



INTERNATIONAL ASSOCIATION  
FOR THE ADVANCEMENT OF  
SPACE SAFETY

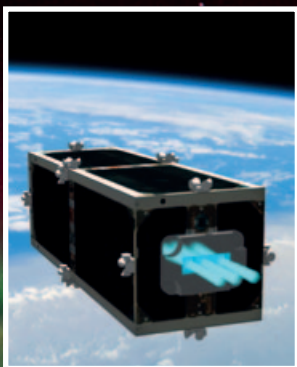


# Space Safety Magazine®

Issue 3  
Spring 2012



## ISSF SPECIAL The Case for Support



## CleanSpace One



## The Legal Frontier of Commercial Space Regulation



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# Space Safety Magazine®

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### Space Safety Magazine

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# Building a Space Safety Institute

**W**elcome 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 reentry 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 consid-



**Safety Design for Space System, the recommended reading for graduate level courses in space safety.**

ered 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

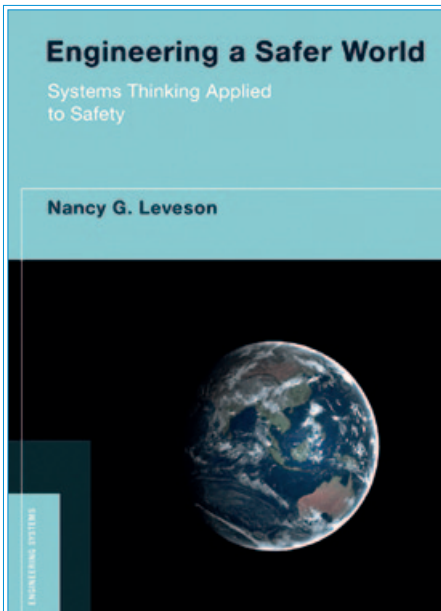
*If you are interested in being a part of this ambitious project or you would like more information, please go to our web site [www.spacesafetyfoundation.org](http://www.spacesafetyfoundation.org) and provide us contact information so that we can answer your questions and get back to you.*



# Engineering a Safer World

By Nancy Leveson

Systems Thinking Applied to Safety



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

**E**ngineering 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

**S**TAMP 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

“STAMP extends the old failure model of accident causation to include new types of accident causes,”

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 re-

defines 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 1999 due to 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 Modes and Effects 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 founda-



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

ation. 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 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.

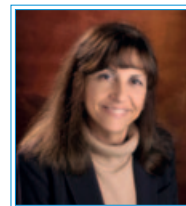
Operability needs to be considered from the start of the development process and appropriate information documented and passed to the system operators. My new book describes what information needs to be documented and how to use this information to create a safety management operations plan. It also 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, IAASS Fellow Member, 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 Merryl Azriel

# CleanSpace One

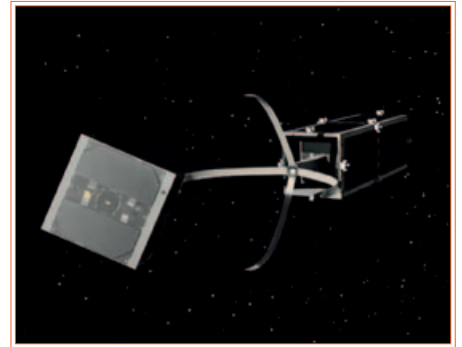
In February, the news rang out to the space debris community: at last a debris removal mission was to become reality. The Swiss Space Center at École Polytechnique Fédérale de Lausanne (EPFL) announced project CleanSpace One, a mission concept intended to serve as the first installment in a family of space debris capturing satellites. Under the project, a 30x10x10cm satellite would be launched in the 2015-2016 timeframe. The craft would rendezvous with one of Switzerland's two cubesats Swiss-Cube and TiSat at an orbital altitude of 630-750 km travelling at 28,000 km/h. Using a biologically inspired gripping system, CleanSpace One would then grab the cubesat with a three-pronged mechanism, and tow the dead craft out of orbit to burn up in Earth's atmosphere along with CleanSpace One.

Space Safety Magazine had an opportunity to discuss the project with CleanSpace One team member Dr. Anton Ivanov. "Obviously we will start with Phase A, which lasts for about one year," said Ivanov, referring to the standard ESA developmental phases A-F encompassing concept through end of life. "One of the results of that phase is a better concept of the spacecraft,

concrete budget and schedule," Ivanov continued.

Ivanov sees considerable opportunities for international collaboration in CleanSpace One's future: "It is likely that next generation will attack the problem of either collecting larger debris (>10m in size) or smaller debris (5mm to 10mm)," Ivanov said, speaking of the Swiss Space Center's plans to expand into a whole family of space debris clean-up craft. "However, these debris do not belong to Switzerland, therefore follow up spacecraft will be developed in cooperation with other National Agencies." These other agencies have their own space debris programs in motion: according to Ivanov,

**"CleanSpace One will demonstrate technologies to clean up low Earth orbits,"**



**As it approaches the target, CleanSpace One unfurls its bio-inspired gripper.**

Copyright: Ecole Polytechnique Fédérale de Lausanne

"these programs will benefit from our in-flight experience."

Ivanov is confident that the impact of a successful CleanSpace One mission - likely the first active debris removal mission to be executed - will be considerable. "We will demonstrate necessary technologies to clean up Low Earth Orbits from junk that is polluting these orbits," he emphasized. "CleanSpace type satellites will be needed until the space debris problem diminishes," Ivanov said, "Current estimates show that it is necessary to remove at least 5 large debris a year to have this problem under control."

Ivanov expects that newer spacecraft will provide for their own end-of-life de-orbiting solutions. With the heightening level of attention apportioned to debris issues, including progress on codification of acceptable international conduct and standards, such provisions are starting to become accepted by major space nations. These measures are all the more necessary as it is no longer possible for any spacecraft in the crowded low Earth orbits to avoid debris damage of some degree, and satellite insurers are starting to take notice. Does Dr. Ivanov foresee insurers chartering future CleanSpace missions? "This depends on the success of the CleanSpace One mission and developments of other programs in the world," he says. "It will be prudent for satellite insurers to support these programs - hopefully including CleanSpace One!"



**CleanSpace One pursues a Swiss cubesat in preparation for capture.**

Copyright: Ecole Polytechnique Fédérale de Lausanne



By Tereza Pultarova

# Space Weather May Increase Risk of Sudden Death

**W**hen the ISS flew over the aurora borealis, as the space station entered a geomagnetic storm earlier this year, the crew was amazed by the beauty of the glowing light through which they travelled. Hypnotized by the million shades of colors, they probably were not thinking about the potential danger that the beautiful phenomenon may have posed to their health.

But according to the results of research conducted by Russian cardiologists on the Mars 500 crew, space weather events can significantly increase the risk of heart attack and stroke even in healthy individuals. "There is a medical condition commonly called 'sudden cardiac death'," explains Dr. Oleg Atkov, former Russian cosmonaut and trained cardiologist working at the Russian State Medical State Research University. "It is a natural, sudden and unexpected case of cardiac failure leading to death, where you don't have any evidence or history of previous diseases. And suddenly, something happens."

Together with his colleague Yuri Gurfinkel from Central Clinical Hospital in Moscow, Atkov studied changes in microcirculation in Mars 500 crew members during major geomagnetic storms caused by powerful coronal mass ejections from the Sun. "We were particularly focused on investigating changes in microcirculation on nail beds or in the eyes," says Atkov, "the research gave us quantitative information on what is going on during the geomagnetic storms – how the blood flow is changing and how the sludge phenomenon occurs."

Blood sludge is a medical condition wherein erythrocytes glue to each other into small blood clots, leading to major cerebrovascular events like strokes and thrombosis, which can cause sudden death in otherwise perfectly healthy individuals. "When the block in microcirculation forms in the right atrium, [...] or in [the] central nervous system, it can have fatal consequences," Atkov concludes. Should an accident like that happen in low Earth orbit, it would take too long to give the stricken astronaut timely medical care.

**"Space weather can significantly increase the risk of stroke even in healthy individuals,"**

The negative effects of geomagnetic storms caused by space weather events on human health have been known for a long time, but it was commonly assumed that space weather could affect only people suffering from ischemic disorders or hypertension. But the research results obtained from healthy Mars 500 crew members suggests that practically no one can be considered safe from the influence of geomagnetic phenomena.

Russian scientists have studied the effects of geomagnetic disturbances on

human health for several years. Medical records collected in Moscow show that during such events an abnormally high incidence of cardiovascular events takes place even on Earth, with an increase in heart attacks of up to 13% and an increase in blood-strokes of up to 7.5%. Data on cosmonauts exposed to geomagnetic disturbances during flight or landing are also available: they show changes in pulse, blood pressure, reduction of heartbeat rate variability, and more irregular heartbeat patterns.

According to Atkov, space weather influences on cosmonauts' health was not yet a research focus at the time of his 8 month mission to the Salyut 7 space station in 1983. Back then, researchers were just discovering the sources of arrhythmia that occurs time to time during space flight.

Despite the medical concerns, astronauts and cosmonauts continue to consider space flight exciting and worthwhile, and keep enjoying the unique view of phenomenon like the stunning aurora borealis of January 2012.



