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Increment 56/57 ISS events put focus on safety role of the Columbus Flight Director

J. Campan, D. Sabath*, G. Söllner*
* DLR, Oberpfaffenhofen, Germany

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INCREMENT 56/57 ISS EVENTS PUT FOCUS ON SAFETY ROLE OF THE COLUMBUS FLIGHT DIRECTOR

Author

J. Campan, DLR, Oberpfaffenhofen, Germany, Jerome.Campan@dlr.de

Co-Author

D. Sabath, DLR, Oberpfaffenhofen, Germany, Dieter.Sabath@dlr.de

G. Söllner, DLR, Oberpfaffenhofen, Germany, Gerd.Soellner@dlr.de

ABSTRACT

In the second half of 2018 during the increments 56 and 57 the German ESA Astronaut Alexander Gerst was living and working on ISS. During these ISS increments – A. Gerst served as ISS Commander during Incr. 57 – two events concerning the safety of the astronauts onboard as well as on the way to and from ISS were perceived by the public:

- A hole in the Soyuz capsule which could be closed in short timeframe without impact to the astronauts
- The launch abort of Soyuz 56 (MS-10) with safe landing of the cosmonaut/astronaut crew

Despite these events were outside of the responsibility of the Columbus Control Center (Col-CC) they also puts the focus on the safety responsibility of Col-CC and especially the Columbus Flight Director.

The safe execution of activities on board the International Space Station (ISS), whether performed by astronauts or directly from ground, is the first priority for the Flight Control Team supporting human spaceflight operations. Safety of the crew, the vehicle and the mission is actually one of the first things new flight controllers learn when joining the project. At the Columbus Control Center (Col-CC) in Munich, Germany, this task is assigned to the Columbus Flight Director. In order to fulfil this task, an integrated process takes place in which several teams are involved. Its outcome is then made available to the Columbus Flight Director who, supported by his team, ensures its implementation for the safe operations performed on behalf of the European Space Agency (ESA) inside as well as outside of the European module Columbus.

This paper intends mainly at describing the safety role of the Columbus Flight director. It will briefly describe the above mentioned safety process in place on ESA side and then detail the operational means made available to the Columbus Flight Director and the Flight Control Team at Col-CC to ensure safe operations onboard the ISS.

Introduction

During the more than ten years of operations of the Columbus module at the ISS, the Columbus Control Center (Col-CC) has supported 10 long-duration and one short-duration mission with 9 different ESA astronauts. Paolo Nespoli and Alexander Gerst were supported twice during this timeframe. All ESA astronauts of the 2009 class have performed at least one space mission and provided high valuable results during their stay on the ISS. Based on the long experience of DLR's German Space Operations Center (GSOC) in manned space operations and the missions to ISS described below, Col-CC is supporting also the current mission "Horizons" with Alexander Gerst

until December 2018. Alexander Gerst will become the first German Commander of the ISS; this will be the second ESA astronaut as commander on ISS after Frank de Winne in 2009.

In the Interim Utilization Phase, which was done in parallel to setting up Col-CC ([4] to [6]) for the later Columbus operations, the Eneide Mission in 2005 and the Astrolab mission with Thomas Reiter in 2006 (see [1] and [2]) were successfully supported. Since February 2008, when Col-CC started its Columbus operations (see [7] to [12] and [14] to [19]), all further missions and increments have been prepared and supported successfully. With this experience Col-CC will be able to operate Columbus in the course of the next decade, assuming that the basic setup will not change (see [13]).

European Astronauts on ISS

On 6 June 2018 Alexander Gerst was launched to space in Soyuz-MS09 (55S) together with his crew mates Serena Auñón-Chancellor and Sergei Prokopyev. The first half of the stay on-board ISS (see [18] and [19]) was a quite normal increment on ISS performing several experiments like GRIP and GRASP. Starting End of August 2019 two events took place that makes Increments 56&57 special in the row of increments in the past years.

- On August 30, 2018, a hole in the Soyuz capsule was detected which could be closed in short timeframe without impact to the astronauts
- The launch abort of Soyuz 56 (MS-10) on October 11, 2018, with safe landing of the cosmonaut/astronaut crew (see Fig. 1)

The whole ISS community and all you get notice of these events were relieved to hear that the astronauts and cosmonauts were not harmed by this events. Especially the launch abort showed the necessity of reliable safeguard systems for manned launchers.

These events have large impacts on the on-board work and schedule, e.g. by reduced crew size for several months or an extra EVA to gather more data on the hole in the Soyuz, while other EVAs have to be postponed.

Due to the launch abort and therefore late arrival of the next crew the landing of Soyuz 55 with the crew members Alexander Gerst, Serena Auñón-Chancellor and Sergei Prokopyev was postponed to 20 December 2018. The expedition 57 crew members returned safely to earth with Soyuz MS09 (see Fig. 2).

