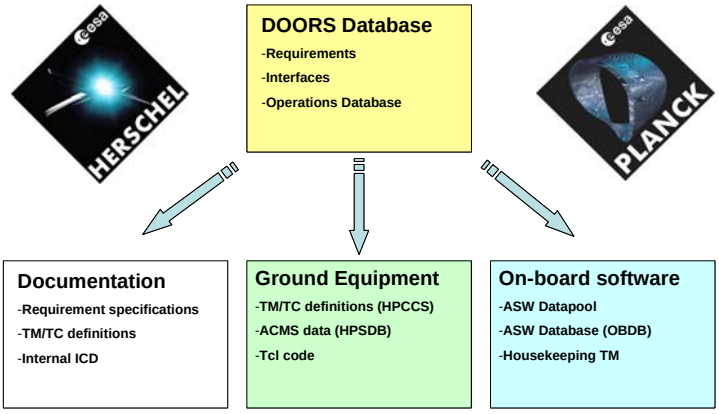
Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

Executive summary

Turning requirements into operations - Herschel/Planck ACMS Database Experience



ESA has commissioned the joint development of two scientific satellites, Herschel and Planck, as part of the Horizon 2000 Scientific Program. The uniqueness of this project is that both satellites - though very different - are being developed jointly at several levels. For reasons of cost effectiveness, commonality between the missions and between the mission phases is a key driver for the development.

The Attitude Control and Measurement System (ACMS) of these satellites is developed under responsibility of Dutch Space. The commonality approach to develop two different satellites in parallel requires specific efforts, e.g. to define data as Common or Herschel/Planck specific. Processes and tools to manage and maintain the commonality have been developed, taking into account project constraints such as using DOORS for requirement management and SCOS-2000 for testing.

The ACMS Test Equipment uses the Herschel/Planck Central Checkout System. This system is based on SCOS-2000, ESA/ESOC's generic mission control system software. This approach ensures commonality between tools and data used during subsystem and system level testing and the operational phase.

The DOORS requirement management tool is used in the generation of several ACMS documents, ground equipment data and on-board software data. An ACMS Operations Database has been developed for definition of TM/TC related data, used during test and operations. The development of this database is described, and more information about the use of the ACMS Database is given.

Experiences and lessons learned are reported, as well as recommendations for other projects. Standardization of a database design/interface for definition of operations and test related information should be aimed at. This

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should not only be achieved for different phases and users of the same project, but should also be beneficial for other space programmes.

NLR has supported Dutch Space in the Herschel/Planck ACMS development with a Lead Engineer for Operations. The work reported has been performed as part of these Operations support activities.

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Turning requirements into operations - Herschel/Planck ACMS Database Experience

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Turning requirements into operations –

Herschel/Planck ACMS Database Experience

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This paper presents the generation and use of the Operations Database for the Herschel/Planck Attitude Control and Measurement System (ACMS). The paper presents the experiences and lessons learned, as well as recommendations for other projects.

I. Introduction

ESA has commissioned the joint development of two scientific satellites, Herschel and Planck, as part of the Horizon 2000 Scientific Program. The uniqueness of this project is that both satellites - though very different - are being developed jointly at several levels. For reasons of cost effectiveness, commonality between the missions and between the mission phases is a key driver for the development.

The Attitude Control and Measurement System (ACMS) for both satellites is developed under responsibility of Dutch Space. The DOORS requirement management tool is used in the generation of

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several ACMS requirement documents and interface definitions. Also an ACMS Operations Database has been developed in DOORS for the definition TM/TC related data for test and operations.

The SCOS-2000 based Herschel/Planck Central Checkout System is used as part of the ACMS Test Equipment, ensuring commonality between tools and data used during subsystem and system level testing and the operational phase.

The main products generated using the DOORS database are shown in Fig. 1. The term ACMS Database is used for all data and tools involved in the definition and generation of the ACMS TM/TC related products, including these products themselves. The term ACMS Operations Database is used to indicate the Operations Database defined in DOORS.

The paper has the following structure:

- Section II provides background information about the missions, the industrial team, the Herschel/Planck programme status, the Attitude Control and Measurement Systems, and the On-Board Software.
- Section III describes the development of the ACMS Operations Database, with its relations to the Herschel/Planck System Data Base, the relation to SCOS-2000, and the ACMS Database architecture.
- Section IV provides more information about the use of the ACMS Database, including overview of the process, database population, versioning/baselines, databases for ACMS Test and Verification activities, and generation of input files for the Application Software and for the Herschel/Planck System DataBase.
- Section V contains a summary of lessons learned and recommendations for further development.

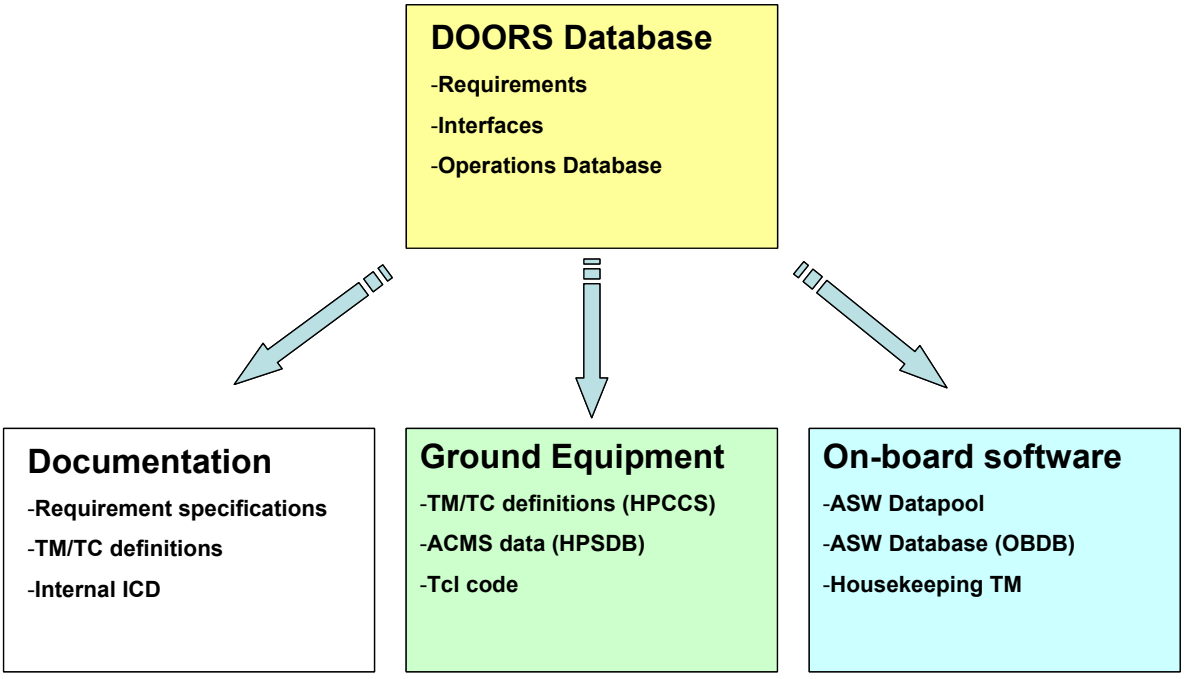

Figure 1. Main products generated using the DOORS database.

