

EVALUATING FAILURES AND NEAR MISSES IN HUMAN SPACEFLIGHT HISTORY FOR LESSONS FOR FUTURE HUMAN SPACEFLIGHT

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ABSTRACT

Studies done in the past have drawn on lessons learned with regard to human loss-of-life events. However, an examination of near-fatal accidents can be equally useful, not only in detecting causes, both proximate and systemic, but also for determining what factors averted disaster, what design decisions and/or operator actions prevented catastrophe.

Binary pass/fail launch history is often used for risk, but this also has limitations. A program with a number of near misses can look more reliable than a consistently healthy program with a single out-of-family failure. Augmenting reliability evaluations with this near miss data can provide insight and expand on the limitations of a strictly pass/fail evaluation.

This paper intends to show how near-miss lessons learned can provide crucial data for any new human spaceflight programs that are interested in sending man into space.

1. INTRODUCTION

Evaluating reliability for forthcoming space programs, particularly man-rated systems, is challenging. One reason for this is that it is rarified territory. There are only three countries to date who have launched humans into space, and those flights took place using a limited number of launch and space vehicles, largely comprised of custom parts. In order to get a sample size large enough for a meaningful reliability estimate, particularly for a dissimilar vehicle, unmanned launch vehicles reliabilities are often used to estimate it.

But failure criteria for a manned and unmanned vehicle are not necessarily the same. A problem that a payload could compensate for might not be as readily survivable for a craft that must return safely to earth. On the other hand, something that would send a payload into a useless orbit may be readily survivable for a manned vehicle, perhaps even without losing the mission, as happened with the Abort to Orbit of STS-51F. Because the mission was to test Spacelab systems and perform

science, the lower orbit was not a hindrance.[1] Under these circumstances, an apparent success may actually represent catastrophic failure for the new vehicle and a previously documented failure may not be catastrophic.

Additionally, launch risk, while a significant portion of the overall risk, is not the only risk for a manned vehicle that must spend some set time in space and then return safely. For that risk, there is a dearth of data outside of previous human spaceflights. Frequently, for ease, reliability tends to be focused on launch, using pass/fail, because that's where the most data is. However, the focus on the launch failures can be misleading especially when one notes that three out of four spaceflights that involved catastrophic results (and several that ended successfully) involved either failures that occurred after launch or manifested during other stages, particularly reentry.

Complex craft, with many goals and many factors, do not lend themselves well to binary pass/fail criteria, or rather, using that pass/fail criteria can skew the results depending on what aspects one is evaluating. The intent of this paper is to provide examples of useful aspects of near miss or catastrophic failures to demonstrate the value of examining these failures in detail. By using that data to drive requirements and designs for future human spaceflight programs, more robust and safer designs can be worked, using lessons learned the hard way. This data can also add depth and refinement to the limited data available for estimating reliability for unproven hardware.

Because failures are not limited to manned spaceflight systems, the term "human" will often be used to indicate the human/safety implications. Human spaceflight and manned spaceflight are used interchangeably in this paper.

2. LAUNCH

2.1. Launch Lessons Learned – From Failures

The best aspect of studying launches for safety concerns is the quantity of data available. Anything going into

space is subject to a well documented launch. Manned and unmanned launches are prone to many of the same issues and, in some cases, use the same hardware. Because of this, a new space program can use considerable history to evaluate a launch system. Solid and liquid rockets, both cryogenic and otherwise, have all been used for both manned and unmanned flights, allowing for a substantial data set for evaluations.

Ideally, any rocket designer would examine as much failure data as possible for lessons learned, particularly those rockets using similar (or even identical hardware), but that review should also encompass key launch systems, like avionics, separation, and software.

One of the two lessons readily learned going through past launch failures (regardless of rocket type) is that even proven hardware and/or software can fail when used in new applications or new configurations. For example, Ariane 5 failed during its maiden flight when untested heritage software was shown to be a poor match for the increased thrust and trajectory of the new, more powerful, rocket.[2] Integrated testing of complex systems is key to a successful program and shaking out incompatibilities before they become deadly.

Another key lesson, demonstrated unfortunately by the Challenger Shuttle disaster involves learning from the failures and danger signals of the past.[3] Rather than accepting anomalous readings or behavior, a rigorous review of even minor anomalies and unexpected results can highlight a correctable problem before it becomes deadly. Many rockets that eventually failed did so only after test anomalies or previous failures were not adequately addressed.

2.2. Launch Lessons Learned – From “Successes”

Since rocketry took off, there have been more than 4500 successful launches of significant rockets (as opposed to test flights and hobby flights), a tremendous accomplishment and source of data, but the data has some limitations. For instance, the amount of data readily available on a successful rocket flight is frequently very limited outside the immediate program.

Many launches are associated with defense systems or proprietary rocketry systems where information, other than overall success or failure, is not publicly available. With spectacular or expensive failure, sometimes the reasons for failure are released to the public. For

successes, it is exceedingly rare for anomalies or other non-catastrophic failures to be advertised at all. This is a serious limitation when trying to glean useful information from launch successes, though such data can be used, if used carefully, for reliability calculations.

Key exceptions to this general trend are previous manned systems. Because of the civilian aspect of those launches and the international cooperation between spacefaring nations, a wealth of information is publically available on the manned space programs of both Russia (formerly the Soviet Union) and the United States. This data is potentially very useful.

For example, the Apollo 12 rocket was struck by lightning during launch. As a result, the crew module’s instruments went off line, cutting off telemetry to the ground. When telemetry resumed, it was garbled and potentially inaccurate. A ground controller figured that the signal conditioner had gone off-line and need to be reset. The command to do so was obscure, but, Alan Bean, the lunar module pilot, remembered it from a training incident a year before. This kind of near disaster not only serves as a reminder to protect against lightning, but demonstrates the importance of exhaustive training and exercises that simulate even obscure failures. Because of the ground controller’s understanding of the systems, he was able to accurately diagnose the problem. It is essential that the ground controller understand his or her systems. Equally important, in this instance, was the knowledge Alan Bean had retained from training. Training at NASA for flights is exhaustive and this was not the last time it saved the situation. [4][5][6]

There was another near miss with STS-61C, where the launch was scrubbed due to weather. Unknown to the ground and crew, a temperature probe broke loose and jammed open a pre-valve, leaking out great quantities of liquid oxygen. Although the potential repercussions are speculative, there are several scenarios that could have led to several unpleasant outcomes, including a turbopump overspeed destroying the hydraulic systems and/or inability to make it up to orbit. [7][8] Foreign Object Debris (FOD) is a huge risk during launch and considerable steps are now taken at NASA to reduce it, including screens internal to the fuel and oxygen systems. FOD has been implicated in a number of unmanned launches as well.

And the problem was not entirely eliminated. On STS-93, a wiring short shut down the primary controllers for two out of three engines. The engines switched automatically to backup controllers which allowed the flight to continue. The Orbiter would have been lost, otherwise and the crew would have tried to bail out, a risky operation. At the same time, a pin broke free in the fuel injector and impacted on the engine bell, cutting across hydrogen cooling lines and releasing liquid hydrogen. Fuel was exhausted prematurely, but, fortunately, was not so severe to seriously impact the flight. The Orbiter made a slightly lower orbit successfully where the mission (releasing the Chandra Observatory) was successfully completed. If the leak had been larger, the crew might have been forced to make a Return To Launch Site (RTLS) abort, another tricky operation that has never been attempted before.[4][9][10] In this case, several key design philosophies worked in concert to prevent disaster, including true and automatic redundancy, that allowed the engines to use backup controllers without requiring direction. Wiring flaws that allowed propagation of failures to multiple components were addressed – the Shuttle fleet stood down to work a number of wiring issues for several months. Future reusable craft, in particular, must be especially cognizant of wiring concerns as work in and around wiring can cause inadvertent damage. And diligence to eliminate FOD must be continuous.

Of course, Columbia was eventually lost to FOD,[11] external to the craft rather than internally – but still deadly. Notable near misses where considerable damage to the Thermal Protection System (TPS) occurred that, under slightly different circumstances, could have led to loss during reentry: STS-27R and STS-45, though the latter might have been orbital debris[12].

2.3. Crew escape

Abort is a term used for both manned and unmanned spacecraft, though the implementation is generally different. Abort is intended to save life and minimize the impact of a catastrophic failure. In an unmanned vehicle, this is done by exploding the launch vehicle to minimize downstream damage (no crashing into cities and towns). In a manned vehicle, this is done by ejecting the crewed element, preferably as far from the rest of the launch vehicle as possible.

Aborts have been used successfully many times to minimize damage from malfunctioning unmanned craft, and have even been used to save crew on at least two different occasions. In one case (Soyuz/Soyuz-18a), a second stage separation failure triggered the crew escape system. Unfortunately, the abort was launched toward earth and landed with very high g-forces (>20 g). Although the crew survived, the landing was dangerous, the landing spot was precarious and it took more than a day to rescue the crew. [4][13][14] Commander Lasarev sustained internal injuries and never flew again.

But there were good lessons here. First, that an abort system is better than none for launch systems – it's unlikely the crew would have survived at all without it. Secondly, that the crew escape system apparently was inadequate to this usage; better to have gone up and away rather than launching directly to the ground. Perhaps attitude sensors could ensure the escape parameters are tailored to attitude.

On Soyuz/Soyuz-10a, a fuel spill caught fire just prior to launch. The abort command from ground control failed because the control lines had already been burned through. As the crew escape capability was not automated nor crew commandable, abort was delayed until the ground was able to link via radio and command the escape system. The escape system activated only two seconds before the booster exploded. The crew, though badly jolted, survived.[4][15]

Both the problems and the final success of this escape highlight the importance of options. An all manual system is dependent on people being alert (and not incapacitated). An automated system is dependent on computer and software working as expected or situations being within expected parameters. Having the option for both, while not without its own risks, leaves options open when the unexpected happens.

Sometimes when a system is not used is also significant. When the crew of Gemini 6 should have ejected from the spacecraft after an early abort (per procedure), they chose not to. Because the launch vehicle had not actually lifted off, the crew's decision turned out to be a good one. But a factor in that decision was a lack of confidence in the escape system.[4][16] A safety system that is unreliable, unproven or is perceived as such by the crew may not be any better than nothing at all. If the crew doesn't realize its limitations, they might not

pursue an alternative with a better chance of success. If it's perceived as unreliable, the crew is unlikely to use it until it's too late.

3. ON-ORBIT FAILURES

Once we look beyond launch failures, the data is largely limited to manned programs. Such things as tin whisker failures on satellites[17] and orbital debris impacts on orbiting crafts[18] are pertinent to manned systems, but the former can be addressed with proper material controls and due diligence. The latter is a considerable problem too large to be addressed within this paper. However, many of the failures on-orbit that are of interest are related to stations and manned orbiting spacecraft. There are a number that provide salutary lessons for future manned space programs.

For instance, several flights struggled with temperature control, including Vostok 4, Vostok 5[19] and Apollo 13 (which was only one of its issues)[4]. Although it seems a minor concern, temperature control is key not only for the crew's comfort but for equipment. Low temperatures and condensation put electronics at risk. Too warm, and components can readily overheat. Thermal control is a non-trivial issue as temperatures can vary drastically in space from less than a hundred degrees below zero (°C) to more than a hundred degrees above zero (°C). Power consumption of nominal equipment can add appreciably to the heat burden. Thermal control often involves a combination of systems, both air and liquid cooling, but steps need to be taken to ensure they work in concert, and that a problem with one can be compensated for in the other.

Attitude control/guidance is another type of failure that endangered missions and crew. On Gemini 8, a failed-on thruster caused an uncontrolled spin. Believing it was associated with the docked Agena spacecraft, the crew module was undocked, which resulted in even faster spinning with the mass of Agena no longer slowing it down. Close to unconsciousness from the g-forces from the 1 rev/s rotations, the crew managed to gain control by turning off the automatic systems and using the reentry systems for control. Although the mission ended early as a result, the crew were able to return safely. NASA adopted provisions that can isolate faulty thrusters.[20]

Inadvertently turning on the wrong guidance system during Apollo 10 caused another uncontrolled spin that

was only corrected by shutting down the system back off and flying manually. A crash was narrowly averted.[21]

Apollo 13 was a spectacular example of what can go wrong (due to a design change that wasn't carried forward to all the affected systems) and how excess capability in other systems can be utilized when things go wrong. That margin saved lives, although it was challenging and uncomfortable. Among the other lessons learned were the advantages of like interfaces for similar systems (such as LiOH canisters – a lesson that has served the Shuttle, extravehicular (EVA) systems and the ISS well) and the importance of knowledgeable systems experts on the ground to help find solutions to challenging problems.[4][22][23][24]

And there are many more on-orbit near misses that provide lessons. For any program contemplating having EVA, the Apollo Lunar Surface Journals provide incomparable data about setting foot on other planetary surfaces.[25] *Walking on Olympus: An EVA Chronology* is also an excellent resource for EVA data. [26]

4. REENTRY/LANDING FAILURES

Our "safe reentry" history is almost entirely restricted to manned spacecraft again. Despite the risks of launch, three of four catastrophic in-flight events have involved reentry. It is an unforgiving phase of flight, subject to several extremes including heat and acceleration.

The first catastrophic event involved Soyuz 1, where Cosmonaut Komarov lost his life when his main chute failed to open. Komarov tried to manually deploy his reserve chute, but the reserve became tangled with the drogue chute which had deployed but not released. Retrorockets also failed to fire. The results were devastating. The rush to space drove unsustainable schedules, and Soyuz was launched with several known problems and more suspected. [27] Schedule pressure is a common theme for many of the most devastating space accidents.

Another painful in-flight failure also involved reentry, in this case, a breathing ventilation valve that was jolted open during separation on Soyuz 11, venting the internal atmosphere. The pyros for separation, rather than firing as planned (sequentially), fired simultaneously, causing damage to the valve. The descent module's atmosphere vented in about 30

seconds and, though the crew recognized what was happening, they did not have sufficient time to shut off the valve before they were incapacitated. The crew were lost.[28] The awkward location of the valve shut-off (and the time required to complete shut-off) were factors in this failure as was the lack of suits for the crew or emergency oxygen for the crew.

