EVOLUTION OF DATA MANAGEMENT
SYSTEMS FROM SPACELAB TO COLUMBUS

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Abstract:

This paper describes the evolution of data management systems, starting with the generic Spacelab design, followed by its utilization during the missions FSLP, D1, D-2, it describes the EURECA System and finally outlines the Columbus plans. It discusses the experience gained in particular from Spacelab development and mission preparation. An attempt is made to formulate Columbus guidelines respectively.

1. S p a c e l a b

1.1 General

In June 1974 an industry consortium led by ERNO won the contract for the design and manufacture of the Spacelab, the European contribution of the STS program and one of the most important, reusable Orbiter payloads.

The Modular Spacelab concept did foresee two principle flight configurations:

- a manned one with a habitable cylindrical pressure shell for accommodation of subsystems, scientific instruments, and up to three astronauts,

- an unmanned one with a pressurized container (so called igloo) for subsystem equipment and up to five pallets which expose instruments to the external space environment.

Spacelab required on orbit time was in accordance with the nominal Orbiter scientific missions duration of seven days with growth provision up to 30 days.

1.2 Data Processing Concept

Different to satellite programs realized by that time in Europe Spacelab had to provide a multipurpose reusable space laboratory satisfying a set of generic requirements derived from a multitude of experiment requirement analyses. Especially in respect to data processing no specific experiment requirements did exist.

Therefore a concept had to be found providing a maximum of flexibility for instruments interfacing the data processing resources.

Different to todays state-of-the-art a computer with acceptable data processing capabilities on one hand and being able to satisfy the unique requirements of a space-laboratory was not easy to find at that time. The task was even further complicated by the political requirement to base the concept on European technology, by which the Orbiter computer (IBM AP 101) was ruled out.

Out of several alternatives finally the French Mitra 125 MS has been selected which was based on a military aircraft computer.

The Control and Data Management Subsystem (CDMS) was divided into two assemblies,

a) for subsystem data processing,

b) for payload processing

with a maximum of commonality between the two.

This split-up provided the feature to configure and verify the subsystem portion for a particular mission independent from the payload integration process. The CDMS blockdiagram is shown in Figure 1.

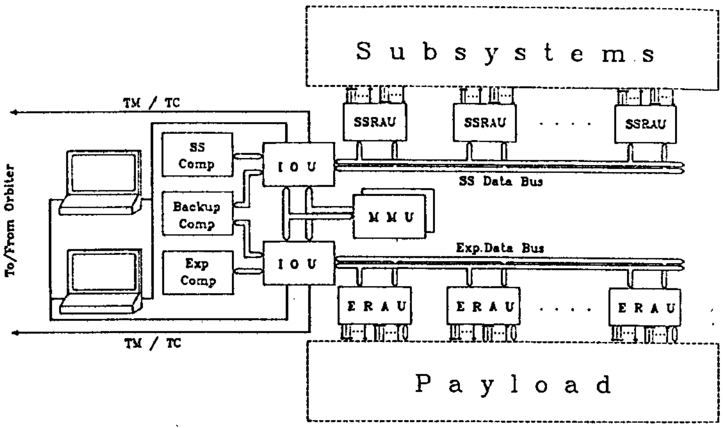

Figure 1: Spacelab Control and Data Management Subsystem (CDMS)

The central point of each CDMS assembly is a dedicated Input/Output Unit (IOU) managing the different data streams to/from the

- computer,
- Mass Memory Unit (MMU),
- Display/Keyboards (one located in the Orbiter Aft Flight Deck, the other one in the pressure shell for the manned configuration),
- Data Bus with Remote Acquisition Units (SSRAU = Subsystem Remote Acquisition Unit),
- Telemetry/Telecommand links via the RF-Equipment of the Orbiter.

The difference between the subsystem and payload section is to be found within the higher capabilities of the Experiment Data Bus and the Experiment Remote Acquisition Units (ERAU).

The major characteristics of the CDMS and its units is visualized in Figure 2.

