Reducing the Cost of the Long Operations Tail

Rick Blake[1], Alastair Pidgeon[2]
SciSys PLC, Methuen Park, Chippenham, Wiltshire, SN14 0GB, Great Britain

The inherent reliability of scientific spacecraft coupled with creative solutions to failures, degradation and other contingencies means that the vast majority of missions continue well beyond the date scheduled for the end of nominal operations. This *long operations tail* brings great benefit in terms of additional science data but, the average mission duration extension of over 300% for recent ESA missions, can make financial planning difficult for operators and funding organisations alike. Furthermore, the resulting extra costs of the operations phase for flying missions are increasingly seen as a cause for delaying new programmes. Examination of historical data on mission extensions suggests that early consideration of mission extensions would allow long-term operations costs to be minimised via alternative operations concepts and modification of the system design to support these. We propose an approach to ensure that new missions analyse, plan for and factor-in possible extensions from the start meaning that operations concepts, tools and extension plans are in place to minimise the costs of all aspects of extended mission operations (including costs of spacecraft & science operations and telecommunications).

I. Introduction

The inherent reliability of scientific spacecraft coupled with creative solutions to failures, degradation and other contingencies means that the vast majority of missions continue well beyond the original date for the end of nominal operations. This *long operations tail* brings great benefit to the science community in terms of continuing high-quality science data, giving extended coverage over a complete natural cycle (e.g. the 11-year solar cycle) or additional cycles (e.g. Martian year) and providing data continuity/coherence between successive missions (e.g. Ulysses, Cryosat II and SOHO). Conversely the average mission duration extension of over 300% for recent ESA missions, can make financial planning difficult for operators and funding organisations and the increased costs of the operations phase for flying missions are also increasingly seen as a cause for delaying new programmes.

Compared with the cost of the overall mission, the individual mission extensions are not necessarily expensive, but:

- Some missions are extended numerous times, so the cumulative costs add-up.
- Spacecraft and Science Operations may not be optimised to minimise costs for a long-duration mission.
- Prime contractor support also needs to be extended.
- Mission extensions are not always easy for funding authorities to plan for and the extensions have to compete with other deserving science projects, including new missions.

Most funding for science missions is based on the nominal mission lifetime. In this context, the mission operations are typically budgeted at around 10% of the overall mission cost. Where there is a long operations tail, as in fact there is for almost all science, EO and navigation missions, the proportion of the mission cost attributed to mission operations can rise substantially.

For future missions programmatic changes are needed to ensure that mission extensions are considered early to allow long-term operations costs to be minimised via alternative operations concepts and modification of the system

[1] Senior Consultant, SciSys Space Division
[2] Business Manager, Space Division

design to support these. Ultimately activities need to be incorpoarted in the operations phase to capture knowledge and progressively reduce the resources required to fly the mission safely during any potential mission extensions.

In this paper we describe the causes of the long operations tail and present historical evidence of its existence. Subsequently we outline analysis of recent missions which suggests possible changes to operational concepts, tools, procedures or technologies relevant to reducing the cost of longer duration missions, using ESA's SMART-1 as an example. Finally we identify potential programmatic changes to ensure the definition of appropriate strategies for mission extensions early in the mission design.

Through all of this the ultimate goal is the reduction of life-cycle costs of the complete mission, including possible extensions, while maintaining an acceptable level of mission safety as well as science data return and quality.

II. Evidence for the Long Operations Tail

Scientific spacecraft and their payloads are usually designed very conservatively to maximise reliability and to meet their required design life. In addition, the nominal spacecraft mission life is often set well below the design life of the spacecraft. Coupled with some creative work from the operations engineers in response to failures, degradation and other contingencies, the spacecraft and payloads can last much longer than the nominal design life and continue to generate high-quality scientific data for the Principal Investigators (PIs) and the wider academic community.