Aurora borealis caused by powerful geomagnetic storm as photographed from ISS in January 2012. - Credits: NASA



By Stavros Georgakas

# Contamination Risk During EVA



Astronaut Robert L. Curbeam, Jr taking part in an EVA during construction of the International Space Station. - Credits: NASA

**E**xtra Vehicular Activity (EVA) is among the most dangerous space operations. Alexei Leonov's first ever spacewalk almost ended in tragedy when his space suit inflated, preventing him from reentering the spacecraft. Early Gemini spacewalkers experienced near-fatal episodes of exhaustion, sweating, foggy visors, and inability to grapple and move themselves around the spacecraft. The fortunate lack of fatal accidents may give the false impression that EVAs are a safe, almost routine activity, but the truth is that they occasionally expose astronauts to extremely hazardous and life threatening situations.

## Toxic Leak Emergency

**O**n February 10, 2001, during STS-98, NASA astronauts Robert L. Curbeam and Thomas D. Jones were

**“EVA is among the most dangerous space operations,”**

exposed to toxic ammonia during an EVA. Their task was to connect cooling lines on the International Space Station for the Destiny Laboratory Module installation. A defective quick-disconnect valve released 5% of the ammonia coolant supply into space. The ammonia was essential for operation of the \$1.4 billion laboratory, and a massive leak would have rendered the laboratory unusable. Ammonia is highly suitable as a coolant due to its low freezing point, but it is also highly toxic. On Earth, there have been many fatal industrial accidents due to hydrous ammonia contamination.

On this particular EVA, the escaping ammonia froze on Curbeam's spacesuit as he tried to close the valve by pulling on a locking device known as a bailer bar. Toxic ammonia crystals 2-3 cm thick covered parts of his helmet and spacesuit. Initially, Jones tried to brush off as much of the frozen ammonia as he could from Curbeam's spacesuit, but Mission Control quickly instructed them to remain outside the Shuttle for an entire orbit to allow the Sun to evaporate the frozen ammonia. Curbeam himself was not affected from a physical point of view, but the ammonia crystals were a contamination risk to the Shuttle cabin. Under different circumstances, a spacewalk with no demanding task to work on would be a great time for an astronaut, and a chance to enjoy the unique view. However, Curbeam remembers this interval as extremely unpleasant, having nothing to keep his brain busy, and worrying that he had lost his supervisors' trust. ➤





Curbeam working on the Destiny module during the second EVA of the STS-98 mission in 2011. - Credits: NASA

## Back inside the Shuttle

Upon returning to the airlock, the astronauts followed an exhausting procedure to avoid any further risks. The airlock was pressurized, vented and repressurized to remove any remnants of ammonia and safeguard the rest of the crew, after which they had to wear oxygen masks for 20 minutes to allow life-support systems to filter the air. Eventually, the entire cabin air volume had been circulated and they were allowed to remove their masks. The other team members were understandably worried, but fortunately no injuries resulted from the incident. No ammonia odor was detected and the procedures followed were deemed successful. Five hours after the leak, the astronauts were informed that the valve was faulty, and that they were not the cause of the accident. However, this incident demonstrated the unexpected risks that may occur even while performing routine operations.

The incident, described as a minor setback during the mission operation, is now recalled by the individuals involved as an important milestone in space safety, and a moment of high tension and adrenaline. A vivid recollection of the

**“Only careful planning, design and execution can reduce the risks to a minimum,”**

event can be found in Thomas D. Jones’ book “Sky Walking: An Astronaut’s Memoir” (Smithsonian Books, 2006).

## The Importance of Training

Only ten days before the flight, the crew had attended a briefing on shutting off ammonia lines during EVA. The briefing was crammed into the schedule and would not have taken place if there hadn’t been a launch delay. Mission specialists and experts considered the possibility of a leak so remote that the standard procedures for that case were not included in the original training schedule. Curbeam reported that during debriefing they were told: “I really sincerely doubt you’ll have a leaky valve, and I can tell you for sure you won’t have a male Q.D. leak” —the exact kind of leak that actually occurred on their mission.

Luckily, Curbeam concluded the mission safely, and travelled into space for a third time in 2006, while still holding the world record for the highest number of EVAs on a single mission. But how can we ensure safety from such incidents in the future?

Crew exposure can be minimized through regular safety reviews and careful hardware engineering. The most effective method to minimize contamination risks like this remains prevention, but toxic substance handling is sometimes inevitable, due to operational and mission requirements.

An important aspect to ensuring safety is alerting the crew when protective action must be taken. Carbon monoxide detectors, Draeger tubes that sense the presence of specific chemicals, and the compound specific analyzer-combustion products (CSA-CP) device are used for this purpose.

Also, active measures must be applied, should the preventive actions fail. The crew must undergo focused simulation-based training and be prepared to actively intervene to ensure their safety. Active measures include the use of oxygen masks and decontamination procedures, and are an essential part of safety engineering design.

Only careful planning, design, and execution can reduce risks to a minimum and achieve optimal risk mitigation. Space is an extreme environment, with many associated risks and dangers. While some accidents cannot be predicted or prevented, good training and valid contingency planning will allow prompt recovery, even from potentially fatal situations.



Curbeam donning his spacesuit with the help of a technician in the Operations and Checkout Building. - Credits: NASA

# WALDO

## A System for Removal of Large Orbital Debris

By Rajiv Kohli  
and  
Ernest Y. Robinson

**A**n effective orbital debris removal and relocation system is critically needed, given the large amount of debris, such as spent rocket bodies and dead satellites, in low Earth orbit (LEO). Presently, thousands of space debris objects are being tracked in order to allow planners to place new systems in an unobstructed orbit, or to help operators to maneuver space systems to avoid collision with space debris. Orbital debris poses disastrous interference and collision threats to neighboring satellites, leading to actual collision incidents. The recent 2009 collision of the active Iridium 33 satellite with the defunct Cosmos-2251 satellite was the first accidental hyper-velocity collision between two intact artificial satellites in LEO. Several smaller collisions had occurred previously, of-

**“At present, there are no proven means to relocate a satellite or to deorbit it,”**

ten during rendezvous attempts, such as the Demonstration of Autonomous Rendezvous Technology (DART) satellite that collided with the Multiple Path Beyond-Line-of-Sight communications (MUBLCOM) satellite. Other threats can arise from uncontrolled reentry of

decommissioned satellites such as the NASA Upper Atmosphere Research Satellite (UARS), the German Roentgen satellite (ROSAT), or other large debris objects such as the Russian Phobos-Grunt spacecraft all of which survived atmospheric reentry; similar future objects could cause harm to humans and property.

### A Hand in the Sky

**A**t present, there are no proven means to relocate a satellite to a supersynchronous burial orbit, or to deorbit it to burn in the Earth's atmosphere. The Aerospace Corporation patented a satellite capture system ►►

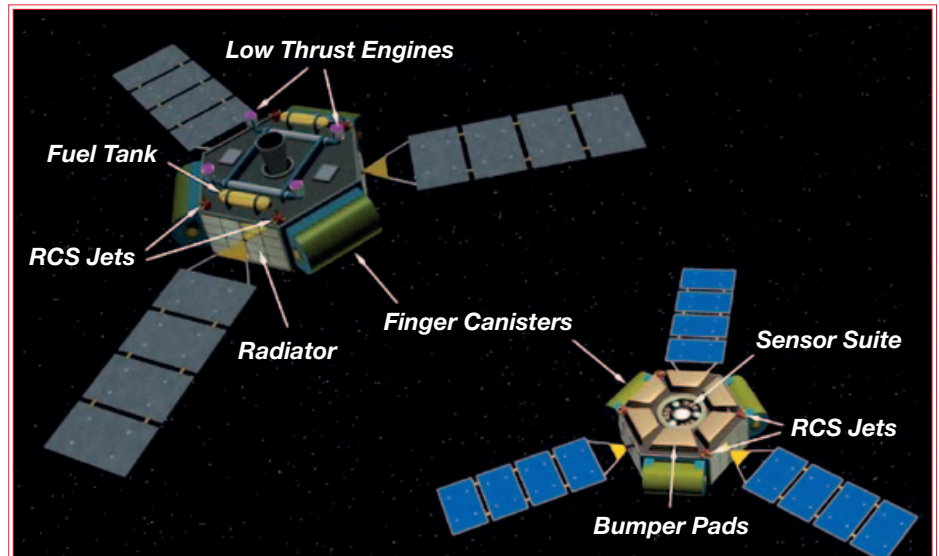


Upper stages of expendable launchers pose great collision risk in Low Earth Orbit. — Credits: U.S. Air Force



“WALDO offers a possible relocation solution via a “hand in the sky””

called WALDO <sup>[1]</sup>, which offers a possible solution via a “hand in the sky” device. WALDO was inspired by “WALDO & Magic, Inc,” a Robert Heinlein science fiction novel, in which the protagonist creates robotic hands, called Waldos, varying in size from microscopic to gigantic. The patented “satellite grabber” comprises a base satellite which, once in orbit, commands pneumatic deployment of long, slender, finger-like pods. The pods can be articulated by longitudinal tendon-like articulations, acting like a finger that curves around and captures the object. A combination of three such pods forms a “hand in the sky,” a Waldo, that captures the target object for removal. In the present case, target objects are assumed to be passive and non-cooperative, as would be expected when collecting random dead satellites. The major advantage of WALDO is its ability to approach a tar-



**Main components of WALDO.** – Credits: R. Kohli and E. Y Robinson

get object from the front, embracing it all around with a controllable soft grab that would not damage appendages.