II. Background

Missions

In February 2008 an Ariane 5 will launch the spacecrafts to their Lissajous orbit about the second Lagrange point of the Earth-Sun system (L2). The two spacecraft will separate soon after launch and will operate independently. The Herschel Space Observatory will be the largest ever infrared space

observatory when it is launched. The Planck mission will collect and characterize radiation from the Cosmic Microwave Background using sensitive radio receivers operating at extremely low temperatures.

For reasons of cost effectiveness, commonality between the missions and between the mission phases is a key design driver.

Industrial team

ESA has commissioned the joint development of two scientific satellites, Herschel and Planck, as part of the Horizon 2000 Scientific Program. The uniqueness of this project is that both satellites - though very different - are being developed jointly at several levels. Alcatel Alenia Space France (AAS-F) is Prime for both satellites, and manages the scientific instruments interfaces. Alcatel Alenia Space Italia (AAS-I) is overall Service Module Responsible. A joint team of Dutch Space (prime), Sener Ingeneria Y Sistemas, and Analyticon Limited are responsible for the Attitude Control and Measurement System (ACMS) for both satellites.

The ACMS Application Software (ASW) is developed by Terma (Denmark). The Basic Software is developed by Saab Ericson Space (Sweden), under AAS-I subcontract.

The Herschel/Planck Central Checkout System (HPCCS) is developed by Terma (the Netherlands), also under AAS-I subcontract.

The Herschel/Planck System Data Base (HPSDB) is developed by GMV (Spain), under AAS-F responsibility.

Other Herschel/Planck product items are not relevant for this paper.

Programme status[1]

The development efforts in industry for both the Herschel and Planck spacecraft are progressing at a good pace. The flight-model integration of the Planck spacecraft has continued at Alcatel Alenia Space in Cannes (F), and it is now well on the way to the first thermal vacuum test on the flight satellite. During this test, one of the two flight models of the NASA-supplied hydrogen sorption coolers will also undergo flight acceptance tests (both coolers having already been delivered).

On the Herschel spacecraft, after completion of the cryo thermal testing of the protoflight model of the Payload Module, it was mated with the structural model of the Herschel Service Module and is presently being prepared for system mechanical testing in early 2006. The flight model of the Herschel Service Module has been integrated during this period at Alcatel Alenia Space in Turin (I) and its functional testing has also started. The functional, performance and electromagnetic compatibility testing of the Herschel instrument qualification models in the modified ISO cryostat has also been completed.

The development of the flight-model instruments has experienced some delays, but a close monitoring has been put in place. The Planck instruments are now progressing towards delivery in mid-2006, and the Herschel instruments towards delivery before end-2006.

The hardware activities on the Herschel telescope were completed during the last quarter of 2005 and the telescope is now fully assembled and aligned. All environmental testing has been successfully completed, with the cryogenic optical testing remaining to be completed in early 2006. For the Planck telescope, the flight-model reflectors have completed all testing and will soon be integrated onto the telescope structure for the final cryogenic optical testing of the telescope assembly.

In December 2005, ESA and Arianespace signed the contract for the provision of the Ariane-5 ECA launcher that will lift the Herschel and Planck spacecraft to their intended orbits around the second Lagrange point (L2). Taking into account the accumulated delays and the recovery actions in place, the launch is presently foreseen for February 2008.

Attitude Control and Measurement System

The Attitude Control and Measurement System of Herschel and Planck have different objectives. The purpose of the Herschel ACMS is to provide a highly accurate pointing attitude, while the Planck ACMS needs to provide a highly stable spinning attitude. The commonality key design driver has lead to many common hardware units, including Star Tracker, Coarse Rate Sensor, Sun Acquisition Sensor and Attitude Control Computer. Also most of the Basic Software (BSW) and main parts of the Application Software are common.

Also ACMS the verification strategy is common were possible. Parallel verification paths for the two different ACMS systems were possible thanks to the EuroSim based simulator – part of the ACMS Test Equipment – which allowed a swift change between the configurations.

The ACMS development is in its final stage. The Data Package for the Qualification Review has been delivered in April 2006.

E. On-board Software

The on-board software plays an important role – as always –for operations of the ACMS. The on-board software consists of unit related software for Star Tracker and Gyro, defining the MIL-STD-1553 messages, and the Attitude Control Computer related software – Basic Software and Application Software – providing the operational interfaces.

The Herschel/Planck telemetry and telecommands (TM/TC) are based on the ESA Packet Utilization Standard (PUS). The PUS services are implemented in the Basic Software and/or the Application Software. The three services which are most relevant for operations are:

- *Service 3, Housekeeping and Diagnostic service*. The service 3 TM is generated by the BSW, based on a datapool definition containing both ASW and BSW parameters.
- *Service 5, Event Reporting service*. Event TM is generated by both ASW and BSW.
- *Service 8, Function Management service*. Most of the ACMS functionality specific telecommands are defined in the ASW.

The ACMS functional and interface requirements for the development of the ASW are defined in several documents. These documents are listed and described below to show how this information and its consistency is maintained.

- *ASW Specification*. This document contains the functional requirements and algorithms for the ASW. The over 500 pages are generated from DOORS using DocExpress. The ASW Specification has no database relation with the ACMS Operations Database. Many of the ASW parameters defined in the ACMS Operations Database do contain a reference to a section of the ASW Specification, but neither consistency nor completeness is guaranteed.
- *ACMS Telecommand definition* and *ACMS Telemetry definition*. These documents contain the telecommand and telemetry definitions relevant for the ACMS. The ACMS telecommand document serves as interface specification for the ASW. The ACMS telemetry document lists all ASW parameters, including those defined in the datapool (see *datapool concept* subsection below). It also contains the default definitions of the ACMS Housekeeping TM packets. Also the TM definition document serves as interface definition. Both documents are maintained in MS Word. This makes that ACMS Telecommand definition is not by definition consistent with the ACMS Operations Database. Most part of the ACMS Telemetry definition document exists of annexed Excel files generated from the ACMS Operations Database, ensuring consistency.
- *On-Board Data Base definition*. The ASW contains an On-Board DataBase (OBDB) which holds the descriptions and values of over 3000 parameters. The document contains a table exported from DOORS, and is thus consistent with the database.
- *ACMS Internal Interface Control Document*. This document contains e.g. the interface definitions of ACMS units as Star Tracker and Gyro. The document is generated from DOORS using DocExpress. The relation with the ACMS Operations Database is limited. This means that e.g. the STR interfaces are defined three times: 1) by the STR supplier, 2) for this ACMS ICD document, 3) as part of the ACMS Operations Database. Consistency between ICD and database it not guaranteed.

