

An Assessment of the European Space Software Industry

Executive Summary
November 2002

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Study prepared for the European Space Agency
Contract N° 15406

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1- Introduction

In this document we report on a one year effort to provide a high level picture of the space software supplier industry in the fifteen member states of ESA. The primary goals were to provide:

- ◆ an inventory of current market positions of the active space software suppliers
- ◆ an easy-to-use analysis for each company
- ◆ a comparative market performance analysis of european versus non-european suppliers, of independent suppliers versus subsidiaries of large consortia, of suppliers to the space sector versus suppliers to other sectors
- ◆ an analysis of the interface between independent space software suppliers and satellite integrators
- ◆ an analysis of the predicted evolution of the space software sector over the coming decade

Sixty-nine (69) companies have participated to this work and it is estimated that more than 95% of the european space software activity in terms of turnover has thus been surveyed. A list of the participants is given in Table 1-1 with the following code to denote company type.

RC	Research Center	LG	Large non-space Group
P	Large satellite integrator	IS	Independent small/medium firm
SA	Space company affiliate	IM	Independent medium/large firm
PA	Affiliate of large satellite integrator	LGS	Subsidiary of large non-space Group

Table 1-1 : 69 participating companies

Austria	ARCs (RC)	Connex (IS)	Siemens Öst. (LG)	
Belgium	Alcatel ETCA (PA) Trasys Space (IS)	Rhea (IS) Verhaert (IS)	SAS (IS)	Spacebel (IS)
Canada	EMS (IM)	Denmark	Terma (IM)	Finland
				SSF (IS)
France	Alcatel Space (P) Erems (IS)	CGEY-F (LG)	CS-SI (IM)	Thalès IS (LG)
Germany	Hoerner&Sulger (IS) Jena Optronik (PA) Vega GmbH (SA)	Anite Systems (LGS) T-Systems ITS (LG) OHB Systems (IM)	CAM (SA) Kayser Threde (IS)	Eta Max (IS) VCS (IS)
Ireland	ESIL (IS)	Sybernet (IS)		
Italy	CGEY-I (LG) Intecs HRT (IS) Carlo Gavazzi (SA)	Datamat (IM) SSI (PA) Technospazio (PA)	Dataspazio (SA) Vitrociset (IM)	Laben (PA) Alenia (P)
Netherlands	Atos Origin (LG) Satellite Services (IS)	Chess (IM)	Dutch Space (IM)	NLR (RC)
Norway	CGEY-N (LG)	DNV (IM)	Kongsberg Seatex (LGA)	Kongsberg Spacetec (LGA)
Portugal	Tekever (IS)			
Spain	GMV (IM) TCP Sistema (IS)	GTD (IM) Crisa (PA)	Iberespacio (PA)	Indra (PA)
Sweden	Swedish Space Corp (RC)	Switzerland	Elca (IS)	
UK	Analyticon (IS) QinetiQ (LG) SSTL (IS)	Avanti (IS) Serco (LG) RAL (RC)	Logica (LG) SEA (IS)	SS(S)L (IM) Vega (IM)
Europe	Astrium (P)	EADS-LV (P)		

2- Scope

Software appears both in a functional role (providing functionalities to space systems) and in a supporting role (providing design and development aides). Following ESA/ECSS standards, nine market segments have been considered, viz :

- **Control centre kernels:** controlling and monitoring the flight and the ground segments, maintaining an operations database (state of the spacecraft/ground stations, archiving of the data received according to their type, etc.), distributing the mission-related data and information, implementing checking/rescue policies, defining/handling and executing spacecraft procedures and automated modes.
- **Flight dynamics software tools :** deriving (from telemetry and ranging) where the spacecraft is, in which attitude, planning the manoeuvres, etc.
- **Mission planning/analysis applications:** planning what can be done according to available resources (ground, flight) and mission goals, and how to achieve those goals ; validating several mission concepts during the design and development phases.
- **Mission exploitation centers:** formatting the mission needs, planning the mission operations, receiving mission data and applying level 1 and 2 processing (formatting of data, cleaning noise, extracting physically meaningful information, preparing packaged data products, etc.), archiving and distribution of the data products.
- **Simulators and EGSE/SCOE:** products used to test, verify and validate the space system software and electrical subsystems during the development and the AIT operation ; products used to train the operators so that they get accurate knowledge of the spacecraft and design accurate handling procedures ; products used during the exploitation of the spacecraft to verify the soundness of the operations, to diagnose failures and check the recovery procedures.
- **On-board applications:** AOCS, OBDH, telemetry and command front-ends, payload software, embedded control software, real-time/multitask embedded kernels, etc.
- **Ground stations and communication subnet:** software products allowing (remote) control of the ground station operation (antenna pointing, data acquisition, local data archiving, data distribution, etc.) and the implementation of communication protocols with satellites (encoding of TC, decoding of TM, data routing, ... etc), as well as low level telemetry processing (level 0 looking essentially at syntax)
- **CAE/CASE tools :** all the tools used to support the technical engineering of the space systems, like software specification tools, target emulators(ICE)/simulators, hardware-in-the-loop tools, configuration management tools, specific compilers, or complete Software Development Environments (SDE) mixing specification and design tools like Rational Rose, HOOD, Rhapsody. This segment similarly contains the engineering CAE tools that are custom-developed for space (excluding the more universal COTS products also employed by space engineering)
- **Space data value-added applications – Administrative software:** commercial applications placed downstream of mission exploitation systems in the value-adding chain of space systems; typically GIS (Geographical Information systems), applications based on the use of localisation/navigation signals, processing of meteorological data for weather forecasts, data access service applications (TV broadcasting, telecom). Administrative software covers conventional applications related to the management of documentation, invoicing, financial control, data warehousing, project management tools, intranet systems, etc.

It was decided that the activity covered in this last category is beyond the scope retained for this study. This activity was consequently not detailed but may nevertheless appear in some of the companies surveyed (for the sake of completeness toward such companies especially when it may represent a significant fraction of the company turnover).

3- The European scene

Importance of software activities on the space scene

Concentrating on the definition, development, deployment and operations of space systems, software (and associated services) activities corresponded to a cumulated (non-consolidated) overall turnover of 639 M€ per year on average over the 1999-2001 period (311 M€ for software houses, 295 M€ and 6 M€ for large and small integrators, respectively, and 27 M€ for sub-system integrators) .

From the data supplied by satellite integrators, it is estimated that approximately 80 M€ out of the 295 M€ in the turnover of LSIs, is sub-contracted to software houses. Part of this (estimated at 30 M€) already appears in the turnover of the surveyed software houses, whereas the remainder (50 M€) is subcontracted by LSIs in the form of manpower provision essentially to local companies which were not surveyed in this study. This results in an estimated consolidated turnover close to **0.6 Beuros** (609 M€ with the above assumption), to be compared to 1.6 Beuros for satellite equipment and 1.2 Beuros for launcher equipment (see Figure 3-1).

In **consolidated terms**, the breakdown of space software activities per type of player appears as follows :

Large satellite integrators in-house activity :	215 M€
Small satellite integrators (essentially in-house activity) :	6 M€
Sub-system integrators (essentially in-house activity) :	27 M€
Software houses :	361 M€

The provision of services is an inherent part of the software supply trade

The provision of services (both engineering-type services and operation support services) represents a significant percentage of the overall activity : 26% at global level, and 32 % for software houses (21 % for operation support - assisting Agencies in the operation of ground stations and facilities - and 11 % for engineering services - providing expert assistance to Agencies' teams for a variety of tasks including mission analysis, programme support, assurance tasks, ...etc) . The development of turnkey space software accounts then for approximately 68 % of the software houses activity (Figure 3-2). Some companies are clearly specialized in the provision of services (for example Serco or Vitrociset) but most players (even some of the LSIs) have this kind of offering which again is an inherent part of the space software trade.

The software market is primarily institutional

Space software supplied to civilian institutional programmes accounts for 60 % of the total activity, whereas defense institutional programmes generate only 14 % and commercial activities 26 % (including commercial ground operations services). A large part of the commercial activity is carried out by the two larger European satellite integrators. A breakdown by company is provided in Figure 3-3.

Sales to non-European customers are exceptional

Less than 6 % of the overall software activity is carried out for non-European customers, two thirds by system integrators and one third by software houses (Figure 3-4).

The European space software market is fragmented with multiple european competencies in each market segment

Excluding the large satellite integrators, there is no dominant player but a continuous distribution of sizes spread among the ESA countries with the maximum turnover peaking at 30 M€ and the minimum one at 0.1 M€. Many companies try to operate in a wide spectrum of software contributions in order to secure the widest possible business opportunities. This means that at European level, a given market segment may have as many as 30 players (case of on-board software). Several factors may account for this situation :

- ◆ Software procurement which, as will be seen, is mainly institutional, may be deliberately spread over the various players as a matter of policy (geo-return)
- ◆ National heritages have favored in the past and today tend to keep maintaining national players as well as significant market differences on the demand side (control and operations practice may present some notable differences which are later translated into software requirements).

Figure 3-5 indicates that in all market segments, only several companies have a turnover larger than 3 M€ whereas quite a few have turnovers below 0.7 M€

As a result of this fragmentation, no-one is at present in a position to really grab a wider part of the market and become market leader .

From small space-specialized firms to IT service giants

69 firms have provided information, making essentially four distinct groups :

- ◆ Large Satellite Integrators (LSIs)
- ◆ Small Satellite Integrators
- ◆ Payload or satellite sub-system integrators (delivering integrated sub-systems that contain some software)
- ◆ Software houses whose primary business is to deliver software and/or associated services , but which may also deliver hardware/software systems (EGSE for instance)

This last category is in itself a complex crowd, from small employee/management-owned companies to large multinational IT service vendors, from large IT technology-oriented groups that target downstream satellite-enabled products and services to niche vendors of ground receiving stations.

