– Columbus Operations –

Joint undertaking between DLR and Industry

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Columbus operation is a special challenge not only for space vehicle development, but also for deploying new operational concepts for ground support. Due to the long runtime of such a project and the related constraints new approaches are necessary to have the project alive over that long period. One new contractual and technical approach of spacecraft operation and maintenance has now been set up between ESA and the industrial consortium EADS/DLR and other major European industrial partners with regards to the ISS and Columbus program. Together with the expertise in hardware and vehicle design of EADS, DLR, one of Europe's specialists in the spacecraft operations, forms the backbone of the new operational set up.

I. Introduction

The combination of industry and agency for the operations of spacecraft is a new approach in Europe. It allows joining forces between an experienced spacecraft operator and a knowledgeable spacecraft developer to create an efficient team for this new and long term task. The main goal of this special setup is to provide a cost efficient service to the European Space Agency (ESA). It can be achieved in a close cooperation between the selected partners and a detailed harmonization of its available technical reputations, experience and knowledge. The close communication within the consortium between the vehicle development teams and the operations team results in short ways for exchange of necessary information between the involved groups. As a result, problems or issues can be addressed in an efficient way and solution strategies can be implemented within reasonable response times. In summary the development phase benefits from an early involvement of the operations people and later operations can rely on the development expertise. The operational consortium forms a community that offers an "End to End" service to the customer not only with regards to the technical processing of the project but also offers the advantage of a lean project management structure on both sides - ESA and the industrial consortium EADS/DLR. This also allows shortening the communications ways within that international project between customer and contractor and helps to solve contractual constraints.

II. ISS and Columbus Background

Columbus as one major contribution to the International Space Station (ISS) has been developed, integrated and finally made ready for launch by EADS ST as prime contractor with major European subcontractors and a broad European consortium. As a logical consequence, the same consortium is responsible for operation of the ISS element. DLR as prime contractor for Col-CC development is now one of the major partner for the industrial operations contract.

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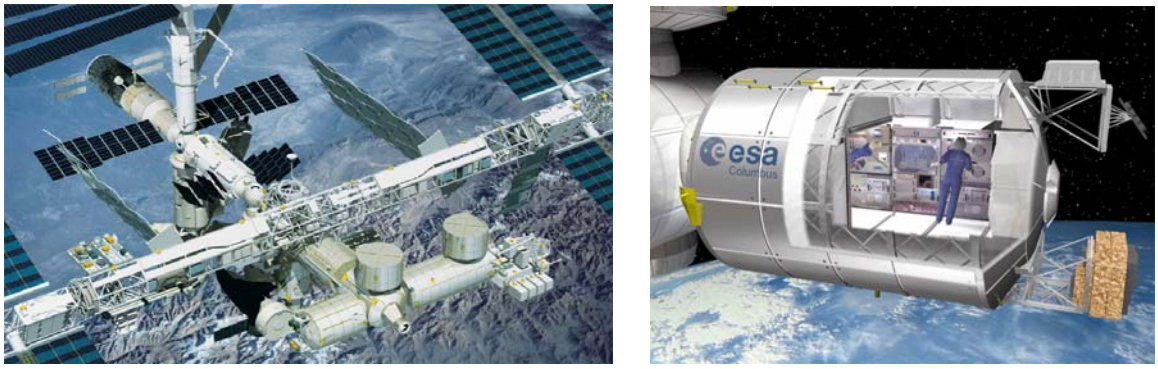

Fig. 1: ISS Overview and Columbus Module

Fig. 1 gives on the left an overview on the ISS with Columbus docked to Node 2. The artist impression on the right side shows the external and internal payload on Columbus which will be coordinated by Col-CC. The current launch manifest of NASA is shown in Table 1 with the 1E launch for Columbus as the 7th planned launch. According to this schedule a launch end of 2007 can be envisaged.

