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J. Wendorff Ph.D.
OHB-System GmbH

V. Leisten
OHB-System GmbH

D. Easterly
OHB-System GmbH

European NODE 2 & 3 Space Station Contributions

J. Wendorff, V. Leisten, D. Easterly
OHB-System GmbH,
Universitaetsallee 27-29, D-28359 Bremen, Germany

1. Introduction

The International Space Station requires three Nodes for the completion of the configuration. The first of these Nodes, designed and manufactured under National Aeronautics & Space Administration (NASA) contract, has already been launched successfully and is waiting for the assembly of further elements.

As a little background, Nodes 2 & 3 were agreed to be designed and constructed in Europe in a Barter agreement between NASA and the European Space Agency (ESA) with the overall management assigned to the Italian Space Agency (ASI). Alenia Spazio (ALS) was awarded the overall prime contractor role. Necessitated by geographical return reasons within ESA programs, subsystem activities were given outside Italy even though this did not adhere to the classical role of prime contractor functions in an optimized standard program. With OHB-System winning the two major sub-contractor roles for the Secondary Structure and the Harness, we are now responsible for designing, manufacturing, and testing these subsystems for Nodes 2 & 3 in an international team approach.

Originally, Node 2 and Node 3 were planned as a rebuild of Node 1, enlarged about 1m in length, and based on existing design plus technology available at ALS from similar programs (Spacelab, SpaceHabs, Columbus & MPLM). Therefore, the Barter agreement aimed at a pure recurring program for 2 identical Nodes 2 & 3. Consequently, the schedule was very compressed from the very beginning of the project. Meanwhile, we are faced with the necessity for developing, designing and manufacturing a new Node 2 where only the outer dimensions are similar to Node 1, and an even different Node 3.

Of course, schedule constraints remain basically the same thus requiring different methods of management to comply with these project demands.

2. The “NODES 2 & 3" Project

The assembly of the International Space Station (ISS) began at the end of 1998 and 16 nations will contribute to it until its final configuration will be reached in 2004 / 2005. A total of 40 launches of the American Space Shuttle and rockets (Russian Proton and European Ariane 5) are required for delivery of ISS modules, accessories, equipment, and finally astronauts [1].

Driven by the volume available inside of the Shuttle cargo bays the main building blocks of ISS resemble cylindrical structures with docking ports at both ends. These modules of ISS have to be connected on-orbit. This requires special elements which provide two docking ports including hatches at both ends as well as 4 ports in radial directions. These special elements are called the Nodes.

In total, there will be three Nodes on ISS:

- Node 1 — “Unity” already docked in orbit with the Russian Module “Sarija”.
  With the next launch the Russian Service Module “Zvezda” will be docked to Node 1, thus providing first crew quarters, experiment facilities, and capabilities for orbit boost maneuvers. The US Laboratory Module “Destiny” is foreseen to dock to Node 1 also.

- Node 2 will be launched and docked to the opposite cone of "Destiny", thus providing ports for the European Module "Columbus", the Japanese Module "Kibo", the Centrifuge Module, and the Pressurized Mating Adapter for the Shuttle.

- Node 3 will provide further crew quarters, experiment facilities, as well as docking ports to the US Habitation Module, the Crew Rescue Vehicle (X-38), and growth capabilities for ISS.

As a consequence, the Nodes have to provide all kinds of connections and links between all other modules, namely electrical links (power, signal, data), optical links for data and video, fluid links (water, coolant, propellant), and various gases. In addition, there will be crew quarters, experiment racks, and communication facilities.

Resulting from different functional requirements as well as constraints of the Shuttles payload bay and center of gravity the Nodes 2 & 3 will be about one meter longer than Node 1.

The other components of ISS can be summarized as follows:

- Solar-Panels,
- the Canadian Remote Manipulator,
- sets of experiment pallets, and
- various additional components like air-locks, docking ports, view ports (Cupola), and small robotic arms [2].

When looking at the broad variety of press releases of space agencies as well as brochures and publications of companies involved in the ISS program, one realizes that the final configuration of ISS is still not fully defined and frozen. With so many elements and modules being under development and production in parallel in 16 countries, financial and technical problems as well as schedule slips dominate the real assembly sequence. However, Figure 1 depicts the present planning for the final configuration of ISS and gives a slight impression about its size and complexity [3].