Few software companies do specialize in space

Only a few companies are fully dedicated to space (small actors in general) and less than a quarter of them are more than 50 % dependent on space. Figure 3-8 provides an overview of companies' dependence on Space.

Some are small outfits trying to occupy niche positions, whereas some others are very large IT service groups in which the space activity is only a quite small fraction. The largest space software players in terms of turnover are medium sized companies that occupy leading positions for the provision of technical software to the Aerospace-Defense community, well in front of the IT services giants that target a much wider customer base (for the automation/support of business processes notably) in their regular business.

Many of the software suppliers are already, or are trying to get, involved in other sectors, typically Defense, Aeronautics, Transportation, Telecoms, Medical systems. Common ground is found in the mission/safety-critical requirements justifying similar methodologies. Within the space activity, specialisation in one type of application (like EO or launchers, for example) is exceptional and suppliers tend to cater for all types of missions (Figure 3-6).

Most companies agree to say that space does not enhance their technological knowledge but rather their methodological approach and that the space software technologies are borrowed (and adapted) from the mainstream IT technological pipeline.

Limited actual competition at european level on a primarily institutional market governed by geographical return opportunities

Most of the companies surveyed tend to consider that they don't really face strong competition to get a share of ESA's business and that the geo-return rule is often a determining factor in one's chances to win ; opportunistic association of competitors (trying to offer the best balance between geo-constraints and technical value) is therefore the rule. Some players have thus developed regular relationships (for instance between some italian and some UK companies) and have been successful at maintaining or even expanding their share of the ESA budget. But in countries with LSIs and other strong equipment suppliers, software houses may be ruled out for lack of geo-return capacity.

In commercial programs, LSIs tend to shop locally, mostly because their procurement strategy (largely dictated by the need to keep dynamic control over strategic system issues) is to buy low-level custom development and manpower provision services rather than ready-made products. The use of a list of pre-qualified software suppliers is then a common practice.

Many software suppliers operate at component or subsystem level and this may be keeping them from strengthening a commercial offer for the open market

Few software suppliers have the opportunity to operate and take responsibility at system levels (involving architectural issues either on-board or in ground facilities) and for many of the smaller actors of space software, this is clearly a complaint on their part : the system level is either controlled by the satellite maker or by the ground system operator (with some exceptions) which then distribute work directly to sub-contractors.

Yet, system issues are likely to get increasingly important in the supply of « space software » as space systems will become integrated within wider systems of systems (in telecommunications, navigation, surveillance, ...etc). System perspective (and experience) will then be essential to develop new and competitive products suited to the new needs. Some US companies are on this track (Integral Systems, L3-Com) but European suppliers are at present largely left out of this game.

On-board software remains a small and rather closed market for system and sub-system integrators

On-board software accounts for 18% of the overall software activity (Figure 3-7), 10 % for the software houses and 24% for satellite manufacturers. This is a measure of the requirements and limitations which have thus far constrained the use of software on-board satellites (extreme reliability, ease of maintenance, cost/weight limits of hardware), thus limiting the role of software to where it is indispensable.

Because the system level work for on-board software is considered critical by the satellite manufacturer (toward market differentiation and toward delivering fault-free service to the end-customer but also in terms of project management over very tight schedules), LSIs systematically want to keep control of the development process and for this reason, the major part is done under their close supervision, if not at their premises

Custom development is still dominant although real efforts take place to establish re-usable core products

Most space software suppliers have found some benefit in the establishment of some level of product re-usability which make their commercial offers more competitive (savings on application development time often in the 50 % range or higher).

The european efforts to establish core products for satellite systems (and especially operations) are quite spread out, each product category claiming at least 4 or 5 kernels, each typically used 2 or 3 times only (up to 10 or 15 for the longer established suppliers), in contrast with the recurrence of some of the american players (more than 120 Epoch applications for Integral Systems, more than 50 for Storm, more than 10 000 for Satellite Toolkit). Again, the reasons for this fragmented picture are to be

found in the existence of a few strong national space programs (including military) which have favoured the pursuit of independent/national paths, leading to parallel efforts for similar products.

It follows that with a highly fragmented (and rather low) R&D effort, the chance for Europe to deliver market winner products on the short term are probably somewhat remote.

Commercial operators are starting to push for standardized and more fully integrated ground segment systems

In addition to reducing costs, there is a general trend to look for rationalization (even simplification) of the task of satellite control by commercial operators especially for fleets of (often) disparate satellites (and subsequently disparate control requirements). This may be favoring the emergence of COTS-type approaches for the provision of ground segments which, by tailoring a pre-integrated and homogeneous suite of tools, are expected to reduce cost, risk and schedule for the operator. However, the status of this demand is still emerging and uneven among the different commercial operators (some seem to privilege individual satellite safety even at the expense of fleet rationalisation).

Space software R&D is unevenly distributed among the software suppliers

Only 25 firms (out of 69) representing 64% of the total unconsolidated turnover have identified R&D activities meaning, for many of those which have not, that they likely do not do any software related R&D (a few companies did not wish to disclose this part of their activities, or on the contrary considered that all of their activity is indeed R&D since each custom delivery is a new piece of software). For most of the players, R&D is usually directed to :

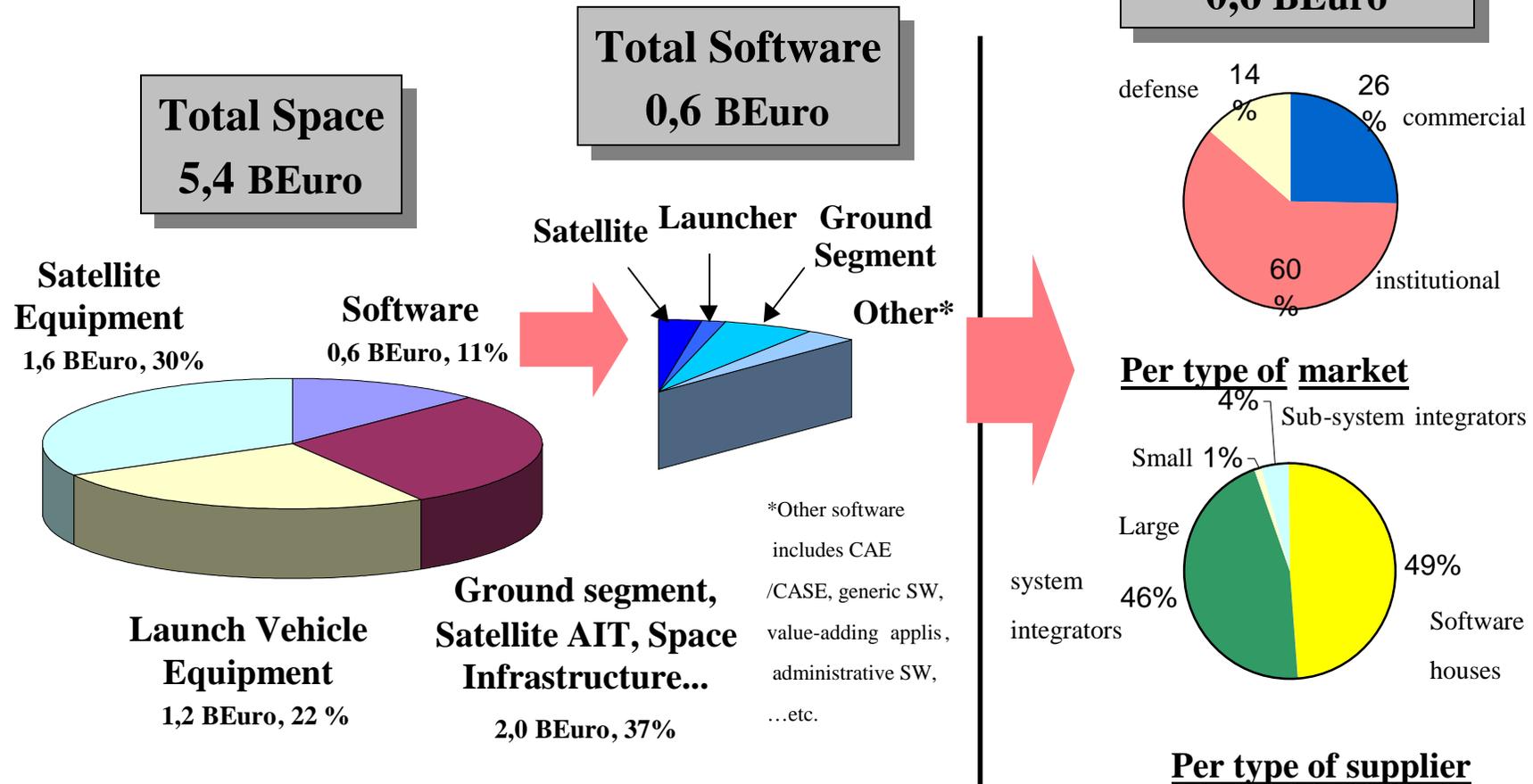
- ◆ expanding mission work into re-usable kernels
- ◆ exploring the potential use of the re-usable kernels in novel applications
- ◆ developing/maintaining/expanding an own toolbox supporting the software process
- ◆ developing prototypes of value added services
- ◆ exploring (at study and/or demonstrator level) new system architectures (distributed on-board processing, formation flying, increased autonomy, ...)

The overall R&D ratio comes to 6.7 % of the corresponding turnover on average. Nearly three quarters of this effort go to ground software, in accordance with the much larger share of ground activity among all players.

Forty percent or more is self funded, whereas the remainder is provided half and half between the national agencies and ESA (case of space software R&D) ; the contribution of ESA is even less in the case of ground software (indicating a strong involvement of national agencies in ground operations).

