Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

NLR-TP-2000-658

Developments in Test and Verification Equipment for Spacecraft

TNG-GEN-TP-001

M.P.A.M. Brouwer, A.A. Castelijn, H.A. van Ingen Schenau,

B.A. Oving, L.J. Timmermans and T. Zwartbol

Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

NLR-TP-2000-658

Developments in Test and Verification Equipment for Spacecraft

TNG-GEN-TP-001

M.P.A.M. Brouwer, A.A. Castelijn, H.A. van Ingen Schenau,

B.A. Oving, L.J. Timmermans and T. Zwartbol

This report is based on a presentation held at the International Workshop on Simulation for European Space Programmes, SESP'2000, 10-12 October 2000, Noordwijk, The Netherlands. It describes work performed as part of NLR's basic research programme, workplan number R.1.A.2.

The contents of this report may be cited on condition that full credit is given to NLR and the authors.

Division:	Space
Issued:	December 2000
Classification of title:	Unclassified

Contents

(20 pages in total)

DEVELOPMENTS IN TEST AND VERIFICATION EQUIPMENT FOR SPACECRAFT

By
Brouwer, M.P.A.M.; Casteleijn, A.A.; van Ingen Schenau, H.A.; Oving, B.A.; Timmermans, L.J.; Zwartbol, T.

The authors are with the Test and Simulations Group of the Space Division of the
National Aerospace Laboratory NLR
P.O. Box 153, 8300 AD Emmeloord, The Netherlands
Tel. +31 527 248 218; Fax: +31 527 248 210
E-mail: mbrouwer@nlr.nl; castelyn@nlr.nl; ingen@nlr.nl; oving@nlr.nl; timmerlj@nlr.nl; zwartbol@nlr.nl

ABSTRACT

Re-use of test and verification equipment in space programmes can significantly reduce the cost, schedule, and risk. The spacecraft lifecycle typically involves design, development, assembly, integration, verification, operations, and maintenance.

This paper describes developments in test and verification for spacecraft, based on the successful application of NLR's Test and Verification Equipment (TVE) in the XMM and INTEGRAL projects.

New developments for TVE intend to bridge both ends of the spacecraft lifecycle, satisfying the needs for cost and schedule optimisation. Test equipment for closed loop testing like TVE must feature both powerful simulation and EGSE capabilities.

The new generation of TVE aims to integrate ongoing developments, such as:

- generic simulation environment EuroSim
- Project Test Bed
- hardware emulation of the on-board computer
- hardware-in-the-loop closed loop testing
- spacecraft operations system SCOS-2000.

1. INTRODUCTION

Based on experience with production and use of test systems for satellites such as XMM and INTEGRAL, NLR is developing a new generation of Test and Verification Equipment (TVE) for on-board control systems. Starting points for the developments are: the existing TVE technology, lessons learned from XMM and INTEGRAL, application of relevant technologies developed in ESA -R&D- programs, modularity and scalability, re-use during the various phases of the s/c lifecycle, use of COTS products.

From past programs, a number of important issues for the optimisation of the spacecraft lifecycle have emerged, e.g.:

- Need to re-use simulation environments and simulation model software, not only during the development and verification phases, but also during commissioning and in-flight operations.
- Need for the development of s/c operational control procedures as early as possible, such that the on-board software and operational procedures are exercised to the greatest possible extend on the ground. The developed operational procedures shall be usable during system level integration and test, commissioning and operations.
- Need for early on-board software prototyping and validation. Historically much simulation effort was spent on the verification of control algorithms functionality and performance, before implementation in the On-Board Computer (OBC). Experience has shown that it is equally important to exercise the (often very complicated) Failure Detection, Isolation and Recovery (FDIR) functions implemented in on-board software of autonomous spacecraft and the possibly associated operational control procedures in an early stage of the development. The use of a simulation facility, possibly coupled to an OBC emulator, will enable early prototyping and validation of control algorithms and autonomy functions.
- Need to use a (central) spacecraft database throughout the lifecycle. As the lifecycle consists of several phases with activities taking place at different locations, it shall be possible to interface to and to use the s/c database in the different phases and at different places. This requires compatibility and import/export capabilities of database tools used.

Recent ESA technological developments address these needs. Among the technologies being developed under ESA programs, are the Project Test Bed (PTB), the Software Verification Facility (SVF), and the new generation Spacecraft Operations System SCOS-2000.

PTB is being developed into a simulation resources environment that can be used throughout the s/c lifecycle. PTB builds upon the EuroSim simulation environment, which adheres to the ESA SMP standard, facilitating exchangeability of models between different simulation environments.

The SVF comprises a hardware emulation of the OBC and a software environment containing a/o telemetry and telecommand (TM/TC) handling and s/c simulation models. However, SVF does not feature an SMP compatible simulation environment like EuroSim.

SCOS-2000, being developed by ESOC as the s/c operations system for ESA spacecraft, is designed to be usable for both the satellite testing and operations phase. It features important Electrical Ground Support Equipment (EGSE) capabilities like database facilities, TM/TC handling, archiving, quick look and post test analysis tools. However, SCOS-2000 does not yet feature test language functionality.

It is noted that also the existing NLR TVE technology has been developed in the context of ESA R&D programs.

The new TVE developments by NLR intend to bridge both ends of the s/c lifecycle, satisfying the above-described needs.

Test equipment for closed loop testing must feature both powerful simulation and EGSE capabilities. The new generation of TVE aims to integrate the technology of the above-mentioned developments PTB, SVF, and SCOS-2000, with existing and new NLR TVE technology. This is accomplished by:

- using EuroSim as the TVE simulation environment, which will make the PTB developments available within the framework of TVE
- using SCOS-2000 as the checkout environment of TVE
- interfacing the SHAM OBC emulator of SVF with EuroSim in TVE.

2. GENERIC CONCEPT DESCRIPTION

The focus of this chapter will be on spacecraft control subsystems requiring closed loop simulation and verification, in particular the avionics subsystem.

2.1 Closed loop control

Figure 1 gives a schematic overview of a generic Attitude and Orbit Control System (AOCS) for spacecraft. The diagram reflects the cyclic nature of the AOCS. A complete AOCS, together with dynamics and environment can be considered as a loop, which is actively closed by the Attitude Control Computer (ACC) or, more general, an On-board Computer (OBC). The OBC cyclically reads out the sensors, performs the control and other tasks (e.g. FDIR, TM/TC) and issues the resulting commands.

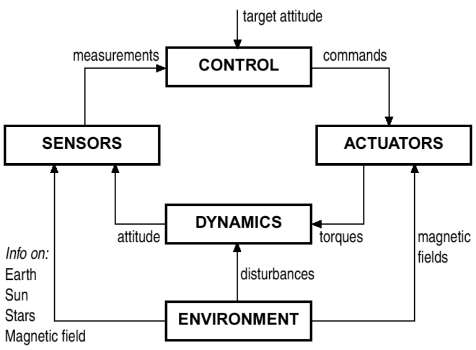


Figure 1: Generic control system for spacecraft attitude

Two generic s/c configurations are distinguished:

- Hierarchical configuration, where a Central Data Management Unit (CDMU) interfaces with the on-board TM/TC subsystem and controls the s/c system bus and a subordinate ACC controls the avionics subsystem bus
- Centralised configuration, where one central OBC performs both CDMU and ACC tasks, without a separate avionics subsystem bus.

2.2 Generic test and verification equipment concept

The test concept described in this paper is based on a closed loop bench test facility (no real motion), see figure 2. Spacecraft dynamics and environment are simulated. The simulation runs at a fixed simulation cycle rate, which generally is a multiple of the OBC sample frequency.

