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Lockheed Martin is the prime contractor building the Orion Multi-Purpose Crew Vehicle, NASA’s first spacecraft designed for long-duration, human-rated deep space exploration. Orion will transport humans to interplanetary destinations beyond low Earth orbit, such as asteroids, the moon and eventually Mars, and return them safely back to Earth. This state-of-the-art spacecraft provides solutions that are extensible to future missions, and focuses first and foremost on crew safety:

- Accommodates a crew of up to six astronauts
- Provides safe ascent abort with no black zones
- Enables safe abort opportunities during all mission phases
- Withstands re-entry at speeds greater than 20,000 miles per hour

1. SOME DEEP-SPACE DESIGNS ARE CLASSIC FOR A REASON

Thankfully, we’re guided by 50 years of NASA’s investment in human spaceflight. You might note that Orion’s shape hearkens back to Apollo. That’s because every aspect of Orion’s design is driven by crew safety, and the laws of physics are the same today as they were in 1960. That’s the shape that has been proven to work best for high-velocity returns from deep space. And just as lessons learned from previous NASA missions help guide Orion’s design, over 500 products resulting from Orion’s development have been shared with commercial space companies. An example of what’s new is Orion’s launch abort system (LAS). On deep-space missions, mass is king. Any extra weight takes away valuable mass required for micrometeoroid protection, radiation protection and life support needed to keep astronauts safe beyond low Earth orbit. So about six minutes into launch, the LAS is jettisoned to save mass. While there are other ways to build a LAS, our design trade studies repeatedly highlighted the advantage of not carrying extra weight past the time it is needed.

2. CREW SAFETY IS BUILT IN, NOT BOLTED ON

Every component — from the heat shield and the flight computers to the fundamental systems and structure of the spacecraft — is designed for the rigors of deep space: Orion’s seats are designed to help prevent loss of consciousness as astronauts experience up to 5 Gs during re-entry. The cooling system keeps the crew cabin at 25 degrees Celsius despite the more than 2,000-degree heat of re-entry. The built-in stowage lockers double as a safe haven during dangerous solar activity. The life-support system is highly reliable and is sized not only for basic functions but also to allow the crew to exercise, which is critical for long stays in zero gravity. Computers and avionics have multiple backups and are designed to self-correct in the event of a failure. Crew module tiles are designed to protect from the inevitable micrometeoroid strikes the craft will face during long-duration missions.

Michael Hawes

EDITOR’S NOTE

This article is an extract from an editorial by Michael Hawes published by Space News in June 2015 with title “Three Things Orion’s First Flight Taught Us”.

Dr. W. Michael Hawes is Orion program manager for Lockheed Martin Space. Michael Hawes is board member of the International Space Safety Foundation (ISSF).
In 1985, following Spacelab’s first two flights, I was appointed as head of the Safety Assurance Section in the newly formed Product Assurance Systems Division in the Product Assurance and Safety Department at the European Space Agency (ESA) technology and research center (ESTEC) in the Netherlands. At the time of the Challenger disaster I was participating in an early ESA Columbus program review. I was reviewing the contractor’s project documentation when a member of the ESA team came into the review room and announced that Challenger had exploded just after launch, with loss of the crew. We were, of course, all shocked and stunned. I was particularly affected, partially due to my new responsibilities for systems safety assurance, but also because I had previously met Dr. Judith Resnik, the other woman crew member (apart from the teacher Christa McAuliffe) to lose her life on Challenger. Needless to say, little review work was accomplished for the rest of the afternoon. We were all wondering what had caused the accident and whether the Shuttle program would continue, and if so, when that would that be. As we were working on a Shuttle-dependent program (ESA’s contribution to the International Space Station) we were particularly concerned.

Within the Product Assurance and Safety Department, our immediate sympathies were with the families of the crew and with our colleagues at NASA. My ESA safety responsibilities had already brought me into contact with Safety, Reliability and Quality managers at NASA Headquarters in Washington and at the Marshall Space Flight Center in Huntsville, Alabama. In fact, I was due to travel with my department head to Washington for a safety meeting at NASA Headquarters within the next couple of weeks. While this meeting was at a difficult time for NASA, it did go ahead as planned. In some ways the timing was fortunate for us as we were there during sittings of the Rogers Commission and while new information on the possible cause of the failure was coming to light. We were very lucky to be able to sit in on the Rogers Commission meeting where, following the questioning of NASA’s Mr. Mulloy on the operation of the solid booster seal joints, Dr Richard Feynman performed his O-ring in iced water demonstration. This highlighted his concern with solid booster O-ring integrity at the low temperatures which occurred on launch day. It later came to light that he had previously been tipped off about this by astronaut Dr. Sally Ride. The press picked up on his demonstration and it made headlines the following day. Co-incident with this was NASA’s release of the photographs showing the puffs of smoke on the right hand side solid booster joint just after booster ignition, a shocking revelation. It was a very interesting and valuable visit, but of course we didn’t achieve what we had originally intended to do.

At that time, ESA was beginning the Columbus and Hermes human spaceflight projects, so we in the Product Assurance Systems Division had initiated a study into spaceflight safety requirements and methods, which produced some very valuable results. Following the Challenger disaster it was decided to initiate a further study to evaluate existing safety processes in other “high tech” industries and also to determine what other space agencies were doing to enhance human space flight safety. The study was completed just over a year later and significantly influenced the further development of ESA’s safety program, technical requirements, and safety analysis. The report’s findings are still valid, and, unsurprisingly, some of its conclusions are the same as some of those in the Rogers Commission Report. The real disappointment that I have is that, in spite of all the good intentions following the Challenger disaster, it seems that some space flight safety lessons remained to be re-learned all over again some years later as in the fatal Columbia disaster.

ABOUT THE AUTHOR

Keith Wright was systems engineer at Bendix Aerospace responsible for the pre-launch operations of the Apollo Lunar Surface Experiments Package at Kennedy Space Center from 1968 until 1972. At the end of the Apollo program he returned to Europe to work in Europe’s expanding space program. In 1975 he became Systems Safety Assurance engineer on the European Space Agency (ESA) contribution to the Shuttle program, the Spacelab project, at the European space research and technology center (ESTEC) in the Netherlands. From 1985 until his retirement in 1994, Keith was head of the Safety Assurance Section in the ESA’s Product Assurance and Safety organization.
A 3 POINT ACTION AGENDA TO ADDRESS COSMIC HAZARDS AND PLANETARY DEFENSE

Joseph N. Pelton,
Former Dean International Space University and Executive Board, IAASS

ABSTRACT

The IAASS and the JSSE gives its prime focus to astronaut safety and safe space transport, but one of its important areas of concern is that of cosmic hazards and planetary. This is a significant area because strategies for planetary defense could involve the safety of millions if not billions of people. This article addresses the latest information as to the nature of significant areas of cosmic risks, gaps in our knowledge, and an agenda for research to further planetary in future years.

