Building a Space Safety Institute

Welcome back to Space Safety Magazine!

Space safety is about manned as well as unmanned missions. It is not only about space vehicle design and astronaut safety, but includes spaceport operations; space traffic management; ground, atmospheric, and on-orbit pollution prevention; and safety of uninvolved public during launch and re-entry operations. Space safety is also about specific technical legal, insurance, and regulatory matters. Finally, it is a national as well as and international matter. Awareness is growing in industry and the general public, but dedicated education, training, and communication opportunities are basically non-existent.

Training is different from *education*. The US Air Force as well as a number of high technology organizations clearly make a key distinction between the concepts of education and training. We accept the concept that education is ***"instruction and study focused on creative problem solving that does not provide predictable outcomes. Education encompasses a broader flow of information to the student and encourages exploration into unknown areas and creative problem solving."*** We also accept that training can be defined as ***"instruction and study focused on a structured skill set to acquire consistent performance. Training has predictable outcomes and when outcomes do not meet expectations, further training is required."***

On the one hand, education requires more time to complete and often culminates with an original research endeavour, especially when we are talking about graduate level education. Such an educational program prepares individuals for careers and includes practice in critical and creative thinking that will in many ways last throughout a career. On the other hand, training is much more short term and typically takes days to a week or two to complete.

Space safety design criteria, methods, and hazard analysis techniques are not generally taught in depth in aerospace engineering schools since up to now they have not been considered as part of a specialized branch of space systems engineering but rather as aspects of various specialist fields of engineering (e.g. in relation to pressure systems, avionics design, etc.). Both manned programs (Shuttle, ISS) and unmanned programs (ELV payloads) clearly demanded formation of a new technical profile, the safety engineer, to support and execute the design safety certification process. These engineers had to gain system knowledge as well as a broad understanding of multidisciplinary safety aspects so as to be able to perform integrated analyses. The engineers initially selected for the tasks had a variety of backgrounds and no dedicated training. They developed their knowledge through internal information exchanges, brainstorming, discussions, short seminars, and so on. Later, experienced safety engineers taught the newcomers in a sort of master-to-apprentice relationship in combination with safety process training courses of a few days duration.

Concurrently, the systems engineering community became increasingly aware that safety had to be designed-in from the very beginning or risk costs escalation, a huge pile of (unjustifiable) waivers, and ultimately devastating accidents.

The need is also arising for education in aerospace operations safety, covering all aspects from launch safety, to on-orbit traffic management, and re-entry safety. Operations safety will require knowledge of rules and methods for on-orbit environment protection such as space debris mitigation, and remediation. In future, space and aviation will share more and more common operational interests due to emerging hybrid systems like suborbital space-planes and the operational use of space-based systems for air navigation, aviation communication, and high resolution weather forecasts.

Only a few elements of knowledge in the space safety field are currently available at universities. Therefore, we are glad to announce that the International Space Safety Foundation (ISSF) in cooperation with the International Association for the Advancement of Space Safety (IAASS) is launching the creation of a cooperative network this year. The network is to include universities and experts from industry and agencies. Called "International Institute for Space Safety," it will offer graduate and postgraduate education opportunities in all space safety technical fields.

Best Regards,

Frederick D. Gregory
ISSF Board Chairman

Tommaso Sgobba
IAASS President

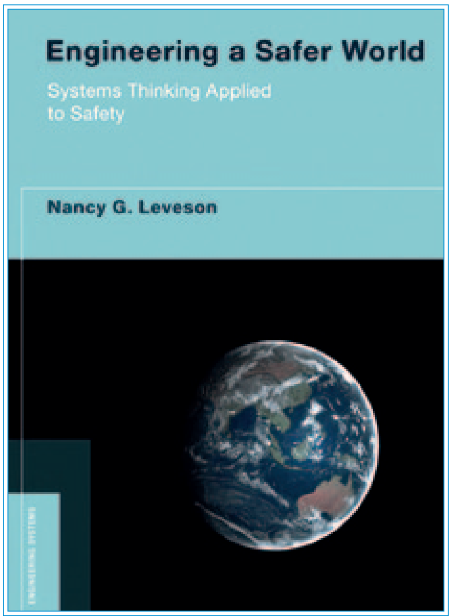
If you are interested to be part of this ambitious project or you want more information, please go to our web site **www.spacesafetyfoundation.org** *and provide us contact information so that we can answer your questions and get back to you.*

Engineering a Safer World

Systems Thinking Applied to Safety

By Nancy Leveson

"STAMP extends the old failure model of accident causation to include new types of accident causes"



The MIT Press (January 13, 2012), Nancy Leveson, MIT.

