6th International Symposium

Reducing the Costs of Spacecraft Ground Systems and Operations (RCSGSO)

Programme & Abstracts

ESOC, Darmstadt, Germany
14-17 June

Organised by
The European Space Agency

European Space Agency
Agence spatiale européenne
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FOREWORD

Space Operations are becoming increasingly demanding due to the increased functionality of today's spacecraft and their payloads, the longer and more complex mission profiles (requiring long-term maintenance of specific knowledge), the evolution of open-source products at the heart of ground-segment infrastructure design, etc. All of this calls for careful rationalisation of Ground Systems and Operations so as to constrain overall mission costs, whilst still satisfying the fundamental mission requirements.

The RCSGSO Symposium provides a unique international forum for Ground Systems and Operations specialists for a constructive exchange of ideas on the above issues. Its primary objective is to highlight and discuss methodologies for and examples of increased efficiency in ground-segment development, validation and mission operations. The topics covered range from programmatic aspects to the detailed design of:

- TT&C Systems
- Autonomous Operations
- Interoperability
- Mission Operations
- Data Processing & Archiving
- Small-Satellite Support
- Mission Planning
- Mission Control Centres
TECHNICAL AND ORGANISING COMMITTEE

Chair: Mr. Paolo Maldari
European Space Agency (ESA/ESOC)

Mr. Leslie J. Deutsch
Jet Propulsion Laboratory (NASA/JPL)

Mr. Barry Geldzahler
National Aeronautics and Space Administration (NASA)

Mr. Peter Allan
Rutherford Appleton Laboratory (RAL)

Mr. Kaneaki Narita
Japan Aerospace Exploration Agency (JAXA)

Mr. Ravil Nazirov
Russian Academy of Sciences (IKI)

Mr. Luca Salotti
Agenzia Spaziale Italiana (ASI)

Mr. Dan Showalter
Canadian Space Agency

Mr. Jean Marc Soula
Centre National d'Etudes Spatiales (CNES)

Mr. Joseph Statman
Jet Propulsion Laboratory (NASA/JPL)

Mr. Paolo Strada
European Space Agency (ESA/ESTEC)
DIRECTIONS TO ESOC

- **By Car:** From the autobahn A5 or A67 exit at the Darmstadt Kreuz, and follow the signs toward Stadt Darmstadt. Having exited the highway, take an immediate right just after you pass under a bridge. Follow this road around and over the bridge, then taking the first right. Take the next left and the ESOC entrance is on the left.

- **By Train:** Leaving the Darmstadt train station by foot, turn right and continue down the main road to the first stop lights. Turn right (in front of the Maritim Konferenz Hotel) on Rheinstrasse. Cross over the bridge, and follow the sidewalk for about five minutes to Robert-Bosch Strasse. Turn right on Robert-Bosch-Str and take the first right about 200 meters. ESOC is on the left.

- **By Air:** From the airport, take a taxi to ESOC, drive via the above instructions on the A5, or take the inexpensive Air Liner.
SOCIAL EVENTS

Reception At ESOC
The Director of ESOC is happy to welcome conference participants and accompanying persons on 14 June for a reception starting at 18:00 hrs. Drinks and snacks will be provided.

Symposium Banquet
The Symposium Banquet will take place on Thursday, 16 June starting at 19:00 hrs at the Burg Frankenstein in Mühltal. Transportation will be provided. Further details will be given at the conference.

For fully registered participants the price of the dinner is included in the registration fee. For other persons wishing to attend, the price is € 60.

Excursion
A tour of Darmstadt*, including a visit to the “Mathildenhöhe”, will take place on Wednesday, 15 June from 18:00 – 20:00.

Places are limited and will be allocated on a first come first served basis. The Information Desk will provide you with the meeting point for the excursion. An English-speaking guide will accompany you on the tour.

The organisers reserve the right to cancel the tour in case of an insufficient number of registrations.

For organisational reasons, we kindly ask you to register at the Information Desk for any of the above activities.

*free of charge
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The Editor's Desk (Foyer) will be staffed during session breaks
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PROGRAMME
Tuesday, 14 June 2005
Plenary Session
Room: HI-IV

08:00  Registration

09:30  Introduction and Logistics
       Maldari, P.; ESA/ESOC

09:40  Welcome and Keynote Address
       Winters, G.; ESA/ESOC

09:50  Keynote Address
       Frank, W.; ESA/ESOC

10:10  Invited Talks/Panel: Ground Segment Technologies for the Efficient
       Operations of Future
       Kaufeler, J.F.*; Weber, B.**; Nazirov, R.***
       *ESA/ESOC; **JPL; ***IKI

12:00  Lunch Break

Session: Mission Planning
Room: H-I
Chair: Salotti, L.; ASI

14:00  Planning with EKLOPS: Lessons Learned and Latest Developments
       Schönhardt, H.
       Anite Systems GmbH

       Earth Orbit
       De Florio, S.; Neff, T.; Zehetbauer, T.
       Deutsches Zentrum für Luft-und Raumfahrt e.V. (DLR)
14:50  Planning for Low-Cost Operations Based on Experience Gained with a Mission Planning System for the Mars Express Mission
Rabenau, E.*, Peschke, S.**
*NOVA Space Associates Ltd; **ESOC

15:15  Increase Performance and Productivity in Planning Orbiter Science
Dimbylow, T.; Hapgood, M.; Chaizy, P.; Ricketts, M.; Hutchinson, G.
Rutherford Appleton Laboratory

15:40  Coffee Break

16:00  Lessons Learned Implementing Multi-Mission Sequencing Software
Needels, L.
Jet Propulsion Laboratory

Session: Ground Communications Rationalisation
Room: H-IV
Chair: Hogan, P.; CSA

14:00  The MUSIC Project: Migration to a Unified Service for Informatics and Communications
Galli, P.*; Franks, J.**; Bertelsmeier, M.**
*ESA/ESRIN; **ESA/ESOC

14:25  Reducing the Costs of Ground Systems Relative to Network Infrastructure and Basic IT Services
Markley, R.; Byrne, R.
Jet Propulsion Laboratory

14:50  A Novel and Cost Effective Communications Platform for ESTRACK
Bertelsmeier, M.*; Buscemi, G.*; Mamedov, F.**
*ESA-ESOC; **ANITE

15:15  Approach to Fulfill Mission Test Data Distribution Requirements
Specht, T.; Bareh, M.; Lee, Y.; Miyamoto, C.; Gilliam, L.
Jet Propulsion Laboratory

15:40  Coffee break
Session: System Test and Validation
Room: H-I
Chair: Maldari, P.; ESA/ESOC

16:25  MCS TVT: A Generic Tool for Timely MCS Testing
Pidgeon, A.*; Pearson, S.*; Rothwell, D.*; Batten, A.*; Lindman, N.**
*SciSys Ltd; **ESA/ESOC

Session: Multi Mission Support
Room: H-IV
Chair: Kearney, M.; NASA

16:00  MAPS a Multi-Mission Analysis Tool for Earth Observation Satellites
Mougnaud, P.*; Galli, L.*; Bencivenni, D.*; Castellani, C.*; Famoso, I.*
*ESA/ESRIN; **ACS

16:25  The Combined Maintenance of Several Satellite Control Systems: an
ESOC Proven Cost Reduction Strategy
For the ENVISAT, ERS and CLUSTER Missions
Pignède, M.*; Rother, F.*
*ESA/ESOC; **Anite Systems GmbH

16:50  CNES PROTEUS/MYRIADE Low Cost Satellite Families: Feedback
Since 2003 Symposium at Pasadena Concerning Ground Segment and
Operations
Crebassol, P.; Gelie, P.
CNES

18:00  Reception at the ESOC Canteen
Wednesday, 15 June 2005

Session: Developments towards Autonomous Mission Operations
Room: H-I
Chair: Kaneaki, N.; JAXA

09:00 Operational Lessons Learned from the Autonomous Sciencecraft Experiment
Sherwood, R.; Chien, S.; Tran, D.; Cichy, B.
Jet Propulsion Laboratory

09:25 ISACS-DOC: Automatic Monitoring and Diagnostic System for Spacecraft
Takaki, R.*; Hashimoto, M.*; Honda, H.*; Choki, A.*; Mizutani, M.**; Nomura, K.**; Kosaka, T.**
*Japan Aerospace Exploration Agency; **Fujitsu Advanced Solutions Ltd

09:50 APEX: Portable Distributable Automated Procedure Execution
Dankiewicz, I.; Thompson, R.; Long, J.
SciSys Ltd

10:15 OGRES: Automatic Generator of Recurring Reports
Michel, C.; Duhaze, M.
CNES

10:40 Coffee break

11:00 Automation of Mission Operations at ESOC
Haddow, C.; Beck, T.; Calzolari, G.; Haag, S.; Pecchioli, M.; Pena, A.; Sørensen, E.
ESA/ESOC

11:25 The Earth Science Afternoon Constellation: Preparing for Autonomous but Coordinated Operations
Case, W.*; Kelly, A.**; Guit, W.**; Work, K.***
*SGT; **NASA; ***Lockheed
Session: Ground Infrastructure SW Development
Room: H-IV
Chair: Strada, P.; ESA/ESTEC

09:00  EGOS - ESA Ground Operations Software System  
Peccia, N.  
ESA/ESOC

09:25  Design of Common EGSE & EGOE System for Satellite Test & Mission Control Element  
Chun, Y.*; Lee, S.*; Ra, S.**; Cha, K.***  
*Korea Aerospace Research Institute; **Chungnam National University; ***Vertical Circuits Inc

09:50  SIMSAT 3.0: ESOC’s New Simulation Infrastructure  
Eggleston, J.*; Boyer, H.*; van der Zee, D.**; Pidgeon, A.**; Burro, F.***; di Nisio, N.****; Lindman, N.*****  
*VEGA GmbH; **SciSys Ltd; ***Dataspazio S.p.A.; ****Terma GmbH; *****ESA/ESOC

10:15  Coffee Break

11:00  REGATES – A New Generation of Automated M&C System  
Landrodie, P.*; Carlier, A.*; Racaud, T.**; Rattez, C.**  
*CNES; **Capgemini Space Unit

11:25  GDSS: A Service Oriented Architecture for Mission Operations  
Thompson, R.*; Peccia, N.**; Cooper, S.*  
*SciSys Ltd.; **ESA/ESOC

Session: Advanced Technology for Mission Operations
Room: H-I
Chair: Allan, P.; RAL

11:50  Advanced Technology for Mission Operations: Opportunities, Experience and Perspectives  
Donati, A.*; Martinez Heras, J.**; Baumgartner, A.***  
*ESA; **Blak Hat; ***Solenix
12:15  Spacecraft Control System with Public Access Based on Mobile Phone Technology  
   Nazirov, R.; Novikov, D.; Eismont, N.  
   Space Research Institute

12:40  Lunch Break

14:00  Application of ESA technology in Commercial Satellite Operations: A Mission Control System Example  
   Reid, S.*; Noguero, J.**  
   *SciSys Ltd.; **GMV SA

14:25  An Advanced Approach to The Atv Cargo Accommodation: The Cast Project  
   Fasano, G.*; Gastaldi, C.*; Lavopa, C.*; Steinkopf, M.**  
   *Alenia Spazio S.p.A.; **ESA/ESTEC

Session: Mission Specific SW Implementation  
Room: H-IV  
Chair: Nazirov, R.; IKI

11:50  Efficient Development of the Herschel-Planck Mission Data Systems  
   Verrier, D.; Dodsworth, S.; Di Girolamo, G.; Spada, M.; Verrier, D.  
   ESA/ESOC

12:15  The Ral Gerb Ground Segment Processing System  
   Smith, A.  
   RAL/CLRC

12:40  Lunch Break

14:00  The MetOp LEOP Support MCS: An ESOC Efficient Development for EUMETSAT -- an ESA External Customer  
   Pignède, M.; Schurig, C.; Van Holtz, R.  
   ESA/ESOC

14:25  An Event Driven System Architecture for James Webb Space Telescope (JWST)  
   Balzano, V.; Isaacs, J.  
   Space Telescope Science Institute
14:50  TRECS – Improvement Based on Field Experience  
*Banwait, R.; Johnson, G.*  
Integral Systems, Inc.

15:15  **Coffee Break**

**Session: Optimisation of Operations of Specific Missions**  
**Room: H-I**  
**Chairs: Soula, J.M.; CNES**

14:50  ENVISAT Mission Automation – A First Demonstration  
*Rudolph, A.*; *Heinen, W.*; *Monham, A.*  
*ESA/ESOC;** Rhea System SA; ***Eumetsat*

*Cordier, G.*; *Gomez-Rosa, C.*; *Knoble, G.*; *McCaleb, F.*;  
*Kelly, A.*; *Walsh, A.*  
*Lockheed Martin;** NASA/ GSFC

15:40  **Coffee Break**

16:00  The Approach to Operations Cost Saving for ESA Planetary Missions  
*Acomazzo, A.; Denis, M.; Ferri, P.; Warhaut, M.*  
*ESA/ESOC*

16:25  Rosetta Ground Contact Minimisation in Cruise  
*Ferri, P.; Montagnon, E.*  
*ESA/ESOC*

16:50  SMART-1: Europe’s Lunar Mission Paving the Way for New Cost Effective Ground Operations  
*Camino, O.*; *McKay, M.*; *Camino, O.*; *Schoenmaekers, J.*;  
*Alonso, M.*; *Blake, R.*; *Milligan, D.*; *De Bruin, J.*;  
*Gestal, D.*; *Ricken, S.*  
*ESA/ESOC;** Science Systems GmbH; ***VEGA IT GmbH
Session: SW Re-Use and Developments for Mission Families
Room: H-IV
Chair: Hogan, P.; CSA

16:00  Mission Data Systems for The Interplanetary Missions Family
       Ercolani, A.; Spada, M.; Delhaise, F.; Verrier, D.; Bru, T.
       ESA/ESOC

16:25  RENATO, a Tool to Support Software Reuse
       Delhaise, F.; Spada, M.
       ESA/ESOC

16:50  Cost Effective Mission Control System Development by Means of
       Mission Family Commonality
       Guerrucci, D.; Reggestad, V.; Merri, M.; Emanuelli, P.
       ESA/ESOC

17:15  Software Re-Use Review: The Benefits of the Common Ground Approach
       Mckerracher, P.; Sibol, D.
       Johns Hopkins University - Applied Physics Lab
Thursday, 16 June 2005

Session: On-Board SW Maintenance/SW Live Cycle/SW Product Line
Room: H-I
Chair: Statman, J.; JPL

09:00 Rosetta On-Board Software Maintenance at the Control Centre: a Way to Reduce Operations Cost
Morales-Santiago, J.*; Steiger, C.**; Montagnon, E.*; Ferri, P.*
*ESA/ESOC; **LSE Space, AG (c/o ESA/ESOC)

09:25 Neptune: A Tool and an Approach for Life Cycle Cost Reduction in Space Ground Segment
Bevilacqua, S.; Del Re, V.; Lezzerini, L.; Moro, F.; Auer, C.
*Vitrociset S.p.A.

09:50 Decreasing Costs of Ground Data Processing System Development Using a Software Product-Line
Chafin, B.
Jet Propulsion Laboratory

10:15 Satellite Operations: The focusSuite framework
Molina, M.
GMV SA

10:40 Coffee Break

11:00 Using COTS for Cost Effective Multiple Satellite Operations
Lin, S.F.
NSPO

11:25 A Generation-Based Framework for Spacecraft Operation
Harauchi, S.
Mitsubishi Electric Corp.
Session: Cost Driven Mission Operations
Room: H-IV
Chair: Salotti, L.; ASI

09:00  Cost-Capped and Risk Adverse: Opposites Attract
      Streiffert, B.
      Jet Propulsion Laboratory

09:25  Seeing on a Budget: Mars Rover Tactical Imaging Product Generation
      Zamani, P.; Alexander, D.
      Jet Propulsion Laboratory

09:50  Evolution of the Cluster Ground Segment: Reducing the Annual Cost for
        the Second Mission Extension
      Volpp, J.; Godfrey, J.
      ESA/ESOC

Session: Standards Related Concepts/Developments
Room: H-IV
Chair: Kaneaki, N.; JAXA

11:00  CCSDS Spacecraft Monitoring & Control Services Concept
      Merri, M.
      ESA/ESOC

11:25  Development of a Generic Monitor and Control System by the Use of a
       Standard Modeling Method
      Yamada, T.
      JAXA/ISAS

11:50  Adoption of Emerging Standards for Ground Systems: Lessons Learned
       from Space Based Infrared Systems Increment 1
      Nadel, M.
      The Aerospace Corporation
Session: Space Communications  
Room: H-I  
Chair: Maldari, P.; ESA/ESOC

11:50  Low Cost Communication Support of Lunar Missions  
Deutsch, L.J.*; Statman, J.I.*; Noreen, G.K.*; Geldzahler, B**  
*Jet Propulsion Laboratory; **National Aeronautics and Space

12:15  Low Cost Support of Critical Spacecraft Communications with the Deep Space Network’s Radio Science Receivers: The Cases of Saturn Orbit Insertion  
Asmar, S.; Jongeling, A.  
Jet Propulsion Laboratory

12:40  Lunch Break

Session: Flight Dynamics and Navigation  
Room: H-I  
Chairs: Nazirov, R.; IKI

14:00  Simplified Mission Operations Using On-Board GPS Navigation  
Dragonette, R.; Boie, P.  
Johns Hopkins University - Applied Physics Laboratory

14:25  Development of Automated Ground Support System for University Satellite’s Attitude Control System  
Sivaprakash, N.  
Madras Institute of Technology - Anna University

14:50  Reducing Costs of Managing and Accessing Navigation and Ancillary Data by Relying on Extensive Capabilities of SPICE System  
Semenov, B.; Acton, C.; Bachman, N.; Elson, L.; Wright, E.  
Jet Propulsion Laboratory

15:15  Efficient Flight Dynamics Support to Mission Routine Operations Phase at ESOC  
Marc, X.  
ESA

15:40  Coffee Break
Session: Telemetry, Tracking and Control Systems
Room: H-IV
Chair: Deutsch, L.; JPL

14:00 Reducing the Cost of Multi-Mission Support by Optimising Antenna Usage
Allan, P.M.; Wright, J.S.
CCLRC - Rutherford Appleton Laboratory

14:25 A Common System for TT&C and Satellite Simulation
van Duijn, P.; Sims, G.; Tatman, B.
Satellite Services BV

14:50 A Cost-Effective Modeling of Near-term Mission Bandwidth Demand
Pham, T.
Jet Propulsion Laboratory - California Institute of Technology

15:15 Low-Cost, Large Aperture for Deep-Space Applications
Statman, J.*; Bagri, D.*; Yung, C.*; Weinreb, S.*; Macneal, B.*; Gatti, M.*; Geldzahler, B.**
*Jet Propulsion Laboratory; **NASA Headquarters

15:40 Coffee Break

18:30 Pick-Up Service from Hotel and Drive to Burg Frankenstein

19:00 Symposium Banquet - Burg Frankenstein
Friday, 17 June 2005

Closing Session
Room: H-I to H-IV

09:00  Results of the 2005 Enhancing Space Operations Workshop Held by the AIAA Space Operations and Support Technical Committee
       Sorensen, T.
       University of Kansas

09:30  Closing Plenary

10:40  Coffee Break

11:00  Guided Tour of ESOC Facilities

13:00  Lunch Break
ABSTRACTS
Mission Planning
Planning with EKLOPS: Lessons Learned and Latest Developments

Anite Systems GmbH, GERMANY

Over the past years, the European Space Agency (ESA) has invested heavily in the creation of infrastructure software for supporting the development of their mission-specific on-ground software. The paper Planning how to cut the cost of Mission Planning [1] presented at RCSGSO 2003 in Pasadena discussed the area of Mission Planning. It showed how the development by Anite Systems of a mission planning kernel to support the implementation of the Envisat FOS Mission Planning System, and its re-use in the context of the Mars-Express mission, have led to a significant reduction of the development and maintenance costs of both systems.

