ESA ASTRONAUT TRAINING FOR ISS - LESSONS LEARNED FROM TWO YEARS OF COLUMBUS ON-ORBIT OPERATIONS

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ABSTRACT

First a general introduction of the International Space System ISS, the ISS operation and the European Columbus module is given. Then an overview of the process of ISS crew training development and implementation is presented, focussing on the ESA Columbus Systems Training. The specific challenges of astronaut training and the various training tools and facilities will be introduced. The "lessons learned" from more than 2 years of experience with Columbus on-orbit operations and the feedback from returned ISS crew members will be discussed. It will be shown how this information is currently used for the training restructuring and improvement of the ESA ISS crew training.

1. The ISS & Columbus

The Columbus module is one of the main contributions of the European Space Agency (ESA) to the International Space Station (ISS) as depicted in Figures 1 & 2. The other main European contributions are the Automated Transfer Vehicle ATV and the European Payloads. Columbus was assembled and tested in the integration hall of Astrium Space Transportation GmbH in Bremen, Germany, which is the Columbus prime contractor of ESA.


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FIGURE 1. Current ISS Configuration (September 2009)

FIGURE 2. ISS Components
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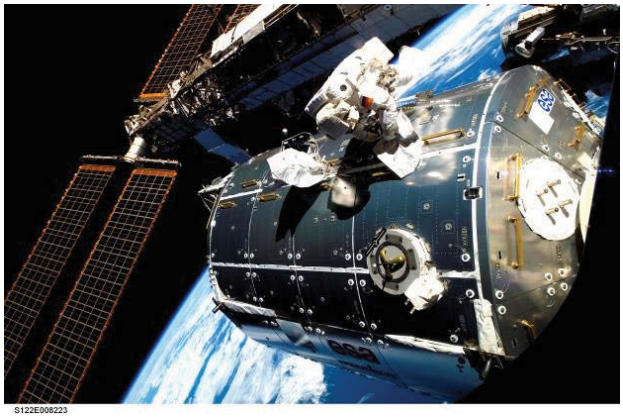
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FIGURE 3. ESA astronaut Hans Schlegel working EVA on the Columbus module during the 1E mission (Photo: ESA)

Columbus was launched as mission 1E on February 7., 2008 by the US Space Shuttle STS-122 (Figure 3). The Columbus module provides the infrastructure for scientific research - either manned or unmanned. Up to 3 crewmembers can work in Columbus simultaneously (Fig. 4). The Columbus systems enabling this are accommodated in both end cones of Columbus, the upper and lower stand-offs and in three deck racks (Fig. 5 + 6).

The Columbus module is four International Standard Payload Racks (ISPRs) long and can

accommodate 16 rack locations: 10 racks are used for PayLoads (P/Ls), 3 for subsystem racks and 3 for stowage. Five P/L ISPRs can be utilised by ESA and 5 by NASA. The respective locations of the racks can be seen from Figure 5.

Furthermore Columbus offers 4 external locations on the External Payload Facility (EPF) for additional P/Ls which require exposure to outer space (see Figure 4).

FIGURE 4. Columbus Module

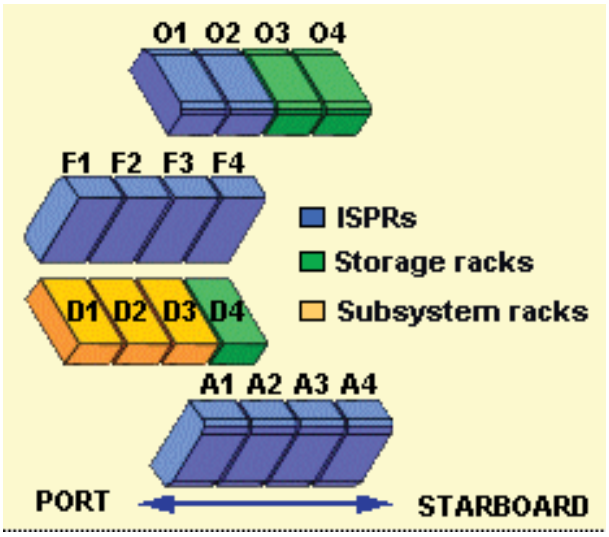

FIGURE 5. Distribution of racks in Columbus

FIGURE 6. Columbus Cabin in June 2009 during Condensate Water Separator Assembly Maintenance (Photo: ESA)

Columbus is approximately 8 m long and 4.5 m in diameter and has a maximum in-orbit mass of about 21.000 kg.