Engineering is facing every day a set of new challenges, caused by a steady technological revolution and by our increasing reliance on systems of increasing complexity. Yet, the basic engineering techniques applied in safety and reliability engineering, created for a simpler, analog world, have changed very little over the years. In the book "Engineering a Safer World – Thinking Applied to Safety", Nancy Leveson, Professor of Aeronautics and Astronautics and also Professor of Engineering Systems at MIT *and IAASS fellow, describes a new approach to safety and risk management, better suited to today's complex, socio-technical, software-intensive world.*

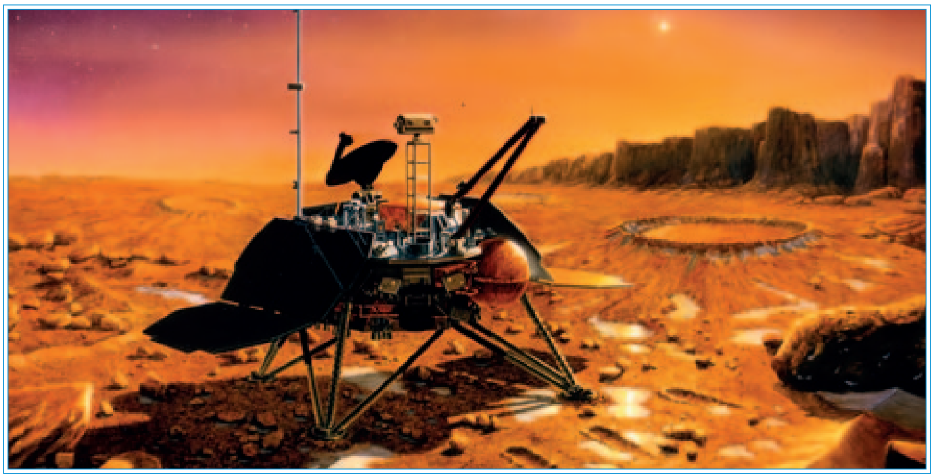
A Case for STAMP

STAMP is a new model of accident causation in complex systems. The traditional model that thinks of accidents as caused by component failures was adequate for the relatively simply electro-mechanical systems for which it was created, but it does not fit the more complex, software-intensive systems we are building today. Accidents, such as the loss of the Mars Polar Lander, are increasingly likely to result from interactions among system components that have not failed, but satisfy their specifications (which were inadequate). The real problems lie in system engineering and flaws in the component requirements specifications and the system design. These problems need to be handled by improved system engineering supported by a top-down hazard analysis technique rather than simply by bottom-up reliability engineering. For Mars Polar Lander, and many other space mishaps, no components failed, in that each satisfied its specification but the understanding by the component developers of the required behavior was incorrect or incomplete. Many of these "component interaction accidents" have been related to software and flawed software requirements.

STAMP extends the old failure model of accident causation to include these new types of accident causes. It redefines the safety problem in terms of control engineering rather than reliability engineering. Preventing component failure is still part of the solution, but the overall problem is changed to a control problem, where the design goal becomes the enforcement of behavioral constraints on the system as a whole and on the components.

STPA (System-Theoretic Process Analysis) is the new hazard analysis based on the STAMP model of accident causality. This hazard analysis method uses basic control theory approaches to identify hazard causes and to generate safety requirements for the individual system components.

STPA can be used early in the system design process, including even high-level architectural tradeoff decisions, to build safety into the system rather than waiting until a design is completed to analyze whether it is safe. In later stages of development, the cost of making changes (rework) may be exorbitant and the most effective design features for preventing losses may no longer be possible to incorporate.



Artist's conception of Mars Polar Lander, which crashed into Mars in 199[illegible] an interaction problem among otherwise working components. - Credits: NASA/JPL

> **"Systems thinking will be needed to increase our probability of success in new missions"**

Success Stories

While the actual publication of *Engineering a Safer World* is very recent, drafts have been available for a while. We and others have been trying STPA on a large variety of real systems, including spacecraft, medical devices, autos, railroads, aircraft, nuclear power, and defense systems. In all cases, STPA found the accident scenarios identified by the engineers using traditional Fault Tree Analysis (FTA) and Failure Mode Effect Analysis (FMEA), but also found important paths to mishaps that the other traditional techniques did not—and could not—identify. In space, for example, JAXA has been experimenting and using STPA on the HTV, on a new scientific satellite, and on the early architectural tradeoff analysis for their planned crew vehicle. The results have been described in papers presented at IAASS conferences. In defense, the deployment and field testing of the new U.S. ballistic missile system was delayed for six months to fix all the paths to inadvertent launch found during the application of STPA in a non-advocate risk assessment right before the system was to be deployed.