This paper will first review the objectives set in [1] for the application of the kernel, today renamed Enhanced Kernel Library for Operational Planning Systems (EKLOPS), to the development of operational mission planning systems. We will discuss the resulting evolution of EKLOPS, and show how it has been used successfully since 2003 in all phases of the development of operational mission planning systems for ESA, from requirement capture to implementation.

We will first address the issue of configurability of the planning rules within EKLOPS, and the improvement brought in this context by the High-level Query Language introduced into EKLOPS in 2003 as a result of the Language for Mission Planning ESOC study.

The development of the EKLOPS-based Mission Planning System for ESA’s Venus Express mission will be introduced, the focus being put on the cost-effectiveness of the kernel re-use, more specifically on the impact of the newest kernel artefacts.

An innovative use of EKLOPS for prototyping of systems in the requirements capture phase will then be discussed. The kernel was used in 2003-2004 for the prototyping of the Galileo Mission Planning, and in 2004 for the prototyping of the planning module of the ESTRACK Management and Scheduling System, a system for the automated scheduling of ESA’s
ground station network service allocation, which is currently in its requirements engineering phase. Early prototyping of the planning systems with an operational planning kernel allows for the addressing of operational issues early in the requirement engineering phase, this resulting in direct improvement of the stability of the requirement baseline. These prototypes also demonstrate the use of EKLOPS in the context of constellation and ground segment planning.

The plans for the use of EKLOPS to support the development of the Automated Planning System, a prototype for the automation of science planning at ESA, will then be described.

To finish, we will present the lessons learned from two more years of applying EKLOPS to mission planning systems development, and give the direction in which the future developments of the kernel should be driven, in order to maximise the expected benefits.
Optimal Operations Planning for SAR Satellite Constellations in Low Earth Orbit

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Satellite constellations for Earth observation are remarkably useful, powerful and flexible tools, but their realization and maintenance pose a big issue on costs. From a design engineering perspective building up a constellation with small and simple satellites is a key component of containing or reducing costs, while from a mission operations engineering point of view, optimal constellation management is a key in cost reduction and an important performance driver. In this paper the problem of the optimization of planning and scheduling of the operations for a SAR satellite constellation is addressed. The system to be operated is constituted by a satellite constellation including two or more satellites in LEO orbit, one or more ground stations for spacecraft monitoring-control and data collection-handling, a list of targets to be observed. The main system limitations are the finite number of ground station contacts for sending commands to the satellite and collecting payload data from it, limited on-board power resource, limited on-board data storage capabilities. The main optimization constraints are the requests of the constellation users on the level of priority, the delivery time deadlines and the type of every payload product. Optimization figures of merit are also determined by the users requests. This leads to a challenging combinatorial optimization problem. As a first approach to its solution, a modified first-in-first-out (FIFO) algorithm has been developed. The possibility to use a heuristic method and a branch and bound approach to find optimal solutions is analyzed. The structure of a software capable of generating an operations plan as output with a given list of targets and requests of the constellation users as input, is presented. Software modules are built around a commercial tool capable to modelize the satellites and to propagate their orbits. Some examples of the capabilities of this planning tool and its foreseen developments are shown.
Planning for Low-Cost Operations Based on Experience Gained with a Mission Planning System for the Mars Express Mission

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Mars Express is not only the first 'Flexi' mission in the ESA long term scientific programme but also the first European mission to Mars. The mission has been designed on a relatively small budget but the mission objectives are nevertheless challenging, as there are: a) high resolution stereo imaging, b) mineralogical mapping of the surface of the planet, b) subsurface sounding, c) atmospheric sounding and d) environmental and radio studies. The MEX spacecraft has been in orbit around Mars since the beginning of 2004 and has provided a wealth of scientific data.

In order to meet the mission objectives, a mission planning concept has been implemented that supports both spacecraft and science operations from the planning stage through to delivering the detailed command schedule. A large number of tasks, constraint and resource checking have to be performed in order to arrive at a consolidated operations plan that is free of conflicts and feasible within the resource envelope of the spacecraft. The major functionalities of mission planning are provided by the Project Science Team at ESTEC, The Netherlands, the Mission Planning System at ESOC, Germany, and the Payload Operations Support centre at Rutherford Appleton Laboratories, UK.

The paper focuses on the contributions of the mission planning element to the overall mission operations costs. It is based on more than one year of operational experience gained by the MEX mission planning group at ESOC operating the Mission Planning System and its external interfaces. It will be shown how the mission planning operations costs can be reduced for similar-type missions and how to stay within the budget envelope in case of additional constraints and changing requirements. As the literature on reducing space mission costs suggests, there is a cost-saving potential if the reduction of cost is planned for and included in mission system engineering.
The scientific return from robotic missions is critically dependent on the quality of support for science operations. It is the role of a Science Operation Centre (SOC) to provide the technical support and expertise necessary to assist a science community to plan and operate the payload on board a robotic scientific spacecraft in an effective and efficient manner. In order to improve performance and productivity the aim of the SOC should be (1) to save human resources (by reducing tedious and repetitive tasks, reducing the iterations between the SOC and other interfaces, reducing SOC staff training time, reducing the need for highly qualified IT people, decreasing the time required to diagnose problems...); and (2) to increase operational reliability and robustness (by decreasing the likelihood of human error). This paper summarises key lessons learned from building and operating SOCs for existing orbiter missions (such as Mars Express) and explores how these lessons may be applied to future orbiters. The key logical elements of a SOC for an orbiter mission are discussed and used to illustrate how SOC performance and productivity can be improved by automating the execution of these logical elements, the functionality of the SOC and the standardisation of the tools and procedures. The most important lesson learned is to make a logical distinction between two key elements: (1) a planning element that establishes the science activities to be performed and ensures that the spacecraft can support those activities (e.g. in terms of power, data return to Earth, etc); and (2) a commanding element which converts the planning into the detailed commanding for uplink to the spacecraft. This second stage includes several elements critical to the quality of observations: e.g. detailed instrument configuration to match observing conditions, fine-tuning of instrument parameters in response to latest data on its performance.
Lessons Learned Implementing Multi-Mission Sequencing Software

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All of JPL’s deep space missions rely on complex sequencing ground software that is responsible for planning and creation of science and engineering activities, checking command syntax, checking mission and flight rules, and translating the commands into packets which can be uplinked to the spacecraft. The ground software is used by operations teams for preliminary stages of sequence development as well as the final stages of sequence development. In previous missions, significant effort was spent validating the software since sequencing errors can cause the spacecraft to enter fault protection or even loss of spacecraft. Over the last decade, in an effort to reduce costs and development time, the sequencing software has been transformed into a multi-mission format. This paper will describe the software and its uses to provide context for its criticality. Different approaches have been taken to implement the software in a multi-mission format. These different approaches will be outlined. The advantages and disadvantages of these different architectures will be discussed. Lessons learned during the development and maintenance of the software will be discussed. There will also be a discussion of use of the software in operations. The implications of using multi-mission software in operations will be described. Finally, the lessons learned from the use of the software in mission operations will be discussed. This paper will provide valuable information to organizations exploring the use of multi-mission software, regardless of whether the change is to minimize spacecraft ground software development time or cost reduction. Similarly, the paper will provide insight into some of the steps that can be taken during software development and operational use that will minimize difficulty later.
Ground Communications Rationalisation
The MUSIC Project: Migration to a Unified Service for Informatics and Communications

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The new ESA organisation foreseen in Agenda 2007 assigns to the Directorate of Operations and Infrastructure (D/OPS) the responsibility, at Agency level, for all infrastructure facilities and services that are of common utility for the Agency’s activities and programmes and of long-term strategic interest for the Agency. Among these, the domain of Information and Communication Technology (ICT) has been identified by D/OPS as one having a high potential for achieving important synergies (and projected savings), in the first place within the various OPS departments, and at a later stage also in the other programme and support directorates of the Agency. Following the entry into force of the new Directorate organisation on 1 April 2004, a working group was established by D/OPS to explore in detail the synergies between the OPS departments providing services in the ICT domain. In its final report the working group, after a thorough analysis of the current situation (customer characteristics and interfaces, ICT management, services and processes) and of the probable evolution of technology over the next 3-5 years, has identified and assessed the potential synergies, trading off the expected benefits against the effort to implement them. Following the recommendations of the Working Group, D/OPS established the MUSIC Project to implement a unified ICT support organisation within D/OPS, and to follow up on the proposed synergies. The objectives of the MUSIC Project have been set by D/OPS as follows: - Integrate and streamline all the ICT infrastructures and services that are currently managed by the different OPS departments into one coherent ICT service under a uniform management structure within OPS. - Meet or exceed the requirements that have been agreed with the customers for the quality, continuity and performance of ICT services, at a lower cost for ESA and without undue risks. - Provide customers with a “one-stop”, short-loop service provision at all ESA sites, ensuring rapid and flexible response to customer needs. - Improve customer awareness, cost transparency, customer involvement in the decision-making process for establishing needs and priorities. - Establish one house within OPS for ESA’s ICT professional staff, work as one team, optimise the management of staff skills and competences, leverage the technical excellence that exists in the different OPS units, increase opportunities for professional
development within the directorate. - Establish a “template” for similar synergy projects in any situation where D/OPS should assist the other programme and support directorates or take responsibility for their ICT infrastructures. During the first half of 2005 the MUSIC project will produce detail requirements and implementation plans for the transition of all ICT services within OPS to a new uniform management model, clearly demonstrating the benefits and the measures to reduce risks. The implementation will be decided by mid 2005 after a thorough management review.
Reducing the Costs of Ground Systems Relative to Network Infrastructure and Basic IT Services

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This paper reports on progress the Deep Space Network (DSN) and the Multi-Mission Operations (MMO) offices have made in reducing and equitable distributing the implementation and operations cost of spaceflight ground network infrastructure. The infrastructure includes wide area networks, local area networks, and basic information technology (IT) services such as domain name services, network time protocol services, and firewall services. While the goal is to provide a secure, highly redundant, and operationally resilient ground network environment for spacecraft operations, costs must be minimized, equitable distributed, and must be generally well defined early in the mission planning cycle. Network services have multiplied due to the increasing degree of distribution of mission operations. Flight projects often have operations distributed not only within the sponsoring country, but also among international partners. A standard MMO implementation has been to implement a single dedicated circuit to the remote site with voice-over-Internet Protocol (IP) operational voice, and Integrated Services Digital Network (ISDN) backup. JPL is investigating lower-cost alternatives to this standard architecture, including the use of carrier IP services such as frame relay and multi-protocol link switching. These costs are usually distributed directly to the missions, and if there are multiple missions sharing a path, costs are distributed based on minimum required bandwidth during periods of potential network congestion. Standard services have been traditionally provided using general-purpose workstations dedicated to particular services such as DNS and NTP. JPL is investigating specialized platforms, that is, appliances.
A Novel and Cost Effective Communications Platform for ESTRACK

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Over the last years, ESA carried out a project for the modernization of OPSNET, the Agency’s Communications Network supporting space mission operations; this activity involved all of the ESA Tracking Stations and their interface to the Operations Control Centre and influenced the new ESA Deep Space Network. The project addressed the evolution of OPSNET from an X.25 network over a dual protocol enabled network to a pure IP network able to support over a single communications protocol all ESA missions and the ESA engagement in inter-Agency collaboration based on SLE. The hand-over of the Deep Space Station Cebreros to routine operations will mark the completion of the new communications infrastructure.

This paper deals with the new cost effective solutions for the Ground Stations communications based on state-of-art LAN technology, the related ESOC part and the evaluation / implementation of a new technique for the Wide Area Network (WAN) interconnection.

A consistent approach was used for all the stations, starting from analysis of the network facilities and services, until the final system implementation and hand-over to routine operations. The network design considered not only existing and confirmed projected utilisation requirements for TT&C and M&C as such (the role of the “traditional” OPSNET), but also technology trends, migration needs, extensions in services and functionality, and the potential for further evolution without need for extensive physical work.

The physical LAN infrastructure has been designed for long-life duration. It is based on a modular structured cabling system (up to 1200 MHz) supporting inserts, patch cords and panels according to the Cat6/Cat7 standard. The latest Layer 3 LAN switch generation guarantees 10/100Mbps access for all user systems, Gigabit Ethernet interconnection over fibre optic backbone, Virtual LAN (VLAN) features and dynamic routing over the station premises. External station traffic and security policy is supported by high-speed routers.

Part of the paper shows how the solution is also cost effective in areas which were traditionally outside the OPSNET scope, such as LAN connectivity for front and back end and building management devices.
traditionally not linked to a LAN, corporate IT networking, video and telephony services, capability for diagnostics and maintenance access, locally, from the OCC and even from 3rd parties. The paper will also highlight how the implementation of the Deep Space Stations has been exploited to migrate the traditional star topology of the OPSNET to a partial mesh, leading to substantial cost savings for international / trans-oceanic telecom lines whilst extending capacity and quality of service. The paper will conclude with conservative estimates on the cost efficiency resulting from the modernisation of OPSNET, in the areas of Operations and Maintenance, service portfolio, service management, re-investment needs, and telecom sourcing.
Approach to Fulfill Mission Test Data Distribution Requirements

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Recent Jet Propulsion Laboratory (JPL) missions have experienced the need for a distributed test data management capability to share test information among participating entities that are developing components for each spacecraft and science instrument. JPL missions are increasingly complicated and highly collaborative with various industry partners, domestic and international, and academic institutions throughout the United States. To meet tight spacecraft and instrument Integration and Test (I&T) schedules and to assist spacecraft and instrument engineers from different locations to work closely together, sharing test data has become essential. Due to the nature of this "Virtual Organization", JPL requires easy and reliable access to partner generated test information, specifically during the Assembly, Test, and Launch Operations (ATLO) phase. During ATLO, the spacecraft is run through an extensive suite of tests to prepare for launch and flight. Test conductors' job becomes very difficult due to the complexity of the tests that may run for long periods. Interruptions and anomalies could occur frequently. Test conductors have to insure test cases are comprehensive and detailed. They manage the test environment, document the test results, and resolve anomalies that occur during the test. During anomaly resolution, test conductors must provide test scenario information and results to on-site and remote subsystem engineers for investigations. More often, I&T engineers, subsystem engineers, project management and development engineers, located on-site or remotely, are interested in test progress and test results in a timely manner. Currently, it is labor intensive to locate test data to meet user's request and hard to recreate test scenario to assist users in analyzing test results. Moreover, recreating specific test scenarios involves finding the correct versions of various configuration files. Collection and dissemination of information gathered from each test becomes critical for test scenario management and anomaly resolution. Considering increasing regulations and restrictions such as "firewalls", International Traffic in Arms Regulations (ITAR), access control issues of critical mission data coupled with decreasing mission development and operations budgets, the following requirements for a tool were recognized for the Spitzer Space Telescope mission: * Assist the test conductor by
capturing all pertinent test information for each test scenario in an automated fashion * Provide a centralized archive for multiple test venues * Support the test conductor or data analyst in recreating test scenarios as required * Aid test data users to better understand test attributes * Allow users to retrieve the correct test data and ancillary data promptly and easily regardless of physical location * Easily modify existing test scenarios or create new scenarios using captured scenarios as templates * Allow users to manually upload any customized files (i.e. test conductor logs, additional configuration files) to the centralized archive through the tool's web interface To meet the above-mentioned requirements, the Spitzer Space Telescope mission requested the development of the TestArchive Tool (TAT) In this paper, the development approach and deployment of TAT in the Spitzer Telescope mission I&T environment, utilizing web-based standards and a well defined directory structure will be presented. In addition, the lessons learned along with future enhancement to the TAT will be discussed.
System Test and Validation
MCS TVT: A Generic Tool for Timely MCS Testing