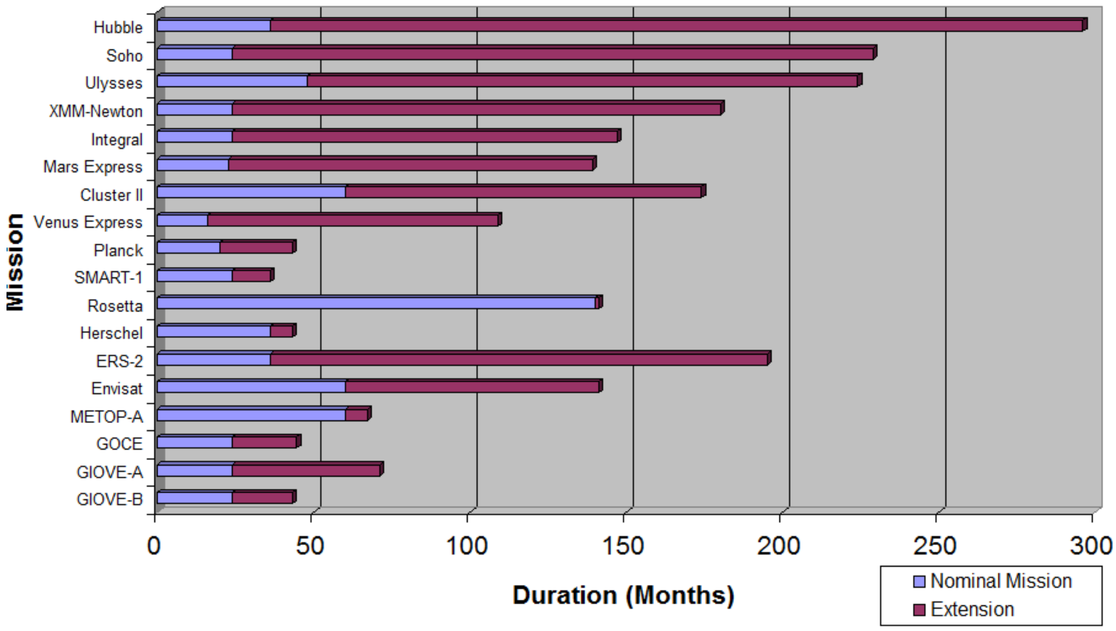


Figure 1. Recent ESA Mission Extensions[2]. *The average total mission extension for ESA missions over the last 2 decades exceeds 300%.*

Fig. 1 shows compelling historical evidence that almost all recent ESA science missions have continued, or are continuing, well beyond the date originally defined for the end of nominal spacecraft and science operations. This is reiterated below in tabular form (Table.1) for recent ESA science and also for Earth Observation (EO) and Navigation missions.

Table 1. Recent ESA Mission Extensions. *Showing actual versus nominal mission duration - based on data as of April 2012.*

Mission Type	Mission	Launch Date	Nominal Duration (Months)	Nominal End	Current End	Extension (Months)	Total Duration (Months)	Extension %
Science	Hubble	Apr 1990	36	Mar 1993	Dec 2014	260	296	**722%**
	Soho	Dec 1995	24	Nov 1997	Dec 2014	205	229	**854%**
	Ulysses	Oct 1990	48	Oct 1994	Jun 2009	176	224	**367%**
	XMM-Newton	Dec 1999	24	Nov 2001	Dec 2014	156	180	**650%**
	Integral	Oct 2002	24	Sep 2004	Dec 2014	123	147	**512%**
	Mars Express	Jun 2003	23	Apr 2005	Dec 2014	116	139	**515%**
	Cluster II	Jun 2000	60	Jun 2005	Dec 2014	114	174	**190%**
	Venus Express	Nov 2005	16	Mar 2007	Dec 2014	93	109	**581%**
	Planck	May 2009	20	Dec 2010	Dec 2012	23	43	**115%**
	SMART-1	Sep 2003	24	Aug 2005	Sep 2006	12	36	**50%**
	Rosetta	Mar 2004	140	Oct 2015	Dec 2015	1	141	**1%**
	Herschel	May 2009	36	Apr 2012	Dec 2012	7	43	**20%**
Earth Observation	ERS-2	Apr 1995	36	Mar 1998	Jul 2011	159	195	**442%**
	Envisat	Mar 2002	60	Mar 2007	Dec 2013	81	141	**135%**
	METOP-A	Oct 2006	60	Oct 2011	May 2012	7	67	**12%**
	GOCE	Mar 2009	24	Mar 2011	Dec 2012	21	45	**85%**
Navigation	GIOVE-A	Dec 2005	24	Dec 2007	Jun 2011	42	66	**175%**
	GIOVE-B	Apr 2008	24	Apr 2010	Jun 2011	14	38	**58%**

III. Survey of Mission Histories

To help identify additional Phase A activities that consider possible mission extensions, it will be helpful to analyse a range of previous and current missions. The aim of this analysis is to identify and document potential operational cost reduction strategies for long duration missions for a range of mission types (e.g. LEO, Observatory and Interplanetary). Of particular interest are those strategies that are generic in nature, having application across a number of missions rather than those that are specific to a given mission's needs.