In the case of Columbia, on STS-107, the failure was tied to breach of the TPS, damaged during launch, which protects the rest of the craft from reentry heating. Hot plasma impinged on wing structure, wiring and eventually hydraulics that led to a catastrophic yaw that caused a break-up during reentry. There were no survivors. There was considerable history of foam impacts to the Orbiter, but no provisions for detecting or repairing catastrophic damage on orbit. Although, with the limited launch data, there was evidence of a significant hit, ground controllers were lulled into complacency by the very history of previous impacts into assuming the damage was sustainable. Details on this are discussed in depth in the Columbia Accident Investigation Report(s). [29][30]

The catastrophic failures provide only part of the available data for a new program. A number of other survived failures highlight what could fail and what provisions prevented tragedy for reentry/landing. Vostok 1, for instance, failed to separate completely from its service module until the wires between the reentry capsule and the service module were burned through during reentry, affording the first man in space, Gagarin, a very rough ride. Because of the design of the capsule, the reentry vehicle righted itself during reentry so that the heat shield took the heating.[31] This same failure (or a similar one involving a restraining strap), has recurred multiple times on Soviet/Russian reentry vehicles, including Vostok 2,[32] Vostok 5,[33] Voshkod 2,[34] and Soyuz-5,[35][36]. The design of the descent module, the designed-to-burn wires connecting the descent and service modules, the titanium airlock, and the thermal protection system have made these failures survivable. However, in several cases, these failures led to rough reentries, overheating, toxic fumes internal to the module, landing far from the original planned target, and very hard landings. In some cases, the original failure, failure of the modules to separate completely, was compounded by descent systems not working or retrorockets failing to fire. Sometimes, it was the cause.[34][35]

Landing outside the expected zone was another common problem for capsules. A combination of factors (distraction, overwork and a malfunction in the automatic alignment system) contributed to Mercury 7 missing its reentry mark such that it landed 400 km from target.[4][37] Separation issues drove Voshkod 2 and Soyuz 5 off the mark. Voshkod 2 was stranded in the woods overnight before rescuers could retrieve them.[35] With Soyuz 5, Cosmonaut Volynov walked to a nearby peasant's house given he knew it would be some time before he'd be rescued, despite the fact his hard landing had broken his teeth.[36] Soyuz 23 performed an emergency landing after an aborted docking (due to electronics failure) but landed in a frozen lake at -20 °C. They could not be retrieved until the next day, where they, amazingly, were found alive.[38] Although the capsule landing system allowed for flexibility in the target, missing the target was not without risks. These landings were survivable because of resilient designs that allowed for delayed retrieval.

On the last Apollo mission, Apollo-Soyuz, a crew error left the reaction control system on during reentry, allowing toxic fumes to enter the crew module through relief valves used for equalization. The challenges of the toxic atmosphere were compounded with a harder than normal landing. Fortunately, the crew did have oxygen masks available. An inhibit scheme that precludes incompatible flight modes (reaction control during times when equalization valves are open) could have prevented this failure.[39]

5. GROUND SAFETY

In addition to protecting the safety of the crew during flight, considerable effort needs to be taken to protect those on the ground. The most obvious concern, of course, is spectacular launch failure or explosion. Early in the space race (October 1960), there was a horrific fire during preparations for a ballistic missile launch. Schedule pressure induced the man in charge, Marshal Nedelin, to have people work fuel leak and electrical problems while the rocket was still loaded with fuel. While work continued on the rocket, Nedelin and many dignitaries were brought close to look over the craft. A critical safety device was left in the wrong position, energizing the systems. When the safety device was reset, the last safeguard was removed. The resulting explosion cost Marshall Nedelin and many other people their lives. [39][40]

The risk of fire during launch is still very much alive. Two Long March launches went awry in 1995 and 1996 resulted in crash landings seconds after launch, with a considerable death toll each time. [41] In 2003, Brazil's space program took a considerable step backwards with a launchpad ignition of one of the solid rocket boosters, killing twenty and destroying the launch pad. [42] Underfunding, a breakdown in training, safety procedures and routine maintenance were all cited as contributors to the Brazilian tragedy as was an electrical fault. [43]

There are other potentials for catastrophic fire that can affect ground personnel and crewmembers. The Apollo 1 fire provides an excellent example of the risks of off-gassing of materials and the flammability risks of high pressure oxygen environments, of insufficient safety precautions available during tests. Three crewmembers were lost when a spark ignited a fire in the capsule. The high internal pressure precluded immediate access to the crew. A number of material and electrical issues were identified as potential contributors, made worse by high pressure.[44][45] Similarities between this fire and one that took the life of Cosmonaut Bondarenko in 1961 during a test make this failure particularly poignant. Crewmembers, like the first man in space, Cosmonaut Yuri Gagarin (1967), and astronauts Clifton Williams (1967) or Robert Henry Lawrence (also 1967) and Cosmonaut Vosovikov (1993), have all been killed during training exercises. Test subjects have been killed or nearly killed in vacuum chambers after being exposed to vacuum.[47]

But ground personnel are also at risk. Ground personnel have been killed in a Delta engine fire in 1963, have fallen from heights in 1964 (Vertical Assembly Building), been struck by lightning (1965), and been asphyxiated with a nitrogen purge (1981). These failures highlight the importance of comprehensive safety precautions and training, personal protective equipment (such as oxygen monitors), etc.[47] The commercial world has already had its first losses as an explosion at a Scaled Composite site has killed three people and injured several more in 2007.[48] We must be diligent.

6. CONCLUSION

The failures and near-failures described here are only examples of the wealth of data available, information that can provide even more important lessons for those who would follow in illustrious footsteps or attempt to

venture beyond where we have been before. There is more data available about these failures and many more incidents than can be covered in this paper.

Studying the mistakes we lived through and those we didn't – allows us to learn what saved us or what failed to, where we went wrong and what we did right that allowed us to triumph after all.

There are lessons about design, which are often readily absorbed. But there are other more subtle lessons are available that are easily lost from program to program, like the importance of comprehensive training, for crew and ground control, the advantages of testing and the importance of examining anomalies in detail for hidden concerns. Having alternate methods to perform critical functions has been the key to recovering from numerous failures, and human judgment was vital in several instances. Additional design margin or flexibility also frequently provided the means that allowed for a non-catastrophic result. Schedule and budgetary pressures that compress testing or tempt programs to sidestep safety precautions have repeatedly led to catastrophic or nearly catastrophic situations.

Human spaceflight is complex, difficult and unforgiving, with so many potential avenues for things to go wrong. But that same human element has been the key to overcoming these issues time and again. And our ability to learn from past failures, to carry these lessons forward and implement protections has been the key to the overall success of our endeavors.

As new countries venture out into manned spaceflight, as commercial companies send humans into space, they have the opportunity to learn from where we have already gone, to implement/improve the design changes or processes that have prevented catastrophe in the past, or provide for those that failed to so.

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EVALUATING FAILURES AND NEAR MISSES IN HUMAN SPACEFLIGHT HISTORY FOR LESSONS FOR FUTURE HUMAN SPACEFLIGHT

There is a wealth of information available in lessons learned for human spaceflight.

- *Although limited in number, human spaceflight history tends to be well-documented in the public forum.*
- *Examining catastrophic failures for lessons learned is standard operating procedure.*
- *Looking at near-miss situations where the results could have been catastrophic is far less common.*
- *Looking at reliability in simply a binary pass/fail manner can miss these important subtleties that can provide excellent information for new programs.*
- *Evaluating both catastrophic and near-catastrophic events makes the most of the limited number of past manned flights.*

Evaluating near miss as well as catastrophic data can add appreciably to the knowledge base for any manned space program.



EVALUATING FAILURES AND NEAR MISSES IN HUMAN SPACEFLIGHT HISTORY FOR LESSONS FOR FUTURE HUMAN SPACEFLIGHT

Near miss failure information can provide critical data for new manned space programs.

- *Near miss information can provide a more complete view of credible failure scenarios that put human spaceflight at risk than can be gleaned from the small number of catastrophic events.*
- *Near miss information also includes key information on what design or operational factors prevented catastrophe.*
 - This allows a new program to ensure that comparable provisions are in place if the failure is pertinent.
 - This also allows new programs to leverage from the successful design philosophies that protected against failures.
- *This information can also add fidelity and refinement to reliability analyses if information on specific systems (and their failure modes) were factored in.*

New programs can take advantage of what failed and what worked and why in past spaceflight missions.



EVALUATING FAILURES AND NEAR MISSES IN HUMAN SPACEFLIGHT HISTORY FOR LESSONS FOR FUTURE HUMAN SPACEFLIGHT

Launch Failure Data

- *Launch failure data, even for unmanned missions, is frequently included when evaluating a new manned program.*
 - Launch data is extensive as there have been more 5000 launches
- *However, pass/fail criteria for unmanned flights do not always equate with success/failure of manned missions.*
 - Some “successes” could end catastrophically for a similar manned mission.
 - Some “failures” might be survivable for a manned mission.
- *Data available on “successful” but anomalous launches is largely limited to manned launches.*
- *For unmanned launches, anomaly data can be limited for failures; many of the failure analyses involve proprietary or classified information, limiting value.*

Launch data is useful and extensive, but has considerable limitations.



EVALUATING FAILURES AND NEAR MISSES IN HUMAN SPACEFLIGHT HISTORY FOR LESSONS FOR FUTURE HUMAN SPACEFLIGHT

Lessons Learned from Launch Failures

- *Use of heritage hardware and/or software in a new application does not guarantee success*
 - Integrated end-to-end testing and extensive flight testing are key to discovering incompatibilities prior to flight
- *Many launch failures were preceded by meaningful anomalies or failures in test or earlier flights that were not adequately examined or addressed.*
 - Evaluation and correction for every anomalous reading during a successful test or failure during a test can be key to preventing catastrophic failure in flight.
 - This can apply not only for identical systems, but systems that use similar/identical components in different launch vehicles.



EVALUATING FAILURES AND NEAR MISSES IN HUMAN SPACEFLIGHT HISTORY FOR LESSONS FOR FUTURE HUMAN SPACEFLIGHT

Lessons Learned From Launch “Successes”

- *Ground controller and crew knowledge of the system and awareness have been key factors in overcoming launch failures.*
 - Training for both controllers and crew has been successful largely because of the combined simulations with response to an exhaustive amount of multi-failure scenarios. Extensive and realistic ops training and sims (and therefore schedule, experts and facilities) are essential for any new program.
- *Foreign Object Debris (FOD) has been and continues to be a serious hazard for launch.*
 - Programs to eliminate FOD must be comprehensive and requires diligence.
- *Automated redundancy (not requiring human action) has also been the key to preventing catastrophe during launch.*



EVALUATING FAILURES AND NEAR MISSES IN HUMAN SPACEFLIGHT HISTORY FOR LESSONS FOR FUTURE HUMAN SPACEFLIGHT

Crew Escape/Aborts

- *Ensure abort systems are capable of performing adequately for all credible situations.*
 - All phases of launch/ascent are covered.
 - Allows for multiple methods to initiate abort, including from crew, ground control and automatically. This lesson could be expanded to cover most if not all emergency systems.
- *Crew escape systems have saved lives.*
- *The perception of the reliability of emergency systems can affect how those systems are used.*
 - A perception of unreliability or serious implications could delay use of the emergency system until its too late
 - Overconfidence in a system might restrict evaluation of other options that might have a higher probability of success.



EVALUATING FAILURES AND NEAR MISSES IN HUMAN SPACEFLIGHT HISTORY FOR LESSONS FOR FUTURE HUMAN SPACEFLIGHT

On-Orbit Failures

- *Micrometeoroids/Orbital debris*
- *Thermal control has frequently been a concern on orbit*
 - Temperature extremes can adversely affect equipment as well as personnel.
 - Gravity driven thermal convection is not available in zero-g or vacuum
- *Attitude control/guidance issues have frequently been a concern on orbit*
 - Wild gyrations can incapacitate crew.
 - Manual/automatic backup control methods can be the key to surviving a failure.
- *Design margin and extraneous capability can allow for unforeseen disaster and add flexibility.*
- *Interchangeability and standardization can allow for excess capability in one system to support another system that's faltering (such as the LiOH canisters on the Shuttle).*



EVALUATING FAILURES AND NEAR MISSES IN HUMAN SPACEFLIGHT HISTORY FOR LESSONS FOR FUTURE HUMAN SPACEFLIGHT

Reentry/Landing

- *Schedule pressure is frequently cited as a key driver, if not the key driver, in catastrophic events.*
- *Loss of atmosphere is catastrophic to all manned spacecraft. Steps to allow for surviving these events can be key to success, such as suits during dynamic phases of flight or backup oxygen.*
- *Corrective actions to failures of single items should be designed to be addressed with the constraints available, such as being crew accessible or correctable within the right time frame. NASA has an exhaustive system to evaluate this.*
- *Flexibility with regards to landing locations and conditions can contribute to survival.*
- *Designs that self-correct for potential failures can contribute to survival.*
- *Human interaction has been both a solution to a catastrophic condition and a cause. Control designs that preclude incompatible modes can reduce the effects of the latter.*

Three out of four catastrophic space accidents have involved reentry.



EVALUATING FAILURES AND NEAR MISSES IN HUMAN SPACEFLIGHT HISTORY FOR LESSONS FOR FUTURE HUMAN SPACEFLIGHT

Ground Safety

- *Ground safety provisions can be readily overlooked or left immature, preliminary and/or incomplete until late in the program.*
- *Launchpad/testing fires/explosions or mislaunches that crash before abort is possible have cost lives on many different occasions. Launch is dangerous.*
 - Only essential and trained personnel should be near a vehicle in a pre-launch condition.
 - Safing hardware before work is performed is a good practice.
- *Many have been killed or nearly killed in training exercises, in the spacecraft, in training craft, and in test facilities.*
- *Ground personnel must be trained and cognizant of particular hazards, like cranes, low oxygen environment and heights.*

Rockets use flammable/explosive materials. Care should be taken at every step of ground processing.