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A problem inherent in MCS development is the difficulty in providing specifically tailored test tools sufficiently early in the product lifecycle. In particular, spacecraft simulators that run the real onboard software (OBSW) usually arrive later in the ground segment development than is required for the start of ground segment testing. The MCS Test and Validation Tool (MCS TVT) is a generic spacecraft simulator provided by ESA/ESOC, which can be used to test and validate early versions of an MCS in periods when the mission specific operational simulator is not yet available. This paper describes how MCS development projects can exploit MCS TVT in order to reduce risks and hence cost. MCS TVT is driven by the spacecraft database (SDB) and has no internal spacecraft models of its own. It can receive telecommands (supporting the COP-1 protocol) and generate telemetry packets. Telemetry parameter values are fixed to a default value in the database or can be forced by the user. MCS TVT also supports various functions for low-level packet and frame-level testing. For telemetry generation and transmission, the MCS TVT provides three levels of simulation: Playback level; the simple to configure Frame level; and Packet Level which has greater functionality. For telecommand processing, there are three levels of simulation: Transparent TC Reception which only logs reception; Frame Level; and Packet Level. The generic MCS TVT has been customized for a number of missions, e.g.: Cryosat and the prototype Galileo spacecraft, GSTBv2. For the GSTBv2 simulator the customisation included interfacing to Telespazio’s Network Control Centre and handling of the IN-SNEC protocol. The GSTBv2 MCS TVT allowed integration and testing of the MCS to be performed at Telespazio several months before the availability of the spacecraft simulator. MCS TVT can also be used for testing of other systems that need to handle packet telemetry or telecommands. MCS TVT consists of four main sub-components. The MCS TVT Configuration Tool and Database allows automatic import of a SCOS 2000 satellite database to minimize manual customization. The MCS TVT Simulator generates and transmits real-time telemetry and receives telecommands. The Telemetry Playback Utility reads telemetry frames from a file and transmits them to Ground; includes a graphical user interface for controlling playback and browsing frames. The MCS Direct Interface (MCS DIF) was developed as a new ground model for directly interfacing with an
MCS to enable testing in complete isolation from any other system. An MCS interfaces with the MCS TVT via the MCS DIF. MCS DIF, which is now delivered as part of ESOC’s simulator Ground Models, has been used for end to end system testing of the GSTBv2 and GOCE simulators. MCS TVT was developed for ESA/ESOC and is available on Windows 2000/2003. It runs in ESA/ESOC’s SIMSAT simulation environment, allowing use of SIMSAT services for data display, simulator commanding and logging via the Simulation Model Interface (SMI). Interface to the MCS is via the traditional Ground Models and NCTRS or via a direct interface called MCS DIF.
Multi Mission Support
MAPS a Multi-Mission Analysis Tool for Earth Observation Satellites

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MAPS (Multi-mission Analysis and Planning Support) is a tool dedicated to Earth Observation (EO) satellites to support Mission Planning Analysis for maximizing both users needs and resources utilization. It provides in a single environment a powerful tool for definition, visualization and optimization of acquisition scenarios. MAPS comes from an ESA research project and is currently being enhanced in order to become a fully operational tool at disposal of EO mission management. It goes beyond the current mono-mission dedicated mission planning systems and offers a useful support tool able to handle ESA/non ESA missions and also futures missions’simulation, allowing the user to deeply describe all involved resources. To accomplish this, resources as satellites/sensors and stations/antennas are highly configurable though a dedicated and powerful GUI and requests can be posted specifying areas of interest, time windows, revisiting times and percentage of coverage, including baseline parameters, range of sensing angle and delta time constraints. In particular, the introduction of correlation among requests/sub-requests as logical and/or correlation in covering a set of areas, allows optimizing the satellite resource utilization in the common scenario of multi satellite configuration which observes the same area. MAPS enables to specifies many characteristics associated to the resources such as the sensor view angles, satellite duty cycle, instruments modes constraints, antenna AOS/LOS, station unavailability periods but also on-board recorders capacity/rate and Data Relay Satellites in alternative to ground stations. Taking into consideration all these parameters MAPS assesses and visualizes all the candidate observations for the scenario, providing the user with different kind of propagation (nominal, TLE). One of the main goals of MAPS is to detect and automatically resolve acquisition conflicts optimizing the user request fulfilment. This complex optimization problem needs a modelling of a wide set of on-board and on-ground constraints, which requires very flexible methods. For this purpose, we have built a specific greedy algorithm. The success of the greedy search methods depends largely on the heuristics used to decide the order in which the constraints are solved and which rules are applied. Therefore, besides the simple priority, we have
taken into account other criteria, such as: the number of opportunities of an observation and the percentage of the remaining area to cover in order to fulfil the user request. The scheduler will prefer observations having the fewest remaining opportunities and, also, it will favour the complete fulfilment of a higher priority user request before beginning the scheduling of another one. In addition to the automatic scheduling, MAPS allows the user to solve the acquisition constraint violation manually via an interactive GANTT display. MAPS includes a powerful tool for generating detailed reports both on propagated and scheduled acquisition, in relation of relative requests, including minimum time for coverage, percentage of coverage, time incremental information, and use of meteorological data to evaluate cloudiness of acquisitions (both TLE file as meteorological data can be automatically imported via ftp and refreshed).
The Combined Maintenance of Several Satellite Control Systems: an ESOC Proven Cost Reduction Strategy for the ENVISAT, ERS and CLUSTER missions

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Traditionally, after development, Mission Control Systems (MCS) are maintained on a project basis independently of one another even when they are based on common infrastructures. However, organisations have recognized that synergies could be exploited, which would bring a more efficient use of available resources both technically and financially. In line with this, the European Space Operations Centre (ESOC) decided in 2003 to fully combine into one single project the maintenance of 3 major yet different missions, which had been launched at very different times. The common denominator of these missions is the use of the previous generation of ESA MCS infrastructure, the Spacecraft Control Operations System 1 (SCOS-1). At the starting point of this endeavour, 3 separate software support teams were maintaining round the clock 3 large MCSs for 3 different user teams, namely for the ESOC controlled space missions ERS-2 (launched in 1996), CLUSTER-II (launched in 2000) and ENVISAT (launched in 2002). The objective of the "Combined Maintenance of SCOS-1 based mission control systems" project (CoSCOS-1) was to group the maintenance of systems using the same infrastructure (together with the maintenance of this infrastructure itself) in order to: · reduce administrative overhead in setting up separate, but similar contracts · allow the Contractor in charge to pool resources in a larger team, to share technical competences and to be more responsive in case of mission anomalies requiring special support · have a sufficiently large critical mass to efficiently support old technologies (Software: SCOS-1, Fortran, Ada; Hardware: VAX and Alpha) · allow easier adjustment to workload conditions on different mission systems with clear price specifications · provide a clear price/service scheme to allow other missions to join the programme. ... and all the above with the aim of providing a better service to users in a more cost efficient manner. ESOC identified the need for 2 pre-requisites before CoSCOS-1 could become working reality: · the definition of a maintenance cost model · the placement of an industrial competitive tender. A maintenance operational framework was developed integrating the concepts of “type of service” (Helpdesk, 1st Line Support, 2nd Line Support), “quality of
service” ("Platinum”, “Gold”, “Silver”), “size of software system” (“Large”, “Medium”, “Small”), and “flexibility to add/remove systems” from the combined maintenance programme. Additionally, a cost model was defined, which allows automatic price recalculation and validation in case any of the above parameters change. After an industrial tender, which contributed to the price reduction, a Contractor was selected for the provision of a team of experts covering the whole brand of SCOS-1 based systems. It is worth noting that the total price of CoSCOS-1 is much lower than the sum of the 3 existing individual contracts and that the CoSCOS-1 maintenance services provided to the operational team of the 3 flying spacecrafts, each managed by an individual Service Level Agreement, are better and more reliable. After almost 2 years of operations, the paper explains in details the organisation of CoSCOS-1 and provides evidence of how its innovative approach has resulted in a drastic reduction of software maintenance costs (by over 50%) whilst providing at least an equivalent or even a better level of service to the users. Finally, it boosts the CoSCOS-1 experience as contributing to lower maintenance and operating costs of future space missions.
In July 2003 at Pasadena, CNES presented its multi-satellites command control ground segment for mini and micro satellites and the associated operational concept. In those times only JASON1 (minisatellite) was in its flight operations phase, and its ground segment was still a monomission ground segment. Presently, we have achieved the development of our multi-missions ground segment for mini and micro satellites. We are about to launch a second minisatellite, CALIPSO (June 2005), while three other minisatellites projects have begun: COROT (launch July 2006), SMOS (launch February 2007) and JASON2 (launch April 2008). Regarding the micro-satellites, we are now operating DEMETER (launched in June 2004), PARASOL (launched in December 2004), and a constellation of 4 other spacecrafts (launched in December 2004 with Parasol). Two forthcoming spacecrafts: MICROSCOPE and PICARD will be launched mid-2008. We consequently present both the feedback CNES has got through this two years period of time and the work in progress for the coming years. Concerning the ground segment, the lessons learned are:

"The initial concept was not tailored to cope with one mini or micro mission every six months or every year like it is planned now and had to be slightly adapted." "The ground segment adaptations for the new missions is tricky, organisation wise, because most of the components are now operational or are involved in mission qualification tests before launch." "Sharing the same architecture and the same software between two different satellite line of products induces a heavier decision process before any adaptation." "Provided that the missions respect the main ground segment architecture constraints, we take great benefit of the multi-satellite concept in preparing the ground segment for the new satellites (a 3 months phase B is enough before the development phase)." "The cost reduction is confirmed, compared to the initial concept that was one independent ground segment per satellite Concerning the in-flight operations, the very promising ops concept, consisting in sharing the ops team, and having operational sequences, procedures, and data, very close from one satellite to the other is facing the reality: two micros in flight, one mini in flight and a second one approaching its launch date. The presentation will confirm the outstanding
advantage of having a "product line", but also will show some limits, as well as the way to enhance the process for the forthcoming activities. As a matter of fact, for Proteus, it turned out that the Calipso spacecraft bus was slightly modified with regard to Jason 1: new star trackers, enhanced battery management and magnetorquer bars. This led to modify many docs and ops data, far more than formerly expected. Though, the benefit of a "product line" was substantial but less than anticipated. Calipso appears more like the first of the 5 platform product line. Corot and SMOS are now around the corner, and the standard Proteus paradigm should definitely apply. The presentation will show the consolidated foreseen process, which takes also into account the in flight experience on the 6 microsatellites.
Developments towards Autonomous Mission Operations
Operational Lessons Learned from the Autonomous Sciencecraft Experiment

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Operational Lessons Learned from the Autonomous Sciencecraft Experiment Abstract - An Autonomous Science Agent is currently flying onboard the Earth Observing One (EO-1) Spacecraft. This software enables the spacecraft to autonomously detect and respond to science events occurring on the Earth. The package includes software systems that perform science data analysis, deliberative planning, and run-time robust execution. Because of the deployment to the EO-1 spacecraft, this Autonomous Science Agent has stringent constraints of autonomy and limited computing resources. We describe these constraints and how they are reflected in our operations approach. A summary of the final results of the experiment is also included. This software has demonstrated the potential for space missions to use onboard decision-making to detect, analyze, and respond to science events, and to downlink only the highest value science data. As a result, ground-based mission planning and analysis functions have been greatly simplified, thus reducing operations cost.
ISACS-DOC: Automatic Monitoring and Diagnostic System for Spacecraft

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Automatic monitoring and diagnostic system for spacecraft has been developed and operated at Institute of Space and Astronautical Science of Japan Aerospace Exploration Agency (ISAS/JAXA), in order to improve the safety of artificial satellite and space probe operations. This system is called ISACS-DOC (Intelligent Satellite Control Software-DOCtor) and it aims to capture important changes and signals of anomaly rapidly and accurately, during routine operations without the continuous presence of specialists. It indicates the diagnosis results and how to solve problems when the cause of anomalies are specified in a high reliability manner, and provide the related information and contact information whether causes cannot be specified. Three systems have been constructed and operated for the features of deep or semi-deep space missions. First system was employed in the geomagnetic observation satellite, GEOTAIL, which was launched in 1992. It was then applied to the Mars orbiter, NOZOMI and the asteroid sample-return spacecraft, HAYABUSA and consequently improved on. The effectiveness of this system is already proved through the actual operations. Development of the next generation system for low earth orbit satellite has just started. Comparing the previous systems for deep space probes, new system requires faster data processing capacity due to the high speed data transfer rate. It is also a key technology for new system to develop knowledge accumulation technology and common database technology including design and operation as well as logical collaboration methods between basic components, such as simulation, database and human interface. This paper presents overview of the next generation system as well as what we learned through the previous experiences of development and operation of the systems.
APEX: Portable, Distributable Automated Procedure Execution

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Automation within spacecraft mission control systems is often limited by the scope of scripting languages or external interfaces provided by the spacecraft control system used. SciSys has developed an approach to automation based on an open, layered service architecture, comprising M&C Data Access, Operations Language, Procedure Automation and Schedule Execution layers. The concept of M&C, Procedure and Schedule Execution layers is consistent with current initiatives to standardise Mission Operations services within CCSDS and as part of ESA’s future Ground Operations Systems (EGOS). It combines a publish/subscribe approach to data distribution with a remote action interface for a set of core data items, including parameters, commands and alert notifications, but can be extended to cover any other service objects. To provide the automated Operations Procedure layer, SciSys has produced APEX - a new, Java-based generation of its UNiT graphical procedure automation system.

APEX procedures are themselves expressed in XML, though full support for procedure scripts compliant with the ECSS PLUTO standard is currently being developed. APEX implements a model of multi-threaded procedures with flow control constructs and a procedure step model that supports asynchronous trigger, action and confirmation phases with built-in failure recovery. Procedure execution status is presented to operators through dynamically updating flowcharts with drill-down outlining capability. Flow control and execution conditions, expressions and actions within APEX are all based on the embedded expression language offered by the Operations Language layer, which itself provides integration with the underlying control system. APEX has been designed for deployment in a distributed, multi-satellite, fleet operations context. It has a true client-server architecture, supporting both multiple execution servers and multiple display clients. Typically, there will be a separate execution engine for each satellite “domain” within the fleet. These domains can be combined on one machine, or spread across several. Procedure displays allow the visualisation of execution status for any domain on any operator workstation – with both single and multi-domain access from a single display, subject to the user’s login profile. Although APEX can support fleet or constellation control, it is equally applicable in smaller
configurations, such as testing with Electrical Ground Support Equipment (EGSE) during the mission development phase. APEX provides an open Schedule Execution layer interface for external invocation and monitoring of procedure level execution, by Schedulers, Contingency Monitoring and similar applications. APEX also provides a fully-featured graphical procedure editor for use by the operations preparation team. Integration with other procedure authoring tools is also possible. The Operations Language layer allows engineering staff to define expressions, and scripts that reference objects and invoke actions at the Data Access layer. An Integrated Common Operations Language (ICOL) has been developed by SciSys to support this. Implemented in Java, it is portable and can be embedded within both C++ and Java applications. ICOL generates executable Java that can be invoked at run-time in synchronous and asynchronous modes. A customisable Data Access layer allows ICOL to be integrated with a range of underlying Data Distribution mechanisms and hence various Spacecraft Control System infrastructures or legacy systems.
Ogres : Automatic Generator of Recurring Reports

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Throughout the production run of the satellites, the satellites/orbitography teams of the control centers periodically produce reports made up of texts, tables, curves, images, etc. These reports are validated then transmitted to the prime contractor, to the technical customers and to the operational teams. In most cases, these reports are produced using specific tools developed by each center. A study of practices has shown that these needs were common to most of the satellite control centers and more widely to operation control centers. In this context, CNES decided to study and produce a generic tool able to be integrated in any project with an aim of automating the processes of generation of recurring reports, validation, management, and filing. From initial requirements written by the Telecom 2 satellite operation team, a generic specification of requirement was written by associating other CNES operation centers (Telecom satellite and orbitography, Earth observation satellites, ARIANE;K) and including the participation of ESOC. The product called OGRES was developed by CapGemini in Toulouse. Today the product is under qualification phase and will be first set up within Telecom2 control center (both for satellite and orbitography), and in the ARIANE telemetry operation center. The OGRES application is composed of two modules: first a module of administration witch makes it possible to manage the whole of the data OGRES, first a module integrated in Microsoft Word allowing the edition of the models and the OGRES reports. Each project must provide a set of specific processing in the aim of extracting and formatting (tabulated text) its data from its specific databases. Ogres provides a set of generic processing allowing the processing and the integration of the data in the report. Ogres is a Windows program, based on .NET Microsoft technologies. It can be deployed in Client/server version or single/user version. Summay of the paper We will present first the objectives of the OGRES project and the principles and guidelines used to write a technical specification with the objective of obtaining a generic software. Then we will present the main functionalities of OGRES, its design features and the technologies used. We will finally present a first return of experiment. A demonstration of the english version of the tool will be proposed.
ESOC is currently defining its approach to increased automation of spacecraft and ground segment operations. Responsibility for mission operations at ESOC is typically split into two parts. The first of these deals with the allocation and operations of shared resources, i.e. ground stations, communications links etc., the second with the actual operations of the spacecraft and associated mission specific resources as well as the usage of allocated shared resources.