Fig. 1: Soyuz 56 Launch Abort (Photo: NASA)

Until the arrival of Expedition 59 in March 2019 the on-board schedule was impacted by the launch abort, because some of the planned experiments and maintenance activities have to be postponed until the nominal crew size was reached again.

This was achieved with the launch of Soyuz 58 on 14 March 2019 bringing the three crew members A. Ovchinin, N. Hague and C. Koch to ISS.

Fig. 2: Landing of Soyuz 55 (Photos: NASA)

The events described above showed that on-board and launch safety is of high importance for human spaceflight operations. The Columbus module forms only a small part of the overall ISS but its role as working place for the astronauts and home for more than 10 Payload racks leads to lot of

challenges with respect to safety in preparation and the execution phase of Columbus operations.

The role of the Columbus Flight Director and his responsibility for the on-board safety in the Columbus module will be described in the next chapters.

Columbus Flight Director

A flight director manages a team called the Flight Control Team composed of experts in various systems in order to achieve a defined set of goals for a dedicated space mission.

The Columbus Flight Director (COL FLIGHT) directs his team at Col-CC in the frame of space mission including men and women in space which adds another degree of complexity to the flight director task in comparison to unmanned space mission. In this case, we are no longer talking about a pure space system to be operated from ground but we are adding a human in the loop which induces additional operational constraints to be considered. The Columbus Flight director needs to ensure that all operations done from Col-CC are done in a safe manner for the astronaut.

The Columbus flight control team has amongst other tasks to guarantee the overall safe Columbus module operation (systems and payloads) as part of the ISS operation. This task is supported by the Flight Control Team, including ESA external centres (e.g. User Support and Operation Centre responsible for science operations) for their payloads and experiment. Even though safety is the task of all involved in the ISS operations, ultimately the Col Flight Director is responsible to guarantee the safe operations from Col-CC. This task is done under the overall supervision of the ISS Flight Director who has the final authority on all decisions made for ISS operations

Safety and Hazard Definitions

Before defining the safety role of the Columbus Flight director, it is necessary to define what safety and hazards are in the frame of the ISS project.

The ISS Safety Requirements Document (SSP 51721) defines the term *Safety* as “A general term denoting an acceptable level of risk, relative freedom from, and low probability of: personal injury; fatality; damage to property; or loss of function to critical equipment”. In other words *Safety* is there to mitigate the hazards present on board the ISS by implemented controls which limit the risk of the hazard to occur.

The ISS program has defined several Hazard categories (e.g. Electrical hazard, Mechanical hazard, Toxic hazard) which are categorized as either Catastrophic, Critical or Marginal Hazards.

These Hazards are all defined in so called Hazard reports which contain amongst other information a description of the Hazard, the consequence of Hazard and most importantly for operations, the control in place to avoid the Hazard to occur.

These controls are simply called Hazard controls and are divided into 2 groups

1. Design Hazard Controls

These controls are implemented in the hardware design. They are typically dealing with Fault Tolerance (e.g. redundancy in the design, Fail Safe) or Design for Minimum Risk (e.g. Proof testing).

2. Operational Hazard Controls

These controls are to be implemented by the operational teams in the OPS Products (e.g. Flight Rules, Procedures) or by training. The implementation of operational controls needs to be agreed with the respective teams.

Fig. 3: Col FLIGHT console at COL-CC (Photo: German Zoeschinger)

The Flight Control Team needs to understand and agree before implementing these controls in their OPS products. That way, it ensures that the flight controller has the full information available when the procedure will be executed during real time operation under the supervision of the Columbus Flight Director.

Safe operations

The ISS normal flight operations are conducted according to the station operational flight rules which are defined as a set of decisions made in advance to minimize real time discussions. When time or circumstances do not permit to follow them, the rule B1-3 defining Real time operation policy states that decisions which have to be made have to comply with the following priorities

1. Crew safety
2. Vehicle safety
3. Protection of the vehicle equipment lifetime
4. Continue with planned operations

This rule dictates us that safe execution of activities on board the International Space Station (ISS), whether performed by astronauts or directly from ground, is the highest priority for the Flight Control Team supporting human spaceflight operations.

In line with this Flight rule B1-3, the Col-CC operations execution strategy emphasizes first and foremost safety of the crew and vehicle. Operations are conducted by dedicated teams composed of certified members, each with their allocated tasks. The Flight Controllers ensure that operations of Columbus payloads and systems are executed in a safe manner, consistent with the established Flight Rules and other OPS Products.

