111135 N95-17550

39-14

31955

p-11

DESIGN OF GROUND SEGMENTS FOR SMALL SATELLITES

Guy Macé

MATRA MARCONI SPACE

31, Rue des Cosmonautes, Z.I. du Palays

31077 Toulouse Cedex - France

ABSTRACT

New concepts must be implemented when designing a Ground Segment (GS) for small satellites to conform to their specific mission characteristics : low cost, one main instrument, spacecraft autonomy, optimised mission return, etc... This paper presents the key cost drivers of such ground segments, the main design features and the comparison of various design options that can meet the user requirements.

Key words : Small satellites, Ground Segment, Mission Control, Data Acquisition.

1- Introduction

The Ground Segment for control of the spacecraft and for exploitation of their data represent a growing part in the space mission budgets. Therefore it has been considered important by Industry and by such Agencies as ESOC (1) and CNES (2) to review the state of the art for the Ground Segments that support the Small Missions, to understand the possible degree of optimisations and the cost implications.

Small satellite missions usually consist of one or two instruments aboard a small spacecraft thanks to technology progress. The development time frame and the programme costs are major drivers that will have to be fully considered for the definition of Ground Segment development and operations. The main driver to optimise the design while considering the cost constraints is thus to consider the space system (Figure 1) as a whole and to ***think integrated system***.

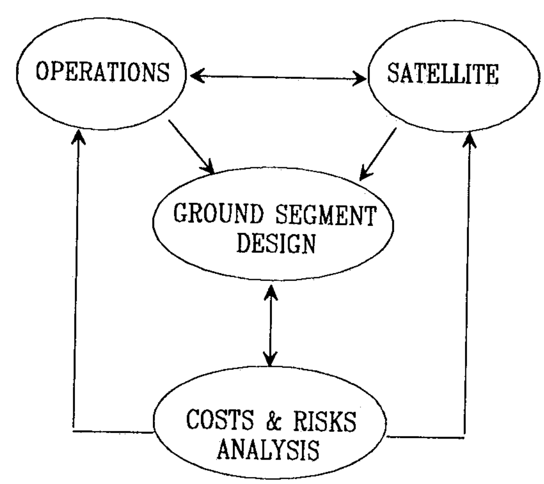

Figure 1 : Concurrent Engineering for Ground Segment design

The paper presents the cost drivers to be examined when designing a Ground Segment, the typical overall Ground Segment design characteristics and the main latitudes for optimisation. Finally the emphasis is placed on the definition of major Ground Segment elements, the Mission Control System and the Ground Stations to highlight where an optimum design can stand.

2- Mission related cost drivers

Since the cost constraints must be considered from the beginning, it is necessary to analyse where lay the cost drivers for ground segments. The cost drivers may vary from one mission to the other, may depend a lot on the category of service proposed by the mission : data for scientists, commercial service for telecommunications. However some general trends have been highlighted from examination of a number of conventional missions and of small missions.

For a typical observation small mission (Table 1), the GS design must consider with specific attention all requirements that may impact the number and definition of the Ground Stations and the Flight Dynamics functions on-ground. In this example, the Ground Station and Flight Dynamics elements have a sizing costs within the Ground Segment costs.

The accuracy of orbit restitution needed for payload data processing is a characteristic of this mission that directly impacts the flight dynamics processing on-ground. The ground station is a unique S-band station that supports both the Payload and the TM/TC housekeeping data. The other elements have a lower importance since either based on reuse of existing components or based on a limited development for a simple mission : for example, the mission planning function is limited due to only one payload instrument with no direct interaction with the users who require a systematic observation.

SMALL SATELLITE MISSION	Ground	Comms	**Mission**		**Control**	
GS DEVELOPMENT COST (Most sizing cost driver graded 5)	Stations	Infrastruct.	Flight Dynamics	Mission Planning	TTC processing	Other functions
USERS REQUIREMENTS						
Mission purpose	4		3		1	
Permitted mission outage	1	1				
Availability of payload data	1	1	1			
MISSION REQUIREMENTS						
Mission Lifetime			1			
Satellite Pointing requirement	2		3		1	
RF Payload constraints	1					
SATELLITE DESIGN						
Orbit control	1		2			
Attitude control	2		3			2
TM/TC interfaces	1					
RF design	3					
Data rates/response times	4	1			1	1
Number/complex Ops modes			1		1	

