission Manager, supported by the SMO operator organization, coordinates the work of all Segment managers (coming from the launch vehicle, bus and ground station organizations) up to the end of contract (on-orbit commissioning, for baseline contract). This teams tasks are mainly the following:

- planning and cost control;
- request for waiver/deviations;
- new situation management; and
- interface management at Segment levels.

Also in this case the Payload responsible, designated by Customer organization, manages changes from the scientific point of view. The Team shall meet on a regular basis at SMO Operator premises and, on call, when a problem occurs. With this approach, interfaces are minimized and all problems are solved rapidly in co-location meetings.

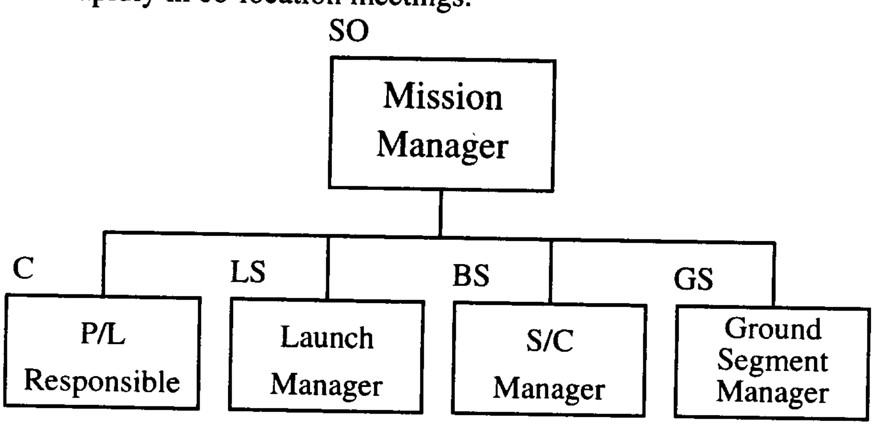
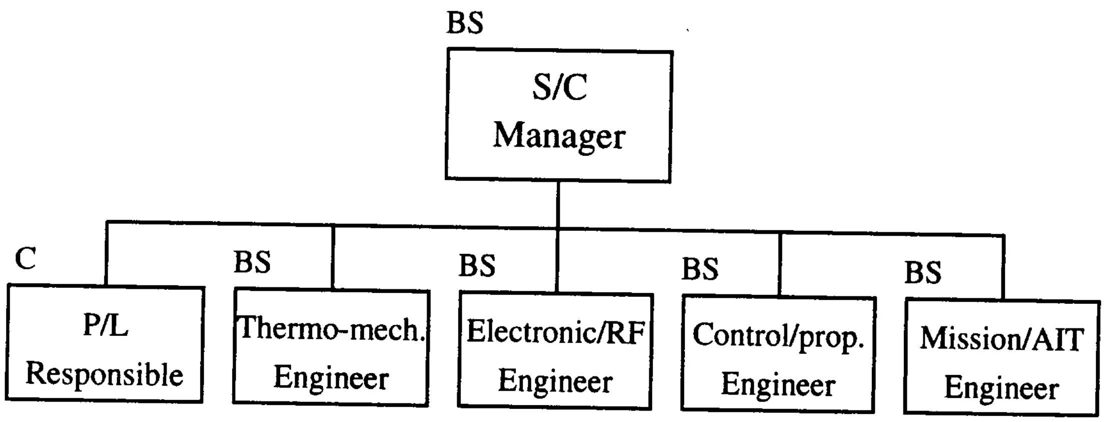


Fig. 3.2.5-3 Mission Implementation Team

In our approach (the basis of our costs derivation), the day-by-day management of the satellite activities is controlled by a spacecraft team located at the Bus service supplier premises. Other approaches are possible (e.g. Globalstar where the bus supplier and system integrator are at different locations). The spacecraft team size is strongly dependent on the spacecraft complexity but it is based on the structure defined in Fig. 3.2.5-4. All the participants belong to the bus service supplier organization with the exception of the Payload responsible who is designated by the Customer organization. The spacecraft manager is responsible for all spacecraft activities and for the communication of spacecraft problematics to the Mission Implementation team.