EVALUATING FAILURES AND NEAR MISSES IN HUMAN SPACEFLIGHT HISTORY FOR LESSONS FOR FUTURE HUMAN SPACEFLIGHT

Conclusion:

- *Evaluation of near-miss and catastrophic failures allow new programs to avoid past mistakes (or prepare for them so they are survivable).*
- *Design factors are often readily assimilated.*
- *Operations and programmatic factors may be harder to absorb. Study of this information can be instructive.*
- *Alternate methods, additional margin, flexibility, self-correcting conditions, thorough testing, failure analysis, exhaustive training and provisions for manual interaction have all been key factors in surviving near-catastrophic events.*

Complexity of manned spaceflight makes it risky. A thorough understanding of past experiences can mitigate that risk.



EVALUATING FAILURES AND NEAR MISSES IN HUMAN SPACEFLIGHT HISTORY FOR LESSONS FOR FUTURE HUMAN SPACEFLIGHT

BACKUP



Type of accident	Fatal Y/N?	Date	Program	Incident Description	Lessons Learned	Source material
CIV	Y	5/17/1930	Austria/ Early testing	Max Valier was an Austrian rocketry pioneer. He helped found the German Verein für Raumschiffahrt (VfR - "Spaceflight Society") that would bring together many of the minds that would later make spaceflight a reality in the twentieth century. Valier was killed when an alcohol-fuelled rocket exploded on his test bench in Berlin.	Lessons learned unknown.	1. http://www.astronautix.com/astros/valier.htm
GP	Y	10/10/1933	Germany/ Early rocket manufact.	Three killed in explosion in rocket manufacturing room in Tilling, Germany	Lessons learned unknown.	1. http://en.wikipedia.org/wiki/Space_accidents_and_incidents
GP	Y	7/16/1934	Germany/ Early rocket testing	Three killed in ground test engine explosion in Kammersdorf, Germany	Lessons learned unknown.	1. http://www.astronautix.com/lvs/v2cology.htm
GP	Y	1944	Germany/ Early rocket testing	An A4-rocket crashes at a test launch in a trench. Several soldiers who were in the trench were killed	Lessons learned unknown.	1. http://www.astronautix.com/lvs/v2cology.htm
IF	N	11/15/1959	US/High altitude balloon testing	Drogue stabilization chute prematurely deployed, Kittinger entered flat spin and shrouds entangled around his neck. Unconscious, Jo Kittinger spiraled downward uncontrollably reaching 120 rpm. Main chute deployed automatically at 12,000 feet. Kittinger survived. Also, Kittinger was at risk of cardiac arrest due to his blood being centrifuged away from his heart.	1. Cannot rely on manual activation of parachute systems.	1. Crew Survivability IAASS.pdf ¹ 2. http://www.nmspacemuseum.org/halloffame/detail.php?id=99
IF	N	8/16/1960	US/High altitude balloon testing	With small stabilizing chute deployed, Kittinger fell for 4 minutes, 36 seconds until 28-foot main parachute opened at 17,500 feet and he safely landed after 13 minute 45 second descent. Right glove developed leak during balloon ascent and hand became swollen, causing extreme pain, but had completely returned to normal by 3 hours after landing. Kittinger survived.	1. Isolated extremity exposure to vacuum is survivable (fact used in the design of some spacesuits).	1. Crew Survivability IAASS.pdf ¹ 2. http://www.nmspacemuseum.org/halloffame/detail.php?id=99 3. http://www.spaceref.com/iss/ops/Orlan_ops.service.module.pdf



GP	Y	10/24/ 1960	USSR/ R-16 ICBN	<p>As a prototype of the missile was being prepared for a test flight, it exploded on the launch pad when its second stage motors ignited prematurely, killing many military personnel, engineers, and technicians working on the project. (The official death toll was 90, but estimates are as high as 200, with 120 being the generally accepted figure.) Despite the magnitude of the disaster, news of it was covered up for many years by the Soviet government and did not emerge until the 1990s. Strategic Rocket Forces Marshal Mitrofan Nedelin, the commander of the R-16 development program, was among those killed in the explosion and fire.</p>	<ol style="list-style-type: none"> 1. Fuel was corrosive, toxic and binary. Pyrotechnic membranes were inadvertently ruptured, forcing a safing procedure or accelerated launch. 2. Rushing led to mistakes which caused the accident. 3. Escape routes are essential - apparently many were needlessly lost, trapped by enclosure. 4. Many people lost were supposed to be safely offsite in bunkers. Only necessary personnel should be exposed. 5. Event timers alone are insufficient. Better to have an event timer that requires another status, such as pressure, before triggering. 	<ol style="list-style-type: none"> 1. http://www.russianspaceweb.com/r16_disaster.html 2. http://www.aerospaceweb.org/question/spacecraft/q0179.shtml 3. http://www.astronautix.com/articles/therophe.htm
IT	Y	3/23/ 1961	USSR/ Training Simulat	<p>Bondarenko was working in a training simulator pressurized with pure oxygen. After removing some biosensors from his body Bondarenko washed his skin with an alcohol-soaked cotton ball which he dropped. The cotton ball landed on an electric hot plate which started a flash fire in the oxygen-rich atmosphere and ignited Bondarenko's suit. The watching doctor tried to open the chamber door but this took several minutes because of the pressure difference and Bondarenko suffered third-degree burns over most of his body. In 1984 the attending hospital physician Vladimir Golyakhovsky said that while attempting to start an intravenous drip he was only able to find an insertion point on the sole of one of Bondarenko's feet, where his flight boots had warded off the flames. According to Golyakhovsky, cosmonaut Yuri Gagarin spent several hours at the hospital as "deathwatch officer" and Bondarenko died of shock eight hours after the mishap</p>	<ol style="list-style-type: none"> 1. Fires in 100% oxygen environments are very destructive very quickly as many materials are explosively combustible in 100% O2. Steps must be taken to remove (a) ignition sources, (b) flammables and/or reduce the percentage of O2. 2. Pressure differentials for fires in enclosed chambers can restrict rescue. 3. Most modern spacecraft use mixtures of continuously replaced oxygen and nitrogen and carefully test materials for flammability. 4. Materials that are flame resistant in 100% O2 may become flammable at pressures higher than 1 atm. This lesson might have prevented Apollo 1. 	<ol style="list-style-type: none"> 1. http://www.jamesoberg.com/usd10.html 2. http://www.thespacereview.com/article/797/1



IF	N	4/12/ 1961	USSR/ Vostok 1	After retrofire, the Vostok equipment module unexpectedly remained attached to the reentry module by a bundle of wires. The two halves of the craft were supposed to separate ten seconds after retrofire, but this did not happen until 10 minutes had passed. The spacecraft went through wild gyrations before the wires burned through and the descent module settled into the proper reentry attitude. Cosmonaut Yuri Gagarin was unharmed and landed via planned ejection/parachute.	<ol style="list-style-type: none"> 1. Separation is incomplete (root cause is not clear with data available). 2. Very limited controls available to cosmonaut. 3. Systems designed robustly can limit implications of failures. In this case, self-correcting reentry attitude by design of capsule and structure/harness designed to be readily burned through. This failure has replayed many times, with no loss of life to date. 	<ol style="list-style-type: none"> 1. http://www.astronautix.com/flights/vostok1.htm 2. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19630043160_1963043160.pdf 3. http://www.russianspaceweb.com/vostok1.html
IF	N	7/21/ 1961	US/ Mercury/ Mercury 4	After Liberty Bell 7 splashed down in the Atlantic, the hatch malfunctioned and blew, filling the capsule with water and almost drowning Gus Grissom, who managed to escape before it sank. Grissom then had to deal with a spacesuit that was rapidly filling with water, but managed to get into the helicopter's retrieval collar and was lifted to safety.	<ol style="list-style-type: none"> 1. Faulty detonator. 2. Water landings involve exposure/drowning risks; pressure suits can increase risk of drowning. 	<ol style="list-style-type: none"> 1. http://www.hq.nasa.gov/office/pao/History/SP-4201/cover.htm 2. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19630043540_1963043540.pdf 3. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20000025483_2000015159.pdf 4. http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf
IF	N	8/7/ 1961	USSR/ Vostok 2	Both cosmonauts suffered from space sickness. Similar reentry issue as Vostok 1 with a failure for the service module to separate cleanly. Cosmonaut Titov was unwell but survived.	<ol style="list-style-type: none"> 1. Separation is incomplete (root cause is not clear with data available). 	<ol style="list-style-type: none"> 1. http://www.astronautix.com/flights/vostok2.htm 2. Aerospace Presentation non-US.ppt²



IF	N	2/20/ 1962	US/ Mercury/ Mercury 6	<p>The "Segment 51" warning light problem was later determined to be a faulty sensor switch. The heat shield and landing bag were in fact secure during reentry. The Texas tracking station told Glenn to retain the retro pack until the accelerometer read 1.5 g (14.7 m/s²). Glenn reported as he crossed Cape Canaveral he had been controlling the spacecraft manually and would use the fly-by-wire mode as a backup. Mercury Control then gave him the 0.05 g (0.49 m/s²) mark, and he pressed the override button. After passing the peak g region, the Friendship 7 began oscillating severely. The astronaut could not control the ship manually. The spacecraft was oscillating past 10 degrees on both sides of the vertical zero-degree point. He activated the auxiliary damping system, this helped stabilize the large yaw and roll rates. Fuel in the automatic tanks was getting low. Glenn wondered if the spacecraft would retain stability until it was low enough to deploy the drogue parachute. The automatic fuel supply ran out at 1 minute and 51 seconds, and manual fuel ran out at 51 seconds, before drogue chute deployment. The oscillations resumed, at 35,000 feet (10 km) Glenn decided to deploy the drogue chute manually to regain attitude stability. Just before he reached the switch, the drogue chute opened automatically at 28,000 feet (8.5 km) instead of the programmed 21,000 feet (6.4 km). Retrofire calculations had not taken into account spacecraft weight loss due to use of onboard consumables. Astronaut John Glenn was unharmed.</p>	<ol style="list-style-type: none"> 1. Faulty indicator. 2. Inaccurate mass calculations (did not account for consumables). 	<ol style="list-style-type: none"> 1. http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf 2. http://www.hq.nasa.gov/office/pao/History/SP-4201/cover.htm
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IF	N	5/24/ 1962	US/ Mercury/ Mercury 7	Partly because he had been distracted watching the fireflies and partly because of his busy schedule, and a malfunction of the automatic alignment system, he overshot his planned reentry mark, and splashed down 402 kilometers off target. Astronaut Scott Carpenter was unharmed.	<ol style="list-style-type: none"> 1. Pilot error. 2. Overwork. 3. System malfunction. 	<ol style="list-style-type: none"> 1. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf 2. http://www.hq.nasa.gov/office/pao/History/SP-4201/cover.htm
IF	N	8/15/ 1962	USSR/ Vostok 4	Life support malfunction allowed temperature to drop to 10 deg C and 35% humidity. Cosmonaut Popovich was unharmed.	Unknown	<ol style="list-style-type: none"> 1. http://www.astronautix.com/flights/vostok4.htm 2. Aerospace Presentation non-US.ppt²
IF	Y	11/1/ 1962	USSR/ High Altitude Balloon Exp	Exited at 86,156 feet (28,650 m) with intentionally opened parachute immediately. Dolgov was wearing the full-pressure suit used for the Vostok space project. As he exited the balloon his helmet visor hit an attachment and cracked. During descent his suit depressurized through the cracked visor and he was found dead on landing. Loss of Pyotor Dolgov.	<ol style="list-style-type: none"> 1. Inadvertent impact and depressurization 2. Protecting pressurized environments from impact, sharp edges and protusions is important. 	<ol style="list-style-type: none"> 1. Crew Survivability IAASS.pdf¹ 2. http://www.astronautix.com/astros/dolgov.htm
IF	N	5/16/ 1963	US/ Mercury/ Mercury 9	On the nineteenth orbit, the first sign of trouble appeared when the spacecraft 0.05 g (0.5 m/s ²) light came on. The spacecraft was not reentering, it was a faulty indicator. On the 20th orbit, Cooper lost all attitude readings. The 21st orbit saw a short-circuit occur in the bus bar serving the 250 volt main inverter. This left the automatic stabilization and control system without electric power. CO2 levels in the cabin and spacesuit also elevated. Manual entry required. Astronaut Gordon Cooper was unharmed.	<ol style="list-style-type: none"> 1. Faulty electrical system. 2. Unclear what caused CO2 elevations. 	<ol style="list-style-type: none"> 1. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf 2. http://www.hq.nasa.gov/office/pao/History/SP-4201/cover.htm



IF	N	6/14/ 1963	USSR/ Vostok 5	Spacecraft ended up in a lower than planned orbit and quickly decayed - temperatures in the service module reached very high levels and the flight returned early. once again the Vostok service module failed to separate cleanly from the reentry sphere. Wild gyrations ensued until the heat of reentry burned through the non-separating restraining strap. Cosmonaut Bykovsky survived.	1. Cause for the failed separation appears to be a restraining strap.	1. http://www.astronautix.com/flights/vostok5.htm 2. Aerospace Presentation non-US.ppt ²
GP	Y	4/14/ 1964	US/ Delta	Delta rocket ignited in assembly room, killing 3 technicians and injuring 9 others. The ignition was caused by a spark of static electricity	1. Static electricity is a significant concern working around propellants.	1. http://www.hq.nasa.gov/office/pao/History/SP-4211/ch10-5.htm
CIV	Y	5/7/ 1964	Germany / Rocket Demonst ration	Student killed by rocket experiment by Gerhard Zucker	Lessons learned unknown.	1. http://www.astronautix.com/astros/zucker.htm
GP	Y	7/2/ 1964	US/ NASA	Oscar Simmons falls from the 46th floor of the Vehicle Assembly Building during construction	Lessons learned unknown.	1. http://www.hq.nasa.gov/office/pao/History/SP-4204/ch12-9.html
IT	Y	10/31/ 1964	US/ T-38 Talon	Theodore Freeman was killed when a goose smashed through the cockpit canopy of his T-38 Talon jet trainer. Flying shards of Plexiglas entered the jet engine intake and caused the engine to flameout. Freeman ejected from the stricken aircraft, but was too close to the ground for his parachute to open properly.	1. The creation of zero-zero ejection seats has eliminated this problem. 2. Develop bird-strike resistant canopies.	1. http://space.about.com/od/deceasedastronauts/p/theodorefreeman.htm 2. http://www.arlingtoncemetery.net/tfreeman.htm 3. http://www.thespacrace.com/people/freeman.php



