OPERATIONS CONCEPTS FOR SMALL SATELLITES - RESULTS A WORKSHOP -

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Abstract
The concept of small satellite missions has been promoted as a reaction to increasing budget cuts all over the world with the goal to reduce the overall cost for a mission considerably. On how mission operations can contribute to this goal and what are the recommendations was the theme of a workshop initiated by the German Space Agency DARA. Members from mission operations organisations, management, space industry and the user community were invited to share their knowledge and put forward ideas towards effective mission operations concepts for small satellites. The paper presents the results of the workshop comprising recommendations, suggestions, ideas and concept proposals. They include the call for long-term programs with multiple small missions, the identification of cost drivers and proposals for cost optimisation, an integrated approach involving management, development and operations teams, the introduction of risk analysis, the conducting of trade-offs between automation and autonomy, real-time and off-line operations, the use of commercial-off-the-shelf (COTS) products and standards, the reduction of real-time requirements and the implementation of design features in the satellite bus to reduce the cost of operations.

List of Abbreviations

- APL  Applied Physics Laboratory
- COTS Commercial-off-the-shelf
- DARA Deutsche Agentur für Raumfahrtangelegenheiten (German Space Agency)
- DIN Deutsche Industrie Norm
- GPS Global Positioning System
- IEEE Institute of Electrical and Electronic Engineers
- ISO International Standards Organisation
- TM/TC Telemetry / Telecommand

1. Introduction

Small satellites have established themselves in the spectrum of mission opportunities as alternatives to the traditionally big missions. While the latter are plagued with long lead times, low mission frequency and high costs, small satellite missions can be innovative, flexible and cheaper as reported at various symposiums and conferences1. Consequently, this could result in higher frequency of missions. It is also argued that the market for small satellites will rise if the costs can be significantly reduced3.

Against this background the German Space Agency DARA defined the goal of reducing the costs for design, launch and operations of a satellite by 50%, the argument being that the satellite technology is available today and that the launch costs can be reduced because of a wide range of available launchers. Also, in the
field of mission operations DARA has been looking for new ways of how to reduce costs. With this in mind, DARA invited experts from mission operations organisations, management, space industry, the user community and mission-operations-consultancy companies to discuss and develop ideas and impulses for new and more efficient mission operations for small satellites in a workshop.

The theme of the workshop was "More Space-flight for Less Money - How can Mission Operations contribute to this Goal and What are the Recommendations?". The occasion as well as the meeting of the experts to discuss new ideas, concepts and give recommendations were unique in the German space community. The definition of what is a small satellite was deliberately not included in the workshop discussions as this would have diverted the attention from the real issue: saving costs in the mission operations arena. Work was carried out in working groups and presented in a plenary session.

This paper presents the results of the workshop as reported by the participants and published in the proceedings.

2. Mission Operations System

The participants of the workshop were encouraged to use a Mission Operations System model as a common baseline. This model defines the mission operations system as an integral part of a space flight mission. It comprises:

- a ground system, i.e. infrastructure, hardware and software to prepare, conduct and support mission operations
- an operations organisation supplying the necessary personnel and procedures to operate and control the spacecraft

![Mission Operations System Model](image-url)

Figure 1: Mission Operations System Model
• a system on board the spacecraft providing for the exchange of information between the ground, the spacecraft and the payload.

As outlined in the mission operations system consists of functions that are necessary to successfully operate the spacecraft. They co-exist with one another and exchange information. Figure 1 shows the functions of the system as grouped around the central management function.

3. Workshop Results

In a co-operative and creative atmosphere the workshop participants developed a number of proposals, concepts and recommendations. The results were presented in a plenary session and discussed. The major contributions are presented hereafter in the context of the functions of the Mission Operations System model.