ULF1.1	Discovery, STS-121
12A	Atlantis, STS-115
12A.1	U.S. Orbiter, STS-116
13A	U.S. Orbiter, STS-117
13A.1	U.S. Orbiter , STS-118
10A	U.S. Orbiter, STS-120
1E	U.S. Orbiter

Table 1: Current STS Launch Manifest

III. IOT Setup

After reaching the final phase of development, design and manufacturing and testing of the major European ISS elements like Columbus, ATV and ERA, ESA has decided to hand over the operation of the European elements to an Industrial consortium led by EADS ST. This new setup allows joining forces between different discipline like payload development and integration, Engineering support, Planning, Training and Operations. The structure of the Industrial Operator Team (IOT) is shown in Fig. 2.

The following provides an overview of the programme and company organizations involved in the ISS operations programme, i.e. the ISS operations services, covering

- Preparation and execution of the Columbus assembly mission and start of nominal Columbus module and Columbus P/L operations
- ATV JV Crew Training, cargo integration and communications support by Col-CC and IGS network of Jules Verne Mission
- Conduct Long Duration Mission and interim utilisation
- Support ESA P/L's in increment preparation and operation
- ATV production program.

ESA is the customer for the integrated ISS Services and will exercise its overall management responsibility w.r.t

- Overall Program and Mission Management
- Strategic and Tactical Planning
- Interfaces to International Partners

- Program oversight of real-time operations
- Final signature of the Certification of Flight Readiness (CoFR) document
- USOC Management (Contract) and Resource Planning
- Crew medical support
- Astronaut coordination and support
- Overall management of commercial utilisation business development

The overall management responsibility means that ESA is defining the requirements for the operational programme including:

- Definition of the ESA ISS Utilisation Programme
- Definition of Mission and Increment Requirements (IDRD/IRD), including mission operations and ground segment requirements - supported by IOT
- Increment Training Requirements Document (ITRD)
- Multilateral Increment Training Plan (MITP)

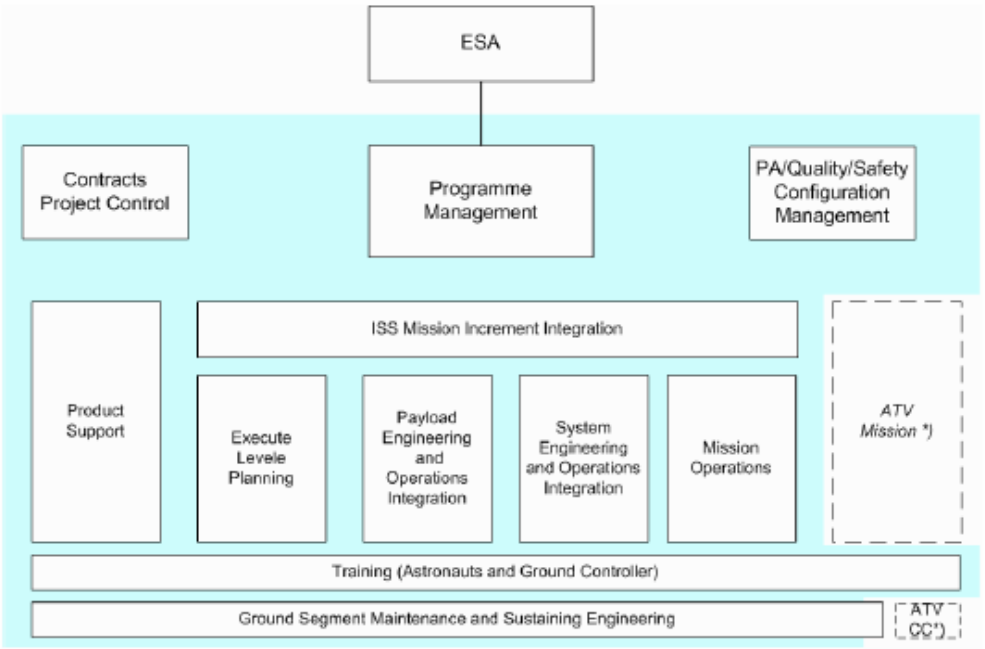

Fig. 2: Structure of the IOT

The "sub services" interrelation is shown in Fig. 2. The ISS Exploitation Contract which has been established between ESA and IOT consists of the following elements:

- The programme level will provide a team that integrates the sub services into an end-to-end service to ESA. This Team includes further key technical management functions and is composed by senior engineers and managers with skills in the various technical disciplines.

