Crew on the ISS: Creativity or determinism?
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Abstract
Analyzing the experience of human flights to the Mir space station in 1986–2000 and to the ISS in 2000–2008, as well as Space Shuttle missions we can define structural and organizational tendencies in human missions to space and mission support. The tendency to the increased determinism in flight operations leads to lower flexibility of the “crew-Mission Control Center” link in case of contingency. We justify the necessity to reduce the centralization of the control process and to hand over some mission control centers (MCC) authority to the International Space Station (ISS) crew. We conclude that human missions to the Moon and Mars where crew actions will be independent to a high degree will be impossible without resolution of this issue. Creativity and determinism should be properly balanced.

1. Introduction
Eight years of the International Space Station (ISS) operation is a reasonably long period to define existing structural and organizational tendencies in the implementation and support of the human flights to space, based on the experience of the crews, mission control centers (MCC) in Moscow and Huston, technical support teams of the countries participating in the program. Statistically solid results may be achieved if we consider the whole spectrum of the achievements in the modern human cosmonautics: the results of 15 years of the Mir space station operation, short-term Space Shuttle missions, work of 17 ISS expedition crews.

Even preliminary analysis of the ISS program from 2000 up to 2008 shows the increase of the bureaucratisation in the mission support, utilization and ISS crews operations. Further we give examples of the ISS flight operation that show the tendency to the growth of determinism in the mission operation that leads to lower flexibility of the “crew-Mission Control Center” link in case of contingency in flight. In this context we need to mention that more liberal and creative atmosphere onboard the Mir space station made it possible to successfully counteract dramatic problems in flight.

It is quite evident that we need to prevent going to almost complete control over the crew from the Earth, increased mission control centralization and we need to give the authority to take some management decisions and provide technical capabilities to the ISS crew. Human missions to the Moon and Mars, further human exploration of the Solar system where crew actions will be independent to a high degree will be impossible without resolution of this issue.

2. Subject matter
For many years we have been discussing pros and contras of the human space exploration compared to the robotic missions. Now nobody argues against the fact that some (perhaps the majority) of the functions can be better performed by the automatic means. Shooting of the Earth, coelosphere in different spectral bands is better performed by robotic vehicles. It is difficult to create pure “zero-g” conditions for the experiments in a crewed vehicle, because life-support systems and the crew itself are disturbing factors for zero-g.
From the very beginning, for instance, the communication and remote sensing satellites were robotic spacecraft.

Then why do we send people to space? Why are human beings better than robotic vehicles?

Automatic vehicles fulfill their functions on the basis of the preplanned programs. The easier is the program, the more repeated elements it has, the more advantages a robotic vehicle has. If the mission plan becomes more complex, if the algorithm branches to take into account different options, the algorithm complexity increases in geometric progression depending on the number of branches we want to introduce. If we need to provide a big number of initial conditions to fulfill the function in the spaceflight, it is necessary to fulfill the subsequent step of the program depending on the results of the previous steps (as it happens during the tests of a new technology and new scientific experiments); here you cannot deal without human beings.

The conclusion is that human being operates better under difficult to predict conditions.

For the first time the attempt to determine decision-making by human beings was raised by Russian cosmonauts during their training for the *Mir-Shuttle* program. When we planned our joint activities with the colleagues from NASA we faced a big number of the so-called “flight rules” originated from the *Space Shuttle* program. There they described the required consequence of crew activities during a short-term shuttle flight for every predicted situation. Depending on the results of these activities further actions were assigned and so on. And this was true for every step going deeper. Everything was clear and logical. These flight rules according to designer’s requirements were to facilitate the decision-making process in flight taking into account time deficiency. And immediately we got a question: how shall we fulfill our multiple long-duration flights without having such rules and how shall we fulfill the crew tasks set by the mission plan?

In reality similar rules existed in Russian practice but they were called differently and were elaborated to lower depth. We simply could not work out in advance all the operational steps for long-duration missions in all the details. That is why we had a relatively short list of contingencies where the actions were stiffly determined and the crew steps were defined based on their knowledge, skills and experience of work in real time. And it always worked.

Both of the above mentioned approaches have their pros and contras. The contra of the Russian approach is higher requirements to the training and qualification of the personnel responsible for decision-making (MCC personnel and spacecraft crew). These requirements become especially stringent under the time deficiency in case of contingency. The pro is that this approach increases the flexibility of the system as such, since a well-trained operator can take adequate decision even under very critical conditions. And it becomes especially vital for long-term flights.

The conclusion follows: the high level of crew actions determinism is justified only for short-term missions or for some vital operations.

The detailed description of crew actions in different instructions and radiograms resembles the programming of the computer. If we conclude that preprogrammed actions are better performed by the computer than by the crewmember and the crewmember has better flexibility than the computer, we eliminate this advantage in real space flight by stiff assignment of crew actions.

