# Computer based astronaut training beyond the ISS

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## Summary

The training and mission operations are vital to the success of manned space programs. Future space missions are expected to last longer and travel further, bringing significant skill retention issues and greater crew independence. With the successful mission of the first European ATV, a new generation of 3D virtual reality training tool has taken the first step towards providing the solution to future training issues. This paper looks at the current computer based training available for astronauts at the European Astronaut Centre and examines the possible next steps which can be validated using the planned fleet of ATV spacecraft.

## Introduction

### Astronaut training

Since the beginning of human spaceflight all international partners have used the same basic principle of crew training; that is to have a backup crew trained in parallel with a prime crew. Both sets of crew follow an identical training flow with a one-to-one backup relationship. Over the past half a century of astronautics, the missions and training have evolved. The initial training focussed on the physical training of the body to prepare for the relatively unknown effects of the three phases of a mission; launch, on-orbit, and return [1]. As it became clearer which human abilities are impaired and which are unaffected by space travel [2], the focus on training moved more towards the mission specific task performance.

Currently with the US Shuttle and International Space Station (ISS) missions the crew are given a Basic Training, Advanced Training, and Mission Specific Training [3] with the last part conducted in parallel with an assigned backup crew.

The result is a crew with common training plus individual specific training dependant on the role of each crew member.

At the European Astronaut Centre (EAC) all ISS crew members are trained on the European elements to the ISS, these being the Columbus Module, various Science Payloads, and the visiting Automated Transfer Vehicle. For all three ESA contributions the training follows a similar flow of mixing classroom lectures, mock-up training, simulations, computer based training, and evaluations. The computer based training (CBT) is used to prepare the trainees prior to their arrival at EAC as well as to refresh training material after the astronauts have left EAC.

Soon the ISS will be completed and with a crew augmentation from three to six people, the science output will be enhanced. The increase in crew size will allow more specialised training and also drives the removal of the parallel backup training concept. Replaced by a 'Single Flow To Launch' concept, the training of a crew will be sufficient to replace at short notice the crew scheduled to fly before them, at the cost of loss of certain mission specific tasks such as experiment conduction. The increased training complexity requirements and new training concept have placed greater emphasis on proficiency training. Both knowledge and skills learned in training will degrade over time, particularly skills retention.

Looking beyond the ISS, future space missions are expected to last much longer and travel farther with manned missions to the Moon and to Mars [4]. These types of missions will bring significant skill retention problems and increased communication delays will lead to greater crew independence from the ground controllers as the volume of information will be overwhelming.

Returning to the Moon is seen as a stepping stone to Mars due to similar radiation and non-zero gravity environment [5], and thus a learning arena. But also during the ISS programme there is an excellent chance to test-bed new concepts and technologies for crew training as related to these future mission profiles. In particular the ATV mission gives a platform to develop and evaluate virtual reality training tools as it will be launched every 12-24 months allowing for modifications and evolutions.

## ATV – Automated Transfer Vehicle

There will be a series of at least 5 European cargo transporters named Automated Transfer Vehicle (ATV) going to the ISS over the next 10 years. Each ATV is a 20-tonne spacecraft capable of delivering equipment, food, water, gas, and fuel to the ISS as well as re-boosting the ISS once per month during a six month maximum stay (see Figure 1).

The operational concept of the ATV is the most complex seen to date, involving three major Mission Control Centres (MCC). The crew operations are controlled either by MCC-Houston (dry cargo) or MCC-Moscow (all other activities such as water and gas transfer) with support from the dedicated ATV-CC in Toulouse. With several control centres and languages involved, the first ATV illustrated the level of difficulty in efficient co-ordination of tasks performed by the Expedition 16 & Expedition 17 crew members.

The training for ATV is also split between the EAC and the Gagarin Cosmonaut Training Centre (in Russia), and also partly in English and partly in Russian.

Therefore there is an obvious advantage in making a training aid which by-passes such language barriers and simplifies the operations in the astronaut (or cosmonaut) mind.