<u>Computer</u>
Word Length: 16 bits
Memory Type: core
Capacity : 64 kwords

<u>Mass Memory</u>
Type : Tape
Capacity: 800 kwords

<u>Data Bus</u>
Clock Rate : 1 Mbps
Max. Length: 50 m
No.of RAU's: up to 30

<u>Display/Keyboard</u>
Screen : CRT, 14 inch
Type : 3 colours
Keyboard: Full ASCII

<u>Operat.System SW</u>
Synchronous with overlays

<u>Subsystem RAU</u>
Inputs : 128
Outputs : 64

<u>Experiment RAU</u>
Inputs : 128
Outputs : 64
Serial : 4 inputs
4 outputs
Time : 4 Clock
4 Update

Note:
Inputs configurable
by SW (Analog or discrete)

Figure 2: Mayor CDMS Characteristics

In course of the various project Requirements and Design Reviews the selected concept was criticized for not providing adequate payload resources and many changes were implemented as the Spacelab design matured.

The most important one was the addition of a High Rate Multiplexer (HRM with a capability of up to 48 Mbps output rate and an associated tape recorder with a capability of up to 30 Mbps input/output rate and 20 min. recording time at highest speed.

In addition the operational requirements were changed drastically upon availability of first operational analyses and scenarios leading to extensive modifications of the software concept.

1.3 Design Responsibilities

ERNO divided the Spacelab System design into several subsystems allocated to so-called co-contractors which were fully responsible for the design and qualification of their subsystem under ERNO technical supervision and management.

The CDMS co-contractor MATRA in France placed several contracts with subcontractors responsible for CDMS unit design and development. The industrial organization is depicted in Figure 3.

Subsystem qualification took place at Matra with a worst case CDMS configuration and all interfaces to other subsystems simulated as far as necessary.

In accordance with the original model philosophy ERNO should have received the individual CDMS hardware and software items as well as other subsystem units and should have integrated them into the complete engineering model of Spacelab for the first time, and the second time into the flight of model Spacelab.

However, derived from first test results on subsystem level it turned out, that too many incompatibilities would show up late, in the project schedule if this original plan would have been maintained. Therefore an <u>E</u>lectrical <u>S</u>ystem <u>I</u>ntegration Model (ESI) was introduced into the program.It covered all units from CDMS and other subsystems which were considered critical in respect to interface compatibility and functional performance.

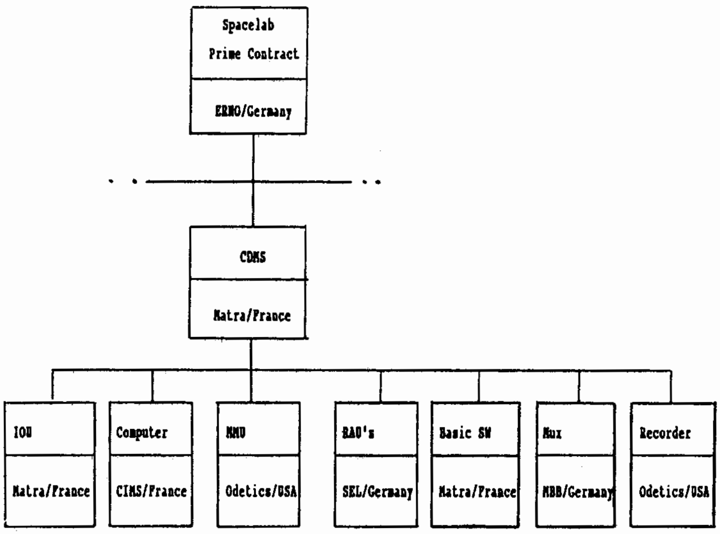

Figure 3: Spacelab CDMS Industrial Organization

This decision was not made easily as the activities for manufacturing of additional hardware and testing had remarkable effects on cost and schedule without knowing if this effort would be compensated by the results received now earlier from the ESI, instead of waiting for the engineering model integration of Spacelab.

Looking back, however, it can be stated clearly, that the ESI test results achieved were extremely important as they did allow the necessary modifications on the units to be integrated into the engineering model without causing further delays. In addition the ESI turned out later on to be a valuable facility for troubleshooting during engineering and flight model integration and even for assessment of some abnormal Spacelab flight events in Europe as all engineering hardware had to be delivered to NASA. For payload integration and testing the ESI is in usage as of today.