An outline operational history would be constructed for each mission which describes the evolution of the space/ground segments and associated operations including the dates and costs associated with any potential or actual mission extensions. The cost analysis in particular allows comparison of the planned and actual costs as a proportion of the overall mission expenditure.

This survey of mission histories involves collection of mission operations data for a selection of different mission types that have been extended, with particular focus on actual or potential evolution of:

- Operational practices.
- Structure and size of operations teams.
- Tool support for mission operations.
- Space and ground based automation.
- Ground station usage.

1. Sources of mission operations data

A prime source of information is the regular Mission Status Reports produced by all flying missions as these describe both the progress of the missions along with any space or ground segment developments that are in hand to support it. Other documentation that will help to determine how mission operations have evolved include :

- Procedures – particularly the change history showing how the set of procedures for flight control, flight dynamics, ground operations and science operations have changed over time.
- Reports on anomalies and solutions. In particular an analysis on the rate of detection/resolution of operational anomalies over the mission lifetime is of interest. Typically this analysis gives rise to a *bathtub* curve[7] with an initial high rate of anomalies during commissioning and early operations, a lower stable, lower rate during routine operations and an increase later in the mission as equipment degrades and, if the mission is extended ultimately passes it's design lifetime.
- Summaries of operation experience and lessons learnt produced when engineers leave the project, during key reviews or at the end of the mission.
- User Manuals for ground based tools such as mission planning, Flight Dynamics product generation and science data processing - particularly the change history showing how the software may have developed over time.
- Change history of the on-board software showing how it has evolved during the mission lifetime.
- End of Mission report (if available).
- Published papers relating to evolution of mission operations.

Most flying missions also have sources of operational knowledge that exist initially outside of the scope of formal documents such as the Flight Operations Procedures (FOP). This information may take the form of a configuration controlled Helpbook used by on-console operators and engineers which captures the essential operational knowledge that evolves on a continuous basis as the mission proceeds. Such a document essentially provides:

- Shortcuts to the small set of formal procedures required to day-to-day operations.
- Information relating to particular monitoring that is in progress at present (e.g. enabling of additional TM packets to support long term analysis).
- Information relating to any potentially anomalous behaviour that has been observed.

Aside from documentation an equally important source of information are the operators and engineers involved in the day-to-day mission operation across the full spectrum of ground segment operations including:

- Flight Control
- Flight Dynamics
- Ground Operations
- Science Operations
- Prime Contractor and associated specialists
- Project Team

2. Evolution of Operational Concept and Technical Solutions

By analysis of the collected mission operations data described above it is possible to understand how the knowledge of a potential mission extension impacted on the mission operations concepts and technical solutions in the space/ground segments. Specifically were any of the following envisaged or developed:

- New or revised operational concepts specifically designed to optimise operations.
- New procedures to simplify or streamline existing processes.

- Reduction in the ground station usage (e.g. fewer passes).
- Additional ground based automation to reduce the level of manual interaction and ensure consistency in future operations.
- Additional space based automation or timelines to reduce the requirements for contact with the ground for the purposes of TM/TC.
- Changes to working practices such as manning of flight control consoles during office hours only.
- Introduction of technology to reduce the need for continuous manned operations, such as automated anomaly detection tied to SMS messaging.
- Tools to support on-going analysis of mission data such as expected or anomalous degradation of equipment over time.
- Reduction of team size by merging of responsibilities.