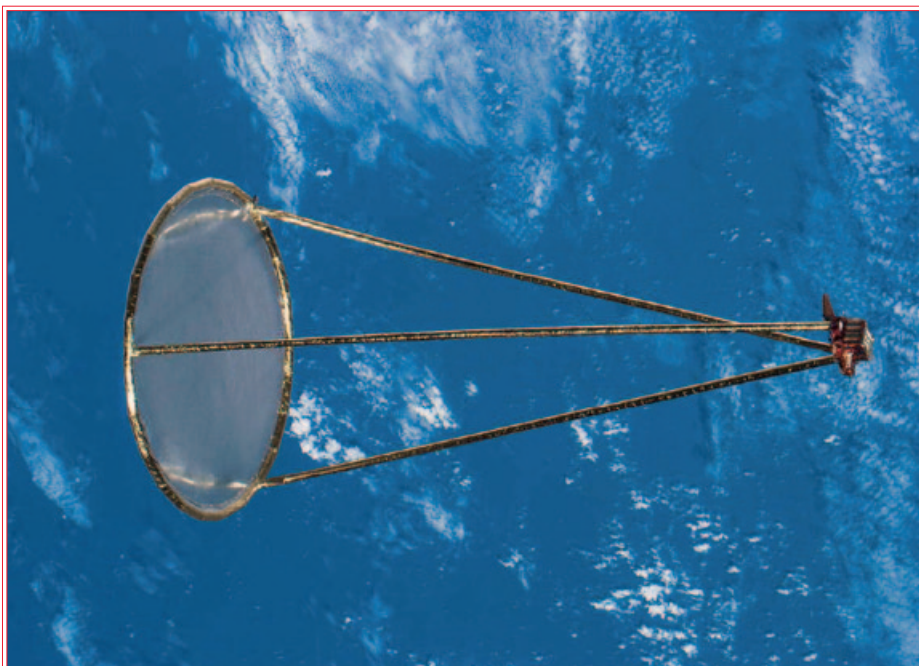
WALDO was inspired by the Jet Propulsion Laboratory (JPL) Inflatable Antenna Experiment (IAE) of May 1996. The IAE was released from the shuttle bay as a compactly stowed package and was deployed by inflation. The long sub-reflector pods and the main dish of IAE are inflated to create a very large space structure. These long slender pods, which extend far out in front of the sub-reflector to form a capture zone, are what inspired WALDO. In WALDO, the pods have articulation

tendons running along the length of the spacecraft, enabling these sorts of large “fingers” to curve around and grab a space object.

## Concept of Operations

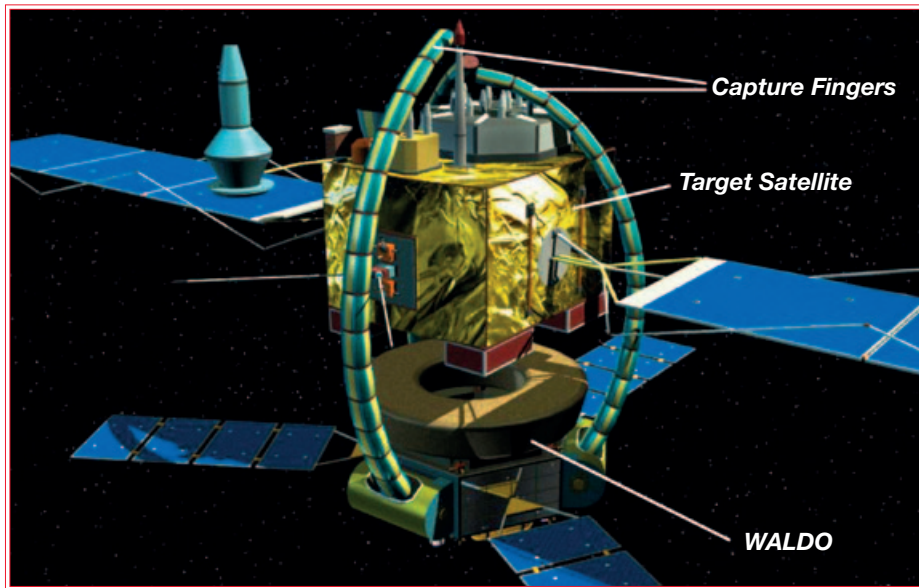
A detailed end-to-end mission concept of operations (CONOPS) for WALDO has been developed. A one metric ton space object, located at 400-600 km, would be captured and then either moved to a suitable burial orbit or deorbited. The CONOPS includes: analysis and assessment of the propulsion system; deployable mechanisms and deployable inflatable articulating fingers; long-range and close-in navigation and control; real-time image processing and target attitude; precise autonomous motion control to achieve formation flying; docking to target; removal to desired orbit or deorbit; control satellite/spacecraft sizing; design, fabrication and test plans; and flight demonstration test plans.

The CONOPS starts with a dead satellite, slowly rotating in a drifting orbit, which must be moved to a burial orbit. Ground tracking details of the target object are programmed into WALDO, along with detailed characteristics and images of the target satellite. WALDO plans the rendezvous trajectory using autonomous navigation, based on the NASA Advanced Video Guidance Sensor (AVGS) demonstrated in the Orbital Express Project <sup>[2]</sup>. WALDO, which is also capable of close-in navigation, ►►



**The Inflatable Antenna Experiment of May 1996 in deployed configuration.**

Credits: NASA



**WALDO fingers deployed for soft embrace and capture of a target satellite.**

Credits: R. Kohli and E. Y Robinson

**“The soft grab target interface allows capturing any target geometry,”**

approaches the target using optical or imaging radar to establish orientation and motion of the object, and plans the final approach and capture. Navigating to a concentric rotation axis, WALDO establishes formation flying with the object, similar to the way in which the Space Shuttle and the Hubble telescope maneuver during repair missions.

As soon as WALDO nears the object at a distance suited to deployment of the fingers, around one to ten meters, the grasping fingers are pneumatically deployed. The fingers are sized and arranged to surround the selected debris object; as an example, the fingers can be thirty meters long, oriented at about 120° angles. The target is then captured as the fingers embrace it in padded physical contact. When the debris is within reach, the motor mechanism pulls and tightens the tendon lines causing the fingers to wrap around the debris to secure the grasp.

After capture, WALDO determines the removal trajectory to the disposal orbit, or the deorbit maneuver for the debris object, and fires its thrusters accord-

ingly, performing either an insertion into the outer supersynchronous disposal orbit or a deorbit maneuver.

## Conclusions

**T**he Aerospace Corporation patented satellite capture system WALDO is a “hand in the sky” concept that offers a possible solution for orbital debris removal and relocation. It comprises a base satellite that, once in orbit, commands deployment of articulating tendons to act like fingers that curve around and capture a target object. A combination of three such fingers captures a non-cooperating target ob-

ject for removal. One major advantage of WALDO is its ability to approach a target object from the front and embrace it all around with a controllable non-damaging soft grab that will not damage or break off appendages. Plus, the non-specificity of the soft grab target interface would allow WALDO to capture almost any target geometry.

Watch the WALDO CONOPS:

[www.bit.li/waldo](http://www.bit.li/waldo)

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[1] Robinson, E.Y. (2003). Spacecraft for Removal of Space Orbital Debris. U.S. Patent 6,655,637.

[2] Howard, R.T., et al. (2008). The Advanced Video Guidance Sensor: Orbital Express and the Next Generation. In Space Technology and Applications International Forum-STAI 2008, AIP Conf. Proc. 969(1), pp717-724.



**Recovered propellant tank from a spent Delta 2 second stage that survived atmospheric entry. – Credits: NASA**



The background of the entire image is a deep blue space scene filled with stars. A bright, glowing yellow and orange arc, representing a celestial body or a comet's tail, curves across the bottom right. A white, stylized graphic element, resembling a crosshair or a stylized 'X', is positioned in the upper right quadrant, partially overlapping the text and the space background.

# ISSF

INTERNATIONAL SPACE  
SAFETY FOUNDATION

**THE CASE  
FOR  
SUPPORT**

# International Space Safety Foundation Case For Support

*After losing radio contact with ground control, Space Shuttle Columbia reentered the Earth's atmosphere disastrously in 2003. The shuttle burned up on re-entry and disintegrated over Texas, killing all seven crew members. Small bits of shuttle debris were spread over a wide area of Texas, including shuttle engines full of highly toxic chemicals. Fortunately, no others were harmed, but the risk of a fatal crash with air traffic was estimated by Federal Aviation Administration to be as high as 1/100 for civil aviation and 1/1000 for commercial aviation.*



The Space Shuttle Columbia break up over Texas in 2003

## Space Travel: Entering A New Dimension

Over a century ago we witnessed the world's first flight—12 seconds that defied belief at that time. Today, our skies have grown almost as busy as our roads. Each day there are 28,537 commercial flights, 27,178 private planes, 24,548 air taxi flights, 5,260 military flights and 2,148 cargo flights either taking off or landing at the 19,990 airports in the U.S. Thus there are about 87,000 flights in the United States a day and 64 million in a year.<sup>1</sup> In 2007, the U.S. alone saw more than 769 million passengers enplaned on scheduled airlines traveling across the country and across the world.<sup>2</sup>

By contrast, there are only a handful of people in space at any one time—astronauts who might have been launched from one of only a dozen spaceports around the world. The number of unmanned spacecraft is also few. To date, only about 500 people have flown into space. While the volume of travel is currently low, the potential for growth is unprecedented.

Far from being science fiction, space travel is a booming industry. In 2004, *SpaceShipOne*, the first private, manned aerospace craft, reached space. And while many dream of an adventure in space,

for some it is a reality. In 2001, Dennis Tito, a businessman from California, became the world's first space tourist when he paid \$20 million to be launched into space aboard a Russian rocket. Five others have since followed, with more hopeful space tourists awaiting their opportunity. *Virgin Galactic* and other members of the Commercial Space Flight Federation have been taking reservations from paying passengers eager to venture into space since 2005 and have unveiled the spacecraft that will take them there. Infrastructure is being developed to launch space tourism excursions with the construction of private spaceports across the world—*Spaceport America*, the first new-built commercial spaceport, with a capital investment of a quarter billion dollars, is on the way to completion. The terminal area was inaugurated in October 2011.