IF	N	3/18/ 1965	USSR/ Voskhod 2	<p>During the first spacewalk, Leonov's Berkut suit ballooned, making bending difficult. After 12 min Leonov reentered Volga. Recent accounts say that he violated procedure by entering the airlock head first, then got stuck sideways when he turned to close the outer hatch. This forced him to flirt with dysbarism (the "bends") by lowering his suit pressure so he could bend enough to free himself. Leonov recently revealed that he had a suicide pill he could have swallowed if he had been unable to ingress Voskhod 2 and Belyayev had been forced to leave him in orbit.</p> <p>Doctors reported that Leonov nearly suffered heatstroke - his core body temperature climbed 1.8 °C (3.1 °F) in 20 min - and Leonov stated that he was "up to his knees" in sweat, so that his suit sloshed when he moved.</p>	<ol style="list-style-type: none"> 1. Overheating is a significant concern for EVA. 2. A pressurized spacesuit is difficult to maneuver in. 3. Hatchways and other internal volumes and/or EVA pathways should allow ample room for suited crewmembers. 4. Pressure drops, without suitable prebreathe, can lead to the bends. 	<ol style="list-style-type: none"> 1. http://articles.gourt.com/en/Voskhod%20 2. http://spaceflight1.nasa.gov/spacene ws/factsheets/pdfs/EVACron.pdf 3. http://www.svengrahn.pp.se/histind/Voskhod2/Voskhod2.htm 4. Http://ston.jsc.nasa.gov/collections/TRS/_techrep/TM-2000-209764.pdf
IF	N	3/19/ 1965	USSR/ Voskhod 2	<p>Voskhod 2 had a troublesome re-entry, when, the automatic landing system had malfunctioned and had to use the manual system, which, for other reasons, lead to a 2000 km overshoot. Finally, the crew landed in an inhospitable and heavily-wooded part of the Ural Mountains and spent a night surrounded by wolves while waiting for their recovery team. Although they had been spotted within hours of landing, immediate rescue was not possible. Cosmonauts Pavel Belyayev and Alexey Leonov were unharmed.</p>	<ol style="list-style-type: none"> 1. Software failure prevented the automatic landing systems from functioning. 2. Direct communication was limited (above ground stations) and hampered efforts to coordinate manual retrofiring 3. Soyuz is equipped with a hunting gun in case of coming down in an inhospitable region. 	<ol style="list-style-type: none"> 1. http://www.svengrahn.pp.se/histind/Voskhod2/Voskhod2.htm 2. http://articles.gourt.com/en/Voskhod%20
IF	N	6/3/ 1965	US/ Gemini/ Gemini 4	<p>Astronaut could barely get back into capsule after first American spacewalk because of a faulty hatch. The inadvertent alteration of the computer memory during the 48th revolution in an attempt to correct an apparent malfunction. This made the planned computer-controlled reentry impossible and required an open-loop ballistic reentry.</p>	<ol style="list-style-type: none"> 1. Faulty hatch. 2. Computer error. 	<ol style="list-style-type: none"> 1. http://www.astronautix.com/flights/gemini4.htm 2. Http://spaceflight1.nasa.gov/spacene ws/factsheets/pdfs/EVACron.pdf 3. Aerospace Presentation US.ppt³



GP	Y	8/3/ 1965	US/ NASA	Lightning killed Albert J. Treib on launch pad B of Launch Complex 39	1. Lightning poses a hazard to crew and spacecraft. Lightning arresting systems can protect pad, people and spacecraft.	1. http://www.hq.nasa.gov/office/pao/History/SP-4204/ch12-9.html
IF	N	8/29/ 1965	US/ Gemini/ Gemini 5	Gemini 5 landed 130 kilometers short of its planned Pacific Ocean landing point due to a software error. The Earth's rotation rate had been programmed as one revolution per solar day instead of the correct value, one revolution per sidereal day. Astronauts Gordon Cooper and Pete Conrad were unharmed.	1. Inaccurate software values can have considerable effect on flight parameters.	1. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19750067642_1975067642.pdf 2. http://www.hq.nasa.gov/office/pao/History/SP-4203/cover.htm 3. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf
IF	N	12/12/ 1965	US/ Gemini/ Gemini 6	All went well right up to ignition--in fact the engines did ignite, but then a plug fell out of the bottom of the rocket, starting the onboard programmer. This was not meant to happen until the rocket had actually lifted off, and the onboard computer detected that there was no upwards motion, causing it to abort the launch. At this point mission rules dictated that the crew should eject from the spacecraft, as the rocket would explode on impact with the pad if its trajectory was off by even an inch. Schirra elected not to eject as neither he nor Stafford had detected any upwards motion, and the ejection seats were seen as a last resort. Astronauts Wally Schirra and Thomas Stafford were unharmed.	1. Hardware was not reliable and not fit for a high vibration environment. 2. Lack of confidence in emergency system can preclude its use.	1. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19790076749_1979076749.pdf 2. http://www.hq.nasa.gov/office/pao/History/SP-4203/cover.htm 3. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf
IT	Y	2/28/ 1966	US/ T- 38 Talon	Crash of T-38 Talon jet trainer. A NASA investigative panel later concluded that pilot error caused by poor visibility due to bad weather had been the principal cause of the accident. The panel concluded that See was flying too low to the ground during his approach, probably as a result of the poor visibility. Loss of astronauts Elliot See and Charles Bassett.	1. Pilot error.	1. http://en.wikipedia.org/wiki/Elliott_See



IF	N	3/17/ 1966	US/ Gemini/ Gemini 8	During Gemini 8, a maneuvering thruster refused to shut down and put their capsule into an uncontrolled spin. Problem occurred while mated to an Agena. Crew thought the spin was Agena related and seperated, which resulted in the spin accelerating since the thruster had less mass to accelerate. The g-force became so intense the astronauts were possibly within seconds of blacking out when they regained control by turning off the orbital maneuvering/attitude system and using the reentry system. Astronauts Neil Armstrong and David Scott were unharmed.	<ol style="list-style-type: none"> 1. Failed on thruster cause was not conclusively identified. Corrective action included provisions to isolate faulty thrusters (still in use today). 2. Original cause was misidentified and led to a remedy that accelerated the problem. Stresses how important it is to know one's systems. 3. Important to be able to reach critical controls, even in high-g environment. 	<ol style="list-style-type: none"> 1. http://www.hq.nasa.gov/office/pao/History/SP-4203/cover.htm 2. http://www.astronautix.com/flights/gemini8.htm 3. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf
IF	Y	5/1/ 1966	US/ High altitude balloon testing	During ascent at 57,600 feet ground control heard a sudden gush of air on radio and heard Piantanida's voice, screaming "Emergency!" Gondola cut from balloon by ground control and drogue chute opened as planned. 25 minutes later gondola landed and rescue team pulled out a moaning and gasping Piantanida. Nick Piantanida died in a hospital four months later.	Lessons learned unknown.	<ol style="list-style-type: none"> 1. Crew Survivability IAASS.pdf ¹ 2. http://www.astronautix.com/astros/dolgov.htm
IF	N	6/5/ 1966	US/ Gemini/ Gemini 9	Astronaut's faceplate continually fogged over during EVA due to heavy exertion. Resulted in shortened EVA and difficulties while reentering spacecraft.	<ol style="list-style-type: none"> 1. EVA involves a great deal of exertion. 2. Cooling for EVA is essential. 3. Antifogging measures for EVA are important. 4.. Metabolic loading is key. Tasks must be planned that do not overstress crewmember and EVAs should be monitored. 	<ol style="list-style-type: none"> 1. Http://spaceflight1.nasa.gov/spacene ws/factsheets/pdfs/EVACron.pdf 2. http://www.hq.nasa.gov/office/pao/History/SP-4203/cover.htm 3. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf



IT	Y	1/27/ 1967	US/ Apollo/ Apollo 1	<p>Fire destroyed the command module (CM-012) during a test and training exercise at Pad 34 (Launch Complex 34, Cape Canaveral, then known as Cape Kennedy) atop a Saturn IB rocket. The crew members were reclining in their horizontal couches, running through a checklist when a voltage transient was recorded at 6:30:54 (23:30:54 GMT). Ten seconds later, the crew reported fire. After nearly ten seconds of frenetic movement noises Chaffee yelled, "We've got a bad fire! Let's get out! We're burning up! We're on fire! Get us out of here!" Only 17 seconds after the first indication by crew of any fire, the transmission ended abruptly with a scream of pain at 6:31:21 as the cabin ruptured after rapidly expanding gases from the fire overpressurized the CM to 29 psi. Toxic smoke from the leaking command module and malfunctioning gas masks disrupted the ground crew attempting to rescue them. It took five minutes to open the hatch, a layered array of three hatches with many ratchets. Loss of astronauts Virgil I. "Gus" Grissom, Ed White and Roger B. Chaffee.</p>	<ol style="list-style-type: none"> 1. Inward opening door precluded rescue because of pressure differential. 2. Fires in 100% oxygen environments are very destructive very quickly as many materials are explosively combustible in 100% O2. Steps must be taken to remove (a) ignition sources, (b) flammables and/or reduce the percentage of O2. 3. O2 pressure was actually above ambient pressure ~16.7 psia. 4. Considerable flammable materials and materials that offgas flammable gases present in crew module. 5. CM-012 was delivered to NASA with dozens of acknowledged but unresolved flaws. 6. Insufficient emergency equipment and capabilities to provide timely rescue. 7. Substandard wiring and plumbing in spacecraft. 8. Corrective actions included: (a) changing air mix to O2/N2, (b) using a quick outward opening hatch, (c) replacement of flammable materials with self-extinguishing ones (including suits), (d) insulating plumbing/wiring, (e) correction of 1407 wiring problems, and (f) improved documentation of spacecraft construction. 	<ol style="list-style-type: none"> 1. http://www.hq.nasa.gov/office/pao/History/SP-4204/ch18-1.html 2. http://www.hq.nasa.gov/office/pao/History/SP-4204/ch18-2.html 3. http://history.nasa.gov/SP-4029/Apollo_01a_Summary.htm 4. http://history.nasa.gov/SP-4029/Apollo_01c_Timeline.htm 5. http://www.hq.nasa.gov/office/pao/History/Apollo204/find.html 6. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf
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IF	Y	4/24/ 1967	USSR/ Soyuz/ Soyuz 1	<p>However, the main parachute did not unfold due to a faulty pressure sensor which had not been detected during manufacture. Komarov tried to activate the manually deployed reserve chute, but it became tangled with the drogue chute, which deployed but did not release. As a result, it fell to Earth (in Orenburg Oblast of Russia) nearly unbraked, at about 40 meters per second (145 km/h). Large retro-rockets should have fired to further slow the descent. Instead, at impact, there was an explosion and an intense fire that surrounded the capsule. Loss of Cosmonaut Vladimir Komarov. (There were a number of other technical difficulties with this flight; however, these are the failures that led to the fatality)</p>	<ol style="list-style-type: none"> 1. The Soyuz craft had never been successfully flown on an unmanned testflight. 2. Soyuz 1 engineers are said to have reported 200 design faults to party leaders, but their concerns "were overruled by political pressures for a series of space feats to mark the anniversary of Lenin's birthday." 	<ol style="list-style-type: none"> 1. http://www.astronautix.com/flights/soyuz1.htm 2. http://news.bbc.co.uk/onthisday/hi/dates/stories/april/24/newsid_2523000/2523019.stm 3. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf
IT	Y	10/5/ 1967	US/ Apollo/ Training	<p>Mechanical failure caused the controls of a T-38 jet trainer to stop responding. The plane went into an uncontrollable aileron roll while astronaut Clifton Williams was flying from the Cape to Mobile, Alabama. Williams ejected but he was traveling too fast and was at too low an altitude. Loss of Astronaut Clifton Williams.</p>	<ol style="list-style-type: none"> 1. Mechanical failure on aircraft. 	<ol style="list-style-type: none"> 1. http://en.wikipedia.org/wiki/Clifton_Williams



IF	Y	11/15/ 1967	US/X-15/ Flt 3-65-97	<p>In powered flight, an electrical disturbance distracted Adams and slightly degraded the control of the aircraft. At the conclusion of the wing-rocking portion of the climb, the X-15 had begun a slow drift in heading; 40 seconds later, when the aircraft had reached its maximum altitude, it was off heading by 15 degrees. As Adams came over the top, the drift briefly halted as the aircraft yawed 15 degrees to the right. Then the drift began again; within 30 seconds, Adams was descending at right angles to the flight path. At 230,000 feet, encountering rapidly changing air pressure, the X-15 entered a Mach 5 spin. Adams held the X-15's controls against the spin, using both the flight controls and the reaction controls. He managed to recover from the spin at 118,000 feet and went into an inverted Mach 4.7 dive at an angle between 40 and 45 degrees. Due to technical problems with the aircraft, the X-15 began a rapid pitching motion of increasing severity, still in a dive at 160,000 feet per minute. Craft broke up before impact. Loss of Pilot Michael J. Adams.</p>	<ol style="list-style-type: none"> 1. Pilot was unaware of heading deviations (potential causes workload/vertigo). 2. Heading data was not included in mission control telemetry so ground support was unaware of deviations. 3. Electrical disturbance degraded control systems. 4. Recommended (a) enhanced ground control telemetry and (b) screening for vertigo for pilots as corrective action. 	<ol style="list-style-type: none"> 1. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20000068530_2000075022.pdf 2. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19650010561_1965010561.pdf 3. http://area51specialprojects.com/adams_x-15_crash.html 4. http://www.dfrc.nasa.gov/gallery/photo/X-15/HTML/E-USAF-X-15.html
IT	Y	12/8/ 1967	US/ pre-ISS/ Training	<p>Astronaut Robert Henry Lawrence, Jr. was flying backseat on the mission as the instructor pilot for a flight test trainee learning the steep-descent glide technique. The pilot flying made such an approach but flared too late. The front seat pilot of the aircraft successfully ejected upon ground impact and survived the accident, but with major injuries. By the time Lawrence ejected, the airplane had rolled onto one side and tragically, his ejection seat, with Lawrence still in it, described a low angle path and struck the ground, killing him instantly. Loss of Astronaut Robert Henry Lawrence, Jr.</p>	<ol style="list-style-type: none"> 1. Pilot error. 2. Late ejection. 	<ol style="list-style-type: none"> 1. http://www.hill.af.mil/library/factsheets/factsheet.asp?id=5878