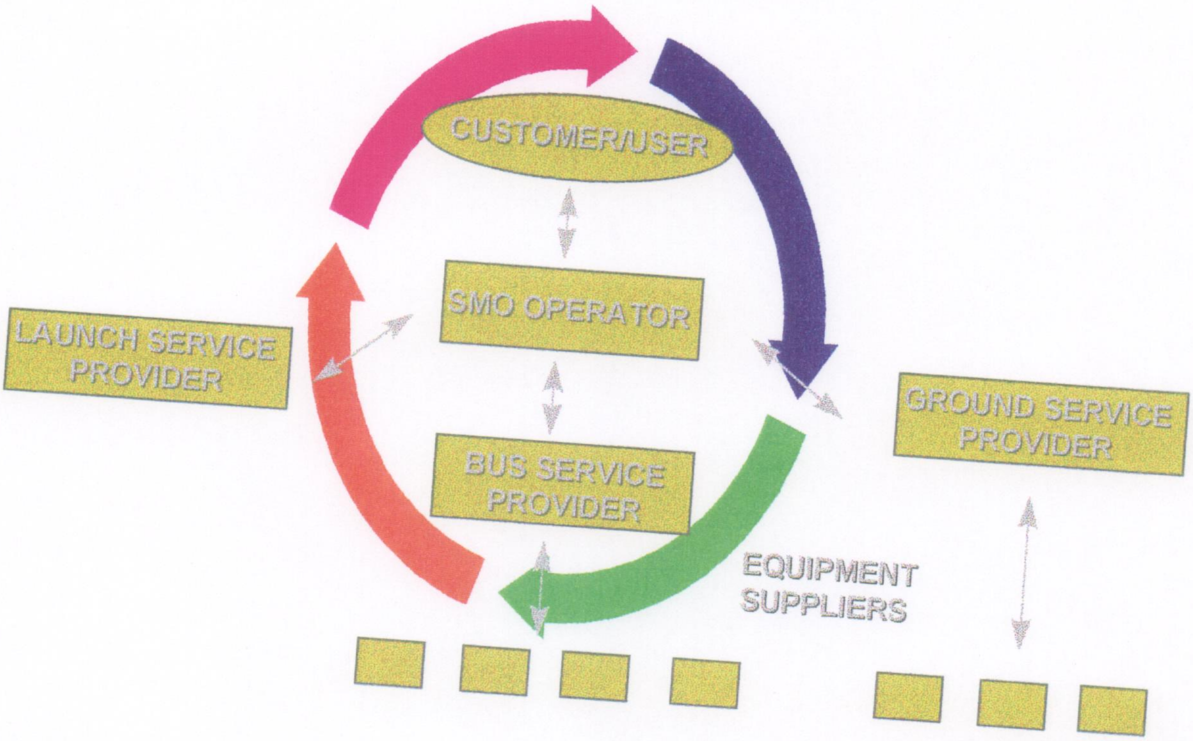
Legend:

SO	SMO Operator representative
C	Customer representative
LS	Launch Service Provider representative
BS	Bus Service Provider representative
GS	Ground Service Provider representative

Fig.3.2.5-4:Spacecraft Team

In summary, our SMO Industrial Organization is focused on the Customer/User as shown in Fig. 3.2.5-5. Missions Teams, including full customer participation, have been defined to execute the mission as per the customers requirements. This figure demonstrates how the SMO Operator interacts continually with the Customer/User and each of the primary service providers to ensure that the mission is conducted as per the clients needs.

Figure 3.2.5-5. SMO Industrial Structure and Interactions.



3.3 *Accommodation studies*

In order to verify and validate our SMO concept, the following accomodation studies have been completed:

MISSION	PARTICIPANTS	OBJECTIVES	DOC
FS1-EO	Finland	Earth observation , ice and snow mapping, forest inventory	6.2.10
FS1-SCI	Finland	Study of magnetosphere & ionosphere coupling, plasma measurements	6.2.11
Romolo e Remo	Italy	Simultaneous measurement of Ionosphere in magnetically coupled locations	6.2.12
Pamela	Italy, Russia, USA, Sweden, Germany	Measurements of spectra of antiprotons, positrons, nuclei	6.2.13
Gilda	Italy, Russia, Sweden	Observation of gamma ray sources	6.2.14
Galileo Galilei	Italy	Test on the equivalence principle and technology demonstration of field emission electric propulsion	6.2.15
BPD	Italy, USA	To investigate background primordial distortion of cosmic microwave	6.2.16
NISSE	Norway	To perform measurements of ionospheric outflow	6.2.17

