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Is it worth the risk? – An astronaut's approach to risk awareness

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Abstract

The need to make human spaceflight as safe as technically possible is a characteristic of this special branch of space missions and drives the cost and feasibility of human space exploration. Between the time prospective astronauts first apply for a chance to fly into space and the actual time when they climb into the spacecraft on top of a rocket for the first flight, risk awareness, mitigation, and assessment are present as a constant background reflection. What drives human explorers to accept the remaining non-mitigatable risks and when is the individual "go" decision made? In light of future long-term missions leading humans again from LEO into deep space a sound understanding of this decision process may lead to an improved selection and composition of capable space expedition crews.

Keywords: human spaceflight, risk assessment, risk mitigation,

Acronyms/Abbreviations

EVA Extravehicular Activity
IVA Intravehicular Activity (with space suits)
SAFER Simplified Aid for EVA Rescue
SCUBA diving with a self-contained underwater breathing apparatus
SRB Solid Rocket Boosters

1. Introduction

The net outcome of the movie "Gravity" released in 2013 from an astronaut's perspective was the complete destruction of four space vehicles (one Shuttle Orbiter, one International and one Chinese space station, and one Russian Soyuz spacecraft in between), all within ninety minutes. Furthermore it showed severe training deficits of the astronauts involved, non-existent risk awareness (the character played by Clooney senselessly spends his SAFER cold gas supplies during EVA), and an incredible number of mission planning deficits. Not to mention the physically impossible depiction of space debris events, which is the dramatic ouverture of the disastrous sequence of events thereafter. But this movie won seven Oscars and grossed worldwide as much as an estimated amount of $723 million, which is comparable to the order of magnitude of a fairly ambitious science satellite project [1]. Discounting the effects of starring Sandra Bullok and George Clooney in the movie this success indicates that the public is (more?) ready to invest its money in seeing a space mission fail than seeing it successfully implemented – or did you hear of people putting in donated money when seeing International Space Station videos on 'You Tube'? Luckily an ISS astronaut's life is far less prone to the series of catastrophic events that plagued the actors in "Gravity". And they are better prepared to react should there be signs of an upcoming misfortunate event that could endanger their lives and their mission. A number of precedence cases can be cited, where the true balance of risk versus achievement of today's astronautics becomes visible and the risk of future exploration missions can be assessed.

2. Tragic losses

It doesn't really mitigate the sadness of having lost a loved person for the family, friends, and colleagues, even if the fallen ones are instantaneously proclaimed heroes once their death becomes confirmed in an accident involving a spacecraft. They are dead and consequently investigations have to be carried out, at least to avoid future losses with the same undetected causes, if not to derive some sense from their tragic fate.

At the time I personally first considered to apply as an astronaut beginning of 1986 two things happened: I witnessed a talk of a German astronaut, Reinhard Furrer († 1995 in a plane crash) and Space Shuttle Orbiter Challenger, on which Furrer had just months before accomplished his Space Lab mission D-1 (STS-61-A) exploded 86 sec after launch because of a failed O-ring in one of its solid rocket boosters (SRB). The astronauts themselves were never involved in the relevant launch readiness meetings in which the final launch decision was taken despite engineers' unresolved worries to clear the different components of the Shuttle stack for launch on that particularly cold day, including the SRB, whose function was sensitive to outside temperature conditions.

While my fascination about the professional auspices of becoming an astronaut and being able to follow Furrer's example to perform µg science in Space was steadfast, the investigations into the accident quickly revealed a chain of managerial and technical misjudgements that could have been avoided with due diligence and would probably have saved the astronauts' lives. Especially the fact, that engineers had seen O-ring burn-throughs before and reported them without action being taken was regarded as a unjustified acceptance of a potential threat to upcoming missions and risk awareness measures were taken to not let those kind of early warnings slip through the grid. [2] It is tragic to state that despite this existing and experience a partly similar negligence in judgement led seventeen years later to the second disaster, this time involving Space Shuttle Orbiter Columbia and its crew of seven astronauts. The culprit cause – icy debris falling down along the Shuttle stack from the insulation elements of the external fuel tank – had been observed before, but again the detailed single reports of Shuttle orbiters returning from Space with impacted heat shields were not condensed to create a risk awareness and result in management action.