U.K. Royal Astronomer, Sir Martin Rees has noted: “Throughout its history, the Earth has been impacted by asteroids and comets and buffeted by solar flares. But the consequences of these natural phenomena are more catastrophic today, because the infrastructure on which our civilization depends is more elaborate and more vulnerable…. …we have instruments, both on the ground and in space, that can give us forewarning of threatening flares and impacts. We are learning how to make our systems more robust and resilient. Moreover, we will not remain helpless in the face of these threats because we are empowered by advancing technology and engineering.” (Rees)

But despite this quite hopeful statement by the U.K. Royal Astronomer, the truth is that there are many severe planetary risks ahead. Current space agency agendas, space instrumentation, changes to the earth’s magnetosphere, and research programs are, in fact, not fully responsive to the needs of a truly effective planetary defense. (Pelton and Allahdadi)

This article sets forth some of the greatest lacks in current space programs and notes new or revised efforts that could better prepare our small six sextillion metric ton planet from cosmic dangers. Currently there are several cosmic concerns. These include asteroid and comet strikes from Near Earth Objects, solar flares and coronal mass ejections, and the build-up of orbital space debris that could endanger the safe launch of critical space infrastructure over the longer term future. This article focuses on potentially hazardous comets and asteroids and severe solar storms.

1. INTRODUCTION

The urgency and importance of cosmic hazards has only recently come into clear focus with the development of historical knowledge that has come from researching the past mass extinction events that have over time eliminated over 99% of all species that have ever existed on planet Earth. The biggest single extinction event occurred some 67 million years ago. This so-called K-T extinction event eliminated over 70% of all species on the planet — both animals and vegetation — and this was caused by a 6 kilometer asteroid smashing into the coast of Mexico and the Atlantic Ocean. Imaging from the International Space Station reveals from space the remnants of the huge crater that is the aftermath of this tremendous collision that created a death cloud over the planet that screened out the life-giving light of the Sun and killed off the dinosaurs.

![Figure 1: Photo from the ISS of the crater along the coast of Mexico from the K-T Mass Extinction Event (Figure courtesy of NASA)]
IT networks and electrical grids to be disabled by solar events. Second the protective shield provided by the geomagnetosphere appears to be weakening. (Wolcover) The magnetic North Pole has slipped down to Siberia and headed further South. Some computer modeling estimates developed at the Max Planck Institute suggest that the protective system provided by the Earth’s magnetic field in coming decades might end up being only 15% as effective as it was just two decades ago. Figure 2 below depicts a modeling of the protective Van Allen Belts that could occur as the magnetic South and magnetic North Poles move closer together in coming decades. The bottom line is that there are many things that can be done to initiate a planetary defense program that are currently not being done that should be undertaken sooner rather than later.

Figure 2: Modeling of Van Allen Belts During a Reversal of Earth’s Magnetic Poles (Graphic Provided Courtesy of the Max Planck Institute, Berlin, Germany)

2. ISSUES WITH DETECTING AND TRACKING NEAR EARTH OBJECTS

There have been concerted efforts to detect potentially hazardous asteroids using both ground and space based systems. The Wide-field Infrared Survey Explorer was repurposed to become the NEOWISE to search for Near Earth Objects. (WISE) This was in response to Section 321 of the NASA Authorization Act of 2005 (Public Law No. 109-155), also known as the George E. Brown, Jr. Near-Earth Object Survey Act. The specific objectives of the George E. Brown, Jr. NEO Survey Program were “to detect, track, catalogue, and characterize the physical characteristics of NEOs equal to or larger than 140 meters in diameter with a perihelion distance of less than 1.3 AU (Astronomical Units) from the Sun” This assignment to NASA was to achieve 90 percent completion of the survey within 15 years after enactment of the NASA Authorization Act of 2005 as signed into law by President George W. Bush on December 30, 2005. Achievement of this assignment by 2020 seems unlikely to be achieved unless NASA could accelerate plans to construct and launch the NeoCam project that has been designed by NASA as a new Infrared telescope that is designed to complete the assigned task of potentially hazardous asteroids. This project has only been picked for “technological definition” and is geared to locating asteroids that are larger than 140 meters—as directed by Congress. (NeoCam) There are those that would suggest that both the assignment from the U.S. Congress and the NASA search capabilities are well off the mark of what is needed for an effective planetary defense effort. This guidance in the so-called George Brown Act of 2005 was not based on careful studies that demonstrate that an asteroid under 140 meters would likely cause only minimal harm. The truth is quite the opposite. Asteroids of 35 meters are “city killers”.

To get an idea of what size of asteroid represents a major threat one only has to look at the evidence from the Tunguska asteroid event of June 30,1904. This space rock traveling at an estimated 54,000 kilometers/hour (or about 33,500 mph) exploded some 8 kilometers (or just over 5 miles) above the Siberian forest with the explosive force more than 1000 times the force the Hiroshima Atomic Bomb. This air-based asteroid explosion flattened and incinerated a forest of 2000 sq. kilometers containing 80 million trees in an almost perfect radial design. This asteroid which could have wiped out San Francisco and Silicon Valley) was not 140 meters in diameter, not 100 meters, not 75 but rather only about 40 meters in diameter. According to Dr. Donald Yeomans, head of NASA’s Near Earth Objects office this rather “insignificant” space rock was able to do an incredible amount of damage. (The Tunguska) The destructive impact of an asteroid that was indeed as large as 140 meters in diameter and traveling at perhaps 50,000 mph (or 80,000 kilometer/hour) — a more typical speed for an asteroid traveling relative to Earth orbit — would collide with a force that was some 65 times greater (or the equivalent of 65,000 Hiroshima bombs). In short, there is a really important problem here and that is that the guidance given to NASA by the U.S. Congress now over a decade ago as to what to look NASA was instructed to look for in terms of size and urgency was, quite simply, WRONG! In fact, asteroids some 35 meters in diameters should be considered major threats. In terms of mass an object that with a 35 meter diameter is 43 times smaller than those being searched for in the NASA search protocol. And that is the least of the bad news. As one looks for smaller and smaller asteroids the numbers go up exponentially. There are likely to be many hundreds of times more potentially hazardous asteroids that are 35 meters or more in size than there are asteroids that are 140 meters in size. The B612 Foundation, that was founded by Apollo 9 Astronaut Rusty Schweickart and now headed by Astronaut Ed Lu,
has now campaigned for years for new space programs that can detect potentially harmful asteroids down to 35 meters in size. Indeed their Sentinel spacecraft positioned in a solar orbit similar to that of Venus is under contract with Ball Aerospace. Currently close to half the funds needed to finish this infrared telescope project and launch it into orbit. This program is far from a panacea and the problem of potentially harmful comets remains to be solved. (The Sentinel Mission)

Beyond the detection of potentially dangerous space rocks, there is much work still to be done. There is a need to develop: (i) better techniques to detect asteroids on a collision course with earth; (ii) improved air burst, water burst and land burst modeling; (iii) greater understanding the impact that solar radiation and gravitational affects can on the orbits of asteroids that come in close proximity to the sun; (iv) better characterization of the shape, size, and composition of asteroids that might have to be diverted; and (v) the best techniques by which asteroids can be effectively diverted in their orbits by such means as directed energy beam systems, laser bees, or possibly even nuclear propulsion. And on top of these technical capabilities, we need to improve on and strengthen the processes that now exist with regard to the Minor Planet Center in Cambridge, Massachusetts and the Space Guard Foundation in Italy and UN authorized International Asteroid Warning Network (IAWN), as well as the Space Mission Planning Advisory Group (SMPAG).