L	N	1968?	US/ NASA	<p>Space suit technician was near instantaneous exposure to altitude of 120,000 feet. He recalled the saliva boiling off his tongue as he passed out, and regained consciousness as the chamber reached 14,000 feet. Since the pressure altitude was above the Armstrong Line, the test subject was subject to the effects of Ebullism.</p> <p>He suffered no neurological sequelae and was not hospitalized. This incident backed up the animal research data.</p>	<p>1. Human exposure to vacuum is survivable if repressurization occurs rapidly.</p> <p>2. Life support fittings and seals are vital in a vacuum environment</p>	<p>1. Crew Survivability IAASS.pdf¹</p>
IT	Y	3/27/ 1968	USSR/ Training	<p>During requalification training, Yuri Gagarin and his instructor died in a MiG-15UTI on a routine training flight near Kirzhach. Cause has not conclusively been determined, but could include poor weather conditions, turbulence from another craft or an open cabin vent that led to oxygen deprivation and unconsciousness.</p>	<p>1. Nothing conclusive</p>	<p>1. http://www.astronautix.com/astros/gagarin.htm</p> <p>2. http://en.wikipedia.org/wiki/Yuri_Gagarin</p>
IT	N	5/6/ 1968	US/ Apollo/ LLRV	<p>LLRV No. 1 went out of control and crashed at Ellington AFB, Texas; Neil Armstrong (pilot) ejected safely. Two NASA investigation boards had reported that loss of attitude control caused the May 6 accident that destroyed lunar landing research vehicle No. 1, NASA announced. Helium in propellant tanks had been depleted earlier than normal, dropping pressure needed to force hydrogen peroxide propellant to the attitude-control lift rockets and thrusters.</p>	<p>Lessons learned unknown.</p>	<p>1. http://av.rds.yahoo.com/_ylt=A0oGkuCHvZILXvAAEA1rCqMX; ylu=X3oDMTBvdmM3bGlxBHBndANhd193ZWJfcmVzdWx0BHNIYwNzcg--/SIG=11ue5kkn1/EXP=1268453127/*http%3A/history.nasa.gov/alsj/LLRV-DFRC.pdf</p> <p>2. http://www.astronautix.com/craft/apoollrv.htm</p> <p>3. http://en.wikipedia.org/wiki/LLRV</p> <p>4. http://www.astronautix.com/details/apo17954.htm</p> <p>5. http://www.astronautix.com/details/os18032.htm</p>



IT	N	12/8/ 1968	US/ Apollo/ LLTV	<p>During a routine flight of lunar landing training vehicle (LLTV) No. 1, MSC test pilot Joseph S. Algranti was forced to eject from the craft when it became unstable and he could no longer control the vehicle. The LLTV crashed and burned. A flight readiness review at MSC on November 26 had found the LLTV ready for use in astronaut training, and 10 flight tests had been made before the accident.</p> <p>An investigating board headed by astronaut Walter M. Schirra, Jr., was set up to find the cause of the accident. And on January 8, 1969, NASA Acting Administrator Thomas O. Paine asked the review board that was established in May 1968 to restudy its findings on the May 6 crash of lunar landing research vehicle No. 1 (LLRV-1).</p>	Lessons learned unknown.	<ol style="list-style-type: none"> 1. http://av.rds.yahoo.com/_ylt=A0oGkuCHvZILXvAAEA1rCqMX: ylu=X3oDMTBvdmM3bGlxBHBndANhd193ZWJfcmVzdWx0BHNIYwNzcg-:/SIG=11ue5kkn1/EXP=1268453127/**http%3A/history.nasa.gov/alsj/LLRV-DFRC.pdf 2. http://www.astronautix.com/craft/apollrv.htm 3. http://en.wikipedia.org/wiki/LLRV 4. http://www.astronautix.com/details/apo18054.htm
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IF	N	1/18/ 1969	USSR/ Soyuz/ Soyuz 5	<p>The Soyuz 5's service module initially refused to separate, causing the spacecraft to begin reentry faced the wrong way. When the Soyuz started aerobraking in the upper reaches of the atmosphere, the combined spacecraft sought the most aerodynamically stable position - nose forward, with the heavy descent module facing directly into the air stream with only its light metal entry hatch at the front to protect it. The gaskets sealing the hatch began to burn, filling the air with dangerous fumes. Fortunately, struts between the descent and service modules broke off or burned through before the hatch failed. The descent module immediately righted itself with the heat shield forward to take the brunt of reentry. The parachute cables partially tangled and soft-landing rockets failed, resulting in a harder than usual impact which broke his teeth. The capsule had come down far short of its target landing site in Kazakhstan. The local temperature was -38 °C, and knowing that it would be many hours before rescue teams could reach him Volynov walked for several kilometers to reach a local peasant's house to keep warm. Cosmonaut Boris Volynov survived.</p>	<p>1. Failure to reliably separate service module from landing capsule was nearly fatal and resulted in a very rough landing.</p>	<p>1. http://astronautix.com/flights/soyuz5.htm 2. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf</p>
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IF	N	5/22/ 1969	US/ Apollo/ Apollo 10	<p>The Apollo 10 lunar module went out of control for several very tense seconds when Cernan and Stafford mistakenly switched on the wrong guidance system. The spacecraft's computers became confused, and, as Cernan noted in <i>The Last Man on the Moon</i>, "all hell broke loose. Snoopy went nuts. We were suddenly bouncing, diving and spinning all over the place ... The spacecraft radar that was supposed to be locking onto Charlie Brown had found a much larger target, the Moon, and was trying to fly in that direction instead of toward the orbiting command module." Finally, Stafford regained control by switching off the computers and flying the ship manually. "After analyzing the data," Cernan reported in his book, "experts later surmised that had we continued spinning for only two more seconds, Tom and I would have crashed. Things had been more than a little tense. Hell, I was scared to death. But we got back on track immediately." Astronauts Cernan and Stafford survived, unharmed.</p>	<ol style="list-style-type: none"> 1. Crew error 2. Flaw in method for guidance 	<ol style="list-style-type: none"> 1. http://www.answers.com/topic/gene-cernan
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IF	N	7/20/ 1969	US/ Apollo/ Apollo 11	<p>As the landing began Armstrong reported they were "running long." The LM navigation and guidance computer reported several unusual "program alarms" as it guided the LM's descent, drawing the crew's attention from the scene outside as the descent continued. Inside NASA's Mission Control Center in Houston, Texas, computer engineer Jack Garman told guidance officer Steve Bales it was safe to continue the descent in spite of the alarms. When Armstrong returned his attention to the view outside it was apparent the computer was guiding them towards a large crater with rocks scattered around it. Armstrong took manual control of the lunar module and with Aldrin calling out data from the radar and computer, guided it to a landing at 20:17 UTC on July 20 with about 30 seconds of fuel left. Also, before leaving the surface, Aldrin accidentally broke the circuit breaker that armed the main engine for lift off from the moon. There was initial concern this would prevent firing the engine, which would strand them on the moon. Fortunately a felt-tip pen was sufficient to activate the switch. Astronauts Neil Armstrong and Buzz Aldrin were unharmed.</p>	<ol style="list-style-type: none"> 1. Fuel gage reading was wrong because of slosh (baffles added to future missions). 2. Radar left on distracted computer software and was causing errors. 3. Suits are bulky, hard to control and limit visibility and cognizance of nearby equipment. They are prone to damage equipment in vicinity. 	<ol style="list-style-type: none"> 1. http://ntrs.nasa.gov/archive/nasa/casi/ntrs.nasa.gov/19710015566_1971015566.pdf 2. Http://ston.jsc.nasa.gov/collections/TRS/_techrep/TM-2000-209764.pdf
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IF	N	11/14/ 1969	US/ Apollo/ Apollo 12	<p>The Saturn V was struck by lightning after launch. The CM's instruments momentarily went off-line and Mission Control lost the telemetry feeds from the spacecraft for several seconds. When ground control regained telemetry lock with the spacecraft, the feeds were garbled and reported incomplete and possibly inaccurate information. A ground controller believed the signal Conditioning Equipment would have automatically gone off-line in response to the kind of disruption to the spacecraft's electrical systems that a lightning strike would cause and malfunctioned.</p> <p>The command to correct this was a relatively obscure one and no one immediately remembered how to implement it; however, lunar module pilot Alan Bean because of a training incident a year prior to launch where just such a failure had been simulated. With telemetry restored, the crew proceeded to parking orbit and was able to restore and verify the functionality of their spacecraft before re-igniting the S-IVB third stage for trans-lunar injection. Astronauts Pete Conrad, Richard Gordon and Alan Bean were unharmed.</p>	<ol style="list-style-type: none"> 1. Lightning strikes are dangerous for launching/landing spacecraft. 2. Simulations of unusual failures are good training. 	<ol style="list-style-type: none"> 1. http://ntrs.nasa.gov/archive/nasa/casi/ntrs.nasa.gov/19760072997_1976072997.pdf 2. http://ntrs.nasa.gov/archive/nasa/casi/ntrs.nasa.gov/19720066106_1972066106.pdf 3. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf
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IF	N	4/14/ 1970	US/ Apollo/ Apollo 13	<p>Two days after the launch, the Apollo spacecraft was crippled by an explosion, caused by a fault in the oxygen tank. The explosion damaged the Service Module, resulting in a loss of oxygen and electrical power. The crew used the Lunar Module as a "lifeboat" in space. The command module systems remained functional, but were deactivated to preserve the vehicle's capability to reenter Earth's atmosphere. Despite great hardship caused by severe constraints on power, cabin heat, potable water, and carbon dioxide removal, the crew successfully returned to Earth. Also, on this flight were excessive POGO oscillations that caused an early shutdown of one engine (through unplanned sensor misreading) and might have torn the second stage apart. Astronauts James Lovell, Jack Swigert and Fred Haise, Jr. all survived.</p>	<ol style="list-style-type: none"> 1. Pogo oscillations, seen previously, were made worse by turbopump cavitations. Anti-pogo measures were enacted as corrective action. 2. Thermostat in the oxygen tank was not properly sized for the voltage source (which had changed from the original design). Configuration management did not provide for propagation of this change to all design teams. 3. Piping was misaligned within tank because of mishandling, but used anyway, which caused unrecognized thermostat damage. This is a schedule/program decision lesson learned. Lack of viable spare may have driven a poor choice. 4. Sensor limitations allowed thermostat failure (and wire damage) to go unrecognized. 5. Damaged wiring (insulation burned off) caused actual explosion. 6. Close proximity to other oxygen tank meant that both were lost. 7. Lithium hydroxide canisters (for CO2 scrubbing) were not interchangeable and had to be "kluged" to work in the LM. 8. Limited power had considerable impact, including minimal heating and resultant condensation, a significant concern. 	<ol style="list-style-type: none"> 1. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19930074343_1993074343.pdf 2. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19700076776_1970076776.pdf 3. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf
IF	N	6/19/ 1970	USSR/ Soyuz/ Soyuz 9	<p>Head-over-heels rotation of Soyuz to conserve fuel and lack of exercise resulted in terrible condition of astronauts on return, as their bodies had a hard time recovering from the time at zero g. The Soviets almost reconsidered their space station plans as a result. Cosmonauts Nikolayev and Sevastyanov survived.</p>	<ol style="list-style-type: none"> 1. Lack of knowledge about the effects of zero g. 	<ol style="list-style-type: none"> 1. http://www.astronautix.com/flights/soyuz9.htm 2. Aerospace Presentation non-US.ppt²



IT	N	1/23/ 1971	US/ Apollo/ Training	Gene Cernan was flying a helicopter as part of his Lunar Module training as Backup Commander for Apollo 14. The helicopter crashed into the Banana River at Cape Canaveral, Florida. Cernan nearly drowned because he was not wearing a life vest and received some second-degree burns on his face and singed hair. According to official reports at the time, the crash was the result of mechanical failure. Later accounts, written by Cernan himself in an autobiography, admit he was flying too low and showing off for nearby boaters. The helicopter dipped a skid into the water and crashed. Gene Cernan was not critically injured.	1. Pilot error. 2. Not wearing life vest. 3. Failure to follow established procedures.	1. http://www.answers.com/topic/gene-cernan 2. <i>The Last Man on the Moon</i> by Eugene Cernan and Donald A. Davis ⁴
IT	N	1/29/ 1971	US/ Apollo/ LLTV	An LLTV crashed at Ellington AFB, Texas. NASA test pilot Stuart Present ejected safely.	Lessons learned unknown.	1. http://av.rds.yahoo.com/_ylt=A0oGkuCHvZILXvAAEA1rCqMX; ylu=X3oDMTBvdmM3bGlxBHBndANhd193ZWJfcmVzdWx0BHNIYwNzcg--/SIG=11ue5kkn1/EXP=1268453127/**http%3A/history.nasa.gov/alsj/LLRV-DFRC.pdf 2. http://www.astronautix.com/craft/apollrv.htm 3. http://en.wikipedia.org/wiki/LLRV
IF	N	4/23/ 1971	USSR/ Soyuz/ Soyuz 10	Crew unable to enter Salyut 1 due to faulty hatch. Jammed hatch interfered with docking mechanism and prevented undocking. Able to undock after several attempts. During landing Soyuz air supply become contaminated and cosmonaut became unconscious. Cosmonauts Vladimir Shatalov, Aleksei Yeliseyev, and Nikolai Rukavishnikov survived unharmed.	1. Insufficient instrumentation 2. Faulty hatch	1. http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf 2. http://www.astronautix.com/flights/soyuz10.htm