In this respect proper information provision to the crew becomes critical. We may assume that during the development and tests of the spacecraft before we stiffly program the sequence of actions with the computer, we create the logic of actions and ask the test-cosmonaut to go through this sequence step by step, but:

- This approach is acceptable only during the test; during the operation of the vehicle or any of its systems, maximum automation of all the processes is required. But unfortunately “computer” algorithm becomes part of the crew procedures and stays there for years.
- The high complexity of computer algorithm, the increase of its scope and branching keeps apace with the development of computer technology. The volume of computer memory and processing speed increases, etc. But up to now we have not found any efficient methods to upgrade human memory or increase processing speed of mental activities (we mean normal people without extraordinary capabilities). The amount of information provided to the cosmonaut already exceeds human processing capabilities. But cosmonauts as you know are human beings.

A good example is onboard instructions requiring quick actions in the limited time (such as emergency escape instruction). The attempts to describe everything in all the details lead to the fact that the reading time exceeds the operation time (actions to be taken within the first 5 min after contingency are described in three to four pages). If the cosmonauts have to learn more information then they will spend more time to get the right answer (action) and as a result they will miss some blocks of essential information. The attempts to solve it (1) by increase of the training scope is a dead end, since the unjustified volume of information provided to the crew very quickly exceeds the level of training and adequate feedback that the cosmonauts get as a result of intensive training. The other way to help a cosmonaut to deal with big amount of information received during the flight is related (2) to the more detailed description of his actions. It is also a dead end since it does not help to solve the problem but as a result leads to turning a human being into a robot and subsequently, to the loss of his advantages as a “thinking being” compared to the robot.

To illustrate the above mentioned provisions we can give examples of real space flights.

(1) Soyuz T-13 flight to the uncontrollable Salyut-7 orbital station (V. Dzhanibekov, V. Savinykh). According to the onboard instruction they had to switch over to manual control at the distance of 400 m from the uncontrollable station. The procedure of manually controlled rendezvous from the distance of more than 5000 m was urgently developed.

According to the flight rules it is supposed to perform an abort in case solar array attitude control system is not functioning. Solar array attitude control system was not functioning, but the crew took a decision to dock.

According to the flight rules it is supposed to leave the station after docking if the internal temperature is lower
than +5 °C. The temperature was lower zero. But the crew took a decision to continue operations.

According to the flight rules it is supposed not to revitalize the station when the accumulator battery charging system fails. The system was not functioning; the voltage in the power buses was zero. A procedure of direct connection of the solar array outputs to accumulator battery bypassing automatic devices was developed in flight with the help of the crew. This allowed to revitalize the station power supply system.

(2) The fourth expedition crew of the Mir space station. The Era deployable structure to be installed on the outer surface of the station during extravehicular activity (EVA) did not deploy after the command was sent. According to the flight rules in this case it is supposed to jettison the structure. The crew (A. Volkov, J.-L. Chretien) came out of the cover and found out that the mechanism was released but was not deployed due to the joints friction. Just by shaking that was not planned in advance and was not verified during training the crew deployed the structure and the planned study was performed.

(3) The collision of Progress M39 with Mir space station. Mir expedition crew 23. After the collision with the station and depressurization of the Spectr module the crew (V. Tsibliev, A. Lazutkin, M. Foale) did not follow the instruction which directs the contingency closure of the hatches since the location of depressurization point was unknown. The crew relying on indirect indications and intuition localized the depressurization point and closed the hatch of the depressed module. They acted “in the spirit, but not in the letter” of the instruction and saved the station from depressurization.

(4) The first ISS expedition crew (W. Shepherd, Yu. Gidzenko, S. Krikalev). During the docking of Progress M1–4 (2P) to the functional cargo block (FGB) Zarya Kurs approaching system was operating in the off-nominal mode. Kurs systems installed on the service module, FGB and cargo vehicle were operating simultaneously. At the distance of 150 m when control was switched over from one Kurs set to the other, Progress went into self-oscillations with increased amplitude. According to the onboard instruction the crew (Yu. Gidzenko, S. Krikalev) switched over to Progress manual control in the TORU mode (actually MCC-M authorized switched over to manual control after it was implemented in reality).

The fogged glass of the TV camera prevented docking (it was impossible to get the proper image of the docking mechanism and the target of the vehicle from the station). According to the flight rules the crew had to send the vehicle away to a safe distance and most likely it would have been lost with all the cargo.

Nevertheless the crew watched the vehicle approaching the station from the window, measured range and range rate by back-up means, managed to bring the vehicle into the hovering mode in the close vicinity from the ISS. With the help of the onboard optical means the crew determined that fogging of the glass was caused by the condensate on the protection glass of the TV camera. They decided to rotate the vehicle to the Sun to warm up the glass, but the heat reflected from the station surface was sufficient to improve the glass transparency and thus they got an acceptable TV image and manually docked the vehicle.