Table 1 : Typical Cost Drivers for a small satellite mission (Observation)

The methodology followed was to identify what are the requirements that can impact the Ground Segment Design. In relation with the Users, the following requirements are identified as having a significant impact : the Mission Purpose that defines mainly coverage (image size, trajectory), resolution and duration of observation, the permitted mission outage expressed in possible interruptions of on-board service or observations, the availability of payload data criterion corresponding to the delay between the observation on-board and the time of reception of data at user site. The Mission Analysis then considers these requirements and the characteristics of a space system to derive such characteristics as the mission lifetime, the satellite pointing requirements or the RF payload constraints (e.g. number of ground stations, RF band selection). From the Mission Analysis a Spacecraft design will also impact the Ground Segment design with such requirements related to orbit control, attitude control, TM/TC interfaces definition, data rates and response times, RF links characteristics and link budget, number and complexity of operations modes that will have to be handled from the ground.

For comparison an observation conventional mission is considered : the GS costs are equally shared between the Ground Stations and Comms development, the Mission Planning and the Satellite Control Centre. For such a conventional mission, the main cost drivers were impacting most elements in a more distributed fashion as shown per Table 2.

The above elements must be given full consideration, when performing the necessary iterations between the Ground Segment design, the costs, the operations and satellite definition.

The main Ground Segment design characteristics for a small mission are now highlighted.

Conventional SATELLITE MISSION GS DEVELOPMENT COST (Most sizing cost driver graded 5)	Ground Stations	Comms Infrastruct.	**Mission Control**			
			Flight Dynamics	Mission Planning	TTC processing	Other functions
USERS REQUIREMENTS						
Mission purpose	3	2	2	3	1	
Permitted mission outage	2	1				
Availability of payload data	1	1				
MISSION REQUIREMENTS						
Mission Lifetime	1	1	1	1	1	1
Satellite Pointing requirement	2		3		1	
RF Payload constraints	2					
SATELLITE DESIGN						
Orbit control	1		2			
Attitude control	2		3		1	1
TM/TC interfaces	1				2	
RF design	3					
Data rates/response times	3	3			1	1
Number/complex Ops modes			1		1	

Table 2 : Typical Cost Drivers for a conventional satellite mission (Observation)

3- Ground Segment design

The Ground Segment design for a small mission must be such as to support the overall mission, but with much emphasis placed on costs aspects both for development and for the typical 3 years mission duration (2 to 5 years depending on the mission).

A first major trend of the design will be to maximise the use of existing components in the ground infrastructure : this trend limits the development costs and the maintenance effort since the hardware is based on off-the-shelf items and the software is flight proven in other programmes. This is why an important design effort will be dedicated to the overall architecture definition to identify the building blocks, to define their interfaces and the missing elements, and last but not least to react on requirements whenever it is felt to simplify the design while meeting the overall mission objectives.

To design a Ground Segment with building blocks will be more easily achieved if the system is built as a distributed system. And since cost efficiency for operations is an other major criteria, the collocation of the Ground Segment facilities must be enforced. Therefore a typical Ground Segment design for a small mission will be based with its components collocated around a Local Area Network (Figure 2) : Ground Station, Satellite Control System, Flight Dynamics, Mission Planning, Payload Preprocessing with the capabilities to communicate payload data to users either by mail or by communication links.

For small missions, the availability requirements can be less stringent than in conventional missions. No hot redundancy will be implemented as a rule : as experienced in conventional missions, it is costly since it requires more hardware, automatisms, specific procedures adding to the complexity of operations, documentation, training and maintenance.