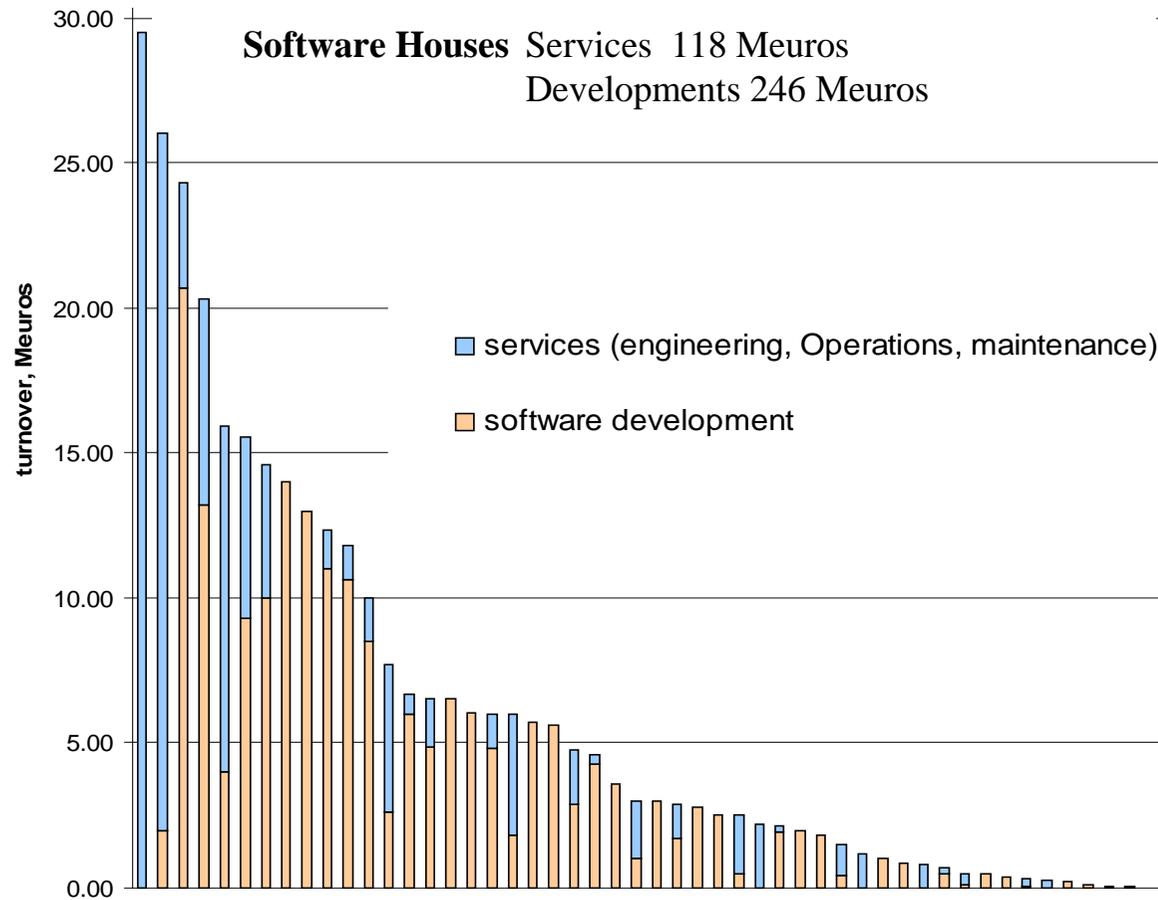
**Figure 3-1. Most representative European space business:
Total Space and Software Activities.**

This figure is based on the estimated consolidation of values provided by 167 European actors (suppliers and integrators) surveyed in the satellite equipment, launch vehicle equipment, ground segment hardware and space software surveys. The figure contains average annual values for the 1999-2001 period.



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Figure 3-2 : Ratios between services and (turnkey) development activities



Global European space software activity (including integrators)
 Services 158 Meuros
 Developments 451 Meuros