At an agency level it is noted that different national and international space agencies will have different approaches for the support of mission extensions. Examination of these approaches will help to summarise the strategies, tools, concepts and practices for supporting long duration missions in a cost effective manner. Common strategies may include:

- Introduction of new operations concepts for new missions covering the whole of the mission or extensions.
- Revision of operations concepts/procedures for existing missions to streamline existing processes.
- Reduction of ground station support by increasing the level of space segment autonomy or by modifying scientific aims or mission planning strategy.
- Use of common tools across missions to avoid excessive training costs.
- Use of automation and/or additional tool support to perform routine tasks to reduction of manpower required to safely fly the mission.
- Modifying roles and merging responsibilities to allow multiple spacecraft that are in their routine operations phase or nearing end-of life to be controlled by a single team. This could result in significant cost savings even if it is only the operator roles that are combined or if an engineer can offer subsystem specific support across a number of missions. A key point here would the harmonisation of tools across missions as mentioned above to allow a common set to be used for extended operations.
- Inclusion of activities in the operations phase to capture knowledge and progressively reduce the manpower and resources required to fly the mission safely. In this way at the point where a decision is required on any mission extension the operations will have been naturally refined to a point where they are lean, efficient and safe - forming a sound, cost effective basis for continued operations.

In looking at the different approaches for reducing manpower it will be noticed that a common thread running through many of them is that operational knowledge is effectively being captured within the system with a corresponding reduction in the requirements for manual intervention. While this is an excellent overall strategy for reducing the long term cost of operations it is important that the information being captured remains visible and can be extracted for consideration by human operators should the need arise. It is essential to avoid the nightmare scenario of an highly efficient and automated mission encountering a new anomaly long after all the engineers required to analyse it have moved on to other things. To protect against this various strategies may be employed, including:

- Maintaining the visibility of captured knowledge (e.g. as human understandable procedures).
- Refresher Training Days that periodically reunite past and present engineers for a given mission to review mission status, discuss recent anomalies and trends and conduct simulations focusing on recent and upcoming developments.

- Ensuring engineering support in depth by defining advisory roles for engineers leaving the project with a structured, documented handover of responsibilities to the team that remains in place.
- Retention of at least one dedicated engineer for each mission who can drawn on an extended pool of mission expertise as required to assist with the analysis of new anomalies and trends.

IV. SMART-1 Extended Mission Case Study

1. Mission Overview

SMART-1 was the first of ESA's Small Missions for Advanced Research in Technology[1] (SMART), with the primary goal of demonstrating the use of solar electric propulsion (SEP) and other scientific instrumentation on an inter-planetary mission to the Moon. The spacecraft was launched in September 2003 with a nominal mission duration of 24 months.

Consideration of extending the mission began shortly after entry into lunar orbit and the Lunar Operations Readiness Review in November 2004 since the combination of a favourable launch date, lower than expected degradation of the solar arrays and correspondingly improved performance of the SEP had given rise to more fuel than was needed to attain the baseline orbit defined for scientific operations[3]. A strategy based on initial optimisation of the orbit to improve the scientific return and allow more extensive use of a number of innovative observing modes, followed in September 2005 by an orbit reboost to extend the mission by a total of 12 months was defined, unanimously endorsed by ESA's Science Programme Committee and successfully implemented.

Towards the end-of-mission the different spacecraft sub-systems were variously affected by the changing orbit and close proximity of the Moon. Operations finally ended with a spectacular planned impact of the spacecraft on the lunar surface in September 2006, almost exactly 3 years after launch and a full 12 months after the original date for the end of operations.

SMART-1 has been chosen for this case study not only because it was the subject of a mission extension but because even in the timeframe of the nominal mission a number of initiatives were aimed at optimising the effort and expenditure required to fly what was always envisaged as a low cost mission.

2. Optimising Flight Control Activities

Operational experience gained on the SMART-1 mission shows that, as the mission progressed, operations became more routine and the scope for reducing the effort required to fly the mission safely was increased[4]. The reduction in effort was facilitated in the following ways:

- The operational roles of spacecraft controller (SPACON) and spacecraft operations engineer (SOE) within the Flight Control Team (FCT) were combined from the very start and on-console support from the FCT was rapidly reduced to the level of office hours only.
- During the routine phase of the mission it was possible to merge the engineering responsibilities of individual members of the FCT as emphasis moved away from real-time monitoring and control towards higher level supervision and reporting engineering. This allowed engineers to start taking responsibility for multiple subsystems, releasing effort for deployment on other activities or missions. This was particularly true where there a natural synergy existing between subsystems e.g. TTC and Data Handling.
- Automation of procedures which had become routine, including well understood contingency recovery activities using a combination of the Mission Planning System and an evolving Ground Operations Automation System (GOAS). By the end of the extended mission routine operations associated with contact handling, data download and some real-time anomaly diagnosis had been successfully automated.
- Ongoing update of the mission planning system to the point where it generated 95% of all of the commands required for platform and payload operations.