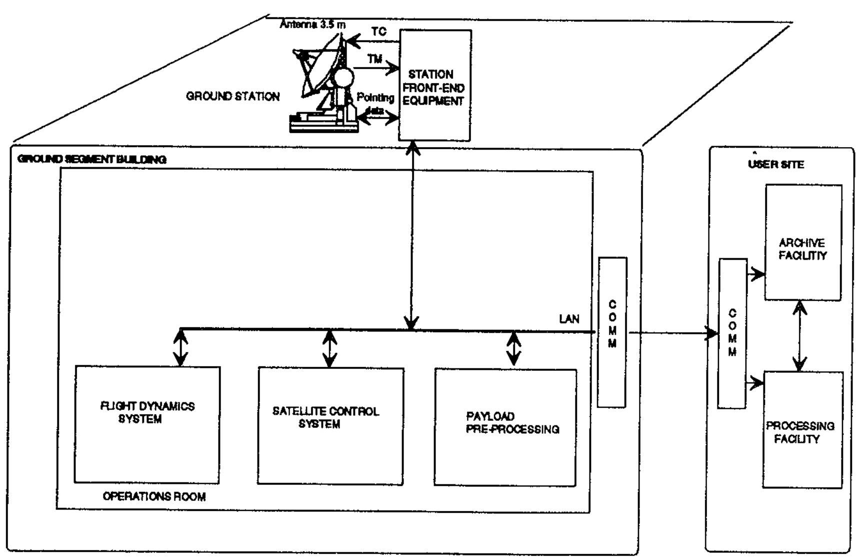

Figure 2 : Typical design for a Small Satellite Ground Segment

The other main features of the GS design for small missions are : collocation of facilities, reduced staffing, use of proven off-the-shelf hardware and software, automation of routine operations, compliance to standards (e.g. CCSDS and ESA COES) to enforce further commonalties for reuse. Table 3 hereafter compares the main features for a Low Cost ground segment option, for a Lower risk ground segment option and for the design attached to a conventional mission. The Lower Risk option will mainly differ from the Low Cost option in the operations concept that will provide a higher security level for operations and a higher mission availability.

How the Lower Risk option can best meet the overall mission requirements and what are the possible risks attached to a Low Cost option are given a preliminary answer in the following section.

	OPTION Low Cost	OPTION Lower Risk	CONVENTIONAL MISSION
MISSION AVAILABILITY	80-90% : normal working hours (+ on-call for w.e.)	> 90% : 7 days/week + on-call at night	> 99.9% : 7 days/week + 24 Hours/day
STAFFING	2 or 3 for all tasks	3 for ops + part support	6 shift x 2 for ops + important part support
FACILITIES DISTRIBUTION	Collocated	1 or 2 sites	Several sites
STATION Design	Standard products, small antennae	Idem + reuse of a station network	New development
MCS Design	Reuse existing packages Minimum adaptations	Reuse existing packages More tailored to ops	New development Many ops requirements

Table 3 : Main features for the overall GS Design

4- Ground segment optimisation

The allocation of costs for a Ground Segment must be carefully considered to select design options that will maximise a mission return criteria, i.e.. the amount & quality of data versus the investment.

Typical costs allocations are shown for a Telecomms conventional mission (Figure 3) and for a Small Mission (Figure 4). The total GS cost includes the following costs : Ground Stations & Comms, Mission Control System, Prelaunch operations (Flight procedures preparation, MCS database definition and validation, ground and flight operations validation and rehearsals) and a normalised period of 3 years operations.

In the conventional mission example, the Ground Stations costs were important due to the number of antennae considered and to a 11 meter antenna supporting accurate angular measurements. The ground station cost for the small mission was limited since VHF/UHF data links were considered both for payload messages (less than 20 Kbps) and for housekeeping TM/TC with no ranging requirements imposed on ground other than processing the on-board GPS transmitted data.

With these characteristics a significant cost of the small mission Ground Segment corresponds to the operations costs. Therefore it is important to analyse how these costs can be reduced and how this reduction can impact the GS availability and the risks for operations.