Whenever an activity is conducted on board the ISS, whether performed from ground or by the crew, the ops community is using procedures. All these procedures are following a process which shall ensure that, amongst other things, all hazards which might occur while executing the procedure are understood and have their associated operational hazard control as explained before, (e.g. an obvious example would be for electrical shock hazard to have a procedure step to deactivate a power outlet before the astronaut executes the step to demate a power cable). When it comes to executing such a procedure, it is the task of the Columbus Flight Director to ensure that this is done as they are written and intended to be executed. During real time operations, any deviation from a procedure shall be mentioned by the procedure executor and shall be approved by the Flight director prior to execution. In order to be able to approve such deviation, it is primordial for the flight director to have a clear understanding on the following: does the procedure being executed contain one or several hazard control steps; if so what is the associated hazard; if the current configuration on board would allow to deviate from the nominal procedure execution.

To help the Flight director in this task, the Product Assurance and Safety Officer (PASO) provides real-time Columbus safety support, e.g. on a daily basis with a safety briefing to the flight control team. This briefing shall contain all Hazard control planned to be executed on a given day as well as the Hazard level response (see Hazardous release section) of hardware to be handled by the astronaut. This information is used by the Columbus Flight Director to have an awareness of the safety related items to be handled throughout that given day.

Hazardous commanding

There are several kinds of commands which can be executed on the ISS. One of them is classified as Hazardous commanding when matching the following criteria:

- the command is one whose execution (including inadvertent, out-of-sequence, or incorrect execution) could lead to an identified critical or catastrophic hazard,
- the execution of the command can lead to a reduction in the control of a hazard (including reduction in failure tolerance against a hazard or the elimination of an inhibit against a hazard).

On a standard basis, a flight controller would request the authorization to the Flight director to start with a commanding activity and after receiving the authorization to proceed would only report to him/her upon activity completion. However for hazardous commanding, the flight controller is required to request the Flight Director approval for each hazardous command before the command can be sent to the ISS.

Before giving the approval, the Flight director needs to understand here as well, what is the associated hazard of the command, what situation it will create and if that situation is acceptable at that time. In that case, the Flight director cannot solely rely on OPS Product but must have a full awareness of the actual on board configuration of the system or payload to be commanded and if anything being done on board the ISS could lead to a hazardous situation (e.g. the hazardous command is meant to change the fan speed which create the air flow required for smoke detection or is meant to activate a power outlet on a hardware the astronaut is working on). This awareness has to be continuously maintained by the Flight director in order to be able to judge such situation. This means having cognizance of the on board configuration at any given time and what is currently being done by the astronaut on board the ISS.

56S Launch mishap

On October 11th 2018 the Soyuz MS-10, carrying part of the Expedition 57 crew (Roscosmos cosmonaut Aleksey Ovchinin and NASA astronaut Nick Hague) suffered a malfunction due to a failure of the Soyuz-FG rocket shortly after launch. The launch was aborted and the crew was put in a ballistic re-entry trajectory. The crew was extracted from the capsule several minutes later in good shape and reported no injury. The only impacts were the loss of the vehicle and the abortion of the mission to the Station. Following this mishap, NASA started the effort to consider the impacts and the preparation steps needed to support a possible decrew of the Station.

The COL FLIGHT team was actively involved in this preparation and requested assessment to be made regarding the safety of the Columbus module in the scenario where no astronaut would be present on board the ISS. In this exercise, various failure cases were analysed and the team had to assess whether the safety of the Columbus module/ISS would be jeopardized.

In case it would have been required to decrew the ISS, per standard procedure the Columbus module would have been isolated from the rest of the ISS by having its hatch closed by an astronaut prior to departure(similar approach is taken for all modules to avoid that a failure is one module could propagate to other modules). Taking into account this configuration, it was also required to assess if the configuration of the Columbus module could be controlled from ground to allow an astronauts to come back on board of the ISS and reopen the Columbus hatch to enter the module safely. For this part of the analysis, items like battery expiration date were taken into account to minimize the risk of these leaking in the Columbus cabin. We also assessed one failure deeper scenario where we for example anticipated the possibility that Col-CC would be unable for technical reason (e.g. hardware issue at Col-CC) to command the Columbus module while crew would come back on board the ISS and made sure that they would have the means on board to command the Columbus module prior to reopening its hatch.

As one of the main goals of the ISS is to allow science experiments to run it was also important to assess which operations can be executed while no astronaut would be on board the ISS to assist with troubleshooting in case of anomaly. In other words, the assessment had also to cover which system or payload can be operated from ground only without taking risk of having it in an unsafe state and unrecoverable from ground. As part of this analysis, we were actually able to safely guarantee the usage of the venting/vacuum line for experiments which was so far not allowed in the decrew configuration.