- Additional tool support in the preparation or analysis of operational data. For example consistency checking of mission planning inputs and automated tracking, correlation and analysis of telemetry parameters relating to equipment degradation
- Tool support for the export, analysis and visualisation of spacecraft telemetry and ancillary mission data via the internet. In the case of SMART-1 this was provided by accelerated development of the experimental Mission Utility Support Tool (MUST) during the mission operations phase co-funded by the ESA General Studies Programme.

The above analysis focuses only on the activities performed by the Flight Control Team. It is envisaged that a wider analysis would reveal comparable optimisations with regard to flight dynamics, science operations and exploitation, software support, network and ground station operations.

3. Implications of the mission extension

The previous section identifies strategies introduced to reduce the effort and cost required to fly the mission safely. Conversely exploiting the scientific opportunities offered by the revised/extended mission required additional effort, for example:

- Several months of simulation and procedure development to prepare for the orbit reboost required for transition to the extended mission. The transition itself then took 2 months (August/September 2005) to complete.
- Redesign of the operations concept and onboard data handling software to cope with vastly increased volumes of payload data and commanding due to lunar orbit duration of 5 rather than 15 hours. This effort was offset by corresponding enhancement of the mission planning/automation systems to remove much of the work associated with telecommand generation and data download from the FCT.
- Replacement of the baseline 2x8 hour ground station contacts per week with an approach based on use of spare capacity in the ESTRACK network. This proved to be highly cost effective and very beneficial for the routine operations, anomaly recoveries and with regard to the increased volume of payload data during the revised/extended mission. On the negative side, planning mission operations to be consistent with a continually changing ground station contact pattern was for a time one of the most demanding activities for the FCT.
- Analysis of pointing constraint and revision of attitude profiles to increase the time available for multi-spectral imaging.
- Studies by ESTEC of the influence of the Moon on the thermal balance of the spacecraft during the final mission phase requiring specific off-pointing of the solar panels.
- Analysis by the spacecraft manufacturer of revised attitude profiles at low lunar altitude to avoid star tracker blinding.
- Operational support for imaging of the Moon at low attitude using the star tracker cameras.
- Novel use of the hydrazine subsystem to support a second orbit reboost phase towards the end of the mission to ensure that the spacecraft impacted on the near side of the Moon during ground station visibility.

V. Programmatics

The lifecycle of a space mission is divided into several phases[5] from initial operational and feasibility assessment through design, production, validation, operations and finally disposal. If mission extensions are to be properly taken into account then additional analysis must be integrated in Phase A activities which defines draft operations concepts and ground segment baselines. This analysis is then elaborated through subsequent phases right through to Phases E/F which cover LEOP, commissioning, routine operations, mission extensions and disposal.

1. Phase A : Mission and operational analysis, feasibility studies and conceptual design

For future missions the programmatic aspects of planning for mission extensions during Phase A studies will be of primary importance and need to be integrated into the mission analysis and operations concept definition activities which are key parts of this phase. The underlying concept is an extension of the Phase A analysis to look at the probable costs across the whole potential mission, including how the operational phase of a mission might be structured to support potential mission extensions. This examination then leads to development of strategies and plans to minimise the resulting full-lifecycle mission operations costs and to ensure that the transition from routine operations to the initial mission extension and beyond is efficient and cost effective.