Nevertheless back in 1986 I upheld my astronaut application in full trust, that a honest and upright investigation must lead to changes in both the technical layout as well as in the way, the whole spacecraft is processed and cleared for flight. I am sure that all the astronauts and cosmonauts that were on their way to the launch pads in the various spaceports of the world after the various spacecraft accidents had that same conviction, that the tragic lessons learned had been implemented and that the space vehicle in front of them was the best and safe that contemporary technology and engineering diligence could provide for them.

Anyhow, between my application in 1986 and the actual spaceflight to the Russian Space Station MIR in 1997 was a span of eleven years full of emergency training, spacecraft safety demonstrations, and technical knowledge down to the innards of the various sure fire Soyuz back-up systems that would kick in once the prime, the secondary, or in some cases even the tertiary system had failed to operate. At the time I applied the spaceflight itself was just a vague possibility in the future. The decision to go into Space on that cold day in February 1997 had been taking shape long ago and was – both by my wife and by myself – regarded as an inaugural flight to my full astronaut qualification and despite the risks the logical consequence of going through all the labours which astronaut training inevitably brings to the astronauts and their families. For the second flight in an astronaut's career this balance needs to be considered anew.

3. Exemplary cases of inflight anomalies and the astronauts' roles

1997 proved to be a year full of near-catastrophic events for the MIR space station. The first element - Base Block Sveszda - was launched in 1986, the same time the space community was shocked by the loss of Challenger and its crew. So it went almost unobserved, although this launch would form the beginning of a new era in many ways: permanent habitation in Space, multi-vehicle logistics, and finally, the onset of continued international cooperation in low Earth orbit. Needless to say that we still today harvest the fruits of that new courageous technical demonstration after the Apollo moon landing programme.

At the time I arrived at the MIR station in February 1997 in a Soyuz TM spacecraft, more than twenty expedition crews had fulfilled their flight programmes with stay duration from a couple of weeks to the epic 437 days, which the medical doctor and cosmonaut Valeri Vladimirovich Polyakov spent in one single flight on board of MIR. The complex had been constructed over ten years, with one of the latest additions in 1995 – a docking adapter module – even allowing Shuttle orbiter dockings to the Kristall research module without having to re-arrange the complex.

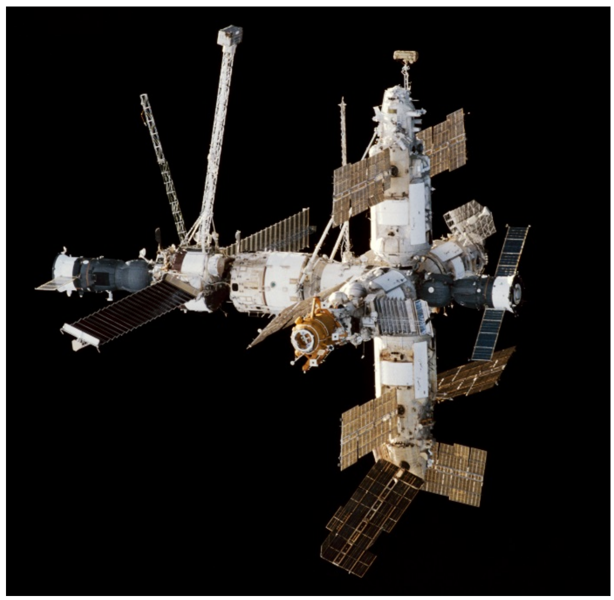

Fig. 1. MIR Space Station complex as viewed by STS 89 in January 1998 [4]. The Spektr module is pointing in the nadir direction

3.1 The MIR fire

At the time I flew up to MIR, some of the deficiencies of the complex started to show and caused increased workload for the crews. The complex, originally not foreseen for a fifteen year lifetime and in the presence of more than three, better only two persons on board, basic systems were becoming unreliable in its core functions, namely the Data Management, the Life Support and the Thermal control systems. The increasing lack of power generation had partially been cured by the addition of the Spektr research module as late as in 1996. Other logistic shortcomings (water supply) were compensated by the enormous upload and download capacities of the Space Shuttle orbiters docking to the station. The use of back-up systems, for example for the generation of oxygen, had become the rule rather than the exception. Especially