Cabin depressurization

On August 30th 2018, during the sleeping period of the astronaut, the MCC-H Flight Control Team observed a slow decrease of the ISS cabin pressure. The leak rate was low enough that the decision was taken not to wake up the astronaut and inform them about the leak and ask them to locate the source only at standard wake up time. After confirming that the leak was on the Russian Segment side, astronauts executed the related emergency response procedure to further isolate the leak. The procedure led to isolating the leak in the orbital module of the 55S Soyuz. The astronauts were able later on to stop the leak and nominal operations could be resumed.

For such an event, it is a common effort between the astronauts on board the ISS and the ground teams located across the world to react accordingly and ensure the safety of the crew. For that specific event on August 30th 2018, even though the COL-Flight Control Team had a relative passive role as the leak was located in the Russian Segment, COL FLIGHT ensured that his team was

closely following the emergency procedure executed by the astronauts and while the leak source was still unknown, COL FLIGHT directed his team to assess any relevant indication from the on board telemetry that could help identify the leak source.

This scenario of cabin depressurization is defined as one of the three technical emergency cases defined for ISS operations (rapid depress, fire, hazardous release) where the safety of the astronauts is in jeopardy.

Hazardous release

This section intends at highlighting the safety role of the Columbus Flight Director whenever hazardous materials are operated by an astronaut.

The ISS program has defined five (0 to 4) different Hazard response levels (HRL) to be executed by an astronaut whenever in contact with a hazardous material. These HRL are assessed based on the toxicity, flammability and bio safety criteria of the material. Each HRL has an associated response to be performed by the astronaut in case the hazardous substance of the manipulated hardware is released in the cabin. The corresponding hardware is identified accordingly with a label visible to the astronaut. On ground, these labels are not always visible even when real time operations are conducted with real time video support. In order to know the corresponding HRL associated with the hardware being operating by the astronaut, the Columbus Flight director has access a database which lists all hazardous materials on board the ISS.

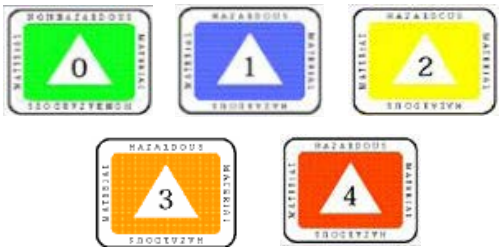

Fig. 4: Hazard labels

The need of a full awareness of the on board configuration and what the astronaut is doing on board the ISS was mentioned before when dealing with Hazardous command. This awareness is also required in the scenario of a hazardous release to the atmosphere and can be achieved in various ways (e.g. based on astronaut reporting on an activity status, by having real time video support). Using all possible means, the Columbus Flight director has to ensure that when handling hazardous materials, the astronaut will never be exposed to them or in case the associated HRL is level 1 or higher, the level of containment of the hazardous material is met (e.g. HRL 1 requires 2 level of containment, HRL 2 and 3 require 3 level of containment). In case of off-nominal situation where the crew is in contact with the hazardous substance or the required level of containment is not met, it is the responsibility of the Columbus Flight director to ensure that the astronaut is aware of the hazardous situation if not already the case and that the appropriate malfunction response is properly executed. In a nutshell COL FLIGHT makes sure that the astronaut knows the related HRL associated to the situation, instructs the crew to which steps shall be performed on the procedure to recover the situation (this is applicable in case the procedure being executed covers the potential case of a hazardous release) or point the crew towards the generic emergency response procedure (procedure written for generic case, i.e. also for unknown substance release). Additionally, the Columbus Flight Director makes sure that the ISS Flight director is kept informed on the situation and the recovery plan.

Conclusion

Two major anomalies with the 56S launch mishap and the cabin atmosphere leak in the 55S occurred in the increments 56-57. These events which could have directly impacted the astronaut safety reminded the ESA Flight Control Team of the important role of the Columbus Flight Director who is responsible for the safe execution of all activities in Columbus as well as for all operations conducted from Col-CC.

When it comes to hazardous situation on a manned mission, the impact of the decision taken by a flight director can not only impact the ISS itself but can also have consequences on the astronauts who are living up there. These decisions, if not done properly and in a timely manner, could lead to injury or worst. Therefore, it requires a significant amount of work in term of training, preparation and during activity execution for each Columbus Flight director to be able to cope with the associated responsibilities. This is especially true for new mission objectives or even new

mission goals like moon and deep space. The required effort and the necessary experience of the ground teams to ensure the safety of the crew have to be taken into account from the first step of mission design. Past manned space missions are there to remind us that mistakes can lead to human loss and that it is the responsibility of the flight directors together with their team to ensure that this will never happen again. The Columbus Operations setup at GSOC is using the experience from past manned missions, e.g. Spacelab D1 / D2 and Euromir-95-Mission. In the same way the current experience from Col-CC for safety will help for the European contribution for future missions like deep space gateway.

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