2. Spacelab Utilization

2.1 First Spacelab Mission

Spacelab utilization started in Europe already in 1977 with preparation of the First Space Lab Payload (FSLP) which was the European complement of the NASA MSFC Spacelab mission 1 (SL 1). This demonstration mission was devoted to basic science out of various scientific disciplines such as material science, life science, earth observation, plasma physics, solar physics, etc.

One of the most important experiment interface is the one to the CDMS because it controls: the data transmission to ground and/or storage, the commanding capabilities by the on-board crew and/or ground personnel, and the on-line monitoring capability by the on-board crew and/or the experimenter on ground. Designs of most FLSP instruments required an extensive usage of the CDMS services. In other words experiment application tasks had to be executed by the Spacelab experiment computer, extensive display requirements had to be implemented on the central display unit and telemetry data of up to 32 Mbits/sec had to send to ground. Some instruments however had Dedicated Element Processors (DEP) with an communication link to the Spacelab computer.

FSLP was data wise a very complex payload which led to a difficult integration and verification sequence. The application software had to be developed and tested by a centralized team utilizing as simulation facility with a ground version of the Spacelab MITRA computer. The requirements or this application software had to be discussed and defined between the scientists and the programmers well in advance, the actual hardware/software testing (instrument and application SW) upon completion of individual software package verification of individual software package verification. This approach extended the payload integration process and was cost intensive.

2.2 German Spacelab Mission D1

The German Spacelab Mission D1 was the first complete Spacelab mission under German mission management responsibility. The mission was dedicated to basic and applied research mainly utilizing effects resulting from absence of Earth gravity in the disciplines material research, biology and medicine.

Experience gained from FSLP led to a changed approach for the data system concept of the D1 payload configuration. Early in the process of mission definition the following groundrules were imposed on instrument design:

- minimize instrument dependance upon Spacelab subsystems to become as autonomous as practical

and

- no application software shall run in the Spacelab experiment computer.

Implementation of these groundrules, however, evolved to a great variety of instrument data management designs as shown in Fig. 4. In some cases no data interface at all was foreseen to the Spacelab computer, which constrained very much the on-line monitoring during the various test steps and during the mission itself. Another disadvantage of stringent interpretation of the a.m. groundrules was the resulting limited capability of programs and parameter sets change flexibility during the system test phase and during the mission. Only those instruments which had their programs and parameters on the central Spacelab memory were in the position to introduce changes easily during the mission.

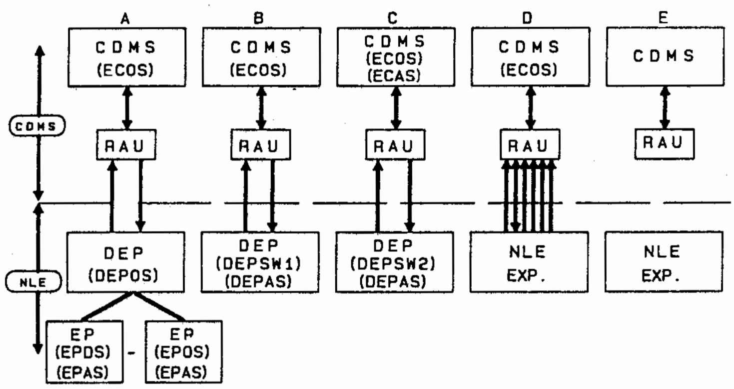

Figure 4: D1 Payloadelement Data Management Interfaces to Spacelab System

The D1 test concept was structured such that it followed the mechanical step by step build up of the payload. The goal was:

- Performance and interface verification as much as possible on the lowest integration level possible

with

- a test environment as close to the flight as possible.

The latter means, usage of flight type software and flight representative hardware for test purposes to the greatest extent practical and feasible. By this means the risk of a malfunction during the final payload verification process prior to launch at KSC was minimized, and by the way proven to be valid.

Figure 5 depicts the D1 integration and test sequence. In addition to the steps shown in Figure 5 software tests with an instrument breadboard model and a payload system software model were performed with the test payload facility at MBB/ERNO to verify early in the project schedule software interface design. This approach minimized the software problems during integrated hardware/software testing. Figure 6 depicts a typical configuration of an instrument breadboard model test.