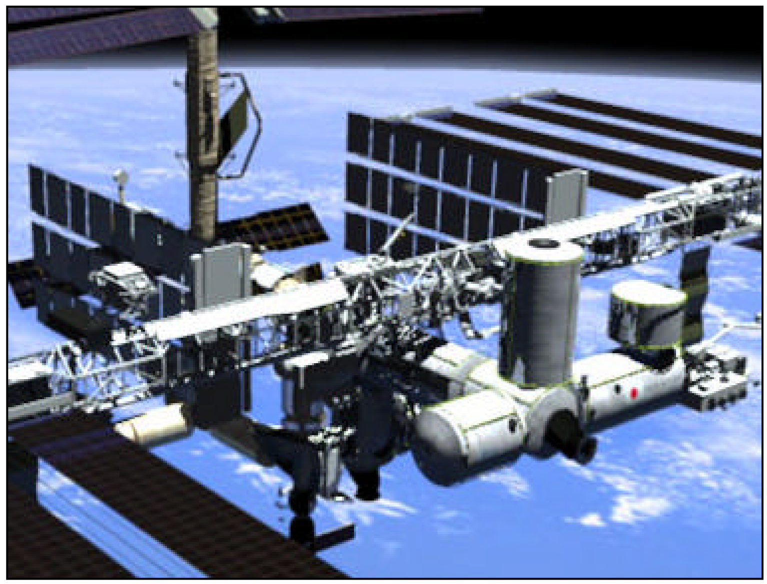

Figure 1: Final configuration of ISS

3. European Contributions to ISS

Europe's contributions to ISS can be summarized as follows:

- Design, development, and construction of the "Columbus" module by DASA, Germany. The "Columbus" module will be permanently attached to ISS for conducting of scientific experiments, research, and development.
- Design, development, and construction of three Multi Purpose Logistics Modules, "MPLM" by ALS. MPLMs are pressurized modules which carry exchangeable experiment racks. They are transported by the Shuttle to ISS and back to earth, and can be temporarily attached to ISS.
- Design, development, and construction of the Automated Transfer Vehicle, "ATV" by Aerospatiale, France. A logistics vehicle launched by Ariane 5 for uploading research and system equipment, gases and propellant, and the destructive downloading of ISS trash.
- European studies of a Crew Transport Vehicle, "CTV", leading to involvement in the X-38 demonstrator and possible participation in the Crew Return Vehicle, "CRV".
- Experiment racks like "BioLab" and "Fluid Science Lab"
- View ports "Cupola"

- Central connecting modules “Node 2” and “Node 3”. In the frame of a barter agreement ESA will pay the European companies while NASA will launch the “Columbus” module on-board of a Shuttle.

These hardware items add up to the largest space program ever initiated, conducted, and financed by the ESA member states. All of the above mentioned European elements have their specific challenges, constraints, and clues, however, this paper will focus on the special conditions and constraints of the Nodes Program.

With the awarding of the contract, ALS, Turin became prime contractor, responsible for:

· Design and Development,
· Meteorite and Debris Protection System (MDPS),
· Mechanical Ground Support Equipment (MGSE),
· Primary Structure,
· Internal Secondary Structure,
· External Secondary Structure,
· Harness,
· Integration and Test.

As several European governments contribute to the Nodes Program, they can expect a fair share in return, called the “geographical distribution”. As a consequence and a following national competition, OHB System GmbH, Germany won subcontracts for Secondary Structures and Harnesses of Node 2 and 3.
These two subsystems are closely interlinked and depend on each other. In the course of this paper we will show how the drastically changed program environment influences engineering approaches, development sequences, as well as schedule and cost.

4. Responsibility of OHB-System GmbH

As a subcontractor to Alenia Spazio, OHB-System GmbH, Bremen is responsible for design, development, and test of:

· Internal Secondary Structure,
· Electrical and Optical Harness

of Nodes 2 & 3.