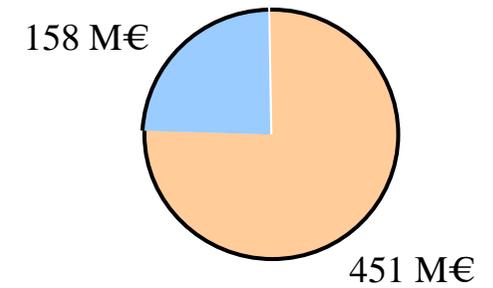


Figure 3-3 : Space software business in Europe - Market Breakdown

Annual average values for 1999-2001, provided by the companies

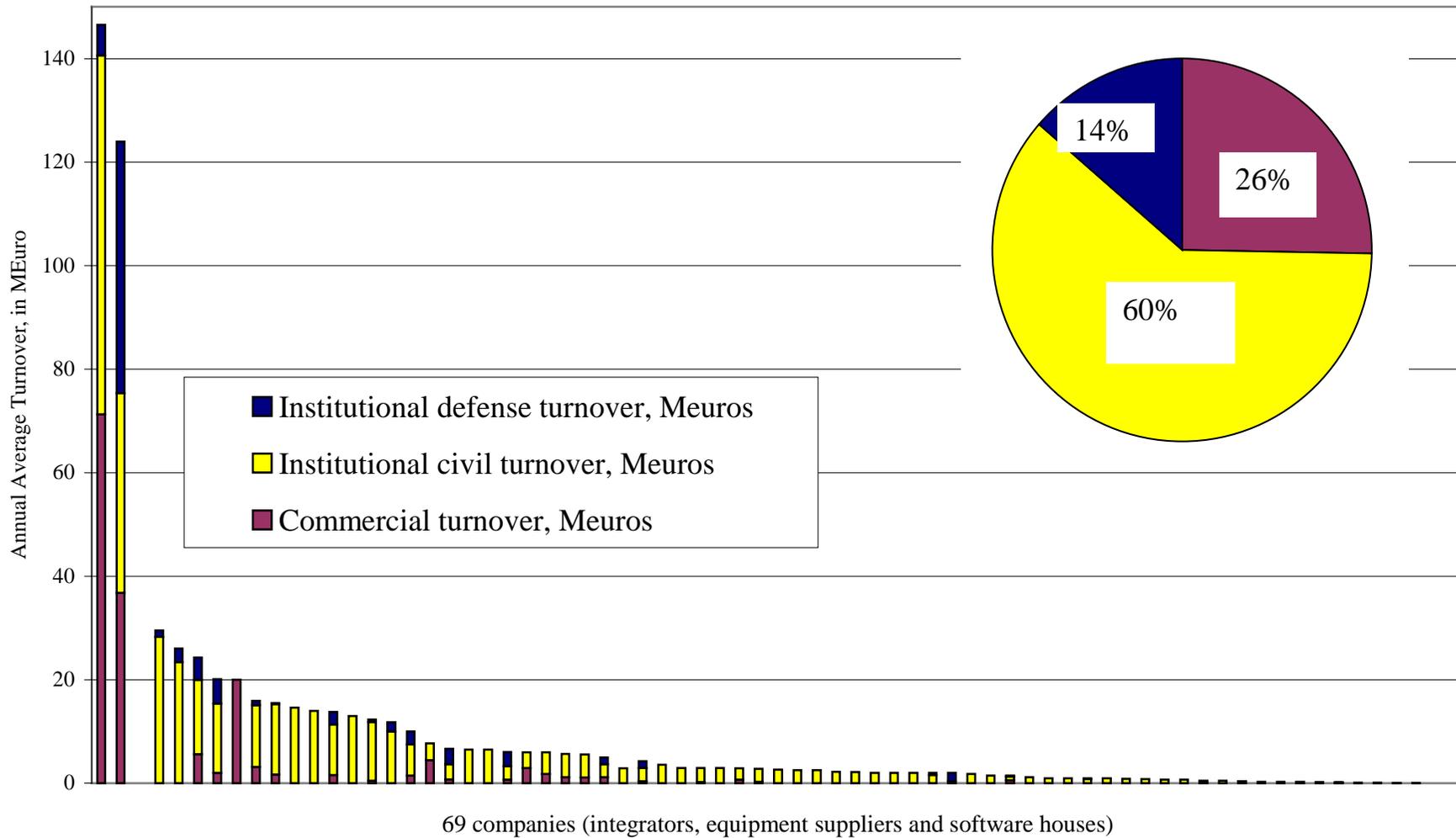


Figure 3-4 : Importance of export of space software

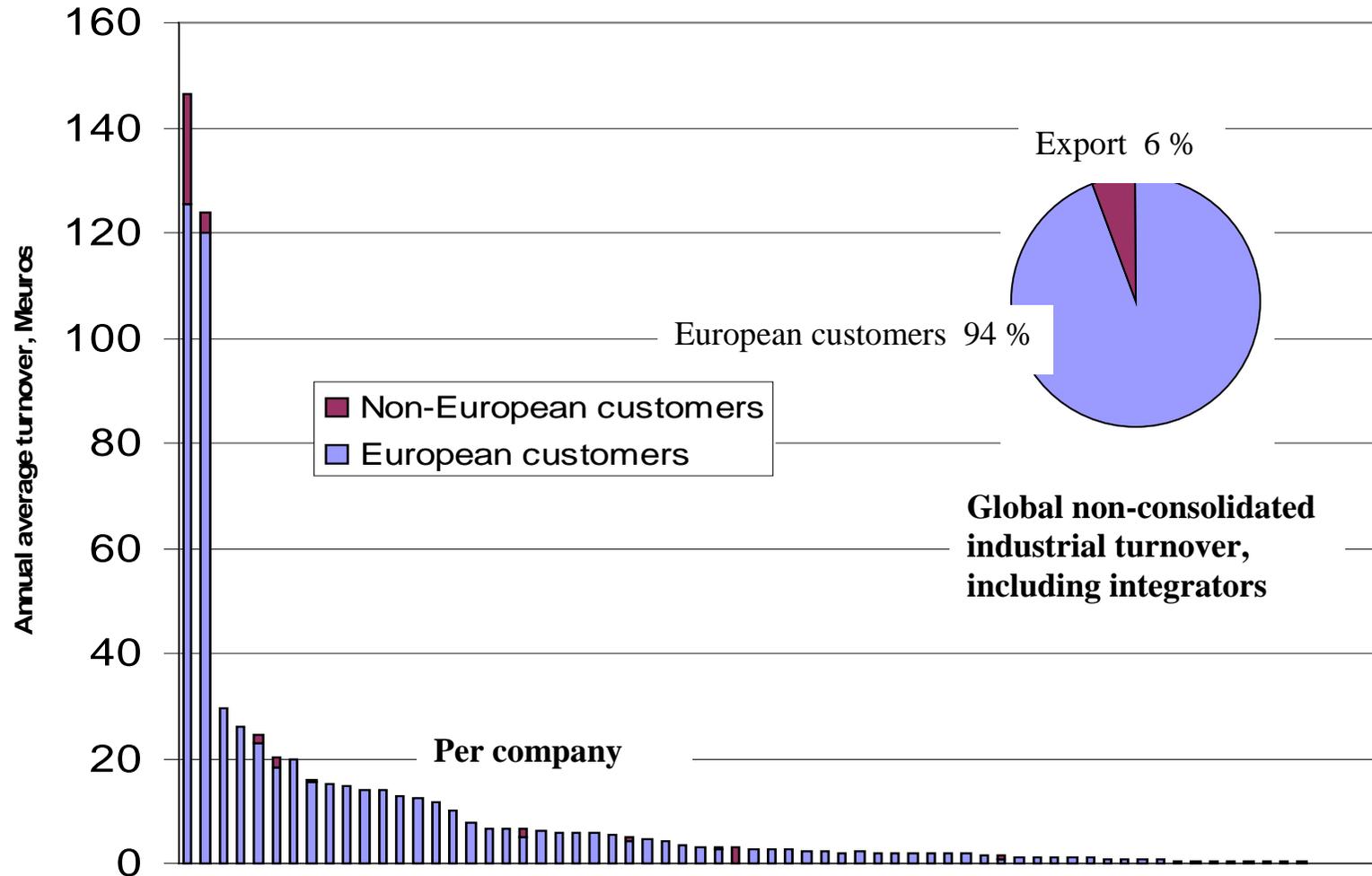


Figure 3-5 : Distribution of company market shares in the various market segments

Number of Companies per turnover segment		
<0.7M€	0.7<<3M€	>3M€
6	12	8
10	6	0
5	5	1
5	7	7
3	12	8
3	8	1
3	5	1
10	12	6
10	19	3