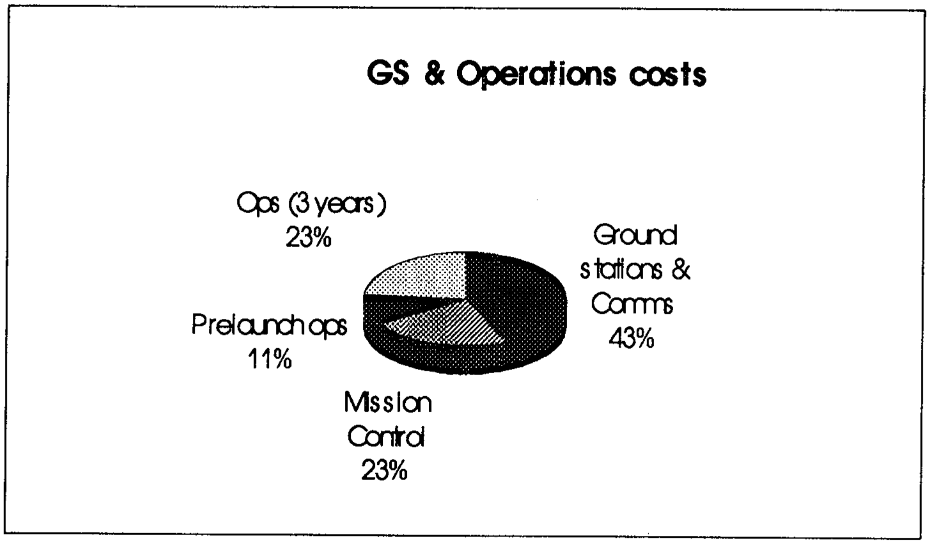

Figure 3 : Cost break-down for a Telecomms Conventional mission

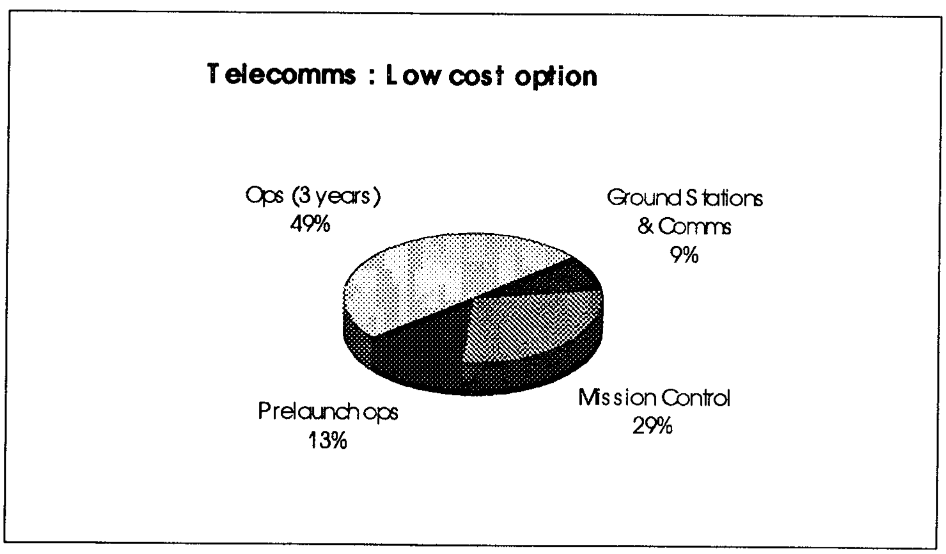

Figure 4 : Cost break-down for a Telecomms Small mission

Figure 5 below presents a typical example of a GS availability as a function of the GS total cost for typical GS options with different design, maintenance and staffing orientations. The availability was computed using equipment failure rates and mean time to repair as checked during several years of operations and the time for intervention considered for exploitation. The main difference between options availability characteristics proceeds from this time for intervention, i.e. time spent between the occurrence of a failure and the staff performing failure detection, investigation and replacement of the faulty equipment. With today's GS equipment high reliability figures, it is the exploitation characteristics that mainly drive the GS availability.

In the Low Cost option, staff is only available during working hours. In the other option (Low cost/24 Hours, ESOC reuse, Low risk) only the design is different when the staff is available day and night, including week-ends to react to any ground failure detected with spare equipment available for ground equipment.

The Low Cost option is interesting since it presents a substantial cost advantage of about 3 MAU with respect to the other options and a higher mission return per cost unit (defined as the amount of data a user can expect over the mission duration, and therefore proportional to the GS availability figure). From the user perspective the mission return is 2% lower but the sensibility of theses availability figures and their statistical meaning show that this will have little effect on the user satisfaction wrt the amount of data acquired over the 3 years. Therefore the 24 Hour Manning Low cost option does not bring a significant advantage to be considered.