Initially, the technical definition of McDonnell Douglas / Boeing for Node 1 was used as the starting point for Node 2 also. However, new and modified equipment, functions, and interfaces to the Primary Structure resulted in significant changes to this baseline. Within less than one year technical concepts for Node 2 substantially deviated from Node 1 and entered a complete re-design for all subsystems.
Subsequently, a brief description of both subsystems being under OHB responsibility will be provided.

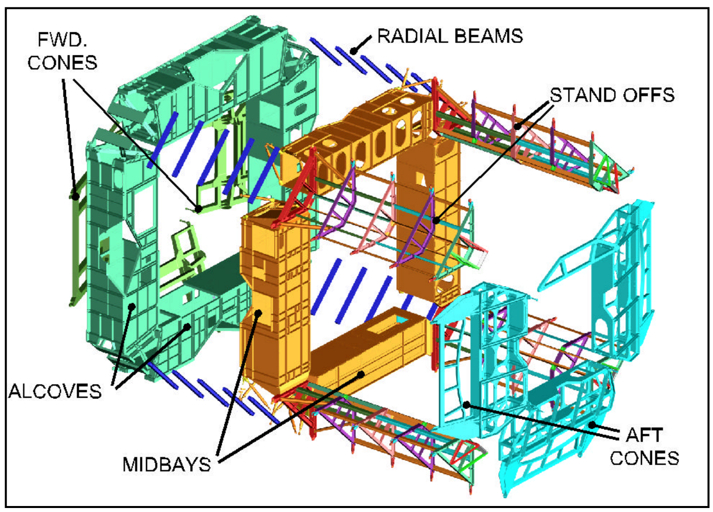

Figure 2: Major elements of Secondary Structure of Node 2

4.1. Secondary Structure

The Internal Secondary Structure comprises various mechanical elements which are mounted via bolts, joints, brackets, etc. to the Primary Structure of the Node, thus allowing moment-free coupling of Primary and Secondary Structure. This concept is needed to adapt to movement of Primary Structure interfaces caused by internal pressure variations, mechanical loads, etc.
Figure 2 provides an overview on the major structural elements of the Internal Secondary Structure.

The major elements of the Internal Secondary Structure are eight box-like structures, called Midbays and Alcoves. These boxes contain other subsystems like Life Support, Communication and Control Systems, air ducts, filters, pipe work, etc. As an example, Figure 3 depicts a typical Alcove Structure including Pump Package Assembly, brackets, Harness, and pipework.

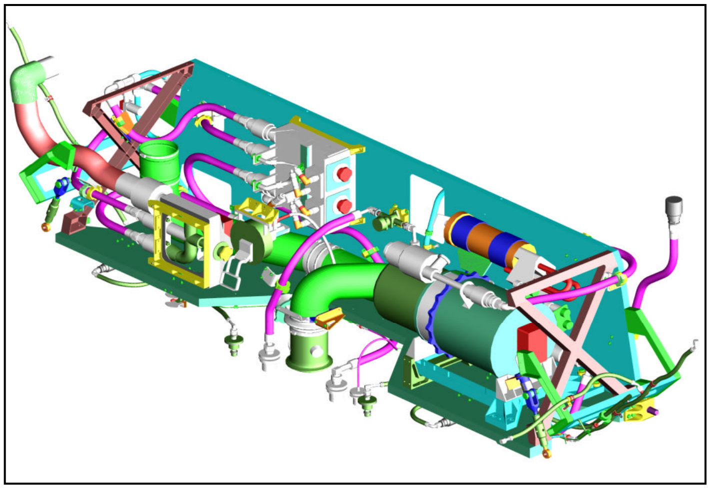

Figure 3: One of the Alcove Structures including Pump Package Assembly, Pipework, and Harness

Flat and low profile structures are used at the forward and aft cone to allow installation of small equipment as well as pipe work and Harness routed to the interface connectors to the US Laboratory and to the Pressurized Mating Adapter (PMA) for the Shuttle.

Similar support functions are provided by Stand-Offs with interfaces to experiment racks and crew quarters as well as Radial Beams with interfaces to the four docking ports and hatches.