The sensor electronics are stimulated by the simulation such that they produce the measurements for the OBC. The OBC will command the actuators to control spacecraft dynamics. The relevant signals from the actuator units are acquired by monitoring interfaces and routed back into the simulation.

During the assembly, integration and verification (AIV) phase, the avionics subsystem is gradually built up, depending on the schedule of incoming units. Hardware units not yet present are to be simulated. The functional behaviour of these units is simulated in software, while the units physical interfaces are simulated by a hardware unit simulation interface, see figure 2. In this way verification can be performed with any combination of real and simulated units; starting from pure software simulations, via integration of a single OBC, gradual replacement of software models by hardware units, up to a fully integrated subsystem.

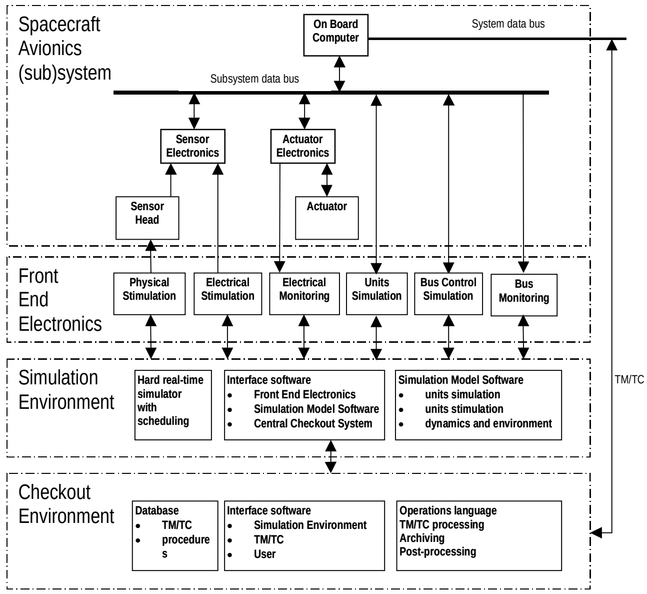


Figure 2: Avionics test equipment conceptual architecture

Four main objects, shown in figure 2, can be identified in test and verification of spacecraft:

1. Spacecraft Avionics subsystem, which needs to be tested as if it is in its operational environment; an important unit is the OBC that controls the s/c
2. Front-End Electronics (FEE). The Front-End Electronics consist of two parts:
   - FE stimulation and monitoring equipment, which electrically or physically stimulates sensors and electrically monitors actuator units.
   - FE data bus interfaces, which are able to:
     - simulate missing units (address, data interface)
     - monitor all traffic (data, instructions) on the bus
     - simulate the bus controller
     - perform fault injection.
3. Simulation Environment (SE), which hosts the Simulation Model Software (SMS) to simulate the spacecraft dynamics and space environment, to calculate stimuli values, and to simulate avionics units
4. Checkout Environment (CE), which contains the knowledge about the (sub)system under test (e.g. procedures and TM/TC database) and from which automatic test procedures are executed and checkout activities are controlled.

The TVE system comprises the CE, SE, and FEE including the cable harness to test interfaces. The simulation models will normally be delivered by the subsystem manufacturer.

On s/c system test level the avionics subsystem test equipment will be integrated with the other special checkout equipment (SCOEs) like TM/TC SCOE, Power SCOE, Solar Array Simulator SCOE, controlled by the system level CE.

Re-use will be facilitated if test procedures developed on unit and subsystem level can directly be used at system level, such that, e.g. while the spacecraft is fully integrated, it is still possible to re-run detailed subsystem or unit tests from the system CE. To this end the lower level CEs shall be identical or compatible versions of the system level CE.

This concept can be extended to s/c flight control procedures as well. If (identical or compatible) versions of the s/c flight operations system are used as CEs at subsystem and system level testing, this will allow development and validation of flight procedures during the s/c development and test phases.

The use of an SMP compatible SE and SMS will further facilitate re-use of simulation model software during the s/c design, development and test phases as well the s/c commissioning and operations phases.

2.3 Checkout concepts

Because of its modularity and scalability, the sketched test equipment concept can cover the complete spacecraft development lifecycle:

- non real-time software simulations; the configuration involves only the SE, without FEE and CE. The activities may involve e.g. mission analysis simulations, development of s/c attitude and orbit control algorithms, development of FDIR concepts and algorithms.

- Simulated real-time closed loop test with an OBC emulator; this configuration involves the SE with s/c dynamics and environment simulation, the CE, and the OBC emulator; the avionics functional behaviour is simulated in software; data bus behaviour is simulated by the OBC emulator firmware.

- real-time closed loop test with a single OBC; this configuration involves the SE, the CE, and FEE with data bus interfaces connected to the OBC unit. The s/c dynamics and environment and the functional behaviour of all avionics system units (except OBC) are simulated.

- unit integration and test; this configuration involves the FEE with data bus interface and (dedicated) stimulation and monitoring interface to the unit, and a (limited) CE to develop and control the test; only the FEE and CE interface functionality of the SE is needed.

- subsystem level AIV; this configuration involves the CE, SE, and FEE with data bus interface and stimulation and monitoring interfaces. At this level, the FEE data bus interface includes bus controller, bus traffic monitoring and unit simulation functionality. Additional electronics to simulate e.g. CDMU functions or the power distribution is also needed, but not shown in figure 2.

- spacecraft system level AIV; this configuration involves the complete TVE system: SE, FEE with avionics bus interface, and stimulation and monitoring interfaces. At this level, the FEE data bus interface includes unit simulation and subsystem bus monitoring functionality. The subsystem CE is replaced by the system CE.

- flight procedure development and test; the configuration may involve any of the configurations discussed above. For re-usability a CE is required that is an identical or compatible version of the one used for actual s/c flight operations.

- spacecraft operator training; this configuration involves a CE and a SE, possibly coupled with an OBC emulator or a single HW OBC model.

- system validation tests; this configuration involves all the SE and FEE on-site with the spacecraft, and two CEs. One CE will be used for on-site control of the spacecraft under test; the other - remote - CE is used at the actual spacecraft operations centre.

- spacecraft operations; in this configuration the spacecraft is controlled by the CE, which will have additional interfaces to e.g. mission planning and flight dynamics systems and an SE incorporating the s/c simulator.

- commissioning support phase; besides the spacecraft operations configuration, the (a second) CE is used by a project support group to monitor the spacecraft operations and provide support during the commissioning phase.

Interfaces to a central s/c database are required for consistent use of s/c data, test procedure versions and software versions throughout the lifecycle.

3. XMM / INTEGRAL TEST EQUIPMENT

NLR has built the avionics test equipment for the XMM and INTEGRAL satellites. The XMM and INTEGRAL avionics Test Equipment architecture is based on the concepts discussed in chapter 2. This equipment has been used at both avionics subsystem test level and system test level. The subsystem and system level configurations differ slightly, as shown in dotted lines in figure 3.

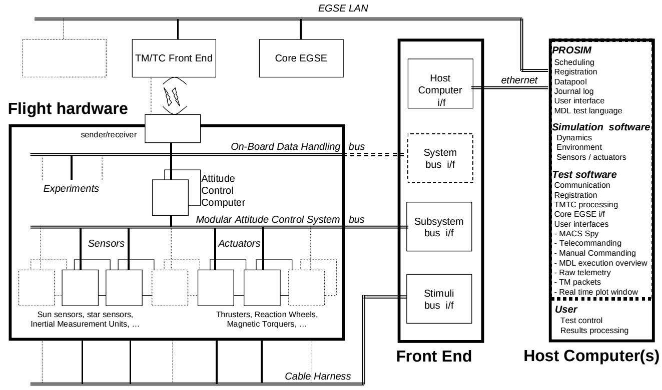


Figure 3: XMM / INTEGRAL test equipment configuration

The equipment consists of two parts: a Front-End (FE) and a Host Computer (HC).