Arthur C. Clarke in his award winning novel, Rendezvous with Rama wrote of a true planetary mission to ward off asteroids from planet Earth. For once humanity could be ahead of science fiction if all of the things were to be undertaken on a truly integrated global effort to achieve an effective asteroid and comet defensive space guard effort. (Rendezvous)

But the problem is more than just asteroid and comet defense.

3. ISSUES WITH SOLAR HAZARDS

The damage that might come with a massive asteroids strike would be terrible indeed. The probabilities of a disastrous “black swan” event carrying out enormous damage to the global economy and great loss of life are actually much higher in the case of a major solar storm. A massive solar flare of X-Rays and even more energetic radiation can elevate the risk of cancer and genetic mutation. This is particularly true where the atmosphere is weakest in the polar region and where ozone holes can exist. The higher incidence of skin cancer in locations such as New Zealand and Southern Australia. (Ozone) But the greatest danger of all comes from the ion storms that can come from the Sun in the form of coronal mass ejections. (See Fig. 3) When the Carrington Event of 1859 occur telegraph offices caught on fire and the Northern Lights were seen in Cuba and Hawaii. In the middle of the 19th century, the risks to electrical systems were small because they did not exist. The Montreal event of 1989 that took out electrical systems from Chicago to Montreal, and the Halloween event of 2003 that damaged the electrical grid in Scandinavia are indicators that we are today increasingly vulnerable to major coronal mass ejections that end up flowing out from the sun and hitting the Earth.

A massive enough coronal mass ejection hitting Earth could possibly damage and take off line critical satellite networks, cripple electrical grids and pipelines, and possibly adversely affect information and communications networks and defense systems. If the GPS system were to be disabled, were would likely lose the synchronization of the Internet.

![Figure 3: A Massive Solar Coronal Mass Ejection](Image Courtesy of NASA)

And as noted earlier, there is data from the ESA Swarm satellite probes that suggest that the Earth’s magnetic poles are shifting and with it the protective shield represented by the Van Allen Belts are weakening. (ESA’s Swarm)

There is now coming into focus a rather disturbing equation. This equation that is possibly becoming true indicates an imbalance. It shows on one hand an increasing global population, more and more electrical grids, more and more critical satellite, and satellites, and more and more dependency on modern infrastructure. On the other hand is a global atmosphere with a weakening protective ozone layer due to pollution, a geomagnetosphere with shifting magnetic North and South poles, and a Van Allen Belt system that is less able to protect against solar storms.

These concerns, if anything are of greater concern than even the threat from killer space rocks. There are other problems as well. These include increasing build-up of space debris, and climate change issues that are also
longer term problems as well and they too require global cooperation and new technological development to address as well. The bottom line is that there needs to be a global agenda for cooperation and technological development to address these very profound space safety issues. The time for action is now. Delay in addressing these issues will likely see the problem getting worse and the solutions more costly and difficult. The urgency of action is hard to convey in a short article. If one would like to hear and see more on why cosmic hazards are to be taken seriously and learn more there are three videos on You Tube that can provide a great deal more background in a very accessible way. These videos are:

1. “If there were a day without Satellite” 3:58 min. https://www.youtube.com/watch?v=5sgM7YC8Zv4
2. “Cosmic Hazards”(Short Version) 5: 50 min. https://www.youtube.com/watch?v=UDGD73aD9s3
3. “Cosmic Hazards” (Long Version) 25 min. https://www.youtube.com/watch?v=RwRdyag2dxA

4. A NEW AGENDA FOR COPING WITH COSMIC HAZARDS

What needs to be done to address these space safety issues? The following 3 point action agenda is recommended.

a. Global assessment. This assessment and inventory of cosmic risks should be started now. Individuals countries should be considering the nature of their vulnerability to cosmic risks, but in addition, organizations such as the IAASS should cooperate to develop a global assessment of risks and possible strategies to mitigate those risks — possibly in cooperation with the UN Committee on the Peaceful Uses of Outer Space. Units or organizations such as the UN Office of Outer Space Affairs, IAASS, the McGill Air and Space Law Institute, the International Space University, the International Academy of Astronautics and other organizations with a global reach and focus could assist with such a global assessment of cosmic risk levels and possible planter defense systems.

b. Space Agencies Raise the Priority of Planetary Defense. All of the space agencies of space-faring nations should formally adopt Cosmic Risk Assessment and Planetary Defense as a Top Priority. This should be more than a token gesture. ESA, JAXA, Roscosmos, CNSA, ISRO, and NASA should create posts just to address cosmic hazards and planetary defense. NASA, for instance, should create an Associate Administrator for Cosmic Risk Assessment and Planetary Defense. This office would oversee research on the sun, solar flares, coronal mass ejections, cosmic radiation, the Earth’s magnetosphere, ozone holes, the Van Allen Belts, climate change, NEO tracking and asteroid and comet diversion techniques, orbital debris remediation, and participation on all international forums related to these topics. Until such actions are taken within space agencies, cosmic hazards and planetary defense will continue to be treated as a low priority and non-essential function by space agencies around the world. The level of funding for such activities need to be raised from less than 1% of space agency funding to at least 5%. If this could be added a new funding to space agency budgets it would greatly facilitate the ready acceptance of this new priority mission.

c. New Priority Research related to Cosmic Hazards. After national and global assessments are made of both major cosmic hazards and potential planetary defense strategies, there should be a global space agency conference to establish a priority space research agenda. This would include such items as: (i) New ways to cope with the reduced protective capabilities of the geomagnetosphere; (ii) Possible dual-purpose deployable protective shielding and solar power generation capabilities at L-1; (iii) Other innovative strategies to address the problem of powerful solar storms during a time of reduced protective strength of the Van Allen Belts; (iv) Acceptable strategies for diversion of potentially hazardous asteroids or comets from Earth impact; etc.

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THE RUSSIAN R-16 NEDELIN DISASTER:
AN HISTORICAL ANALYSIS OF FAILED SAFETY MANAGEMENT

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ABSTRACT

On October 24, 1960, at the USSR’s Baikonur Cosmodrome, an electrical malfunction led to the deadliest launch accident in space industry history. Shortly before a test launch of the first Soviet R-16 intercontinental rocket, the second stage engines prematurely ignited, detonating the first stage fuel tanks. We hypothesize that the primary contributing factor to the tragedy was a systemic flaw in safety management caused by cultural and political values. Through the use of interviews, literature, and a chronology of the events leading up to the failure, an interpretive analysis identifying contributing factors to the disaster was conducted. This study found that cultural and political influences were primary causes to the loss and also led to a safety management environment that continued to threaten the success and integrity of aerospace development in the USSR and other space-faring countries.

1. INTRODUCTION

In 1921, the USSR established a research and invention laboratory for the renowned Soviet engineer Nikolai Tikhomirov for the development of “rocket propelled weapons.” [1] The establishment of Tikhomirov’s lab marked the beginning of the Soviet Union’s quest for sophisticated weaponry and, as history would soon document, a leader in manned space flight. During the development of dirigibles and other airships, early rocketry experienced many failures. In most cases, launch-vehicle failures result in research and development setbacks and economic loss. However, the history of rocketry and space flight is also marked with failures resulting in the loss of human life. On 24 October 1960, at the Baikonur Cosmodrome, the attempted launch of a prototype Soviet R-16 missile resulted in a tragic loss. This failed launch was under the command of the Chief Marshal of Artillery, Mitrofan NeDELin, who was killed in the R-16 explosion and would later be the namesake reference to the disaster.