In addition, Close-out Panels (not shown in Figure 2) are used to cover all these areas and provide smooth, homogeneous, and flat surfaces to the interior of the Node, which is the living and working area of the crew.

4.2. Harness

The second subsystem under OHB responsibility is the complete electrical and optical Harness of the two Nodes. While the electrical Harness distributes power, telemetry & telecommand signals, and data, the optical Harness is used for high speed data links as well as video signals.

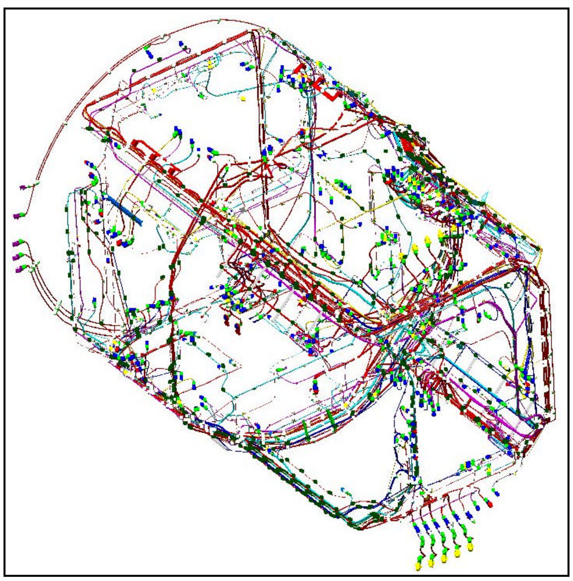

Figure 4: Complete Internal Electrical and Optical Harness of Node 2

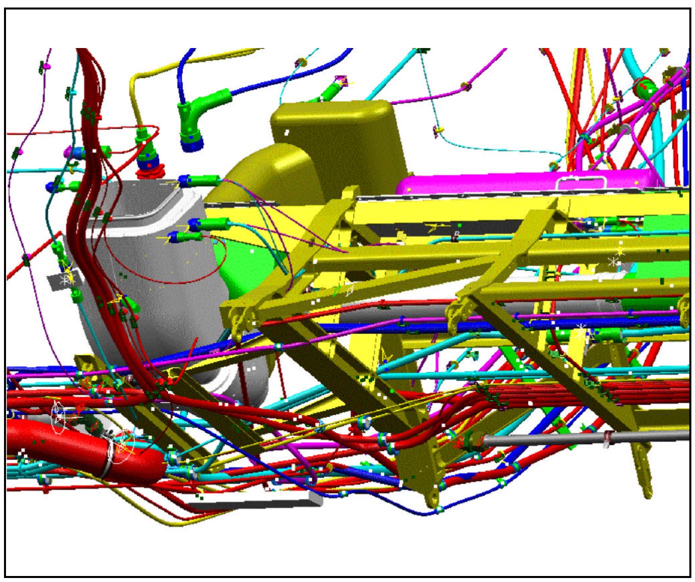

Figure 5: Snapshot, Harness Bundles in one Midbay Transition Zone and Stand-Off

In addition to the internal Harness, there will be external Harness mounted on the outer hull of the Node connecting heater circuits, sensors, and video systems.

Figure 4 gives a good impression of the quantity of the internal electrical and optical Harness (about 11,000 meters of cables and 750 connectors), its complexity, and its allocation inside of the Node.
Since the Harness has to provide connections between the various equipment located in the Node as well as between the 6 docking ports it is like a cobweb concentrated along Radial Beams and Stand-Offs.

5. Engineering Tools

The complexity of the Node 2 as well as schedule and cost constraints demand that all engineering and design activities for Harness as well as Secondary Structure are performed with Computer Aided Design (CAD) tools. There will be no mock-ups, structural test or engineering models, but a direct step-over from CAD engineering to the manufacturing and test of flight hardware.

Secondary Structure design is performed with EDS Unigraphics (UG) software and all necessary Finite Element (FE) analyses are conducted with NISA / DISPLAY III or NASTRAN.