- On system level this team will provide an oversight of the individual sub services and management of the interfaces between them. They will retain the responsibility for all activities and the overall requirements, budgets, and processes towards the customer and will provide the technical and managerial capability to manage within the end-to-end service priorities, technical issues, and risk.

- The PA/S and CM managers are responsible for a consistent implementation of the PA and CM requirements and overall processes for the ISS operations services programme. They manage as well system level boards, such as the MRB and support the technical change processing. The individual CM and PA effort for the sub

services is provided within the related WPs, in some cases, e.g. Mission Operations they provide the system level support to the IOT WP Manager. The result is the provision of an integrated service to ESA.

- In terms of overall scheduling and preparation of the increment the ISS Increment/Mission Integration sub service assumes a lead function for the overall process. This is assured by the appointed manager(s) for the increment and/or mission, the integrated schedule, blank books, and the appropriate engineering capability. They will detail the IRD/IDRD and provide detailed requirements via the Increment Integration Plan to the other sub services.

- On the sub service level one manager has been appointed per sub service who shall assume full responsibility for his/her task. The team structure identifies individual work packages or office functions to integrate and manage the work. Interfaces between the sub services shall be handled by the individual sub service managers. The tasks of the various subservices are described below.

The Industrial Consortium implements an integrated Service to ESA to provide the tasks and functions required to implement the agreed mission scenario. The Management service will organise the individual sub services and integrate the service to the customer. The service will include the following elements:

- Management of the end-to-end service and of the individual sub services
- Management of Interfaces to Customer
- Support to USOCs (support to ESA and agreed technical tasks)
- Support to ESA for International Partners' interfaces
- Management of sub-contractors and service providers
- Conflict resolution on industrial level
- Risk management

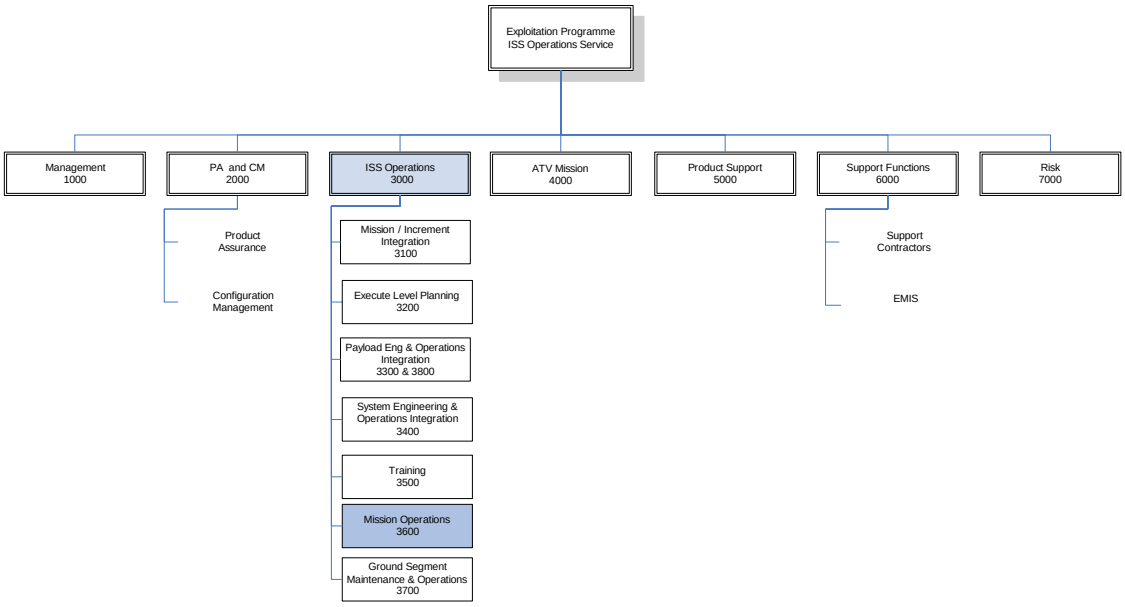

Fig. 3: The WBS of the ISS Exploitation contract including the Mission Operations Service