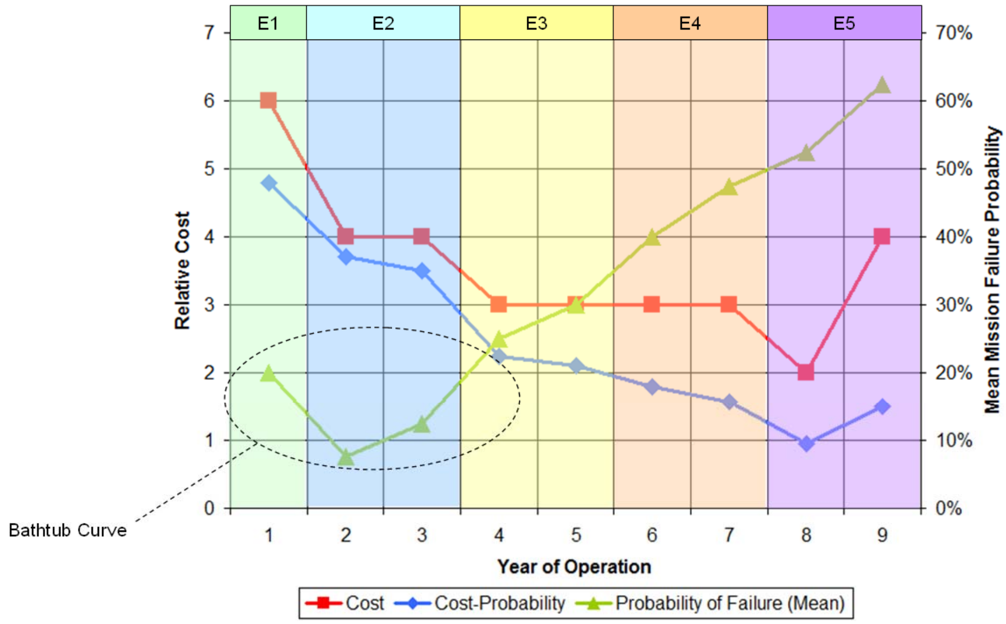
Phase A analysis is typically based on the assumption that after the completion of Operational Readiness and Flight Readiness Reviews (ORR/FRR) the mission consists of the following phases and sub-phases[4]:

- Mission Operations Phase E
  - E1 LEOP/Commissioning sub-phase, covering launch, early orbit and commissioning.
  - E2 Routine Operations sub-phase covering operations up to nominal end of the mission.
- Disposal Phase F covering mission termination and space/ground segment disposal operations.

We propose that Phase A analysis be augmented to identify additional sub-phases of the mission operations (Phase E) to cater for potential extensions of the nominal mission and/or subsequent *twilight* extensions with revised mission objectives. This gives rise to a set of mission operations sub-phases E*1* to E*n* whose definition will be driven by:

- The proposed mission objectives/scientific return for each sub-phase. These objectives may be a simple continuation of the nominal mission perhaps giving extended coverage over one or more complete natural cycles, a revision of the orbit and/or attitude profile with revised scientific goals or they may relate to the provision of data continuity/coherence between successive missions. In looking at revised mission/science objectives the costs associated with ground support for the required mission/science operations must be assessed.
- Revision of nominal operations concept and technical solutions for each sub-phase with an assessment of the associated costs. This may include:
  - The concept of non guaranteed service during later *twilight* phases as expensive data recovery mechanisms and resources are descoped.
  - Modification of mission planning/onboard timeline requirements and strategy to reduce the frequency of mission planning cycles and ground station contact.
  - More flexible requirements for contact with increased dependency on spare capacity in the ground station network.
- Analysis of the transition to each sub-phase including required initial conditions, duration of transition activities and any associated risks.
- Requirements for on-board software upgrades to exploit new opportunities or support revised operations concepts.
- Requirements for ground segment upgrades in the timescales implied by each extension.
- Overall assessment of the technical/programmatic feasibility of supporting each sub-phase.
- Reliability engineering to assess the probable failures during initial operations (early failures), during routine operations (random failures) and most importantly in the later stages of the mission as equipment degrades and starts to fail (wear out failures). Such analysis frequently gives rise to the widely accepted bathtub curve[7] of hypothetical failure rate versus time. This allows correlation of likely failures with each sub-phase along with their probability and the possibility/cost of continuing the mission in the event of these failures. At the same time it must be ensured that none of the defined mission operations sub-phases pose an unacceptable risk to conduct of the required space segment disposal activities (phase F).

It is proposed that a key output of the reliability engineering activity be a *Cost Probability Profile* which combines the estimated cost of each year of possible mission operations with the probability that the mission will not suffer a failure from which it is not possible or cost effective to continue. An example of such a profile is shown in Fig.2 using artificial data which highlights how application of the probability of failure (green) to the raw estimates of mission operations cost (red) result in the cost-probability profile (blue).