The VME-based FE contains the FEE interfaces to the Modular Attitude Control Systems (MACS) subsystem data bus and to the On-Board Data Handling (OBDH) system data bus. Furthermore, it contains the stimulation and monitoring equipment.

The HC hosts both the Simulation Environment and the Checkout Environment, which are strongly coupled in the general-purpose simulation support tool PROSIM (Programme and Real-time Operations SIMulation) and the TVE Test Software (TSW).

The PROSIM/TSW consists of two parts:

- a real-time part taking care of the activities related to the closed loop simulation, data acquisition and routing, TM/TC processing, test script execution.
- a non real-time part taking care of data archiving and user interfacing; for system level tests interfacing with the TM/TC FE and the Core EGSE was included.

The OBC sample and control cycle frequency of the XMM and INTEGRAL AOCS was 2 Hz, whereas the simulation, stimulation, and data acquisition cycle frequency was 40 Hz.

The real-time part of the TSW has been designed to run on a single- or multi-processor workstation. Its real-time processes are controlled by a dedicated scheduler that can be synchronised with the operating system clock or with the 40 Hz arrival of Ethernet messages from the FE containing the acquired actuator data. The user interfaces are loosely coupled to the real-time processes via Ethernet connections and can be executed on the real-time workstation and/or remote workstations.

The real-time processes communicate mainly via a static Global Data Store (GDS) for user level data and a dedicated dynamic buffer pool for FE data. The buffer pool facilitates decoupling of time-critical processes on one hand and data archiving and user interface related processes on the other hand. The open structure of these interfaces, combined with the precise scheduling of the involved processes, provides reliable direct access to important data for test scripts, graphical user interfaces, and archiving processes.

An important function is the automated execution of real-time tests. These tests are in general controlled via scripts written in Mission Definition Language (MDL). MDL scripts can be used as Automatic Test Procedures (ATPs) since they can be initiated by certain conditions in the GDS. MDL scripts can also be initiated by other ATPs or via the Graphical User Interface (GUI) by the test conductor.

Note that all MDL scripts are executed synchronously with the Simulation Model Software (SMS) at a frequency of 40 Hz. MDL commands can also be executed interactively in a dedicated Manual Commanding window.

The GUI includes facilities for defining test set-up and test control, for monitoring of MACS bus traffic, for monitoring and modifying of GDS variables, for telecommanding and for displaying telemetry.

The SMS has been developed by Astrium Bristol (formerly MMS UK). The function of the SMS depends on the presence and configuration of the real AOCS units during the actual test. The SMS can simulate sensor heads (for generation of stimuli data), actuators or complete sensor and actuator units. The SMS interfaces to the TSW via the GDS. This part of the GDS includes simulation variables for engineering data like torque magnitudes and attitudes.

The host computers used are an SGI Indigo2 and an Indy workstation running under an IRIX 5.3 operating system. The Indy workstation was used as a second (remote) user interface.

4. NEW DEVELOPMENTS

4.1 Introduction

The NLR Test and Verification Equipment has successfully been applied in the XMM and INTEGRAL projects. However, new developments are taking place in order to enhance TVE modularity and scalability and use of COTS products, so as to facilitate re-use throughout the s/c lifecycle as described in chapter 2, and to prepare TVE for future missions.

The new generation of TVE aims to integrate before-mentioned developments of EuroSim, PTB, SVF, and SCOS-2000, with existing and new NLR TVE technology. This is accomplished by:

- using EuroSim as the TVE simulation environment, which makes the PTB developments available within TVE
- using SCOS-2000 as the checkout environment of TVE
- upgrading of the TVE FE
- addition of available data bus interfaces.
- interfacing the SHAM OBC emulator of SVF with EuroSim in TVE.

NLR has started the development of the new generation of avionics test equipment in the framework of NLR's TVE Next Generation (TNG) R&D program.

The basic architecture of TNG is identical to the architecture sketched in figure 2. It is noted that for subsystem level tests additional FE equipment, not shown in figure 2, will be present, see section 4.4.

The use of EuroSim as the simulation environment and SMP compatible SMS will allow simulation models developed in the early phases to be re-used throughout the of the lifecycle. Furthermore, it makes the developments of PTB available within the framework of the new generation of TVE.

EuroSim is a product of the Dutch EuroSim consortium. As a member of the EuroSim consortium, NLR is also actively involved in the further development of EuroSim.

The checkout environment will be based on the spacecraft operations system SCOS-2000, being developed under ESOC direction. The SCOS-2000 system is designed to be usable for both s/c operations and s/c testing. Extensions are required for command and control of the SE and for ATP scripting and execution. When used early in the lifecycle, it allows a consistent TM/TC database and well-tested flight procedures. Furthermore, it will reduce the training effort.

It is foreseen that SCOS-2000 will be in use at least in the 2000-2010 period, replacing eventually the SCOS-I system, which is presently used for some spacecraft control systems (e.g. CLUSTER, ERS, ENVISAT, XMM).

Other additions concern FEE interfaces to the s/c data buses. Besides the already available OBDH and MACS bus interfaces, recent developments include a MIL-1553 bus interface, an IEEE-1355/SpaceWire serial interface, and the 04-255 OBDH extensions.

An important step in the lifecycle is the replacement of OBC software simulation by a hardware emulator. To this end, the TVE will be extended with an interface to the simulation-handling module SHAM from the Dutch company CHESS, developed for the ESA Software Verification Facility (SVF).

These tools will have the following important benefits:

- standard tool throughout project lifecycle
- tool knowledge available
- easy transfer from subsystem to system level
- easy transfer of project-specific knowledge
- Linux and Windows NT versions in the near future.

The benefits of these COTS tools will lead to cost reduction and a general use in the European space programmes.

4.2 EuroSim

EuroSim is a configurable simulator tool that is able to support all phases of space and non-space programmes through real-time simulations with a person and/or hardware-in-the-loop.

EuroSim is based on the principle that each simulator can naturally be broken into an invariant tool part (simulation environment) and a part that is specific to the subject being simulated: the latter is called the (simulation) model. The model is a software representation of the behaviour of a particular real-world system.

By means of a careful design of the tool part, it can be used for both small and large simulator, and it can support the portability of simulation models. This allows them to be reused between projects and to exchange one model for another, e.g. one offering higher fidelity.

TVE-specific FE and SCOS-2000 interfaces will be developed as extensions to EuroSim. EuroSim currently features MIL-1553, PCI-VME, GPIB, and External Interrupts and IRIG-B interfaces.

EuroSim has the possibility to interface with other simulators via the so-called external simulator access. High Level Architecture (HLA) functionality for distributed simulation is planned in the near future.

Furthermore, EuroSim can handle the replacement of software models by hardware items without the need to redesign the simulator interfaces to hardware devices.

NLR has developed an automated software model import interface between Matlab/Simulink and EuroSim in the MOSAIC project [Ref. 2]. Moreover, NLR has already proposed to ESTEC the extension, dubbed MOSAIC II, for the automatic generation of SMP compliant models starting from Matlab/Simulink. The generation of SMP & EuroSim compatible model from MatrixX will be the subject of MOSAIC III.

4.3 SCOS-2000

SCOS-2000 is the advanced Spacecraft Operations System, based on long-time experience at ESOC [Ref. 3]. It provides all essential functions to monitor and control a satellite both in orbit and during testing. Since many functions of an EGSE are similar or even identical to a Mission Control System (MCS), particular attention has been paid to obtain a design usable for both the satellite testing phase and the satellite operations phase.