The Harness design and 3D-routing of cable bundles is performed with CATIA E3D software. Harness designers use the actual CATIA models of Primary and Secondary Structures, equipment, pipework, and ducting for routing and fixation of cables. Physical properties of cables like diameters and minimum bending radii, connectors including backshells, and fixation elements as well as constraints resulting from integration sequence on system level and on-orbit maintenance activities can also be handled with this software.

After acceptance of 3D-models of Harness Manufacturing Units (HMUs) by ALS system configuration control, the 3D CATIA models are converted into 1:1 scale 2D-plots (formboards) on paper which can directly be used for manufacturing of the Harness.
Figure 5 shows a snapshot of one of the most crowded areas of Node 2. It should be mentioned that the area shown is only partially integrated, i.e. the real configuration comprises additional structural parts and pipework.

In order to allow merging of all CAD models by the prime contractor on system level, they have to be provided as CATIA models. As a consequence of that, STEP Processors (<u>St</u>andard for the <u>E</u>xchange of <u>P</u>roduct Model Data) using the Application Protocol AP-214 are used for both transfer of UG files to CATIA and vice versa [4].

6. Project Management

Technical aspects of Harness and Secondary Structure subsystems may be challenging and complex, nevertheless, they can be handled and solved. About two years into the program, constraints imposed by schedule and budgets turned out to be the real areas of concern.
Typical projects are conducted by using a step by step or sequential approach, i.e. activities / tasks are only started when results and outputs of their logical predecessors are available, see Figure 6. The more subsystems depend on each other the more this approach is needed.

When the barter agreement between NASA and ESA was signed, the parties agreed - more or less - on a “pure duplication of Node 1”, i.e. provision of two identical flight units called “Node 2” and “Node 3” which should be based on the already available McDonnell Douglas / Boeing documentation for “Node 1”.
Consequently, the financial envelope and schedule agreements reflected this approach very clearly:

> “The two Nodes can be done at a low - recurring - price and within a short timeframe.”

In order to meet the stringent schedule requirements several activities were conducted in parallel. Manufacturing of Primary Structure was started while detailed analyses of primary and secondary interfaces were not yet available. Harness routing was done on CATIA models derived from Node 1. In parallel to all of that the detailed design of Secondary Structures was performed (cf. Figure 6).

Having in mind the typical conditions of a recurring program everybody agreed to this approach. The political goal, short development and manufacturing times for recurring hardware will result in low cost for manpower, seemed to be achievable.

But within a few months following the formal kick-off, the Nodes project evolved into something completely different:

- Instead of being required to apply the well known ESA procedures and standards for space projects, all European companies – from prime contractor down to the humblest subcontractor – have to implement the detailed and sophisticated NASA specifications in addition.
- Lessons learned during development and assembly as well as on-orbit operation of Node 1 had caused and still cause changes to the design.
- Experiences made during development of other modules as well as requests issued by the Astronauts Office lead to additional requirements in the area of "Human Space Flight".
- While modules like "Destiny", "Columbus", and "Kibo" can be designed and developed by their national agencies and industrial consortiums quite independently, situation for the two Nodes is completely different. All other ISS modules are connected to at least one Node, i.e. changes or new requirements affecting those modules have a high probability of causing changes to the Nodes too.
- Financial constraints and deletion of the US Habitation Module resulted in a rearrangement of ISS functionality, thus imposing additional requirements on and forcing new equipment and functions into the Nodes.
- The unique contractual situation, NASA taking care of technical aspects and dealing directly with the European contractor while ESA provides the money as firm fixed budget, turned out to be both challenging and complex.