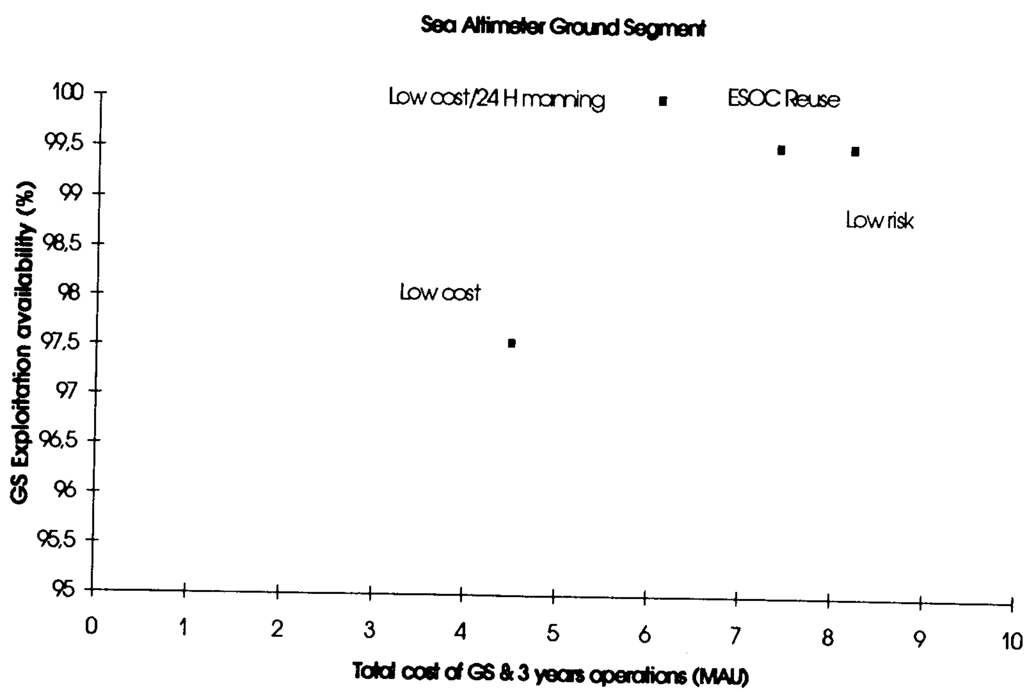

Figure 5 : Staffing & Maintenance impact on GS availability and cost

An alternative could be to change some characteristics so that the mission return be much lower at a significant saving. From the cost drivers analysis this orientation would bring a minor cost saving with a substantial degradation of mission return and a higher risk: for example operators only working upon automatic anomaly detection could be felt more risky without a significant advantage.

This is why it is of the utmost importance to appreciate the risks induced by the Low cost approach in comparison with the more conventional approaches. The following elements contribute to the risk specific to the Low Cost option and not supported by the other options :

- The whole expertise (spacecraft and ground) is supported by a 3 engineers staff coming from the spacecraft development team. In the other options an operations support infrastructure is identified that support spacecraft contingency analysis or such expertise domains as flight dynamics, or ground equipment maintenance. The difficulty consists in the level of skills required from this 3 engineers team and whether they can efficiently support contingency cases. The typical spacecraft autonomy of 1 week, the on-board securities and the expertise gained by the staff during spacecraft development should compensate most of the risk.

- The simulator is not foreseen in the low cost option and limited testing will be performed with the spacecraft (or its engineering model) on ground. A number of operations will not have been tested prior to launch : this could be accepted if the spacecraft is safe, robust to ground errors and that a number of spacecraft specialists are available at the beginning of life so that operations imperfections be detected quickly and correct procedures be validated. The beginning of spacecraft lifetime would lead to less data availability, what could be accepted since a first period is often considered for calibration and with full support of the spacecraft engineering team. However it is strongly recommended to keep the simulator even in a low cost option, since the foreseen benefit for operations security is important with regards to the cost of such a recurring product which represents less than 3% of the total mission cost.

Each of the GS components are further examined with emphasis on the major design options.

5- Mission Control System

The Mission Control System (MCS) is composed of the following functions : TM/TC function with real time control and satellite performance analysis, flight dynamics and mission planning. The main outcome for small missions will be the reuse of existing software packages. Most packages are running now on Unix workstations and the integration can be limited when only exchanging few data files.

An important trend to reach additional cost saving for small missions, will be to consider all Ground Systems needed in a programme : with reuse of existing EGSE and MCS building blocks, it is now envisaged to build a "Universal Test Bench" that can be used in all stages of the satellite development and operations.

Figures hereafter (Figures 6 to 8) examine the relative development costs for observation missions : a Conventional mission, a Sea Altimeter small satellite mission and a Cartographic small satellite mission.