The *datapool concept* as defined for the Housekeeping and Diagnostic service 3 provides flexibility in the definition of these TM packets. However, the use of this service is limited to the parameters available in the datapool (although a dedicated feature has been implemented to obtain periodic data from any memory location). This means that are parameters of interest should be part of the datapool and identified and defined to build the software.

In the begin phase of the project the datapool for was completely defined by the Basic Software (BSW). This required specification of the list of ASW datapool parameters to the BSW before start of ASW development, limiting the flexibility to add new ASW parameters when needed. To overcome this problem a set of ASW “pointer” parameters was defined, containing data structures of which the contents could be defined by ASW supplier during the development.

Later in the project a new datapool interface was defined made the ASW part of the datapool independent from the BSW. This BSW interface allowed the ASW to use a range of 16/32/64 bit parameter entries in the datapool and specify the entries and identifiers themselves.

The ASW datapool definition used for on-board software generation is an export generated from the ACMS Operations Database, assuring consistency in the definitions on-ground and on-board.

Changes in names and values of Datapool IDentifiers (DID) of ASW and BSW parameters are handled by the Operations Database.

III. ACMS Operations Database development

Development of a dedicated database with all ACMS TM/TC data was initially not foreseen. The need for this database will did arise during phase B of the project. Main reasons were that:

- due to the high amount of parameters, the consistency of the Telemetry definition document could not be maintained manually (using a Word document)
- the TM/TC interface turned out to be more complex and extensive compared to other ACMS subsystems developed by Dutch Space
- the use of SCOS-2000 as part of the ACMS Test Equipment required the definition of all TM/TC details, including operational identifiers
- the unavailability/immaturity of the Herschel/Planck System Data Base at that time became clear, and the associated risk of using the HPSDB was not acceptable for the ACMS development

The following subsections describe the development of the ACMS Operations Database, with its relations to the Herschel/Planck System Data Base, the relation to the Herschel/Planck Central Checkout System with SCOS-2000, and the architecture of ACMS Database.

Herschel/Planck System Data Base

The Herschel/Planck System Data Base is procured by AAS-F to support the consistency of data between the different users (engineering, on-board software, AIT, and flight operations). The HPSDB, developed by GMV, also supports the commonality between the Herschel and Planck satellites. This subsection provides some background information about the HPSDB concept, required for a better understanding of the ACMS Database.

The HPSDB can be used to define and maintain data at different *levels*:

- *Element level*. Elements are the building blocks for data at subsystem level. Element examples are Star Tracker and the ASW elements for Common, Herschel and Planck ASW data.
- *Subsystem level*. Examples of subsystems are the ACMS and the Central Data Management Subsystem. Also the Ground Support Equipment (including the ACMS Test Equipment elements) is defined as subsystem in the HPSDB. Subsystem data consists of specified element level data (e.g. STR) and of subsystem specific data (e.g. ACMS TM Packet with ASW and STR parameters). Subsystems are the building blocks for data at model level.
- *Model level*. Examples of models are the ACMS Herschel and Planck Service Modules, or the Prototype Flight Models. Model data consists of specified subsystem level data (e.g. ACMS).
- *Generic level*. Generic data can be used by the definition of any other data. Examples are ON/OFF curve definitions and TM and TC packet headers.

Instantiation is used to support the consistency and commonality. A set of element, subsystem or model data is defined as a *box*. At least two instances of each box are defined:

- *Theoretical boxes*. These boxes contain the theoretical data definitions, e.g. a default reaction wheel friction coefficient .
- *Real boxes*. These boxes contain the actual data definitions, e.g. the measured friction coefficient for a specific reaction wheel.

Logical instantiation is used to build subsystems from elements, and models from subsystems. *Physical instantiation* is used to create multiple *real* copies of a *theoretical* box, e.g. two real Star Tracker boxes.

The HPSDB is used at a central site, where the final data is stored and consistency is maintained, and at several mirror sites. One of the locations originally planned to use the HPSDB was the ACMS subcontractor premises. However, Dutch Space was reluctant to be (one of) the first user(s) of the HPSDB.

During phase C/D is was decided and agreed that instead of using the HPSDB, Dutch Space would provide input to the HPSDB in an HPSDB compatible XML file format. The ACMS Database is used as source for the generation of the ACMS part of the HPSDB, and the architecture of the ACMS Database reflects the HPSDB concept.

Data defined in the HPSDB can be exported to several format and users. HPSDB export files are e.g. used to create the on-board software and to define the TM/TC definitions in SCOS-2000 format as used during AIT and operations.

SCOS-2000 based ACMS Test Equipment

SCOS-2000 is the current generation of the Spacecraft Control and Operations Systems used by the European Space Operations Centre (ESOC). SCOS-2000 will be used as Mission Control System for the Herschel and Planck spacecraft. By using a SCOS-2000 based test platform for the Assembly, Integration and Test phases of the missions, commonality is reached between the AIT and the Operations phase. This commonality allows using the verified data and tools from the test campaign during the flight campaign.

For AIT at spacecraft level the Herschel/Planck Central Checkout System (HPCCS) has been developed. The HPCCS is based on SCOS-2000, but offers additional functionality required for testing.

The ACMS Test Equipment, developed by Dutch Space, is based on the EuroSim real-time simulator tool and the HPCSS. This accomplishes another level of commonality: between ACMS subsystem AIT tools and spacecraft system AIT tools. EuroSim is commanded and monitored by the HPCCS using Remote Messages and Remote Commands. This RM/RC data has the same format as spacecraft TM/TC, but is routed to Ground Support Equipment. With SCOS-2000 as part of the ACMS Test Equipment, an ACMS Database was required to generate the SCOS-2000 input files.

Although available, the SCOS-2000 MS Access database did not fit the ACMS needs. One of the most important reasons is that the commonality concept is not supported. The MS Access database is suitable for a single mission only, while the data for two missions, including a set of common data, must be defined. Also configuration control at object level is not provided in MS Access. Furthermore a large part of the ACMS data is from the Application Software, and the SCOS-2000 MS Access database can not relate the ASW TM/TC data to the data defined in the ASW Specification.

ACMS Operations Database architecture

The ACMS Operations Database has been implemented in DOORS. Below a short description of DOORS is given, as introduction to the architecture of the Operations Database.

DOORS is a requirements management tool from Telelogic. Projects can be structured in folders, each containing modules. Documents are contained in formal modules, and the relations in link modules. The modules contain data objects with attributes. Several default attributes are provided (e.g. last modification time, last modified by, …). User defined attributes can easily be added as well.

An *formal module* can be compared to a table, with each of the rows as an object. The table itself can be structured with section as a normal document. This is e.g. useful when using inheritance, such that only are parent level the data is defined.

A link module is used to define a typical relation between modules (e.g. “is verified by”). The allowed links are defined in linksets. Many-to-many relations are used by default.