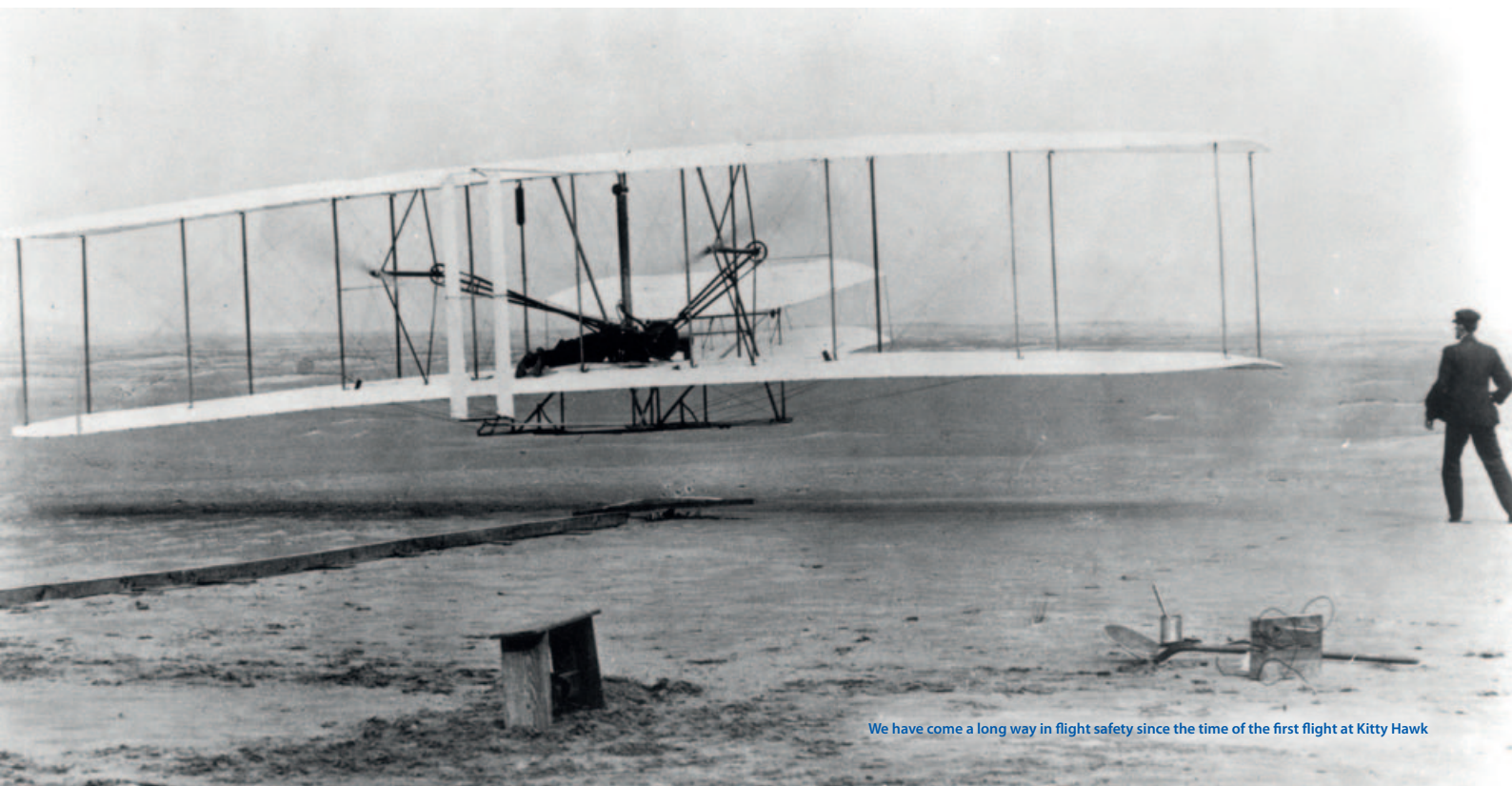
With advancements by world governments and private enterprises, plans in motion for commercial spaceflight and space tourism will mark a dramatic change in the number of spacecraft being launched and with it a substantial increase in the volume of space traffic.

Airplanes, just like spacecraft, were once the exclusive domain of governments. At the start of commercial air travel, flight was risky, costly and accessible only to the rich. Now that air travel has been brought to scale, our skies are busier and managing flight has become much more organized and subject to international standards. The result is airline travel that is impressively safe. If the right leadership and steps are taken today, the same will happen for the space industry tomorrow.

<sup>1</sup> National Air Traffic Controllers Association, accessed January 2009  
<http://www.natca.org/mediacenter/bythenumbers.msp>

<sup>2</sup> US Bureau of Transportation Statistics, National Transportation Statistics accessed January 2009  
<http://www.census.gov/compendia/statab/>





We have come a long way in flight safety since the time of the first flight at Kitty Hawk

Public acceptance of aviation as a safe and fast method of transportation is rarely questioned today, thanks to the strict safety standards that ensure the well being of the crew and passengers and people on the ground. Such standards are the results of accumulated experience as well as of technical progress in which private research played a fundamental role since the very beginning. In the rare event that an accident occurs, protocols and procedures for responding to an emergency are in place: when an airliner went down in the Hudson River early in 2009, all 155 people survived without injury thanks in part to the safety standards that guide the airline industry.

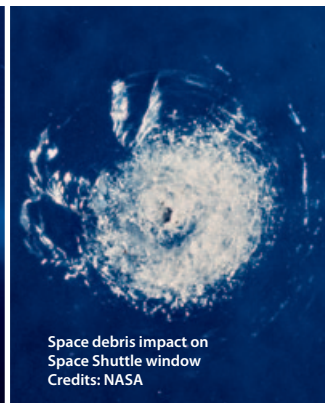
Despite various regulatory oversight responsibilities shared by government agencies in the United States and "space treaties" among international organizations, there is not yet in place an extensive, coordinated international program that tracks and manages space travel and commerce to ensure the safety of those in the industry and of the general public. The dangers and potential for accident in space is unprecedented.

## ***Danger of Orbital Accidents***

**T**oday, more than 21,000 pieces of space debris ranging in size from large, derelict satellites to a few inches (10cm) are circling the Earth. There are tens of millions more uncatalogued space debris objects greater than 1 mm in size.

At speeds reaching 27,400 km per hour, even the smallest bits of space debris can cause serious harm to spacecraft; larger

NASA's 2006 post-flight inspection of the space shuttle Discovery STS-114 found 41 impacts on the vehicle caused by orbital debris, the largest of which left a crater in one of the shuttle's windows. NASA estimated that it was caused by a particle with a diameter of just 0.22 mm. This impact was among the largest ever recorded.



Space debris impact on Space Shuttle window  
Credits: NASA

Space debris impact on Space Shuttle blanket  
Credits: NASA







Space debris reentry  
Credits: Kristhian Mason



ATV reentering the atmosphere  
Credits: D.Ducros / ESA

Each year, nonfunctioning satellites come crashing back to Earth uncontrollably. The only way to control these falling satellites is to shoot them down. When China shot down one of its satellites in 2007, the explosion left large amounts of debris orbiting the planet, posing risk to spacecraft. In 2006, 270 passengers on board an airliner above the Pacific had a lucky escape when the wreckage of a blazing Russian satellite narrowly missed their aircraft. In early 2008 the United States shot down a missile containing toxic fuel. Small pieces of the broken-up satellite, caused by the explosion, fell into the Earth's atmosphere, posing risk to the environment and to human life. In 2009, an Iridium commercial satellite and a defunct and out of control Russian Kosmos satellite crashed, destroying both spacecraft and creating a deadly shower of debris in low Earth orbit.

ones threaten the lives of astronauts and can cause catastrophe. A fragment of about two thirds of a pound (300 grams) can destroy an airplane at cruise altitude and speed. As recent history shows, an object as seemingly insignificant as a paint chip can cause significant damage.

The United Nations Committee on the Peaceful Uses of Outer Space has, after over a decade of debate, adopted guidelines to limit space debris, but there remains far more to be done to ensure human safety. As space travel advances, there will be an exponential increase in space traffic and more discarded debris. More objects in orbit will mean greater chance of collisions in space. The first dramatic collision took place in 2009 between the US Iridium 33 satellite and Cosmos 2251, a Russian communication satellite that ceased active operations in 1995.

## Risk of Accidents on Ground

Approximately one cataloged piece of space debris has fallen to Earth every day for the last 40 years.<sup>3</sup> Right now, there are several hundred spacecraft in Low Earth Orbit that will reach end of life, no longer be able to maintain orbit, and destructively re-enter the atmosphere in the coming decades—exact numbers are not tracked. Sometimes a satellite can be lost at the very beginning of, or during operations and become a public safety hazard.

Between 10 percent and 40 percent of the mass of these spacecraft are projected to survive re-entry in the form of fragments. As the number of objects hitting land increases, the risk of human injury and damage to aircraft and property becomes greater.