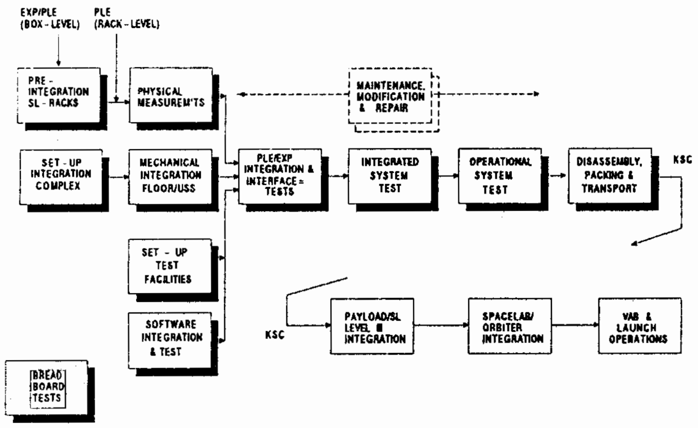

Figure 5: D1 Integration & Test Sequence

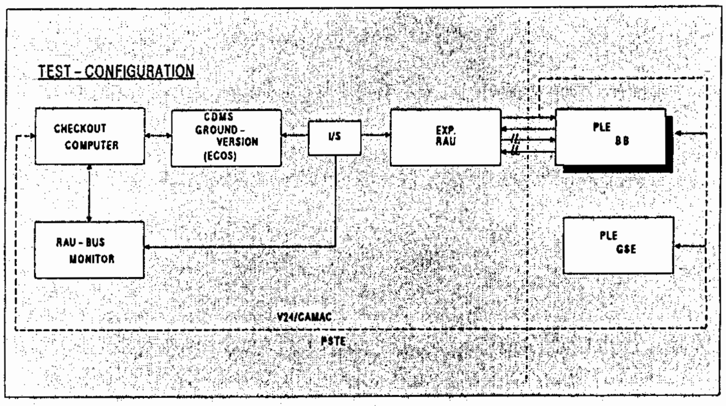

Figure 6: Typical Instrument Breadboard Test Configuration

2.3 German Spacelab Mission D-2

The German mission D-2 will be the logical next step after D1 and will be again dedicated to basic and applied research. The payload composition will be different from D1 however some of the D1 instruments will fly again. The D-2 mission is in the conceptual design phase right now, the payload configuration is not finally selected. However as far as the data management design is concerned an approach will be implemented which will take both lessons learned, FSLP and D1, into account. The now valid guidelines can be defined in the following way:

- experiment application tasks shall be executed in decentralized processors on the lowest level possible.

- instrument upstream to the Spacelab computer system the standard provided interface services shall be utilized to guarantee

  1. full transparency of experiment status to the on-board crew and ground personnel, and

  2. easy change of programs and parameter sets during test and mission.

- downstream from a dedicated element processor to individual task controllers (microprocessors) a standard serial interface shall be used (RS232) to ease software development and test and checkout.

- decentralized display capability shall be foreseen were required to ease operations. The Spacelab display shall be the backup.

A new aspect within the D-2 payload will be the image processing or video data management. Video data was available in previous Spacelab mission also, however with the CCD-technologie as of today the capabilities of installing CCD sensors at multiple locations can be extended by an order of magnitude. Within the D-2 payload several CCD cameras will be integrated within instruments to monitor experimental processes and will provide on-line the images to the scientists on ground, even in 3-D technique. The first step towards telescience will be made. MBB/ERNO is in the process of developing a CCD-camera family for STS and Spacelab application.

The D-2 test concept will follow very much the D1 approach taken, however streamlining of individual steps and upgraded user services in terms of display and quick-look processing will be implemented.

2.4 Payload Design Responsibilities

Payload design integration and systems engineering is a complex task, since not all instrument developments are the responsibility of a sole contractor. They are funded by various agencies (ESA or NASA) and/or national authorities and designed by many independent companies, in some case by the institute of a particular scientist. The only way to impose system level requirements are specifications, handbooks and guidelines defined by the system integrator and be made binding by the mission manager. Very often facts like available hardware flown on other missions, commercially available equipments etc. govern the real world and waivers and exceptions have to be granted throughout the mission preparation process.