The DOORS eXtension Language (DXL) can be used to construct any information resulting from the defined data, e.g. the size of a TM packet calculated from it parameters.

Custom filters can be applied and are used to display a selection of the data (e.g. for export). Import of data in DOORS is possible. If the import data contains an existing unique identifier for each of the objects, DOORS updates these objects with the provided information.

Although available at Dutch Space, DOORSNet – a web interface to the DOORS database – was seldom used. The functionality provided by DOORSNet was too limited to allow efficient population and analysis of the database.

The *ACMS Operations Database architecture* is such that information related to HPSDB, SCOS-2000 and ASW is contained in different modules, with a minimum need for duplication of information. An overview of the modules and relations is given in Fig. 2.

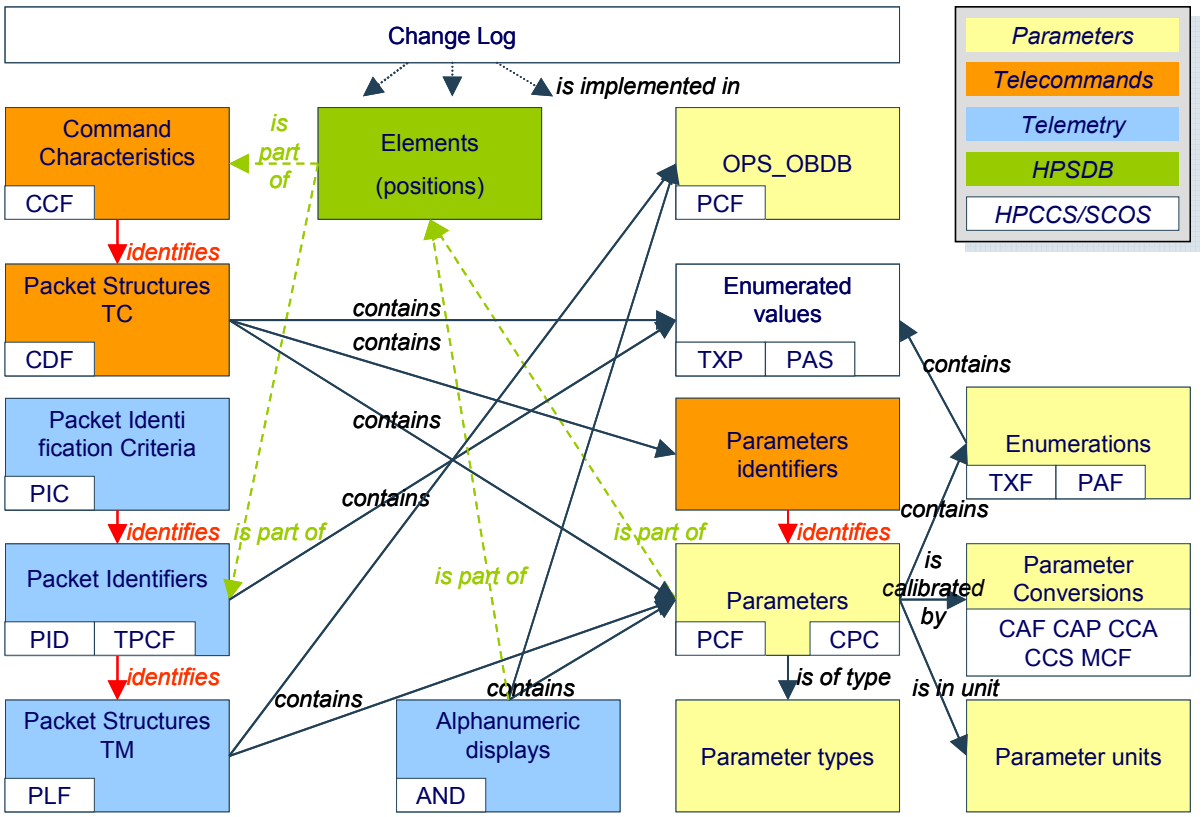

Figure 2. Overview of ACMS Operations database modules and links

The Operations Database contains the following formal modules:

- Parameter related modules
  - *Parameters*. Contains all parameters definitions, except that for the OBDB. A single object is used for command parameters and their related telemetry parameters. Two different attributes are used for operational telecommand and telemetry parameter identifiers. Several links exist: 'is of type' links to Parameters types module, 'is in unit' links to Parameter units module, 'is calibrated by' links to Parameters conversions module, 'contains' links to Enumerations and 'is part of' links to the HPSDB Boxes module.
  - *OPS_OBDB*. Contains the On Board Data Base parameters and values for the Application Software. No links to other modules.
  - *Parameter types*. Contains the list of allowed parameters types. For each parameter type is defined a description, a short identification (e.g. uint16, enum8, …), the number of bits, the Parameter Type Code and Parameter Format Code (PTC/PFC). No links to other modules.
  - *Parameter units*. Contains al list of allowed parameter units, including their representation in HPSDB and SCOS-2000 (with a maximum of four characters).
  - *Enumerations*. Contains a list of textual calibrations. This module has 'contains' links to the Enumerated values module.
  - *Parameter Conversions*. Contains numerical calibrations for interpolation, extrapolation and polynomials. Also the actual values are defined in this module. No links to other modules.

- Telecommand related modules
  - *Command Characteristics*. Contains a list of telecommands and related information. This module has 'identifies' links to the Packet Structure TC module.
  - *Packet Structures TC*. Defines the telecommand structures. Each telecommand structure is defined by objects below with a 'contains' link to the Parameters module. Other 'contains' links to the Enumerated values and Parameter identifiers modules are used when the value of a telecommand parameter needed to be defined.
  - *Parameter identifiers*. This module contains a list of datapool parameters as used for the Housekeeping and Diagnostics service 3. For each object the Datapool IDentifier (DID) used by the software is defined, and the DID value for each of the software versions. The relation with the parameters is defined with 'identifies' links to the Parameter module.
- Telemetry related modules
  - *Packet Identification Criteria*. This module defines how the TM packets are identified. The PIC table required by SCOS-2000 is valid for all spacecraft TM packets. Since the PIC definition was not available at the start of the verification activities, this module has been used to export the PIC table to the ACMS Test Equipment.
  - *Packet Identifiers*. Contains a list of telemetry packets and relation information. This module has 'identifies' links to the Packet Structure TM module.
  - *Packet Structures TM*. Defines the telemetry structures. Each TM structure is defined by objects below with a 'contains' link to the Parameters or the OPS_OBDB module.
  - Alphanumeric displays. Contains the AND definitions for SCOS-2000. Each AND is constructed by objects below with a 'contains' link to the Parameters or the OPS_OBDB module. The operational identifier is constructed[7] with 'is part of' links to the HPSDB Boxes module.
- HPSDB related modules
  - *HPSDB Boxes*. This module is actually called *Elements*. It contains a lists of ACMS related HPSDB boxes and their box numbers. These numbers are used to construct the operational identifiers. This module has 'is part of' links to the Command Characteristics and Packet Identifiers modules. Note that the direction of these links should have been *to* the HPSDB Boxes module, but the limited DOORS knowledge at time of implementation forced to use this direction.
- Multi-related modules
  - *Enumerated values*. This module contains for each enumerated value object the value, a description and the actual textual conversion as used by SCOS-2000.
  - *Change Log*. This module contains descriptions of the changes made in the ACMS Database, including references to e.g. Software Problem Reports and Non Conformance Reports. The module has 'is implemented' links to any of the other modules.