Fig. 2. MIR crew in full-face mask (Photo Ewald/DLR)


Fig. 3. Spent full-face masks (Photo: Ewald/DLR)

in times of crew handover with six persons on board the oxygen had to be replenished by $LiClO_4$ cartridges, which released up to 600 l (in normal pressure conditions) of oxygen into the cabin. The candles had reliably functioned thousands of times in non-space related situations, the 1001st exploded in a torch flame of fire in the hands of board-engineer Alexander Lazutkin on the evening of February 23, 1997, a Sunday, the fourteenth day of our three-week joint German-Russian mission programme MIR '97. It forced us to spend two and a half hours in the full face breathing masks, an experience that had been mimicked for a short time frame during our emergency training, but without the oxygen flow and the closed breathing cycle into and from a rubber bag. With the on board fire water-based extinguishers the fire could be extinguished or at least cooled down such that the oxygen releasing reaction stopped. Still the complete station atmosphere was filled with smoke, water vapour, and unknown by-products, which we could not measure exactly. In the debriefs that followed it became known that some of the fire extinguishers were still bolted to the walls with their launch locks, gas masks would become fully functional only after a latency time out of the trained specs, and inter-module ventilators had to be shut down manually rather than by the programmed sequence in the event of an off-nominal situation.

All that experience did not leave an impression of helplessness or immediate danger of loss of our lives with the crew. On the contrary everybody worked according to the trained procedures with the exception that the just arrived so-called visiting crew did not retreat to the (newly arrived) Soyuz for immediate departure, but supported instead the main station crew to overcome the fire and its consequences. Even though access to the Kvant-1 docking port where the Soyuz spacecraft for the main crew was attached, , had been temporarily blocked by the fire that fact did not lead to attempts to prematurely attempt to reach this Soyuz. All in all concentrated and focused response to the event with a clear chain of command in place helped to overcome the situation, there was no place for movie type heroes. The necessity to clean all the surfaces of the MIR station from the soot and the limited capacity for oxygen production were the most noticeable aftermath of the fire for the weeks after the event. Reflecting back, the deep-rooted trust into the rescue capacity of the attached Soyuz spacecraft has been the most reassuring basis for our actions, taking one step after the other as long as we had options. At every instance all six crewmembers agreed on the "what if" ways to proceed.

Once the air-revitalisation resources of the first set of masks would run out we would look at each other for signs of deteriorating health conditions while breathing the contaminated cabin air (CO poisoning, shortage of oxygen), in which case we would have used the second and last available set of masks to escape in our respective Soyuz spacecraft under emergency descent conditions in hermetically sealed space suits , assuming that the Soyuz air volume likewise had been contaminated by the fire. This would have brought us into Northern Canada in the middle of their night with no way to inform the Moscow Control Center, as line-of-sight VHF communication from MIR to them could only have been regained in the early morning hours, when our flight path would have lead us again over former Soviet territory.

And still: it was our stead-fast conviction that perhaps we would live through a memorable long night and difficult period before rescue, but in the end survive thanks to the assured return capability of our Soyuzes.

3.2 The Progress collision event

On 25 June, 1997, the Progress M34 cargo ship collided with the MIR station complex while performing an approach test under manual remote control from the control set-up in the MIR base block. The cosmonauts lost control and sight of the approaching vehicle due to a chain of misjudgements in the (ground) preparation of the test. It collided with the solar panel array of the Spektr module and other structural components of MIR before floating away. As a consequence of that hit, the Spektr module vented air into Space at a rate that triggered the alarm of first the air flow sensors, and later the sensors that would detect a critically dropped pressure within the complex.