Table 3.3-1 Accommodation Studies

These missions represent a spread of potential European payloads, in the fields of Earth observation and fundamental physics. The main mission characteristics have been evaluated for each of them using our SMO architecture. These parameters examined included:

- orbit altitude and inclination
- operative life
- mass budget
- power budget
- batteries and solar panel sizing
- stabilization type
- dowlink characteristics

The primary results are summarized in Table 3.3-2.

	unit	FS1-EO	FS1-SCI	Romolo & Remo	Pamela
Orbit					
altitude	Km	600	1200	500 parking orbit 825 final orbit	700
inclination	deg	98.7 sun.synchr	100 sun syncr.	60	98
Operative life	year	3	3	2	3
Mass	Kg			(x2)	
payload		79	46	79	396
core		184	105	184	190
Power budget	W				
solar array power		196 W EOL	126 W EOL	142W EOL	330 W EOL(*)
core power		97 W OAP	21 W OAP	108 W OAP	75 W OAP
P/L power		22 W OAP	71 W OAP	25 W OAP	294 W OAP
Battery sizing		16 Ahr NiCd	12 Ahr Ni Cd	16 Ahr Ni Cd	20 AhrNICd critical
Stabiliz. type		3 axis	spin	3 axis	gravity gradient
Dowlink char.	Mbps	1	0.5	2	2
S/C dimensions(**)	m				
diameter		1372	1.168	1.55	<2.1
height		1.4	0.9	1.4	1.26
Launch vehicle		Taurus	Pegasus	Vega K3	Vega K3
Complexity		medium	low	medium	low

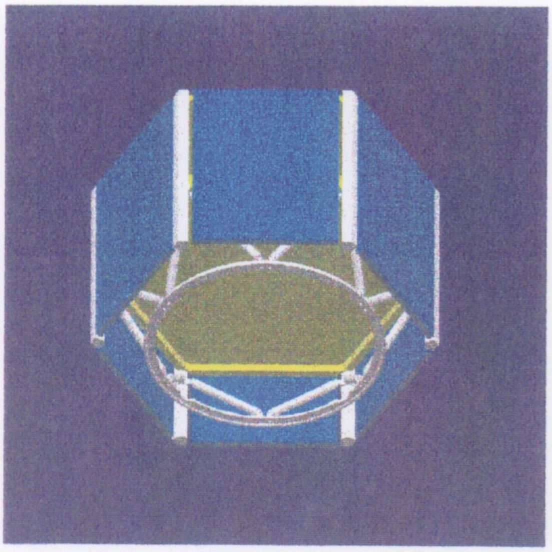
NA: Not Available
(*) Power balance not met
(**) Launch configuration

	unit	Gilda	Galileo Galilei	BPD	Nisse
Orbit	Km	700	520	700	1200
altitude					
inclination		98	0	98°	98
Operative life	year	3	1	3	0.5
Mass budget	Kg		147	264	221
P/L mass		306			
core mass		170			
Power budget	W			117(average)	
solar array power		330 W EOL	108 W EOL		110 W EOL
core power		75 W OAP	50 W OAP		22 OAP
payload power		240 W OAP	41 W OAP		72 OAP
Battery sizing		16Ahr Ni Cd	8 Ahr Ni Cd	8 Ahr Ni Cd	12 Ahr Ni Cd
Stabiliz. type		Gravity gradient	spin	3 axis	3 axis
Dowlink char.	Mbps	1	0.001	1.3	2.4
S/C dimensions	m				
diameter		1.372	1.168	1.372	1.168
height		1.6	1	1	1.1
Launch vehicle		Taurus/Vega K3	Pegasus/Vega K0	LLV1/Vega K0	Pegasus
Complexity		low	low	medium	medium