3. E U R E C A

3.1 General

Beginning 1985 MBB/ERNO got the prime contract for the design and manufacture of the European Retrievable Carrier (EURECA).

Eureca is a platform to be put into its initial orbit by the Orbiter from where it will boost autonomously into its operational orbit to perform for half a year microgravity experiments.

At the end of the mission it will descend to the rendezvous orbit where it will be picked-up by the Orbiter again to be brought back to earth.

3.2 Data Processing Concept

Different to Spacelab MBB/ERNO was given this time also the responsibility to integrate the first payload as well as the task to ensure that adequate generic resources are available for later payloads.

Due to the overall responsibility which included mission preparation and payload integration and due to the experiences gained during Spacelab utilization, a more decentralized payload data processing has been selected. The overall platform data management, however, is more centralized, that is to say subsystem tasks and payload tasks are executed by one computer. The configuration is shown in Figure 7.

It is based on the data bus system and the Remote Acquisition Units developed for Spacelab. The new computer is equipped with the integrated CPU 80C86 and relies on the standard INTEL computer architecture (equipped with a 128 kbytes memory) and RMX based operating software.

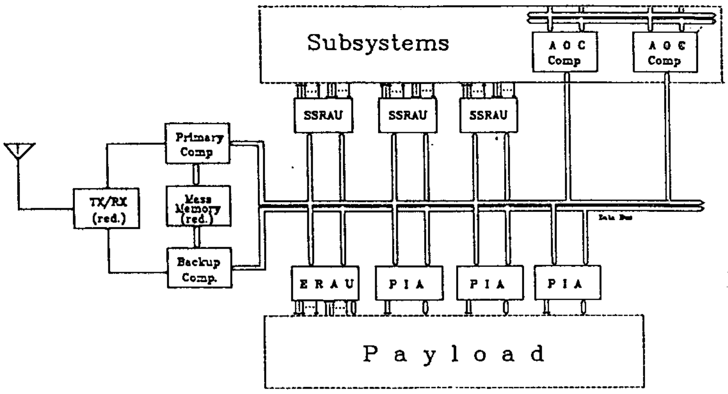

Figure 7: EURECA Data Handling Subsystem Configuration

Already during Spacelab System development it became obvious, that the future trend will go clearly towards decentralized data processing and therefore the Spacelab contract had been extended to develop a further peripheral called "Payload Interface Adapter" (PIA) allowing a more elegant data exchange between the central system management computer and the payload computers via an IEEE 488 bus interface compared to the serial RAU channels.

For program and intermittent data storage a Bubble Mass Memory with internal redundancies and a capacity of 128 Mbits will be implemented.

The Data Handling Subsystem (DHS) will perform overall platform management (incl. failure detection, isolation and recovery) and payload initialization. The specific function of attitude and orbit control will be performed by a dedicated, cold redundant computer communicating with its peripherals via its own real time bus.

3.3 Design Responsibilities

The Spacelab C/D contract covered the development of the Spacelab hardware and software only and excluded payload design integration and detailed operational analyses covering the end-to-end utilization.

As mentioned before many changes had to be implemented during the C/D phase and work-around solutions had to be found during the Spacelab utilization phase.

Set up of the EURECA contractual structure is different to Spacelab. Contract responsibility covers also payload design integration, ground segment involvement and spacecraft operations. Also the continuous discussions with the investigators developing the instruments for the first Eureca flight allow to gain a high confidence on the design and therefore a "Protoflight" model philosophy. (Protoflight means: - functional qualification with the Flight Model) will be implemented. For early Software integration and verification an Eureca simulator is used.

4. C o l u m b u s

4.1 General

Since 1983 studies were performed (initially on German/Italian initiative only) to reuse Spacelab design concepts for future programs, especially in cooperation with NASA's manned space station scenario. The results of these studies led to the decision to make Columbus one of the most important European space programs for the next decade under the leadership of the European Space Agency (ESA).

Presently the phase B2 is running to specify the concept in such a detail that an industrial proposal covering the implementation phase C/D can be submitted in beginning 1988.