As of May 2010, the following payloads are installed in Columbus:

- 4 European payloads: Biolab (in rack position A2), European Physiology Module (in A3), European Drawer Rack (in F1) and Fluid Science Lab (in O1) and

- 4 US payloads: Human Research Facility 1 (in F4), Human Research Facility 2 (in A4), Material Science Glovebox (in F2) and the Express Rack 3 (in A1). In addition there are some so called centre aisle P/Ls accommodated in Columbus.

All resources for operating Columbus are provided by the ISS. Power is provided by the US Orbital Segment (USOS) at a voltage of 120 V and distributed and converted to 28 V by the Columbus Electrical Power Distribution system. Nitrogen is provided by the USOS as well and distributed by the Environmental Control and Life Support System (ECLSS) of Columbus to the 10 ISPRs and the Columbus Thermal Control System (TCS). Furthermore respiratory air is delivered to the Columbus ECLSS. The USOS Active External TCS provides the essential heat rejection function to the Columbus TCS. Columbus also provides voice and video services to the crew via its

Communication System (COMMS). Downlink and uplink of data and commands is provided using the USOS assets. All the commanding and monitoring of the Columbus systems and P/Ls is managed by the Columbus Data Management System (DMS) in cooperation with the US Command & Data Handling (C&DH) system.

The crew can operate the systems and potentially the P/Ls via a station common laptop configured with Columbus specific software - the Columbus Portable Workstation (PWS). For certain, i.e. vital tasks the crew has to use a US Portable Computer System (US PCS) laptop.

2. ISS Operations Organisation

The European Space Agency (ESA) together with European countries and industry established an industrialisation concept for efficient and affordable long-term operations and utilization of the European contributions to the International Space Station ISS. Since January 2006 an integrated end-to-end service is provided by the Industrial Operator (IO) to the ESA covering all ISS operations preparation and exploitation activities [9]. Astrium Space Transportation GmbH in Bremen is Prime Contractor of this ISS Operations Service which comprises a set of sub services:

- Training
- Mission / Increment Integration
- Execute Level Planning
- Payload Engineering and Operations Integration
- System Engineering and Operations Integration
- Mission Operations
- Ground Segment Maintenance and Sustaining Engineering
- Product Support.

The IO manages all operational tasks, all interfaces between services and provides operational integration. ESA is providing overall program and mission management**,** interface to International Partners, overall program and mission management, strategic and tactical planning, program oversight of real-time operations, User Support Operations Centres (USOCs) management (contracts) and resource planning, Crew medical support and Astronaut coordination and support.

An important advantage of this single contract, integrated operations service in general is the improved and more effective interaction between the different sub services, e.g., the interaction between the Training Service and the service which is responsible for all training facilities used, the Ground Segment Maintenance and Sustaining Engineering Service.

3. ESA Crew Training responsibilities

Training of the ISS flight and visiting vehicle crews is an essential part of increment preparation and execution to ensure safe and effective operation of the key European contributions to ISS.

The ISS crew training comprises a variety of training areas, e.g. P/L, systems like Thermal Control System or Communication System, Extravehicular Activities (EVA), Robotics etc..

Crew training is a shared responsibility in the ISS program. Each partner is responsible for training all ISS crew members (NASA, European Space Agency ESA, Russian Space Agency RSA, Canadian Space Agency CSA, Japan Aerospace Exploration Agency JAXA) on their respective contributions. The entire catalogue of crew training lessons is constantly harmonized and coordinated on an International Partner level.