One of the most surprising results we have found is that not only is STPA more powerful than current hazard analysis techniques, it also appears to be easier to use, according to the feedback we are getting, and less costly. Safety engineering activities are often not cost-effective. *Engineering a Safer World* provides some reasons for this problem and presents a more cost-effective way to manage system safety.

In addition to the new hazard analysis technique, the book describes a new structured, more comprehensive mishap analysis technique, called CAST (Causal Analysis based on System Theory), using the STAMP model as a foundation. CAST has been used on dozens of real accidents and identified many more causal factors, including flawed organizational design and management decision making that contributed to the loss than were identified in analyses based on standard practice.

The H-II Transfer Vehicle (HTV) cargo spacecraft developed by JAXA using STPA (System-Theoretic Process Analysis). - Credits: NASA

The Human Factor

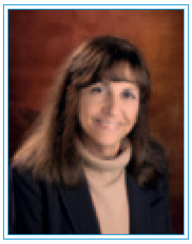
Accident analysis and hazard analysis often stop with some unsafe operator action or inaction and then assign blame to the human operator. STAMP helps to identify the design and contextual features that contributed to the erroneous actions or flawed decision-making so that similar errors can be prevented in the future. *Engineering a Safer World* contains information about how to better understand human error in accident investigations and also about how to design systems from the beginning to reduce human error.

Operability needs to be considered from the start of the development process and appropriate information documented and passed to the system operators. My new book describes what information needs to be documented and how to use this information to create a safety management operations plan. It also discusses how to design important safety-related operations functions such as managing and controlling changes and creating feedback channels to detect performance changes that may be leading to increased risk during operations.

Safety has to be carefully managed. A chapter is included in the book on how to manage safety in complex system development and in operations. Another chapter describes the very successful nuclear submarine safety program, called SUBSAFE, and the approaches used in this program that have allowed the U.S. to avoid losing a submarine in the last 49 years since the program's inception in 1963 after the Thresher loss.

Final Remarks

To improve the success of our new space ventures, we need to go beyond the techniques and processes created decades ago for much simpler systems. They are not powerful enough for the increased complexity and new technology being incorporated into today's spacecraft. Systems thinking will be needed to increase our probability of success in new missions. The techniques and ideas in *Engineering a Safer World* are a start, but we will need to improve and build on them for the future.



Prof. Nancy Leveson has conducted research on all aspects of system safety including design, operations, management, and social aspects. She has published over 200 research papers and two books. She served on the NASA Aerospace Safety Advisor Panel and was a consultant to the Columbia Accident Investigation Board and an expert advisor to the Presidential Oil Spill Commission.

by Michael Listener

The Legal Frontier of Commercial Space Regulation

The advent of commercial space, in particular space tourism via suborbital flights, is causing a paradigm shift from government spaceflight activities. This transition, which has found support in the United States, brings legal and policy challenges that will test the current body of international and domestic space law and influence its evolution.

Frans G. von der Dunk, Harvey and Susan Perlman, Othmer Professor of Space, Cyber and Telecommunications Law LL. M. Program at the University of Nebraska-Lincoln, College of Law, is a worldwide authority on legal issues of commercial space. Professor von der Dunk is also the administrator of Black Holes BV, a firm he founded in 2007 to offer consultation on matters regarding international space law and policy.

> “Suborbital flights will likely present legal and policy problems”

The Issue of Liability

The first wave of space tourism came with the Russian Federation sale of Soyuz capsule seats for trips to the International Space Station brought the first wave of space tourism. These flights have been infrequent, and do not present many legal issues except for perhaps the insistence by NASA that tourists visiting the ISS waive liability against the United States for any injuries they might sustain within modules registered to the United States.

More controversial is the emerging commercial suborbital flight industry, promoted by companies like Virgin Galactic. Unlike tourist flights to the ISS, suborbital flights will be more frequent, and as such will likely present more legal and policy problems. One significant legal challenge is liability. Startup companies such as Virgin Galactic face the threat of substantial liability, given the high-risk nature of the suborbital space flight, a threat that could very well prevent companies from getting off the ground because of exorbitant insurance costs.

A possible solution is the approach taken by the Warsaw Convention at the beginning of the airline industry. The Warsaw Convention proposed to ▶▶

Virgin Galactic's SpaceShipTwo will enable a new and potentially controversial era in commercial spaceflight.
Credits: Virgin Galactic/Mark Greenberg

Artist's conception of Virgin Galactic's passengers. The legal status of space tourists, and whether or not they should be granted the title of astronaut astronauts, is still undefined.
Credits: Virgin Galactic

"Limited liability will not be granted to commercial space flight companies indefinitely"

insulate the airline industry from liability, allowing it to move past its infancy. Similarly, the commercial space industry in the United States is finding havens with many states including Virginia, Texas, and Florida, which passed limited or no liability statutes for commercial space flight companies doing business within their jurisdictions.