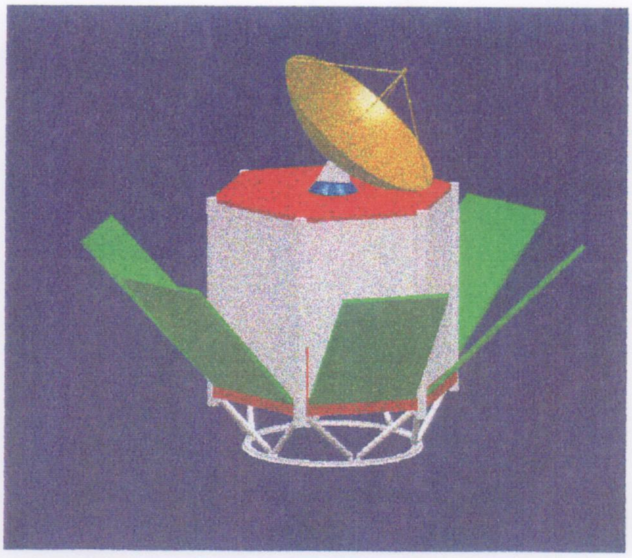
NA: Not Available

Table 3.3-2 Accommodation Studies Results

The relevant detailed results can be found in R.D.6.2-9 through R.D.6.2-16. The accommodation studies demonstrated that our proposed concept is capable of satisfying the requirements for each mission. In some cases minor issues were identified which can be easily managed at mission level.

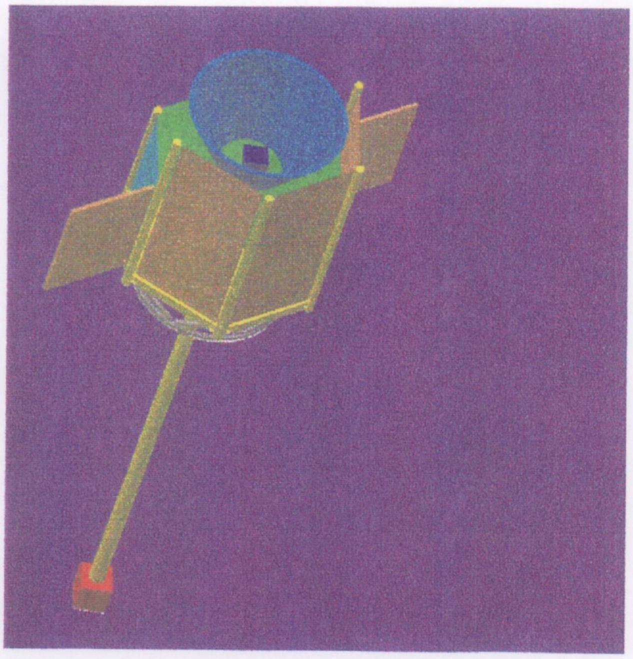


FS1-SCI



FS1-EO

PAMELA



BPD

Fig 3.3.1 Accommodation examples

4. SMO service programmatics

4.1 Implementation plan

The proposed implementation plan is driven by the results of the market survey. As mentioned previously, the market analysis showed that:

- short time to market is required and
- low mission recurring costs are vital for the mature service offering.

Therefore a "near-term"phase (first 5 missions) has been defined which enables an evaluation the "market response" to the availability of SMO so that a proper investment strategy can be developed and implemented for the medium/long-term (after the fifth mission).

An ESA "anchor-tenancy" role, as defined in the ITT (AD 6.1.1), was assumed. We also consider the management of small satellites technologies development a crucial role for ESA. This technology development effort should focus on identification of the most promising new technologies, priorities definition, and overlapping / synergies control.

The program implementation plan is shown in Fig. 4.1-1.