ESA is therefore responsible for the development, preparation, organization, and implementation of the training of all ISS astronauts and cosmonauts on Columbus Systems, Columbus Payloads, and ATV operations [2, 3, 4, 5].

Furthermore each International Partner is responsible for the Basic Training of its newly selected Astronaut Candidates: e.g., generic spaceflight and science knowledge together with general astronaut skills like flying, diving, survival, and any necessary language training (e.g., Russian). A minimum set of requirements for Basic Training has been agreed between

ISS partners. The Basic Training of a new class of 6 ESA Astronaut Candidates is just under way (see Figure 7).

FIGURE 7. New class of 6 ESA Astronaut Candidates (From clockwise from top left: Timothy Peake, Andreas Mogensen, Alexander Gerst, Luca Parmitano, Thomas Pesquet and Samantha Cristoforetti) (Photo: ESA)

The European Astronaut Centre (EAC) located in Cologne, Germany, is managing and implementing the training [6]. ESA has selected Astrium Space Transportation GmbH as the industrial prime contractor for crew training. The training is developed and implemented by a team of about 25 certified crew instructors.

Instructional Design support is provided to the Training Service by experienced experts to harmonize and ensure the quality of the training material, provide pedagogical support to the instructors and simulation officers and oversee the certification standards and guidelines for instructors and trainees.

4. Crew Training development challenges

Crew training is usually very operations oriented and hence training development is depending on the operations documents and operations products like flight displays, data files, Crew specific tools and in particular on crew procedures.

The operations documents and products are developed very late in the spacecraft development process and are often not available at the time required. The documentation available is usually design and engineering oriented.

Resulting from the situation described above Crew training needs become one of the drivers for operational products from content and schedule point of view.

4.1 Crew Qualification Levels

In general, the ISS Systems training is organized by crew roles and responsibilities at 3 different qualification levels: User, Operator or Specialist. Each Training lesson is specifically designed and marked for the relevant qualification level:

User:

- receives user level lessons only
- Safe living onboard ISS.
  The user is capable of utilizing systems/operations/payloads to the extent, which is required for safe living on-board and to achieve the individual's mission objectives. It is assumed that each system/operation/ payload is maintained and controlled by other crewmembers that have a higher level of qualification.

Operator:

- receives user and operator level lessons
- Nominal and maintenance tasks (frequent, i.e. performed more than once a year) and
- Off-nominal tasks needing quick response (i.e. within 10 minutes)

Specialist:

- receives user, operator and specialist level lessons

- Nominal and maintenance tasks (infrequent, i.e. performed less than once a year)
- Off-nominal tasks not needing quick response
- Increment specific tasks and repairs

FIGURE 8. Typical Crew Workday Onboard ISS
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4.2 Skills Based vs Task Based Training

ESA has extensive experience in manned space flight and crew training dating back from the Spacelab, D1, D2 and various Sojuz Taxi missions [1]. Nevertheless, the continuous training of a large number of students, i.e. of all ISS crew members during the next 10 years presents a new challenge [7].

For short term missions like Space Shuttle the approach of Task Based Training can be applied: there is a limited number of well known crew tasks and so each individual crew task can be trained in very detail. For such short mission times crew can work in two shifts of 12 hours each with a very packed schedule.

For longer missions, i.e. several weeks or months like ISS, there is a very large number of potential crew tasks. Furthermore not all crew tasks can be planned several weeks in advance. Unexpected tasks may come up at short notice. Consequently, the approach of Skills Based Training has to be applied: as it is not possible to train each one of the numerous potential tasks, the training focuses on providing the generic skills to the crew required to handle the various tasks which are scheduled and those which may come up during their stay on the ISS [8]. To not overstress the crew during such long mission times, the working schedule is based on a regular 8 hours daily schedule with sufficient recovery and physical work out times, as depicted in Figure 8.