		LEOP & Commisioning	Routine Operations		Extended Routine Operations		Revised Science Operations 1		Revised Science Operations 2	
Year of Operation		1	2	3	4	5	6	7	8	9
Relative Cost		6	4	4	3	3	3	3	2	4
Mission Failure Probability	Min	15%	5%	10%	20%	25%	30%	35%	40%	45%
	Max	25%	10%	15%	30%	35%	50%	60%	65%	80%
	Mean	20%	8%	13%	25%	30%	40%	48%	53%	63%
Cost Probablity		4.80	3.70	3.50	2.25	2.10	1.80	1.58	0.95	1.50

Figure 2. Cost-Probability Profile. *Cost-Probability provides a year-on-year estimate of overall mission cost for each mission operations sub-phase, taking into consideration the probability of mission failure over time.*

2. Phase B-D : Design, Production, AIT and Verification

Throughout the design, production, test and verification, phases the operations concepts defined in Phase A will be elaborated, the operations organisation will be defined and the required mission operations data produced and verified. In parallel the individual ground segment systems will be designed, implemented, integrated and tested.

Based on the augmented Phase A analysis these concepts, systems and associated operations data will still be targeted primarily at the LEOP/Commissioning and Routine operations sub-phases but now with a clear evolutionary path for support of subsequent mission extension sub-phases.

3. Phase E : Mission Operations

For ESA the ECSS Ground systems and operations standard[5] defines the ground segment/operations engineering process and associated reviews for a mission operations phases split into the basic E1/E2 sub-phases, as described above. These processes include the following activities which require revision to support the concept of additional mission extension sub-phases:

- Space segment performance and trend analysis: must be correlated with the output of reliability analysis initiated in Phase A to ensure that transition to subsequent sub-phases is not impacted.
- Handling of space and ground segments anomalies: must also be correlated with the output of reliability analysis to ensure that planned transitions to subsequent sub-phases are still valid.
- Mission operations data production: now includes revision of mission operations data and plans to support subsequent sub-phase.
- Ground segment maintenance: now includes maintenance and upgrade processes associated with support for operations in the next sub-phase. Obsolescence management and migration activities may have higher precedence based on better visibility of future mission extensions.

With regard to formal reviews in a mission operations phase that is segmented into multiple sub-phases:

- All of the reviews associated with the E1 LEOP/Commissioning sub-phase remain.
- The scheduling and focus of In-Orbit Operations Reviews (IOORs) which assess the performance of both space and ground segments needs to be geared to the duration of each sub-phase and the requirements of subsequent sub-phases. The outcome of the IOORs may drive revision of future sub-phases, for example unexpected equipment degradation/failure, the desire to implement lessons learnt from operational experience or to exploit unforeseen technical/operational opportunities.
- A new Sub-Phase Readiness Review (SPPR) will be required prior to the transition from one mission operations sub-phase to the next. The aims of this review will be similar to the Flight Readiness and Operational Readiness Reviews (FRR/ORR) conducted prior to launch but focused on verifying that the objectives of the current sub-phase have been met and the readiness of the space/ground segments, operations teams and data to support transition to/operations in the next sub-phase.
- The End of Life Review (ELR) at the end of the final mission operations sub-phase and Mission Close-Out Review (MCR) at the end of the disposal phase remain.

Fig 3. below summarises this review activity.