This paper recounts and analyzes the events and contributing factors leading to the R-16 Nedelin disaster. Due to past secrecy surrounding this mission failure, very little information is openly published about the R-16 Nedelin event. With the release of formerly classified reports, the authors are able to synthesize the documented memories of eyewitnesses to the tragedy, along with relevant data and information found in now declassified Soviet documents. Witnesses include engineers, military personnel, and service operators present at the failed launch. Documented in this study are accounts from Lieutenant Colonel Boris Aleskin; Senior Technician Ivan Koval; Sector Chief Vladimir Kukushkin; Evgeniya Alya-Brudzinska, the wife of senior test engineer Captain Ivan Murashko; and Chief Engineer of the Yuzhnoye Design Bureau, Mikhail Yangel. In memoirs and interviews, these eyewitnesses provide a personal glimpse into the details surrounding the Nedelin disaster, and when coupled with information from English and Russian sources, enables the authors to present an interpretation of the primary contributing factors to the R-16 Nedelin disaster.

2. THE HISTORY OF THE R-16 AND THE LAUNCH SEQUENCE

The world’s first intercontinental ballistic missile, the R-7 Semyorka, officially Glavnyye raketno-artilleriyskoye upravlenie MO RF (GRAU) (Main Missile and Artillery Directorate of the Ministry of Defense of the Russian Federation) index 8K71, also known by NATO reporting name SS-6 Sapwood, was created by Sergei Korolev in 1957. [2] The R-7 delivered the first artificial satellite, Sputnik 1, into space and the first cosmonaut, Yuri Gagarin, into orbit. The missile found a long application in the Soviet and Russian space programs but proved impractical as a ballistic missile. Derivatives of the R-7 include the Vostok, Voskhod, and Soyuz rockets. With the Cold War in full force, the Soviet government was under pressure to gain momentum in the arms race. Prior to October 1960, the U.S. performed a successful test launch of an Atlas intercontinental missile, and the Soviet government was determined to advance their missile program as an appropriate response to this perceived threat. Launch preparation for an R-7 required almost 24 hours due to...
fuel management issues. Korolev designed his rockets exclusively around a combination of kerosene and liquid oxygen – relatively safe components. While using a safer fuel mixture was a design advantage, the process to produce liquid oxygen at that time was long, causing a significant delay in launch preparations. Such a delay was obviously unacceptable in a nuclear exchange. [3]

The USSR needed a rocket with a quick fuelling option that could be ready in minutes instead of hours. A combination of hypergolic unsymmetrical dimethyldyrazine (UDMH) (C\textsubscript{2}H\textsubscript{8}N\textsubscript{2}) and dinitrogen tetroxide (N\textsubscript{2}O\textsubscript{4}) seemed to be a solution to the problem since this combination allowed the rocket to be ready for launch in only 20-30 minutes. Moreover, the rocket could remain fueled for almost a month. However, a significant drawback is that UDMH is extremely corrosive and toxic and produces gas that is poisonous when burned.

Nikita Khrushchev originally assigned the task of building a rocket fueled with UDMH and dinitrogen tetroxide to Korolev. However, Korolev refused. Khrushchev chose not to argue with Korolev and instead assigned the new project to Mikhail Yangel, Korolev’s future competitor. Yangel was Korolev’s assistant but later became the Director of the Scientific Research Institute of Rocket and Missile Engineering and Korolev’s superior. Even during their early working relationship both men had conceptually different views regarding rocket design strategies. In 1954, another reassignment split them apart when Yangel was transferred to Dnepropetrovsk [4] as the new Chief Engineer of the Yuzhnoye Design Bureau.

[5] The first test launch of Yangel’s new R-16 (GRAU index: 8K64, NATO reporting name: SS-7 Saddler) rocket was scheduled for October 1960 in honor of the Great October Revolution. Workers assigned to the program struggled under the burden of double shifts to meet the October launch objective. [6]

To bolster the number of workers, a Soviet artillery regiment was urgently transferred to Baikonur from far Eastern Russia. Prior to departing for their new assignment, the soldiers were not made aware of the challenges they were about to face, nor did they comprehend what was to be required from them. Even their leader, Lieutenant Colonel Boris Aleskin, was not informed of the details of their new assignment until they arrived at Baikonur. [7] Aleskin recalls his first impression of Baikonur:

*Where are we? Everywhere you look – nothing but a desert. We couldn’t see a city. The only thing we saw from the distance was a metal carcass of some metal constructions...and that was it. On the other hand – we were very excited; there was some sort of sensation of anticipation of seeing and meeting something new. We were even jealous of our comrades who we saw and met the first time and who were there before us...* – Lt. Col. Boris Aleskin [8]

Marshal Nedelin closely monitored and supervised the preparation process. Nedelin, “one of the brightest and most accomplished officers in the artillery sector”, an experienced combat general, the first rocket marshal, and a Baikonur insider, knew every “nut and bolt,” every technical aspect of the construction of the launch site and, as such, was a knowledgeable and experienced rocketeer. He was the Master-Chief-Executive of Baikonur’s development and construction, loved and respected by his workers. A competent and experienced leader who participated in all nuclear and rocket test operations, Nedelin arrived at the launch site three days before the launch to personally attend to the final details. When he arrived, the new rocket was still in the integration and test facility waiting to be hauled to the launch pad. A team of scientists, engineers, and mechanics were working day and night to identify and eliminate design and workmanship defects in several modules. Equipment that failed to meet specification was removed and immediately sent back to manufacturing in Moscow, Kiev, and Dnepropetrovsk. Once a failed component was replaced, the repaired equipment was rushed back to Baikonur. The circulation of parts, components, and subassemblies between Baikonur and the design and manufacturing facilities never stopped. [9]

Nedelin personally reported to Brezhnev, General Curator of the Space Industry, about the progress of the preparations. However, the crew was given an order to ensure the launch regardless of any issues that arose.

Days before the scheduled launch, another chief engineer, Yangel’s deputy-assistant, Lev Berlin, the second highest-ranking engineer in the Yuzhnoye design bureau, arrived unexpectedly at Baikonur. Officially, Berlin was still on vacation—his first in five years. Yet, when he returned to Dnepropetrovsk, he found the design bureau abandoned as everyone had traveled to Baikonur to witness the launch. Berlin immediately re-packed his suitcase to rush to the launch site, but circumstances were against him. Relatives persuaded him to stay and celebrate his 40th birthday at home and insisted that he skip this launch. That was not a persuasive argument to Berlin, as he had never missed a previous launch. All direct airline and train tickets were sold out, so Berlin traveled by car, transit train, and plane from one city to another. He finally arrived at Baikonur just before the scheduled launch. [10]

Early on October 23, while fueling the rocket, it was reported to Marshal Nedelin: *“We have a problem, we*
have a leakage of the fuel tanks, 140 drops per minute.”
Nedelin consulted Yangel and other specialists and made the decision on the spot to continue the fueling operation and proceed with the launch schedule. The leaking fuel would be contained and removed from the immediate vicinity. [11]