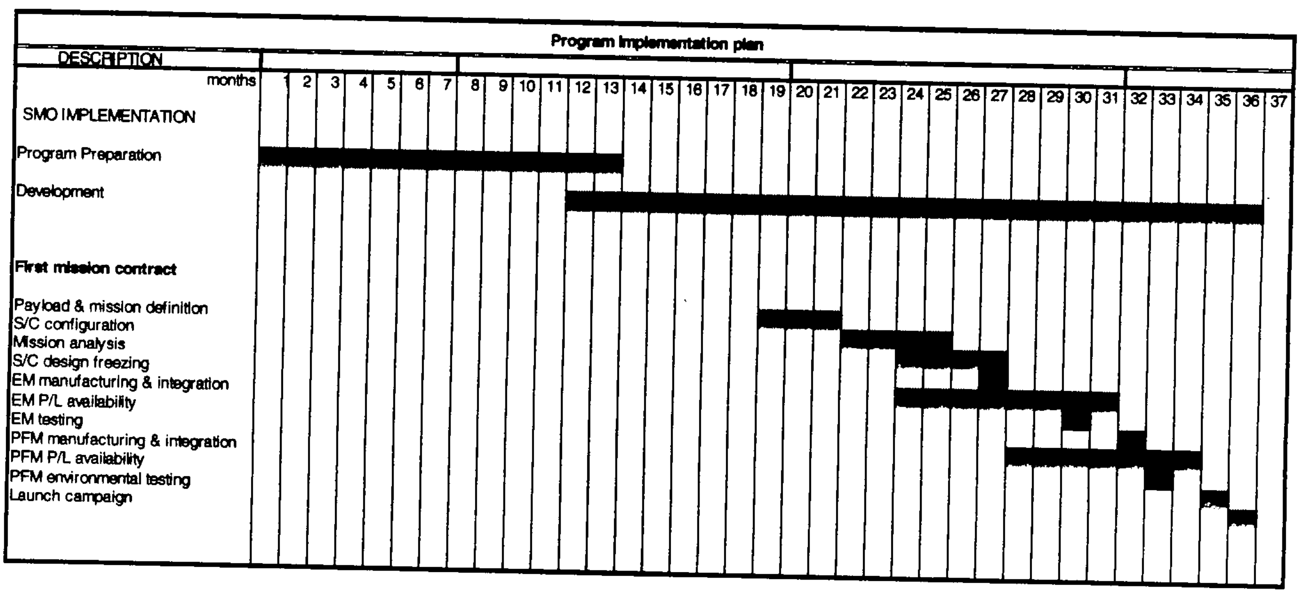


Fig.4.1-1 SMO Implementation Plan

4.2. *Costs*

Guidelines

From the market survey results we assumed that the SMOI could capture 2 missions per year on the commercial market in addition to the two ESA missions per. As noted in Section 3.1, this is a conservative estimation based on:

- 2 ESA missions per year (a total of 10 over five years) out of a total European potential of 36 missions
- 2 commercial missions per year (total 10 over 5 years) on a worldwide commercial market ranging from 130 to 1000 satellites (see para 3.1)

On the basis of a 10 SMOI mission contract, we defined as:

near term	the first 5 missions

and as

medium - long term	the last 5 missions

as per section 3.1.3.

The total cost for 10 ESA mission has been evaluated taking by assuming that, after the first 5 missions, a validated market will exist and the necessary well focused investments can be determined.

Therefore, our proposed strategy is the following:

- enter the market in very near term while minimizing non-recurring investments, in order to achieve low non-recurring costs for the first five missions,
- once the market has been sized and consolidated, implement the remaining part of the non-recurring costs in order to reduce mission recurring costs (through the optimization of logistics/facilities, GSE and operations).

Results

Cost summary for 10 ESA missions

The <u>total cost</u> of 10 ESA SMO missions over 5 years, as requested in AD 6.1.1, is estimated to be:

311 MECU

The European return and recurring /non recurring cost breakdown are shown in Fig 4.2-1

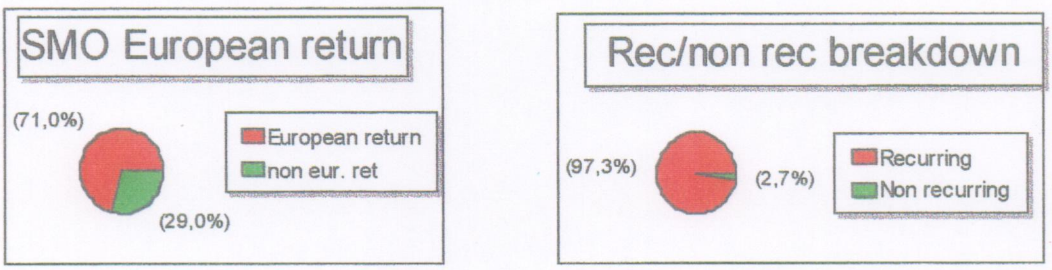


Fig. 4.2-1 SMO european return and recurring/ non-recurring breakdown

This is the result of a detailed costs analysis reported in R.D.6.2-4.