For each of the modules in Fig. 2 the generation of SCOS-2000 data, e.g. PIC table, is shown as well. This detailed information is meaningful for those who are well-known with SCOS-2000, but further explanation is beyond the scope of this paper.

[7] E.g. the ACMS Mode telemetry parameters – part of the Herschel and Planck mode status words in the ASW – have 'AESMG' as first five characters of the operational identifier. The Herschel and Planck ASW box numbers are '002' and '003'. The complete operational identifiers are constructed as AESMG002 for Herschel and AESMG003 for Planck.

IV. ACMS Database usage

Introduction

The ACMS Database not only consists of information defined in DOORS. Additional data is merged with the DOORS data to generate the input files used by ASW, SCOS-2000 and HPSDB. Fig. 3 shows the related processes and data. The use of the database to generate ASW related documents has been described above.

Three different areas – each representing a part of the spacecraft and the responsible organization – are identified:

- Application Software data used by Terma
- Service Module (SVM) data used by AAS-I
- ACMS data used by Dutch Space.

The ACMS area contains a sub area to identify the tools and processes involved in the automated generation ACMS Database products. The subsequent sections discuss subjects related to items shown in Fig. 3.

ACMS Database population

The DOORS database at Dutch Space used for Herschel/Planck is located in a secure zone. This allows external users to access the database. In practice, the ACMS Database was often being used by two or three persons from Dutch Space and one user from SENER (Spain). Besides licenses for the full DOORS functionality also some DOORSNet licenses are available.

Most of the ACMS Database population is performed manually. The DOORS import functionality has also been used frequently. In later stages of the project the DOORS eXtension Language was used to construct specific OBDB Telemetry packets by creating links automatically.

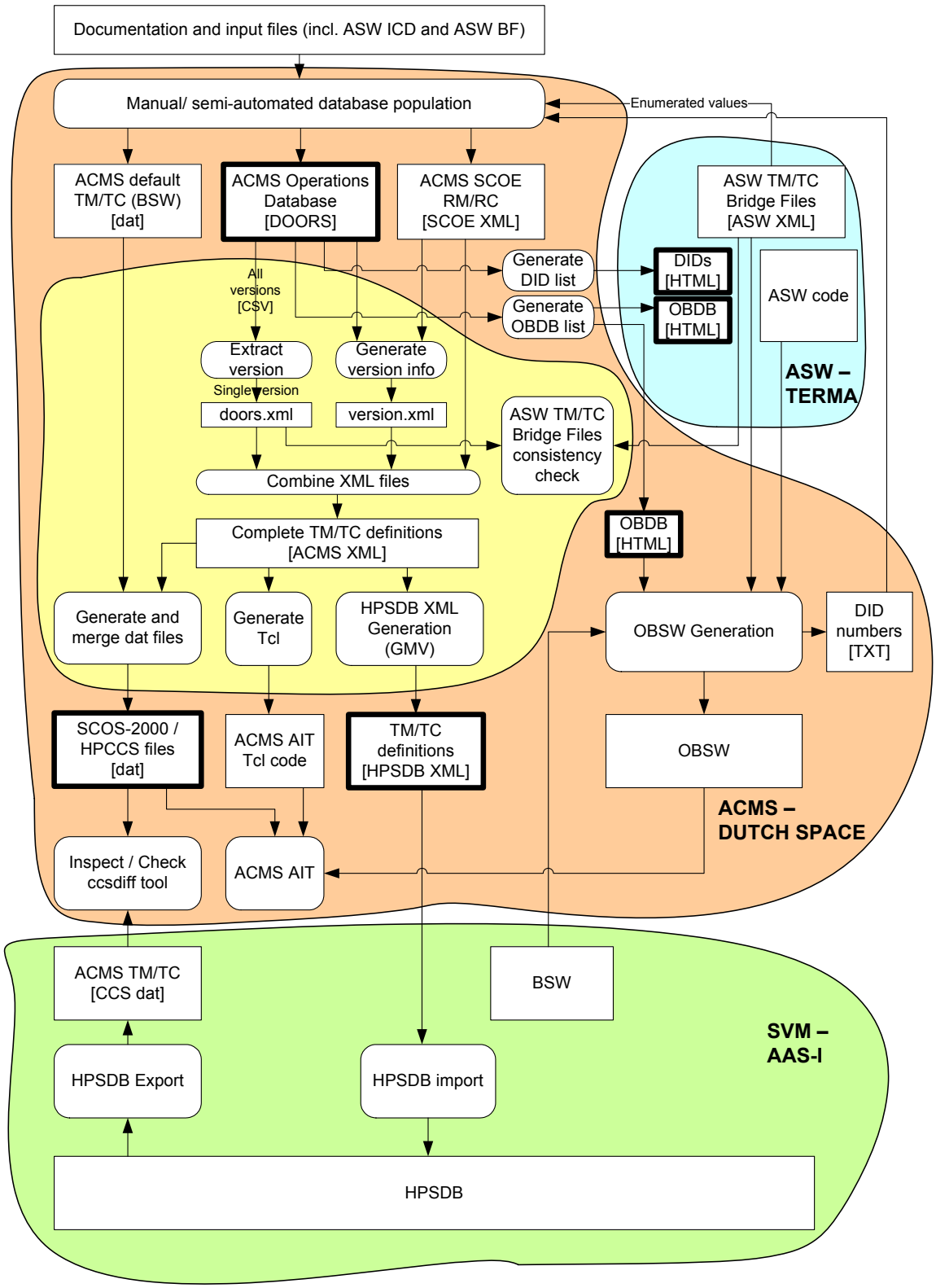

Figure 3. Processes and data involved in the generation of Application Software, SCOS-2000 and Herschel/Planck System DataBase input files using the ACMS database.

Versions and baselines

During the development and population of the ACMS Database, many versions have been created. Configuration control is important for all (flight) software, and in most situations branching is used to maintain different versions of the software. For the ACMS Operations Database branching is not used, at least not at source level.

Every object in the ACMS Operations Database contains the following version information:

- *S/C*. Defines for which spacecraft the data is used (Herschel, Planck or Common).
- *VersionSW*. Identifies the software related to the object (ASW or BSW).
- *VersionFrom*. Identifies the first version in which the data is used (e.g. 02.04.000).
- *VersionTo*. Identifies the last version in which the data is used (e.g. 01.99.999).

This information is used to build specific versions of SCOS-2000 or HPSDB files from the same Comma Separated Value files exported from the ACMS Operations Database.