[Major Mahna] was walking with this bucket throughout the day ... He would put the bucket under the leak and wait till it filled ... Then he would dump it right outside in the desert... a desert was all around us, you know... – Lt. Col. Boris Aleskin [12]

Later in the evening at 19:00, 30 minutes before the scheduled launch, the final, prelaunch testing and inspection were underway when something went wrong within the electrical components of the rocket. The nature of the issue was not immediately clear, as diagnostic equipment at this point in the Soviet launch program was rudimentary. In 1960, the principal, field-diagnostic tools were still the eyes and ears of the engineers and technicians, as described in the following accounts:

Electricians went to check their part of the deal, trying to figure out what happened. I got approached by Yangel’s assistant, Berlin, and he told me that we could try to figure it out on our own, that is, we could check whether the membrane was damaged or not. He gave me a large wrench and told me – hit it above and below the membrane and we’ll figure out by the different sonorous responses whether the fuel is present there or not. I told him, you know... I’m not a musician and I can’t figure it out just by listening. Sorry, I can’t! – Sector Chief, Vladimir Kukushkin, Yuzhnoye [14]

I remember we had quite an interesting testing methodology. You would literally hit a sensor with a stick and see if there are any changes. So we had quite a subjective approach to automation and control – Sr. Tech., Ivan Koval, Yuzhnoye [15]

Technician Ivan Koval had become a new father just before his trip to Baikonur, and Evgeniya Alya-Brudziniskaya, the wife of a senior test engineer at Yuzhnoye, was expecting. However, new families were an insufficient excuse to reject the assignment and miss the launch for Koval or Alya-Brudziniskaya’s husband, and it was unthinkable to delay or defer the launch. Although separate from family and friends at a secret location, Koval’s team dedicatedly pursued the launch of this first-of-its-kind intercontinental rocket. Ivan Koval remarked on the secrecy of the mission, “we even had a different postal physical address – Tashkent 90, and as you know, Baikonur is in Kazakhstan, not Uzbekistan. So everything was top secret...everything was highly classified...” [16]

At 18:40, 20 minutes before the scheduled launch, a short-circuit damaged the sequence switch, a major component of the electrical control circuit roughly equivalent to a countdown sequencer. The situation rapidly escalated once test engineers discovered that fuel had already begun migrating toward the engines in the last step before ignition and launch. At this point, the only two practical alternatives were to launch the rocket or to remove the fuel and start over. Marshal Nedelin asked for quick evaluations of potential solutions to the problem. Yangel provided his input: “There is no turning back. We can’t reverse the fuel flow back into the tanks. We either conduct a launch or cease the entire project.” Nedelin decided to delay the launch by one hour until 20:00 and, in the meantime, formed an ad hoc team to select the best alternative. Everybody knew the right decision — to drain the fuel and put the project on hold until all the necessary modifications and adjustments were properly made. However, the right solution had one significant drawback — the rocket was not reusable, many of its components would not work again once the fuel had been drained. In addition, the team had a strict order to ensure a successful launch per the schedule provided. If the fuel were emptied from the rocket, it would take at least a month to prepare and manufacture another one, destroying any chance of meeting their mandatory launch schedule. [17] Koval describes Nedelin’s involvement in the decision to move forward with the launch:

Almost all the test engineers were present at the government committee meeting. Everybody could attend it. And these questions were discussed among all the specialists. Military people proposed their solution to the problem — that was, to figure out where the failure occurred, determine the source of the problem and even send the rocket back to the plant if necessary. But the person most insistent on keeping the project going forward and continue with the launch was Nedelin. I mean he stood out the most out of all the members of the committee. He insisted on providing everything necessary to conduct the launch — Ivan Koval [18]

The commission decided to postpone the launch by one day to October 24 but included in their decision a non-standard, and, in retrospect, fatal decision to use the additional time to fix the electrical control system on-site with the rocket remaining fully fueled. With this decision, the committee did not only violate their own procedures, they blatantly ignored them. During the night of October 23, new instructions and procedures were created and signed. On October 24, the team resumed their attempt to overcome the problems in the electrical system reassuring themselves that collectively, they were a knowledgeable and experienced team that had already conducted several rocket launches. Several times before crewmem-
bers had experienced last-minute problems, and it was an accepted, if not common, practice to institute ad hoc changes and modifications at the launch site as necessary. Of course, the R-16 rocket, like the entire nascent space industry, was new, unproven, and still experimental. [19]

Meanwhile, new tests were revealing new problems in the control system. The experienced test engineers anticipated these problems would happen and expected they would eventually all be eliminated and fixed prior to another successful launch – but no one had expected fixing problems on a rocket fully loaded with toxic fuel. [20]

When you are already pulled into this kind of business, when you worked this problem for 10-12 hours and you see the light at the end of the tunnel, you don’t want to delay your work till tomorrow, you want to finish it, you know? – Vladimir Kukushkin [21]

They were all attracted to their ‘toy’ like children. It was their creation, their brainchild…You see, [my husband] even had to leave me alone with a little child when he left to work on the project. I was absolutely alone and had no help – Evgenia Alya-Brudzinskaya [22]

If I was thinking rationally by today’s standards, I would have never allowed people to be around the rocket at the launch site when the rocket was already fueled! Normally, nobody is allowed to be anywhere close to the rocket after the fueling is complete! – Lt. Col. Boris Aleskin [23]

Although the procedures that had been redlined and signed the previous evening stipulated that only designated workers with specific tasks were to be near the launch stand, at one hour before the scheduled launch, the site was still crowded with officers, engineers, and soldiers, including Marshal Nedelin, who scoffed at suggestions that he leave the pad area. “What’s there to be afraid of? Am I not an officer?” he was reported to have asked. Even the executive command hierarchy was not following the process they had approved 24 hours earlier. The team of chief engineers was supposed to supervise the launch process from the safety of a bunker. However, Marshal Nedelin remained close to the test stand well past the deadline when their process stated that he and the entire crew should have removed themselves to safety. No personnel dared to confront Nedelin with a reminder of the need to follow their safety procedures. Instead, safety was subordinated to comfort when a folding chair for Marshal Nedelin was brought forward and placed meters from the launch stand. [24]

Well, the Marshal was sitting on that folding chair, smiling and looking at me. I approached his aide-de-camp and told him – what are you doing, look how complicated

the situation is here. It’s scary! But he looked at me and replied – Well, what can I tell him, what can I do? He is the Marshal! – Capt. Ivan Murashko [25]

During the final hour before launch, the remaining tasks were scheduled in a serial fashion. The next task was not supposed to start until the previous task had been successfully completed. However, glitches that took longer to fix than estimated and process steps that took longer to execute than scheduled were threatening to overwhelm an already tight launch schedule. Pressed for time, it was decided to push aside serial testing, thereby limiting the number of people at or on the launch stand to only those conducting that particular test or process step, to testing several components simultaneously, a decision that resulted in approximately 200 workers crowded together in close proximity to the launch site. [26]

There was a combat squad…and nobody else was supposed to be present at the launch site. But we were not launching a military rocket, but rather an “experimental” and therefore, people who designed and created it needed to be present at the launch table. You know, getting a rocket ready for a launch – it is a test of its own, therefore, the people conducting the tests needed to see how the rocket was fueled during normal procedures and how different components worked. During these observations, additions, changes and improvements were documented along with potential flaws in design and function. The observer’s notes would be added to the military documentation for further evaluation…So these people were not just staring at the rocket, they were there to work – Sector Chief Vladimir Kukushkin [27]