Developing of crew training is a strictly formalised process with several review points and lesson material update loops, dry runs and Training Readiness Reviews. This process ensures highest possible quality of the training material as well as verification of technical correctness and instructor readiness to teach the lesson. As a result, this process is very time consuming.

Nominally Columbus systems operate autonomously, supervised by the ground, enabling the crew to concentrate on performing science. Nevertheless certain tasks require procedure based crew intervention, like e.g. maintenance tasks like the replacement of H/W components (e.g. a filter).

4.3 Crew Procedures

Crew procedures are defined as a collection of steps or actions which are required to accomplish a given task. There are different types and classes of procedures for different purposes, e.g. Activation/De-activation, nominal, malfunction, and corrective procedures. Manual Crew Procedures (MCP) will be executed with the help of genuine hands-on activities - like e.g. cleaning or exchanging a filter. Integrated/Multi-Element Procedures are for off-nominal events like emergencies. They will be carried out via the US PCS or the ground and contain portions, i.e. individual commands for Columbus - addressed to the nominal and / or vital layers. Subsequently they require cooperation and communication between ISS and Columbus.

The crew procedures are the foundation for the Columbus systems training development. The skills based training uses selected procedures only. The selection of the procedures which are trained needs to be done in a way that the crew acquires all the skills necessary to handle the entire set of procedures.

4.4 Crew Training Boundary Conditions

Increasing the ISS crew from 3 to 6 astronauts presented a new challenge for crew training. Several goals have to be reached when training a 6-Person Crew:

- Reduce costs significantly
- Reduce loads on the training resources and personnel
- Increase crew retention and efficiency.

Simultaneously the safe operation of the ISS and Soyuz vehicles are not to be compromised at all.

In order to accomplish these goals, the former requirement of training a full 1:1 backup crew is replaced by a scheme whereby for each Soyuz launch the prime crew is backed up by another Soyuz crew, which is nominally scheduled to launch 6 months later (as the prime crew for increment x+2). So prime crewmembers and backup crew members are always trained together.

This training approach is called “Single-Flow-to-Launch”.

5. Crew Training Facilities

All training for the European Contributions to the ISS is performed at the European Astronaut Centre (EAC) in Cologne (with the exception of some multi-segment training performed at the NASA Johnson Space Centre in Houston, USA) using the following training facilities:

a) Technically well equipped classrooms

b) Computer Based Training Facility

c) Columbus Trainer Europe (Col-TRE, see Fig. 9): Simulator that provides flight like commanding and telemetry to the crew (and for GSP at the Col-CC during IS). It uses the actual flight software and crew laptops. Focus of the facility is on the commanding and S/W driven operations. It is used for crew training on Columbus systems operations and simulations (EAC stand-alone and ESA integrated simulations).

d) Columbus Mock-up (Col-MU, see Fig. 10, 11 and 12): Volumetric Mock-Up, for support of all manual crew activities during training and simulations: nominal operations, P/L training, preventive maintenance (e.g. filter exchange) and limited corrective maintenance

FIGURE 9. The Columbus Trainer Europe COL-TRE (simulator at EAC in Cologne, Germany) (Photo: ESA)

FIGURE 10. The Columbus Mockup COL-MU (at EAC in Cologne, Germany) (Photo: ESA)

FIGURE 11. Communications Training in the Columbus Mockup COL-MU (at EAC in Cologne, Germany) (Photo: ESA)

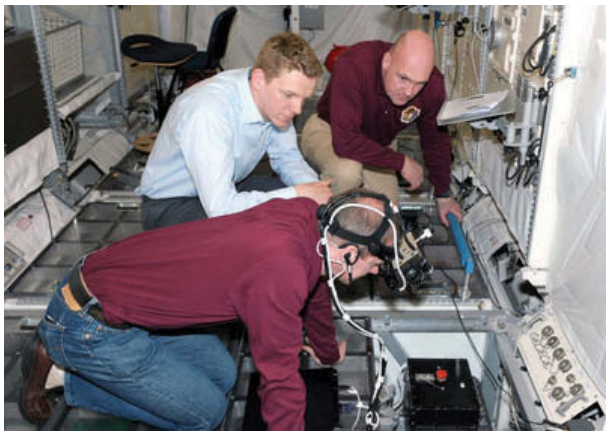

FIGURE 12. Payload Training in the Columbus Mockup COL-MU (at EAC in Cologne, Germany) (Photo: ESA)