As far as the ISS is concerned, we would like to mention that it is primarily a test bed for new hardware, new technologies that are required both for ground application and for the further advance of humanity to space, for the exploration of the Solar system. Being far away from the Earth the crew must take important decisions by itself. And we need to train the crews to do that, therefore it is a requirement imposed by the time-partial decentralization of the existing approach to decision-making in the area of human spacecraft control. It is important that management and control personnel are ready to move in this direction and after that they may hand over part of the MCC authority to the crew, e.g. during rendezvous and docking, relocation of the vehicles on the ISS. We need to build (or rather restore) trust in the crew being one of the main links in the management decision process. This approach was to a large extent implemented in the Mir station control process.

As an example we may consider off-designed contingency that happened on the Mir station on February 19–20, 1997, when gyrodine magnetic suspension failed and when the station was outside coverage area. Attitude control was provided by the gyrodines. At the end of the working day MCC informed the crew that six out of twelve gyrodines of Kvant-2 module were switched off. Guidance, navigation and control (GN&C) specialists allowed continuing operation with the six working gyrodines till morning. The next communication session through the relay satellite was planned for the second part of the night. But before the cosmonauts went to sleep the elements of the operating gyrodine magnetic suspension started failing. It could lead to GN&C system failure, switching it off and attitude control loss if the number of functioning gyrodines was less than four. It would have resulted in the problems with onboard power, loss of communication through the relay satellite and loss of the Russian–German mission MIR-97. The situation would have become unsafe for the joint 22–23 expedition crew (V. Korzun, A. Kaleri, J. Blaha, V. Tsibliev, A. Lazutkin, J. Linenger). The loss of attitude control due to the impossibility to rotate the station with the help of the weak control means aggravated the situation. The charge level of the storage batteries dropped and the situation became really threatening. The crew changed the attitude with the help of the available control means and oriented the station to the Sun, the most beneficial position from the point of view of storage battery charging, before they handed over control to MCC during the closest communication session. MCC relatively quickly coped with this contingency and the crews continued to implement the mission plan. The ISS crew does not have the capability to send independently this kind of control commands.

The last (28th) expedition crew to the Mir station (S. Zaletin, A. Kaleri) gives a good example of independence in making decisions. If it was not the case, they would have terminated the mission before the appointed time. The crew creatively worked to overcome problems in real time to reactivate some systems, to urgently repair vital assemblies (separation of the thermal control system loops). The crew independently found the leak before they started planned operations for leak detection.

The ISS-8 expedition crew (M. Foale, A. Kaleri) also found the leak but in the process of leak detection in the systems and subsystems.
3. Methods to solve the problem

1) Actions in contingencies (and recovery methods) should be treated as nominal operations. It should be treated as an important operator skill. It may be compared to chess (a play of grand master)—contingency prediction. Test pilot should easily switch over from one task to another. He flies on different types of the planes, that is why he needs to have universal skills. The same is true for a cosmonaut.

2) We need to reduce the nomenclature and volume of the documentation, including onboard documentation that is used for the spacecraft operation. The exception may be done for the documentation used for the tests of the spacecraft systems.

3) We need to aim at the optimization of the operations performed by the crew. As a rule it is a creative process, intuitive, individual and related to the freedom of choice. On the other hand, selection of the optimum solution (and the only right one!) may be considered as a process close to the determined decision.

4) The level of crew training for utilization purposes is a necessary but not sufficient condition for its solution. To make it sufficient we need to add intuition based on the accumulated experience, special knowledge, general engineering training and mental stability under stress. The level of crew training may be considered as the knowledge and the feeling of the system based on the knowledge. Cosmonaut’s creativity is an ability to adequately analyze the actions in contingency and select the optimum recovery means.

4. Conclusions

Human flights of increased technical complexity in the near-Earth orbit, missions to the Moon, Mars and asteroids require high level of crew independence. This drives the necessity of more profound and multi-profile training to fulfill the given task (training at the level of skills, but not at the level of operations).

As the tasks in space become more complex, the participation of human being in this process becomes more important. This participation as we know from practice in some cases becomes more efficient compared to the robotic vehicles, both from the operational and economic point of view. A good example is *Atlantis* (STS-125) flight to repair *Hubble Space Telescope*: NASA had to prefer human mission to robotic space means.

The probability of crew mistakes should be reduced not by increasing the number of instructions and making them more detailed, but by improved man–machine interfaces.

The necessity of multiple instructions is an indication of program drawbacks in the development of the hardware rather than of the crew inability to accumulate all the information in short time.

If the vehicle control actions may be formalized, they should be performed by the machine and this is being implemented in the human cosmonautics from year to year. But a human being-operator should always have the right to decide when to use automatic mode or take control for the implementation of the vital operations.

We can definitely state that the tendency to increase the determinism in flight operations reduces both the control efficiency and utilization efficiency of the spacecraft, actually hampering the progress of the human cosmonautics on its way from the Earth to the Moon, Mars and beyond. Creativity and determinism should be in a reasonable equilibrium.