3.1. Cost Drivers

As cost is the major concern for small satellite missions, cost drivers need to be identified, analysed and evaluated before recommendations can be reached. Some typical cost driving mechanisms were identified. They include

• complex sponsor requirements with regards to volume, quality, schedule, documentation, service availability and reliability
• low margins and low failure tolerance leaving no room for change
• undue political constraints and non-technical requirements, i.e. high number of interfaces increases overhead and reduces flexibility
• high user expectations, i.e. in real-time data availability
• time constraints, long lead times
• unnecessarily complicated satellites
• too complex missions
• development philosophies not consistent with cost-saving philosophies
• not enough missions - according to the philosophy that more missions can be cheaper
• excessive operations time and coverage requirements.

3.2. Management

Overwhelmingly, the workshop prioritised efforts in the area of Management to be of utmost importance for reducing cost. Management in this sense is not restricted to Mission Operations but incorporates the mission as a whole as well as political and programmatic leadership.

Political and Programmatic Management

In order to achieve the required cost-effectiveness long-term programs and funding commitment are required by the political leadership and the agency responsible for program management. Additionally, it was deemed necessary that in the German environment a national consensus on space programs should be reached by the politicians responsible for vision and budget, the program management, the national aerospace facilities and the aerospace industry.

The call for long-term programs includes planning for multiple scientific small missions, the argument being that more missions can

• reduce the total development costs by reducing the effective cost per unit
• allow for a steep learning curve by learning from errors
• introduce flexibility
• facilitate long term strategic planning
• provide for continuity
• allow for better utilisation of people, hardware and resources.

Mission Management

The concept of integrated missions has been widely discussed in the industry for some time now\(^\text{5,10,11}\) to help reduce costs. In order to be able to introduce integrated mission concepts a
strong and committed management is required. The integrated mission requires that:

- communication takes place between all levels of a project and at all times
- interfaces are co-ordinated
- the aspects of mission operations are introduced into the project as early as possible, i.e. operations should participate from the very start of a project and not be left to "inherit" a satellite as often happened in the past
- effective cost and success control mechanisms are installed
- trade-offs are performed to find the optimal solution, e.g. risks vs. reliability, commercial-off-the-shelf products vs. specific developments, cost vs. performance, cost vs. mission objectives, autonomy and automation vs. mission control requirements
- the aspects of standards and standardisation are considered.

Additionally, small and effective teams in a flat hierarchy and provided with competence can enhance the effectiveness of a project. These teams need to operate in an environment set up for short decision paths, and decision making processes need to be optimised, e.g. no changes are allowed after the design has been released.

The introduction of standards must be planned and it is the task of the management to ensure their acceptance by everyone involved. In fact, standards should be developed by the users. It has to be taken into account that the implementation of standards may not be effective in all situations. It was suggested that common standards be made mandatory, e.g. ISO, IEEE, ANSI, DIN. Project management has to assess the applicability of standards on a case by case basis, e.g. whether investments for standardisation are worthwhile for a stand-alone system, or whether to introduce standards for life cycle control and/or coding.

The time for mission development, i.e. from conceptualisation to launch, should be drastically reduced to less than two years. This improves motivation, minimises development costs, assures timeliness, adds pressure to simplify, reduces the administrative burden and call for new documentation techniques or at least improving on documentation.

Management should plan for optimisation of mission duration and its exploitation. This ensures the maximum return for minimum cost. However, this is contrary to funding cycles in which budgets are allocated for short periods of time rather than whole projects. Also, this requires discipline not to keep changing requirements.

Management should define the mission risk and the permitted degradation of a mission. This will directly influence redundancy and margin concepts.

A recommendation was put forward to contract the mission as a whole, i.e. spacecraft, payload, launch and operations. This would enable management to optimise the whole system in contrast to optimisation of a partial system.

Overall, management efforts, the definition of clear policies, and overall communication within a project can clearly contribute to cost savings in all aspects of a space project. This is not restricted to small satellite projects or even only for mission operations but it should be much easier to be implemented for small satellite missions.

### 3.3 Mission Control and Activity Planning

In the areas of Mission Control and Activity Planning ideas were put forward to make effective use of existing facilities, software, hardware and know-how.