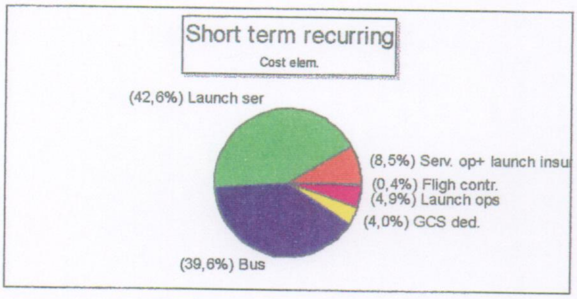
Recurring costs

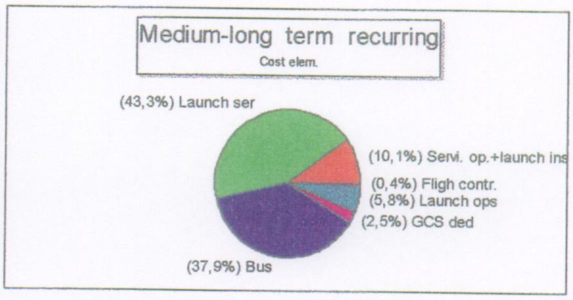
Recurring costs, that is cost of 1 average intermediate complexity mission (e.g. FS EO, Romolo & Remo, BPD, Nisse, see Table 3.3-2) have been evaluated:

for the near-term (first 5 missions) 32 MECU with a 52% European return

for the medium/long-term (last five missions) 27.7 MECU with 91% european return

The cost breakdowns are shown in Fig. 4.2-2.





Launch Service	14
Service Operator	2.8
Flight Control	0.12
Launch operations	1.6
GCS ded.	1.31
Bus	13

Launch Service	12
Service Operator	2.8
Flight Control	0.12
Launch operations	1.6
GCS ded.	0.68
Bus	10.5

Fig. 4.2-2 Recurring costs (MECU)

Non recurring costs:

Non recurring costs have been evaluated as follows (see also document 6.2.4):

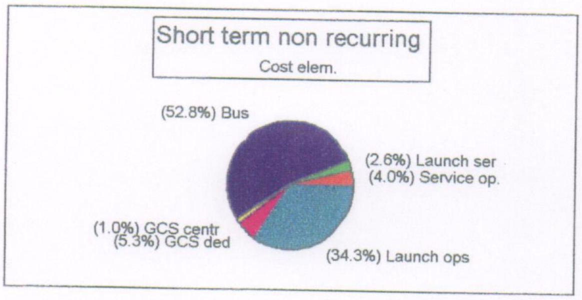
for near term 37.89 MECU with european return 89 %

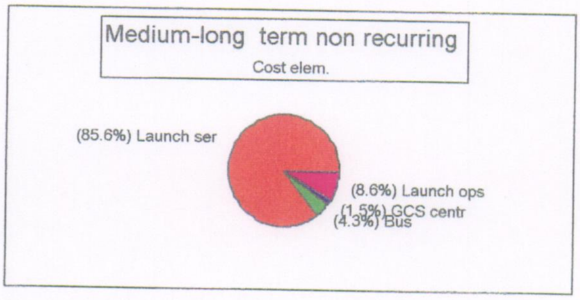
of which: *33 MECU* *to be born by industry and/or national agencies*
4.89 MECU *to be born by ESA (eur.ret.100%)*

for medium-long term:: 244 MECU with european return 98.8%

of which *240.5* *to be born by industry and/or national agencies*
3.64 *to be born by ESA (eur. ret. 90%)*

The cost breakdowns are shown in Fig.4.2-3.





Launch Service	1
Service Operator	1.5
Launch operations	13
GCS centralised	0.39
GCS ded.	2
Bus	20

Launch Service	209
Service Operator	tbd
Launch operations	21
GCS centralised	3.64
GCS ded.	0
Bus	10.5

Fig. 4.2-3 Non recurring costs (MECU)

Non recurring costs recovery:

In the near-term, the 37.89 MECU non-recurring value includes 20 MECU for bus development, qualification and GSE; 13 MECU for European launch base adaptation for near-term use of a US launcher; and 4.89 MECU (covered by ESA) for service opeartor, launch service and GCS. The part not covered by ESA (33 MECU) should be recoverable as follows:

- 13 MECU (launch base adaptation) is recoverable though use fees for non-SMO launches
- 20 MECU will not be needed if a suitable European satellite platform is available for SMOI use in 1999. In the other case, they will be paid by the bus developing company.

In the medium/long-term, when the market is more mature, the 244 MECU non recurring value includes 209 MECU for launch vehicle development and qualification (VEGA), 21 MECU for launch pad adaptation in Kourou, 10,5 MECU for a suitable bus development and 3.64 MECU (to be covered by ESA) for GCS development. The part not covered by ESA (240.36 MECU), will be covered by national and industrial investments, independently of SMOI.