Currently the responsibility, during routine operations, for monitoring and operating the shared resources falls under the network operator whereby the responsibility for the mission specific elements are under the spacecraft controllers. Coordination and synchronisation between two areas is achieved during the planning phase by the generation of schedules covering the requested resources allocation and during the execution phase via voice loops between the network operators and the various spacecraft controllers.

This operations model has proved to be successful and robust over many missions and has a clear distinction of responsibility. In view of this, it has been decided to maintain this model in the approach adopted to increasing the automation of the ground segment operations, thus resulting in a concept composed of two systems.

The first of these in the Estrack Management System (EMS) which is composed of 3 main components. The ESTRACK Planning System (EPS) generates and maintains the ESTRACK Management Plan that allocates ESTRACK facilities to missions. The generation of EMP is based on mission requirements entered into the EPS configuration database and dynamic input data (event files) provided by flight dynamics and client missions via the individual mission’s Mission Planning System (MPS). The ESTRACK Scheduling System (ESS) takes the plans generated by the EPS, along with inputs from the mission planning systems, and uses them to generate the schedules.
In future ESOC will only use CCSDS SLE services to communicate with its ground stations and thus the ESS generates the appropriate Service Instance Configuration Files (SICFs) to enable a scheduled use of the ground station resources. The ESTRACK Coordination System loads the schedules and SICFs generated by ESS to the target facilities and optionally to external providers. The ECS also monitors the service provision by the ESTRACK facilities and compares it with the evolution of the plan.

The second system is the Mission Automation System (MAS). This will be driven by schedules generated by a particular mission’s MPS and will control the operations of the mission control and network interface systems and will thus be responsible for initiating connections to the ground station, uplink of commands to the spacecraft, starting specific processing activities, etc.. Access of the MAS to the automation services supported by the different control data systems will be achieved through a standardised layer, ensuring complete transparency of the actual requests implementation details (e.g. current location of the process supporting a given service).

In order that the EMS and MAS are aware of the status of the other system, a bi-directional message interface will be defined allowing status reports to be exchanged. Initially it is expected that this will only be used for information purposes, but later it would be possible to use these messages as the basis for recovery procedures in the event of a ground segment anomaly.
The Earth Science Afternoon Constellation: Preparing for Autonomous but Coordinated Operations

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This paper describes how the challenges of coordinating the autonomous operations of geographically dispersed mission control centers for several small and large satellites are being overcome. The Earth Science Afternoon Constellation, also referred to as the “A-Train”, is an international grouping of five NASA satellites (two major NASA EOS missions and three NASA/Earth System Science Pathfinder missions) and one French satellite orbiting in close proximity. This grouping of satellites provides scientists with the opportunity to perform coincident observations using data from two or more instruments on various satellites with measurements taken at approximately the same time. Three of the six missions are currently on-orbit, with the two missions expected to join the constellation later this year and one mission in 2007. The operational challenges are daunting for several reasons. There are several Mission Control Centers (widely separated on two continents), operating autonomously under tight budget constraints. All of the Mission Control Centers have reasons to be concerned about safety while flying in close proximity to other satellites, but most Centers did not have the resources or the desire to address this concern alone – the interfaces are too numerous and anticipated operations too costly. Clearly, an efficient approach was needed. This paper describes the steps taken to make this Earth science constellation a reality. Agreements were forged to allow the Mission Control Centers to maintain their autonomy, while ensuring their satellite’s safety. Each member mission in the constellation operates independently in accordance with its own mission requirements, but the member missions have agreed to coordinate their operations, i.e., orbital positions and control to ensure the safety of the entire constellation. A centralized system was developed at NASA Goddard Space Flight Center to collect, analyze, and distribute ephemeris data used by each of the mission teams to determine the positions of the satellites in the constellation. The system issues warnings regarding possible dangerous configurations, eliminating the need for redundant capabilities at each Mission Control Center. On-orbit contingency situations were identified and analyzed; agreements were reached in advance of contingency operations to ensure that coordination between the Mission
Control Centers can be handled expeditiously and fairly. In this manner, recovery from anomalous situations can be more quickly realized, thereby increasing the science return and reducing costs. The process used to develop these contingency procedures and the systems used to facilitate the contingency resolution are described as well.
Ground Infrastructure SW Development
The European Space Agency (ESA) has always been one of the most forward-looking and innovative civilian Operations Centres world-wide. The development of a Multi-Mission Control Centre in the 1970s and the use of software simulations for launch preparation in the 1980s are just two examples of the pioneering work carried out in Darmstadt. All Ground Segment software produced is defined as “operational software” and as such the Intellectual Property Right (IPR) lies with ESA and is freely available to any European Industry and / or Organization for its further commercialization. Over the last 20 years European companies have been very active in exploiting ESA’s technology in the commercial market. Many of the most successful space export initiatives on the civilian European market have been based on it. ESA’s Ground Data Systems (GDS) comprises a range of different “products” and “software building blocks”, offering flexible and scalable solutions to the space market, namely: - Base-Band System at the Ground Station, - Ground Station Monitoring & Control, - Network Interface System, - Flight Dynamics - Mission Control System Infrastructure (including Mission Planning and Automation) and - Infrastructure Software supporting the development of spacecraft simulators and test tools. ESA is strategically committed to the harmonization of GDS infrastructure to support its space missions. In line with this strategy, ESA is developing EGOS (ESA Ground Operations Software Systems), which will be the next milestone in the evolution of our infrastructure. This initiative is ESA’s vision for the future harmonization of GDS firstly within the ESA context and, through the European Ground Segment Harmonisation activities, throughout Europe. The objective of EGOS is to establish an architectural framework that - Rationalizes the GDS to minimize duplication of effort and to ensure that its components fit seamlessly into a common architecture based on a common service definition, information and middleware. - Builds on open standards for software (e.g. OMG MDA and UML2) and space data systems (e.g. CCSDS) to create a best-in class GDS infrastructure that has minimal dependencies on COTS products and is implemented vendor independent. - Supports interoperability with other space agencies and operators - Establishes a product focus for GDS software elements and supports a plug-and-play approach, allowing interoperability of products supporting a
common information model and service definition The main principles behind this approach are: - To reduce the cost and increase the efficiency of Ground Segment Development and its operations - To stimulate and improve European Industry competitiveness on the world market - To encourage European self-sufficiency in space and space related technologies - To encourage and advance innovation The paper will address the EGOS architecture, its roadmap, its cost rationale, the ESA IPR software policy and the internal / external customers using our infrastructure addressing the potential benefits for them and for European companies.
During the satellite development phase, dedicated satellite test sets have been conducted to verify the satellite functionality and performance. The Electrical Ground Support Equipment (EGSE) typically is a part of space segment used in various stages of the satellite development, integration/test & launch while Electrical Ground Operation Equipment (EGOE) typically is a part of ground segment used in operation of the satellite. The S/W and database backbone for EGOE is also commonly referred to as Mission Control Element. Also many application and implementation overlaps between EGSE and EGOE, it is common to observe independent development of these equipment and ending up performing compatibility tests to eliminate the differences toward the tail phase of the integration & test program prior to launch. This paper is to identify feasibility of developing common equipment to be shared to minimize unnecessary effort during development and same equipment to support the span of satellite lifetime from test bed verification to the operation. Also, this paper describes sharing data processing and handling architecture involving satellite database utilization, as benefit of this can be easily seen to bring significant cost saving as well as risk reduction assessment for EGSE & EGOE.
ESOC has many missions, with a wide variety of targets and details. Despite these differences, all simulators have common features and requirements in order that they can be successfully deployed, such as having an easy to use interface for controlling the simulation and the provision of common core functions such as logging and scheduling events. Rather than allow or require each mission to create their own versions of this common behaviour and core functionality, ESOC decided that they would develop a core system, called SIMSAT, that would be freely available and mandated for use by all ESA operations simulators. That SIMSAT family has provided the common simulation infrastructure for spacecraft simulators at ESOC for the past 12 years. SIMSAT significantly reduces the cost of each project and avoids users and developers having to learn a new system for every simulation. This paper will cover the features and usage of the latest version, SIMSAT 3.0. SIMSAT 3.0 has been designed to be platform independent, but at ESOC, SIMSAT 3.0 will run on Linux based PCs. SIMSAT 3.0 provides two main blocks of functionality, in the Kernel and the MMI. The Kernel consists of several interlinked components each of which provides a key functional element to the run-time system. The MMI allows end users to interact with the Kernel and study the models’ behaviour. Models are created by the simulation development team and attach to the Kernel, providing the mission specific spacecraft systems modelling. CORBA provides the middleware between the SIMSAT components. A scripting engine allows the users to execute JavaScript that can be used to control the execution of a simulation and can also be used to control the SIMSAT Kernel and MMI components, which are also scriptable. Both Kernel and MMI are component based. They consist of a framework, which loads plug-in components into the simulation. SIMSAT is deployed with a standard set of components, however, new mission specific components for either the Kernel or MMI can be developed and added at run time, either replacing or complementing the available basic SIMSAT components. SIMSAT 3.0, with its extensible set of tools and components will provide new missions with unparalleled flexibility for
simulation needs. It provides a platform for the simulator, allowing redefinition of both the user interface and model interactions with the Kernel. We are convinced that it should allow the emergence of a wide set of tools and useful components, by allowing simulation modelling teams to take part in its design and evolution. Contact Details:
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REGATES – A New Generation of Automated M&C System

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CNES operates a set of ground stations and multi-mission facilities used for both on-station control and LEOP operations of satellites. These ground stations are currently monitored and controlled by a 15 year old system called GASCON. The obsolescence of GASCON, as well as demands for increased functionality for stations operations, have led CNES to start a study in 2002 for a new generation of highly automated station M&C system called REGATES. The contract for the supply and the full deployment of the REGATES system was awarded to Capgemini, Toulouse Space Unit, in March 2003. The development of the system had to face a number of constraints: · Interface with existing on-station equipment whose replacement was not on the agenda, · Migration of 15 years of operations data, from equipment details up to complex operations procedures, · Increased reliability constraints introduced by the requirements for unmanned stations operations capabilities, · Trouble-free operations during the technical and the operational qualification phases of the new system, · In the end, increased efficiency in the ground stations M&C activities leading to a significant reduction of ground systems operations. These constraints in mind, REGATES will bring out new, innovative functionalities: · Innovative, fully Java based Man Machine Interfaces, jointly defined by the Capgemini Web Studio and the future REGATES operators, · Up-to-date technical platform running on Linux and designed for 10 years of operations, · In addition to local and remote control modes, fully automated stations M&C operations, particularly useful for routine operations of LEO spacecrafts. The actual configuration and follow-up of the automated procedures will be performed from the centralized Network Operations Centre (NOC) in Toulouse, · Simplified maintenance procedures, most of which can be conducted from the NOC. The REGATES system is currently being deployed and is planned to be operational by mid 2005. The full paper will briefly describe the functional and technical architecture of the REGATES system, and will highlight its expected benefits in terms of operations costs savings. The paper will conclude with a presentation of the current status and future orientations.
GDSS: a Service Oriented Architecture for Mission Operations

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Service Oriented Architecture (SOA) has been employed with significant success in e-commerce and internet-based applications. This paper considers how SOA can be applied to space mission operations, initially focussing on ground-based Mission Control, but ultimately considering end-to-end mission operations at system level. SOA aims to achieve loose coupling between interacting software components or agents. In traditional software systems, where components are strongly coupled, the interface between any pair of subsystems is often explicitly defined in terms of the full stack of protocols employed from application down to low-level communications. This leads to closed architectures, in which it is difficult to replace, or re-use, software components from one system to another. In an SOA, a backbone of standardised service interfaces is defined in which individual components act either as a provider or consumer of the service. Services are also layered, such that specific application-level services are implemented using more generic messaging services, which themselves use an underlying communications protocol. Specification of a standard service interface requires: an information model for the service, which defines the data objects exposed at the service interface; and a dynamic model that defines the operations that can be performed on those objects, and the events that report changes in their state. This approach unifies the definition of messages exchanged between service provider and consumer, with the associated configuration [operations preparation] data and logging of history. The benefits of this approach include: „H Plug-and-play interoperability of MCS components „H Re-use of common infrastructure across multiple systems „H Independence of core application software from underlying implementation technology „H Scope to evolve a system, by replacing components or changing underlying technologies „H Reduced mission-specific deployment costs „H Independence of mission configuration data and history from system implementation ESA is currently developing the architecture for the future ESA Ground Operations System (EGOS) and a number of studies are supporting this. The Ground Data System Services study, being performed by SciSys, is specifically focussed on the definition of end-to-end Mission Operations services. This draws upon the approach developed in the context
of the CCSDS Spacecraft M&C Working Group. Around a dozen standard Mission Operations services have been identified that support the end-to-end application level interface between collaborating software components or applications: „H Monitoring & Control „H Procedure Execution „H Schedule Execution „H Planning Request „H [Human] Operator Interaction „H Location and Timing „H Flight Dynamics „H Performance Reporting „H On-board Software Management „H Data Product Delivery „H Remote Data Buffering These Mission Operations services are overlaid over a much smaller set of common messaging services that support a limited number of basic interaction patterns: publish-subscribe, transactional request-response, mailbox and file transfer. These common services can then be overlaid on communications protocols appropriate to the physical characteristics of the links between collaborating network nodes. In principle, collaborating components can be distributed across computers, ground system sites, or even between space and ground.
Advanced Technology for Mission Operations
Advanced Technology for Mission Operations: Opportunities, Experience and Perspectives

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Mission complexity and cost are among the most challenging topics ever faced by the design and implementation of the ground segment and the operations preparation and execution. The pressure for outstanding quality of operational services and for cost reduction requires careful analysis to find a balanced compromise in terms of hardware, software, procedures and operational staff required to fly a mission. Automation and autonomy are keywords guiding and inspiring the way we envisage to carry out future flight operations at ESOC. In this context the Mission Control Technologies team at ESOC in Darmstadt is facilitating the introduction and exploitation of innovative but proven technologies to support improved mission control processes, such as planning and scheduling, monitoring and control, diagnostic and failure management, training and knowledge management. The activities are driven by user requirements and the technology is serving to enable effective solutions in terms of overall cost and performance. This paper will introduce the approach and the methodology the team so far followed to transfer technology in ground segment and operations in a smooth and affordable way, within acceptable risks. Furthermore a set of cases are briefly introduced and discussed: from the experience currently matured in diagnostic (e.g. Gyro Monitoring and Diagnostic Tool for ENVISAT), in performance analysis (Mission Utility Support Tool for Smart –1, now being deployed for other five ongoing missions), in ongoing projects (e.g. Space Weather Information System for Mission Control and the CESADS end-to-end link monitoring tool) up to planned future projects. Benefits and limits of innovative technology applied to mission control will be addressed as well as their impact in overall mission cost operations reduction. So far we have and are gaining on-the-field experience through the deployment and extended operational validation of specific operational prototypes. Some output of the lessons learnt is to focus more on the following: · the paradigm of shifting from failure detection to failure forecasting (impact on potential reduction of “out-of-service” time). · the paradigm of increased level of automation in the routine operations tasks (impact on reduction of operations manpower cost) · the paradigm of remote monitoring and alarming (impact on reduction of on-call service cost) · the shift from monitoring to supervisory task (potential impact on reduction of
operations manpower cost) · a possible refined metrics for reliability and risk analysis –including software and human behaviour - to better quantify risk and identify the optimal trade-off between risk and cost (impact on risk mitigation). · support in diagnostic and recovery form anomalies. A perspective of what we might expect from the future along with our vision will conclude the paper.
Spacecraft Control System with Public Access Based on Mobile Phone Technology

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Fast progress in electronics and information technologies (IT) at large allow to develop new concepts in design of spacecraft (s/c) and their systems including ground segments. The problems earlier solved by comparatively big s/c now are in the area of accessibility of small and micro s/c. Ground systems become more compact with much easier maintenance in terms of money and manpower consumption. But the most significant progress is achieved in mobile phone technology. Now it can be considered as the most reliable and cost effective contemporary industrial product. In the paper the approaches are considered based on implementing the mobile phone ITes for spacecraft systems construction. It is obvious that GSM mobile phone is in fact more complex than spacecraft service system including control one. So using mobile phone hard and soft ware it is possible to build the space system consisted from spacecraft and ground facilities which includes now existing nets with some slight modifications. Such system is expected to be sufficiently cheaper and more reliable than traditional contemporary systems, simultaneously the public access to s/c Instruments may be delivered automatically. Introduction into operational phase third generation of mobile systems under Universal Mobil Telecommunication System (UMTS) concept allows to realize this new approach without significant additional investments.
Application of ESA Technology in Commercial Satellite Operations: A Mission Control System Example

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This paper will demonstrate how Satellite Operators world-wide can benefit from the use of ESA technology. When compared with purely commercial COTS solutions, this brings significant benefits and reductions in cost-of-ownership over the typically long lifetime of a commercial MCS. The concept is demonstrated by the great success of hifly® - a complete, flight-proven monitoring and control solution targeted at commercial and satellite fleet operators. Uniquely in its market, hifly uses ESA technology, specifically SCOS-2000, as its core. hifly is at the heart of a framework of an ESA-derived technology and expertise that may be combined to form a complete satellite operations service. SCOS-2000 is ESA’s core satellite control kernel. It supports most of ESA’s current and future missions and will be used for all future ones, including the forthcoming Galileo Satellite Control Facility. Continuous maintenance and development by ESA ensures the kernel is kept up-to-date, compliant to relevant standards, and has a long term future. All SCOS-2000 users, including hifly customers, may benefit directly from this work. hifly is an extensive tailoring of SCOS-2000 for support of commercial fleets, featuring special features and tools, an extensively tailored MMI, payload management and built-in support for popular communication platforms worldwide from Astrium, Alcatel, Boeing and Alenia.
An Advanced Approach to The ATV Cargo Accommodation: The CAST Project