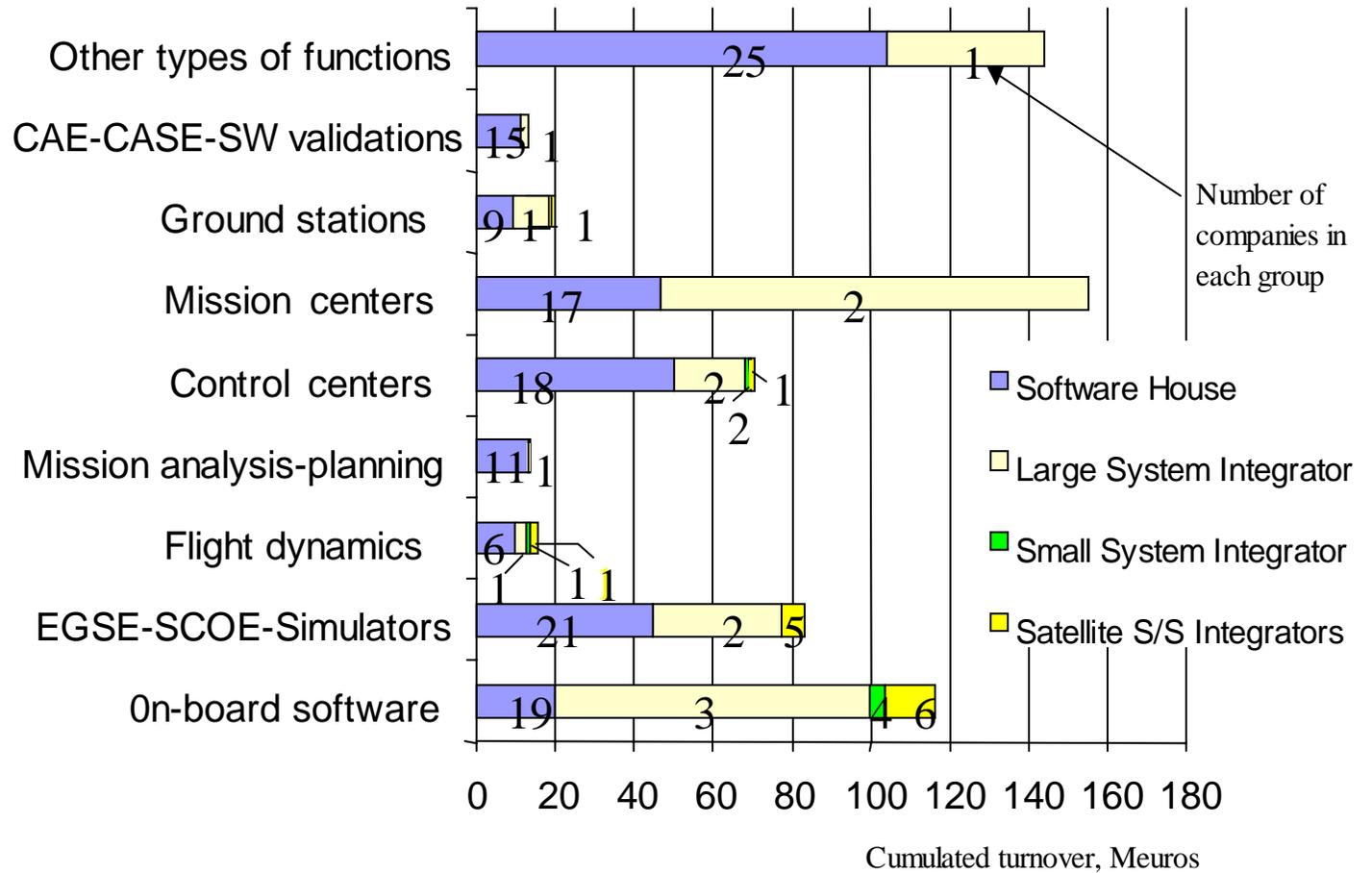


Figure 3-6 : Distribution of activity per type of mission

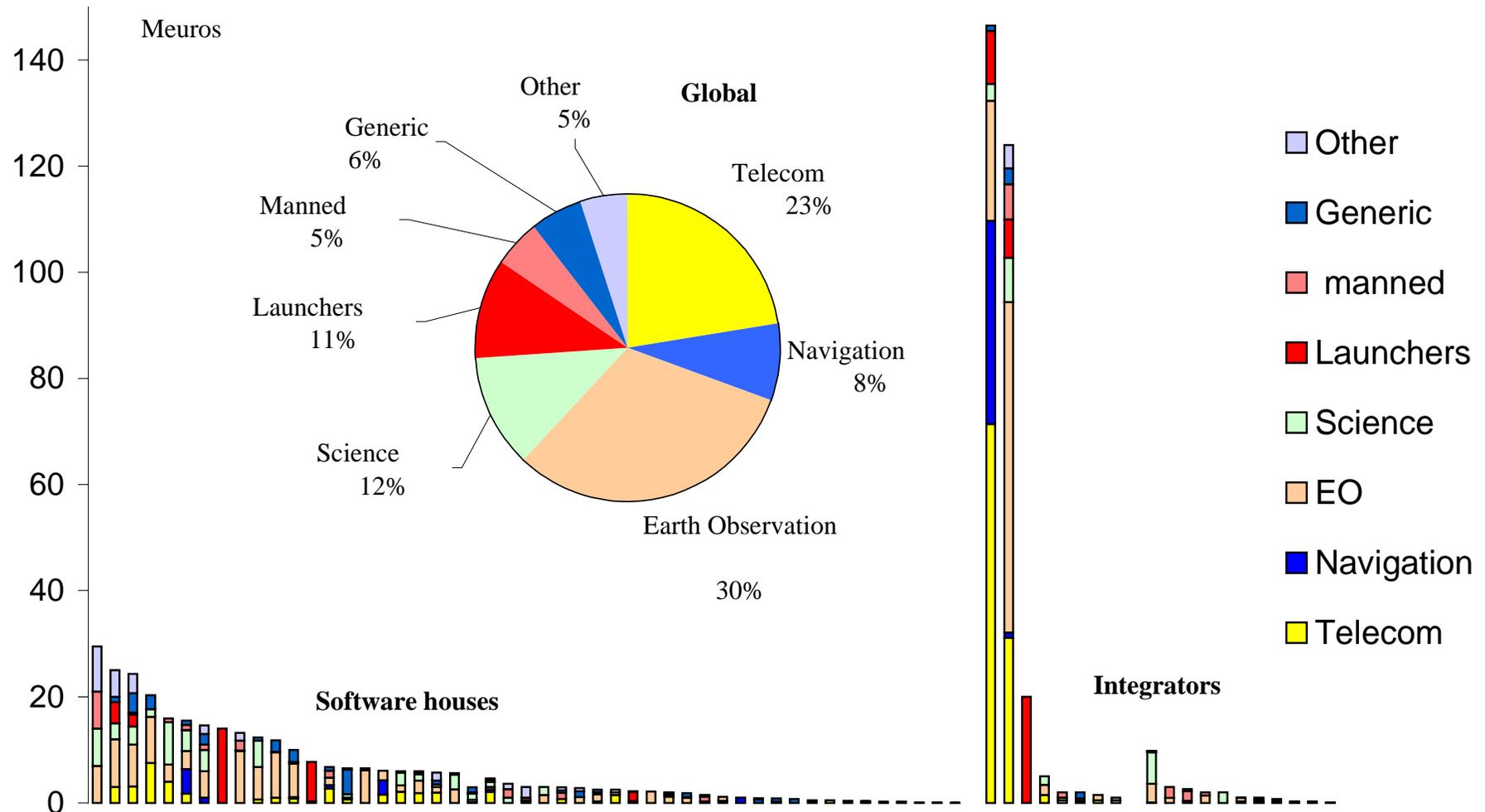


Figure 3-7 : Breakdown of software activities per market segment

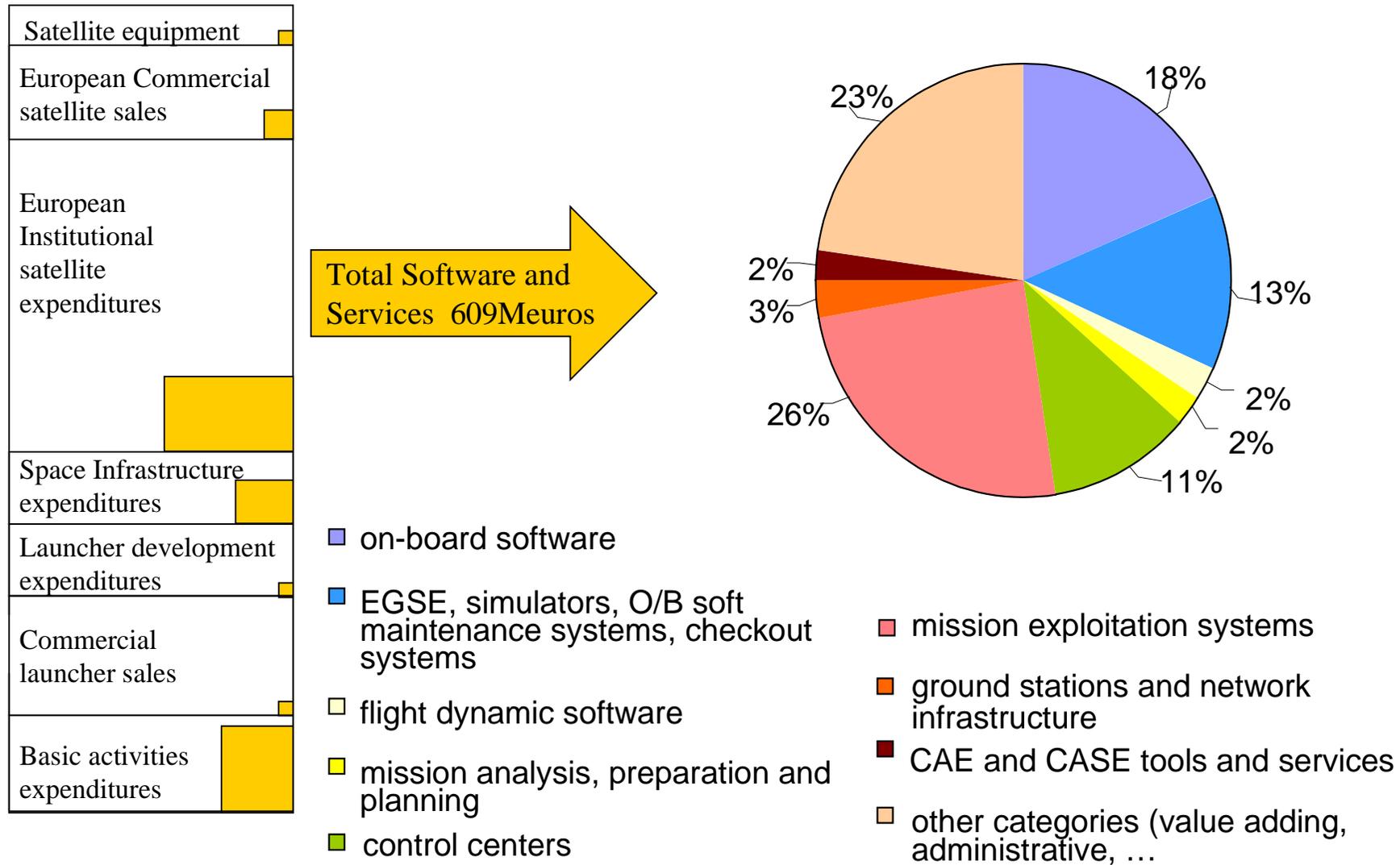


Figure 3-8 : Importance of space for the software suppliers

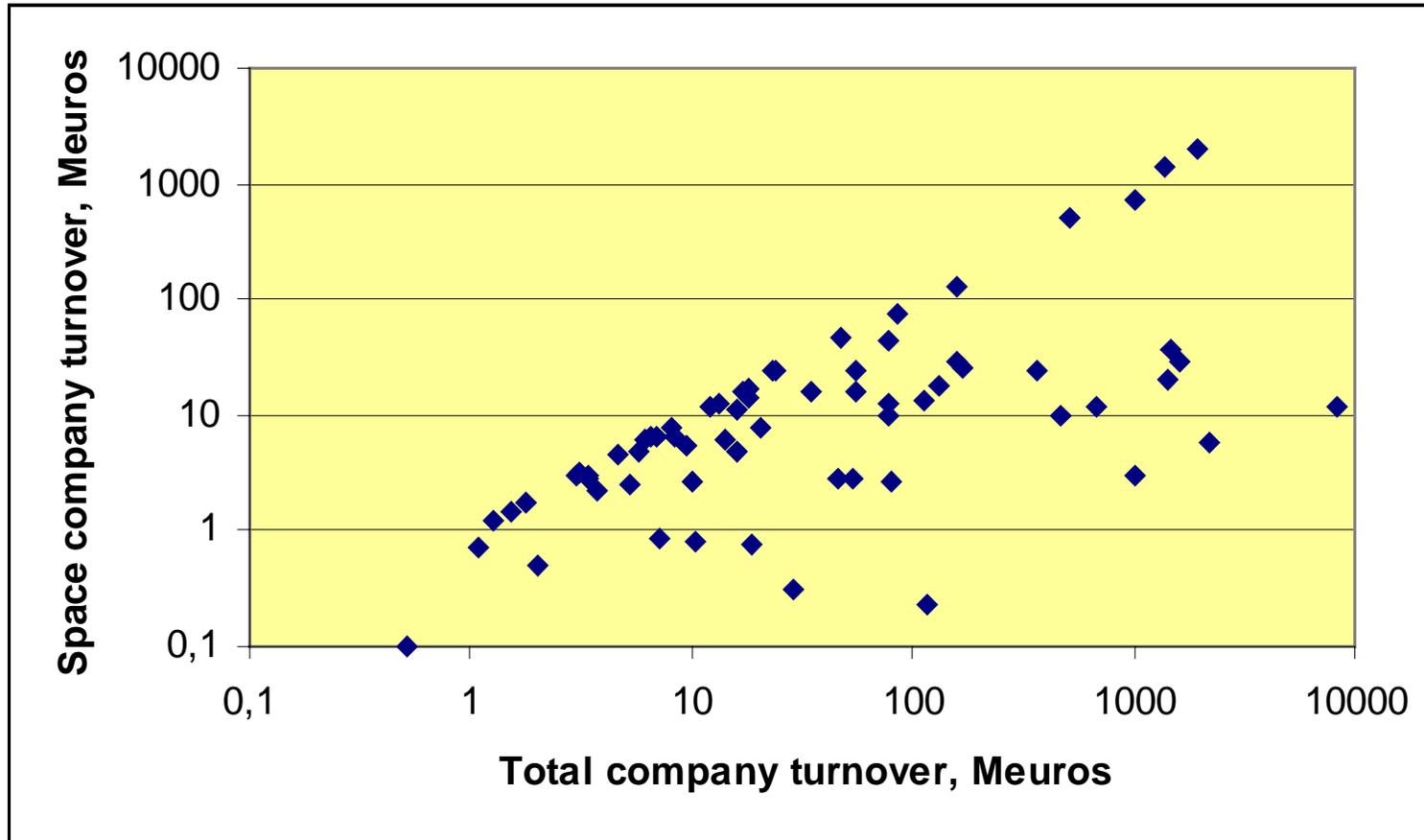
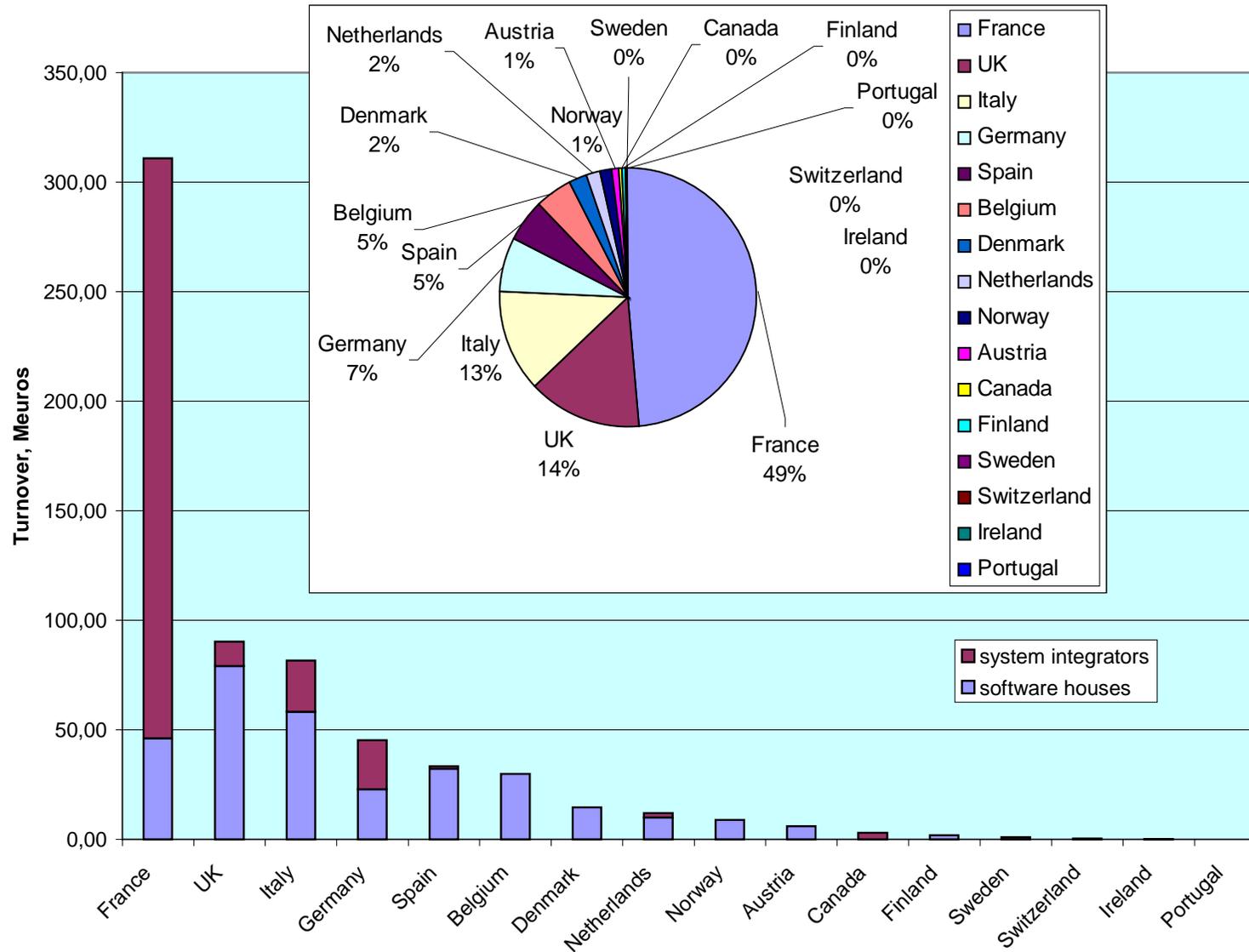