Fig. 3 shows the WBS of the ISS Exploitation Service including the services described above. The tasks of the ISS operations sub services for ISS operations are as follows:

- Mission/Increment Integration
  The Increment/Mission integration sub service has the lead for overall scheduling of the preparation for an increment. As such they will assume a project management role for preparation of the

increments and/or missions. They will work with the other sub service managers to assess feasibility and technical implementation.

- Execute level Planning
  Execute Level Planning works with all entities of the ISS operations programme to collect the ground rules and constraints. They interface to ESAs tactical planning process and provide inputs. They receive the mission objectives by ESA through the definition of the utilisation scenario and interact with the MII team, Col-CC and USOCs. The planning process is coordinated with ESA through the MCCB, for real time operations they will report to the Flight Directors.
- Payload Engineering & Operations Integration
  The Payload Engineering and Operations Integration Sub Service interfaces with all other organisations. They provide inputs to the planning process, procedures and databases for payload operations at the USOCs, support the USOCs for integration activities and development of operations products and support the missions.
- System Engineering and Operations Integration
  The System Engineering and Operations sub-service has the overall responsibility for Data Integration (delivery of MDB), operations product integration and co-chair the ODF CB. They provide system software update and finally the flight tapes and provide them to the Ground Segment O&M for adaptation and installation at the various locations, including USOCs.
- Training
  The Training Sub Service provides an integrated service covering the whole increment / mission training for the European part of ISS, i.e., Crew Training (Columbus Systems, ATV and Payloads) and Ground Support Personnel (GSP) Training (Columbus systems and payload operations) including simulations. The GSP includes Col-CC Flight Control Team (FCT) and Ground Control Team (GCT), On-Site Engineering Support Team (EST), European Planning Team (EPT), Med Ops, CICs/Instructors, P/L Ops Reps (TBC), ESA OMT/MMT Reps (TBC), and USOC FCTs.
- Mission Operations
  The Mission Operations sub service interfaces with all other organizations to receive the mission operations requirements derived from the IRD and its annexes, the increment preparation and operational schedule. Based on this information, a mission operations implementation plan will be established to define in detail the mission operations activities w.r.t. mission preparation, mission execution and finally mission evaluation. This will be the basis to prepare the control centre related operations products and perform the mission.
- Ground Segment Maintenance and Operations
  Ground Segment Maintenance and Sustaining Engineering will maintain the entire ground segment developed and delivered under ESA contracts. They will further install the software and databases in accordance with the mission preparation schedule and prepare for simulations and missions.

IV. Mission Operations Service

1. Mission Operations Service Scope

The objective of the Mission Operations EtE sub-service is to ensure the mission operations management for various missions, the multiple increment operations preparation according to ESA IRD's. This includes the operational products development and validation, the conductance of multiple increment operations execution including the Flight and Ground controllers team, and the support of the post increment evaluation. The mission operations service will perform these tasks to this objective with his personnel and facilities supported by the other services.

The Mission operations sub service will contain as basic elements the following tasks:

- Management of Mission Operations service for multiple increments includes in general
  - Flight Director Office (FDO) Management
  - Approval of relevant Ops Products, and documentation of review process

- Project Management and Flight Control Team/Ground Control Team lead
- FCT teams definition, nomination and allocation according to the increment needs
- Provision of teams to the training and certification process
- Scheduling of Col-CC infrastructure usage and maintenance for mission preparation and execution activities
- Coordination with the other sub-services