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The International Space Station (ISS) Program gives rise to challenging cargo accommodation issues a fleet of different vehicles is dedicated to upload and download the material to and from the ISS. A high level plan (Cargo Manifest) defines, for each launch and for each carrier, mass types and quantities to be uploaded and downloaded. A detailed (analytical) cargo accommodation of each single cargo has then to be performed, in order to meet the Cargo Manifest requirements. The Automated transfer Vehicle (ATV) is the European transportation system to support the ISS. From the cargo accommodation viewpoint, the ATV consists of an un-pressurized module and a pressurized module. The un-pressurized cargo, consisting of fluids, is transported inside the un-pressurized module, while the pressurized cargo is accommodated into the pressurized module, by means of racks. Geometrical and functional conditions have to be considered, in addition to the static and dynamic balancing constraints, deriving from very tight attitude control requirements. A set of accommodation rules is then defined. Goal of the analytical cargo accommodation is to satisfy the Cargo Manifest, in compliance with the given accommodation rules. The request of satisfying, at the same time, all accommodation rules makes the problem extremely complex and the necessity of finding a solution that is beyond all criticism, from the practical point of view, leads frequently to compare different operational scenarios, in order to select the most suitable one. 'Last minute' upgrades, due to possible re-planning of the Cargo Manifest, may moreover arise and this implies the further capability to readapt quickly the current solutions to the new situations. Looking into efficient solutions, quickly, by means of a manual approach alone, would represent a tremendous effort, even for an experienced designer. Consequently, an advanced approach, based on Mathematical Programming and Operations Research methodologies, has been implemented by Alenia Spazio S.p.A. (Turin) to make the analytical cargo accommodation analysis highly efficient, as well as time and cost effective. This approach is the basic concept of CAST (Cargo Accommodation Support Tool), an advanced software tool funded by ESA and developed by Alenia Spazio (with the co-operation of the Polytechnic and University of Turin, together with IBM, Business Consulting Services, Rome) and GMV (Spain) to support the ATV
cargo accommodation. CAST is based on a heuristic procedure that decomposes the whole accommodation problem into sub-problems. Sub-problems are solved step by step, following an iterative procedure. A mathematical library is the main core of CAST. Each mathematical library module is dedicated to a specific sub-problem. A two-way interface with a graphical system (CAD) allows the user to interact with the numerical elaboration, by suggesting partial solutions. An overall graphical user interface (GUI) makes the use of CAST quite friendly. A description of the ATV cargo accommodation problem is given in this paper. The CAST philosophy and its general architecture will be described together with some case study, to point out the advantages of the adopted approach in terms of efficiency, as well as time and cost effectiveness.
Mission Specific SW Implementation
Efficient Development of the Herschel-Planck Mission Data Systems

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This paper presents the Mission Data Systems for the Herschel-Planck project, which is part of ESA’s Astronomical mission family. The Herschel-Planck missions represent a major step forward in terms of performance demanded and technology supplied. The spacecraft and instruments are designed for autonomous operations driven by an on-board schedule, relying on a single 3-hour telecommunication period per day. Huge amounts of data will be stored on-board and downlinked at data rates (1.5 Mbps and up to circa 700 packets/second) that are unprecedented for such missions. The short contact window and high data rates impose very high performance demands on the Mission Data Systems. In particular, there are very high monitoring and archiving requirements on the mission control system. Furthermore, emulation of the on-board processors (2 per spacecraft) is extremely demanding and is the main driver of the simulator design and platform selection. From a performance requirements point of view, Herschel Planck is an example of the new generation of scientific missions. The large amount of on-board storage also impacts the simulator resources and performance. Herschel and Planck are also the first ESA missions to adopt the promising concept of a “Smooth Transition”, involving both space and ground segment development, which can be summarized as “Reuse and share rather than redevelop”, with obvious advantages in terms of cost-effectiveness. The Herschel-Planck project is the latest step in the continuous improvement of the Mission Data Systems (MDS) development process at ESOC. The paper describes how the development strategy emphasises the importance of efficient and effective validation in a world of scarce resources and less and less time to develop systems that are more and more complex. The approach adopted by the Herschel-Planck team maximises the usage of MDS infrastructure test tools for mission control system and simulator validation and introduces automated system testing based on new tools. It also provides solutions that relax the dependence of the simulator development on external inputs during the different stages of its development. This paper describes ESOC’s contribution to the smooth transition concept, the benefits this brings to the project and, in particular, the benefits for the Mission Data System development. The following areas are covered: The use of the Spacecraft
Control and Operations System (SCOS-2000) as the central control and monitoring element of the various Electrical Ground Support Equipments; The early development of the On-Board Software Maintenance System (OBSTM) as part of the mission control system for use by the scientific community during payload development; The use of the latest test and validation infrastructure to increase testing efficiency; Changes to the simulator development process to reduce the dependence upon the space segment; Mission Data Systems commonality between the two missions and reuse from previous missions of mission data systems and EGSE developments.
The Ral Gerb Ground Segment Processing System

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The first Geostationary Earth Radiation Budget (GERB) experiment was launched on the Meteostat Second Generation (MSG-1) satellite in August 2002. GERB exists to make high accuracy measurements from geostationary orbit of the outgoing components of the earth radiation budget at high temporal resolution. GERB underwent commissioning starting in Dec. 2002, and entered operations in late 2003. The GERB Ground Segment is distributed between EUMETSAT, the Rutherford Appleton Laboratory (RAL) and the Royal Meteorological Institute of Belgium (RMIB). RAL designed and operates the GERB Ground Segment Processing System (GGSPS), which generates Level 1.5 filtered radiance products from raw data, whilst the RMIB system performs higher level processing to generate Level 2 fluxes. The GGSPS then generates monthly means from the Level 2 fluxes. The GGSPS maintains a long-term archive of products at all levels, and provides access to GERB data products for registered users via its web pages and catalogue search tool. Both processing systems operate in near real time, generating products within 4 hours of data acquisition. The GGPS is designed to run continuously with minimal operator intervention. Once daily the system generates a daily summary product and plots of parameters for instrument monitoring. This paper will describe the design and implementation of the RAL GGSPS and experience of operating the GGSPS system over the first two years of GERB and MSG commissioning and operations.

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ESA is in charge usually of supporting space missions which belong to its own programmes such as those carried out in the earth observation (e.g. ENVISAT) or in the planetary exploration domains (e.g. MARS EXPRESS). There are however other projects delivering systems to ESA external customers. The EUMETSAT Polar System (EPS) is one new case in this latter category of ESA undertakings. The European Space Operations Centre (ESOC) has been entrusted with the task of providing for EUMETSAT (the European Organisation for Meteorology Satellites) the Launch and Early Orbit Phase (LEOP) ground support of the MetOp satellite. MetOp is the first European polar-orbiting weather satellite and will be launched by a Soyuz Fregat rocket in early 2006. The responsibility of ESOC extends from rocket separation to reaching the routine polar orbit at which point the control of the satellite will be transferred to EUMETSAT for the rest of the mission. This paper presents the development by ESOC of the MetOp Mission Control System (MMCS). This essential component of the LEOP ground segment will be established at ESOC. The paper addresses this development under different angles: technical, programmatic, strategic and explains how a major increased efficiency was achieved. Extremely attractive costs were achieved by minimizing requirements whilst still guaranteeing mission support and satisfying fundamental mission requirements (including that facility for sending spacecraft telemetry to EUMETSAT in real time simultaneously to its processing at ESOC). Furthermore industrial competition for software development and maximum reuse of existing components played a key role in optimising costs. Similarly the SRS, the Architectural Design Document and the Interface Control Documents are “delta” documents with respect to existing documentation, hence saving the effort that would have been consumed in preparing full scope documents. The biggest cost saver has been the use of the Spacecraft Control and Operations ESOC infrastructure System (SCOS-2000) which the MMCS is built upon. This comprehensive infrastructure allows all mission functionalities to be configured without any change in the software itself and also allows mission specific components to be plugged in smoothly. The paper will explain how this integration with SCOS-2000
has been optimised even though the MetOp satellites are not compliant with the ECSS Packet Utilisation Standard (PUS) regarding the TM and TC formats. Additionally ESOC standardised database formats and other common tools (like onboard image conversion tools) have been adopted hence giving ESOC real assets for providing a highly cost competitive implementation. Availability of matured infrastructure products is crucial for reducing new development costs. The productivity of the contractor together with the innovation brought into the project by young staff have been essential cost reduction factors, too: young engineers are up to speed on latest software technologies so that these technology advances are present for supporting the future space flights. This paper deals with the cheapest, but by no means the simplest, MCS software ever developed by ESOC (the MMCS ) and from this makes recommendations considered particularly relevant for future projects which will be bound all to be ‘low cost’ projects if they want to have ever a chance one day to exist. The MMCS development costs remained within the budget available to it and will contribute to lowering the operations cost of upcoming missions.
An Event Driven System Architecture for James Webb Space Telescope (JWST)

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The James Webb Space Telescope (JWST) will use an event driven system architecture to provide efficient and flexible operations with a simplified, high-level ground command interface. In this paper we describe the operations concepts and corresponding software architecture for this high-level event driven system. We also describe the operations concept for development and test of these elements by ground operations personnel working with flight hardware and software development and test personnel, and the synchronization of these concurrent development and test efforts leading to Observatory launch. A scripting environment was used by the ground system to generate command loads for the Hubble Space Telescope. We show that using a standard scripting environment and implementing that environment in the flight system provides increased operations flexibility, simplifies implementation of the event driven operations concept, and greatly simplifies ground system software and operations. We show how this concept serves to reduce the complexity and cost of ground system software and the overall cost of ground system operations.

The event driven operations concept is based upon a command concept that allows the use of command execution status to determine when to execute the next command in a sequence. This allows for variable durations of activities, shifting execution times for activities, and responses to system availability or activity failure. The architecture provides an on-board scripting environment (JavaScript) that is used to execute scripts developed by operations personnel. The elements of this architecture are an Observation Plan Executive, Script Library, Command Formatter, Telemetry Monitor, and Event Messenger. The Observation Plan Executive controls execution of the Observation Plan, which is generated by the Ground System and which specifies sequences of activities to be executed. Each activity results in the execution of a script in the Script Library, with parameters specified in the Observation Plan that are used to initiate execution of the script. The script can call other scripts in the Script Library, can construct flight software commands through the Command Formatter, can monitor system status and command execution status through the Telemetry Monitor, and record execution status to telemetry through Event Messenger. Event messages, which indicate when activities and scripts are
executed, are placed into telemetry by the Event Messenger. The Command Formatter uses a Command Definition Database, which defines commands available for execution by the scripts. The Telemetry Monitor uses a Telemetry Definition Database, which defines telemetry monitors available for monitoring by the scripts. These databases are subsets of the Ground Command and Telemetry Database. The Observation Plan Executive, Script Library, Command Translation Database and Telemetry Monitor Database are all developed and maintained by ground operations personnel.
TRECS – Improvement Based on Field Experience

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Quality of service and rapid, efficient restoration and reconfiguration of payload services are key items of concern to satellite operators. Changes in configuration may be required by equipment failures or customer service change requests. TRECS (Transponder Reconfiguration System) was developed to support operations personnel in these tasks. The original design, presented at the 5th International RCSGSO Symposium has been significantly upgraded based on customer feedback and field experience. This paper presents a case study of how design modifications and new features added to the TRECS product based on our initial field experience have been made to improve user productivity and reduce costs. In summary, TRECS allows rapid determination of the number of feasible paths (defined as input channels on each uplink antenna to output channels on each downlink antenna) that are possible based on equipment status. From these, TRECS proposes a list of choices for configuration to accomplish any feasible request. These options can then be sorted based on several criteria. Once a choice is made, required configuration information is provided to the user, either as data or in EPOCH IPS friendly format. One of the major areas where it became obvious that redesign would contribute to significantly improved productivity was in the area of TRECS model building. In the original design, payload models were built in a database structure on a component by component basis. All items were specified in this way and when finished, a drawing was generated by the completed database. The user had little control over the layout of the drawing which resulted. The process proved to be cumbersome, error prone and difficult to troubleshoot. The new implementation addresses all these issues. The new design reflects customer and model designer input now offering a “drag and drop” interface where components are selected from a menu of available components and dropped onto a virtual canvas. Interconnections between the components are added by point and click actions in a WYSIWYG (What You See Is What You Get) environment. The end result is that a database structure is seamlessly developed that now becomes populated through a GUI interface to complete the model. Extensive internal error checking is performed to aid in any necessary troubleshooting. These changes have provided a 5 to 10 times improvement in model generation and troubleshooting times (and associated costs) Slow solution search times
were also defined as an area of reduced productivity in the original TRECS. Search times for solutions have been reduced by the introduction of new methods so that instead of using a slow, brute force method of solution generation, highly efficient algorithms can now evaluate millions of possibilities in only a few minutes. Additionally, these solutions can be rated based on several criteria of interest to operations personnel allowing quick evaluation of possibilities. The new TRECS provides the essential capabilities of the old product and new features with significantly improved user productivity and reduced costs. This evolution provides an excellent case study in product improvement based on field and expanded operational experience.
Optimisation of Operations of Specific Missions
ENVISAT Mission Automation – A First Demonstration

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ESA/ESOC is currently investigating the potential to introduce a higher degree of automation into the organisation’s flight operations activities. A significant element of this process has been a study into analysing the operations of ESA’s ENVISAT Low Earth Orbit Earth Observation mission. Launched on 1-March-2002, ENVISAT is ESA’s largest and most complex Earth Observation satellite mission to date. The current operations concept is supported by a level of automation on-board and in the control system and mission planning system sufficient to allow secure operations with close to 100% mission data return with the permanent presence of a single (shift) operator. In fact this operator is also used to control the ERS-2 satellite (since visibilities do not occur in parallel). While this already provides a very low operations cost relative to the value of the high quantity of data this large satellite returns, future satellite missions in preparation are much smaller in scale and the operations costs are proportionately higher. The goal of the automation activity was firstly to analyse the potential to reduce the need for the permanent operator presence during satellite visibilities, such that operation staff can be distributed over multiple spacecraft missions and only have to perform duties for which humans are better equipped. Secondly, an existing procedure automation tool (MOIS) was to be used to generate automated procedures capable of performing typical nominal and some well-defined anomaly diagnosis and recovery procedures, in order to provide a demonstration and test-bed to gain further operational experience. The MOIS tool is already the baseline tool for procedure development in ESOC and was used for creating the ENVISAT Flight Operations Plan. It also provides a procedure executor with an interface to the ENVISAT Mission Control System, which is based on ESOC’s SCOS1 kernel, for procedure validation which already existed. Building on this interface several enhancements on both sides, Mission Control System as well as Automation tool, were identified and implemented for this study. The study made a detailed analysis of the way the operators currently interface with the flight control ground systems as well as the procedures available to them, which have been generated to support a manual operations concept. A feature of the manual procedures is that events and actions can be relatively loosely described, leaving the
human brain to determine the precise actions to be taken. A significantly higher degree of precision in the generation of the procedures is required for the automation and this must be done without losing the usability of the same procedures for manual operations. Automated execution of selected ENVISAT procedures (nominal and contingency recovery procedures) using the automation system was demonstrated successfully to a wider audience in ESOC. The paper will present the results of this demonstration and the lessons learnt from the study. It will conclude with an outlook on the next, potential steps towards an operational system for the ENVISAT mission.
EOS Operations Systems: Planned and Proposed Changes to Reduce Operations Costs

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The Earth Observing System (EOS) Program consists of three major satellite missions (EOS Terra, EOS Aqua, and EOS Aura) which together cover a total mission lifetime of 15 to 18 years. These satellites provide a comprehensive set of data that will help the scientists to observe, understand, and model the Earth system, to discover how it is changing, to better predict change, and to understand the consequences for life on Earth. The ground systems that support EOS need to be operated and maintained during this period. This paper addresses the cost-reduction plans for two of the operational systems, namely, the EOS Data Operations System (EDOS) and the EOS Mission Operations System (EMOS). EDOS is the data capture and Level Zero processing system. EMOS is the satellite control center system. This paper looks at several aspects of systems and operations which can be modified and simplified to reduce recurring cost and increase efficiency. These include: the overall distribution and allocation of the functions; the concept for scheduling real-time contacts with, and science data playbacks from the satellites; the communication links between various parts of the real-time and data systems; the data storage upgrade, and data distribution method. Some of the proposed changes may require retraining of personnel as dictated by the reallocation and streamlining of operational tasks, but the benefits of more efficient systems and the anticipated cost savings will outweigh the initial pain during the period of adjustment. With any modification to systems or operations, it is important to ensure that the modified systems and/or operational procedures undergo careful and thorough testing to ensure that there is no adverse impact to operations and to the end users of the data from the missions.
The Approach to Operations Cost Saving for ESA Planetary Missions