Figure 3-9 : Space software activity per country



4- The US scene

A similar traditional approach to space software on both sides of the Atlantic

The pre-eminent role of satellite and payload integrators in self-supplying the spacecraft software is also present in the US. The situation for ground software is more diversified.

Until recently, it seems that large satellite makers like Boeing/Hughes or Lockheed Martin were making in-house virtually all of their software including ground software. Today after the Hughes ground software activities have been taken over by Raytheon, Boeing are procuring their control systems from them and their EGSEs from Integral Systems. Loral procure from Integral Systems on a case by case basis. Orbital Science Corporation procure both control centers and EGSEs from Integral Systems but also do in-house. Lockheed Martin are still pretty much vertically integrated as they get more and more centered on government programs (one of their divisions, LM Space Mission Systems&Services, has extensive business with NASA and DOD for the provision of software and services). TRW are in a similar position to LM (with their Systems Integration Unit, part of the Global Change Group Initiative Division, in charge of space-to-ground interfacing of NASA's Mission to Planet Earth Program). Spectrum Astro, manufacturer of small to medium (essentially) government satellites, is also making software in-house.

Apart from the satellite integrators, ground software is produced by four types of suppliers :

Large software services firms (Computer Science Corporation, Computer Associates, Unisys Corporation), which have quite extensive businesses with the space agencies providing essentially custom services including software development (292 M\$ for Computer Sciences Corporation).

Large aerospace/defense contractors targeting the lucrative government information and communication systems (L3-Com, Raytheon, Harris, Litton).

The considerable increase (30 to 60 billion \$ over the next years) in government spending for homeland security and defense (which has a rapidly increasing space component) has prompted the large defense contractors to import competence for satellite control (example Raytheon acquiring Hughes teams), which is likely to be a main piece in the development of such systems.

Relatively small firms specializing in the provision of satellite control systems and which were able to capture a significant share of the market (Storm, Integral System). Among those, Integral Systems seems to emerge as the main independent player equally active on the commercial and on the governmental markets.

A large number of small firms, either specialized in space, or catering for a wider customer base, with unique base-products (often developed for NASA or DOD and for which the agency retains some IPR) and associated services (Interface and Control Systems, Dynacs, Essex Corporation, Talarian/Tibco, Omitron, Analytical Graphics,...etc)

A number of the previous two categories were eventually bought out in recent years by the large aerospace/defense contractors (Storm acquired by L3-Com, Hughes ground systems by Raytheon, Software Technologies by Harris) or by non-defense communication network companies (Talarian acquired by Tibco).

The push for a more commercially-oriented space market has led to software COTS products for ground operations of satellites

Integral Systems, which 10 years ago used to propose custom-developed control software, switched to a COTS approach (with their Epoch 2000 suite) and has now won 50% of the US commercial market. There are two driving forces for the advent of COTS ground systems. One is the increasing pressure on operating costs. The other driving force is the need to start harmonising facilities through some kind of standardization to facilitate integration of satellite operations in larger end-user systems

(Intelsat has initiated this). Integral Systems has banked on this emerging trend and has multiplied their sales by a factor of 5 over the past 10 years.

Storm Control Systems is on the same track but apparently may have lost some ground to Integral Systems, as their only remaining major client appears to be Inmarsat. Storm has also sold in Europe (to Telespazio) and has made a long term agreement with Astrium for their Eurostar 3000 telecom satellites.

Lower cost and all-encompassing integration of satellite-based ground systems seem to be a major market force

In line with their corporate acquisitions (Newpoint, SAT, ...), the aim of a company like Integral Systems is to offer a complete and fully integrated kernel capable of meeting in one package all the needs of satellite operators (IOT, signal monitoring, payload data processing, ...). Storm have the same approach with their In-Control NG suite aimed as a supervision layer integrating a variety of COTS ground operation tools.

Defense oriented contractors are also moving in this direction to better serve the new national security needs. With Equinox and Eclipse, Raytheon are looking at the planning/scheduling and command/controlling of a variety of resources that eventually go beyond satellites.

Alliances between COTS products vendors and software services suppliers (or even satellite manufacturers) are emerging as a strategy for the commercial market.

Products and services have traditionally been mixed in the largely custom-based satellite software market. The advent of COTS products may eventually structure this market in two parts, product vendors on the one side, and service suppliers (including customization) on the other side.

Already, Integral Systems is recognizing the need for partnerships with service suppliers (CGEY, Atos-Origin, SSI in Europe, Computer Science Corporation in the US, for example) on the argument that those are two different trades. Indeed, product vending is about determining market needs cross sections, constructing robust software packages and especially maintaining/evolving those efficiently on the long run, whereas customization services are about maintaining competencies and solving customer specific needs.

Storm is also striking alliances in Europe ; they have made a long term agreement with Astrium to supply control centers for the Eurostar 3000 missions (starting with the Inmarsat 4 satellites), « as long as they remain competitive ».

A factor of ten between US and EU space software&services suppliers respective activities

The factor of ten or so between american institutional spending and european institutional spending is readily apparent in the comparative sales levels of american and european space software suppliers and particularly for the IT service giants ; for instance with 292 M\$ space sales in 2001, Computer Sciences Corporation, a major custom supplier to the american government, is 10 times bigger in space than the biggest european service supplier (at 30 M€). Computer Associates and Unisys are also major suppliers of the space custom software market. At least half a dozen or so companies this size share the bulk of the custom government market ; for most of them, like CTA, Harris, Litton, LM Space Mission Systems and Services, L3-Com, TRW, Raytheon, the software activity is part of a wider systems activity involving also major hardware.

5- The wider software engineering scene

The customer is not the driving factor but the class of software is

The survey tends to show that the application domain (here space) is not the driving factor, but rather the class of application is structuring the way in which software is produced : for instance the requirement for safety- and/or mission-criticality influences more the development profile than the customer application-domain (be it financial, medical, transportation, ...etc).

Yet, many stress the importance of domain knowledge to successfully develop « space-grade » software, which in most instances translates also as a major requirement to the non-space sectors. Then, even if the basic technologies, methodologies and tools are the same, there is still an inherent specialization of suppliers dictated by domain knowledge.

Space software has some unique features

In practice, space software still presents some unique features stemming from the domain constraints, but also from a certain lack of maturity in comparison to other sectors.

- ◆ Space engineers traditionally are invited to design for a unique system (a mission) with a limited lifetime. This does not favor the long-term thinking necessary to derive multi-use or even COTS solutions which can more easily take place in other sectors where people think in terms of lines of products.
- ◆ The design of space systems (on-board) is hardware driven and software must be adapted in the end to the finally available equipment. One reason is the risk involved in the development of mission specific equipment, contrary to other sectors (like Telecom or even Transportation) where the hardware equipment is fully known to start with (more comfortable for an architecture job).
- ◆ Space missions requirements often change significantly in the course of development, which presents specific difficulties for hardware/software partitioning (especially with limited interface standards) and subsequent stability of software specifications. This happens also to some extent in other complex engineering domains like Defense or Aeronautics but for which standards are more common.
- ◆ Design for remote and « hot » maintainability whereas in all other sectors the system can usually be shut off for maintenance at no harm. Software is in the end the only component which can be changed (upgraded, adapted to new circumstances, ...) on board a satellite.
- ◆ Space flight software must be made to run on older generation devices because a number of years (equivalent to one or more generations) are needed to adapt the new devices to space requirements. This means less capacity (speed, memory) compared to contemporary terrestrial applications but also older generations of enabling CASE tools and associated expertise.