IF	Y	6/30/ 1971	USSR/ Soyut/ Soyuz 11	<p>On June 30, 1971, the recovery team opened the capsule to find the crew dead. It quickly became apparent that they had suffocated. The fault was traced to a breathing ventilation valve, located between the orbital module and the descent module, that had been jolted open as the descent module separated from the service module. The two were held together by explosive bolts designed to fire sequentially, but in fact, they fired simultaneously while over France. The force of this caused the internal mechanism of the pressure equalization valve to loosen a seal that was usually discarded later, and normally allowed automatic adjustment of the cabin pressure. When the valve opened at 168 kilometers (104 mi), the gradual loss of pressure was fatal within seconds. It is estimated that the cabin lost all its atmosphere in about 30 seconds. Within seconds, Patsayev realized the problem, and unstrapped from his seat to try and cover the valve inlet and shut off the valve, but there was insufficient time. Loss of Cosmonauts Georgi Dobrovolski, Vadislav Volkov, Victor Patsayev.</p>	<ol style="list-style-type: none"> 1. The valve was impossible to locate and block the leak before the air was lost. 2. Cabin atmosphere leaked out in 30 s; 60 s required to close valve manually. 3. Other crew was not able to help because of confinement. 4. Ground crew was unaware of issues until recovery (insufficient telemetry). 5. Corrective action: redesign Soyuz to allow two pressure-suited crew during reentry (rather than three without pressure suits). 6. Other potential corrections: emergency air system capable of replacing worst case valve failure; backup valving with auto close; ensuring sufficient time to correct for all malfunctioning equipment. 	<ol style="list-style-type: none"> 1. http://nssdc.gsfc.nasa.gov/nmc/masterCatalog.do?sc=1971-053A 2. http://www.astronautix.com/flights/soyuz11.htm 3. http://www.space.com/news/spacehistory/Salyut1_Anniversary_010419.html 4. http://history.nasa.gov/SP-4209/ch8-2.htm 5. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf
IF	N	7/26/ 1971	US/ Apollo/ Apollo 15	<p>One of the three main parachutes failed, causing a hard but survivable splashdown. Crew astronauts Irwin, Scott and Worden survived.</p>	<ol style="list-style-type: none"> 1. RCS fuel jet firing to deplete fuel damaged parachute. 	<ol style="list-style-type: none"> 1. http://www.astronautix.com/flights/apollo15.htm 2. Aerospace Presentation US.ppt³



GP	Y	6/26/ 1973	USSR/ Kosmos	<p>According to a post-USSR source, a routine launch of a Cosmos 3M was planned for 1:32 a.m. on June 26, 1973s. The preparation, however, run into trouble, when due to a sensor malfunction, the fuel tank was overfilled. The personnel drained part of the fuel and refueled the launcher. Apparently, at this point, the fuel tank developed a leak and 15 seconds before the liftoff, the launch sequence was automatically suspended. The launch was canceled and more than 40-member launch team tried to deactivate the vehicle. At 4:18 and 4:20 a.m. two crews of 13 people were dispatched to the launch pad. At 4:22 a.m. a dual explosion shook the complex, followed by the fire. Seven people were killed at the spot, 13 were injured, two of those later died in the hospital.</p>	Lessons learned unknown.	<ol style="list-style-type: none"> 1. http://www.russianspaceweb.com/cosmos3.html 2. http://www.daviddarling.info/encyclopedia/P/Plesetsk.html 3. http://www.russianspaceweb.com/plesetsk.html
IF	N	4/5/ 1975	USSR/ Solyut/ Soyuz 18a	<p>The Soyuz 18a mission nearly ended in disaster when the rocket suffered a second-stage separation failure during launch. This automatically triggered the launch abort system and caused an attitude error that caused the vehicle to be launched towards the Earth and triggered an emergency reentry sequence. Due to the downward acceleration, the crew experienced an acceleration of 21.3 g rather than the nominal 15 g for an abort. Upon landing, the vehicle rolled down a hill and stopped just short of a high cliff. The snow, the high altitude and the terrain meant the rescuers had great difficulty in making contact with the cosmonauts and it was the next day before they were safely air-lifted out. Cosmonauts Vasili Lazarev and Oleg Makarov survived, but Lazarev, the mission commander, suffered internal injuries due to the severe G-forces and was never able to fly again.</p>	1. Booster might have been an older model that was not appropriate for this usage or was inappropriate integrated.	<ol style="list-style-type: none"> 1. http://spaceflight.nasa.gov/history/huttle-mir/references/documents/mirhh-part1.pdf 2. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf 3. http://www.astronautix.com/flights/soyuz181.htm



IF	N	7/24/ 1975	US/ USSR/ ASTP	A serious problem that arose was due to the Apollo crew making a mistake during their preparations for re-entry that resulted in a very rough landing and the capsule filling with noxious fumes. The reaction control system was inadvertently left on during manual drogue deployment (automatic deployment had failed), producing uncombusted thruster propellant which was then sucked into the capsule relief valves as its pressure equalized with the outside air. Brand briefly lost consciousness, and Slayton reported suffering nausea. Crew experienced eye and lung problems. As a precaution, the three astronauts were hospitalized for two weeks in Honolulu, Hawaii. Astronauts Thomas Stafford, Vance Brand and Deke Slayton survived.	<ol style="list-style-type: none"> 1. Faulty drogue deployment. 2. Failure to turn off RCS system before manual deployment. 3. Design that allows propellant products to get into crew cabin is an issue even after a failure. 	<ol style="list-style-type: none"> 1. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19750067869_1975067869.pdf 2. http://www.hq.nasa.gov/office/pao/History/apollo/soyuz.html 3. http://www.hq.nasa.gov/office/pao/History/apollo/apsoyhst.html 4. http://www.hq.nasa.gov/office/pao/History/SP-4209/toc.htm
IF	N	8/25/ 1976	USSR/ Salyut/ Soyuz 21	Mission cut short due to crew member illness, potentially psychotic, potentially from toxic fumes. Cosmonauts Boris Volynov and Vitali Zholobov unharmed but for potential illness.	<ol style="list-style-type: none"> 4. A system that precludes allowing a function if the current configuration is incompatible can preclude recurrence. 	<ol style="list-style-type: none"> 1. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf 2. http://www.astronautix.com/flights/soyuz21.htm
IF	N	10/16/ 1976	USSR/ Salyut/ Soyuz 23	The spacecraft experienced a remarkable and near-catastrophic return to Earth. It descended onto a frozen Lake Tengiz in the middle of a snowstorm. The parachutes quickly filled with water, and dragged the capsule and its crew beneath the surface. Numerous attempts by recovery teams to reach it by amphibious vehicle failed. Inside the capsule, the heating had to be turned down in order to conserve power. Eventually, swimmers attached a cable to the capsule that allowed it to be dragged clear of the lake by a helicopter. The recovery team found the crew still alive. Cosmonauts Vyacheslav Zudov and Valeri Rozhdestvensky survived.	<ol style="list-style-type: none"> 1. Off nominal landings are a reality. Equipment and crew must be designed/trained to provide for off-nominal conditions. 	<ol style="list-style-type: none"> 1. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf 2. http://www.astronautix.com/flights/soyuz23.htm



IF	N	5/31/1979	USSR/Salyut 6	Fire caused space station to fill with smoke. Crew almost had to evacuate.	Lessons learned unknown.	1. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf
IF	N	8/15/1979	USSR/Salyut 6	During separation from Salyut, antenna on capsule snagged on station antenna. Required EVA to disconnect antenna.	Lessons learned unknown.	1. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf
GP	Y	3/18/1980	USSR/Vostok	Vostok-2M rocket exploded on its launch pad at Plesetsk during a fueling operation, killing 48. An investigation into a similar -- but avoided -- accident revealed that the substitution of lead-based for tin-based solder in hydrogen peroxide filters had resulted in the breakdown of the H2O2 and the resulting explosion.	1. Incompatible materials can have devastating results.	1. http://www.astronautix.com/craft/tse/linad.htm 2. http://www.russianspaceweb.com/pl/esetsk.html
IF	N	6/3/1980	USSR/Salyut/Soyuz 35	Landing retrorockets failed. Capsule impacted with high velocity. Seat emergency shock system actuated. Crew had minor injuries. Cosmonauts Farkas and Kubasov survived.	Lessons learned unknown.	1. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf 2. http://www.astronautix.com/flights/alt6ep5.htm
GP	Y	3/19/1981	US/Shuttle	Cole, 50, and John Bjornstad, 51, of Titusville, died after inhaling pure nitrogen in a shuttle engine compartment after a launch pad test. The two Rockwell International mechanics were part of a five-man crew sent back to work after an allclear signal was sounded prematurely. Four other technicians were left unconscious. Mechanics died from anoxia during preparations for STS-1.	1. It is essential that ground personnel have oxygen monitors to preclude going into areas low on oxygen. 2. Purging with gases other than "air" can add to risk for ground personnel. 3. Communications of when an area was "clear" to enter failed. 4. Safety steps to preclude risk failed. 5. Procedures between ground personnel and test directors were not in sync.	1. http://www-lib.ksc.nasa.gov/lib/archives/chronologies/1981CHRONO1.PDF 2. http://www-lib.ksc.nasa.gov/lib/archives/chronologies/1981CHRONO2.PDF



IF	N	4/10/ 1981	US/ Shuttle/ STS-1	Launch scrubbed due to timing difference between primary and backup flight software. Significant thermal protection tile damage during launch (16 lost and 148 damaged) due to overpressurization wave created by solid rocket boosters. Overpressurization wave also pushed body flap beyond safe limits. Astronauts John Young and Robert Crippen were unharmed.	1. Preflight models did not encompass all of reality. 2. Complex systems that have not been flown altogether can have unexpected effects and interactions.	1. http://www.jsc.nasa.gov/news/colombia/anomaly/STS1.pdf 2. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf 3. http://members.aol.com/WSNTWOYOU/STS1MR.HTM
IF	N	11/21/ 1981	US/ Shuttle/ STS-2	Experienced erosion of the primary O-ring in the right SRM aft field joint. The erosion was the deepest experienced in flight in a case field joint, until the loss of the space shuttle Challenger on flight STS 51-L. Planned five day mission cut nearly three days due to failure of one of three fuel cells that produce electricity and drinking water. Crew astronauts Engle and Truly were unharmed.	1. Deficiencies in O-ring design.	1. http://www.astronautix.com/flights/sts2.htm 2. Aerospace Presentation US.ppt ³
GP	N	6/4/ 1982	US/ NASA	In 1982 a technician was decompressed to greater than 74,000 feet (22,555 m), and remained there for 60 seconds. By the time the chamber was opened the victim had been above 63 millibar for 1 to 3 minutes. The patient was cyanotic, frothing and had bilateral pneumothorax and grade 4 otic barotrauma. He was given IV Decadron and recompressed to 6 ATA using NITROX (50% nitrogen 50% oxygen) 5 hours after exposure. By 24 hours after exposure he was awake and alert; he was extubated at day 5, and at 1 year follow-up had neurological performance superior to testing before the accident.	Lessons learned unknown.	1. Crew Survivability IAASS.pdf ¹ 2. http://www.astronautix.com/astros/dolgov.htm



IF	N	4/14/ 1983	US/ Shuttle/ STS-6	First use of the lightweight SRM case. When the SRMs were dismantled, blowholes through the putty in both nozzle joints were found. The O-rings were affected by heat, but were not eroded. Impact damage led to structural overheating on the leading edge of both OMS pods. Crew Astronauts Bobko, Musgrave, Peterson, and Weitz were unharmed.	1. Deficient design of SRMs. 2. Impact damage.	1. http://www.astronautix.com/flights/ts6.htm 2. Aerospace Presentation US.ppt ³
IF	N	8/19/ 1983	USSR/ Salyut/ Salyut 7	During refuelling by Progress 17, the main oxidiser line of the Salyut 7 propulsion system ruptured. The seriousness of the malfunction was not immediately apparent in the West. However, after the malfunction, Salyut 7 had to rely on the main propulsion systems of visiting Progress freighters for maintaining orbital altitude. Required five EVAs to repair. Crewmembers were unharmed.	Lessons learned unknown.	1. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf 2. http://www.astronautix.com/flights/alt7eo2.htm



IF	N	9/26/ 1983	USSR/ Soyuz /Soyuz T-10-a	<p>Shortly before the planned liftoff, fuel spilled around the base of the Soyuz launch vehicle and caught fire at T-90 seconds. Launch control activated the escape system but the control cables had already burned, and the crew could not activate or control the escape system themselves. Twenty seconds later ground control was finally able to activate the escape system by radio command, by which time the booster was engulfed in flames. Then the escape system motor fired, dragging the orbital module and descent module, encased within the upper shroud, free of the booster with an acceleration of 14 to 17g . Two seconds after the escape system activated the booster exploded, destroying the launch comple. The descent module discarded its heat shield, exposing the solid-fuel landing rockets, and deployed a fast-opening emergency parachute. Landing occurred about four kilometers from the launch pad. Cosmonauts Vladimir Titov and Gennady Strekalov were badly bruised after the high acceleration, but had survived.</p>	<ol style="list-style-type: none"> 1. Lack of automatic launch abort or crew capability was a factor. 2. Backup command capability (such as radio used here to launch the launch abort system) was a key capability for survival. 	<ol style="list-style-type: none"> 1. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf 2. http://www.astronautix.com/flights/oyzt101.htm
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IF	N	12/8/ 1983	US/ Shuttle/ STS-9	<p>During orbiter orientation, four hours before re-entry, one of the guidance computers crashed when the RCS thrusters were fired. A few minutes later, a second crashed in a similar fashion, but was successfully rebooted. Young delayed the landing, letting the orbiter drift. He later testified: 'Had we then activated the Backup Flight Software, loss of vehicle and crew would have resulted.' Post-flight analysis revealed the GPCs failed when the RCS thruster motion knocked a piece of solder loose and shorted out the CPU board. Columbia landed successfully. Right before landing, two of the orbiter's three auxiliary power units caught fire due to a hydrazine leak. The leak was later discovered after it burned itself out and caused major damage to the compartment. Astronauts John W. Young, Brewster H. Shaw, Owen K. Garriott, Robert A. Parker, Ulf Merbold (ESA, West Germany), and Byron K. Lichtenberg were unharmed.</p>	<ol style="list-style-type: none"> 1. Solder problem affected multiple redundant computers (single failures affecting redundant critical items should be eliminated wherever possible). 2. Single hydrazine leak affected multiple APUs (single failures affecting redundant critical items should be eliminated wherever possible). 	<ol style="list-style-type: none"> 1. http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf 2. http://www.astronautix.com/flights/ts9.htm
IF	N	2/3/ 1984	US/ Shuttle/ STS-41B	<p>Experienced O-ring erosion in both the right hand nozzle joint and the left SRB forward field joint. The O-ring erosion extended over 2 to 7 cm with a maximum depth of 1 mm. The concept of 'acceptable erosion' began to be advocated by SRM builder Thiokol and NASA management. Crew Astronauts Brand, Gibson, McCandless, McNair and Stewart were unharmed.</p>	<ol style="list-style-type: none"> 1. Deficiencies in O-ring design. 	<ol style="list-style-type: none"> 1. http://www.astronautix.com/flights/ts41b.htm 2. Aerospace Presentation US.ppt³
IF	N	4/6/ 1984	US/ Shuttle/ STS-41C	<p>Experienced erosion of the primary O-ring in the right-hand nozzle joint. Crew Astronauts Crippen, Hart, Nelson, Scobee, and van Hoften were unharmed.</p>	<ol style="list-style-type: none"> 1. Deficiencies in O-ring design. 	<ol style="list-style-type: none"> 1. http://www.astronautix.com/flights/ts41c.htm 2. Aerospace Presentation US.ppt³