Professor von de Dunk notes however, that a condition of limited liability will not be granted to commercial space flight companies indefinitely. He foresees liability as an evolutionary issue, where commercial space flight companies are initially granted a non-liability regime, and later transitioned gradually to a regime of liability. This regime will evolve as the industry matures and grows, and with it the regulatory environment and the consumers' demand that commercial operators accept more liability for their operations. However, even with no liability or limited liability, commercial space operators are not guaranteed that an incident during operations will not result in a lawsuit. It is likely that an incident resulting in injury or death of a tourist will cause lawyers to test the legal validity of no liability or limited liability waivers in the courts of the United States.

Regulation of the Commercial Space Industry

Another area of concern is regulation of the commercial space industry. Commercial space in the United States falls under the regulatory authority of the Federal Aviation Administration (FAA). The FAA's involvement with commercial space began with the passage of the Commercial Space Launch Amendments Act of 2004 (CCLA), which established a protocol of "informed consent" for spaceflight passengers, and created a new experimental launch permit for test and development of reusable suborbital launch vehicles.

However, some representatives of the commercial suborbital and orbital space flight industry were concerned that a regulatory framework for commercial human space flight could be detrimental to the industry. This concern was not unanimous as many in the industry, including commercial spaceflight advocates, insurers, suppliers and infrastructure institutions responsible for spaceports, felt that a regulatory framework would be an important prerequisite to commercial human spaceflight activities. Congress agreed with this view and included a provision within the CSLAA that limits the ability of the FAA to promulgate safety regulations for commercial human spaceflight vehicles. The provision was slated to end December 23, 2011, but Congress granted an extension until 2015.

While the provision in CSLAA prevents the FAA from issuing new safety regulations, it does not prevent the FAA from actively monitoring commercial human spaceflight activities, nor does it prevent the FAA from performing other duties granted to it by the CCLA. Despite the extension of this moratorium, it is apparent that the commercial

Dennis Tito, the first paying space tourist to fly to the ISS , pictured here at the 40th Space Congress in 2003. - Credits: NASA human spaceflight industry will not be shielded forever from the FAA's scrutiny. Professor von der Dunk feels that when the FAA regains full authority to issue safety regulations, it will be keen to maintain a balance between regulating the operators and safety, instead of proceeding in an overly burdensome manner.

The Status of Passengers Flying into Outer Space

Another area of legal and policy issues identified by Professor von der Dunk is the status of passengers flying into outer space. To be recognized as an astronaut, the current regime of international space law poses three conditions: a person must be in an object located in space, conducting activities for the benefit and in the interests of all countries, and he must be regarded as an envoy of mankind. A person who meets this definition has certain legal rights, most notably the right of being rescued and returned to his nation of origin in case of distress in accordance with the Rescue Agreement of 1968.

The upcoming generation of space tourists, however, may not meet the legal definition of astronauts primarily because they are in space for leisure. Professor von der Dunk observes that aside from not meeting the legal definition of astronaut, there is also the further distinction of whether future participants in commercial space activities are acting as flight crew or space flight participants, and whether they will be afforded the rights of astronauts under current international law. He speculates that even though future commercial space participants may not technically qualify under current international law, basic humanitarian rights, which constitute customary law outside of the treaties, will persuade nations to come to the rescue also of these individuals as appropriate.

> "It is too early to consider a legally-binding treaty"

A Paradigm Shift

While the paradigm shift of commercial space has the support of the government of the United States, other nations, including the European Union (EU) members, have expressed mixed feelings. According to Professor von der Dunk, the culture of the EU is less inclined to allow commercial enterprise to enter into government controlled activities. On the other hand, the EU and its members acknowledge the potential benefits that commercial space could offer, and so he expects that the EU will observe the United States to evaluate the development of commercial space before venturing into its own program.

If and when the EU will engage in commercial space, it will need laws and regulations to address activities. To that end, Professor von der Dunk comments that from the viewpoint of the EU, there are two levels to regulating commercial space. First, the EU sees commercial space law as already being regulated by the current international space law treaties, including the Outer Space Treaty of 1967 and the Liability Convention of 1972. Second, at the domestic level, the EU may follow to a certain extent the United States' approach, including legislation and FAA regulations, like Sweden was considering for its own commercial space industry.

A Soyuz capsule upon landing. Will the Rescue Agreement apply for space tourists making an emergency landing in a foreign country? - Credits: NASA

Final Remarks

International law concerning commercial space could prove more problematic than domestic law. Professor von der Dunk notes that it is too early to consider a legally-binding treaty because there is a lack of experience with commercial space flight. However, customary international law for commercial space flight could provide legal precedent based on practices and experience from the commercial space activities of the United States.