Emergency training on the ground had comprised of a session in a full-size mock-up of the Base Block of the MIR station within a surrounding baro-chamber. After artificially creating a hole in the pressurized mock-up the crews' task had been to first assess the reserve time given the indicated flow rate and the known volume of the MIR complex. Sufficient reserve time then would allow to isolate the leak by a series of module-hatch closures and measuring the flow rate. In our training case the leak had been created in the descent module of the attached Soyuz mock-up, with only 3.5 m^3 the smallest of the compartments by a factor of several hundreds. Consequently the leak flow rises enormously when the hatch is closed between the small volume and the large station volume. An impressive warning of the imminent dangers was the completely destroyed dash board of the training Soyuz, where an inattentive crew had not equalized the pressures between the leaking Soyuz descent module and the rest of the station before unlatching the hatch. The force of the air-pressure difference on a 1-m diameter hatch surface could have killed the crew member as the hatch explosively opened into descent module volume. As a consequence of the leaking Soyuz and following the procedures in our training case we took our personal contour couches and space suits into the stable station volume and sealed off the descent module's hatch, in theory waiting for a rescue plan in contact with the ground and using the MIR station as safe haven until future Soyuz space craft arrived for our return to Earth.

On that fatal 25 June 1997, the crew exactly followed the same procedures, being almost immediately aware of the dangerous leak and the subsequent drop of station pressure. As a deviation from the rule quite a number of power lines, airflow tubes, and data cables had been routed through the open hatches of most of the MIR modules, giving evidence of ad-hoc improvisations due to the unexpected endurance of the ever growing complex, which engineers originally hadn't foreseen. Consequently the cosmonauts in that situation first had to cut those connections that did not have a quick disconnect, reportedly by heavy cable cutting devices, also under the risk of electrical shorts and shocks. Given the described increased air-pressure drop rate in an isolated module they had one chance of quickly sealing off the leaking module with a lid from the side of the station, as the inner hatch lid of the Spektr module contained the docking mechanism and had been completely secured out of the way. They had one chance of doing that as the enlarged pressure drop immediately would press the closing lid to the hatch sealing surface.

The provisionary lid later was replaced by a new crew by a hatch that would allow the repaired power cables from the Spektr solar panels be again routed through the hatch, thus regaining part of the urgently needed power from the Spektr power control system. This Intravehicular Activity (IVA) in bulky space suits within the small volume of the connecting node was an adventurous and laborious affair, for which the most experienced Russian space walker Anatoli Yakovlevich Solovjev and his engineer crew mate Pavel Vladimirovich Vinogradov were specially trained. They even gave thought to recuperate some of the personal items of NASA astronaut Michael C. Foale, which he had to leave floating in vacuum inside Spektr, where he had arranged his personal sleeping place during his stay on board.

The best accounting of both MIR critical incidents in 1997 and many more of the plagues that beleaguered the MIR complex in its late stages can be found in the voluminous documentary book by Bryan Burrough [5].

3.3. ISS incidents

Given its lifetime and increased complexity severe incidents aboard ISS have been extremely rare, being limited either to false alarms, imminent danger of loss of ammonia cooling agent, and work-arounds for failing equipment or could be mitigated by measures such as orbital Debris Avoidance Manoeuvres (DAM), or contingency EVAs. Two incidents should be considered for the purpose of this paper.

3.3.1 Drowning in Space

On 9 July 2013 ESA astronaut Luca Parmitano and his experienced EVA NASA colleague Chris J. Cassidy exited from the Quest airlock of the International Space Station in Extravehicular Mobility Unit (EMU) space suits to perform some planned repair works outside the station. The EVA went extremely well and the pair could even prepare some ahead-tasks, to save time on the second planned EVA shortly thereafter. It had been the first EVA for Luca personally and the first for an Italian born astronaut. Given this success everything was in good shape for the next planned EVA.

On 16 July 2013 the pair went out again and translated to different work sites on the station, Cassidy taking one route around the USOS modules, Parmitano another route. Both astronauts had their spring loaded long-reach tethers secured to a fixed point near the airlock hatch. Less than an hour into the EVA Parmitano noticed a tickling feeling on the back of his bald shaved head, which he accredited to water inside his helmet. His impression was that it was different from the feeling he had when sweating inside the bulky spacesuit and that the water volume increased with time.