e) Payload Training Models: stand-alone P/L models used for training of Payload operations for the 4 major ESA Payloads: European Physiology Module (EPM), Biolab, Fluid Science Lab (FSL) and European Drawer Rack (EDR)

f) Integrated Payload Models: so called 'Glass Racks' integrated into COL-TRE: a set of 3 touch screens each representing the front of the respective P/L connected to specific computers running a software which simulates the P/L operations. They are used for integrated training of Columbus and P/L operations and Integrated Simulations.

In addition, there are training facilites for Columbus training at NASA/JSC in Houston: the Columbus Trainer US (Col-TRU): a duplication of Col-TRE which is connected to the Space Station Training Facility (SSTF) at NASA/JSC to allow for multi-segment ISS training and for simulations for both crew and ground support personnel (Col-CC and MCC-H). Furthermore there is a basic Columbus Mockup attached to the Space Station Mockup Training Facility (SSMTF). The SSMTF is e.g. used for emergency training.

Within the scope of training preparation and implementation potential weaknesses in the flight S/W, the procedures, the synoptic displays and in manual H/W handling would become obvious. Since the training activities were started several years before the Columbus launch the training outcome can be used to remove any deficiencies in time. The astronaut training is a continuous source for feedback since it is performed during the entire lifetime of Columbus.

6. Lessons Learned and Ongoing Work

After more than two years of Columbus on-orbit operations and the first successful ATV launch, several ISS crews that were trained by ESA returned from their mission. They provided valuable feedback on the structure, content and effectiveness of the training based on their operational experience.

In addition, improvements in the operational concepts and in particular in the crew procedures were achieved by operational experience. Furthermore various new procedures had to be written and the maintenance concept was improved.

Based on these inputs, an evolution effort is under way to rework und upgrade the ESA crew training, i.e.

- Reduce the user level training contents and shift it to operator and specialist level training
- Condense the theoretical knowledge part of the training
- Focus even more on hands-on training of crew relevant skills
- Based on the changed set of crew procedures: re-do the selection of crew procedures used in the training lessons
- Verify that all skills required for performing each available procedure is gained within the Columbus crew training
- Stress the emergency and safety relevant Columbus aspects
- Make sure that crew still gets sufficient system understanding information to feel comfortable when working in Columbus.

SUMMARY

An essential part of increment preparation and execution to ensure the safe and effective operation of the International Space Station ISS

is the proper training of the astronauts and the ground support personnel, e.g. the Flight Control Team at the Columbus Control Centre in Oberpfaffenhofen, Germany.

With respect to astronaut training, the European Space Agency ESA is responsible for the

- basic training of its own astronauts: training of a new class of 6 ESA Astronaut Candidates is just under way
- training of all ISS crew members (from NASA, RKA, JAXA and ESA) on the European contributions to the ISS program, i.e. training of the crew operations of Columbus Systems, ESA P/Ls and ATV.

The ESA crew training is mainly performed at the European Astronaut Centre EAC in Cologne, Germany. In addition, some multi-segment training is performed at the NASA Johnson Space Centre in Houston, USA.

The European Astronaut Centre (EAC) located in Cologne, Germany, is managing and implementing the training [6]. ESA has selected Astrium Space Transportation GmbH as the industrial prime contractor for crew training. The training is developed and implemented by a team of about 25 crew instructors.

The ISS crew training comprises a variety of training areas, e.g. P/L, IP systems, EVA, Robotics etc. This paper concentrates on the training for Columbus Systems operations. In general, the ISS Systems training is organized by crew roles and responsibilities in User, Operator and Specialist Level training. Furthermore the entire training catalogue is constantly harmonized and coordinated on an International Partner level.