It is not just spent satellites or fragmentary remains of craft that fall to Earth. Hazardous materials and poisonous substances, including noxious gases and radioactive materials, carried inside spacecraft that fail to burn up on reentry fall on Earth and have the potential to cause serious damage to public health and safety and the environment. USA-193, also known as NRO launch 21, was an American military spy satellite launched on December 14, 2006. The satellite malfunctioned shortly after deployment, and was intentionally destroyed 14 months later on February 21, 2008, by a modified SM-3 missile fired from the warship USS Lake Erie, stationed west of Hawaii. According to Federal Emergency Management Agency (FEMA) reports the satellite contained

*"We have rules of sea and we have rules of flying over territories and countries, but once you get into space those rules are not established."*

*Richard Stuart, founder, CEO, and President of ARES Corporation/Board President, International Space Safety Foundation*

<sup>3</sup> NASA



hazardous materials that could have survived reentry: half a ton of frozen hydrazine and beryllium.

Since the beginning of space travel, ten space failures have dispersed radioactive material to the Earth's surface and oceans—but pollution from rocket fuel and contamination from fallen space debris are increasing concerns.

Accidents also occur at launch sites, where nearly 200 people (35 since 2000) have been killed by rocket explosions during processing, test, launch preparations, and launches.

## Frontier Environment

In the extremes of space, there are no mutual aid provisions and travel patterns are not coordinated. Each country has its own unique technologies and systems—from space suits and vehicles to terminology. Were there to be an accident on a space flight, there is no universal method to transmit distress and no international code of conduct for responding to a call for help in space. Preliminary (and uncoordinated) efforts to create international standards for exploration on the Moon are underway and initial efforts have demonstrated how application of these standards could save lives.

## Safety of Future Space Exploration

The space industry needs a “quantum leap” in the area of safety. People around the world are at risk from spacecraft launch and reentry operations as well as falling space debris. We need to act now to protect the safety of citizens of all nations, to reduce the impact on our environment, foster safe human space travel and increase international cooperation for the benefit of all space exploration.

We need protocols in place to reduce the risks to public safety. We need effective rules and commitments for tracking and reducing existing space debris and limiting future debris. We need to substantially advance system safety through dedicated studies. We need to set industry standards for space equipment design, and we need standard operating procedures in the air and on the ground. In essence, we need the same innovations in safety for the space industry that we have for commercial aviation—black boxes, traffic management rules, and quality monitoring programs such as Flight Operational Quality Assurance and the Aviation Safety Action Program.

## THE GUGGENHEIMS AND AIR SAFETY

On any given day, more than 87,000 flights are in the skies in the United States. Public acceptance of aviation as a safe and fast method of transportation is rarely questioned today; however, regular, safe passenger service on airlines was not a reality until aeronautical engineering programs were established and reliable aircraft engines and instruments were developed. Between 1925 and 1930, philanthropists Daniel and Florence Guggenheim invested more than \$2.6 million (the equivalent of \$31 million in 2008) in research and educational activities to develop airplane safety that ultimately led to safer air travel and paved the way for a nascent commercial air flight industry.

Flight was extremely risky, plagued by accidents and fatalities. In the early days of scheduled transportation from 1922 to 1925, one pilot was killed for every 10,000 hours of flying. According to the Flight Safety Foundation, if the world had the same accident rate now, there would be several hundred serious air transport accidents a year. Certainly, one or two would occur every day somewhere around the world. Safety has been improved dramatically, and today the air transport industry has a very low accident rate. Today, taking a plane is a journey safer than catching the bus or crossing the street, due in part to the vision of people like the Guggenheims and those committed to aviation safety that have continued their work.

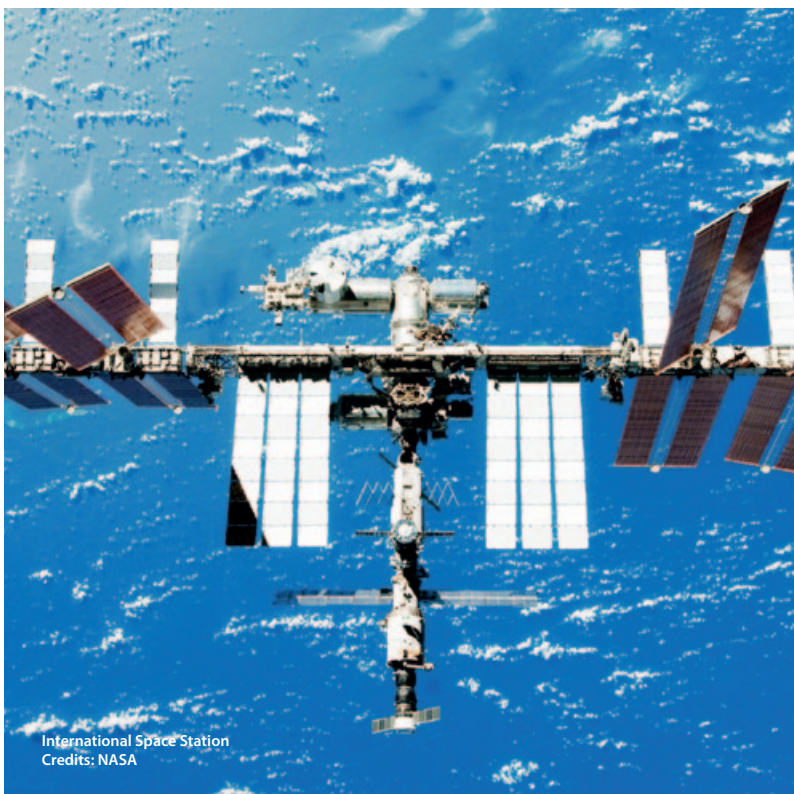


Jumbo Jet Airliner





Pilot Neil Armstrong with X-15  
Credits: NASA



International Space Station  
Credits: NASA

## Priority Actions to Advance Space Safety

The diversified efforts of government agencies, the military, commercial firms and private entrepreneurs have enabled limited access to space. However, present codes of conduct and current methods of coordination are insufficient to insure a safe and sustainable use of space. Now is the time to establish an enhanced process for space safety and to develop an international, cooperative culture for advancing this cause.

It is critical to undertake three priority actions:

1. Develop through advance education and training a space industry workforce more knowledgeable of space safety engineering and management;
2. Research and develop innovative safety practices and effective tools; and
3. Help to establish a minimum set of global voluntary standards for improving space flight safety, reducing space debris and implementing international space traffic management.

## International Space Safety Foundation

Recognizing the urgent need to advance safety practices in the rapidly increasing use of space, the International Association for the Advancement of Space Safety (IAASS) was formed in 2004. This organization spurred of new research, published unique books,

articles and opinion pieces and began to work with the space agencies, space industries and private space entrepreneurs to advance the field.

In the United States, a group of dedicated safety experts from the private, commercial, government, and academic sectors of the space industry saw the need for American leadership in this critical new field. Inspired in part by the impact on aviation flight safety achieved by the Guggenheims and by Jerome Lederer, the group formed the International Space Safety Foundation in 2008. The Foundation's mission is quite simply to enhance access to space for future generations. Its vision is a safe space for people on Earth, for the environment, and for explorers and astronauts in space.

The International Space Safety Foundation is the only organization in the United States that is dedicated entirely to furthering policies of international cooperation and scientific progress in the field of space safety. The Foundation is a non-governmental organization operated by an independent Board of Directors with knowledgeable and experienced representatives from each sector of the space industry, and supported by a think-tank of experts, the Advisory Council.

The International Space Safety Foundation cooperates closely with IAASS in undertaking and promoting conferences, workshops, research, education and training, and development of space safety standards.

The Foundation seeks to engage all segments of space program management, policy makers, and elements of engineering and operations to advance space safety research,





The spectacular ignition sequence of a Delta IV Heavy  
Credits: Vandenberg Air Force Base



The Multi Purpose Crew Vehicle  
Credits: Lockheed Martin

to push the use of improved technologies and inherently safe systems solutions, and to promote independent certification processes, design and verification methods. The Foundation is independent of the space agencies, government regulatory agencies, space enterprise, private space flight industries and specific aerospace interests. The Foundation joins all of these entities, as well as space-related foundations, in the quest to make the future of space safe.

## A Plan for Success

The Foundation has set forth an ambitious plan to address the challenge of human and environmental safety and to improve access to space. The plan encompasses three strategies to significantly improve space safety. It will **catalyze space safety private and academic research** to ensure safe access to, use of, and transit through space and to safeguard any space object operating in space and preserve the Earth's environment and human safety on the ground and in aircraft; **advance knowledge and application of space safety** by building expertise in the field among the broader space industry workforce through advanced education and comprehensive training.

The Foundation is seeking an initial funding of \$1 million that will launch efforts to create an international space safety institute to advance knowledge and application in the space safety field, and to fund a focused research program. The Foundation will seek to leverage, where possible, the initial funding through joint projects with partner organizations and foundations, including the IAASS.

## Catalyze Space Safety Voluntary Standards and Certification

The Foundation will establish an international institute for space safety whose mission will also include promoting the development of voluntary standards and independent safety certification processes in support of commercial and private space flight companies. The Institute will seek to support regulatory bodies at national and international levels for the civil use of space. These efforts are not intended to directly support military or defense space programs, although the civil space voluntary safety standards could benefit non-civil programs. The Institute will network a group of internationally renowned advisors and system and subsystem analysts to test, evaluate, and independently certify the safety of private spacecraft.

## Advance Knowledge and Application of Space Safety

The Foundation will advance safer design and the development of dedicated safety equipment by awarding research grants for key space safety projects and building the knowledge and capacity of the field by supporting publications, monographs, conferences, workshops, training sessions, and web-based seminars. Already the Foundation has provided support for the publication of **Safety Design for Space Systems** (recently translated to Chinese) and its follow-on project, **Space Safety Regulation and Standards**.



Edward H. White II, pilot of the Gemini 4 spacecraft  
Credits: NASA

## Award Innovation and Leadership

The Foundation will provide incentive awards and other recognition to thought leaders encouraging the field of space safety. Awards to be developed will be targeted to innovative practitioners to increase their education and professional development and carry out key research and development projects.