Whether commercial space will live up to its expectations remains to be seen. What is certain is that the legal and regulatory environment will challenge and evolve the current body of space law and regulation to meet demands placed upon it. Whether that evolution will meet the demands created by commercial space remains to be seen.

Michael is an attorney and policy analyst with an emphasis on space law and security. Michael also writes as a Senior Contributor for DefensePolicy.Org. Opinions expressed are those of the author and do not constitute legal advice or create an attorney/client relationship. Michael can be contacted at: michael.listner@spacesafetymagazine.com
Follow Michael via Twitter: *@ponder68*.

By Joel Spark

Coolant Tank Crashed in Brazil

Early in the morning on February 22, Valdir José Mendes was asleep in his home in the Brazilian village of Riacho dos Poços when he heard what sounded like an explosion. "I thought it was a plane that had fallen, or an earthquake," Mendes later told reporters. When he looked outside, he discovered a metal sphere, roughly 1 m across, embedded in the ground near a severed cashew tree.

Through word-of-mouth, online blogs, and eventually local news stations, news of the mystery object spread across the world, bringing thousands of locals flocking to the village. "It was a huge uproar here. Some feared it was the beginning of the 2012 end of the world, others said it was 'alien', but I think it is a piece of satellite," said Max Garreto Mauro, a resident of the nearby town of Mata Roma who traveled to see the object.

Although local police confirmed that the sphere was non-hazardous being inert and not radioactive, two days after it crashed Brazilian military police confiscated the object, taking it first to the barracks in Mata Roma, and then to the Alcantara Space Center. They declined to offer an opinion on what it was, stating that they lacked the equipment required to identify it. Some speculated

> "Some feared it was the 2012 end of the world"

that it could have fallen from an aircraft, or from a weather balloon; some more far-fetched theories surfaced claiming it was from a secret military aircraft or an extraterrestrial spacecraft.

As details continued to surface, however, more likely explanations began to circulate. William Ailor, an expert on reentry and a scientist at The Aerospace Corporation's Center for Orbital and Reentry Debris Studies and IAASS fellow, suggested that the object could actually be part of a spent upper stage. The morning that the object nearly crashed into Medes' home, an Arianne 4 upper stage body, (object 1997 016C in the NORAD database), was scheduled to reenter over the Pacific Ocean west of South America, making it entirely possible that debris from the rocket body could have fallen in Brazil. If the metal sphere is indeed part of that rocket, then it is most likely a helium coolant tank.

The mysterious sphere discovered around near the Brazilian of Riacho dos Poços.

Locals gather around the "space sphere".

The case of the Brazilian sphere isn't the first time the problem of space debris and space object reentry survival has stirred up some excitement on the ground. Last December, for example, a 1.1 m metal sphere landed in Namibia. The sphere was later identified as a Composite Overwrapped Pressure Vessel (COPV). In September, NASA's 6.8-ton Upper Atmosphere Research Satellite (UARS) made headlines when it reentered without control although it ended up splashing harmlessly in the Pacific Ocean. In January, the ill-fated Phobos Grunt probe caused a stir when Roscosmos lost control and the 7 ton spacecraft along with its full tank of toxic hydrazine fuel reentered the atmosphere, even earning it a mention on the American comedy news show "The Colbert Report."

With nearly 1500 rocket bodies and other mission-related objects tumbling in low Earth orbit, this likely isn't the last time a space ball will come crashing down in someone's village. In the meantime, it's up to launch vehicle operators to reclaim the fallen objects, and study them for information on how they reentered, and develop methods to prevent uncontrolled space objects from potentially impacting populated centers in the future.

Under Pressure: A Brief History of Pressure Suits Part 3

By Phillip Keane

The Future

In the last issue, we looked at high speed, high altitude aviation, the dawn of the space race, and the pressure suits that kept the pilots and astronauts alive in those extreme environments. We also noted that pressure suit design is a long process, and that the state of the art of aerospace vehicles can often overtake that of pressure suits, meaning that pressure suit design really hasn't changed in over half a century. In this chapter, we will look at the future of pressure suit design.

Spacediving

One of the better publicized developments in recent history came from the David Clarke Company that designed and manufactured the suit worn by Felix Baumgartner for the Red Bull Stratos project. On 14th October 2012, Baumgartner completed his historic jump from 38.969 km and became the first man to break the sound barrier without the aid of an engine. Baumgartner ascended in a pressurized gondola and utilized a custom pressure suit made by the David Clarke Company for his descent. As skydivers require visual cues from their environment, the Red Bull suit featured mirrors and a heated visor to defog the screen from breath-induced condensation. The suit was both flame retardant and offered thermal protection in the range of +37 °C to -67°C. To aid stability, the suit contained a drogue parachute and sensors that would deploy the chute in the event that its wearer lost consciousness. In addition to accelerometers and gyros for measuring linear and angular acceleration, pressure sensors were routed through a controller which regulated the pressure within the suit according to altitude. It is hoped that the information gleaned from the jump will aid development of fighter pilot suits for use in the event of high-altitude bail out.