For many space software suppliers, space is not so different from other high-level engineering domains

The participants were asked to identify the non-space domains for which they are also active delivering software applications and services. A dozen fields were cited, the most common ones being Defense/C3I systems, Telecom systems and Aeronautics/avionics both civil and military. It appears that :

- ◆ Domain expertise is equally important, with some minor differences probably reflecting specific sets of circumstances.
- ◆ Percentage work on the customer's premises is very dispersed in all domains (even space), and this is an indication that the various software supply modes (turnkey and manpower provision essentially) are used in all domains

- ◆ Percentage use of COTS products appears slightly higher (although still quite dispersed) for most domains except Defense
- ◆ The typical size of projects may be significantly larger in non-space domains (especially Telecom, Aeronautics, Defense/C3I, but not so much automotive/transportation) but this appears more linked to the size of the software player (system experience and commercial liability).
- ◆ There is no clear discriminating trend regarding the allocation of effort/value in the main phases of a project (specification-development-testing). Looking at the more experienced players, all domains are perceived similarly, which may follow from the essentially custom nature of the activities enjoyed by the space software suppliers.

6- Space software market outlook

Because institutional missions provide the major part of the space software market (the commercial part was measured at 26% over the past three years), and because the trend for institutional satellite spending in Europe is expected to be flat in the coming years, the assumption made is that the overall market for space software (with perimeter taken in this study, that is excluding value-added applications of space data, be it EO- or Navigation-based) should remain rather stable over the next few years, in the **500 to 600 M€range**.

7- Situation per market segment

On-board software

The satellite makers consider that on-board software is strategic to their business efficiency and market success and as a result they usually want to keep full control over its development. This has two sorts of consequences :

Sub-contracting is limited (10 to 40%, depending on workload) and usually more in the form of manpower provision as opposed to turnkey procurement based on specifications with fixed budget and delivery. Sub-contracting is then to preferred suppliers (when there is no procurement constraint from the end customer), which have built competence in their client internal tools and methods, probably making it harder for the others to compete. Forcing the sub-contracting to any supplier (for instance for georeturn in institutional projects), especially in a turnkey mode, is considered as invariably generating extra cost and delay.

The satellite makers tend to rely on self-developed tools to support their software process

In fact, the two larger satellite integrators have both engaged in major R&D programmes in the past years to build adequate toolboxes for the upcoming challenges that they will have to meet in the marketplace. This makes it harder for specialized tool developers (usually SMEs supported by ESA) to promote and sustain their products unless such products have been specified and developed in very close intelligence with the satellite maker (ensuring that the product will meet at least the LSI's needs). As suggested above, this also tends to narrow the circle of suppliers with which the satellite maker is able to efficiently collaborate.

There are yet some good reasons for this seemingly selfish attitude. One may want to consider two extreme situations, viz :

- In situations of recurrent making (especially in commercial telecom projects) there simply is no software business to sub-contract as the on-board software can be re-used for a same platform with very little modification (especially true for data handling or AOCS). The main effort is made once in generating the toolbox. This is of course an ideal situation and, because the market needs change as well as the technologies, software requirements must be constantly adapted. But a fairly high degree of standardisation (within a given satellite maker) is likely to prevail as a result of the competitive pressure in the commercial satellite business, and that part of the market should keep a quite small value.

- For one-of-a-kind makings in which relatively unique software functionalities must be implemented (this is likely to be found in institutional projects, but could also be the case with novel telecom payloads), the software market appears to be severely constrained by the limitations in current systems engineering processes. These processes should first resolve system issues and then turn them into specifications by which software sub-systems could be sub-contracted out. But in practice and for a number of reasons, system issues (like hardware selection or hardware/software partitioning and architecture or autonomy level, ...etc) usually do not get fully resolved until the end of the project, making for « floating » and/or changing software requirements. This situation basically arises from the high (and increasing) complexity levels (new technical challenges, multiple objectives of various patrons, ...) that need to be addressed by satellite makers. This invariably creates problems for both the satellite maker (keeping up with system requirements, meeting deadlines and budgets) and the sub-contractor (difficulty to commit on a firm fixed price and delivery). With increasingly tight delivery schedules the only way is to set up a very dynamic software production system tightly connected to the satellite systems engineering on the one hand (to take on board evolutions, but also to bring software constraints and opportunities in the systems engineering work) and capable of reacting quickly to changes at minimum cost on the other hand. Such seems to be the rationale for LSIs to keep full control over the on-board software development and to call on sub-contractors as mere « coding hands » under their supervision depending on the workload.

Consistent with this centralizing strategy for on-board « intelligence », LSIs are still somewhat reluctant to procure « intelligent » sub-systems and equipment from vendors (that is, comprising both the hardware equipment and the running software) especially for their commercial projects. In the case of institutional projects, the rule is for the (usually independent) payload manufacturers to develop the accompanying on-board software most often embedded with specialized hardware in the form of separate computers (but therefore with little interference with the centralized IT system).

Working with a largely self-made and fully adapted toolbox is also perceived by the LSIs as a way to tackle system complexity and the requirements for very high dependability (the major system and sub-system developers use an in-house operating system). It is thought that working with commercial tools might not allow the same level of mastery over system behavior. However even if this situation can satisfy the current system needs, there seems to be a real danger on the long run as space engineering might get cut from advances made in the mainstream commercial IT markets. Also, the high specificity of in-house tools makes it difficult to entertain a wide sub-contractor basis (need for a specialized competence), although it may have beneficial effects in controlling operating costs (versus cost of multiple licenses of a COTS tool).

The situation with small satellite integrators is not so different in the sense that on-board embedded « intelligence », materialized in software, is also a strategic aspect of systems engineering and thus largely self-procured (Surrey Satellite Ltd., OHB, Carlo Gavazzi), albeit with less emphasis on self developed tools (more use of standard COTS products such as Rtems, VxWorks, ...etc).

To summarize, because they are dealing with non-stabilized complex systems with demanding performance, satellite makers feel the need to manage the on-board software development process themselves down to quite low levels, leaving very little room for external sub-contracting, apart from local specialized manpower provision.

Now the question is whether the situation could be run differently in order to make more room for independent suppliers. There seems to be two routes to this with two quite different timelines. On the short term, one may want to examine ways to better manage the complexity of satellite systems engineering and thus carve a better role for suppliers. On the longer term, one might want to try bringing spacecraft engineering closer to more traditional engineering of complex industrial systems (say a plant, or a car, or an airplane) for which systems engineering is primarily an architectural job based on the integration of externally engineered and supplied building blocks. However, the relative lack of maturity and constant evolution of the demand side is presently a major roadblock in that direction.

Control centers

A rough picture is that LSIs used to supply the control center (along with the satellite) to their commercial customer and that for institutional missions, control centers were sub-contracted to software houses under the technical leadership of the concerned space agency (which would often be the mission operator later on).

As a result, there is a fairly large number of TM/TC kernels used in Europe (adapted to the various platforms and also reflecting the various control philosophies) and owned either by the satellite manufacturers or by the space agencies.

TM/TC kernel	Organization	Remarks
G1	Alcatel	Developed by CS-SI for ASPI
OpenCenter	Astrium	Not used for control centers (Astrium has chosen the Storm product)
Stentor kernel	CNES	Developed by CS-SI – to be used for ATV
Spot/Helios kernel	CNES	Developed by Astrium and sub-contractors
Proteus kernel	CNES	Developed by CS-SI
Framtec	CAM	Used at DLR and Eumetsat
SpaceUnit	Science Systems Ltd.	Is more an integration framework
SCOS-2000	ESA/ESOC	Developed by several software houses

This makes for a fragmented market in which no-one can become market leader with a widely distributed and accepted product to compete outside Europe. In fact, one may question whether the limited european space budget can afford to keep up all these parallel efforts (the cost of building reliability/safety in a given tool and of making it up to market standards can be as high as 30 to 50 Meuros)

Even if the platforms are different (in a given orbit category like GEO), resulting in different command strings and sequences as well as different TMs, it seems that a unifying framework concept is possible (as witnessed by the american « COTS » products of Integral Systems) with subsequent customization to the operator’s specific requirements. Actually, more than proposing a simple generic control system tool, their aim is to provide a fully integrated operations system suite that covers all functions (IOT, quality monitoring, planning and scheduling, command&control, archiving, ...etc). The commercial market is actually moving in that direction today both to reduce costs (compared to fully custom solutions) and to harmonize control operations of heterogeneous satellite fleets (this latter fact is today a longer term goal for the big SatOps which presently are maybe less sensitive to operations cost than smaller newcomers and which also have a larger legacy to deal with).

Satellite makers may thus have increasing difficulties to supply their own solutions (Astrium telecom business unit selected Storm rather than the in-house OpenCenter) as operators pressure them to provide more standard solutions for a component of the space system which remains in any case marginal in terms of value (1 to 2% of the satellite value). This general market trend, imposed by end-customers, might prompt the satellite makers to make it easier for ground satellite product vendors to efficiently interface to their proprietary platform database, thus making it more attractive to develop COTS ground products.

To summarize, satellite manufacturers seem to be getting out of the control center game ; the european capacities of software houses are quite dispersed among many actors and none of those does have all the competence and experience required to offer a comprehensive integrated suite, nor do they have the freedom to go their own way (IPR of base kernels are with agencies or LSIs). Despite the existence of a truly open commercial market (which though may narrow in the future following probable SatOp concentrations), the control center market, even that of COTS products, appears dominated by institutional clients (both in Europe and in the USA). Even if the case for a real COTS control center

product (as opposed to custom integration of proven building blocks) is not entirely clear at present (more hands-on experience is needed to assess advantages and drawbacks), some consolidation at european level would clearly strengthen the control center industry.

EGSEs and test/validation benches

EGSEs and test benches are regarded by LSIs as an integral part of their development toolbox, which they want to rationalize (to gain efficiency) and to fully control. As a result, they spend considerable efforts developing integrated suites of tools (including test languages and management interfaces) tuned to their satellite building processes.