IF	N	10/10/1984	US/ Shuttle/ STS-41G	In response to the American Strategic Defence Initiative and continued military use of the shuttle, the Soviet Union fired a 'warning shot' from the Terra-3 laser complex at Sary Shagan. The facility tracked Challenger with a low power laser on 10 October 1984. This caused malfunctions to on-board equipment and discomfort / temporary blinding of the crew, leading to a US diplomatic protest. Crew was unharmed.	1. Equipment and crew can be affected by ground-based lasers.	1. http://www.astronautix.com/flights/ts41g.htm 2. Aerospace Presentation US.ppt ³
IF	N	6/26/1984	US/ Shuttle /STS-41D	Pad abort at T-4 seconds when anomaly detected (potential fire) in one main engine. Experienced primary O-ring erosion in both the right-hand forward field joint and the left-hand nozzle joint. There was a small amount of soot behind the primary O-ring, indicating short duration blow-by. This was the first occurrence of blow-by in either the case-to-case or nozzle-to-case joints. Crew was not harmed.	1. Evacuation was not encouraged because escape system had not been tested. 2. Inadequate training for abort scenarios. 3. Deficiencies in O-ring design.	1. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf 2. http://av.rds.yahoo.com/_ylt=A0oGkt_7wZILvW0B1AJrCqMX; ylu=X3oDMTBvdmM3bGlxBHBndANhdI93ZWJfcmVzdWx0BHNIYwNzcg-=-/SIG=13bekcl1e/EXP=1268454267/**http%3A//www.wylelabs.com/content/global/documents/Health%2520Threats%2520-%2520Clark.pdf 3. http://www.astronautix.com/flights/ts41d.htm 4. Aerospace Presentation US.ppt ³
IF	N	4/12/1985	US/ Shuttle /STS-51D	The inboard right-side brake locked on landing, resulting in severe brake damage and the explosion of the tire. Experienced erosion of the primary O-rings in both nozzle joints. There was no blow-by past either nozzle O-ring. Severe elevon TPS damage caused carrier panel burth-through and structural damage to elevon leading edge. Damage to thermal barrier interfere with external tank umbilical door closure during flight. Crew was unharmed.	1. Deficiencies in O-ring design.	1. http://www.astronautix.com/flights/ts51d.htm 2. Aerospace Presentation US.ppt ³



IF	N	4/29/ 1985	US/ Shuttle /STS- 51B	Suffered the worst O-ring erosion experienced prior to the loss of Challenger on STS-51-L. The left-hand nozzle primary O-ring eroded to a depth of 4 mm inches over a 4 cm span with considerable blow-by. The secondary O-ring was eroded to a depth of 8 mm inches over an 8 cm span. Right OMS Y-web broken carrier panel caused overheating and delamination of OMS pod substructure. Crew was unharmed.	1. Deficiencies in O-ring design.	1. http://www.astronautix.com/flights/ts51b.htm 2. Aerospace Presentation US.ppt ³
IF	N	7/29/ 1985	US/ Shuttle /STS- 51F	Five minutes, 45 seconds into ascent, number one main engine shut down prematurely due to a faulty high temperature sensor. This was the only in-flight main engine failure of the shuttle program. At about the same time, a second main engine almost shut down from a similar problem, but this was observed and inhibited by a fast acting flight controller. The failed SSME resulted in an Abort To Orbit (ATO) trajectory, whereby the shuttle achieves a lower than planned orbital altitude. Also experienced a blow hole through the putty in the right-hand SRM nozzle and the primary O-ring was affected by heat. The crew was unharmed.	1. Faulty sensor. 2. Deficiencies in O-ring design.	1. http://science.ksc.nasa.gov/shuttle/missions/51-f/mission-51-f.html 2. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf 3. http://www.astronautix.com/flights/ts51f.htm 4. Aerospace Presentation US.ppt ³
IF	N	10/30/ 1985	US/ Shuttle /STS- 61A	Experienced erosion of the right-hand nozzle primary O-ring and the first case-to-case field joint O-ring anomaly since mission STS 51-C. There was blow-by past the primary O-rings in the centre and aft field joints on the left-hand SRM. The O-rings were not damaged. The crew was unharmed.	1. Deficiencies in O-ring design.	1. http://www.astronautix.com/flights/ts61a.htm 2. Aerospace Presentation US.ppt ³



IF	N	11/21/ 1985	USSR/ Salyut/ Soyuz T-14	Cosmonaut Vasyutin returns to earth early due to illness (infection). Soyuz T-14 demonstrated the wisdom of maintaining a Soyuz at Salyut 7 as an emergency medical evacuation vehicle: the mission commander Vasyutin fell ill which forced an early termination of the planned 6 month mission.	1. Emergency evacuation route important when medical care is minimal on orbit.	1. http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf 2. http://av.rds.yahoo.com/_ylt=A0oGkt_7wZlLvW0B1AJrCqMX;_ylu=X3oDMTBvdmM3bGlxBHBndANhd193ZWJfcwVzdWx0BHNlYwNzcg-_-/SIG=13bekcl1e/EXP=1268454267/**http%3A//www.wylelabs.com/content/global/documents/Health%2520Threats%2520-%2520Clark.pdf 3. http://www.astronautix.com/flights/sal7eo42.htm
IF	N	1/6/ 1986	US/ Shuttle/ STS- 61C	On a 6 January 1986 launch attempt, a temperature probe inside a propellant line broke off and went into a fluid control valve in one of the SSME's, jamming it in the open position. Had the launch not been scrubbed for other reasons, the valve probably would have caused a turbopump engine overspeed at engine shutdown, resulting in disintegration, and loss of both nearby hydraulic systems. Columbia would have made it to orbit, but been unable to return to earth. This would have been compound by a massive undetected loss of liquid oxygen propellant before the launch. This would have meant Columbia would have run out of propellant, not reached orbit, then lost its hydraulic systems, and then burned up on reentry. Crew for actual flight was unharmed.	1. Temperature probe became FOD.	1. http://www.astronautix.com/flights/ts61c.htm



IF	Y	1/28/ 1986	US/ Shuttle/ STS- 51L	<p>The Space Shuttle Challenger was destroyed 73 seconds after lift-off on STS-51-L. Analysis of the accident showed that a faulty O-ring seal had allowed hot gases from a shuttle solid rocket booster (SRB) to weaken the external propellant tank, and also the strut that held the booster to the tank. The tank aft region failed, causing it to begin disintegrating. The SRB strut also failed, causing the SRB to rotate inward and expedite tank breakup. Challenger was thrown sideways into the Mach 1.8 windstream causing it to break up in midair with the loss of all seven crew members aboard: Greg Jarvis, Christa McAuliffe, Ronald McNair, Ellison Onizuka, Judith Resnik, Michael J. Smith, and Dick Scobee. NASA investigators determined they may have survived the initial explosion but, while possibly unconscious from hypoxia, any survivors of the breakup were killed when the largely intact cockpit hit the water at 200 mph (320 km/h).</p>	<ol style="list-style-type: none"> 1. Design flaw, as O-ring performance could be too easily compromised by factors including the low temperature on the day of launch. 2. Failure of both NASA and its contractor, Morton Thiokol, to respond adequately to the design flaw. 3. "...failures in communication... resulted in a decision to launch 51-L based on incomplete and sometimes misleading information, a conflict between engineering data and management judgments, and a NASA management structure that permitted internal flight safety problems to bypass key Shuttle managers." 4. Feynman argued that the estimates of reliability offered by NASA management were wildly unrealistic, differing as much as a thousandfold from the estimates of working engineers. "For a successful technology," he concluded, "reality must take precedence over public relations, for nature cannot be fooled." 5. Excessive ice in place and lowest temperature launch. 6. Corrective actions included: (a) redesign of SRB and (b) creation of SR&QA office, and (c) making efforts to make Shuttle schedules more realistic. 	<ol style="list-style-type: none"> 1. http://science.ksc.nasa.gov/shuttle/missions/51-l/docs/rogers-commission/table-of-contents.html 2. http://history.nasa.gov/rogersrep/v6c_h6.htm 3. http://history.nasa.gov/kerwin.html 4. http://history.nasa.gov/rogersrep/acti ons.pdf 5. http://www.archive.org/details/ChallengerAccidentandInvestigation 6. http://history.nasa.gov/sts51l.html 7. http://science.ksc.nasa.gov/shuttle/missions/51-l/docs/events.txt 8. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf
IF	N	11/4/ 1987	USSR/ Mir 3	<p>Kvant module failed to dock to Mir. Crew performed EVA to remove foreign object from docking port.</p>	<ol style="list-style-type: none"> 1. Space environment can badly degrade materials. 	<ol style="list-style-type: none"> 1. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf



IF	N	9/5/ 1988	USSR/ Mir/ Soyuz TM-5	Soyuz TM-5 undocked from Mir. They jettisoned the orbital module and got ready for the deorbit burn. The deorbit burn did not occur because the infrared horizon sensor could not confirm proper attitude. Seven minutes later, the correct attitude was achieved. The main engine fired, but Lyakhov shut it down after 3 seconds to prevent a landing overshoot. A second firing 3 hours later lasted only 6 seconds. Lyakhov attempted to manually deorbit the craft, but the computer shut down the engine after 60 seconds. After three attempts at retrofire, the cosmonauts were forced to remain in orbit a further day, until they came into alignment with the targeted landing site again. The cosmonauts were left for a day in the cramped quarters of the descent module with minimal food and water and no sanitary facilities. Reentry occurred as normal on September 7, 1988. Cosmonauts Alexandr Lyakhov and Abdul Ahad Mohmand (from Afghanistan) survived.	<ol style="list-style-type: none"> 1. Quick thinking and breaking protocol saved crew's lives as a package that allowed deorbit was almost automatically jettisoned. 2. Critical module was subsequently retained until after deorbit burn to preclude a similar situation. 	<ol style="list-style-type: none"> 1. http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf 2. http://www.astronautix.com/flights/mirep3.htm 3. http://en.wikipedia.org/wiki/Soyuz_TM-5
IF	N	12/2/ 1988	US/ Shuttle/ STS- 27R	At T+85 seconds a large piece of debris struck the shuttle. The orbiter took 707 hits, 298 greater than an 2.4 cm in size. One tile was knocked off, but behind it was a thick plate covering the L-band antenna. Otherwise burn-through would have occurred. A leak in the left inboard wheel/tire assembly occurred on orbit of 1.4 psig a day. The crew landed unharmed.	<ol style="list-style-type: none"> 1. It was later found that the nose cone had failed during ascent due to a change in the manufacturing process of the ablative material that protected the SRB's during launch. 	<ol style="list-style-type: none"> 1. http://www.astronautix.com/flights/sts27.htm 2. Aerospace Presentation US.ppt³
IF	N	7/17/ 1990	USSR/ Mir 6	Airlock hatch failed to seal after EVA. Crew members transferred to backup airlock. Hatch was repaired during later EVA. Crew unharmed.	Lessons learned unknown.	<ol style="list-style-type: none"> 1. http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf 2. http://www.astronautix.com/flights/mireo6.htm



IF	N	3/24/1992	US/ Shuttle/ STS-45	Damage to wing RCC Panel 10-right, most likely due to orbital debris [though that is now in dispute]. Because of the location of the damage on the top side of the RCC, burn through did not occur. However, similar damage in a different location could have caused failure of the RCC as occurred on STS-107. The crew landed unharmed.	Lessons learned unknown.	1. http://www.astronautix.com/flights/ts45.htm 2. Aerospace Presentation US.ppt ³
IF	N	3/22/1993	US/ Shuttle/ STS-55	Pad abort at T-3 seconds due to incomplete ignition of one main engine. The problem was traced to a leak in the liquid oxygen preburner check valve. All three SSMEs were replaced as a precaution. Crew unharmed.	1. Faulty valve.	1. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf 2. http://www.astronautix.com/flights/ts55.htm
IT	Y	7/11/1993	Russia/ Mir	Pilot Cosmonaut Sergei Vozovikov drowned during water survival training in Black Sea.	Lessons learned unknown.	1. http://av.rds.yahoo.com/_ylt=A0oGkt_7wZILvW0B1AJrCqMX;_ylu=X3oDMTBvdmM3bGlxBHBndANhd193ZWJfcmVzdWx0BHNiYwNzcg_-/_SIG=13bekcl1e/EXP=1268454267/**http%3A//www.wylelabs.com/content/global/documents/Health%2520Threats%2520-%2520Clark.pdf 2. http://www.spacefacts.de/bios/cosmonauts/english/vozovikov_sergei.htm
IF	N	8/12/1993	US/ Shuttle/ STS-51	Pad abort at T-3 seconds due to faulty fuel flow sensor. Crew unharmed.	1. Faulty sensor.	1. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf 2. http://www.astronautix.com/flights/ts51.htm