- Increment Operations Preparation (for several increments in parallel)
  - Participation in the ESA controlled increment requirements definition process from Mission Operations point of view
  - Development of Mission Operations Implementation Plan (MOIP) according to overall requirements and implementation concept
  - Ops Products development, validation and maintenance including operational interface procedures and Flight Rules with the international partners
  - Training and Simulations participation defined by the Training sub-service
  - Participation of FCT in the training and certification process according to different missions needs
  - Coordination of/participation in the Col-CC related payload operations preparation activities according to increment requirements
  - Col-CC Operations validation including the integration and validation of the different operational products, the ground procedures, facilities setup, and certified teams

- Increment Operations Execution
  - Real Time operations execution in line with the timeline, and flight rules in accordance with the processes established in the increment specific Mission Operations Implementation Plan (MOIP).
  - Console shift scheme setup and shift preparation
  - Operation and operational configuration of the ground segment according to increment operational products and procedures
  - Real time payload operations coordination
  - Real time coordination of engineering support activities provided by the engineering support centre at EADS ST in Bremen
  - Initiation of and support to anomaly resolution

- Post Increment Evaluation
  - Contributions to Post Increment Evaluation Report (PIER). The mission operations service will contribute to the overall mission evaluation reports from his specific field of experience during mission execution. This will comprise the following topics:
    - keep track of actual resource usage over time in support of the Post Increment Evaluation Report.
    - In the Post-Increment phase the planners collects information and generates reports for the Post Increment Evaluation Report
    - Experience reports about operating the onboard subsystems
    - Experience about operating the ground segment
    - Proposals for improvement
    - Lessons learned and improvement proposals

1. Mission Operations Management Setup

The Mission Operations Service is one of the key elements of the ISS Exploitation Contract. The operations of the Columbus Module as well as the coordination of payload activities within the Columbus Module, the Russian and the US segment of the ISS are the task of this service. Hence, the Mission Operations service has the key role in the execution of the mission and also in their preparation.

The MOS establishes and maintains an effective project management organisation for the purpose of accomplishing the objectives of the contract. This organisation, under the direction of the integrated EADS and DLR FDO management, controls all technical activities and project resources of the Operations service's effort to ensure mission operations success.

The Flight Directors Office - collocated at Col-CC - sets up all tasks for Mission Operations Sub Service and coordinates these activities with preparation and execution of Pre-Columbus and Columbus operations on execution/increment level. To fulfil these tasks the FDO establishes close interfaces to the other services, to the IOT project management and the ESA OMT as well as to all real-time functions for performing operations. The organizational structure of the FDO is shown in Fig. 4.