Twenty minutes before launch, the combat squad was frantically trying to catch-up, but time was running away from them. Yangel was getting nervous and decided to have a cigarette. Maj. General Aleksandr G. Mrykin, Nedelin’s point man for missiles and space, convinced him to follow procedure and wait until he was safely inside a bunker 70 meters away from the rocket before lighting up. [28]

3. THE CATASTROPHE

On October 24, 1960, at Cosmodrome Baikonur, the R-16 stood fully fueled on the launch table in preparation for lift off at 19:00. The missile never became airborne, as 30 minutes before the planned launch, the second stage roared into life and within seconds, the fuel in the first stage exploded into flames. [29]

Several of the engineers and technicians on the launch platform implementing repairs and preparations when
The second stage ignited were probably killed immediately. Many who survived the initial explosion ran to escape the inferno, some by jumping or falling from the platform to the launch table – a concrete surface surrounded by a barbed wire fence – 6 meters below the R-16. Those who survived the plunge and made it to the fence tore their bodies trying to get past the barbs. Others tried to run for safety, their clothes and hair burning, but succumbed to the toxic fumes in minutes. [30]

There was nobody to rescue the survivors. Following directives in place at that time, the fire-fighting installation was located only 50 meters from the launch table and was one of the first damaged during the explosion. Furthermore, although many individuals were seriously injured and needed immediate medical attention, medics were not allowed to be pre-stationed at the launch site – again, per directives in place in late 1960. With the destruction of the on-site medical rescue and fire-suppression facility, the next closest assistance was 1000 km from the launch site. As it was, the first evacuations of the injured did not begin until almost three hours after the accident, when the fire had finally calmed. [31] Even as late as a minute after the explosion, there was no chance to rescue anyone within a 100-meter radius. [32]

Shortly before the catastrophe, during the systems evaluation intended to determine the readiness of the electrical systems, the sequence switch, a key element of the control system, was manually turned to a neutral position. However, while the operator turned the sequence switch to neutral, the switch momentarily moved through an operational position and triggered the second stage engine start sequence. The last-minute evaluation testing had armed the second stage engine, the previous day’s aborted launch had left fuel at the engine and finally an unsafe sequence switch design was able to start an armed and fueled second stage engine while it sat on the launch pad, directly in line with a fully fueled first stage. Furthermore, all the failsafe systems that should have prevented a premature start of the second stage had been turned off to conduct the electrical system evaluation. Once the fuel and oxidizer merged inside the second stage engine, the blazing exhaust quickly burned through the first stage oxidizer tank, followed shortly by the fuel tank erupting the entire fuel supply in a horrific explosion. Soon the rocket split apart, ejecting 130 tons of fuel in a fountain of flames and toxic gas. Aleskin recalls the sight of the explosion:

I didn’t know what happened. I just saw a bright flare and suddenly everything around me got bright, although it was after 7 pm in October, when it was getting dark around that time. I heard the roar of the engines and I immediately realized that it was the rocket...I got scared... Everything was so bright. – Lt. Col. Boris Aleskin [33]

Based on statements made by those who managed to survive the fire, it was discovered that at the time of the explosion, Yangel’s assistant, Lev Berlin, and Marshal Nedelin were only 15 meters away from the foot of the rocket. Chief Engineer Yangel and Lieutenant Colonel Boris Aleskin were 50 meters away, while senior technician Ivan Koval from Yuzhnoye had been inside the safety of the bunker. The location of others was impossible to determine. Eyewitness accounts tell of a gruesome and horrific scene, as fuel and oxidizer consumed the test area:

At the moment of the explosion I was about 30 meters from the base of the rocket. A thick stream of fire unexpectedly burst forth, covering everyone around. Part of the military contingent and testers instinctively tried to flee from the danger zone, people ran to the side of the other pad, toward the bunker...but on this route was a strip of new-laid tar, which immediately melted. Many got stuck in the hot sticky mass and became victims of the fire...The most terrible fate befell those located on the upper levels of the gantry: the people were wrapped in fire and burst into flame like candles blazing in mid-air. The temperature at the center of the fire was about 3,000 degrees. Those who had run away tried while moving to tear off their burning clothing, their coats and overalls. Alas, many did not succeed in doing this. [34]

...automatic cameras had been triggered along with the engines, and they recorded the scene. The men on the scaffolding dashed about in the fire and smoke; many jumped off and vanished into the flames. One man momentarily escaped from the fire but got tangled up in the barbed wire surrounding the launch pad. The next moment he too was engulfed in flames. [35]

Above the pad erupted a column of fire. In a daze we watched the flames burst forth again and again until all was silent... (After the fires had been extinguished,) all the bodies were in unique poses, all were without clothes or hair. It was impossible to recognize anybody. Under the light of the moon they seemed the color of ivory. [36]

The same night, Yangel spoke to Khrushchev about the accident and the deaths of dozens of people. Khrushchev listened silently and at the end of the report asked only one question: “And how come you survived?” [37] Leaving his office late that night, Yangel asked his colleagues to gather and announce that the government had expressed their distrust in him.

Of note is that immediately following the explosion of the R-16, Khrushchev made a call to Korolev asking for his opinion about Yangel’s fate. Korolev thought for some time before he replied that this kind of accident...
could have happened to him just as well as to any other Chief Designer. Unfortunately, Korolev’s comment was prescient as exactly three years after the Nedelin tragedy, on October 24, 1963, eight people were killed at Site 70 in another accident at Baikonur during a test of an R-9A ballistic missile designed by Korolev’s organization. [38]

4. THE AFTERMATH

On October 25, the day after the catastrophe, a government investigation led by the Curator of the Space Industry, Leonid Brezhnev, was launched to determine the cause of the catastrophe. [39] The Soviet government hoped a successful launch of the R-16 would provide a suitable response to the U.S. bombers that were stationed around the USSR border and provide a strong negotiating card in their Cold War with the West. The unfortunate launch failure caused their trump card to be lost before it could be played. The Soviets knew they could not publicly announce the failure of the R-16 test launch. Therefore, an objective of the investigation was to classify everything related to the launch as soon as possible. Under a Top Secret label, all the documents pertaining to the investigation, technical evaluations, and eyewitness statements were sequestered in classified archives. Finally, Brezhnev announced the only official conclusion of the committee: “Do not punish those who were responsible for the failure, they were already punished by the explosion.” [40]

On October 28, 1960, major Russian newspapers published an announcement from the Central Committee of the Communist Party of the Soviet Union and The Presidium of the Supreme Soviet of the USSR. The brief announcement stated: “The Presidium of the Supreme Soviet of the USSR and The Council of Ministers of the USSR, with the deepest regret, informs that on October 24, 1960, Marshal Mitrofan Nedelin, Deputy Minister of Defense of the USSR, came to a tragic end as a result of an aviation catastrophe.” No further details were given about Nedelin’s death and not a mention was made of those who died with the Marshal. It was not until 1989 that the world learned of the true circumstances of Marshal Nedelin’s death and the total scale of the tragedy. “There are still many discrepancies in reports of the final human toll... ranging from a lower limit of ninety two to an upper limit of 165. By October 28, seventy-four people had been identified as dead.” [41]

The Central Committee mailed death notifications to the families of the dead. According to the notice, all of the test engineers, technicians, and service workers were killed in the same airplane accident that claimed the life of Marshal Nedelin. While many family members did not believe this official version, it was simply impossible to discover the truth. [42] The survivors from the test launch were examined at medical facilities, but in order to comply with the highly classified nature of the disaster, they were not allowed to talk about their injuries, and the doctors were not allowed to ask questions. Ivan Koval reported his experience, “I answered only one question – how much time did I spend wearing and breathing through a gas mask? ... They were very surprised [by my answer] and made an entry into a medical log.” [43] Koval was prohibited from discussing anything about the accident, even with his family, until the catastrophe was declassified.