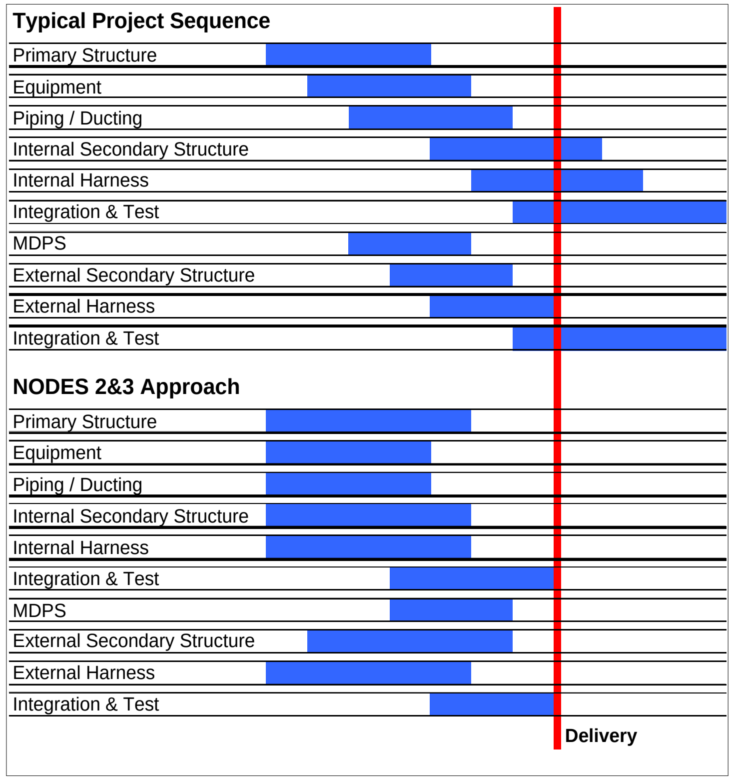

Figure 6: Typical Project Sequence versus Nodes 2 & 3 the Approach

Today, about two years into the Nodes program ISS has no longer three identical Nodes, but three with significantly different functionality, equipment, and complexity.
Consequently, the Node Program turned into a full scale design and development program for two ISS Nodes which lost nearly all commonality to Node 1 and even between themselves. - To no one's surprise, budget and delivery dates agreed on ministerial levels survived nearly unchanged.

The situation forced by the compressed schedule can be described as follows:

- Activities which continuously undergo changes and heavily depend on each other have to be managed in parallel,
- Work packages do not wait for results of their logical predecessors, but were started in parallel and have to exchange data continuously,
- Harness is routed on Secondary Structures which do not represent the final design,
- Secondary Structure elements are released for manufacturing without availability of final Harness bundles and brackets,
- Manufacturing is started prior to availability of detailed FE analyses.

While the classical projects start their work packages more or less in a sequence, the Nodes 2 & 3 work packages of Secondary Structure and Harness undergo an iterative process:

- Design work had to be started on an initial set of data and assumptions (mainly derived from Node 1),
- Design has to be corrected / adjusted - sometimes fully re-started - in between by feeding in new requirements, data from other elements and subsystems, and results of preliminary analyses,
- FE analyses have to be repeated several times, thus providing feedback instead of final confirmation of detailed design work.

As a consequence of the above, the swift exchange of information, data, and CAD files is of paramount importance for both work packages of one subsystem as well as work packages of Harness and Secondary Structure. The same applies for the interface with our customer, as depicted in Figure 7. Here the situation becomes even more complex since two different CAD systems (CATIA and UG) are used in parallel and are only linked via the STEP process.

With a typical data flow rate of several 100 MB of CAD files per week, fast data links (FTP), a strict application of configuration control tools aiming at a precise tracking of actual design status and all changes becomes mandatory.