Commonality is the main reason for this method of versioning. A change in a single object in the Operations Database often changes multiple versions of the SCOS-2000 and HPSDB files. These files are generated automatically, and dedicated directories are used for configuration control of the different versions.

The DOORS functionality to create baselines of modules has not been used very often. The process takes a considerable amount of time, during which the ACMS Database should not be used. Also baselining "removes" the DOORS history of object changes which turned out to be useful for problem investigation.

Instead of using DOORS baselines, all formal ACMS Database exports to create SCOS-2000 and HPSDB files are stored under configuration control (using CVS). This is even more meaningful, as the exported files not only depends on the actual data defined in the database, but also on the columns and filters defined as part of the export views.

ACMS Test and Verification activities

The ACMS Database has been used intensively during the ACMS Test and Verification activities. The Operations Database defines the majority of these TM/TC definitions used during the ACMS subsystem level tests.

Tcl code, used in test scripts and test support library functions, is generated from the ACMS Database using. The generated Tcl code is used for many purposes, including:

- conversion of identifiers used by ACMS AIT and those used by SCOS-2000 and HPSDB, including
  - parameters
  - telecommands
- encoding and decoding of parameter values
- event decoding for event buffer dumps
- creation of a log file with events

Diagnostic TM/TC packets for test specific data structures are also defined in the Operations Database. The consistency between Housekeeping and Diagnostic service telemetry packets and telecommand packets is checked automatically during the generation of the ACMS database products. The values of the datapool parameters identifier in the service 3 telecommand packets depend on the version of the software and created automatically.

ACMS SCOE remote messages/commands are also defined in the ACMS Database, but not as part of the ACMS Operations Database. A dedicated ACMS SCOE XML file is used instead, from which also ACMS SCOE interface documentation is generated.

Generation of Herschel/Planck System DataBase files

To make the ACMS TM/TC related data available in a format suitable for import in the HPSDB, a tool has been developed by GMV, who also developed the HPSDB. The tool takes an ACMS XML file containing the complete ACMS TM/TC definitions as input, and uses ACMS Database implementation

logic and HPSDB rules to check and generate an XML file in HPSDB format, containing the ACMS TM/TC definitions.

To ensure that the ACMS definitions in the HPSDB are the same as those used during ACMS test and verification, the SCOS-2000/HPCCS *.dat files generated by the HPSDB are compared with the *.dat files used during ACMS AIT. The comparison is performed by the 'ccsdiff' shell script, developed by Dutch Space, which compares two directories with *.dat files and only shows the relevant differences.

V. Recommendations and lessons learned

Based on the experience gained with the development and use of the Herschel/Planck ACMS Database from the requirements to operations, the following recommendations are made:

1. Improve integration of the database with at least (software) specifications and interface control documents. Also design documentation should be generated from a database.
2. Improve integration of test development with the database. Test specifications should use identifiers defined in the database.
3. Support independency between identification of TM/TC definitions used in requirements, software, test and operational. Independency limits the impact of changes for the different activities. The relation between these identifiers must be traceable and documented.
4. Include version information for each object defined in the database. This allows consistency checks to be performed and version specific data to be generated.
5. Use inheritance and instantiation where possible. Minimize duplication of data, even if this makes the database more complex.

Most of these recommendations can only be implemented if proper tools are available (or developed) in the initial phase of the project. The lessons learned from the use and development of Herschel/Planck System DataBase will also provide important feedback on this subject.

Standardization of a database design/interface for definition of operations and test related information should be aimed at. This should not only be achieved for different phases and users of the same project, but should be beneficial for all space programmes.

Acknowledgments

L.J. Timmermans thanks the Herschel/Planck ACMS project teams at Dutch Space and Sener, and the ACMS users at AAS-I, AAS-F and ESA for the fruitful cooperation in the past years.

References

[1]ESA, "Programmes in Progress" *ESA Bulletin*, No. 125, 2006, pp. 83-84.

Appendix A Presentation

Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

Turning requirements into operations – Herschel/Planck ACMS Database Experience

ir. Leo Timmermans
R&D Engineer, Space Department
Aerospace Systems & Applications Division

SpaceOps 2006 Conference, Rome, Italy, 19–23 June 2006

Overview

Presentation overview

Introduction
- Missions
- Database context
- DOORS
- Documentation
- Ground Support Equipment
  - Herschel/Planck System DataBase
  - Herschel/Planck Central Checkout System
  - ACMS Test Equipment
- On-Board Software

ACMS Database
- Processes and data
- Operations Database architecture
- Versions and baselines

Conclusion
- Recommendations and lessons learned
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Introduction

Missions

Herschel and Planck are major ESA scientific missions

Both procured on the same contract

Commonality: reuse and share components where possible

To be launched on the same Ariane 5 in Feb. 2008

Introduction

Herschel Space Observatory

Largest ever infrared space observatory when it is launched.

Equipped with a 3.5 metre diameter reflecting telescope and instruments cooled to close to absolute zero.

Will observe at wavelengths that have never previously been explored.

After a four-month journey from Earth, Herschel will spend a nominal mission lifetime of three years in orbit around the second Lagrange point of the Sun-Earth system (L2).

More info on http://sci.esa.int/herschel

SpaceOps 2006 Conference, Rome, Italy, 19–23 June 2006 4/12/2007 5

Introduction

Planck Space Observatory

Will collect and characterise radiation from the Cosmic Microwave Background (CMB)

Sensitive radio receivers

- operating at extremely low temperatures
- will determine the black body equivalent temperature of the background radiation
- will be capable of distinguishing temperature variations of about one microkelvin.

These measurements will be used to produce the best ever maps of aniosotopies in the CMB radiation field

More info on http://sci.esa.int/planck

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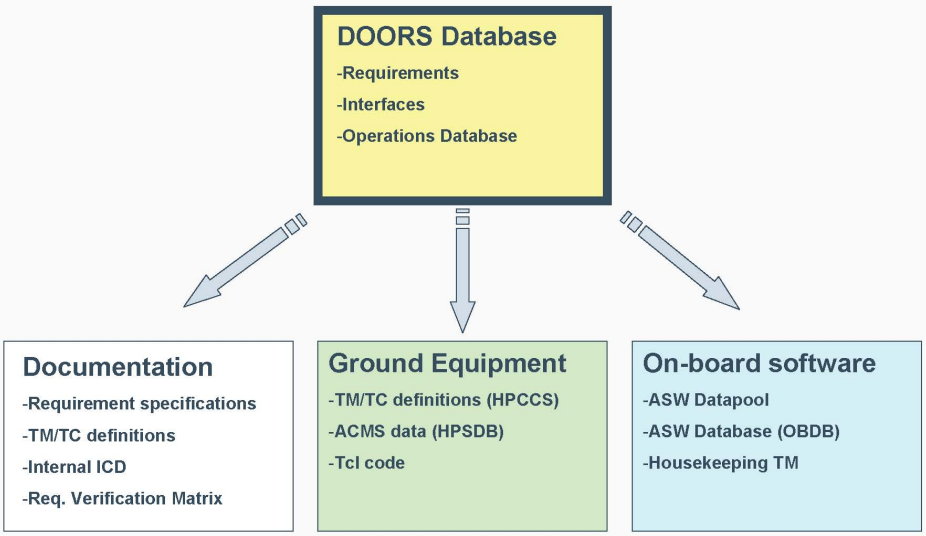
Introduction