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In support of the ESA Scientific Programme the European Space Operations Center (ESOC) has developed and operates the ground segments for Rosetta (launched March ‘04), Mars Express (launched June ’03) and Venus Express (to be launched October 2005). At the beginning of each project, Rosetta being the first, it was not known that the others would exist, nevertheless thanks to the commonality of the space platforms, the three ground segment systems have been developed with a large extent of commonality in terms of systems, facilities, and resources. Despite the complexity of the mission operations and of the required ground systems significant cost savings have been achieved both for Mars Express and Venus Express ground segments as followers of Rosetta. Commonality is exploited in all areas: the three missions are operated with the same mission control system, the three spacecraft simulators share large parts of the code, the TM/TC database editor and converters are the same, the Mars Express and Venus Express mission planning systems are identical configured with mission specific rules. This has been achieved with a continuously coordinated development activity. Common control areas have been created for the deep space missions. Currently only Venus Express uses a dedicated area due to the development stage versus operational phase of the other two, it is however planned to share also this facility in the future. Commonality in this area needs to be further exploited and might lead to other costs savings in the future. Only partial sharing of human resources could be achieved across the three missions, however significant efficiencies have been achieved in re-deploying a portion of the Rosetta flight control team to Mars Express and Venus Express when required. Efficiency in developing a ground segment has also benefited from the commonality imposed to the three projects leading to the capability to prepare the Venus Express ground segment in about 2.5 years with a Flight Control Team limited to 2 engineers up to 16 months before launch. This paper presents the achievements, analyses the problems encountered, and proposes possible ways to improve efficiency and further reduce costs including running costs of mission execution.
The International Rosetta mission is a cornerstone mission of the ESA Scientific Programme. It consists of an interplanetary probe, launched on 2nd March 2004 on a 10.5 years journey to rendez-vous with a comet. Once reached the nucleus the Rosetta probe will orbit it from distances down to a few kilometres for about 1.5 years. It will also deliver a small lander module, Philae, onto its surface. The long interplanetary journey is necessary, as to match the orbital velocity of the comet Rosetta will require four planetary gravity-assist manoeuvres: three times with the Earth and once with Mars. The probe will cross twice the main asteroids belt, with fly-by opportunities of the asteroids Steins and Lutetia. In between planet swing-by or asteroid fly-by events the Rosetta spacecraft is generally kept in a low activity mode, minimising the number of active units and avoiding all operations which are not strictly necessary for the survival of the spacecraft and the safe continuation of the journey. The quiet cruise periods have a duration of typically six months each. Several measures have been taken in order to minimise the operations cost over the 10.5 years cruise. As the largest cost driver in cruise is the use of the deep-space ground station in New Norcia, the efforts concentrated in achieving the right level of spacecraft autonomy and establishing an operations concept that minimises the need for ground contact. A second cost driver, the manning of ground station and control centre during the necessary contact periods, has also been scrutinised and measures adopted to reduce cost in these areas in an incremental way during the mission. This includes remote operation of the ground station, partial manning of the operations centre during the pass, gradual introduction of automation tools, sharing of spacecraft controllers with other missions. This paper describes the approach adopted for the Rosetta mission to minimise operations cost during the quiet cruise phases. The experience of the first year of flight and the consequent adaptations of the initial ideas and future plans are analysed in detail. The problem of maintaining expertise, skills and motivation in the small team in charge of the long interplanetary journey is presented and the solutions adopted for Rosetta described.
SMART-1 is the first of a series of ESA Small Missions for Advance Research and Technology (SMART program) where elements of the platform and the payload technology have been conceived as a demonstration for future cornerstone missions and an early opportunity for science. It was launched on 27th of September 2003 and inserted into a Geostationary Transfer Orbit (GTO) where it spiraled out over a 14 month period until being captured by the Moon on 17/11/2004. The primary mission of Smart-1 set to demonstrate Solar Electric Propulsion and other advanced technology elements is considered a success at this time. The spacecraft is currently in orbit around the Moon commencing its scientific mission with all instruments on-board fully operational. The price is about fourth/fifth the price of a medium science mission and about one tenth of the price of an ESA cornerstone mission. The main principles that drove the design of the ground segment and the operations concept are summarised below: · All ground facilities are based on extensions of existing infrastructure. · The number of ground stations, the duration of the station passes, the choice of specific antennae were chosen to minimise the overall cost of investment and operations. · All monitoring and control activities were optimised to cope with non-real time operations (nominally 1 pass every three/four days lasting 8 hours, engineering support only during working days). Several spacecraft anomalies have posed operational challenges of varying degrees for the mission team, they entailed a high workload for the operations team, the navigation teams and the scheduling and ground station staff. The paper will show the pros and contras in some of the choices made for Smart-1 together with the developments and the solutions implemented to mitigate the problems found during the mission: * Impact of on-board problems on operations * Ground Segment automation * Keeping the mission control team reduced * The increased importance of the Mission Planning System * Fast distribution of spacecraft data through internet for anomaly identification and analysis * Summary of lessons learnt.
SW Re-Use and Developments for Mission Families
Satellites are extremely complex systems whose operations require a technologically advanced ground segment infrastructure comprising ad-hoc sophisticated systems. The development and maintenance of these systems requires a high level of know-how and experience. ESOC has more than 35 years of experience in the field and has developed unique capabilities in this domain. Very demanding requirements in terms of availability, reliability, maintainability, and above all high quality standards are cost drivers, since they imply usage of sophisticated technology and extensive validation. However, containment and reduction of costs is one of ESOC priorities and in fact ESOC has managed through the years to drastically reduce the cost of the ground segment systems, through the development of a powerful reusable software infrastructure and by fostering cooperation and competition at European level. Based on the concept of software reuse and commonality of requirements, a new initiative has been taken in the last years by the ESOC Mission Data Systems Division in the Ground Systems Engineering Department to exploit in a systematic way the commonality across missions, and in particular within Mission Families, throughout the whole engineering lifecycle of Mission Data Systems (MDSs), which comprise Mission Control Systems (MCS) and Simulators. The adopted strategy is one of systematic and documented reuse of common software elements. The focus is on the reduction of cost and risk for the ground segment mainly thanks to the following factors: - reduction in the amount of code and documentation to be produced - reuse of parts of software already used operationally by previous missions - same look & feel that allows exchange of operational staff between the mission teams - possibility to have a single effective software support team to serve all the missions in the family. This paper outlines the application of the reuse experience within the Interplanetary Mission Family, currently comprising the Rosetta, Mars Express and Venus Express Missions. A single MCS, including the Data Disposition System (DDS), has been developed for the three missions, based on largely common requirements, which is instantiated on a different platform for each mission. This system, originally developed based on the classic line of the MCS infrastructure, SCOS-2000, has been ported to the latest MCS infrastructure version, SCOS-2000 evolution as part of the
Venus Express MCS development project. The ported system will be adopted by Rosetta and Mars Express as well, following minimal configuration changes. Despite the design of simulators highly depends on the spacecraft design, which differs for some subsystems between the three interplanetary missions, reuse has been highly exploited for the simulators developments and maintenance for these missions, with substantial cost reduction benefit. The paper will also elaborate on the benefits of reuse for the Mission Planning System (MPS). The Mars Express MPS was initially developed based on the Envisat MPS, and has been adopted by Venus Express with minimal changes, and therefore limited delta-cost, mainly including rationalization and optimization of the software. Keywords: Rosetta, Mars Express, Venus Express, Mission Data System, Mission Control System, Simulator, Mission Planning System, Data Disposition System, Reuse. Symposium Topic: RCSGSO 2005, Track 2: Ground Segment Engineering and Architectures.
Software reuse, when done with due caution, is a strategy for both cost and risk reduction for new software developments. Reuse reduces the amount of code and documentation that has to be developed and maintained. ESOC has pursued a strategy of software reuse for Mission Data Systems (MDS) since the mid 1970’s. We distinguish two main sources of software for reuse:

· Software components expressly designed for reuse, commonly referred as infrastructure software, SCOS-2000 for Mission Control Systems and SIMSAT for Simulators
· Software elements developed for specific missions, having the potential for reuse

This paper outlines the actions taken by the ESOC Mission Data Systems Division in the Ground Systems Engineering Department as concerns reuse of MDS software across missions. Each new MDS developed at ESOC is based on the infrastructure software. Therefore the software engineering life cycle is based on a “delta” approach, where delta or modified requirements with respect to this infrastructure are the focus. The first step in the direction of re-use of software developed for specific missions is the identification of requirements from previous projects which are also applicable to the new one. The benefits of the identification of similar requirements from previous missions and their harmonisation at the level of the Software Requirements Specification (SRS) are numerous, including:

· The quality of the SRS is enhanced by the adoption of requirement specifications that have already been reviewed or have even been implemented and/or operationally validated;
· The assumptions for potential software re-use are equally made known through the SRS to all MDS development bidders, enhancing competition on the same ground; When the requirements for a new MDS are defined, the SRS of the previous missions are carefully reviewed in order to identify requirements applicable to the new development. In the past each new mission repeated this effort in the context of its own projects. Since the number of MDSs based on the same infrastructure is ever increasing, this task has become more and more complex and expensive and almost impossible to be completed in an exhaustive manner. A REquirement maNAgement TOol called “RENATO” has been developed at ESOC. RENATO is based on an industry-standard, commercial application Telelogic DOORS. DOORS is a sophisticated product that can manage requirements on large products. It incorporates a macro-programming
language (DXL) similar to C++ in nature that enables ESOC to create tailored functionality. As a start RENATO stores the requirements of all the ESOC SCOS-2000 based MCSs in a single database. The numerous facilities offered by RENATO, including requirements classification, selection, dynamic linking, powerful editing and filtering, export to widespread editing tools and its integrated configuration control make this tool an excellent mean for overcoming the above mentioned shortcomings. Another major benefit of RENATO is that by supporting a systematic review of the MDS mission-specific requirements it enables the definition of classes of requirements candidates for implementation at infrastructure level. It also provides statistics aimed at keeping visibility and control of the extent reuse is applied across missions and within mission families. It is the plan that RENATO will be extended to support other MDSs such as simulators. Other extensions are also planned in the direction of tests and validation, and software design.
Cost Effective Mission Control System Development by Means of Mission Family Commonality

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The European Space Agency (ESA) has always based its approach to Mission Control Systems (MCS) development on the ability of re-using experience, procedures and software from previous missions. This has resulted in a powerful and stable software infrastructure now at its 3rd generation, SCOS-2000, that is developed and maintained by ESA and used as the MCS kernel for most ESA missions. SCOS-2000 provides generic functionalities for spacecraft monitoring and control such as telemetry reception and processing, telecommand uplink and verification, data archiving, display and retrieval, remote telemetry and data disposition. However, SCOS-2000 is usually not sufficient to cover all functionality needed by a space mission and it still requires extensive configuration effort. In any case, this is just a small fraction of the effort that would be necessary if the MCS were produced from scratch. In the last few years, other initiatives have been started with the aim of further reduce the cost of the MCS development. Firstly, an initial cost saving has been achieved in the software requirement phase: MCS requirements are no longer produced in full, but rather as “delta” with respect to SCOS-2000. This results in a quite slim requirement document that is quicker to write and review, that highlights very clearly where new developments are needed, and that allows better cost estimation and development risk assessment. Clearly, the economical advantages of this approach extend also to all the other phases of the project, i.e. the software architectural phase, the software development phase, and the software maintenance phase. Secondly, it was noted that missions with a similar profile require the development of similar mission-specific features. Typically, these features are not included in SCOS-2000 as they are not generic enough. On the other hand, they can be grouped into classes that map into well-defined “Mission Families”. So far, four mission families have been identified, which are listed below together with some of the characteristics that make them a “special family”: - Earth Observation mission family: low Earth orbit, short visibility periods - Planetary mission family: long propagation delay, on-board autonomy - Observatorv mission family: long visibility periods, proposal based observations - Navigation mission family: mid Earth orbit, constellation. With this concept, it is now possible to apply twice the cost saving approach
described above: the first time by using the SCOS-2000 infrastructure, second time by using the applicable “mission family kernel”. In fact, functionalities responding to common needs within a mission family are grouped in the mission family kernel as a software layer on top of SCOS-2000 infrastructure. Clearly, there might still be mission-specific features that have to be specified, designed, implemented and tested on top of the SCOS-2000 infrastructure and of the mission family kernel. This approach provides higher quality products that are based on well-proven systems. The paper provides details on implementation of the mission family approach with of the Earth Observation mission family as a practical example. Currently, this family includes the CRYOSAT, GOCE, AEOLUS and SWARM missions and we intend to use this approach for all new missions in the family.
Software Re-Use Review: The Benefits of the Common Ground Approach

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The Johns Hopkins University Applied Physics Laboratory develops custom, one-of-a-kind satellite systems, including Mission Operations Centers. In the past two years the Ground Software Applications group changed its approach to software re-use. The old re-use paradigm required taking a snapshot of an existing ground software system, then developing and maintaining the new system separately. We replaced this old snapshot paradigm with a new Common Ground approach. The Common Ground approach provides complete life-cycle re-use and a shared team of software developers. The Common Ground approach requires the development of a shared source code repository, shared configuration management procedures, and libraries of common code. The system is developed mostly in C++ with an object-oriented architecture. The goals of the Common Ground effort are to increase system reliability, to reduce risk and to decrease overall mission costs. We recently completed development of the first mission to use the Common Ground with metrics to judge the success of this approach. Our metrics confirm that project risk decreases, because an operational system is delivered earlier. Metrics for software change requests and for problem reports also show improvements. The reduction in risk and the number of required software changes translates into lower costs to the mission. Although cost-savings are difficult to quantify in dollars, the metrics provide another means of quantifying the savings. Examples of metrics resident in the Common Ground configuration management repository include: the number of functional units delivered; the delivery profiles for each mission; the number of change requests, per month, by category; and the total number of change requests over a particular mission phase. Figure 1 demonstrates ground software error reduction through implementation of the Common Ground approach. Here we compare ground software errors across three missions. The mission with the largest numbers of errors per month was the first mission to use the Common Ground approach. The two follow-on missions show reduced errors per month. Additional plots correct for differences in mission timelines and functional complexity. In addition to reviewing metrics, we will summarize some lessons-learned. We review the strategies selected for separating common and mission-specific code. Some decisions provide successful solutions, others lead to unanticipated problems. Future missions must
consider whether to build upon the existing Common Ground system, or whether it is more cost-effective to apply the lessons learned in the development of a new system. References: [1] 102-A0052, "Complete Ground Software Re-Use: The Common Ground Approach to a Re-Usable, Shared Ground System"; Mckerracher, Priscilla and David S. Tillman, R. Michael Furrow, Leeha R. Herrera; 5th International Symposium on Reducing the Cost of Space Ground Systems and Operations; Pasadena, CA; July 8-10, 2003. Figure 1 Comparison of Ground Software Errors on 3 Missions.
On-Board SW Maintenance/SW Live Cycle/SW Product Line
The International Rosetta mission is a cornerstone mission of the ESA Scientific Programme. It consists of an interplanetary probe, launched on 2nd March 2004 on a 10.5 years journey to rendez-vous with a comet. Once reached the nucleus the Rosetta probe will orbit it from distances down to a few kilometres for about 1.5 years. It will also deliver a small lander module, Philae, onto its surface.

The European Space Operations Centre (ESOC) has assumed the responsibility for On-Board Software Maintenance for the Rosetta Avionics, which includes the Data Management Subsystem (running the On-Board Control procedures, also under ESOC OBSM responsibility), the Attitude and Orbit Control Subsystem, the Autonomous Star Trackers, the Navigation Cameras and the Solid State Mass Memory. The responsibilities include full cycle maintenance tasks, from problem identification, source code modification, unit-functional-operational level validation, to final spacecraft uplink. Payload maintenance activities are reduced to those related to command generation and uplink verification.

In order to properly execute the on-board software maintenance activities, a set of tools has been inherited from the pre-launch development and testing environment set-up by Industry (software development and validation facility, a dedicated On-Board Control procedures development environment, and the full engineering model of the Rosetta spacecraft). In addition, tools have been developed as part of the Rosetta ground segment, including the On-Board Software Maintenance module on the Mission Control System and the System Simulator, which is based on a software emulation of the on-board avionics processors that can run the actual on-board software code.

On-Board Software Maintenance responsibility has just been transferred to ESOC, after about 10 months of flight. However software maintenance activities at ESOC have already started in several areas long before the actual launch, including testing and validation of software provided by
Industry (new versions and patches), development of new On-Board Control Procedures, implementation of the changes on-board the spacecraft before and after launch, analysis and investigation of in-flight anomalies.