Here also, some consolidation (standardization ?) at european level should be beneficial to have LSIs and suppliers cooperate efficiently.

Satellite simulators

This is also a by-product of the satellite maker's development work which requires a very intimate knowledge of the satellite design that only the satellite manufacturer may easily and most efficiently collect (satellite simulation is used for testing and verification). This clearly is a recurrent difficulty when sub-contracting to external software houses especially in terms of cost effectiveness.

Flight dynamics and orbitography

Used in AOCS on-board software (the search for autonomy – for instance week-end autonomy – will clearly enhance this need) as well as in the ground operations. Satellite manufacturers and suppliers seem to co-habitate smoothly in this specialized market segment.

Mission planning&scheduling - mission centers

These are market segments which are relatively disconnected from the intricacies of satellite design and which could be the main playground for independent software vendors (there does not seem to be any strong reason why satellite vendors should claim this market segment).

The fact is that independent vendors are largely present in these markets, but so are the big satellite manufacturers on the claim that they only can bring the right system dimension. Mission planning&scheduling, and more generally satellite operations, are likely to become important customer systems (for instance in the context of systems integration) with significantly more value than « simple » control systems or simulators.

Ground stations and communication subnets

The institutional market is largely a market for services (excluding here the hardware equipment covered in another study) well in the hands of independent software and communication services suppliers. The particular nature of one of the LSIs (Alcatel) also makes it a major and valuable contributor to this market segment.

Two european players are present on the burgeoning market of small professional ground stations (meteorological and EO) along with a few US companies.

Space data value-added applications

Clearly this is an area in which software houses are especially expected and many of them (particularly the larger generalist software houses) do target this market, either in earth observation and/or in navigation/localization services or in the new telecommunication services. Still most of that activity is still preparatory (developing prototypes for instance) or uncertain (mobile or IT services infrastructures).

8- Conclusion

This work has shown that in Europe, the space software industry has been serving an essentially institutional market (both on-board and ground software for commercial systems are significantly smaller in terms of value, if one ignores the « downstream » activities which are connected to satellite-enabled commercial services which tend to fall in the mainstream of the software markets). This means that governments' spending has fueled the development of space software competence and products and the acquisition of domain knowledge among a variety of players in Europe, which was sufficient (even if the overall euro efficiency was not optimum) to meet the institutional needs (in an ad hoc way) and which, at the same time, satisfied other political motives (european integration). Even if the US did not have such political requirements, the rationality of their approach to space software does not appear much different (ad hoc developments and ways by the different agencies, multiple companies supporting a diversity of tools), at least until now.

Yet, there are indications that the situation is changing. The approach to space engineering is becoming more common and therefore space software is likely to follow the same path as software did in other industrial sectors, where the market is structured in rather well defined categories of players, viz :

- ◆ product vendors supplying a large number of customers with fairly standard and closed products, often across several or many industrial sectors (from basic tools like operating systems to finished application products like CAE suites)
- ◆ system integrators which deliver customer-tailored solution (based on the right vendor products) often specialized for one sector of industry (importance of domain knowledge)
- ◆ specialized services firms usually with fairly narrow expertise which supply support services as well as specific supporting software in one (sub-) sector of industry.

The long term trend (fueled by an increasing commercial use of space and also by an effort to reduce institutional missions costs - particularly acute for Defense) is therefore for the space software market to move from an essentially ad hoc supply mode to a more structured mode of the kind above. This trend is presently visible in the US market, where a number of « COTS products » are increasing their market share against ad hoc solutions.

With the present geo-return-based procurement strategy of space software in Europe, each european player is (more or less) assured of receiving a piece of the institutional pie, but has very little chance of getting beyond this share even if he has a good product (no strong incentive to invest in own product development when visibility of market access is low). The integration of new ESA members (in which software would probably be even more the avenue for reaching the georeturn balance) should not change that picture too much, provided the ESA budget grows in proportion (and the new members budgets would be small anyway). Yet, there would then be new players acquiring space domain knowhow, developing basic tools, and providing ad hoc solutions, but unable to exploit those fully (even to push them to market standard) because of the restricted market opportunities.

Even with purely institutional needs in mind, this strategy is likely to prove dangerous when the open market would have finally structured as suggested above : cheap products and consolidated customer experience would make the ad hoc supply mode untenable.

For the ESA newcomers (and even for some of the currently established players), one possible strategy would then be to anticipate on the suggested market evolution and to concentrate efforts on developing generic technologies/products capable of addressing a wider market than space (for example CASE tools, middleware products, ...). Space would be the experimenting ground and one of the funding sources, but requirements and market objectives should reach beyond space right from the start.

9 - Recommendations

ESA's challenge is to direct industry to stable and strong market positions with proper response to the real market needs and to intake the right dose of software-based innovation while respecting the hard requirements of today's competitive satellite making. Below are a number of recommendations which are made in this spirit.

1- ESA could try to foster the gaining of system experience and expertise in the larger software houses.

As a first target, this recommendation can apply to ground systems (which agencies often procure directly) and which are somehow disconnected from the intricacies of space hardware. On the longer term, a larger participation of software specialist firms in the space segment system work could significantly extend the potential for innovation (intake of new IT technologies, spin-in of other domains' successful experience).

On the short term, the aim would be to gradually build system expertise among the larger software houses through adapted procurement strategies, which would place them in a better position to compete in the international market and to bring in their innovation capacity. There are three immediate reasons why this could be a good idea, viz :

- ◆ There seems to be a regular (even if small) flux of newcomers to the satellite services business (communication- or EO-based) which are looking for turnkey system solution providers.
- ◆ There will be a refurbishment market with established SatOps in which system integration (harmonization of heterogeneous systems) will play a major role
- ◆ The trend has been initiated for an independent offer (independent from satellite vendors and/or space agencies) of ground system solutions and products and it seems that SatOps are beginning to see some advantages in such an offer. This means that satellite vendors should become increasingly cooperative to ensure seamless end-customer satisfaction.

One transitory difficulty to solve is the management of technical and financial risks associated with the delivery of ground solutions, which the smaller space players may find difficult to take (customer-imposed liability levels)

2- In cooperation with the national space agencies, ESA could carry out a study of ground system kernels existing in Europe

The objective would be to understand the commonalties and differences between the various kernels and to carry out an in-depth investigation of current and future user needs (both institutional and commercial). This is ground work useful to software vendors in establishing their strategies. It would also be a useful step toward harmonisation of operation practices and associated tools in Europe. No-one but ESA (with european-wide perspective and legitimacy) would be in a better position to do such work at european level.

3- It may be time for ESA to spin off the SCOS effort into industry in addition to developing it for its own needs.

SCOS is a collective effort managed by ESA/ESOC which resulted in expertise scattered in various companies. Even if this setup may be satisfactory to meet the needs of ESA when they arise, it is questionable whether this is the best solution to turn SCOS into a competitive marketable product. Having a market-minded setup in charge of SCOS might be a better solution. However, a careful analysis of the market demand is required (this would be the aim in the previous recommendation) to determine if and how a software company could take the SCOS legacy on-board in view of turning it into a COTS-like product. In particular the size of the non-ESA immediate market

needs to be assessed (it is assumed that ESA procurement would follow the same collective development as used so far, although this could be open for debate). This discussion of SCOS could also be extended to systems other than control (for instance orbitography and mission planning/scheduling)

4- ESA could take the general position that mission exploitation ground systems are (and will increasingly become) primarily a software integrator business and not a derivative of satellite making

There are two problems to solve in this respect. One is that of liability (and possibly credibility) in the large and complex mission centers that are procured by government agencies (EO, meteorology for instance). The other one is to come up with a smooth interface to the satellite system which is firstly essential to develop successful and safe/reliable ground systems, and secondly controlled by the satellite vendor.

5- ESA could look into new mechanisms to facilitate the early integration of small players' technologies and skills in program development

Smaller players often complain that they are invited too late in programs to put their technologies and expertise to bear. Satellite makers complain that ESA sometimes supports small players R&D without looking at the full picture of requirements and needs, resulting in technologies and prototype products which are inadequate or poorly adapted. This in fact links to the more general problem of having large and small actors enhance each other's business through proper harmonisation and communication (extends beyond software).

6- It would be useful for ESA to promote methodologies that facilitate the concurrent engineering of complex systems in a multi-actor environment.

Space systems are likely to remain highly complex for a while, and it is not sure that vertical integration of system vendors is the best answer. New working methods must be experimented along the line of « extended enterprise » models and tools (that can greatly facilitate engineering communication).

Such an initiative could include a review of best practices both in the space domain (« faster-better-cheaper » trend at NASA) and in other sectors like the aircraft and automobile industries.

7- Investigation work (particularly regarding market needs and constraints) and R&D is required to determine the feasibility of « plug-and-play » on-board « intelligence ».

One way to gain freedom from systematic, painstaking and high-cost full custom on-board software development, is to go for « plug-and-play » architectures. This route offers the additional advantage of giving maximum room to equipment suppliers for proposing innovative products, often on the basis of embedded « intelligence ». This is the route taken in the automobile industry (with the OSEK standard), but it remains to be demonstrated (particularly to satellite integrators) that satellite engineering has more to gain with this kind of approach than to loose (by loosing on reliability for instance).

8- Among their needs, ESA could identify software technologies/products which have a generic value to the general software market, and direct their developing suppliers accordingly

The idea would be for ESA to help software suppliers address a wider market than their « piece of space pie » by adapting their requirements (generalizing them, introducing flexibility, ...) and by providing (or instead requiring from) the candidate supplier the right perspective on impacted software technologies/products and markets. This could be a positive way of approaching new ESA members by directing them to niche markets where ESA has or will have a need, but where similar needs also exist in other markets. Those new members could then become less dependent on ESA procurement.