## Fund Raising

We are seeking funds to support creation of an international space safety institute, carry out key research, publish key books, training materials and monographs, provide awards for outstanding efforts in the field and other related activities. Support will be obtained by means of:

- a. Exceptional Donors – individuals, institutions or corporations that make substantial grants to build our endowment base
- b. Members – corporations or institutions that make annual donations:
  1. Benefactor: \$25,000 or more
  2. Patron: \$ 15,000 - \$24,999
  3. Contributor: \$10,000 – \$14,999

## Join Us

Advancing space safety is critical to environmental health and human safety on Earth and to increased viability for all space programs, manned and unmanned. Space safety can also

contribute to the growth of a multitude of new space industries, from space communications to space tourism, from geomatics to clean hypersonic transport. Together, we must place a premium on safety.

Significant investment is needed in the programs and research that will catalyze space safety innovation, voluntary standards, advance knowledge and application of space safety. We invite you to join us in the quest.

By investing now in the work of the International Space Safety Foundation (ISSF), commercial space companies will help develop and expand research and development activities critical to improving space safety, support educational and training programs as well as conferences and workshops related to space safety improvements, and spark innovation and leadership in the field. Your leadership in building a safe and science-based approach to space safety will help expand horizons, increase the opportunities and preserve viability for future generations of explorers.

We particularly invite interested organizations and corporations to contact us, so see how you can be a part of the foundation by being a **sponsor, patron or benefactor** by providing either annual support or an endowment grant to the ISSF. We are also looking for people to help support our initiative to create new educational programs in space safety, to carry out research project in the field, to support training program, to serve on committees, to join our board, or to advance our case in other ways.

Please go to our website and provide us contact information, so we can answer your questions and get back to you.

[www.spacesafetyfoundation.org](http://www.spacesafetyfoundation.org)



By Leonard David

# Spacecraft Reentry: Safety by Design

While the sky  
is not falling...  
things do fall  
from the sky

**L**ast year saw the uncontrolled reentry of NASA's Upper Atmosphere Research Satellite (UARS) on September 24, followed by the downfall of Germany's Röntgensatellit, or ROSAT, a month later.

In the case of UARS, some twenty-six satellite components, weighing a total of about 545 kilograms, were assessed to probably survive reentry and strike the surface of Earth. Similarly, an appraisal of ROSAT indicated that a significant amount of satellite remainders could live on after their fiery fall through Earth's atmosphere.

Then there was the blazing encore to

these satellite reentries of the out-of-control Russian Phobos-Grunt spacecraft on January 15 of this year. Scraps of the errant interplanetary probe were deemed likely to endure reentry, particularly the spacecraft's nose-cone shaped descent vehicle. It was built to bring back to Earth bits and pieces of Phobos, a moon of Mars, and was designed to make a hard landing on terra firma, *sans* parachute.

Each spacecraft, according to orbital debris analysts, yielded leftover

**“Responsibility  
for a project  
must encompass  
the entire  
lifespan,”**

space junk that survived the plunge and reached the surface of our planet. Adding to public angst – driven in part by extensive media coverage of these reentries – is that orbital debris experts are unable to pinpoint in advance the time and location of when and where an uncontrolled spacecraft will auger in, coupled with no guarantee that residual rubbish would not lead to subsequent harm to person or property.

Although the majority of the Earth's surface is covered by water, and much of the remainder is uninhabited, uncontrolled reentries can still pose a small but estimable risk to the human population.

In the case of Germany's ROSAT reentry, Johann-Dietrich Wörner, Chairman of the Executive Board of the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt; DLR), headquartered in Bonn, personally drew a number of lessons from his country's satellite fall: ▶▶



Recovery of the Hayabusa sample return capsule. A similar capsule was part of the ill-fated Phobos-Grunt. - Credits: JAXA



**Artist's impression of an ATV spacecraft upon reentry. Controlled reentry over the open ocean greatly reduces the risk connected with falling debris.** - Credits: ESA

- Responsibility for a project must encompass the entire lifespan and take every eventuality into consideration.
- National and international collaboration, regardless of whether personal or institutional, has now achieved a level that is marked by a very engaging, positive attitude and mutual trust, which must be used accordingly.
- Communication concerning projects should be as transparent as possible, but always reliable and correct in every respect. In this regard, successes and potential risks must be communicated equally.

## Design for demise

New efforts are now underway to purposely build spacecraft hardware to generate the least number of fragments possible during reentry.

A risk greater than 1 part in 10,000 for any reentry is considered by NASA to be unacceptable, and measures are taken to reduce that risk. One approach is to design the spacecraft so that it can perform a controlled reentry into the open ocean at the end of mission life.

Yet another avenue is to redesign some of the surviving components so that they are likely to burn up during reentry heating. Indeed, one tactic is to redesign a component to a different shape, such that it will reenter faster, thus generating more heat during reentry.

This approach and other steps have been termed by orbital debris specialists as "Design for Demise", or D4D for short.

"D4D involves first identifying those components predicted to survive reentry which could most reduce the reentry

risk by 'demising' instead," said Scott Hull an orbital debris engineer at NASA Goddard Space Flight Center in Greenbelt, Maryland. "This could be a result of either a very large component – like a propulsion tank – or a large quantity of a single surviving component type. Large quantities of surviving objects have a higher likelihood of causing an injury, somewhat analogous to a shotgun blast compared to a rifle bullet...so it is beneficial to address any objects which could survive in high quantity," he explained.

Pursuit of the D4D strategy, Hull told *Space Safety Magazine*, could mean switching to a different material, altering the shape of a component, using two smaller objects to perform the same job, or switching to a whole new technology.

**“A risk greater than 1 in 10,000 is considered unacceptable by NASA,”**

Some common materials on spacecraft with high heats of ablation include titanium, stainless steel, glass, ceramics, and beryllium, Hull pointed out, whereas graphite-epoxy composites, aluminum, and polymers all generally have low heat of ablation.

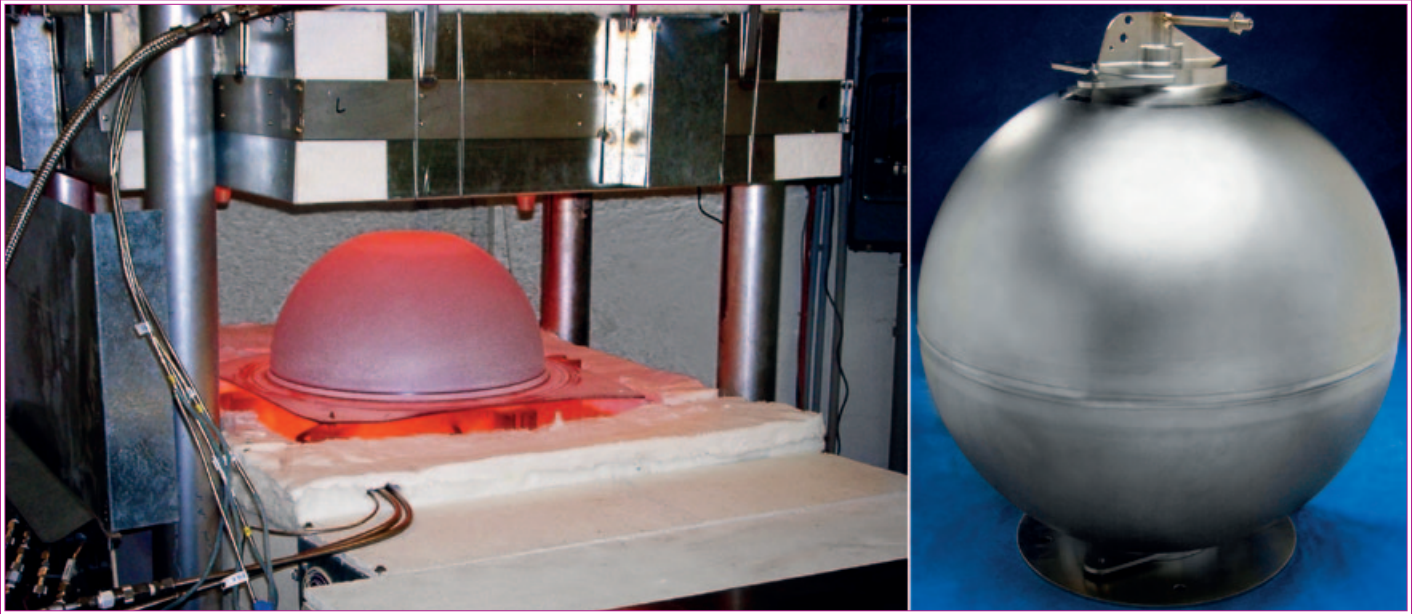
"In consultation with the component designers, it is often possible to redesign a titanium component using graphite-epoxy, for example, to retain approximately the same thermal expansion coefficient, but with a component that will now burn up on reentry," Hull said.

Of course, all material properties must be taken into account, since titanium may have been selected initially for its chemical properties or strength, which the new material might not meet, Hull added. Aluminum can be a handy substitution material because it not only has a low heat of ablation, but also experiences generous oxidation heat- ➤



**The Global Precipitation Measurement (GPM) satellite, under construction, is fitted to the bed of the High Capacity Centrifuge for spin testing. This spacecraft has undergone a "Design for Demise" overhaul.** - Credits: NASA/GSFC





**Forming of an Ariane 5 titanium fuel tank, and the final result. Titanium tanks are among the components that are most likely to survive reentry.** - Credits: ESA

ing and burning, generating even more heat during reentry, especially at lower altitude.