The Z-1 is the first officially endorsed NASA suit design in 20 years

Felix Baumgartner stands in his pressure suit right before his 14 October jump.
Credits: Red Bull Content Pool

ILC Dover: Still Going Strong

Since the design of the Space Shuttle's semi-rigid EMU (Extravehicular Mobility Unit) suit in 1980, ILC Dover has supplied an unbroken run of innovative designs. In 1988, the company unveiled the developmental ILC Dover Mk III, which featured a rear-entry system for more rapid entry than the waist-entry EMU suit. The high operating pressure (57 kPa) of the Mk III would enable astronauts to transfer from a pressurized air environment such as a space station, into an oxygen rich suit without a pre-breath required to avoid the bends. The combination of hard and soft materials enabled a wider range of motions, including bending fully at the knees, than early Apollo and EMU suits. Despite the success of tests, this suit was never used in space, as NASA favored an even more flexible soft suit option.

I-Suit

Design features from the Mk III carried over to the I-Suit. Development started in 1997, with the first generation waist-entry suit being delivered the following year. The second generation featured improvements, and included a rear-entry system, a redesigned helmet for greater visibility, and weight reduction measures. A heads-up display was incorporated into the helmet, and GPS functionality added. The I-Suit was developed for planetary excursions, using fewer heavy bearings and more soft fabrics to minimize the weight. The I-Suit featured a pure oxygen breathing system, water cooling, and was pressurized to 29.6 kPa, which also allowed for greater mobility.

NASA Z-Series

The Z-Series is the culmination of the previous efforts of ILC Dover. The Z-1 was the first prototype in the Z-series, revealed in November 2012; it is the first officially endorsed NASA suit design in 20 years. Z-1 a full-pressure design, with power supply, CO2 scrubbers and thermal control. It features a rear port intended to connect to a docking port on a Lunar or Martian ground vehicle. This will prevent astronauts from bringing contaminants such as abrasive lunar regolith or toxic Martian soil into the vehicle. The port will enable astronauts to don the suit much faster than is possible than with current suit designs. With the suit at the same pressure (57.2 kPa) and gas mixture as its connected vehicle, there will be no need for the user to pre-breath oxygen before an excursion. ILC Dover has already won the contract to design the Z-2. If all goes well, the best elements of both suits will be combined into the production level Z-3, to be tested on the International Space Station in 2017.

Constellation Suit

The Constellation Space Suit System (CSSS) concept was designed by Oceaneering, a company that previously specialized in deep-sea exploration technologies. This was the first NASA award to a company outside the "big 3" suit makers. The CSSS has two configurations: an IVA soft-suit, similar in design to the ACES pressure suit, which could be worn during launch and reentry operations for protection in the case of cabin pressure loss and a hard shelled mode for EVA use, providing protection from micrometeoroids, radiation, and abrasive lunar dust. The suit was originally intended to be worn by the Orion capsule crew, but development was axed along with the majority of the Constellation Program.

The ILC Dover Z-1 prototype suit, which NASA plans to test on the International Space Station in 2017. – Credits: NASA

The ILC Dover Mk III is tested by Desert Research and Technology Studies (RATS) team in Arizona Desert. – Credits: NASA

Mechanical Counterpressure Suits

Earlier segments in this series explored the design flaws that have traditional space suits, largely due to pressurization needs. The gas envelope within the suit can cause a ballooning effect when worn in a vacuum environment that restricts the wearer's movement, as well as tiring astronauts due to the extra effort required to perform each motion.

In 1959, whilst working on the Mercury project, German born engineer Hans Mauch and his team noticed that when a closed cell foam was subjected to lower than ambient pressures, the cells within the foam would expand. When contained in a tight-fitting outer garment, this expansion would provide a force perpendicular to the body surface. This effect was similar that utilized by the gas and fluid filled bladders in g-suits. Thus, the concept of the Mechanical Counterpressure Suit (MCP) was born. The system was developed further as part of the X-20 DynaSoar project, but was abandoned in 1962 when the suit was shown to be less mobile than predicted.