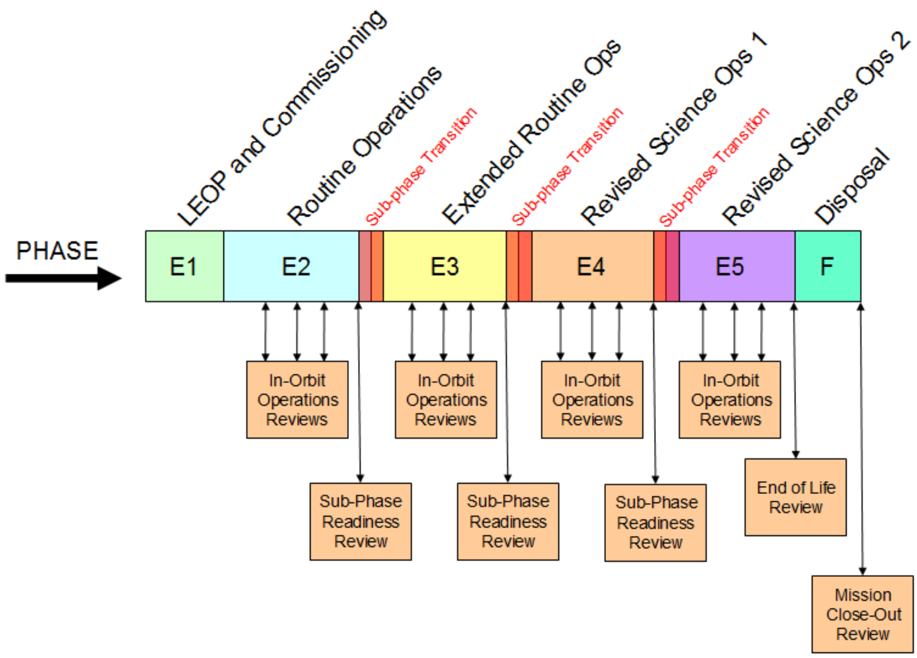


Figure 3. Example of Revised Phase E/F Programmatics. *Showing multiple mission operations sub-phases and associated reviews. Note the reviews in sub-phase E1 are as defined in by the appropriate ECSS standard*[6]

VI. Conclusion

Our work to date has looked at the programmatic aspects of analysing and planning for mission extensions during Phase A mission studies. To underpin this we have defined an approach based on examination of mission histories in order to identify a range of potential changes to operational concepts, tools, procedures or technologies relevant to reducing the cost of a longer duration mission. This approach has been used to analyse the operational history of a recent ESA interplanetary science mission, namely SMART-1.

Preliminary analysis has identified areas where we believe mission operations costs could have been reduced if the prospect of mission extensions had been addressed during the mission design. More comprehensive analysis would help to formalise guidelines and recommendations to:

- Enable missions to address long-term operations costs right from the start by defining and then elaborating operational concepts and technical solutions to minimise them.
- Allow funding authorities such as ESA, national agencies, national science bodies and the European Commission to plan their future finances and have confidence that additional costs will be minimised - not just for one mission but spread over all of the missions that are going to fly.

.

Appendix A
Acronym List

AIT	assembly, integration and test
CNES	Centre National d'Études Spatiales
DLR	Deutsches Zentrum für Luft- und Raumfahrt
ECSS	European Cooperation for Space Standardisation
ELR	End of Life Review
EO	Earth Observation
ESA	European Space Agency
FCT	Flight Control Team
FOP	Flight Operations Procedures
FRR	Flight Readiness Review
GOAS	Ground Operations Automation System
IORR	In-Orbit Operations Review
LEO	Low Earth Orbit
LEOP	Launch and Early Orbit Phase
MCR	Mission Close-Out Review
ORR	Operational Readiness Review
PI	Principle Investigator
SOE	Spacecraft Operations Engineer
SMART	Small Missions for Advanced Research in Technology
SPACON	Spacecraft Controller
SPPR	Sub-Phase Readiness Review
SMS	Short Message Service
TC	Telecommand
TM	Telemetry
TTC	Telemetry, Tracking & Control

Appendix B
Glossary

Long Operations Tail	The continuation of payload and spacecraft operations beyond the end of the nominal mission lifetime.
Mission Operations	Operations associated with monitoring and control of both the scientific payloads and the spacecraft platform on which they are flown.
Science Operations	Operations associated with monitoring and control of scientific payloads.
Spacecraft Operations	Operations associated with monitoring and control of the spacecraft platform.

References

Reports, Theses, and Individual Papers

[1]Camino O., de Bruin J., Schoenmaekers J., Rathsman P., Kugelberg J., Bodin P., "SMART-1 Impact on the Moon", ESA Bulletin 131, August 2007

[2]ESA, "Programmes in Progress", ESA Bulletin 149, February 2012

[3]de Bruin J., et al., "SMART-1 Lunar Mission: From Capture to Impact", IAC-06-A3.6.6, Proceedings of the 57th International Astronautical Congress, Valencia, Spain, Oct. 2-6, 2006,

[4]Camino O., et al., "SMART-1 Operations Experience and Lessons Learnt", IAC-06.B5.3.8, 57th International Astronautical Congress, 2-6 Oct. 2006, Valencia, Spain.

Books

[5]ECSS, "Space Engineering – Ground systems and operations", ECSS E-ST-70C, July 2008

[6]ECSS, "Space Project Management – Project planning and implementation", ECSS M-ST-10C, March 2009

Electronic Publications

[7]Jenkins D.J.,"The Bathtub Curve and Product Failure Behavior," *Reliability HotWire* [online journal], Issue 21, November 2002, URL: http://www.weibull.com/hotwire/issue21/hottopics21.htm