Then this experienced military test pilot, used to make lonely real-time life-or-death decisions, in his second ever EVA, set to fulfil the tasks given to him with highest efficiency and performance – made the call that saved his life! Instead of going on in the wish to not compromise the EVA mission, he reported back to Houston about his observation. With the possibilities similar to SCUBA diving that a two-person EVA offers in terms of buddy-to-buddy support, Cassidy translated over to Parmitano and shone a penlight into his helmet. Together they went through all possibilities of water presence in the helmet, Parmitano even drinking up his water bag, but the water flow did not stop. With his eyes and ears already covered by the increasing water layer on his head, the abort decision was called and the two EVA astronauts started to retreat to the airlock. Because of the different routings of their tethers, Cassidy and Parmitano had to go separate ways. The other four Russian and US crew mates assembled in the inside compartment of the airlock module to administer help as quickly as possible. Parmitano made it to the airlock deaf and blindfolded by the water inside the helmet, by using the light tug of the spring-loaded tether to guide him home. After re-pressurization an estimated amount of more than one and a half litres of water was mopped from inside the helmet and Parmitano's face. A lengthy fault tree evaluation later concluded that an undetected faulty clogged valve would reroute cooling water into the breathing tubing instead of the cooling garment that astronauts wear to prevent overheating. [6]

3.3.1 A hole in the Soyuz

The most actual news (September 2018) from the ISS again report a leak, this time in the orbital compartment of Soyuz MS-09, having arrived at the Space Station on 8 June 2018. The leak could be detected by sound measurements of the airflow, and a sequence of hatch closures, while watching the pressure drop indications. Contrary to our training experiences (see section 3.2) the leak does not necessitate an immediate isolation of the Soyuz – endangering the assured return of the Expedition 57 crew - but could be fixed by a patch considerably lowering the air flow by orders of magnitude. At this moment it is unknown what caused the 2 mm sized leak and a commission has been formed to investigate the root cause. Again the crew aboard reacted with outmost prudence and calm, the procedures were successfully executed, and the mission goals are not compromised.

Despite this rumours are going strong, fired by social media tweets of authorized and unauthorized sources. The whole range from meteorite impact to fabrication negligence to planned sabotage is discussed in the pertinent (and sometimes impertinent) social media fora.

Also contrary to the situation back in 1997 the crew becomes aware of these suspicions, when reading the news sources available on board.

5. Discussion

As described in the previous sections crews in numerous spaceships have escaped in critical situations, mostly by applying enhanced awareness of unusual circumstances that could lead to catastrophic developments. This raised awareness is mostly due to the prolonged training which includes an seemingly endless repetition of off-nominal situations played-in by the instructors. In the real case the crews acted according to the predefined command chain, even in cases where senior crew members found themselves under the authority of a less experienced person. Aboard space station the deep-rooted trust in the assured return by the Soyuz is an important element in assessing emergency situations and the decision whether to fight or to leave. The Shuttle astronauts perishing in the two tragic disasters did not have that chance at all, as they were left unaware of the defects in their vehicles.

The situation changes drastically when an easy way down is not available, such with expeditions on a non-return trajectory beyond the Moon and on to Mars. Here we talk about prolonged phases of boredom and monotony and a considerable non-mitigable risk of a catastrophic technical failure plus an assured increase in the probability of radiation inflicted diseases.

The only argument to positively tip the balance of potential achievements vs. risk to the side of mission accomplishments is a deep felt and proven conviction that the gain in both research knowledge and personal maturity during the complete mission duration is enough to carry the astronauts through even a two-year mission to Mars. Future crew selection needs to take this into account as a personality trait, it cannot be learned.

If wanting to be the First to set foot on Mars is the only motivation, it is definitely not worth as an argument enough to balance the risk of going.

6. Conclusions

One concluding word for the esteemed reader: once up to cruising altitude on your next long-haul flight you will be surrounded by an environment as deadly and hostile as Space. But after carefully following the safety demonstration you will still unfold your newspaper and relish the inflight meal. You will not sit cataplectic and wait for the worse to happen. See – this is how astronauts approach the routine days of their flight! Only when something extraordinary happens they will switch into emergency mode. Contrary to your role as a passenger it is the crew and the quality of their training that will make your day.

Acknowledgements

Writing this paper brought all back the memories of our great time together as MIR '97 space crews on the way up, aboard MIR, and on the way down. We were literally glued together by escaping unharmed from a scary scenery, where each of us would have been lost if not for the comradery that evolved during our time together in training and spaceflight. Thank you, Vasily (Tsibliyev), Sasha (Lazutkin), Sasha (Kaleri), and CDR Valery (Korzun)

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