The advantages of the MCP largely stem from elimination of gas pressurization. Contrary to popular belief, exposure to hard vacuum does not cause the body to explode but tends to make the body swell and expand, and take on the appearance of a bodybuilder. The elastic fabrics of the MCP would apply pressure to the body to counteract the swelling, keeping the astronaut alive. Additionally, due to the soft materials used, if the astronaut were to get hit by a micrometeoroid then the damage would be localized to the impact area, and would not result in a rapid decompression as would be the case in a gas pressure suit.

The development of improved fabrics spurred NASA engineer Paul Webb to revisit the concept of the MCP, and in 1968 he published an article in Aerospace Medicine that attracted positive attention from the industry. Now referred to as the "Space Activity Suit," and described as an "elastic leotard for Extravehicular activity," contracts were awarded for the development of the new suit. The Space Activity Suit was tested in vacuum chambers, with puncture holes up to 1mm in diameter and showed no lasting harmful effects to the wearer, asides from a small blemish which faded quickly.

The concept had been validated, but due to problems with maintaining constant pressure over the joints in the body, the program was dropped, and research into MCPs all but stopped for nearly thirty years.

The advantages of the MCP largely stem from elimination of gas pressurization

Bio-Suit

It is apparent that future visitors to Mars will be involved in strenuous physical activities, that require a more agile space suit than the current state of the art allows. For this purpose, Prof. Dava J. Newman at MIT has been working on an undated version of the MCP, aka the "Bio-Suit." Like the MCP predecessors, the Bio-Suit is also a skin-tight garment, but where the previous versions were made from foam, the Bio-Suit uses a fabric woven into a 3D matrix. The lines visible on the exterior of the suit are elasticated, and follow lines of non-extension over the body. The matrix acts in compression and tension, exerting a constant mechanical pressure over the body, but unlike previous iterations, the Bio-Suit retains equal pressure over joints, even when they are bending. Professor Newman is an expert in the field of biomechanics, and in particular has extensive experience in the use of computers for monitoring body movements, a critical factor in overcoming the shortfalls of prior MCP suits. Similar to previous designs, the Bio-Suit can withstand small punctures without risk of rapid decompression, and the punctures can be healed immediately with strips of elasticated fabric, providing the wearer time to return to the safety of a pressurized environment.

Skin-tight space suits have been a staple since the early days of science fiction for various reasons, ranging from aesthetics to advanced mobility. Buck Rogers wore one in the early comic books, and a similar garment called the "walker" was used for exploration of the Martian surface in Kim Stanley Robinson's Mars Trilogy. In a lot of respects, the Bio-Suit seems to be making the transition from art into reality...or it was. Like most of the innovative designs in this chapter, development of the Bio-Suit has been put on hiatus.

The Ideal Suit

The ideal suit should be easy to don and doff and provide protection for intra- and extra-vehicular activities, both on planet and off. It should be lightweight and mobile, yet should offer protection against radiation, micrometeoroids, dust, and temperature extremes. It seems like a tall order, but the technologies to achieve all of these objectives have been developed, prior to cancellations.

One thing is for sure: we can't rely on designs that are half a century old, á la aviation pressure suits. Perhaps the biggest challenge facing suit design is the lack of direction for crewed space programs. It is relatively easy to design for a lunar mission when you know where your destination is, but designing for all scenarios without concrete direction can be expensive and time consuming.

The biggest challenge facing suit design is the lack of direction for crewed space programs

The BioSuit was invented by MIT Professor Dava Newman(pictured here), designed by Guillermo Trotti (A.I.A., Trotti and Associates, Inc., Cambridge, MA) , and fabricated by Dainese (Vicenza, Italy). – Credits: Donna Coveny

And Don't Forget to Eat!

By Tereza Pultarova

Is nutrition key to success (not only) in space?

Medieval seafarers were losing their teeth, suffering painful wounds, and dying in large numbers due to a condition caused by improper nutrition. And still, with the availability of fresh fish and the rather large size of the ships allowing storage of a decent amount of food compared with confined space capsules, one would say the mediaeval crews on vessels cruising the world's oceans in the Age of Discovery were in a much better situation than 20th and 21st century astronauts.

It took until 1932 to identify severe vitamin C deficiency to be the main cause of scurvy and to understand that it was actually the lack of fresh fruit and vegetables limiting the success of early maritime travel.

Though modern science has managed to advance the understanding of human nutritional needs up to the level of milligrams of micronutrients a day, getting the right balance in a diet of someone without access to any fresh supplies still remains a challenge. Especially when this 'someone' has one of the most demanding jobs one can imagine.

Charles Bourland, a retired space food scientist who served at NASA since the 1960s, admits that up until American space station Skylab in the 1970s, astronauts, including those landing on the Moon, consumed only about half the amount of food they should have consumed, given the demands of the situation.