Database context



Introduction

DOORS database

Requirements management tool from Telelogic

Limited experience at start of project

Data structured in projects, folders and modules

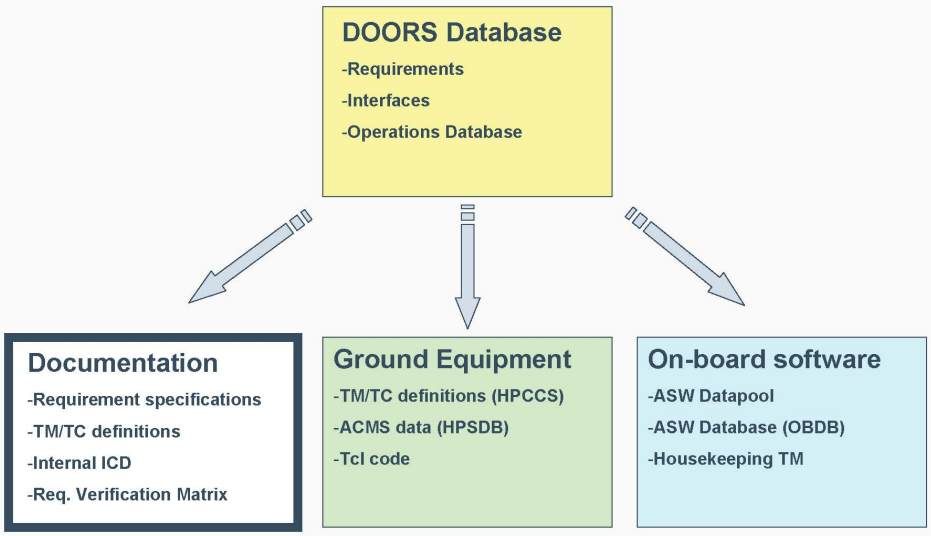
Relations between objects in modules by links

DOORS eXtension Language (DXL)

Note: DOORS is used as design database for Galileo GMS

Introduction

Database context



Introduction

Documentation

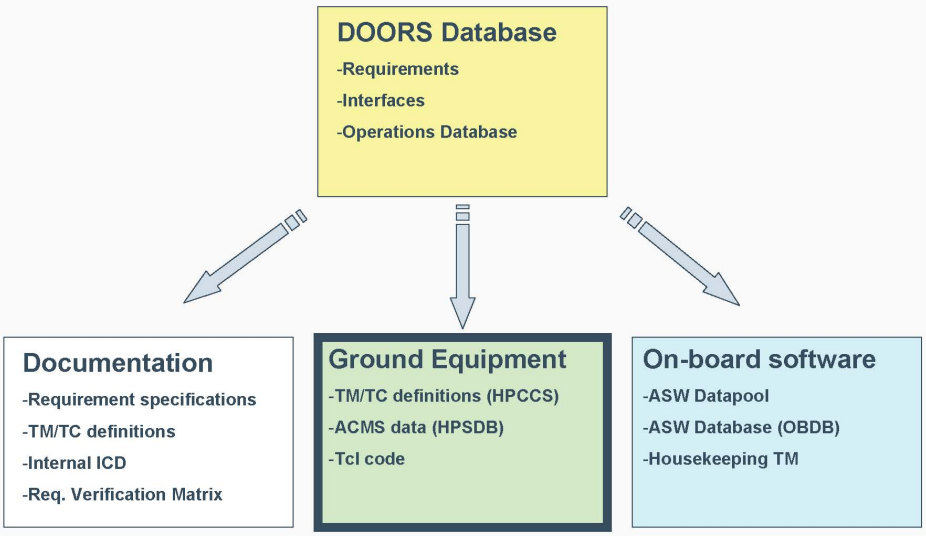
ACMS documents (partly) using DOORS data
- Unit Requirements Specifications
- Internal ICD
- On-Board Database
- Telemetry definition
- Requirements Verification Matrix

Multiple definitions of data used in documentation
- Application Software parameters
- MIL-STD-1553 interfaces
- Possible cause of consistency problems

Document generation from DOORS not straight-forward
- Additional tools needed (DocExpress)
- Include exported tables of documents (formatting)

Introduction

Database context



Introduction

Ground Support Equipment (1)

Herschel/Planck System Data Base (HPSDB)

- Supports consistency of data between different users
- Supports commonality between Herschel and Planck
- Data levels
  - *Element* data (units)
  - *Subsystem* data (e.g. Planck ACMS)
  - *Model* data (e.g. Herschel SVM)
  - *Generic* data (e.g. TM/TC packet headers, ON/OFF curves, ...)
- Theoretical and real boxes
- Logical and physical instantiation

HPSDB not used during ACMS development

- Unavailable/immature at start of phase C; risk not acceptable
- However, HPSDB is populated from ACMS Database

Introduction

Ground Support Equipment (2)

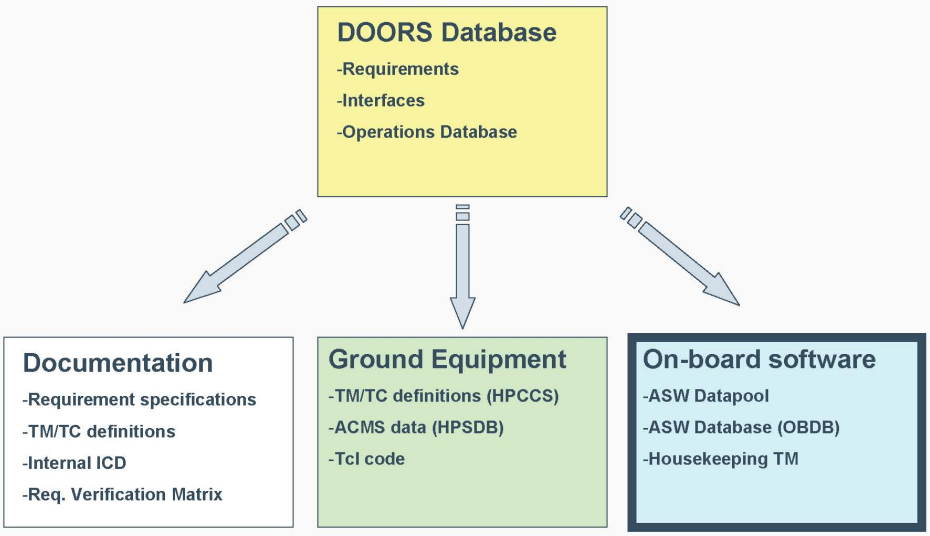
Herschel/Planck Central Checkout System (HPCCS)
- Based on SCOS-2000, as used during Mission Operations
- Offers additional functionality required for testing
- Developed for testing at system level