This paper describes the approach taken at ESOC for on-board software maintenance of a long-duration mission like Rosetta. The environment and the implementation concept are discussed, also through the experiences accumulated in the two years of operations on ground and in flight. The experience and lessons learnt are critically discussed from the point of view of a quality/cost trade-off with more traditional solutions.
Neptune: a Tool and an Approach for Life Cycle Cost Reduction in Space Ground Segment

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The Spacecraft Ground Systems maintenance logistics cost reduction is everyday an mandatory objective. The LCC approach, in accordance to ECSS-M-70A, is strictly linked to the LSA process and takes into account all relevant aspects in terms of LORA, SO, etc.. In fact, the solutions resulting from the LSA process define the logistic and maintenance costs during the whole system life cycle. The logistic and maintenance cost reduction is the aim of the LSA methodology applied by Vitrociset. In particular this methodology is split as follows: 1)Development phase: 1a)Planning: focused to identify the best LSA/LCC strategy; 1b)Preliminary LSA: focused to identify several scenarios, evaluate the LCC linked to each one and linked performances following a trade-off analysis. In this phase only some ‘relevant’ cost elements have to be taken into account. It is an ‘iterative and concurrent’ process focused mainly to provide feedbacks to the system design; 1c)Detailed LSA: focused to select the most efficient scenario (matching both target performance and cost saving) and for it, to detail all the analysis in terms of LORA, Maintenance planning, SO, LCC (taking into account all costs elements), etc. 2)In-service phase: 2a)Recurrent LSA: performed during the operative phases and focused to refine LSA concepts taking into account on-field feedbacks. In this phase an FRACAS approach is adopted. For instance, on one hand, the output of the SO tool will define the warehouses stock levels and then it will be the input of the Maintenance Management Tool, on the other hand, data collected on field by MMT (MTBF/MTTR) can be used to refine performed analysis by SO tool and update the warehouses stock levels. 2b)Maintenance and Operations: performed during the operative phases and focused to operate and maintain the system for instance managing spares, consumables (procurement, storage, movement and distribution) and personnel (maintenance technicians availability). Vitrociset applied and is applying this LSA methodology in the development of several geographically distributed systems involving complex organizations in both Commercial/Civilian and Military context (e.g. COSMO-SkyMed, Helios, EGNOS, ENAV logistics, etc.). Starting from these experiences, Vitrociset developed a Logistic System, Neptune. Neptune is based on a Database (NEPTUNE DB) compliant with the MIL-STD-1388-2B and implement
innovative methodological and technological solutions based on Object Oriented, Java, and web-based approaches. Neptune architecture has been developed following a modular approach in order to allow, on one hand, to collect data and perform analysis during Development phase, and on other hand, to collect & use on-field data and manage operations and maintenance during In-service phase. The logistics and operational needs during “in service” phase drive to have two or more different ‘virtual’ DBs. One DB dedicated to MMT activities and one or more ones DBs dedicated to LSA. The LSA DB(s) could reflect changes in the H/W or S/W configuration proposed during the operational phase, requiring for example a new LCC analysis and/or new LORA (for system upgrades, obsolescence, etc.). The ‘virtual’ DBs are managed by creation of several ‘scenarios’ in the Neptune DB. Neptune tool is a powerful instrument for LCC reduction allowing to store in-service and development data in a unique tool. It avoids DBs inconsistencies and speeds up LSA processes (i.e. import/export of data, real time input, etc.) focused to define the most efficient logistic scenario.
Decreasing Costs of Ground Data Processing System Development Using a Software Product-Line

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A wide variety of sensors sponsored by either NASA or ESA provide the world’s scientific community with data. These instruments include imagers, spectrometers, lidars, and radar, as well as other, less common hardware. Some are located on the ground; some orbit the Earth; some orbit other planets. Analysis of their data produces an even wider variety of scientific products. This diversity prevents processing of this heterogeneous dataset by a single Ground Data System. Each Ground Data System contains many characteristics which differ from all other Ground Data Systems, as well as characteristics which all hold in common. These differences drive the development of systems with mostly unique components and, often, infrastructure. Development of reusable infrastructures and component libraries usable by Ground Data Systems has reduced the cost of development of some systems. The next step is development of a complete, reusable architecture. A software product-line architecture is a single architecture designed for use by multiple systems. The architecture formally specifies aspects common to all potential systems, such as communication between processing components. It also specifies how unique aspects, such as scientific algorithms, are incorporated into the product-line architecture to create a specialized architecture. Using a product-line architecture, and library encoding the common components, frees Ground Data System developers to concentrate on the distinctive characteristics of their system. The reuse of a proven architecture and associated code reduces both the cost and risk of developing a new Ground Data System. In this paper, we provide an overview of how to develop and use a software product-line architecture for Ground Data Systems. We identify the issues such an architecture must address. We specify the common system characteristics that must be included in the architecture, as well as potential system-specific characteristics that may be added to create a specialized system. Finally, we describe, at a high-level, an example product-line architecture.
Satellite Operations: The focusSuite framework

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Satellite operations are normally driven by the imperative need to develop operational software based on the reuse of legacy software, exhaustively exploited during years of operations qualified as “flight proven”, and also by the desire to use modern software technologies which dramatically boost system usability, accessibility and stability. In order to fulfil those objectives the “framework” concept appears as the required support for future operational systems development. Framework concept is thus oriented to minimize programme development schedule, costs and risks, and at the same time to improve the efficiency of operations (minimising operations workload) and reducing the risk of human errors. In order to meet these ambitious goals the framework provides a number of ready to use components for data manipulation, visualization and events logging, communications layers, process management, automation and reporting. Nevertheless, the real power behind the framework lies in its ability to integrate components/algorithms. While the integration of disparate software is usually a hard task (programs not conceived to act as components, wealth of protocols and formats, unclean interfaces, etc.), the framework makes this issue straightforward. Interface between the framework and the operational component/algorithm is based on the implementation of a simple API in order to manage correctly the processing and the data interfaces. The framework also provides well-designed, high performance, robust, customisable, extensible, flexible and coherent Man Machine Interfaces (MMIs), providing graphical capabilities. Management of new entities (e.g. satellites) is simply performed by modification of editable configuration files. Those configuration files are interpreted by the framework system in order to create the required database structure, to construct the overall MMI and to generate the operational functionality including additional (if required) generic functions like plotting or data acquisition and pre-processing. The issue of users and privileges needs also to be managed by the framework, in addition to automation which deserves special attention., GMV has developed a dedicated tool, called focusSuite, conceived as a real framework for all type of satellite missions (including GEO, LEOP, LEO, satellite formations, constellations, interplanetary missions, re-entry, ascent, rendezvous, etc.) as it is demonstrated by its major functionalities: a computation and data layer based on the extensive
reuse of existing and improved software, a client/server architecture, a database driven system, an advanced MMI (based on desktop applications philosophy: “everything-in-one-working-area” and “all-one-click-away” and using a proprietary toolkit called TkForms that allows a development through configuration files in ASCII format, rather than through code), procedures automation capability through the AutoFocus extension (based on a dedicated language SoL -Spacecraft Operations Language- also developed and integrated by GMV), advanced graphical capabilities, 2D/3D visualization, portability (e.g. UNIX/Windows NT), extensibility (any extra functionality following certain I/O rules can be easily integrated within Focus via configuration files), automatic regression testing and finally, capability to perform unlimited Undo/Redo operations. At this stage focusSuite is fully operational for flight dynamics operations on GEO and LEO satellites through its products focusGEO and focusLEO and is evolving for other members of this suite.
Using COTS for Cost Effective Multiple Satellite Operations

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The National Space Program Office uses its satellite control system in all areas of satellite development including Integration and Test, Launch support, and on-orbit operations. NSPO has found that a major advantage of the system is its built in flexibility. This flexibility allowed NSPO to use the system for the operation of the ROCSAT-1 (renamed as FORMOSAT-1) satellite with the existing software while allowing for the installation of the software upgrade for use in the operation and integration and test of the new FORMOSAT-2 and FORMOSAT-3 satellites. This inherent flexibility of the EPOCH IPS (Integrated Product Suite) based system ensures that enhancements and upgrades to the system can be accommodated for current or any future FORMOSAT programs. By using the same ground control system to support the FORMOSAT-series satellite ensures the consistency of operations and preservation of all functions previously in use by the NSPO operations team. Hence NSPO is able to keep a familiar and consistent operational approach for all its missions. Although different spacecraft manufacturers designed these satellites, NSPO found that EPOCH easily supported in adding the new FORMOSAT-2 satellite. NSPO will also use system for the FORMOSAT-3 satellite constellation following its upcoming launch. The FORMOSAT ground control system uses a multi-stream, client-server architecture to provide for fleet commanding and control. No special software is required to monitor and control multiple satellites simultaneously. Under operator control from the client program, the same system server can manage a single satellite, multiple satellites from different manufacturers, or an entire constellation of satellites. The system’s robust design provides support for all phases of the satellite lifecycle including integration and test, launch and early orbit, and end of life operations. NSPO was able to rapidly staff up and staff down during the different phases based on its needs, and also able to control the satellites via different remote TT&C sites throughout the world without having to change the software. The database driven architecture allows the software to be configured for unique satellite specific characteristics without costly software modifications.
A Generation-Based Framework for Spacecraft Operation


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Spacecraft operation is accomplished by using SOP (Spacecraft Operation Procedures). The SOP consists of sequential order of operation commands and remarks, and is developed by utilizing commercial spreadsheets or custom tools supplied with specific T&C (Telemetry & Command) software. For understanding the outline of execution of the SOP, OFD (Operation Flow Diagram) is also used in spacecraft operation. The OFD is usually developed with commercial drawing tools. It is difficult to keep consistency between the SOP and the OFD. In case developing the OFD with commercial drawing tools, various functions are supported by the tools, and flexible layout is allowed. However, since relationship between the SOP and the OFD is not maintained by the tools, inconsistency will be easy to occur and consistency check must be required. Furthermore, when modifying the SOP, corresponding OFD must be modified. Since the OFD are used for understanding of the SOP, modification of the SOP requires not only adding new figures, but also rearrangement of the layout of existing figures of the OFD. Sometimes, this modification will become to be time consuming work.

From above reasons, we are developing a new framework for managing OFD and SOP, based on automatic generation from PSD (Procedural Source Description). The PSD is represented by using a domain-specific language, designed for the framework, which describes procedures such as command execution, telemetry verification, branch points and so on. In this framework, OFD and SOP are generated from corresponding PSD.

This framework has following features. First, the framework generates various products from the PSD such as operation documents and check lists, as well as OFD and SOP. This generation can reduce time and effort to develop these products, and the quality and consistency between these products can be achieved. Second, the framework supports developing PSD. For example, PSD editor provides multiple views for the target PSD, and various types of views are provided, by using results of command execution or various parameters which are specified by users. This feature enables to
modify the SOP quickly, even in case of emergency, with keeping consistency between OFD and SOP. This paper describes details of the PSD, and design and implementation of the editor. This editor is now being introduced into HTV (H-II Transfer Vehicle) mission operation.
Session: Cost Driven Mission Operations
Cost-Capped and Risk Adverse: Opposites Attract

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Currently, space missions generally fall into one of two categories. They are either one of the small cost-capped missions in the Discovery, New Frontier or Scout programs or they are larger missions that have multiple instruments and a greater number of scientific goals. The smaller missions are cost-capped and that cap is part of the proposal. Typically, these missions use existing proven technology. The larger missions have their budgets set by NASA Headquarters and those budgets are generally smaller than in the past. At the same time that funds are shrinking, there remains pressure for missions to be successful. In the end missions have the mantra of being cost efficient and risk adverse. Two different missions at Jet Propulsion Laboratory have different approaches to this attraction of opposites. One of the missions is the Kepler Mission – a search for terrestrial planets. It is a cost-capped Discovery Mission. The Kepler scientific goals are to look for earth-size planets around distant stars. Kepler’s approach to fulfilling the mantra is to simplify the mission. This mission has one instrument, a photometer. This instrument stares into the same area of space for its entire mission. The only significant attitude changes are quarterly rolls about the photometer boresight to maintain sun angle on the solar arrays. In addition to simplifying the mission, it is relying on reuse of software for both flight software and ground operations software. Lastly, it allows the various partners in the mission to use their own procedures and processes for software development and ground operations. On the other hand, Mars Science Laboratory (MSL) is a larger mission with ten instruments. Its budget is set by NASA Headquarters. Even though it has a greater number of instruments and a significantly longer prime mission, its cost is similar to the Mars Exploration Rovers (MER) that are currently roaming Mars. The Mars Technology Office has an MSL Focused Technology splinter. This splinter looks for ways that technology can help MSL. One of the focused technology tasks is the Next Generation Uplink Planning System. This group is looking at reducing costs and cost risk by examining the ground system and prototyping promising technologies. The team is focusing on refactoring of functionality, software reuse via components and a unified user input mechanism. They will prototype these promising technologies using the MER Uplink Planning System. These two missions have two different ways of solving a similar
problem. However, both ways look reasonable and achievable. The paper will describe in detail these two approaches to the same problem including their progress and successes (or failures) in these areas. Kepler launches in 2007 and MSL launches in 2009. Judging whether these approaches are successful will be determined when the spacecraft are successfully on their way and their respective flight and ground systems work beautifully.
Seeing on a Budget: Mars Rover Tactical Imaging Product Generation

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The Mars Exploration Rovers (MER), Spirit and Opportunity, have been operating on the surface of Mars since January 4, 2004 – over 385 SOLs (Mars days) at the time of this writing. A suite of imaging products provided the tactical information needed by a rover team to plan the activities of the rovers. These products – elevation maps, slope maps, terrain meshes, reachability maps, range maps, surface normal and surface roughness maps – were generated within an unprecedented turnaround time. Products that, for prior missions, required several days to produce were made available to the rover planning teams within one hour of telemetry receipt. This paper will provide an overview of the subsystem which is responsible for the above mentioned products. The Operational Product Generation Subsystem (OPGS) is an element within the MER's ground data system data and provides the connection between the mission's downlinked data and the mission analysis and planning element. Key tradeoffs were made during the implementation of the software, definition of the team structure, and processes used during operations. This paper will discuss the various trade elements and the effects of the decisions made relative to team's daily work schedule and the efficiency of operational data processing. During the software requirement definition, it became evident that schedule and budget constraints demanded a creative approach to the implementation effort. Modification to the flight system and operational concepts mandated a flexible system able to adapt rapidly to these changes. Use of legacy software developed from an existing core, with adaptation to MER-specific models proved efficient and flexible. The process by which this design was reached is discussed. Staffing for the Mar's SOLs vs. the Earth days – 24 hr 40 min day vs. 24 hr day – became a challenge and and a cost driver as operational readiness testing revealed. Efficient use of workforce was needed to meet the operational demands and provide a semi-rested crew. Constraints on team scheduling were made complex by issues relating to project needs, personal commitments, institutional guidelines and government labor laws. The tradeoffs considered and the solution employed for scheduling teams and facilities will be discussed. The paper will also address some of the early technical and procedural decisions made which were proven during the operational phase of MER to be cost reducers. The efficiencies of well designed and rehearsed procedures and rapid access to
information generated during previous operational SOLs proved to be invaluable during operations. These processes will be defined and examples will be provided. At the completion of the primary mission – first 90 SOLs – a number of extensions to the mission were approved which continue to this date. Adjustments for a long-term mission had to be made at a sustainable level. Our teams' 90-day commitment to MER's intensive operations is over and their commitment to other JPL missions mandates adjustments to a changing workforce. The tradeoffs in staffing will be discussed.
Evolution of the Cluster Ground Segment: Reducing The Annual Cost for The Second Mission Extension

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The Cluster ground segment mostly consists of that which was built in the early 1990s for the original Cluster mission. The four Cluster spacecraft were destroyed in 1996 by a launch failure, but as Cluster was an ESA “Cornerstone 2000” programme with great scientific relevance, the four Cluster spacecraft were rebuilt and launched in Summer 2000. The Cluster-II mission has been in its routine operational phase since February 2001. In 2002 the first mission extension, until the end of 2005, was approved together with data extension phase, which added the upgraded Maspalomas terminal as a second Cluster-II dedicated ground station to the original VILSPA-1 station. As Cluster-II is providing the scientific community with unique multi-spacecraft measurements of the magnetosphere and while all 4 satellites including their payload are still in excellent condition, a second mission extension from 2006 to the end 2009 is in preparation. With a considerable re-design and upgrade of the ground segment the annual mission costs for the additional 4 mission years can be reduced by 25% while maintaining the prime requirements of the mission. The rationale for the re-design and upgrade is subject of the paper presented. It is shown how a combination of greatly differing measures can lead to this considerable reduction in cost: By altering the ground station configuration, replacing VILSPA-1 by Perth, which also takes advantage of the orbit evolution, the staffing of Spacecraft controllers can be reduced significantly. By making use of redundancies and margins in the space segment, sharing of the Perth station with the XMM project is possible. To share a station between two projects is facilitated by the migration from the old telemetry processors (TMPs) to the new generation Telemetry and Telecommand System (TMTCS). The TMTCS also allows a more cost efficient tailoring of ground station support time, because the station is not blocked by Cluster-II during the data transfer time to ESOC. Last but not least, the technical evolution of the Internet during the last 10 years allows a cost reduction for the distribution of the science data without producing and mailing 80000 CD-ROMs per year to a widespread user community and to avoid the communication costs for the decentralised planning process.
Standards Related Concepts/Developments
CCSDS Spacecraft Monitoring & Control Services Concept

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This abstract presents a reference architecture and service framework for spacecraft monitoring and control. It has been prepared by the Spacecraft Monitoring and Control (SM&C) working group of the CCSDS Mission Operations and Information Management Systems (MOIMS) area. The deployment of standard services and interfaces for the provision of high level services can significantly reduce the amount of customisation required for the support of the high level operations of a spacecraft. The SM&C working group have produced an informational CCSDS Green Book and are currently working on several CCSDS Blue Book Recommendations which expand on and define the services outlined in the Green Book. The informational Green Book covers: 1) Key Service concepts: definition of the key concepts such as service based architecture to promote software reuse, layering to promote interoperability, adapters to promote easy of integration. 2) Operational Concept: definition of an operational concept that covers a set of standard operations activities related to the monitoring and control of both ground and space segments. 3) Core Set of Services: definition of an extensible set of services to support the operational concept together with its information model and behaviours. This includes (non exhaustively) ground systems such as Automatic Command and Control, Data Archiving and Retrieval, Flight Dynamics, Mission Planning and Performance Evaluation. By combining the information from both the operational context and the reference architecture it was possible to derive a list of high level services.