The current concept foresees three flight configurations:

- A pressurized, 4-segment laboratory (double in length of the long Spacelab module) permanently attached to the ISS, shall provide basic research capabilities under continuous supervision of astronauts

- A Man - Tended Free - Flyer (MTFF) shall perform microgravity experiments during its half year unmanned operation and then being serviced/reconfigured by astronauts at the ISS or by docking with a servicing vehicle (Orbiter or Hermes),

- A Polar Plat Form (PPF) shall perform earth research in an 900 km orbit and shall descend to a lower orbit to be serviced by a servicing vehicle every 4 years.

4.2 Data Processing Concept

Concerning payload data processing the situation is quite similar to Spacelab, that is to say no specific data processing requirements can be derived from the user side.

In addition there are other requirements and constraints which will influence the data processing concept quite strongly, such as:

- On-orbit repair and reconfiguration for new payloads,

- Infinite (30 years) life time, with adequate on-orbit grow-up and implementation of improved resources as new technology becomes available and is qualified for space application (e.g. artificial intelligence).

Analyzing the requirements related to the various flight configurations it turns out that the concept driving requirements are identical and can be satisfied by a common design ,which has to be extended by man - machine related functions for the manned configurations.

The principle concept of the Columbus Information Management System (CIMS) for the MTFF, which is the most complex one, is shown in Figure 8.