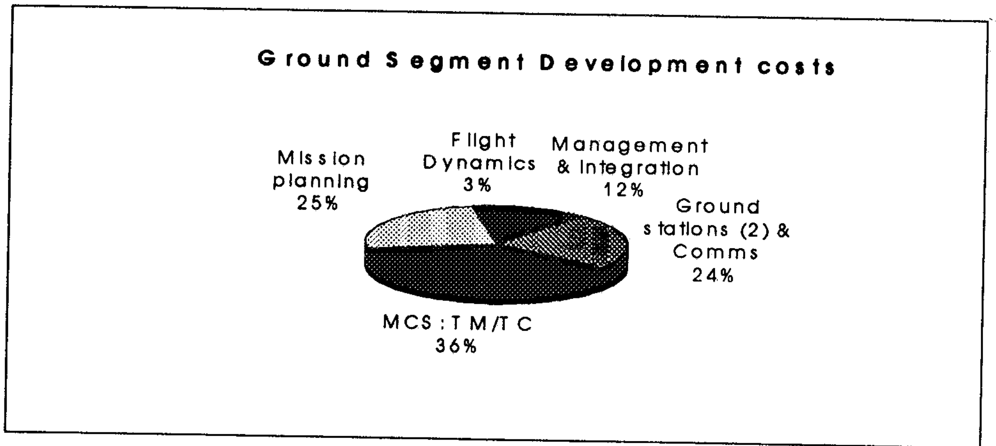

Figure 6 : MCS costs for a conventional mission (Observation)