SCOS-2000 is a spacecraft control system framework, which uses an object oriented analysis and design approach. It provides the basic processing expected of a spacecraft control system, covering:

- telemetry processing
- telecommanding
- online database
- online archive
- general services and utilities
  - operation language
  - roles & privileges
  - events & actions
- on-board software maintenance.

SCOS-2000 is a configurable system and provides a library of components to be used for the implementation of a spacecraft control system. Individual classes may be used to develop mission specific applications. If they do not offer precisely the behaviour required, they may be customised by sub-classing.

SCOS-2000 provides mechanisms for event driven update of displays, events and actions, representation of parameters. These mechanisms are used at application level by SCOS-2000 components and may be used when implementing mission specific applications.

SCOS-2000 itself provides database facilities, as well as data base import facilities that allow import of s/c data, TM/TC definitions, test procedures, etc, from a central s/c database.

For use as CE in TVE, it is necessary to extend the SCOS functionality with an interface to the Simulation Environment, and with test language functionality allowing ATP scripting and execution.

4.4 Front-End

The FE is a modular VME system. It contains the hardware interfaces: to the OBC emulator, to the s/c data buses, and to the subsystem units for stimulation & monitoring, etc.

It is noted that at subsystem test level additional FE equipment will be present, not shown in figure 2. For example the TM/TC link requires a s/c bus interface, which may involve simulation of CDMU functions.
Furthermore, hardware simulators of a Power Distribution Unit (PDU), Reaction Control Subsystem (RCS), Remote Terminal Unit (RTU), Reaction Wheels (RWs), separation switch (SS), may be part of the subsystem test configuration, as the pertinent s/c subsystems are not available at avionics subsystem test level. Indeed the above mentioned simulation

equipment was part of the XMM and INTEGRAL avionics subsystem test configuration.

The FE data bus interfaces comprise two boards: a low-level physical bus interface board and a PowerPC board. The real-time software running on the PowerPC board performs the data communication between data bus interface and SE, including buffering, time-tagged execution, and allows inclusion of project-specific protocols.

The FE stimulation and monitoring interfaces comprise a set of low level interface boards, which provide the physical electrical interfaces to the equipment under test, controlled by a PowerPC board. The real-time software running on the PowerPC boards controls the low level boards and takes care of the data communication between stimulation and monitoring interfaces and the SE.

An important feature of the stimulation and monitoring equipment is that all stimuli channels are written-to synchronously and all monitoring channels are read-out synchronously, triggered by a stable clock. In this way, there is virtually no jitter of the stimulation/simulation cycle time.

The FE is upgraded by modernising both hardware and software:
- The PowerPC VME boards replace Motorola 68040 processor boards, which are being phased out
- the pSOS real-time kernel and development environment has been replaced by VxWorks
- communication with the Simulation Environment will be via a direct VME interface for real-time performance
- additional data bus interfaces, such as MIL-1553, IEEE-1355, and ESA 4-255 OBDH are made available.

Furthermore, IRIG-B time distribution will be used in order to enable correlation of data from various sources, which is useful for testing and post-processing purposes.

4.4.1 Stimuli and monitoring equipment
The stimuli and monitoring equipment provides the interfaces with the electronics of real (physical) subsystem units to support hardware-in-the-loop testing.

For electrical stimulation of avionics equipment under test, NLR has developed the Analogue Stimulation Interface (ASI) VME board and the Bi-level Stimulation Interface (BSI) VME board, which provide configurable, high-resolution current/voltage stimuli channels. These channels have fully isolated test interfaces with overvoltage and overcurrent protection.

For acquisition of signals to be monitored, NLR has developed the MOnitoring Interface (MOI) VME board and the General Timer (GTM) VME board. The MOI board provides 5 channels for acquisition of analogue values and 8 channels for bi-level values. The board can be configured for the desired range of currents or voltages to be acquired. The GTM board provides 14 timers for the measurement of time duration, e.g. the time that RCS valves are open.

Features of the stimuli and monitoring boards are:

Analogue Stimulation Interface board (ASI):
- 5 fully isolated analogue stimuli channels
- configurable current and voltage trip levels, power supply +/-15V watch
- configurable voltage output range 1- (+/-)13V fs
- configurable current output range 350µA- (+/-) 50mA fs
- resolution 16 bits, drift <0.001% /oC fsr, non-linearity <0.0016% fsr
- software calibrated.

Bi-level Stimulation Interface board (BSI):
- 12 fully isolated bi-level stimuli channels
- configurable current and voltage trip levels
- configurable voltage output range 1 – 13V fs
- configurable current output range 20µa – 50mA fs
- accuracy better than 1% fsr.

MOnitor Interface board (MOI):
- 5 fully isolated analogue monitor channels
- 8 fully isolated bi-level monitor channels
- configurable as voltage or current input
- resolution 16 bits, drift < 0.001 %/ oC fsr, non linearity <0.01% fsr
- software calibrated.

General Timing Monitor board (GTM):
- 14 isolated timing monitor channels (used for RCS mon)
- resolution timing monitor channels 1ms
- 4 RW tacho simulator channels, range 0-400 pulses / 25ms
- provides synchronisation clock (40Hz sync).

Current developments include miniaturisation of the electronics.

4.4.2 MIL-1553 interface
A MIL-1553 bus interface has been added to the available bus interfaces, in view of upcoming missions featuring the Mil-1553 bus.

The interface consists of a COTS VME MIL-1553 interface board and a VME PowerPC processor board. The PowerPC processor board runs the real-time software to control the MIL-1553 board, to acquire and process data received from the board, and to perform communication with the Simulation Environment.

COTS MIL-1553 boards are available from various suppliers. A MIL-1553 board with IRIG-B decoder has been selected.

The MIL-1553 board has the following capabilities:
- bus controller
- remote terminal simulation
- bus monitoring
- error injection.

The bus controller function is required for unit integration and testing on subsystem level. The bus controller function allows a single unit to be accessed by the test equipment, while the OBC is not yet present or switched off.

The Remote Terminal (RT) simulation function of the selected MIL-1553 board can simulate up to 31 RTs on the MIL-1553 bus via address and data. Via this mechanism, avionics units that have not yet been integrated on the MIL-1553 bus (or are switched off) can be simulated.

The bus monitor of the MIL-1553 board has the capability to monitor all traffic on the bus. Data exchange on the bus will be time-stamped to support analysis of unit behaviour and events. The monitoring capability is also required to be able to trap and analyse any errors, which occur on the bus.

Programmable error injection on per word basis is needed to simulate (unit) failures. Error injection is a powerful tool to investigate failure detection, isolation, and recovery (FDIR) of autonomous on-board systems.

4.4.3 IEEE-1355/Spacewire VME interface

ESTEC proposes the SpaceWire standard for use in the spacecraft on-board infrastructure. SpaceWire is an upgrade of the IEEE-1355 standard, targeting space applications. SpaceWire is especially interesting for interprocessor communication and high-speed point-to-point communication links, as needed for payload instruments and navigation cameras.

Under ESTEC contract, NLR has developed an IEEE-1355/Spacewire VME interface [Ref. 4], which basically consists of one or two slave IEEE-1355 PMC boards plugged onto a standard Motorola PowerPC carrier board and real-time driver software running under VxWorks.

The PMC boards contain the SMCS332 communication chip of TEMIC that provides an interface between a DS link and CPU communication and data memory. The PMC board does not have a local CPU, so that the PowerPC processor is used for controlling the SMCS332.