Thirty years after the accident, disturbing images captured by Baikonur’s staff cameraman, Valentin Anohin, of technicians running away from the fireball, clothing on fire, were released to the public for the first time. It was standard procedure to film every launch at Baikonur, and the launch of October 24 was no exception. Immediately after the disaster, Anohin’s film was collected, and every image was carefully analyzed and reviewed by Brezhnev’s Investigation Team. The most terrifying images of smoking corpses and people burning alive were immediately edited, and the rest of the film remained classified and locked away in Soviet government archives for the next 30 years. [44]

The first partially successful launch of an R-16 was conducted on February 2, 1961, one hundred days after the Nedelin explosion, but the missile impacted only 520 km from the launch site. The first fully successful launch was finally achieved 20 days later. Preliminary approval for military use came on October 20, 1961, and following a series of trials, full usage was approved on June 15, 1963. The R-16 remained in service until 1974 and 195 were still deployed in 1970. [45]

In 1994, all of the investigation committee’s documents related to the accident were declassified. Then in 1999, thirty-nine years after the disaster, a presidential decree of the Russian Federation awarded 99 launch participants the Order of Courage – 63 of them posthumously. Oberg [46] suggests that failing to share the knowledge and lessons learned from the Nedelin disaster perpetuated the tragedy as the failures were subsequently repeated with tragic consequences, “... such Soviet secrecy may have cost American lives, as they made mistakes which NASA, unwarned, later repeated [e.g., the Apollo-1 fire followed by six years a similar Soviet tragedy].” [47] Or as Chernok [48] concluded, ‘Teaching a course called ‘large rocket-space systems’ to students at MFTI [Moscow Institute of Physics and Technology] and MGTU [Moscow State Technical University], in the unit on ‘reliability and safety,’ I utilize the account of the events of October 1960.” [49]
5. CONCLUSIONS

The USSR rushed development, testing, and initial launch of the R-16 to commemorate the anniversary of the Great October Revolution. Additionally, “a few days before [the scheduled launch], Khrushchev had made a speech to the United Nations about the might of the Soviet armed forces, in which he claimed that rockets were being produced ‘like sausages from a machine.’” [50] The Nedelin Disaster is an extreme example of the need for systems safety engineering throughout the development of high-energy products and also the need for testing small-scale, prototypes before full-scale flight units.

Several contributing factors exacerbated the proximate design defect in the launch sequence electronics [51]:

- Inadequate safety procedures that were ignored or dismissed
- Uncorroborated decisions to maintain schedule in spite of serious contemporary anomalies
- Approximately 150 personnel making repairs and uncoordinated, coincident testing in proximate vicinity of a fully-fueled rocket
- Cavalier treatment of hazardous chemicals
- Critical, out-of-line decisions were made without measured deliberation
- No validated contingency plans to deal with anomalies or an on-pad abort

Finally, the decision of the Soviet government to not fully investigate and disseminate lessons learned from this complex system failure within their own space program, let alone the world space community, potentially contributed to subsequent failures in the USSR and the USA. As former NASA Chief Engineer Dr. Michael Ryschkewitsch proposed, one of the best ways to improve systems engineering in any organization is to study and understand as many failures as possible. [52] While several of the technical problems and procedural issues that contributed to the tragedy have been solved in the five decades subsequent to the disaster, the nature of human psychology has not shared similar progress. The space industry has to use its intellect and communication skills to distribute knowledge and learn from other mistakes in the aviation and aerospace industries and likewise, to accept feedback from the experience of others.

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DESIGN OF SENSOR SYSTEM TO DETECT PRESENCE OF ANOMALOUS WATER IN AIR LINES IN THE EXTRA VEHICULAR MOBILITY UNIT

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ABSTRACT

The behaviour of fluids in microgravity imposes a risk to an Extravehicular Activity (EVA) crewmember. The intrusion of water into air conduits used for pressurization and breathing would flow with minimum resistance in the direction of pressure differential. Such an intrusion would cause water to enter into the helmet breathing space and could cause suffocation and drowning in addition to loss of vision and loss of communication. It is hence prudent to detect this water intrusion before it accumulates undetected to a dangerous level.

This paper offers a design to address this risk. A sensor system is described that detects the water intrusion into the air lines that are part of the Extravehicular Mobility Unit (EMU) life support system. Upon detection, the EVA can be terminated before a harmful state is reached.

1. INTRODUCTION

Extravehicular Activity or EVA is one of the most hazardous and also indispensable aspects of human spaceflight. EVA’s have enabled feats like construction and maintenance of the International Space Station and the Hubble repair mission. The safe execution of an EVA with minimal compromise on functionalities is hence a prime motive.

On 16th of July 2013, astronauts Luca Parmitano and Christopher Cassidy began Extravehicular Activity 23 aboard the International Space Station. About 44 minutes into the EVA, Parmitano reported water at the back of his helmet which slowly migrated to the front of his face. The EVA was terminated and Parmitano struggled to make it back to the airlock, having vision out of the visor impaired and breathing with the suspended water arduous. He also had audio communication issues due to the water in the helmet interfering with the communication system. However, he relied on tactile feel of his safety tether and ingressed into the airlock. Both he and Cassidy were re-pressurized. It was found that about 1.4 litres of water had accumulated inside the helmet. The mishap investigation board labelled this incident as a “High Visibility Close Call”. The astronaut was determined to have been exposed to potential loss of life due to drowning [1].

The sensor system described in this paper mitigates the consequences of the failure, which is water intrusion into air lines. This is done by detecting the presence of water, and upon exceeding a particular quantity limit, a warning is issued. This warning may lead to an EVA termination. The water detection would enable termination of the EVA and a safe re-pressurization before the water build-up becomes hazardous.

The system introduced is an initial concept. Further Research & Development and testing is needed in order to address practical issues (like proper calibration of sensors considering the innocuous presence of moisture due to breathing, and perspiration due to physical activity) in implementing it to Extravehicular Activity space suits.

2. THE EXTRA VEHICULAR MOBILITY UNIT

The Extravehicular Mobility Unit or the EMU is a self-containing life support system for astronauts performing spacewalks outside the protection of the spacecraft environment in low earth orbit [2]. Following is a brief description of the EMU parts relevant to this paper. An overview of the different parts of the EMU are presented in Fig. 1.