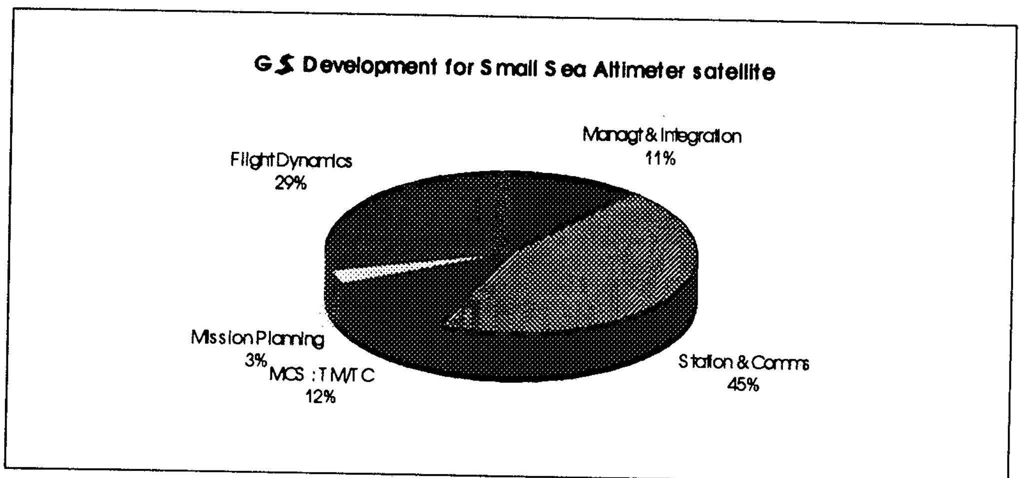

Figure 7 : MCS costs for a Sea Altimeter small mission

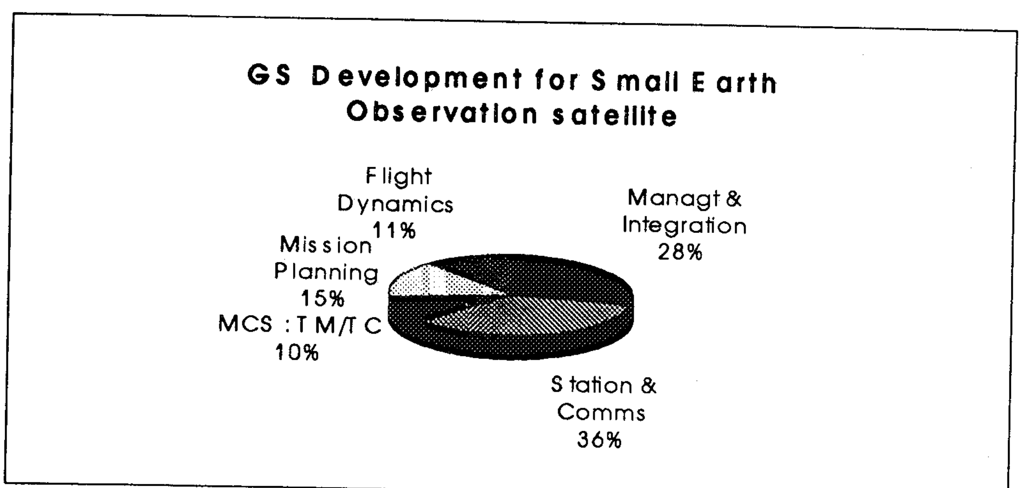

Figure 8 : MCS costs for a cartographic small mission

The above examples show that with this strategy of reuse with minimum adaptations, the amount of the Mission Control System in the overall development costs is lower than for conventional missions. Depending on the ground station characteristics, the MCS can weight 36% to 44% of the Ground Segment development cost.

6- Ground stations and Communications

The Ground Stations and the ground Communications part of a Ground Segment is usually a sizing ratio of the total development cost. Therefore special attention must be granted to the characteristics that contribute to the costs (Table 4).

The Antenna itself in the ground station can be the sizing cost element when high performances are required from the specified bandwidth and data rates. This is why a ground and board optimisation must take place to review the data rates with respect to user requirements, to review then the budget link requirements, to retain only one system of communications both for payload and housekeeping operations. The choice of the frequency bandwidth (X band, S band or lower band such as UHF) and the mission orbit characteristics will then make the price of the antenna. A common characteristic of many small missions is that only one antenna system is used for communications of both payload and housekeeping data of the satellite platform.

The RF equipment and Baseband equipment are then to be considered in the cost but they are usually off-the-shelf equipment with high reliability figures : the Monitoring & Control equipment can limit itself to the set-up of equipment configuration and to support investigation and no longer as a procedure driven system to act on the redundancies and switches. In addition, for a low cost solution, a new range of VSAT equipment is available at a lower cost with possibly lower reliability performances that can be adequate for small missions. As for other elements of the Ground Segment, a major contributor to costs, as experienced in passed conventional programmes, is the development of specific equipment or of new technology when off-the-shelf equipment exists.

COST DRIVERS	SMALL MISSION	CONVENTIONAL
OFF-THE-SHELF EQUIPMENT	Systematic	cost of technology changes
ANTENNA & RF	Only 1 station for payload and data	Network of stations Sizing costs
RANGING	Use of GPS	Can be costly on ground
LEOP	Interface with existing network Transportable TTC station S/C autonomy wrt LEOP	Specific requirements
COMMUNICATIONS	Collocation on LAN as baseline Files transfer at low data rates	Usually low relative costs

Table 4 : Cost drivers for Ground Stations and Communications

An other important cost item can be related to the requirements imposed on ground to perform the ranging. In conventional missions these requirements imposed range equipment in the station, or large antenna with complex mechanics for accurate angular measurements. For small missions these requirements are alleviated either by lower performance requirements on orbit determination or by the availability on-board of GPS or other equipment that provide orbit measurements.

Finally communications can be achieved more simply than in conventional missions with relaxed requirements for data timeliness that defines the time spent to provide the user with data. Depending on missions, simple mail procedures can be accepted or an electronic file transmission system using standard networks (e.g. INTERNET or other national or international networks) can be used. To decrease the communications costs, one solution if feasible may consist of having users collocated at Ground Segment site and receiving their data on the LAN. The communications analysis can impact the place where the data demultiplexing can be performed : either at Station or at Control Ground System level.

7- Conclusion

Small missions constraints enforce a new approach for development of both the satellite and its associated ground systems. With due consideration to existing technology and products, the project team must review in an iterative way the requirements, design and costs implications on both the satellite and the ground systems for satellite testing and for operations. This new approach can be summarised as the Integrated System Approach relying on a new ground system means, the "Universal Test Bench" which building blocks will be used according to satellite development and operations stages.

ACKNOWLEDGEMENTS

Mr. Van der Ha (ESOC), Mr. Oberto (MMS)

REFERENCES

(1) Small Satellite for Ground Segment and Operations : ESOC study conducted in 1993-1994 under Mr. J. Van der Ha 's responsibility
(2) Ellips study : CNES study conducted in 1994