## Chronic survivor

**A**lso spotlighted by Hull are spacecraft flywheels, a chronic survivor of reentry, that don't necessarily have to be. Off-the-shelf reaction wheels sometimes use stainless steel or titanium flywheels which allow higher torque or faster wheel speeds in a small diameter.

"We've found that the same torque can often be created by using a larger diameter flywheel made from aluminum, which will demise readily," Hull continued. "There is a penalty to the project in that the wheel is larger, but this impact is often preferable to the additional hardware and other constraints imposed to perform a controlled reentry."

Metal Hydride battery cells have been a concern for a while, due to their large quantity. If they survive, then the battery alone typically exceeds the Debris Casualty Area (DCA) threshold for the entire spacecraft. One way to deal with that is to ensure that the cells remain together as a single object with lower overall DCA.

NASA's Nicholas Johnson, chief scientist for orbital debris at the Johnson Space Center in Houston, Texas, said that the future launch of the Global Precipitation Measurement (GPM) spacecraft is a mission that has undergone D4D scrutiny.

An analysis of GPM done years ago had flagged the spacecraft's titanium tank – to be loaded to the brim with more than 500 kilograms of hydrazine – as a significant reentry risk. A NASA-sponsored effort produced a flight-qualified, equal-capacity aluminum tank and an all-aluminum internal propellant management device. The result was that the re-entry risk for the tank was reduced to zero. At the same time, a weight savings in the tank was also achieved.

## JAXA work underway

**T**here is growing interest in D4D beyond NASA. This was in evidence at the just concluded forty-ninth session of the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space in Vienna, Austria.

Officials from the Japan Aerospace Exploration Agency (JAXA) announced that work is underway on a demisable propellant tank.

"A propellant tank is usually made of titanium alloy, which is superior because of its light weight and good chemical compatibility with propellant. But its melting point is so high that a propellant tank would not demise during reentry, and that presents one of the major risks of ground casualty," a JAXA document observed. Research is in progress in Japan to replace the tita-

**“Large quantities of surviving objects have a higher likelihood of causing injury,”**

nium tank design for hazard prevention.

NASA's Nicholas Johnson said, within the United States, spacecraft component vendors need to do a better job defining what is acceptable or not acceptable. Doing so takes time and will not happen quickly. There's an educational aspect to D4D, he concluded.



*Leonard David is an American space journalist and a senior research associate with Colorado-based Secure World Foundation. He is a winner of last year's*

*National Space Club Press Award. His articles can be seen at SPACE.com, AIAA Aerospace America, and now as contributor to Space Safety Magazine.*

by Michael J. Listner

# The Legal Frontier of Commercial Space Regulation

**T**he advent of commercial space, in particular space tourism via sub-orbital 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

**T**he 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 inju-

ries they might sustain within modules registered to the United States.

More controversial is the emerging commercial sub-orbital 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, is still undefined.**

Credits: Virgin Galactic

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

**A**nother area of concern is regulation of the commercial space industry. Commercial space in the United States falls under the regulatory author-

ity 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 (CSLA), 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 space-

**“Limited liability will not be granted to commercial space flight companies indefinitely,”**

flight 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 CSLA. 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

**A**nother 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

**“It is too early to consider a legally-binding treaty,”**

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.

## A Paradigm Shift

**W**hile 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.

## Final Remarks

**I**nternational 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:*

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*Follow Michael via Twitter: @ponder68.*



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



By Joel Spark

# Coolant Tank Crashed in Brazil

**E**arly 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 Mendes' home, an Ariane 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 near the Brazilian village of Riacho dos Poços.

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.



Locals gather around the "space sphere".

by Curt Botts

# Pay No Attention to the Team Behind the Curtain...



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**W**hen the Atlas V vehicle rose from Cape Canaveral's Launch Complex 41 at 10:02 am EST on the 26th of November 2011, the world witnessed a picture-perfect liftoff, sending the Mars Science Laboratory rover Curiosity on its voyage to the Red Planet.

This feat was accomplished through the valiant efforts of the men and women of United Launch Alliance, who proved once again their prowess in expertly containing the incredible power of the rocket, precisely unleashing the thrust needed to push the neatly folded payload skyward.

What you may not have been aware of was the team waiting in the wings to provide swift emergency management action, had anything gone awry that day, ready to thwart the "flying monkeys" of fate.

**"In any potential accident there was an extremely low risk of exposure to plutonium dioxide,"**

What you may not have experienced were the exacting evaluations of potential risks and implementation of mitigating processes to control the powerful "beast" that serves humankind in delivering exploratory equipment from the gravity well of Earth to the Keplerian thoroughfares used to access the distant neighborhoods of space.

Who were these brave characters that faced the "wicked" hazards of rocketry to allow the safe initiation of the journey? Follow the yellow brick road...

## The "Wizards"

**B**ehind the heavy curtain resided the "great and powerful" team that



NASA's Mars Science Laboratory (MSL) spacecraft launch atop a United Launch Alliance Atlas V rocket. - Credits: NASA

maintained the Radiation Control Center (RADCC), where real-time monitoring, risk evaluations and public affairs announcements were managed and delivered. In any potential accident during this launch there was an extremely low risk of exposure to plutonium dioxide, the fuel used to provide heat to be converted to electricity to power the Curiosity rover on the Martian surface. Nonetheless, it was important to realize and report any launch accident conditions that may have released the material from the confines of Curiosity's Multi-Mission Radioisotope Thermoelectric Generator's (MMRTG) General Purpose Heat Source (GPHS) Modules [1].

This required the capability to gather air samples from sites around the launch pad and surrounding county, transmit the information to the RADCC, evaluate the readings, and manage message traffic to the local and national news stations, emergency management response forces, and the "twitter-verse."

## The "Tin Men"

**T**he 30 high-tech Environmental Continuous Air Monitors (ECAMs) may not have had individual hearts, but their combined data transmitted from the field provided the heartbeat of the ongoing analysis conducted from the RADCC. Each instrument's readings were efficiently transferred via a data pathway through the Very Small Aperture Terminal (VSAT), uplinked ►►



Radiation Control Center wizards. The RADCC is where real-time monitoring, risk evaluations and public affairs announcements are managed and delivered. - Credits: NASA



to the WildBlue satellite and back to feed the Lawrence Livermore National Atmospheric Release Advisory Center (NARAC) ECAM Data Analysis Program (eDAP), modeling software providing the ability to plot a predicted radioisotope release dispersion pattern. These results were immediately available via NARAC's Consequence Management Web Site (CMWeb). This allowed an informative approach to response awareness giving the team zones for consideration of shelter-in-place announcements. By informing the public and personnel to remain indoors as a post launch accident precaution, ECAMs could be relocated to verify safe exposure levels and declare the area clear for normal activities.

## The "Cowardly Lion"

**C**onsider the strength of the King of the Jungle, when combined with his healthy fear of what could go wrong, and you gain the ability to conquer those worrisome consequences that accompany the launch of a nuclear power system. By always scrutinizing the pathways to failure and eliminating or minimizing them to the point of risk acceptance, the benefits of conducting a hazardous endeavor can be realized. The astute evaluators of risk from a rocket launch leave no [yellow] brick unturned to understand the possibility of events that could lead to potentially harmful conditions. The combined efforts of the RADCC and the 45th Space Wing's Risk Assessment Center (RAC) personnel provided real-time knowledge of any risks from debris impacts, toxic effluent dispersions, or distant focusing overpressure effects that are

**“By scrutinizing the pathways to failure, the benefits of conducting a hazardous endeavor can be realized,”**

considered during any launch countdown. Should the assessment demonstrate risks above acceptable limits, the team recommends further evaluation, initiates mitigating protective actions, or holds the launch process. These scientists, engineers, mathematicians, technicians, and staff certainly deserve a medal of courage for their efforts.

## The "Scarecrow"

**T**he utility of an ominous arbiter of warning dutifully stationed in a cornfield is obvious to the protective Kansas farmer. Similarly, the ability to calmly convey situational awareness when you're at your last straw is vital to prevent a pandemic of panic. The rapid evaluations and decisions of the Coordinating Agency Representative (CAR) Management Group (CMG) constituted the brain of the RADCC and Joint Information Center (JIC). Constantly firing synapses were able to sort through the plethora of information to issue up-to-date status of the team's activities to the news media and local, county, state,

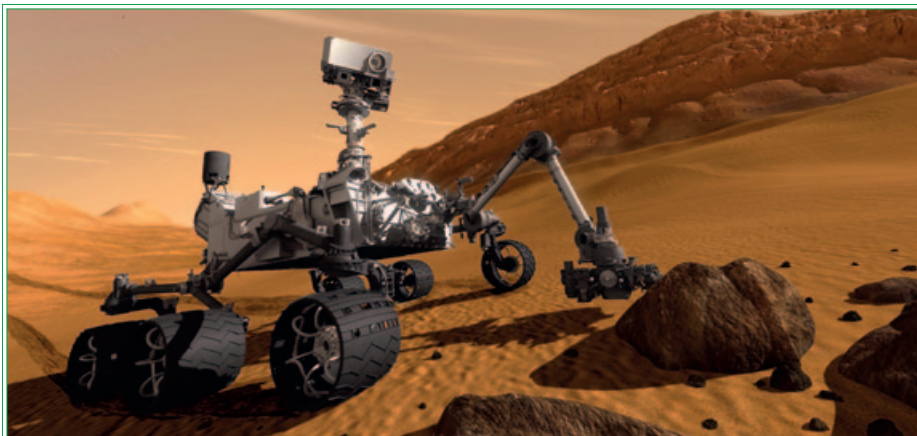


**Environmental Continuous Air Monitors (ECAMs), the heart of RADCC.**

and federal emergency response agencies. Had an anomaly occurred prior to liftoff or during ascent, the appropriate level of emergency response would quickly be defined to maintain safety. External assets could be deployed as necessary, in order to address any potential areas of concern and begin the recovery process.