"In fact, on Skylab, they had the best intake they've had. I guess the space station crews are getting closer to proper intake now but not even on a Space Shuttle did they have such a good intake as on Skylab," says Bourland, explaining that motion sickness and a packed work schedule have always had a bad effect on astronauts' food discipline.

While such a problem might go basically unnoticed on a short mission, once we consider a months-long journey to Mars and beyond, the astronauts might find themselves in life-threatening situations.

Can poor diet trigger dementia?

It's not only scurvy. Malnutrition is the root of many conditions and there is no doubt a malnourished crew would hardly perform according to expectations.

In the mid-2000s, NASA helped to discover that malnutrition might not be the result, but the cause of cognitive decay of some elderly people.

Focusing on micronutrients that are also among key nutritional concerns in human spaceflight, the researchers compared two groups of elderly people from Texas – healthy, active seniors and those obviously self-neglectful, displaying symptoms of depression and dementia.

After blood samples were taken and analyzed using methodology developed for astronauts' nutritional assessment before long duration missions, the scientists have found that while healthy seniors had normal levels of vitamins B12 and D, folate and antioxidants, cognitively-impaired

Securing a balanced diet for astronauts on long duration missions is one of the biggest challenges.
Credits: Bill Ebbesen

Scurvy is one of the well-known conditions related to vitamin deficiencies. – Credits: The UK National Archives

self-neglectors displayed severe deficiencies.

"This study is an example of how NASA research and capabilities not only benefit astronauts, but can contribute to basic science and to public health," said Scott M. Smith, NASA nutritionist at the Johnson Space Center.

"I think that malnutrition may not just be an outcome but may actually be an initiating factor," he says.

Now, let's imagine a mentally (and physically) unfit crew landing on a desolate planet millions of kilometers away from Earth… That's a disaster waiting to happen.

Iron Overdose and Salt Cravings

According to Dr. Bourland, astronauts, similarly to Earthlings, need to consume some 2000 calories a day, with the exact amount depending on their body mass, gender, and activities.

Though many of their nutritional needs are identical to those of Earth-bound people, after more than 50 years of human spaceflight, scientists have managed to tune the astronauts' diet to, at least partially, make up for the space-induced changes in a human body.

"They don't need as much iron for example," Bourland says. "In fact the requirements for males and females are the same for iron, while they are different here on the ground where females require more."

The reduced need for iron is a result of the decreased production of blood cells known to take place in space as less blood is needed to power the body.

In fact, consuming too much iron in space could build up toxicity. An iron-overdosed astronaut would become dizzy and tired and could suffer from headaches and weight loss, feel nauseas and short of breath.

With too much iron in the system, the body also cannot absorb zinc properly. In the long term, without reducing his or her iron intake, the astronaut could develop serious problems including liver damage, arthritis, or heart conditions.

Similarly, the balance between potassium and sodium becomes rather delicate in space. Those two compounds maintain the fluid balance of the human body, regulate blood pressure, power cells, and enable neural signal transmission. Some studies even suggest these two elements contribute to healthy bones.

However, as the water economy of the organism changes in space, so does the sodium-potassium equilibrium. Researchers have concluded that, on average, astronauts tend to consume too much sodium and too little potassium. The high content of sodium makes many types of terrestrial food, which would otherwise qualify for spaceflight, in fact, unsuitable.

"Space nutritionists are actually trying to reduce the sodium content because there was some evidence that high sodium might contribute to vision problems they've had on some of the missions," says Bourland, explaining that, as the sense of taste worsens in space, astronauts tend to crave more salt and always find a way to get it.

"On some of the early Shuttle missions, they took some of the salt away from them" Bourland recalls. "Unfortunately, [the astronauts] had salt tablets that they have to take before reentry to retain more fluid and they got some of them and they ground them up and made their own salt."

Leafy Vegetables and the Lack of Sunlight

While early seafarers were suffering from the lack-of-vitamin-C-induced scurvy, in the case of astronauts, vitamin D deficiency becomes a major issue.

Throughout the evolution of men, nature was able to take care of this matter, equipping humans with the ability to synthesize vitamin D in their skin when exposed to sunlight.

However, spacecraft have to be shielded from the Sun, as without the presence of protective atmosphere, the solar rays become too powerful.

Low levels of vitamin D hinder absorption of calcium in the bones and increase bone loss - already a major problem during space flight.

Last year, NASA scientists discovered that the deficiency of folate, the substance identified to be responsible for the cognitive impairments in the elderly, might be one of the causes of vision changes experienced by about 20 % of astronauts after an ISS mission. The role of vitamin B12 in this process is yet to be identified.

Like it or not, we are what we eat and space science has helped to advance our understanding of nutrition, not only to secure success of space missions, but also to improve the quality of life for those bound to Earth.

A can of space food floating aboard the ISS. – Credits: ESA