IF	N	1/14/ 1994	Russia/ Mir/ Soyuz TM-17	Soyuz bumped into Mir twice during fly around when thruster control momentarily froze. Crew unharmed.	1. Switch set improperly.	1. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf 2. http://www.astronautix.com/flights/mireo14.htm
IF	N	8/18/ 1994	US/ Shuttle/ STS-68	Pad abort at T-1.9 s when all 3 engines shut down due to high temperatures in oxidizer turbopump.	1. New engine turbopumps. Resolution unclear.	1. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf 2. http://www.astronautix.com/flights/sts68.htm
IF	N	10/15/ 1994	Russia/ Mir 16	Oxygen generator ignited inside space station, resulting in small fire. Crew unharmed.	Lessons learned unknown.	1. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf
GP	Y	1/26/ 1995	China/ Long March	Long March rocket veered off course after launch. Loss of no less than six.	Lessons learned unknown.	1. http://space.newscientist.com/article/dn8144-timeline-chinas-spaceflight-history.html 2. http://www.astronautix.com/lvs/cz2e.htm
GP	Y	5/5/ 1995	Guiana Space Centre, French Guyana	Anoxia; Luc Celle and Jean-Claude Dhainaut died during an inspection in the umbilical mast of the launchpad	Lessons learned unknown.	1. http://en.wikipedia.org/wiki/Space_accidents_and_incidents



IF	N	10/20/ 1995	US/ Shuttle/ STS-73	Concerns for the radiators and orbital debris induced the program to fly with one of the payload bay doors partially closed. Several significant impacts including the largest orbital debris impact to date on the outside of the open payload bay door including the largest known orbital debris impactor to date (a piece of solder board). The Extended Duration Pallet, which carries extra supplies of oxygen and hydrogen, was in the payload bay at that location. The crew was unharmed.	1. Micrometeoroids/orbital debris pose significant risk to the Space Shuttle	1. STS-73 MMOD report ⁵ 2. http://science.ksc.nasa.gov/shuttle/missions/sts-73/mission-sts-73.html
GP	Y	2/14/ 1996	China/ Long March	Long March rocket veered off course 2 seconds after launch, crashing in the nearby village and destroying 80 houses, according to the official Chinese count, killing 59 people, but with U.S. defense intelligence officials estimating 200 dead.	1. China blamed the accident on a low-tech problem, the faulty soldering of a wire on a computer circuit board.	1. http://www.astronautix.com/lvs/cz3b.htm 2. http://en.wikipedia.org/wiki/Space_accidents_and_incidents



IF	N	2/23/ 1997	Russia/ Mir	<p>There was a fire on board the Mir space station when a lithium perchlorate canister used to generate oxygen leaked. The fire was extinguished after about 90 seconds, but smoke did not clear for several minutes. Breathing devices did not work properly (or crewmember did not properly know how to use them) nor did fire extinguishers close to hand. Although protocol requires evacuating in Soyuz, the fire was between crew and one of their escape craft (Soyuz). Two-foot-long flame burned for about 14 minutes before contained. Crew had to wear respirators for several hours due to smoke and potentially toxic fumes in station. This was followed by continued problems with the oxygen, control, and thermal control systems, including a CO2 removal system failure. There were six crew on board at that time so access to a single Soyuz was insufficient. Cosmonauts Valery Korzun, Alexandr Kaleri, Vasili Tsibliyev, Aleksandr Lazutkin, German astronaut Reinhold Ewald and US astronaut Jerry Linenger survived.</p>	<ol style="list-style-type: none"> 1. Using combustion to create oxygen can be risky. 2. PPE and emergency gear must be in good repair and reliable. Finding the limitations during an emergency is not good planning. 3. Crew must be properly trained in the use of all emergency gear. 4. Lack of alternatives can dictate actions. 5. Potentially risky ventures should not be taken without a viable escape route. 	<ol style="list-style-type: none"> 1. http://history.nasa.gov/SP-4225/nasa4/nasa4.htm 2. http://commdocs.house.gov/committees/science/hsy126000.000/hsy126000_0.htm 3. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf 4. http://www.astronautix.com/details/mir50651.htm 5. http://www.astronautix.com/flights/mireo23.htm
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IF	N	6/25/ 1997	Russia/ Mir	At Mir during a re-docking test with the Progress-M 34 cargo freighter, the Progress collided with the Spektr module and solar arrays of the Mir space station. This damaged the solar arrays and the collision punctured a hole in Spektr module and the space station began depressurizing. The on-board crew of two Russians and one visiting NASA astronaut were able to close off the Spektr module from the rest of Mir after quickly cutting cables and hoses blocking hatch closure. Module sealed off, but 30% of station power lost due to damaged solar cell. Crew was not harmed.	<ol style="list-style-type: none"> 1. Testing of a manual docking method to eliminate the automatic (but reliable) system ended in failure. 2. Learning by attrition is very expensive. 3. In order to isolate the punctured segment, cables and hoses had to be severed to close the hatch. 4. Fortunately, this was a slow leak that allowed for isolation (8 minutes to close hatch). 5. Losing a segment with vital capabilities (like power) can be debilitating. 6. Loss of a key supplier can lead to difficult choices. 	<ol style="list-style-type: none"> 1. http://www.janes.com/aerospace/civil/news/jsd/jsd030203_3_n.shtml 2. http://commdocs.house.gov/committees/science/hsy126000.000/hsy126000_0.htm 3. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf 4. http://www.astronautix.com/flights/mireo23.htm 5. http://www.astronautix.com/details/mir50750.htm
IF	N	8/17/ 1997	Russia/ Mir EO23/ Soyuz TM-25	The Soyuz landing rockets failed to fire on touchdown, giving one of the roughest landings experienced by a returning Mir crew. Cosmonauts Lazutkin and Tsibliyev survived the landing.	Lessons learned unknown.	<ol style="list-style-type: none"> 1. http://www.astronautix.com/flights/mireo23.htm 2. Aerospace Presentation non-US.ppt²
IF	N	11/3/ 1997	Russia/ Mir 24	Kvant module out airlock hatch failed to seal after EVA. Inner hatch was used to seal station until replacement hatch could be brought to orbit. On orbit crew was unharmed.	Lessons learned unknown.	<ol style="list-style-type: none"> 1. Http://ston.jsc.nasa.gov/collections/TRS/techrep/TM-2000-209764.pdf 2. http://www.astronautix.com/flights/mireo24.htm 3. http://www.astronautix.com/details/mir50779.htm



IF	N	7/23/ 1999	US/ Shuttle/ STS-93	Five seconds after liftoff, an electrical short knocked out controllers for two main engines. The engines automatically switched to their backup controllers. Had a further short shut down two engines, the orbiter would have ditched into the ocean, although the crew could have possibly bailed out. This wiring failure led to a program-wide inspection of the wiring in all orbiters. Concurrently a pin came loose inside one engine fuel injectors and impacted a cooling line in the engine nozzle inner surface, allowing a hydrogen fuel leak. This caused premature fuel exhaustion, but the vehicle safely achieved a slightly lower orbit. Had the failure propagated further, a risky transatlantic or RTLS abort would have been required. Astronauts Eileen Collins, Jeffrey Ashby, Steven Hawley, Catherine Coleman, Michel Tognini were unharmed.	1. Electrical short caused by damaged wiring. Entire fleet grounded while wiring issues (multiple) were reworked. 2. Loose pin was corrected and extra effort put in place to limit FOD and it's potential damage.	1. http://spaceflight.nasa.gov/shuttle/archives/sts-93/ 2. Http://ston.jsc.nasa.gov/collections/TRS/_techrep/TM-2000-209764.pdf 3. http://www.astronautix.com/flights/sts93.htm
GP	Y	10/1/ 2001	US/ Shuttle	Crane operator Bill Brooks was killed in an industrial accident at Launch Complex 37	Lessons learned unknown.	1. http://spaceflightnow.com/news/n0110/02slc37accident/ 2. http://en.wikipedia.org/wiki/Space_accidents_and_incidents
GP	Y	10/15/ 2002	Russia/ Soyuz- U	A Soyuz-U exploded 29 seconds after launch, killing a soldier, Ivan Marchenko, and injuring 8 others. Fragments of the rocket started a forest fire nearby, and a Block D strap-on booster caused damage to the launchpad	Lessons learned unknown.	1. http://www.astronautix.com/chrono/20024.htm 2. http://en.wikipedia.org/wiki/Space_accidents_and_incidents



IF	Y	2/1/ 2003	US/ Shuttle/ STS- 107	<p>The Space Shuttle Columbia was lost as it reentered after a two-week mission, STS-107. Damage to the shuttle's thermal protection system (TPS) led to structural failure in the shuttle's left wing and, ultimately, the spacecraft breaking apart. Investigations after the tragedy revealed the damage to the reinforced carbon-carbon leading edge wing panel had resulted from a piece of insulation foam breaking away from the external tank during the launch and hitting shuttle's wing. Loss of Astronauts Rick D. Husband, William McCool, Michael P. Anderson, David M. Brown, Kalpana Chawla, Laurel B. Clark, and Ilan Ramon.</p>	<ol style="list-style-type: none"> 1. NASA management failed to recognize the relevance of engineering concerns for safety. 2. Model used to estimate TPS damage was not inappropriate use of model. 3. Model resulted in large damage and was discounted; rationale based on flawed logic and insufficient data. 4. NASA management took position that an unsafe condition had not been proven. 5. Subsequent testing indicated that TPS materials were more susceptible to foam impact damage than previously believed. 6. Subsequent arcjet testing indicated that TPS, particularly RCC, was considerably more susceptible to damage from overheating than previously believed. 7. Organizational structure and processes were sufficiently flawed that compromise of safety was expected no matter who was in the key decision-making positions 8. Safety organization not independent from program management. 9. Corrective actions included (a) developing TPS repair options, (b) mandating capability for rescue flights, (c) increased visibility into ascent debris damage during launch, (d) changes to NASA culture (which may not be verifiable). 10. Additional crew survival lessons in the Columbia Crew Survival Investigation Report 	<ol style="list-style-type: none"> 1. http://caib.nasa.gov/ 2. http://caib.nasa.gov/events/public_hearings/default.html 3. http://www.nasa.gov/columbia/foia/index.html 4. http://www.nasa.gov/columbia/media/index.html 5. http://www.nasa.gov/news/reports/index.html
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IF	N	5/4/ 2003	Russia/ ISS EO-6/ TMA-1	During the re-entry, the first for the Soyuz TMA-1 model, the guidance failed and the capsule reverted to a rolling ballistic re-entry. This subjected the crew to over 8 G's during re-entry, as opposed to the 3 G's of a normal Soyuz lifting re-entry. It also resulted in a landing 460 km short of the target, and a delay of over two hours before recovery forces arrived at the capsule. Astronauts Bowersox and Pettit and Cosmonaut Budarin survived.	1. First flight of the TMA-1 craft.	1. http://www.astronautix.com/flights/iss6.htm 2. Aerospace Presentation non-US.ppt ²
GP	Y	8/22/ 2003	Brazil/ BSA	On August 22, 2003, a massive explosion destroyed a Brazilian Space Agency VLS-1 (VLS-1 V03) rocket as it stood on its launch pad at the Alcântara Launching Center in the state of Maranhão in northern Brazil. Twenty-one people, standing on the launch pad, died when one of the rocket's four first stage motors ignited accidentally. The explosion caused a fire in the nearby jungle brush, and produced a large cloud of smoke that was visible for large distances. 21 personnel lost.	1. BSA criticized for using solid propellants that cannot be throttled back or stopped once ignited.	1. http://news.bbc.co.uk/2/hi/americas/3175131.stm 2. http://www.spacedaily.com/news/rocketscience-03zw.html 3. http://www.astronautix.com/lvs/vls.htm
IF/CIV	N	9/29/ 2004	US/ Commerical/ SS1	Asymetric thrust at high mach/ low AOA resulted in right roll of 190 deg/sec at 60 seconds into rocket burn. Pilot Mike Melville reduced roll to 140 deg/sec with aerodynamic control but needed reaction control jets to overcome roll Vehicle control regained just prior to apogee. Pilot Mike Melville unharmed.	Lessons learned unknown.	1. Crew Survivability IAASS.pdf ¹ 2. http://av.rds.yahoo.com/_ylt=A0oGkt_7wZILvW0B1AJrCqMX; ylu=X3oDMTBvdmM3bGlxBHBndANhd193ZWJfcmVzdWx0BHNlYwNzcg=-/SIG=13bekcl1e/EXP=1268454267/**http%3A//www.wylelabs.com/content/global/documents/Health%2520Threats%2520-%2520Clark.pdf 3. http://en.wikipedia.org/wiki/SpaceShipOne_flight_16P



CIV	Y	7/26/2007	US/Commercial	Explosion during a test of rocket systems by Scaled Composites during a nitrous oxide injector test. Three personnel lost with three more left in critical condition.	1. Cause has not yet been advertised.	1. http://www.guardian.co.uk/uk/2007/jul/27/spaceexploration.world 2. http://www.space.com/news/070727_scaled_explosion_update.html
IF	N	10/27/2007	USSR/Soyuz/Soyuz TMA-10	Ballistic reentry instead of standard entry because of damage to a cable in the spacecraft's control panel, which connected the control panel with the Soyuz descent equipment	1. Damaged cable	1. http://ruspace.blogspot.com/2008/01/soyuz-tma-10-ballistic-landing-cause.html 2. http://www.spacefacts.de/mission/english/soyuz-tma-10.htm 3. http://en.wikipedia.org/wiki/Soyuz_TMA-10
IF	N	4/19/2008	USSR/Soyuz/Soyuz TMA-11	Soyuz performed a ballistic reentry, a reentry steeper than a normal aerodynamic reentry, due to a malfunction and landed 475 km from intended landing point. The spacecraft's hatch and antenna suffered burn damage during the unusual reentry. The Russian news agency Interfax reported the ship may have entered the atmosphere hatch first. Although no injuries were initially reported, at least one crewmember is currently having some after effects.	1. Cause not yet determined.	1. http://www.spaceflightnow.com/stat/mission/exp16/080422descent.html http://www.ctv.ca/servlet/ArticleNews/story/CTVNews/20080419/soyuz_landing_080419/20080419 3. http://en.wikipedia.org/wiki/Soyuz_TMA-11

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2. "Non-US Space Transportation Failures," I-Shih Chang and E. Joe Tomei, 26th International Symposium on Space Technology and Science, June 3, 2008.
3. "US Space Transportation Failures," E. Joe Tomei and I-Shih Chang, 26th International Symposium on Space Technology and Science, June 3, 2008.
4. *The Last Man on the Moon: Astronaut Eugene Cernan and America's Race in Space*, by Eugene Cernan and Donald Davis, March 1999.
5. JSC 27323, STS-73 Meteoroid/Orbital Debris Impact Damage Assessment Report Part 1, Ronald Bernhard and Eric Christiansen, December 15, 1995.