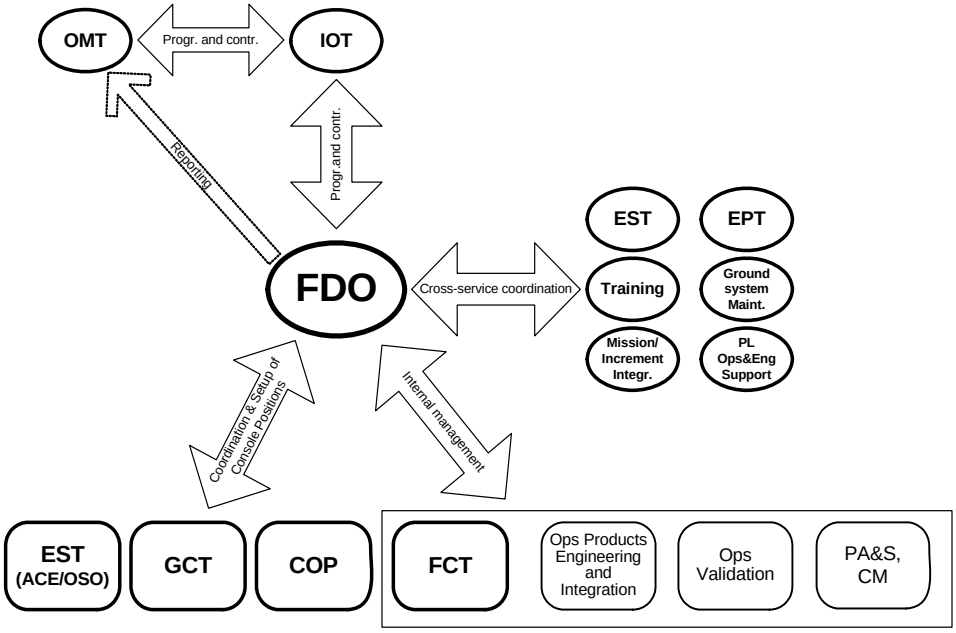

Fig. 4: The organizational relationship of the FDO

For coordination on work level the FDO sets up a weekly FDO staff meeting with following participants:

- The FDO has 2 project managers
- Flight directors are members of the FDO for Columbus mission ops tasks
  - The FD's are lead of the Flight and Ground Control teams for Col preparation and execution tasks
- Operations Leads are foreseen for Pre-Columbus Increments, LDM and precursor missions
- The lead of the Ops Products Engineering and Integration group
- Coordinator for Ground Control and ATV mission support
- Representative from the planning service
- Representative from the training service

Service-related, programmatic and contractual issues between different services are discussed and agreed in regular service overlapping management meetings.

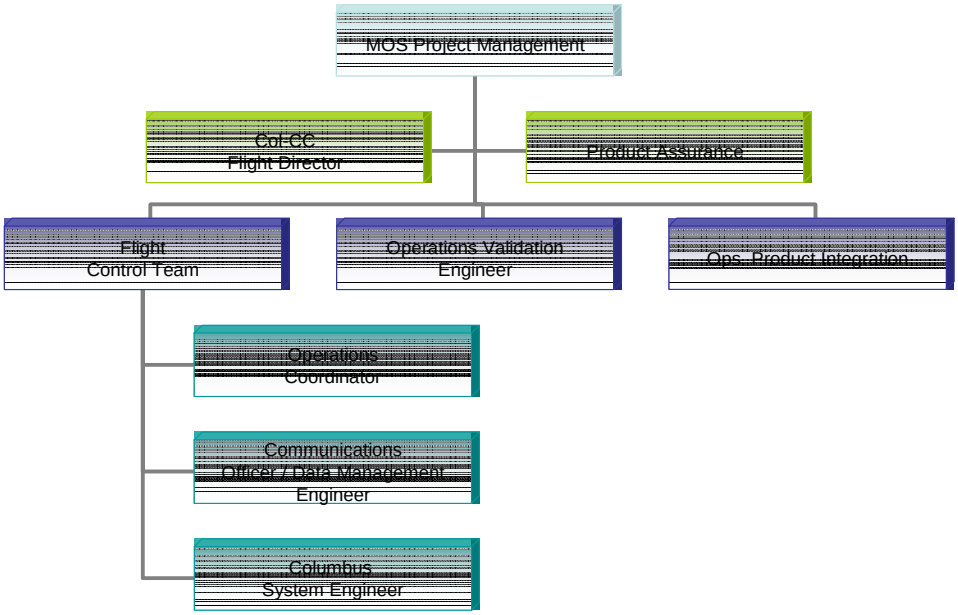

Fig. 5: The MOS team setup

As shown in Fig. 5, the FDO is directly managing

- the Flight Control team both for ops preparation and for mission execution tasks
- The Ops Products engineering and integration group
- The ops validation group and finally the ops related PA and CM activities

Additionally close coordination is established with the following services as shown in Fig. 4:

- The engineering support team especially for their integrated Flight Control Team members and the ACE and COSMO position which is exclusively foreseen for 1E or special cases during nominal Columbus mission
- The Ground Control Team which is allocated to the FOM service, but for the operational need coordinated within the FDO
- The planning team for the COP console position but also for direct coordination between the planning and mission operations tasks

V. Operational Goals

1. Interim Utilization

The ISS Utilization programme does not only comprise the Columbus element but in agreement with the international partners NASA and RKA also interim utilization. There are three increments foreseen from 2006 until 2007 in preparation of the Columbus programme, the major one is including the Increment 13 to 15 covering also the Long Duration Mission (LDM) with a German ESA astronaut on board the ISS.