It must be noted that our SMO cost structure is based on 10 missions. Since we have spread costs recovery over the full program duration of 10 missions and our batch procurement approach is based on 10 missions, a contract for ten missions is needed to assure our average per mission price.

The global, baseline SMO initiative costs are shown, distributed by year, in Fig. 4.2-4. Here it is assumed that the near-term non-recurring costs of 4.89 MECU are spent during the first year of the program (assumed to be 1997). The first ESA SMO mission is assumed to take 24 months, while the subsequent 9 are assumed to use an 18 months development schedule and are launched every 6 months following the first launch. The medium-long term non-recurring cost of 3.64 MECU are used in the fourth program year for dedicated SMO ground station development.

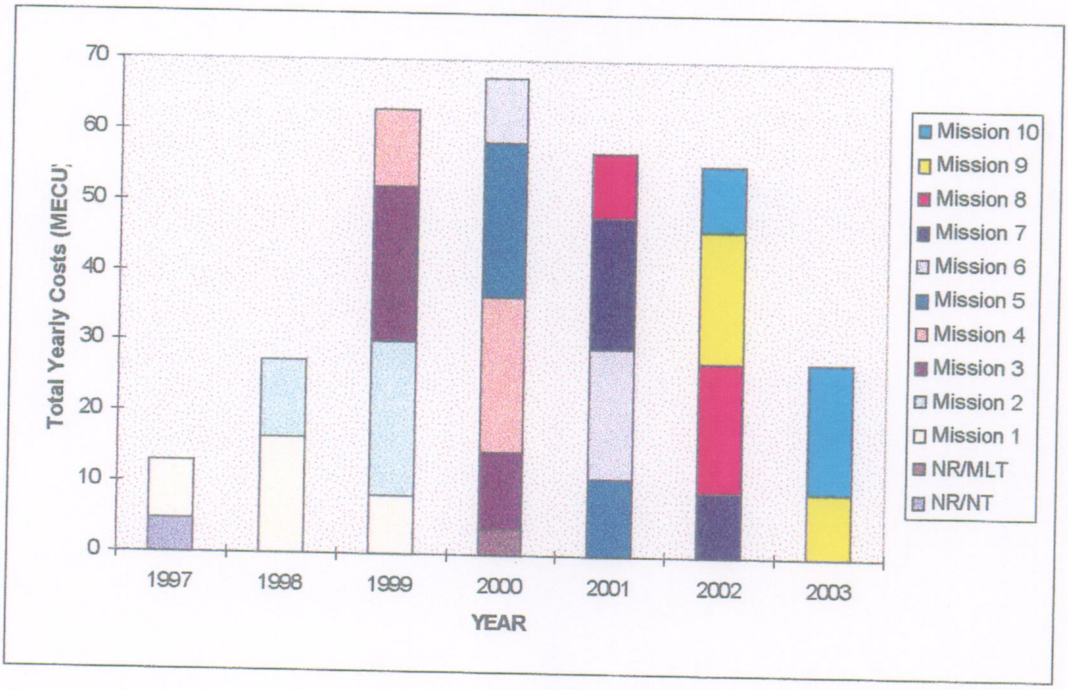


Figure 4.2.4. Timeline for SMO Operator Baseline Recurring and Non-Recurring Costs for 10 ESA SMO Missions.

Investors and financing

Organizational, institutional and/or private investments in the SMO Initiative can provide an alternative path to spread the non-recurring investments risks. Over the last several years, investors are shown a great deal of interest in investments in space utilization proposals. Small satellite based programs such as Iridium, Globalstar, Orbcommm and Seastar have successfully secured financing and direct investments

The SMO initiative offers several attractive features which should make the Initiative attractive to investors. The focused purpose of SMO is to provide the various payload providers simple and direct access to space on a timely schedule. The implementation of SMO is based on the use of existing equipment (proven technology) as much as possible to get the service on line and keep it competitive. The use of existing equipment (based on fixed price contracts) means that the first revenue producing missions can be flown relatively quickly following the start of the program. In addition, ESA's proposed anchor tenancy role for 10 missions will provide an assured source of revenue . .

5. *CONCLUSIONS*

A market for small missions exists for European suppliers ; it consists of at least 2-4 missions per year capturable by SMO operator. This market appears to be growing with time along with the number of non european service competitors; time to market is considered a major driver

A baseline technical solution has been identified for the SMO service and is characterized by a 91,7% European return in the medium/long-term. Its technical feasibility has been verified though mission accomodation studies on realistic European missions.