## "Dorothy"

**L**et us not forget the daydreaming Ldamsel that started this Baum-esque allegory. Her decidedly unsafe practice of missing the call to shelter in the relative safety provided by the storm cellar is certainly deserving of reprimand. But, without this risky behavior, she never would have experienced (or did she?) that horrific tornado of hazards swirling around her vessel during, you guessed it, ascent, trajectory translation, and suborbital impact. Our "Dorothy" then, is the Curiosity Rover endowed with an inherent and relentless inquisitiveness that may land it in some troublesome situations, but will surely reap valuable lessons for the "Kansas farm" known as Earth.



**Artist's impression of the Mars Science Laboratory Rover Curiosity. - Credits: NASA**

[1] Andrea Gini, "Safety of Nuclear Powered Missions", Space Safety Magazine, Issue 1, Fall 2011.

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## NASA Completes Successful Robotic Refueling Mission

NASA's Robotic Refueling Mission (RRM) successfully completed its first on-orbit satellite servicing test on March 9. According to Frank Cepollina, veteran of five Hubble Space Telescope servicing missions and Associated Director of the Satellite Servicing Capabilities Office (SSCO), "RRM showcases the best of what the ISS can offer as a test bed for state-of-the-art space technologies."

RRM is an ISS based experiment designed to demonstrate the technologies, tools, and techniques needed to robotically service and refuel satellites in orbit whether or not they have been specifically designed to be serviced. The experiment utilizes the Special Purpose Dexterous Manipulator (Dextre) – a two-armed robot developed by the Canadian Space Agency – complemented by a set of interfaces called "representative satellite fueling interfaces," a fluid transfer system, and four robotic tools.

**Source:** Inés Hernández.

Read the full story:  
[http://bit.ly/rrm\\_dextre](http://bit.ly/rrm_dextre)

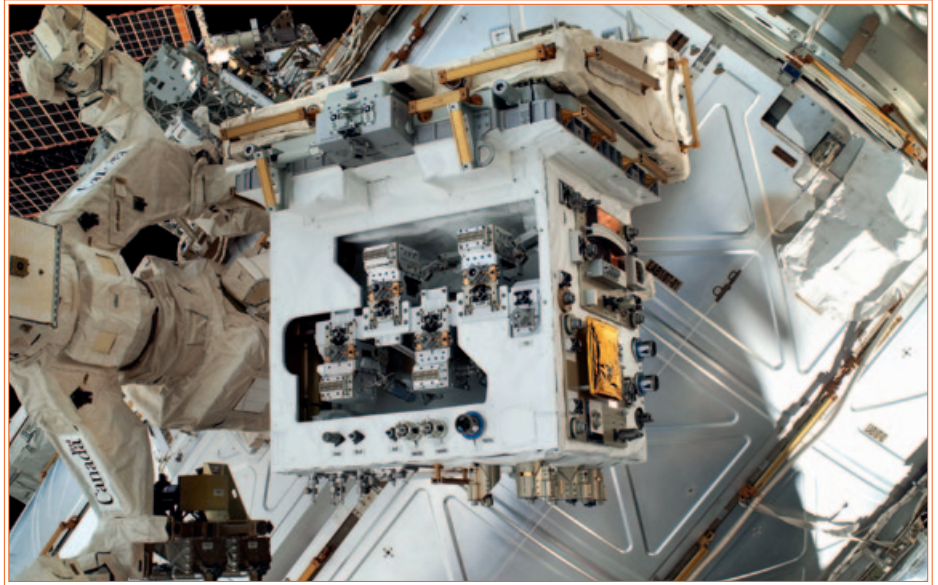
## Mexican Space Agency Supports Fuel Cell Innovation

Professor Gabriel Luna-Sandoval from Centro de Estudios Superiores del Estado de Sonora (CESUES) and Instituto Politécnico Nacional (IPN) has developed the



**Dr. Gabriel Luna-Sandoval showing a urine-powered fuel cell prototype.**

**Credits:** Gabriel Luna-Sandoval



**The Robotic Refueling Mission (RRM) module.** - Credits: NASA

new Urine Fuel Cell or Celda de Combustible de Orina (CCO), intended to transform astronauts' urine into hydrogen and oxygen, vital elements on a space mission. The hydrogen can be used as fuel in the main or auxiliary power system, while oxygen can be used for the life support system. Both gases can be stored as a reserve, enabling mission extension by providing additional fuel and oxygen supply. Filtered urine also produces water.

**Source:** Carmen Felix.

Read the full story:  
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## Virgin Galactic Prepares to Host Experiments

Virgin Galactic announced that it had signed a contract with Nanoracks to outfit SpaceShip Two with experimental racks substantially similar to those used aboard the International Space Station (ISS). The racks are intended to allow researchers to transition experiments between the suborbital SpaceShip Two and ISS. Virgin Galactic head of special projects Vice President William Pomerantz said that the ship is being equipped to allow for both manual and automated experiments. Although providing just a few minutes of microgravity as compared to months of exposure aboard ISS, SpaceShip Two will offer researchers unprecedented access to space. Researchers will be able to accompany their experiments and perform more experimental runs due to lower costs. Pomerantz indicated that the cost

for flying an experiment aboard SpaceShip Two would be proportional to the \$200,000 ticket cost for a tourist's seat, and significantly less than typical costs for flying an experiment aboard ISS.

**Source:** Merryl Azriel.

Read the full story:  
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## Solar Flare Blinds Venus Express Probe

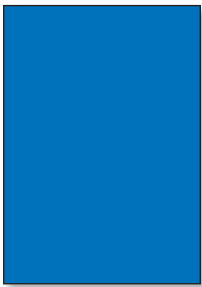
The European Space Agency's Venus Express probe seems to have been "blinded" by a recent solar flare and its related Coronal Mass Ejection (CME). The spacecraft's primary and backup star tracker sensors appear to have been damaged by the high dose of radiation it received from the March 6 solar activity. "We were not able to detect any stars, so we decided to switch to the B unit, but we saw exactly the same thing," said Octavio Camino, the operations manager for the Venus Express at the ESA center in Darmstadt, Germany. "Both of them were blinded by heavy solar activity. Since then, we have not been able to get them back on track, so we are doing a lot of things in order to keep the spacecraft in a safe configuration." Venus Express, launched in late 2005, has been operating in orbit around Venus since 2006, studying its atmosphere.

**Source:** Joel Spark.

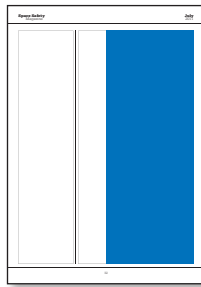
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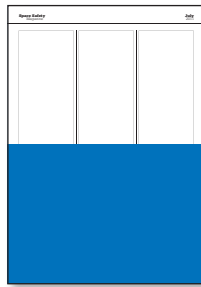
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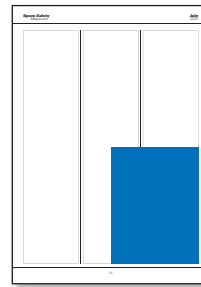
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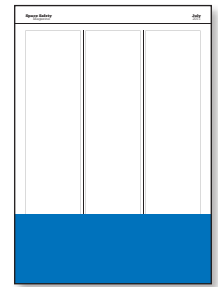
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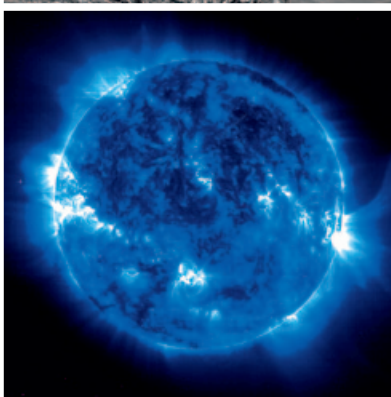
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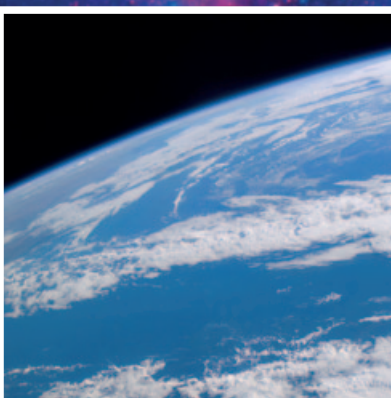


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## Commercial Airlines, Electrical Grids Weathering the Solar Storm

Despite warnings that Tuesday's massive solar flares and associated coronal mass ejection (CME) might cause disruption to power grids on Earth, there are no reported effects as the CME is predicted to

## Robotic Refueling Mission Demo Underway on ISS

Tests of tools and techniques for in-space servicing and refueling of satellites has begun on the ISS with the Robotic Refueling Mission (RRM) system, which was delivered to the ISS

## Capturing Aurorae from Space

Astronaut Don Petit is no stranger to aurorae. He's taken photographs of aurorae from space on each of his three missions - to ISS in 2002, the Space Shuttle in 2008 and now on his second stay aboard the space station.

## Red Lines in Outer Space

Source: Matthew Kleiman and Sonia McNeil for The Space Review Secretary of State Hillary Rodham Clinton recently announced that the United States would join international efforts to develop an International Code of Conduct for Outer Space Activities.

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