<table>
<thead>
<tr>
<th>Service</th>
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<td>SM&amp;C Common Protocol</td>
<td>Common Monitoring and Control protocol</td>
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<td>SM&amp;C Core Automation</td>
<td>Core Monitoring and Control service</td>
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<td>Scheduling</td>
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<td>Planning</td>
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<td>Flight Dynamics</td>
<td>Constraint and resource planning</td>
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<td>Orbit determination, flight plan generation, etc.</td>
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For each service given, the CCSDS SM&C working group is proposing the production of a CCSDS Blue Book Recommendation to define and specify the service. The first two Blue books to be produced are the SM&C Common Protocol and the SM&C Core Service. The paper presents the status and the achievements of this activity.
Development of A Generic Monitor and Control System by
The Use of A Standard Modeling Method

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Sharing of spacecraft monitor and control (M&C) systems among different
space agencies is not very common because there are many differences
among spacecraft developed by different agencies and among ground
systems used by different agencies, and most importantly, because there are
differences among the methods used by different agencies for describing the
characteristics of spacecraft. Therefore, reduction of development cost of
M&C systems by using standard components or by reusing components
developed by another agency is not easy. However, by adopting a standard
method for modeling spacecraft, reduction of development cost becomes
possible even if there are differences among spacecraft. The standard
method for modeling spacecraft provides a unified framework for
describing the characteristics of spacecraft. With this method, a spacecraft is
modeled as a set of objects, each of which possesses attributes and performs
operations. The standard model defines types of objects and specifies a
unified way of describing the attributes and operations of objects. Different
spacecraft may be made up of different components, but each component is
characterized in a unified way using the standard model as an object with
attributes and operations. Therefore this method enables virtualization of
spacecraft. By virtue of using the standard model, the characteristics of any
spacecraft can be presented in a unified way. This enables development of a
generic database that can store the information on any spacecraft. By using
this generic database, a generic system for monitoring and controlling
virtual spacecraft can be developed because specific information on each
individual spacecraft can be extracted from the generic database. This
generic M&C system can be used for any spacecraft as long as its
information is stored in the generic database. This method enables reduction
of development cost of ground systems by virtue of using the following
standards even though spacecraft themselves are not standardized: (1) a
standard model for describing the characteristics of spacecraft, (2) a generic
database that can store information on various spacecraft, and (3) a generic
M&C system that can be used for various spacecraft. The Institute of Space
and Astronautical Science (ISAS) of the Japan Aerospace Exploration
Agency (JAXA) is planning on developing a prototype to demonstrate the
validity of the concept of this generic M&C system, which will include a
prototype of the generic database, a prototype of the generic M&C system, and a set of simulated onboard instruments. The standard spacecraft model to be developed will be based on a model that is currently being developed by the Systems Architecture Working Group of the Consultative Committee for Space data Systems (CCSDS).
Adoption of Emerging Standards for Ground Systems: Lessons Learned from Space Based Infrared Systems Increment 1

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Reusable infrastructure and development of standards have generally been viewed as keys to reducing the cost of future ground systems. Adoption of standards can provide long-term savings by providing flexibility for interfaces with multiple users, minimizing the effort involved in reuse of commercial hardware, software and databases, and enhancing operability. However, emerging standards may fail to be widely adopted, resulting in costly rework to support specific user needs. Minimizing life cycle costs requires balancing supportability of old standards against the risk that newly adopted standards will fail to achieve widespread acceptance. This challenge was one of many that was faced by the United States Air Force in the consolidation of legacy missile warning assets to build the Space Based Infrared Systems (SBIRS) ground system, also known as SBIRS Increment 1. While this consolidation is projected to save the Air Force $18 million per year, the project was completed two years behind schedule and at nearly three times the original cost projection. The original plans were based on extensive reuse of Government Furnished Equipment (GFE) and Commercial Off the Shelf (COTS) software. One of the major causes of the delays and cost growth was the new non-commercial software development needed when the GFE and COTS implementation could not be realized. However, there were also missed opportunities for cost savings when standards that could have minimized rework were not implemented. This paper discusses the SBIRS Increment 1 experience with proposed standards in three areas: 1) standards for geophysical (both astronomical and terrestrial) data, 2) standards for data dissemination and archiving, and 3) standards for commanding and state of health monitoring. The lessons learned from this experience are used to propose a methodology for evaluating when (and whether) to adopt emerging standards.
Space Communications
Low Cost Communication Support of Lunar Missions

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With the renewed interest in the exploration of Earth's moon, NASA has proposed a comprehensive program of robotic and human missions to this destination. Exploration of the Moon is also viewed as a step toward human exploration of other planets, beginning with Mars in the 2030 time frame. The proposed lunar exploration program is quite aggressive, including comprehensive characterization of the Moon by robotic orbiters and landers, development of a Crew Exploration Vehicle (CEV) to carry humans, and possible establishment of a human base on the lunar surface. The schedule is also very aggressive, with the first robotic mission launching in 2008 and the first human flight in or around 2015. We present a concept and architecture for providing the communications infrastructure to support this set of missions. The architecture has two major elements: a set of Earth-based stations and a small lunar relay constellation. The Earth Stations would leverage the development of the Deep Space Network (DSN) array of small antennas. A small number of these antennas would be used to provide services to the initial robotic missions. Capability would be added with time to support the more ambitious human missions, taking advantage of the modularity and expandability of this design. Development, maintenance and operations costs are based on the model being developed for the DSN array. The lunar relay constellation consists of low-cost elliptical orbiters that will provide continuous coverage to the South lunar pole to support intense exploration and resource utilization there. In addition, these relays will provide some backside coverage to support critical events and exploration of backside locations. Additional Earth antennas will be added to support these relay satellites (both data and control.) This architecture can be established very quickly, enabling the early missions. Additionally, it can grow with the expanding mission requirements and eventually support human missions to the moon and then to Mars.
Low Cost Support of Critical Spacecraft Communications with The Deep Space Network’s Radio Science Receivers: The Cases of Saturn Orbit Insertion and Huygens Landing

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NASA’s Deep Space Network utilizes Radio Science Receivers (RSR) for the acquisition of data in the open-loop mode for Radio Science investigations of planetary atmospheres, rings, surfaces, gravity fields, as well as the Sun and aspects of the theory of general relativity. These receivers are independent of the tracking receivers used for all mission support and are typically directly operated by JPL scientists who generate the tuning frequency prediction files and select the configuration best suited for the particular experiments. Due to the sophisticated capabilities of these science instruments as well as their operational flexibility and optimized post-processing extraction of weak signals under dynamic conditions, the RSRs have been increasingly relied upon for special engineering activities such as monitoring the radio signals of spacecraft in distress or in the process of performing critical maneuvers. In the past 18 months alone, the DSN RSRs have been successfully used to receive the carrier signals of the Mars Exploration Rovers during their entry, descent and landing, as well as the Cassini carrier during the Saturn Orbit Insertion, and the carrier from the Huygens probe during its descent and landing onto Titan (not received at the Network). In the case of the Mars rovers, they also received multiple tones signifying the occurrence of critical events in the spacecraft landing sequence. In the absence of these receivers these missions may have had to resort to significantly more costly alternatives in the mission design, ground data systems design, or communications strategies. This paper will describe the use of the Radio Science Receivers as a low cost method to monitor spacecraft during critical maneuvers with emphasis on recent examples from Cassini and Huygens. The paper will also explore future applications and potential enhancements in the design of the next generation receivers to serve the science and engineering users of the Deep Space Network.
Flight Dynamics and Navigation
Simplified Mission Operations Using On-Board GPS Navigation

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The Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED) program is the first mission in the NASA Solar Connections Program. The ongoing TIMED mission is studying the Mesosphere, Lower Thermosphere and the Ionosphere (MLTI) region of the atmosphere (60-180 km altitude) from a 625 km circular orbit inclined 74.1°. On-board the spacecraft are a pair of redundant GPS Navigation Systems (GNS) that maintain knowledge of TIMED position to less than 300 meters in the x, y and z directions, and velocity to less than 25 cm/sec in the x, y, and z directions using coarse acquisition (C/A) signals received from the GPS constellation. The GNS has contributed significantly to reducing the effort required for mission operations, by performing on-board orbit determination, generating predicted spacecraft operations planning products, and by maintaining the onboard clock accuracy to less than 1 microsecond. The GNS provides the current spacecraft position and velocity to the onboard guidance and control system once a second eliminating the need for ranging and spacecraft ephemeris uploads. On-board clock accuracy is maintained using time data received in the GPS navigation messages. To assist operations planning, the GNS writes a series of data products to the recorders once every 12 hours. The GNS 12 hour products include: a series of two-line element sets generated for long-term and short-term orbit propagation, a table of predicted orbit milestones, and a table of predicted AOS and LOS times for the next 15 ground station contacts with a user selected primary and secondary ground station. For each ground station contact, the GNS generates short-arc two-line element sets used to point the ground antenna, a state vector used to predict spacecraft position at AOS, and sets an onboard AOS flag that is used to power up the RF system prior to the predicted AOS. The predicted contact information enables the TIMED mission to simplify lights out operations because the spacecraft autonomously powers its RF system on and tells the ground station where and when to point its antenna to acquire the spacecraft. The GNS aids science data collection by enabling orbital event based commanding. Once a second the GNS outputs to the instruments a series of event flags indicating
the occurrence of a number of software programmable orbital milestones, including:
entering/exiting the South Atlantic Anomaly, entering/exiting the polar region, entering/exiting solar eclipse, in/out of view of the primary or back-up ground station. Since solar observation is the primary goal of the TIMED mission, the GNS also outputs the position of the sun relative to the spacecraft once a second. The TIMED mission is in the third year of a 5 year mission. The paper will focus on both a discussion of the functionality of the GNS system and a presentation of the system's successful operation in orbit.
Development of Automated Ground Support system for University satellite’s Attitude Control System

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A New approach in Ground Station Software development for a Micro-satellite was discussed in this paper. The software is dedicated only for the Attitude control system of Micro-satellite which has only Magnetic torquers as actuators and Magnetometers as sensors. There is no need for any human intervention in commanding Telecommands from Ground segment. The Software receives Satellite status when it becomes visible and using the telemetered magnetometer data it will estimate the spin rate and attitude of spin axis. If there is any deviation from the desired requirements the telecommands are generated automatically and uplinked when the satellite comes into Visibility region. Keywords: Ground station, Attitude control, spin rate control, ACS support system.
Reducing Costs of Managing and Accessing Navigation and Ancillary Data by Relying on Extensive Capabilities of SPICE System

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The SPICE system of navigation and ancillary data possesses a number of traits that make its use in the modern space missions of all types highly cost efficient. Unlike many other ground software tool sets that are or consist primarily of application programs, the core of the SPICE system is a software library that provides API interfaces for storing and retrieving various types of navigation and ancillary information such as trajectories, orientations, time conversions, and instrument field-of-view geometry parameters. Any application utilized during any stage of a mission life-cycle -- from design through development and operations to archiving, -- and needing these kinds of data can call SPICE APIs to get access to them. In addition to the basic functions of retrieving the ancillary data, SPICE provides a wealth of high level API interfaces for computing and manipulating derived geometric quantities required for observation planning, engineering assessment and processing of acquired science data. Because SPICE is implemented in a few different languages, popular in both the science and engineering communities, supported on more than twenty different computer environments, and distributed with source code and complete documentation, incorporating it into existing and new applications is a reasonably straight forward task. As the result of constant development and application during the last fifteen years in over twenty active space projects, SPICE includes a multitude of truly multi-mission capabilities that are applicable to all types of space missions -- flyby, orbiters, observatories, landers and rovers. More importantly these capabilities have been tested extensively by everyday use in operations and science data processing. As demonstrated by experience both inside and outside of the US, the initial adaptation of SPICE for the first mission or experiment in a series, or at a new agency, requires a modest effort. But this is greatly facilitated by available detailed documentation, multi-mission data production tools and freely available examples from past missions. This initial effort has always paid off because SPICE adaptation for subsequent missions/experiments has always been just a small fraction of the initial investment, with the majority of tools based on SPICE requiring no or very minor changes. This was one of the main reasons why European
Space Research and Technology Centre (ESTEC) decided to adapt SPICE for Rosetta, VEX and SMART-1 after its successful application for MEX and why Japan Space Exploration Agency (JAXA) is deploying SPICE on its Hayabusa and SELENE missions. The work described in this paper has been conducted by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.
ESOC has been supporting a few Earth observation missions since ERS-1 (launched in 1991). This support has also been covering routine operations of these missions. The flight dynamics division of ESOC has developed and implemented an operational concept to ensure continuous support to these missions. This concept, fully integrated in the overall division work approach and organization, relies on partial operational task automation supported by a core team of experts. The technical solutions required by this concept are simple and cheap to implement. Returns in terms of lower manpower expenditure, efficient operational support and increased service quality (e.g. fast response time) are the proven benefits of this concept. In addition the paper shows how this concept contributes to securing flight dynamics division assets such as core competences and expertise for upcoming missions and projects.
Telemetry, Tracking and Control Systems
Reducing the Cost of Multi-Mission Support by Optimising Antenna Usage

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The RAL ground station has been a part of the world-wide network for the NASA/NOAA ACE mission for several years. We have continuously taken data using our 12m antenna and we have achieved a high reliability in doing so. In developing our ground station, we have added a 2.4m antenna and in doing so, we have found that this is perfectly capable of taking data from ACE under most circumstances. We are currently in the process of evaluating exactly when the smaller antenna will provide an adequate service for ACE, with the intention of making the 2.4m the primary antenna for that mission and using the 12m antenna on new projects. This will allow us to continue to provide support for ACE, to have a 12m capability for new missions, and all for the cost of a 2.4m antenna (less than $100k for everything). The paper will describe the incorporation of the new antenna into the ACE ground system, and how that system makes it simple to add and remove antennae, while preserving a continuous flow of data. It will also describe the automated nature of the operations which means that we can support several missions with the equivalent of a single person, and how the ground station operations can be safely modified from half way round the world (the Falkland Islands, to be precise).
A Common System for TT&C and Satellite Simulation

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Most existing TT&C and Satellite Simulators offer limited flexibility and re-use possibilities. This paper describes the recent development of an Integrated Modem and Baseband unit (IMBU) undertaken by Satellite Services BV for the ESOC PSS project that has resulted in a common platform that can be used in both TT&C and Satellite Simulation domains that is both flexible and cost effective. The IMBU is designed as a modular system that includes IF modulation/demodulation at 70/230MHz, TM/TC processing up to 24Mbps and LAN level interfacing all in one single unit. The functions are implemented as stand-alone module which allow processing of data from IF to Ethernet for both the up and down links. The system utilizes software based on the SIMSAT, SCOS and SSBV’s standard control and monitoring software to generate models and provide the higher-level baseband processing functionality. This flexible approach to the architecture means that both multi-stream and multi-functional elements can exist in the same environment. This in turn means that one system can be used for both mission operations and Satellite Simulation activities. The first phase of the IMBU development has now been competed and it has been proven that it is possible to have a single system that is both flexible and performant. It has also been shown that the IMBU can easily be configured for both domains. The intention now is to use this as the basis to further developed the concept of modular TT&C /Simulation systems.
A Cost-Effective Modeling of Near-term Mission Bandwidth Demand

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The NASA Deep Space Network is often known for its large antennas, the largest being the 70-meters. These antennas offer a very high performance, in term of antenna gain versus system noise temperature, suitable for tracking distant spacecraft that travel toward the edge of the solar system. However, the DSN operation involves more than just tracking antennas. Once captured by antennas, the data need to be delivered – via a terrestrial communications network - to various mission operation centers in a timely manner. An ability to accurately estimate the needed bandwidth for the terrestrial network is important, both from mission support and cost perspectives. A link of too much bandwidth would be expensive to subscribe. A link of not enough bandwidth would prevent the DSN to meet its delivery commitments to customers. Being able to accurately model and forecast the required bandwidth is important to DSN Operations. In this paper, we look at a new approach in estimating the aggregated data from the mission set that the DSN supports. It is a probabilistic model, based on projected tracking schedule. For comparison, past practices tend to focus on the worst conditions where all data come down at the same time. This results in an over-specification of the capacity. The new probabilistic model helps identify the capturing rate and transferring bandwidth for the terrestrial network. It accounts for both spacecraft telemetry data and non-telemetry flows of monitor data of tracking passes, voice and network monitoring, science observations and calibration, etc. The estimate applies to network loading over the next five years, circa 2005-2010. With proper implementation, the model helps to bring about a system of sufficient capacity to meet the customers' need. At the same time, it avoids the high cost associated with excessive capacity.
Low-Cost, Large Aperture for Deep-Space Applications

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JPL, in conjunction with the NASA HQ Science Mission Directorate, is evaluating methods of obtaining large apertures at low cost by arraying small diameter antennas (or elements). The key driver is the desire to greatly increase the amount of information received from and transmitted to deep-space missions—both human and robotic. This report optimizes the total cost of a required total aperture with respect to two parameters: size and reliability of an individual antenna. We report our computed antenna-related life-cycle-costs (LCC) as a function of either the antenna diameter or antenna reliability and select the values that minimize the LCC. The antenna-related LCC is approximated by the sum of the Recurring Engineering (RE) for the antenna-related components and the Operations and Maintenance (O&M) costs for the antennas over 20 years (assuming that the RE is amortized over 20 years as well). The antenna diameter and reliability that minimize the LCC will change over time, as the relative costs of mechanical and electronic components change, and as the cost of reliable components varies. The article shows data for the proposed DSN array and discusses the projected change trend of time.
Closing Session
The Space Operations and Support Technical Committee (SOSTC) of the American Institute of Aeronautics and Astronautics (AIAA) holds an annual workshop to explore current issues in space operations. The workshop used to be entitled the “Reducing the Cost of Space Operations” workshop until 2002 when it was decided that a more encompassing title should be used and it became the “Improving Space Operations Workshop.” In May of this year the workshop was sponsored by the Houston Section of the AIAA and held at the NASA Johnson Space Center and was retitled “Enhancing Space Operations Workshop”. The purpose of these workshops is to explore issues of importance in space operations and support as determined by members of the SOSTC and of relevance to the local space professionals. The topics that were explored in the 2005 workshop were addressed in six separate tracks: (1) advanced concepts and automation, (2) mission operations (with an emphasis on manned space flight), (3) risk management, (4) tools and technologies, (5) best practices, and (6) simulation and training. Each track was led by an expert in the topic either from the SOSTC or NASA JSC. This paper presents the results of the workshop in each of these six areas. The results should be of importance to space operations personnel interested in reducing the cost and improving the performance of space operations.