ACMS Test Equipment
- Based on HPCCS and EuroSim real-time simulator
- Fully used at ACMS level and partly re-used at system level

Provided MS-Access database not suitable
- Commonality not supported
- Limited to data required for SCOS-2000
- Poor configuration control

Introduction

Database context



Introduction

On-Board Software (1)

Two on-board computers ...
- Central Data Management Unit (CDMU)
- Attitude Control Computer (ACC)

with two software packages each ...
- Basic Software (BSW)
  - with commonality between CDMU and ACC
- Application Software (ASW)
  - with commonality between Herschel and Planck

with operational interfaces provided by ASW and BSW
- based on ESA Packet Utilization Standard (PUS)
  - service 3: Housekeeping and Diagnostics
  - service 5: Event Reports
  - service 8: Function Management

Introduction

On-Board Software (2)

Datapool
- Part of Housekeeping and Diagnostic service 3
- TM/TC packets for service 3 are handled by BSW
- ASW and BSW parameters
- Parameters identified by Datapool IDentifier (DID)
  - Actual DID numbers depend on OBS version

ASW datapool parameters
- Partly specified to ASW subcontractor
- Details agreed with ASW subcontractor
- Definition in ACMS Operations database
- Export from database used for ASW source code

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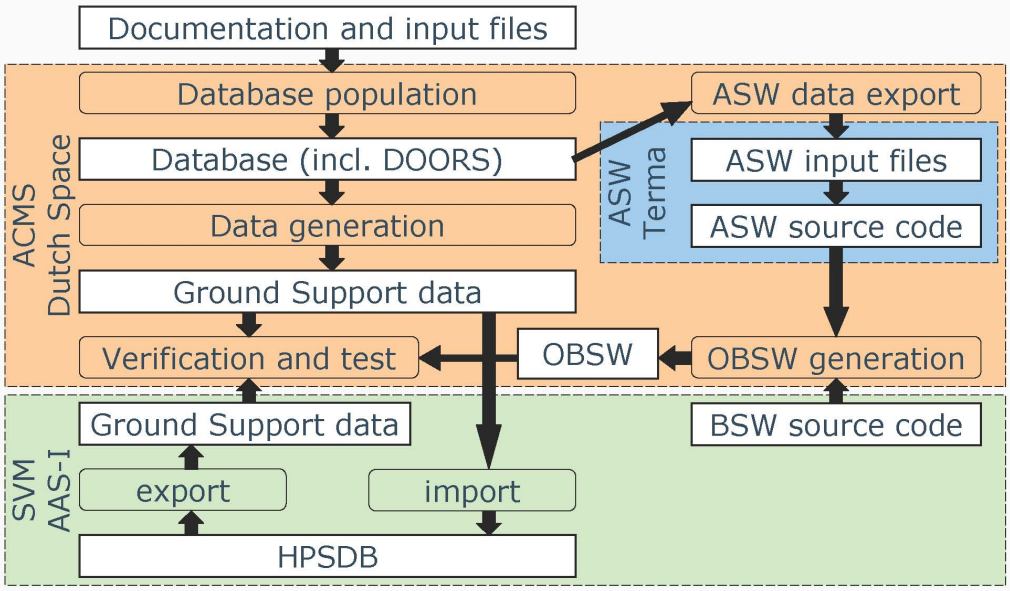
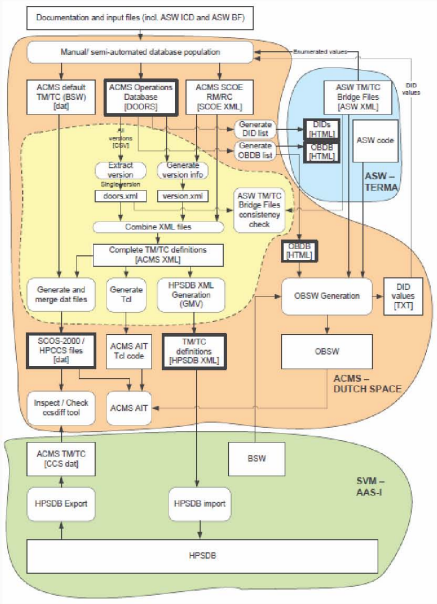
ACMS Database

Overview of processes and data



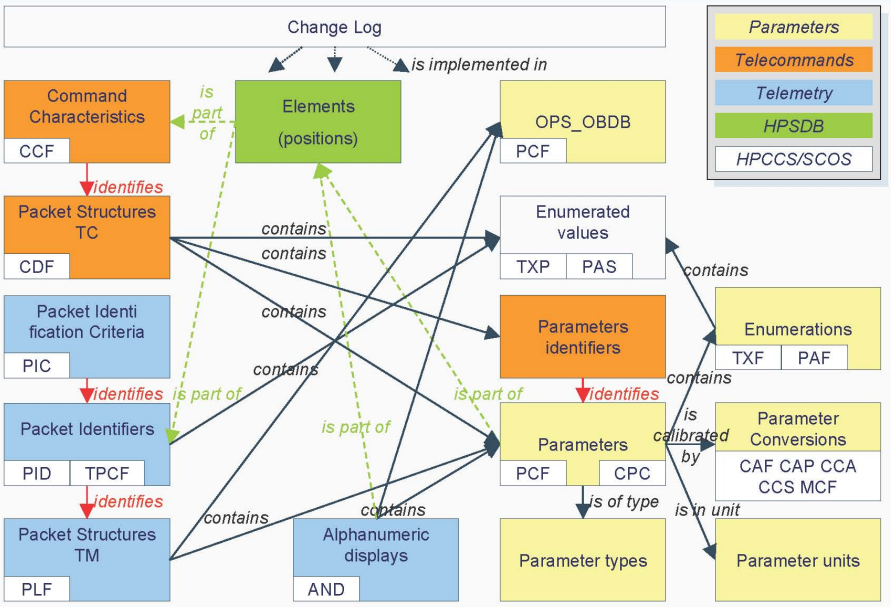
ACMS Database

Details of processes and data



ACMS Database

Operations Database architecture



ACMS Database

Versions and baselines

No branching used
- limit effort to maintain consistency over versions

Version information defined for each object
- S/C
- VersionSW
- VersionFrom
- VersionTo

All versions exported from Operations Database

Single database version filtered and generated
- Including version related checks

Generated databases maintained in different directories

DOORS functionality for baselines seldom used

Overview

Presentation overview

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Recommendations and lessons learned

Improve integration of database with
- documentation
- test development

Support independency between identification used for
- requirement
- software
- test
- operations

Include version information in the database

Use inheritance and instantiation to minimize duplication

Standardization of database design/interface from requirements to operations should be aimed at.

Conclusion

Questions

???