ESA has extensive experience in manned space flight and crew training dating back from the Spacelab, D1, D2 and various Soyuz Taxi missions. Nevertheless, the continuous training of a large number of students, i.e. of all ISS crew members during the next 5 to 10 years, presents a new challenge. After more than two years of Columbus on-orbit operations and the first successful ATV launch, several ISS crews that were trained by ESA returned from their mission. They provided valuable feedback on the structure, content and effectiveness of the training based on their operational experience. In addition, improvements in the operational concepts and crew procedures were achieved by operational experience. Based on these inputs, an evolution effort is under way to rework und upgrade the ESA crew training.

The “lessons learned” from more than 2 years of experience with Columbus on-orbit operations and the feedback from returned ISS crew members are e.g. ‘condense the theoretical knowledge part of the training and focus more on hands-on training of crew relevant skills’, ‘stress the emergency and safety relevant aspects’, ‘make sure crew still acquires sufficient system understanding to feel comfortable’.

REFERENCES

[1] E. Messerschmidt, J.-P. Haignere, K. Damian, 10 Years of the European Astronaut Centre (EAC), ESA bulletin 104, November 2000, 109-115

[2] H. Bolender, L. Bessone, A. Schoen, H. Stevenin, Training ISS: First International Astronaut Class Trained at EAC, on station no. 11, December 2002, 12-13

[3] P. Eichler, M. Teichwart, A. Schön, E. Khanina, Crew Training for the First ATV Mission, SpaceOps 2004 Conference, paper 312-158

[4] H. Bolender, J.-F. Clervoy, A. Schoen "ATV Ahoy! - Crew Training for the First ATV" on Station no. 86, November 2004, 16-17

[5] N. Illmer, BIOLAB Crew Training. In: ESA (Editor): ESA Scientific Publications - Proceedings of the "Life Sciences Symposium" 2005, SP 585

[6] K. Damian, M. Tognini, The European Astronaut Centre - A look back at 15 years of astronautical expertise, ESA bulletin 123, August 2005

[7] M. Aguzzi, R. Bosca, U. Müllerschkowski, Astronaut training in view of the future: A

Columbus payload instructor perspective, Acta Astronautica, Vol. 66, Issues 3-4, February-March 2010, Pages 401-407

[8] Prof. Dr.-Ing. Wilfried Ley, Prof. Dr. rer. nat. Klaus Wittmann, Prof. Dr.-Ing. Willi Hallmann (editors), Handbook of Space Technology, ISBN-10: 0470697393, bublished by John Wiley & Sons, 15. Juni 2009

[9] P. Eichler, A. Bade, The Integrated End-to-End Service for ISS Crew and Ground Support Personnel Training, SpaceOps 2006 Conference, paper 56727