Cost efficiency can be achieved by avoiding shift operations or by limiting the shift personnel to one-man operations. This can be achieved by design features in the satellite, the ground segment and relaxation of the requirements, i.e. automation, routine operations by
the experimenter, off-line monitoring, separation of satellite bus and payload operations.

Simulations could be used throughout a project to support trade-off studies, team training and to validate the ground system and procedures before launch, thus improving the evaluation of test results and saving time. Indirect cost savings could thus be achieved by having a tested system with less error likeliness and better trained personnel.

3.4. Data Transfer and Data Processing

In the areas of Data Processing and Data Transfer cost reductions could be achieved by using COTS, reducing real-time requirements and the introduction of data transfer standards. Direct routing of payload data together with data archiving optimisation concepts could further contribute to the overall goal.

The number of communication links and the effective downlink data rate for the transfer of telemetry and command (TM/TC) and payload data should be minimised, i.e. ideally only one link should have to be available. Abandoning redundancy contributes to cost reductions.

3.5. Engineering

Efforts in Engineering should concentrate on

- minimisation of documentation
- introduction of standards
- compatible interfaces between industry and operations, e.g. compatible data bases for data and procedures at different locations.

Additionally operations experts should participate in the check-out of the system. An integrated project development team for both ground system development and on orbit operations could provide the motivation, continuity and the chance to achieve best trade-offs. The goal should always be to find the simplest technical solution.

The commonality of the equipment used for satellite check-out and mission operations should be put to advantage. Telemetry, telecommand and data processing functions are common to the check-out equipment and mission operations. Thus, the transfer of this equipment to operations after the completion of the check-out eliminates the need for procurement of near-identical equipment at the operations facility.

3.6. Orbit and Attitude

The Orbit and Attitude functionality could be increased by

- the usage of the Global Positioning System (GPS) as a substitute for ground stations
- involving the user in the activities
- a careful analysis of the orbit and attitude requirements as to what is really needed and what can be omitted, e.g. a number of small satellites may not need expensive attitude control mechanisms.

It should also be analysed how standardisation of sensors and actuators can be employed as well as the type of mission according to attitude control, i.e. scan mission vs. pointing missions.

3.7. Planning the Satellite Bus and Payload

Planning the satellite bus efficiently can influence operations, i.e. operations functions are transferred to the satellite to increase autonomy. The amount of autonomy is largely dictated by the payload requirements, e.g. data dumps, safemode, timeline requirements. It should be considered whether payload operations can be conducted without real-time interactions from the ground. The autonomy concept requires early integration into the whole mission concept. It directly influences the operations concept, i.e. shifts, ground stations, etc.

4. Conclusion

The DARA workshop on “Mission Operations Concepts For Small Satellites” brought together experts from all fields of spaceflight and
provided the unique opportunity for discussing "across the board". In order to achieve the goal "More Spaceflight for Less Money" and the projected 50% cost reduction the workshop unilaterally called for long term program commitment with multiple small satellites. Cost drivers were identified and recommendations, ideas and concepts put forward of how to reduce costs. An integrated team approach involving mission management, satellite development, payload and operations was seen as the most suitable way to conquer the complex tasks of risk analysis, trade-offs, questions of autonomy and automation, reduction or relaxation of requirements, reduction of real-time requirements, acceptance of degradation in the mission, the use of COTS and standards in order to reduce the cost of mission operations.

Finally, it was suggested that a possible solution to the dilemma of the space industry struggling for new ways of how to do business in a budget-tight environment could be found by a) looking back to how things were done in the very beginning of spaceflight and b) trying to solve the riddle:

"Why are a lot of common-sense requirements neglected in many space projects?"

The reports from the working groups will be used for inputs to DARA's future work. DARA has been analysing the results and will start to implement as much as possible of the workshop results into their future work. A follow-on meeting is planned for 1997 to check the results of the efforts.

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