The IEEE-1355/SpaceWire VME interface is marketed by Satellite Services BV.

4.4.4 4-255 OBDH interface

The ESA 4-255 data bus standard is part of the new (draft) ESA 4-201 Data Handling Systems standard. In recent years, a number of protocol extensions for use with the 4-255 OBDH have been defined. Each protocol extension provides interrogation word formats, which extend the generic capabilities of the bus.

The 4-255 OBDH allows mixtures of cyclic and non-cyclic data transfers to be applied, supporting both regular telemetry and time-critical command and control. Furthermore, it supports transfers of large blocks of data between remote terminal units via the block transfer bus. A significant new feature is the support of polling and servicing-on-request of remote terminal units.

The 4-255 Test Equipment [Ref. 5] under development incorporates a VME board containing a 4-255 Bus Controller Simulator, being developed by the Swiss company ADELSY, for the interrogation, response, and block transfer bus. Again, this board is controlled by a PowerPC board. The equipment can be used in the next generation of TVE to test spacecraft utilising the 4-255 OBDH.

4.5 SHAM

SHAM is an acronym for Simulation HAndling Module [Ref. 6] and is developed by the Dutch company CHESS under ESA contract. Its purpose is to simulate (functionally and timing wise) the hardware of an embedded computer system and presenting an environment in which software for that embedded system can be tested.

The SHAM is primarily used for the validation of spacecraft On-board Software (OBS), such as an AOCS or Data Handling System (DHS). In a validation system, the SHAM emulates the hardware (CPU, memory, and I/O) of a s/c sub-system, thus simulating an environment in which the OBS can run as if it was executing in the real spacecraft.

The ROSETTA mission currently uses the SHAM as a software development tool, its testing and debugging features helping the OBS designers. The XMM project employs the system as a software validation facility. Additionally, it aids in maintaining the OBS in the maintenance phase. New versions of the XMM OBS will undergo a regression test on the SHAM before they are uploaded to the satellite. In the Cluster and ISO projects, the SHAM is furthermore being used as a training facility to train the ground personnel to operate the spacecraft.

The full system consists of a host workstation connected to the SHAM VME board. The SHAM VME board contains the same target CPU as in the real s/c sub-system. This target CPU makes it possible to execute the actual binary image of the OBS. In addition, the SHAM emulates the I/O environment of the target CPU.

All kind of I/O devices can be simulated taking into account both its function and timing. Presently, OBDH and MACS simulations are available in firmware. However, SHAM can be extended with other bus simulations such as MIL-1553.

Two very important aspects of the SHAM are its simulated real-time behaviour towards the OBS, and the ability to simulate I/O devices in simulated real-time. Simulated real-time implies that execution does not take place in real-time, but all timing relations are preserved as in real-time.

5. CONCLUSIONS

NLR is actively contributing to the trend of maximising re-use of software and hardware throughout the spacecraft lifecycle. It is developing modular and scalable equipment that can be used for simulation and verification from the beginning of the project until the end. Commercial-of-the-shelf products are applied as much as possible, where standardisation of tools is taken into account.

6. ACKNOWLEDGEMENTS

NLR thankfully acknowledges the fruitful discussions with the ESA Technical Operations and Support Directorate, especially the Mission Control System Division, the Test and Operations section, and the Modelling and Simulation section.

7. REFERENCES

[1] H.A. van Ingen Schenau, L.C.J. van Rijn and J. Spaa, *Test and Verification Equipment for the Attitude & Orbit Control System of the XMM satellite;* NLR-TP-98236, paper presented on DASIA 98 Conference.
http://www.nlr.nl/public/library/1999-1/98236-tp.pdf

[2] W.W.F. Lammen, A.A. ten Dam and W.W.M. Heesbeen, *MOSAIC: Automated Simulation Model Transfer from*

MATLAB/SIMULINK to EuroSim; User Manual: version 1.0, NLR Contract Report CR-99563, 1999

[3] M. Schick, *SCOS-2000 System Level Architectural Design Document*; S2K-MCS-ADD-0001-TOS-GCI, Issue 3.0 (Final), 13/01/2000

[4] H.A. van Ingen Schenau and M.B. Beitler, *IEEE 1355 VME Interface Project, Summary Report*; NLR-CR-2000-113, IV-RP-NLR-002

[5] B.A. Oving and A.A. Casteleijn, *Central Node Simulator Project, System Description Document*; NLR-CR-99157, CN-SD-NLR-001, Issue 3, September 2000

[6] A.M. Bos, A.M. Geerling, M.H.G. Verhoef, J. van der Wateren (Chess), *Development of Safety-Critical Software Using Formal Methods in IDE*; paper IAF-99-U.2.02

[7] A. Elfving, *The Attitude and Orbit Control of XMM*; ESA bulletin 100, December 1999

8. ACRONYMS AND ABBREVIATIONS

ACC	Attitude Control Computer
AIV	Assembly, Integration, Verification
AOCS	Attitude and Orbit Control System
ASI	Analogue Stimulation Interface
ATP	Automatic Test Procedure
BSI	Bi-level Stimulation Interface
CE	Checkout Environment
CDMU	Central Data Management Unit
COTS	Commercial-Of-The-Shelf
CPU	Central Processing Unit
DHS	Data Handling System
EGSE	Electrical Ground Support Equipment
ESA	European Space Agency
ESOC	European Space Operations Centre
ESTEC	European Space Research & Technology Centre
FCV	Flow Control Valve
FDIR	Failure Detection, Isolation, Recovery
FE	Front-End
FEE	Front-End Electronics
fs	full scale
fsr	full scale resolution
GDS	Global Data Store
GTM	General Timing Monitor
GUI	Graphical User Interface
HC	Host Computer
HLA	High-Level Architecture
ISO	Infrared Space Observatory
LV	Latch Valve
MACS	Modular Attitude Control Systems
MCS	Mission Control System
MDL	Mission Definition Language
MOI	Monitor Interface
MMS	Matra Marconi Space
NLR	National Aerospace Laboratory
OBC	On-Board Computer
OBDH	On-Board Data Handling
OBS	On-Board Software
PDU	Power Distribution Unit
PROSIM	Programme and Real-time Operations SIMulation support tool
PTB	Project Test Bed
RCS	Reaction Control Subsystem
RT	Remote Terminal
RTU	Remote Terminal Unit
SCOE	Special Check-Out Equipment
SCOS	Spacecraft Operations System
SE	Simulation Environment
SGI	Silicon Graphics Incorporated
SHAM	Simulation Handling Module
SMP	Simulation Model Portability
SMS	Simulation Model Software
SVF	Software Verification Facility
TM/TC	Telemetry/Telecommand
TNG	TVE Next Generation
TSW	Test Software
TVE	Test and Verification Equipment

Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

Developments in Test and Verification Equipment for Spacecraft

by

Bertil Oving and Leo Timmermans

NLR Space Division, Test and Simulations Group

Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

Presentation overview

- **Introduction**
- **Existing TVE**
- **Developments**
- **Conclusion**

DASIA'2000 High Level consideration #1:

- ***Necessity for Europe to adjust to the evolution of the ground segment software market***
  - evolution characterised by trend to more general use of COTS, caused by economic pressure
  - however, individual s/w selections for easiest (better advertised (US)) solutions…
  - attempts to curb this trend, like e.g. SCOS-2000, have to be encouraged

Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

Needs

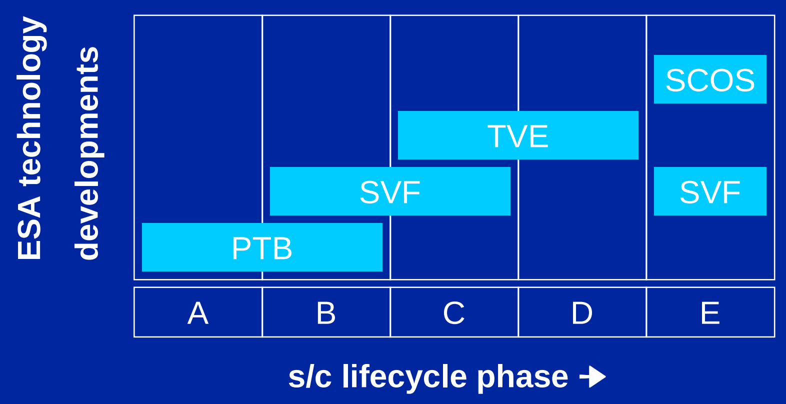
- **Reduce project cost, schedule and risk of s/c lifecycle, e.g. by :**
  - early validation
  - concurrent engineering
  - re-use
  - database usage

Solutions

- **Needs are addressed by ESA developments like**
  - Project Test Bed (PTB), based on EuroSim
  - Spacecraft Operations System (SCOS-2000), used by ESOC
  - Test and Verification Equipment (TVE), used for XMM and INTEGRAL AOCS
  - Software Validation Facility (SVF), based on SHAM

Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

ESA technology lifecycle coverage



International Workshop on Simulation for European Space Programmes, SESP '2000, 10-12 October 2000, ESTEC, Noordwijk, The Netherlands

Technology integration

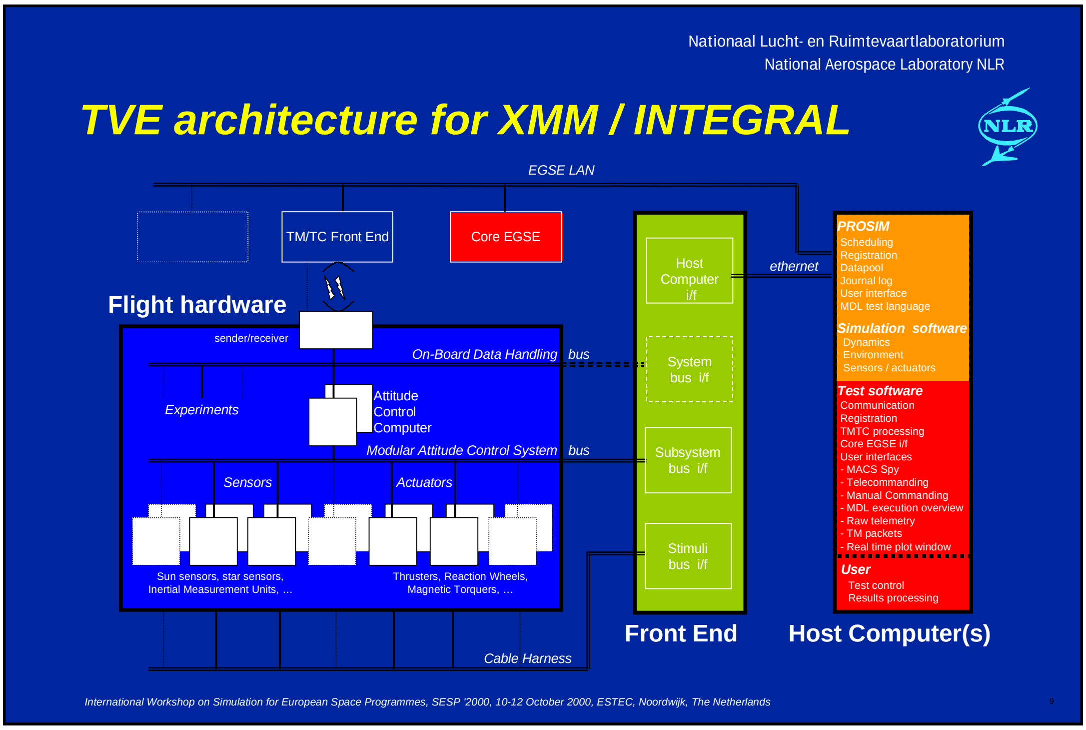
- **Currently no seamless transition between developments**
- **In phase C/D both *simulation* (phase A/B) and *operation* (phase E) tools are needed**
- **Re-use will be facilitated by using common tools for TVE**

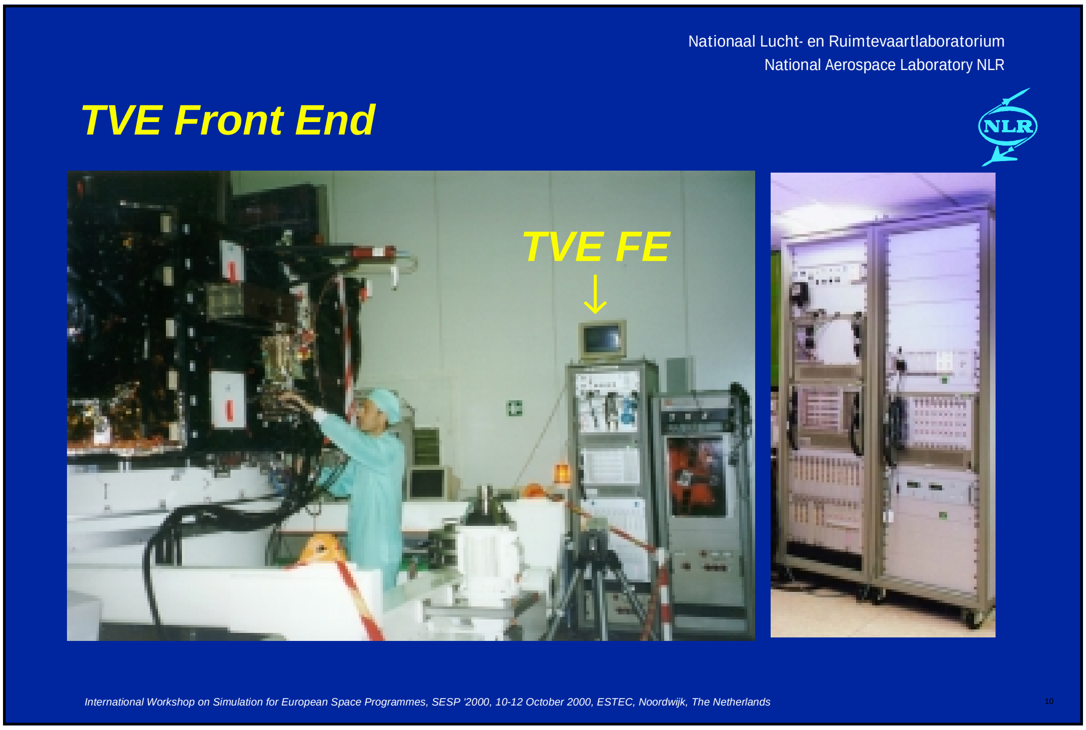
Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