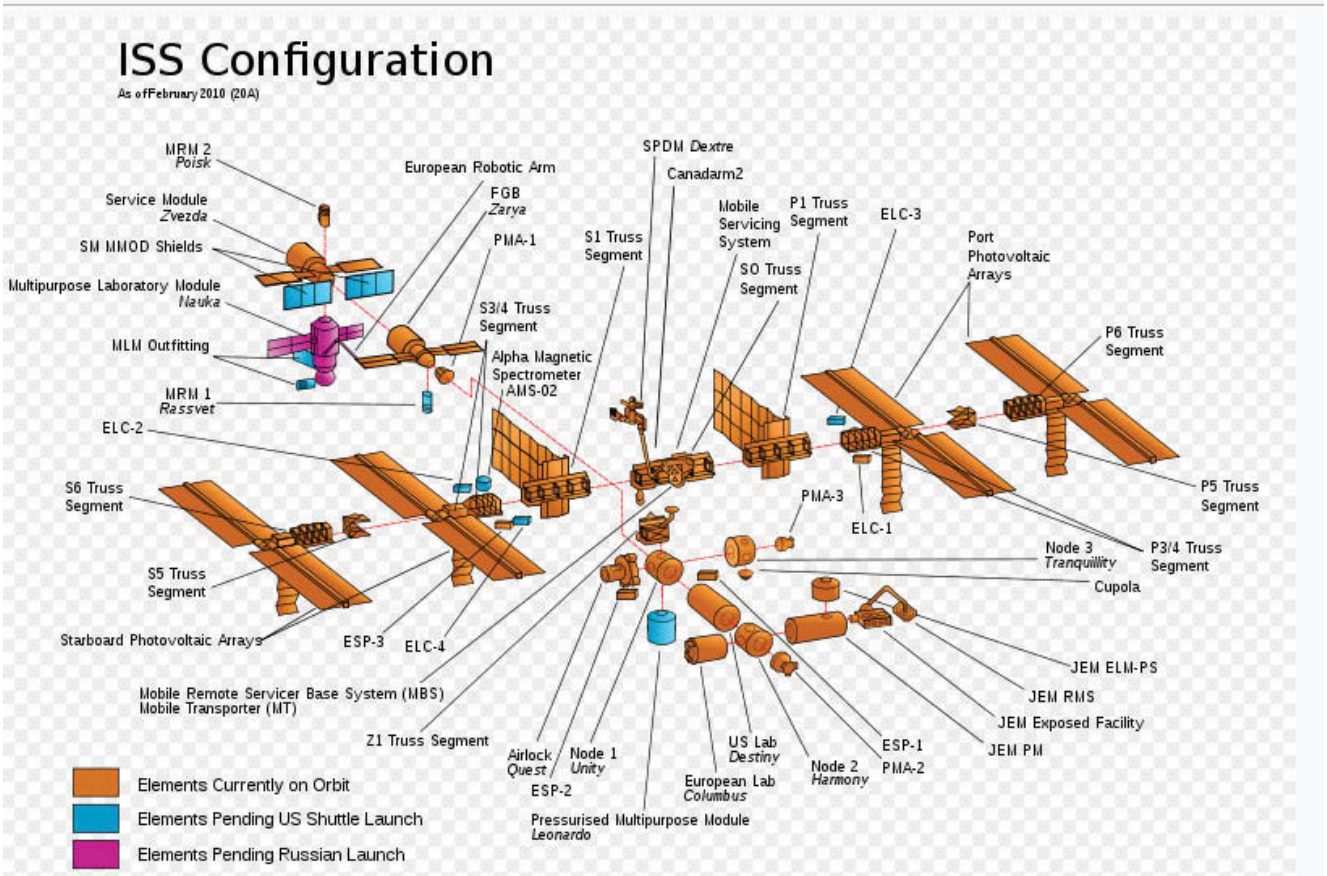

FIGURE 2. ISS Components

6:00 – 7:00	Post sleep	1.5 Hours	Morning Station Inspection Morning Hygenie, Morning Meal
7:00 – 8:00	Planing/Coord.	0.25 Hours	Morning Daily Planning Conference
8:00 – 9:00 9:00 – 10:00 10:00 – 11:00 11:00 – 12:00 12:00 – 13:00	Work/Excercise 	5,25 Hours	8 hours of work and 2,5 hours excercise per day: Work: - ISS System Operations -Payload Operations
13:00 – 14:00	Midday Meal	1 Hours	
14:00 – 15:00 15:00 – 16:00 16:00 – 17:00 17:00 – 18:00 18:00 – 19:00	Work/Excercise 	5.25 Hours	Excercise: -Cardiovescular (cycle or treadmill) or strenghening - Equipment set-up and stowage, -Personal hygenie
19:00 – 20:00	Planing/Coord.	0.25 Hours	Morning Daily Planning Conference
20:00 – 21:00 21:00 – 22:00	Pre sleep	2 Hours	Evening Meal, Preparation of Daily Food Rations Evening Hygenie
22:00 – … … – 06:00	Sleep	8.5 Hours	

FIGURE 8. Typical Crew Workday Onboard ISS (Time = Greenwich Mean Time)