Recurring and non-recurring costs of the baseline technical solution have been identified and validated through potential suppliers feedback.. The total estimated cost for 10 missions is 311 MECU.

It has been assumed that a European Small Launcher will be developed in parallel to the SMO implementation contract in order to achieve independant European access to space and to boost European return on the Small Missions Program.

The proposed ESA implementation phase based on 10 missions over 5 years enables industry to absorb the major part of the program non-recurring costs.

6. DOCUMENTS

6.1 Applicable Documents

6.1.1 ESA ITT; AO/1.3004/95/F/TB:
Study on an initiative for small mission opportunities (SMO)
Item N.95.197.01 in ESA IPC(95)7.

6.1.2 BPD proposal : PRE GEN 00015 iss.1 Rev.0
Proposal for a study on an initiative for the Small Mission Opportunity

6.2 Study output Documents

6.2.1 SMO BPD TNO 001 "SMOI Study - Concept Report"

6.2.2 SMO BPD TNO 002 "Market potential for SMO"

6.2.3 Small Mission Opportunities and the scientific community:
Proceeding of the Workshop (Colleferro - Italy 12-13 October 96)

6.2.4 SMO BPD TNO 024. "Cost report for SMO implementation "

6.2.5 SMO BPD TNO 016 "SMOI dedicated ground station and customer terminalprocurement bid package"

6.2.6 SMO BPD TNO 005- "SMO Launch Service Bid Package Request For Quotes," .

6.2.7 SMO BPD TNO 008 "SMOI ground station service bid package"

6.2.8 SMO BPD TNO 015 "SMOI centralized ground station service bid package"

6.2.9 SMO BPD TNO 009, "SMO Program - Bus and Bus Service Bid Package"

6.2.10 SMO BPD TNO 011, "SMO Program -FS1-EO Mission - Mission Report"

6.2.11 SMO BPD TNO 014 "SMO Program - FS1-SCI Mission - Mission Report"

6.2.12 SMO BPD TNO 013 "SMO Program - Romolo & Remo Mission - Mission Report"

6.2.13 SMO BPD TNO 010 "SMO Program - PAMELA Mission - Mission Report"

6.2.14 SMO BPD TNO 012 "SMO Program - GILDA Mission - Mission Report"

6.2.15 SMO BPD TNO 020 "SMO Program - GG-FEEP² Mission - Mission Report" .

6.2.16 SMO BPD TNO 023 "SMO Program - BPD Mission - Mission Report" .

6.2.17 SMO BPD TNO 019 "SMO Program - NISSE Mission - Mission Report"

6.2.18 Handout of the Mid-Term Presentation - ESTEC -March 96

6.2.19 Handout of the Final Presentation - ESTEC - 24 Sep. 96

FiatAvio

LIST OF ACRONYMS

AIT	Assembly Integration and Test
ASI	Italian Space Agency
ATM	Additional Tankage Module
CDR	Critical Design Review
C&DH	Command & Data Handling
CSG	Centre Spatial Guyanais
DDS	Data Dissemination System
DL	Dedicated Launch
EGSE:	Electrical Ground Support Equipment
EIP	Experiment I/F processor
EIRP	Effective Isoentropic Radiated Power
EM	Electrical Model
EMC	Electro Magnetic Compatibility
EOL	End Of Life
GCS	Ground Control Station
GSE	Ground Support Equipment
He/S	Helio Synchronous
HW	Hardware
KOM	Kick Off Meeting
I/F	Interface
ITT	Invitation to Tender
LEO	Low Earth Orbit
LR	Launch Range
LS	Launch Service
LV	Launch Vehicle
Mbps	Mega bit per second
MCC	Mission Control Center
MMS	Matra Marconi Space
OAP	Orbit Average Power
P/L	Payload
PBL	Piggy Back Launch
PCC	Payload Control Center
PDR	Preliminary Design Review
PFM	Proto Flight Model
PIM	Propulsion and Interface Unit
PM	Payload Module
RAAN	Right Ascension of Ascending Node
RF	Radio Frequency
S/C	Spacecraft
SCOE	Special Check out Equipment
SM	Service Module
SMO:	Small Mission Opportunity
SMOI	Small Mission Opportunity Initiative
SO	Service Operator
S/S	Subsystem
STB	Standard Bus
SW	Software
TT&C	Telemetry Tracking and Command