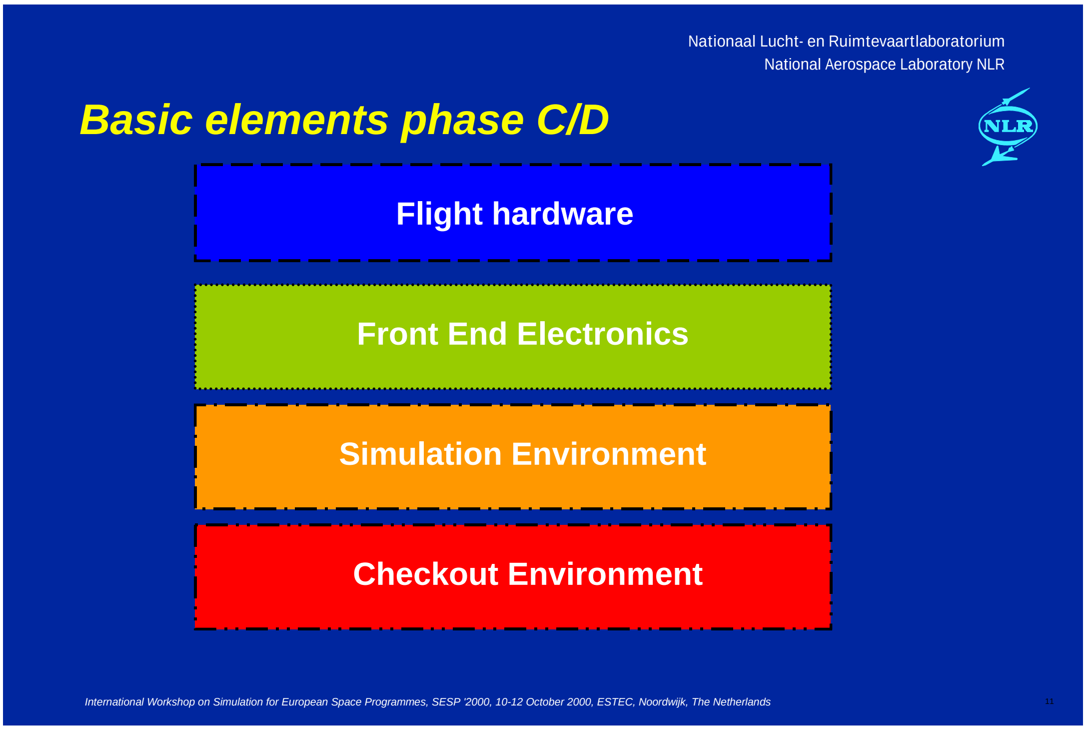
NLR history in Test and Verification

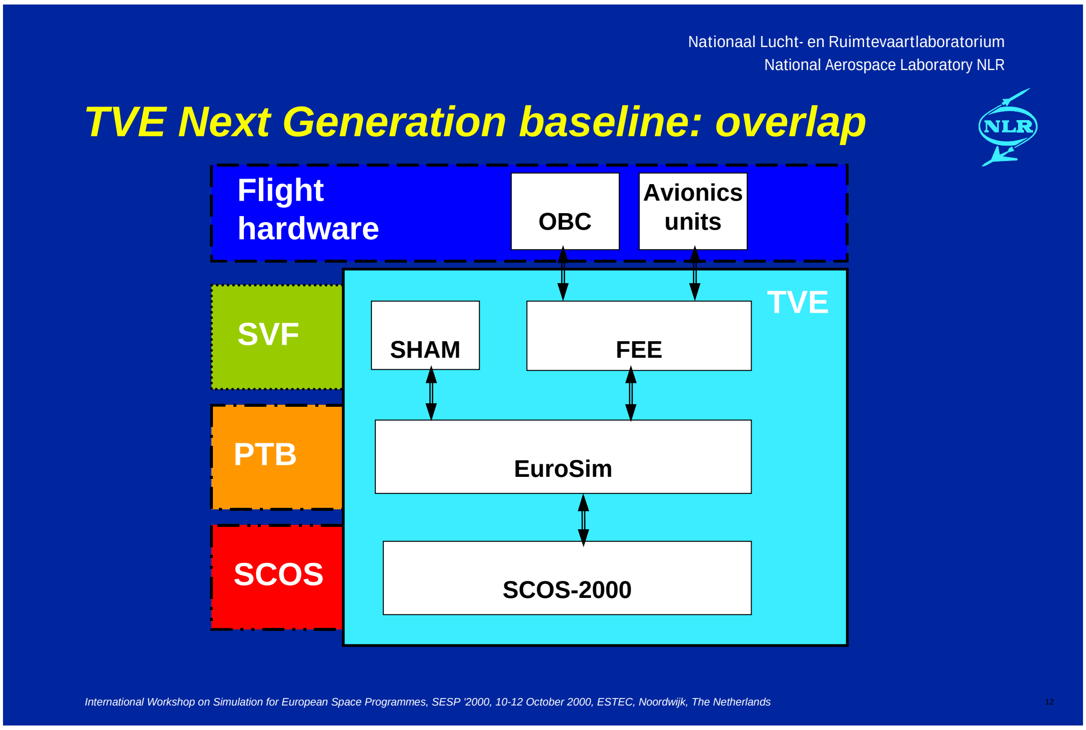
- **First generation 1985 - 1992**
  - MACS TSA — Test and Simulation Assembly for ESA-ESTEC
  - ISO — TSA for Fokker Space and Aerospatiale
  - SOHO — TSA for ESTEC-ESA
  - SAX — TSA for Fokker Space and Alenia Spazio
- **Current generation 1993 - 2001**
  - TVE — Test and Verification Equipment for ESA-ESTEC
  - XMM — TVE for MMS-UK and DASA-Dornier
  - INTEGRAL — TVE based on XMM for MMS-UK and Alenia Spazio
- **Next generation 2000 - ....**
  - new developments ...

International Workshop on Simulation for European Space Programmes, SESP '2000, 10-12 October 2000, ESTEC, Noordwijk, The Netherlands


Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR
TVE architecture for XMM / INTEGRAL
EGSE LAN
TM/TC Front End
Core EGSE
Flight hardware
sender/receiver
On-Board Data Handling bus
Experiments
Attitude Control Computer
Modular Attitude Control System bus
Sensors
Actuators
Sun sensors, star sensors, Inertial Measurement Units, ...
Thrusters, Reaction Wheels, Magnetic Torquers, ...
Cable Harness
Host Computer i/f
System bus i/f
Subsystem bus i/f
Stimuli bus i/f
Front End
ethernet
PROSIM
Scheduling
Registration
Datapool
Journal log
User interface
MDL test language
Simulation software
Dynamics
Environment
Sensors / actuators
Test software
Communication
Registration
TMTC processing
Core EGSE i/f
User interfaces
- MACS Spy
- Telecommanding
- Manual Commanding
- MDL execution overview
- Raw telemetry
- TM packets
- Real time plot window
User
Test control
Results processing
Host Computer(s)
International Workshop on Simulation for European Space Programmes, SESP '2000, 10-12 October 2000, ESTEC, Noordwijk, The Netherlands


Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR
TVE Front End
TVE FE
International Workshop on Simulation for European Space Programmes, SESP '2000, 10-12 October 2000, ESTEC, Noordwijk, The Netherlands


Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR
Basic elements phase C/D
Flight hardware
Front End Electronics
Simulation Environment
Checkout Environment
International Workshop on Simulation for European Space Programmes, SESP '2000, 10-12 October 2000, ESTEC, Noordwijk, The Netherlands


Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR
TVE Next Generation baseline: overlap
Flight hardware
OBC
Avionics units
SVF
PTB
SCOS
TVE
SHAM
FEE
EuroSim
SCOS-2000
International Workshop on Simulation for European Space Programmes, SESP '2000, 10-12 October 2000, ESTEC, Noordwijk, The Netherlands

Developments overview

- **Use EuroSim as generic Simulation Environment**
- **Use and extend SCOS-2000 as generic Checkout Environment**
- **Implement new FEE interfaces to flight hardware**
- **Create EuroSim interface to SHAM**

Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

EuroSim

- **Features**
  - re-use of developed software models
    - MOSAIC for conversion of Matlab/Simulink models
    - SMP for compatibility with other simulation environments
    - HLA for distributed simulation
  - scaleable: low-end PC to high-end SGI workstation
- **TVE NG activities**
  - create real-time interface EuroSim - FEE

Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

SCOS-2000

- **Features**
  - not only *operations* but also (designed for) *testing*
  - TM/TC handling (monitor & control)
  - database access
- **TVE NG activities**
  - extend SCOS-2000 with test language capabilities
  - create interface SCOS-2000 - TVE

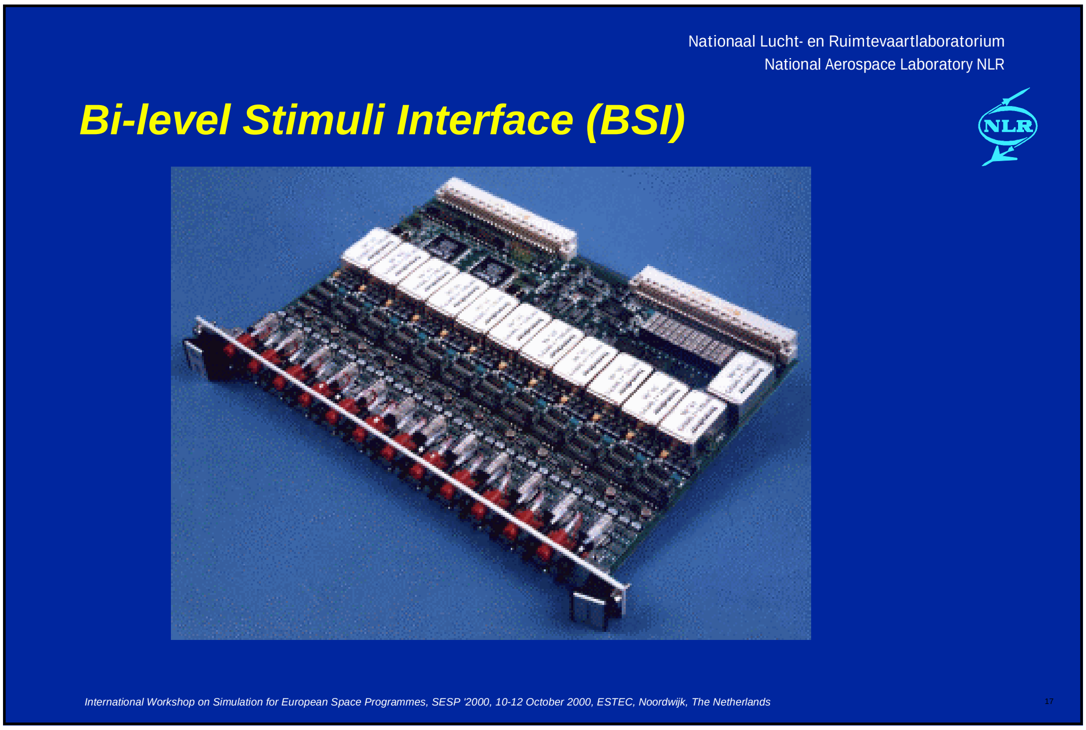
International Workshop on Simulation for European Space Programmes, SESP '2000, 10-12 October 2000, ESTEC, Noordwijk, The Netherlands 15

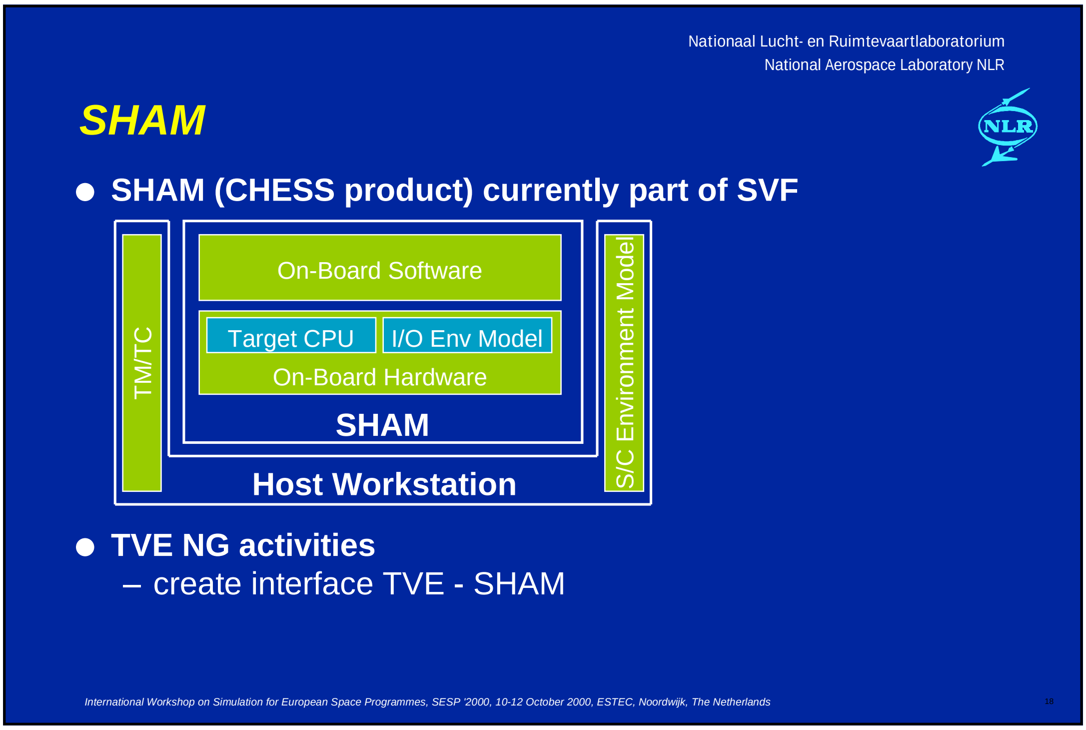
Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

Front End Equipment

- **Modular, scaleable, reliable**
  - VME crates, boards & extenders
- **Current available interfaces (OTS)**
  - stimuli & monitoring ASI, BSI, GTM, MOI
  - (sub)system data buses OBDH, MACS
  - serial interface IEEE-1355/SpaceWire
- **TVE NG activities**
  - implement data bus MIL-1553 in FEE

International Workshop on Simulation for European Space Programmes, SESP '2000, 10-12 October 2000, ESTEC, Noordwijk, The Netherlands 16


Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR
Bi-level Stimuli Interface (BSI)
International Workshop on Simulation for European Space Programmes, SESP '2000, 10-12 October 2000, ESTEC, Noordwijk, The Netherlands


Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR
SHAM
● SHAM (CHESS product) currently part of SVF
TM/TC
On-Board Software
Target CPU
I/O Env Model
On-Board Hardware
SHAM
Host Workstation
S/C Environment Model
● TVE NG activities
– create interface TVE - SHAM
International Workshop on Simulation for European Space Programmes, SESP '2000, 10-12 October 2000, ESTEC, Noordwijk, The Netherlands

Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

Conclusion

TVE Next Generation

- **implements DASIA high-level considerations**
- **re-uses tools (EuroSim, SHAM, SCOS-2000)**
- **enables re-use of results (simulation models, test procs, flight procs)**
- **has an open, scaleable and modular design**
- **stimulates standardisation of tools**

International Workshop on Simulation for European Space Programmes, SESP '2000, 10-12 October 2000, ESTEC, Noordwijk, The Netherlands

Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

Conclusion

And will **B**ridge the spa**C**ecraft **D**evelopment lifecycl**E**

International Workshop on Simulation for European Space Programmes, SESP '2000, 10-12 October 2000, ESTEC, Noordwijk, The Netherlands