**Figure 1** The first ATV, named Jules Verne, attached to the ISS

In 2008 the first ATV, named after Jules Verne, was attached to the ISS from April to September. The rendezvous and automated docking was during Expedition 16, being Commander Dr Peggy Whitson and Flight Engineer Yuri Malenchenko. The attached phase and undocking was during Expedition 17, consisting of Commander Sergei Volkov and Flight Engineer Oleg Kononenko.

All crew were trained at EAC, along with their backup crew, during the year before the ATV launch. The delay between training and operations required refresher training on-board.

# Current CBT Technology

## EAC CBT strategy

Computer Based Training has been used for several years as an effective distance learning tool. For the Columbus training flow there is a CBT which is a prerequirement for the trainees to study prior to arriving at EAC for full training with instructors and dedicated facilities (mock-ups and simulations). For the Payload training flow, CBT is used to maintain proficiency of the trainees between training sessions at EAC [6]. In both these cases, the CBT remains available to the crew after they leave EAC to remind them of the training received. For the ATV training, the CBT has been taken to a new level. The crew are given initial training at EAC by instructors using high fidelity mock-up facilities [7]. The crew are then introduced to the ICC Viewer tool (explained in more detail in section 'ICC Viewer') and they can use this to refresh skills learned at EAC. This same tool is then made available on-board the ISS to be used as part of the preparations for each of the dedicated ATV tasks.

As an example, for the first ATV the most hazardous procedure performed by the crew was that of delivery of 100% oxygen directly into the cabin (see Figure 2). This presents a serious fire hazard and there have been many precautions taken, such as the installation of a dedicated smoke detector close to the gas outlet. Due to the importance of this operation it was decided to have a dedicated on-board training (OBT) session with the crew prior to performing the operation. This training session was guided by an EAC instructor from MCC-M and the ICC Viewer tool was used to refresh the task as well as highlight particular safety concerns. The result from this training was a faultless operation and no questions from the crew. This test case proved that the ICC Viewer is intuitive enough to be easily followed remotely and many months after receiving the physical training.


**Figure 2** Snapshot taken from OBT ATV First Oxygen Delivery

# ICC Viewer

In 2004 the European Space Agency selected Parallel Graphics to produce an interactive Computer Based Training tool. Using the web-based virtual reality manual technology CORTONA, standard CAD models are input to generate a highly effective 3D interactive environment. Combined with astronaut flight procedures the result is an animated 3D rendering of equipment with which the crew interact in real time. Called the 'ICC Viewer' this training tool focuses on the Integrated Cargo Carrier (ICC) which is the pressurised section of the ATV cargo transporters. Designed to require minimal training to use, this tool has proven to be well appreciated by all the crew who have seen it. The interface is based on ‘natural language’ [8] using the common communication ability learned by all astronaut and cosmonaut candidates. This makes the tool very intuitive and easy to use (see Figure 4).

This tool is highly interactive with the astronaut able to control several parameters of the procedure simulation as well as being able to pause the simulation and change the viewing point to better view a particular detail or just to fly around inside ATV. The simulation is accompanied by a step by step duplication of the procedure and the astronaut can choose to run the entire sequence or jump to a particular step. As each tool or item specific to the procedure is used, it will be available in a side menu which, upon clicking, will highlight just that item. This can be used to help identify each part employed by the procedure.

The ICC Viewer is already well suited to perform cross training of the crew whilst on-board the ISS. As stated by J. McCandless et al. [4] and M. Aguzzi et al. [6], the future missions will require the on-board creation of training and the transfer of training within the crew. This can already be performed on the ISS using the current version of ICC Viewer.