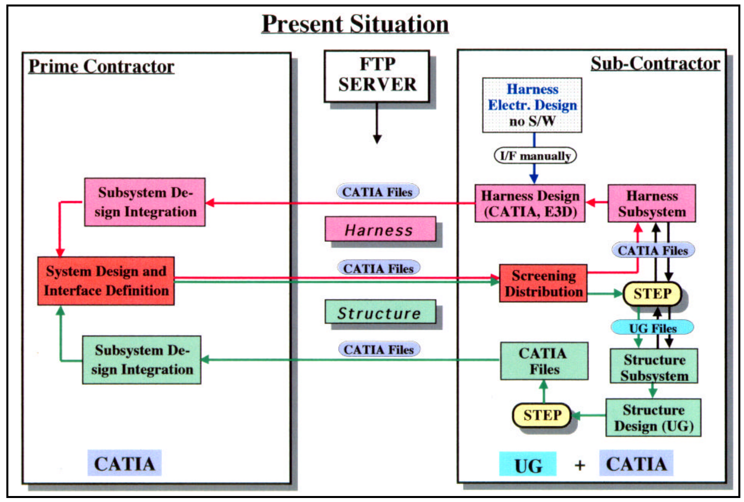

Figure 7: Data Exchange between OHB Subsystems and ALS

Parameter	Classical Project	Nodes 2 & 3 Approach
Manpower demands		
- total demand in man months	O	+
- peak demands to solve specific problems	O	++
- achievable efficiency of team members	O / +	O / -
- required skills & flexibility of personnel	O	+ / ++
- required motivation of personnel	O / +	++
Capability to achieve a short schedule	O / -	O / +
Utilization of tools		
- exploitation of mock-ups and engineering models	+	-
- necessity of CAD tools	O	++
Keeping of a stringent budget	O	O / -
Communication demands incl. performance of networks / IT		
- with customer	O	++
- within the team of one subsystem	+	++
- between different subsystems	-	++
Required efforts w.r.t. configuration control		
- during normal course of work	O	++
- for implementation of changes	+	++
Risk for duplication of work packages		
- partially	O / -	++
- completely	-	+
Embedded technical risks	O	+
Legend : - low, O average, + high, ++ very high		

Table 1 : Comparison of Requirements for, Classical Projects vs. Nodes Project

Detailed design on subsystem level and proper configuration checks on system level are only feasible if all parties use the same data base in parallel. However, running several activities in parallel and having to apply an iterative concept for each individual task may shorten the schedule but requires definitely more manpower.

Without modern communication tools (fax, email, telephone conferences, FTP, PCs and workstations for each member of the project team) the massive paralleling of tasks could not be performed. Furthermore, closely interlinked subsystems like Secondary Structure and Harness of Nodes 2 & 3 require an intensive and close co-operation of the project teams, which is luckily the case at OHB.

Project management as well as all team members have to leave the common traits of task-oriented working and have to increase communication thus respecting and implementing the various inputs and feedbacks from work packages executed in parallel.

Table 1 provides a short comparison between performance parameters of "classical" projects and the concept which had to be adopted for Nodes 2 & 3.

7. Lessons Learned

Assembly and operation of the first International Space Station turn out to be the greatest challenge to all space going nations. Stringent budget and schedule requirements demand new concepts in project management and concurrent engineering.

The classical program approach to stagger or waterfall the design activities to achieve a logical progression of the design had to be put aside. The time constraint has forced the design activities to all be performed in parallel. In principle, the parallel actions on the Primary and Secondary Structure sides lead to an optimization of the schedule, but results in more numerous changes to the Harness routing as well as Secondary Structure which, therefore, requires a higher peak of manpower.

As outlined in Table 1, the envisaged optimization of the schedule does not necessarily mean an optimization of the costs. Shorter times often imply higher costs and risks. In order to compensate for this, diverse measures and methodologies were applied. For example, the design effort for the Harness and Secondary Structure is being performed totally by 3D-CAD without any mock-ups or engineering models. Additionally, integrated test activities are foreseen for both subsystems to reduce the amount of test-time on system level and manufacturing effort of non-flight hardware.

The project management approach selected for the Nodes 2 & 3 program places high demands and requirements on all project team members.
Rapid exchange of data files between all parties involved is certainly one part of the story, but intensive, open, and co-operative communication between all team members is even more essential.

In spite of these non-standard program requirements, the Secondary Structure and Harness efforts as well as the overall Node Program, continue to make progress in meeting the presently scheduled dates for system integration and test activities at ALS.

8. Literature

[1] NN., 2004: The Space Odyssey, Space Business International, Quarter 2, 1999, 62-64
[2] NN., International Space Station Assembly Sequence, Rev.E, NASA IS-1999-06-ISS011JSC, June 1999
[3] NASA Human Space Flight Gallery, http://station.nasa.gov/gallery/, July 1999
[4] R. Schlitt, M. Alemanni, G. Willmes, W. Beuck, Initiative to Introduce STEP for CAD Data Exchange in the European Space Industry, SAE-99ES-38, in: Proc. 29th Int. Conf. on Environmental Systems, July 12 –15, 1999, Denver, Colorado, No. 1999-01-2124