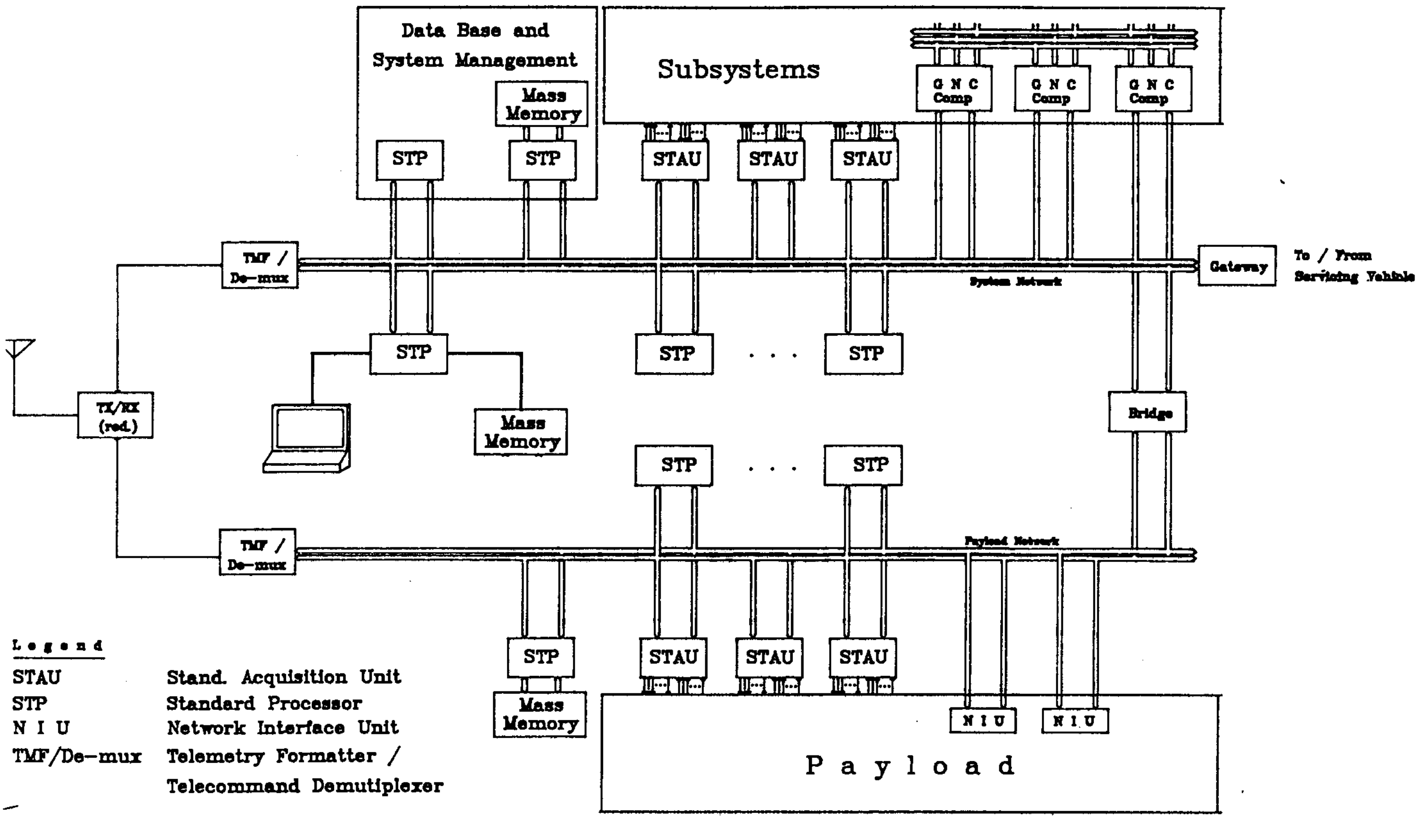

Figure 8: Columbus Information Management System (CIMS)

A fully decentralized data processing concept is proposed with an open architecture of data processing nodes connected by a Local Area Network (LAN).

Data will be gathered and distributed by Standard Acquisition Units (STAU's) comparable with the previous Spacelab RAU's but with own local intelligence for preprocessing (limit checking etc.). The main data processing will occur in Standard Processors (STP's) which can be allocated to a single, so-called "intelligent" subsystem advantageous, that is to keep complex functions isolated from others and in addition to allow independent qualification.

For the Guidance Navigation and Control (GNC) computer a standard processor will be equipped with an interface for driving a real-time bus, which is necessary to fulfill the time homogeneity requirements for precise attitude control. For the two - failure tolerance requirement 3 GNC computers and 3 busses will be provided.

The overall system management (including data base management) will be performed by the system node.

For the manned configurations a Crew Work Station will be added with display/keyboard and voice recognition and synthesis for efficient communication between crew and the system.

4.3 Design Responsibilities

For the three flight configurations covered by the Columbus program commonality and standardization is to be implemented wherever advantageous for minimization of the overall mission-life-cycle costs.

Especially for the data processing hardware and software this principle is considered being applicable. Therefore a working group has been established composed of the flight responsibility system engineers of the particular configuration under the leadership of the anticipated Prime Contractor MBB/ERNO coming up with a.m. described CIMS concept.

Due to the key role of the data processing hardware and software for the timely development of the various flight configurations and the anticipated commonality to minimize operational costs, a special responsibility scheme has been defined by MBB/ERNO, which is the implementation of a Common Subsystem Contractor (COSCO) under one contract to the Prime Contractor MBB/ERNO. This role will be given to MATRA, who will control the design and qualification of the data processing hardware and software and will deliver it as "Prime Contractor Furnished Equipment" to the companies being in charge for a particular flight configuration.

The overall system model philosophy copes for one engineering model and one flight model per flight configuration.

As mentioned above for early design assessments, software integration and qualification a Columbus Simulation Facility (CSF) is foreseen, which will be available to all Columbus consortium members, and will contain in the final implementation phase real CIMS hardware, so that all software functions can be exercised by influencing the simulation models of the subsystems which could run on a host computer as software environment.

5. Summary

The past development of Spacelab and its utilization, the ongoing development of Eureca and the present design and specification phase of Columbus with their different design concepts and responsibility distributions allow to setup some ground rules, which should be considered when planning/defining space programs.

1. Data processing concepts:
   the development of special architectures, interfaces and protocols should be avoided and performed only, if existing commercially available solutions cannot be used. The architecture design shall be such that technology progress can be accommodated efficiently.

2. Model Philosophy
   The more and more complex data processing concepts need powerful simulations not only for early testing but for in-depth and efficient assessment and monitoring of the data processing system performance. A flight model philosophy on system level will not pay off over a long utilization period of the system, since engineering models and/or qualification models can be utilized later on as perfect test beds for payloads.

3. Responsibility Distribution:
   A design responsibility structure could be set up which corresponds mirrorwise to the data processing architecture. However care must be taken to keep directly related hardware and software developments in one hand.
   User- and operational requirements change system design very often as they mature. Distribution of design responsibilities shall take this into account.