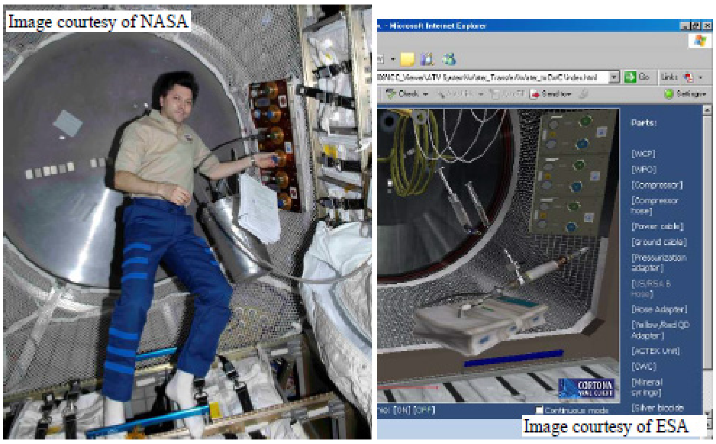


**Figure 3** ATV first Water Transfer (note procedure floating) and ICC Viewer snapshot

The ICC Viewer CBT can not only be used for crew training but also during onorbit operations. Figure 3 shows an example of a water transfer operation and a typical view from ICC Viewer of the tools required. The crew is supplied with a list of needed equipment, in terms of a serial number, and their retrieval typically takes more time than the operation itself. This is due to the fact the ISS has thousands of tools and a complex storage system. Having a visualisation of the tool can accelerate the process of tool collection as they are identified much more readily by their shape.

There are currently twenty five lessons available covering all aspects of the attached phase operations expected to be conducted by the crew concerning an ATV mission. These lessons are all created from procedures which the crew use during the operations and it is possible that these lessons will eventually replace the paper version procedures. The procedures come from various sources, in line with the international nature of ATV, in form of MCC-Moscow standard format Operational Data Files (ODF) and MCC-Houston standard procedures.

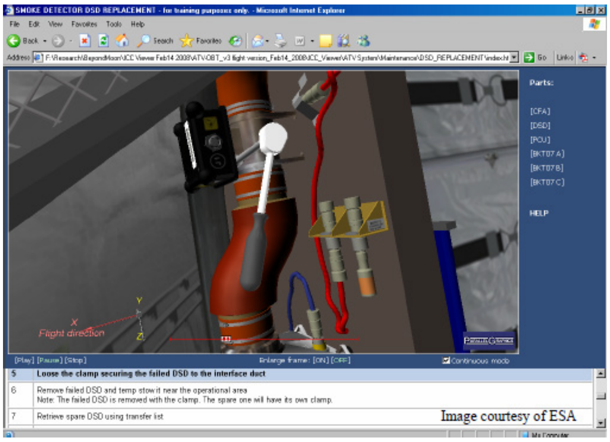


**Figure 4** Snapshot of the ICC Viewer

These different standards are written in a very different style and this can be harmonised through the ICC Viewer which uses a 3D visualisation of the actual task, accompanied with line by line instructions. The lessons included cover the following topics:

- *Ingress of ATV*
- *Egress from ATV*
- *Cargo Setup Dry*
- *Cargo Transfer*
- *Drinking Water Transfer*
- *Liquid Waste Collection*
- *Gas Delivery*
- *In Flight Maintenance*

These are all physical skill tasks, requiring various pre-requisite knowledge. Personal previous crew experience will apply at different levels for each of these groups of tasks. In all cases the individual crew members will require varying degrees of training input to perform correctly the required tasks.

# Future technology

## Requirements of Moon and Mars training

The key to human exploration beyond the low Earth orbit will be flexibility. The crew will need to be more independent from the support of ground controllers as their distance from this source of assistance increases. Procedures will have to be created during the mission and therefore trained during the mission. Flexibility will therefore also be a key requirement of future training technology. Along with flexibility will come the need for a portable platform training aid. Embedded training is an example of this, where the flight hardware can be placed into a simulation mode for training, thus eliminating the need to bring additional hardware dedicated to training. Portable needs may also arise if the crew members need to carry the training aid with them while performing a critical or new task.

As already mentioned, as the crew is further from the Earth, they will need greater independence. Missions where replacement items from Earth are unlikely will raise tasks to being critical, as erroneous performance can be irreversible. Under such conditions it is essential to evaluate the proficiency level of a crew member prior to performing a task. Simulations and guided practice sessions will play an important role [9].

During the MIR and Skylab long-term missions, up to 400days, lessons were learned about the importance of crew morale and motivation. These lessons are being applied today with the standard six month ISS duration. As the distance and time from Earth increases with long term habitation of the Moon or long duration space travel to Mars, so motivation will become a significant factor in mission success [10]. Training must become a pleasurable, rewarding activity rather than an obligation in order to be self-motivating.