This mission is the first ESA long-term mission to ISS and also the first long-term mission related to ISS which is to be supported by the Columbus Control Centre (Col-CC) in Oberpfaffenhofen, Germany. It offers an excellent opportunity to enhance advocacy for Human Space Flight through a visible role of Col-CC. Starting with Increment 13 in April 2006 the European experiments and the support of a European astronaut on board ISS is coordinated by the Col-CC flight control team. This setup makes use of the Mission Operation Service in the new frame of industrialization and puts the established ground infrastructure to operational use. The Long Duration Mission (LDM), also called Astrolab, allows gaining extensive experience in ISS payload and system operations by coordinating and supporting the execution of experiments in the US and Russian part of the Space Station as well as following major hardware assembly and maintenance activities. The main operational tasks are the coordination of

the operations between the scientific users and the European astronaut during on-orbit commissioning of payloads and the execution of the experiment programme. In addition the presence of the European astronaut allows the Col-CC team to follow MPLM operations and cargo transfer, Soyuz and Progress operations, further ISS assembly operations, Crew rotation and EVA operations.

2. Columbus Mission Scenario

The initial phase of the 1E mission will include the transport of the Columbus Module to the ISS and the subsequent berthing to the Node 2 Starboard Port. The Columbus module will be launched from the Kennedy Space Center (KSC) on-board the Space Shuttle, and is the focus of the 1E mission. The assembly tasks start with the disconnection of the Columbus module from the Orbiter Auxiliary Power Unit and incorporate all activities needed until the Columbus module is berthed to ISS Node 2. This includes the manual connection of all mechanical, electrical, fluid and data interfaces in the Node 2 - Columbus vestibule. The activation will commence upon supplying power to the module and is considered complete when the payload operations can be supported.

The activation will be performed as much as possible from ground with the crew as a backup. Columbus-CC will perform the Columbus activation as soon as possible, i.e. after the initial MCC-H commands on the hardwired interfaces.

The Routine Steady State Operations can be already started during the commissioning phase. It represents the normal operations period supporting system and payload related activities. The Steady State Phase is maintained for the majority of time during the operational life of the Columbus module. It may only be interrupted through specific events, which require the flight configuration to continue operations with reduced performance and capability. Such events can be caused by a sequence of Columbus module internal failures, or it can be originated by failures or loss of capabilities on the ISS side (e.g. thermal or power control). System and payload servicing and maintenance activities such as replacement of failed units will normally be performed within this phase. This will include pre- and post-servicing activities such as de-/re-activation and checkout.

During the Routine Operations Phase up to three crew members may work simultaneously in the Columbus module. Due to the high level of automation of Columbus system most on-board reconfiguration activities will be initiated and controlled by flight software automatically. For onboard interactive control of Columbus system and payload functions the crew is supported by the Columbus Portable WorkStation (PWS) and US Portable Computer Station (PCS). To prevent unnecessary loading on the busy crew, the ground teams will perform routine control tasks whenever possible such as control for system and payload operations. Columbus-CC will provide various reporting mechanisms to inform ESA, NASA and other participants regarding Flight and Ground Segment Operations preparation and execution progress, status and performance. On top of real-time reporting via voice loops, the reporting activities will be performed on a daily, weekly, post flight and post-increment basis.

VI. Conclusion

The Columbus module is the next major milestone for the European human spaceflight programme. With the activation and checkout of the module after launch and docking to the International Space Station during mission 1E the Columbus Control Centre will be responsible for the operations of Columbus under ESA contract. To prepare for this long-term task industry and DLR have joined forces and prepare themselves for a successful launch and activation end of 2007. It is foreseen that Columbus will be commonly operated by industry and DLR for several years and provide a unique research opportunity in space for the science community. The experiences gained during this long term operations could be brought in further human spaceflight activities in the next decade.

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