In addition to these specific mission requirements we should apply the latest principles of learning to enhance the astronaut training and retention. It is commonly recognised that a varying learning environment is best for connecting to long term memory. Therefore a multi-stimuli tool is sought, for example with the ultimate goal of virtual reality involving all of our natural senses. Also any learning is a personal interpretation and we must therefore be conscious to avoid the many pitfalls of believing the learning is more complete than will be proven when the task is badly performed. Finally, the technological solutions to training must be compatible with the general requirements of the human body and mind.

Bearing all this in mind, the next section will examine what possible courses are available to take the next steps in the CBT experience.

## Using ATV fleet as a test-bed

Over the next 10 years there will be a series of ATV going to the ISS. For each mission there will be dedicated training campaign at EAC in Germany. In addition there is an opportunity to update the CBT which is on-board the ISS computer.

This makes the ATV fleet a perfect test-bed for improving the CBT and evaluating the impact through crew performance and feedback when they are debriefed upon return to Earth. Due to the success of the ATV-1 mission it is also probable that more ATV will be launched, perhaps themselves modified to new mission objectives. In this section we will examine some of the possible modifications to the ICC Viewer to propose solutions to the above requirements.

Currently the ICC Viewer has flexibility by being web-based software. This makes it easy to use on any standard laptop configuration. As can be seen in Figure 3, a paper version of a procedure can be kept near the work area during a task performance. Similarly a laptop can be mounted nearby using a standard ISS seat-track arm. A future laptop could use a stereoscopic screen, such as the Sharp Actius

RD3D, to produce a 3D stereoscopic image to enhance realism. Flexibility is also shown in the structure of ICC Viewer, where individual lessons can be updated on-board by simple up-linking of files. This enables the latest information on operational procedures to be given to the crew. It should be noted that this would require an effective configuration control system to inform the crew when a lesson has been changed.

As a part of proficiency training it is vital to begin with an assessment of the current level of crew memory retention. The ICC Viewer could be adapted to include an evaluation for the crew. In this respect it has been shown [11] that the best technique is to give minimal cues to the student to see if they recall the procedure from long-term memory. The software can be used to increase the cue level in an interactive way. This can also be used to form a guided practice session. If paced over set time periods, as defined by proficiency analysis, tasks can be held in memory for long periods of time [12].


**Figure 5** Future WEAR project (Expedition 19/20)

We have already discussed that the language barrier in both the initial training and use of text procedures is removed, to a large extent, by the visual approach of the ICC Viewer. However, there is currently no audio content. This can be added, along with an initial selection of language to suit the individual crew member.

Looking at another ESA project, the WEAR project (see Figure 5), it is possible to include voice recognition software to improve the interaction of the user. For example, a varying level of help could be commanded from the user, making the tool as efficient as possible (proficiency training can be achieved with minimal time spent). The WEAR design will be able to recognise objects in front of the crew and track the location of items to aid during task performance. Such features could be incorporated into the ICC Viewer so the crew can find the tools they need in advance of real-time operations.

A new aspect of Mars missions will be the need for cross-training on-board. Due to the long duration of travel to Mars prior to on surface operations, there is a need to keep the crew occupied and motivated. This time can be used ideally to cross train each other on certain tasks. In such a scenario a virtual reality tool is essential and the ICC Viewer is already in a mature state in this regard. Further improvements could include use of sensory input devices such as virtual reality gloves or full body suits, coupled with image visor. Training in a virtual world without first experiencing the training using a mock-up would leave the sensory feeling missing.

## Conclusions

It is clear that with long term goals of a permanent Moon base and Mars exploration, the technology will improve significantly beyond what is available today. However, important lessons can be learned today regarding the strategy and direction that future training will take. Use of the ATV programme over the coming decade can give a valuable database of tried and tested learning techniques, setting up the future use of smarter technology. Having a series of near identical spacecraft allows researchers a step-by-step approach to achieving the goal of maintaining training knowledge and skills over the long duration between initial training on Earth and eventual use in space. ESA plans to link ICC Viewer with the on-board International Procedure Viewer tool, becoming an operational system. Looking further ahead such a tool can be integrated into a heads-up display and replace completely the paper-based procedures used today. More interaction will improve astronaut motivation to use CBTs and maximise their performance during the challenging environments the future will undoubtedly bring.

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