The EMU consists of two main components:

- The pressure garment or the Space Suit Assembly (SSA) which provides pressurized envelope, mobility and thermal control.
- The Primary Life Support System (PLSS) with a Secondary Oxygen Pack (SOP) which provides life support, power and communication systems.

The PLSS comprises of four main circuits:

- Oxygen Ventilation Circuit
- Primary Oxygen Circuit
- Feedwater Circuit
- Liquid Transport Circuit

The Primary Oxygen Circuit provides oxygen at regulated pressure to the Oxygen Ventilation Circuit which the astronaut uses for breathing. It is also used for pressurizing the Space Suit Assembly, aiding in water expulsion from the water tanks on PLSS and its pressurization. The exhaled Carbon Dioxide goes through a METOX canister where it is removed and dumped overboard. A fan-pump-separator system is used to both circulate the...
exhaled air through the air processing components and to partially remove the water vapor in air. The remaining humidity removal and oxygen cooling occurs in the sublimator. The water collected is directed back to the water storage tanks. Water storage tanks are part of the Feedwater Circuit, so is the sublimator. The water storage tanks supply water to the Liquid Cooling and Ventilation Garment (LCVG) which is a garment worn inside the EMU, lined with cooling water tubes and is part of the Liquid Transport Circuit. This is used to remove body heat produced during the EVA operations and is re-cooled in the sublimator. The water storage tanks also supply expendable water to the sublimator, where after collecting heat, is dumped overboard as it freezes.

The Secondary Oxygen Pack provides 30 minutes of backup oxygen supply. This could be initiated either if the primary supply is exhausted, the primary regulator fails or if one of the purge valves (purge to space) is opened.

Other components of the PLSS/SOP assembly are the space-to-space radio, Enhanced Caution and Warning System (ECWS) and the Display and Control Module (DCM). ECWS monitors the system operational conditions and the DCM allows the crewmember to control them.

The two parts (SSA and PLSS/SOP) are covered by the Thermal Micrometeoroid Garment (TMG).

4. PROPOSED SENSOR TO MITIGATE THE RISK

The schematic of the sensor system is shown in Fig. 3. The basic concept used is the absorption of light energy by the leaked water droplets. Two sections of the air conducting pipe have a sensor assembly in between them, joined by pneumatic fittings. The portion of the pipe in the sensor assembly is transparent in order to allow light energy to be transmitted. On one side of sensor, an Infrared (IR) light source is placed. The light generated by this source travels through the pipe diametrically and falls on a photodiode. The photodiode generates a nominal current as long as the obstruction to the IR light is sufficiently low. It is calibrated for this nominal operation, taking into account the absorptive coefficient of the transparent pipe, full range of air flow rates, directivity effects of the IR emitter and receiver and moisture expelled from the body.

In the event of a fluid leak into the air pipe, the water droplets (suspended due to microgravity) pass between the IR source and the photodiode. Absorption of the light energy by the water causes the intensity of light falling on the photodiode to drop beyond the set limit. This in turn causes a drop in current output which activates a warning system, part of the ECWS.
A cross-sectional view of such a setup is shown in Fig. 4. As shown, the setup may be enclosed in a rectangular frame with two opposite sides fixed and supported to the EMU. This prevents relative motion between the sensor and the pipe. One side of the frame may be removable to make assembling and disassembling easier. There may be a cover along the cross section to prevent outside light from affecting the detector reading.

There may be several of such sensors placed at various points in the air circuit. This achieves two objectives. One, there may be several sources of water intrusion into the pipe and having the sensors downstream of the possible locations maximizes the probability of detecting the water presence. Second, having more than one sensor makes it possible to confirm the warning generated by the first sensor. As the water is carried by the air flow, it activates successive sensors with a certain time delay. This asserts the presence of water. The concept is illustrated in Fig. 5.

5. CALCULATING THE DETECTOR REQUIREMENTS

An equation is derived that relates the fractional reduction in intensity of IR light detected to the size of water droplet, the size of the sensor and the absorption coefficient of water at the IR wavelength. This aids in selection of the sensor based on the maximum allowable water quantity passing through the sensor.

\[ \Delta I/I_o = (4/3) \times (\mu R^3/S^2) \] (1)

\( I_o \) is the intensity of IR light emanating from the IR LED (Light Emitting Diode), \( \Delta I \) is the drop in intensity detected at the photodiode, \( \mu \) is the absorption coefficient of water at the IR wavelength, \( R \) is the maximum allowable radius of water droplet passing through and \( S \) is the diameter of received light on the photodiode. The variables are illustrated in Fig. 6.

Assume the following:

\( \mu = 10 \text{ m}^{-1} \) (for IR source wavelength of 940 nm)

\( S = 0.01 \text{ m} \)

\( R = 0.005 \text{ m} \)

Plugging these numbers into Eq.1, the fractional drop in intensity, \( \Delta I/I_o \) obtained is 1.667%.

With the given requirement for droplet size detection, the pipe size and the IR source wavelength, the detector needs to detect a drop in intensity of 1.667% and higher which is also the minimum resolution required. This also means that the error in the detector must be less than half of this value, i.e. 0.833% of the nominal intensity value.

6. SIGNAL PROCESSING

This section describes how the output from the detector is processed and how a warning to ECWS is issued in the event of a fluid breach.

The output from the photodiode is first sent into the bandpass filter, centred at an output frequency with a certain bandwidth. Signal noise is removed at the bandpass filter. It is then sent to the power amplifier, which makes it easier for the filtered signal to be further processed by increasing its power. The analog to digital converter then converts this analog signal to a digital signal so that it can be used in the microcontroller. The microcontroller then verifies if the signal current is less than current for nominal operation by a certain tolerance value. If the signal current is less than the nominal current by a certain value, corresponding to the minimum intensity drop calculated above, another signal is generated which is the warning signal. This warning signal goes to:
1. The communication cap earpiece where the warning signal is converted to a sound of required characteristics.

2. A light display on the Display and Control Module (DCM) on the EMU.

3. Space to Space Antenna where the signal is sent to the ISS crew and onward to the Mission Control Center.

This processing is done for each sensor output.

7. OVERVIEW OF SYSTEM SPECIFICATIONS

The major components of the sensor system are the IR LED and the photodiode.

7.1. Infrared LED

It can be seen in Fig. 8 that the absorption coefficient for water is higher in the near infrared region than in the visible region. This is preferable because higher degree of absorption leads to a greater drop in intensity measured at the detector and makes it possible to detect smaller droplets with greater accuracy. The wavelength of the light used in Eq. 1 falls in this region.

7.2. Photodiode

The photodiode chosen needs to work in the bandwidth of the IR LED described above. This is shown in Fig. 9 which corresponds to a wavelength of 940 nm used in Eq. 1. The output frequency of the sensor is 30 kHz [4]. The output signal must be filtered for frequencies around the output frequency with necessary bandwidth in order to remove noise. As such, noise due to ambient light is expected to be negligible due to the fact that this system is inside the Space Suit Assembly and the detector only receives light from the IR source.

7.3. Overall weight and power requirements

A total number of five sensor systems is assumed to be required in the EMU considering the total length of the air conduits and the possible water intrusion points. A sensor system includes: the IR LED, photodiode, band-pass filter, power amplifier, analog to digital converter and microcontroller. The total power requirement for the five systems is estimated to be less than 600 mW, the total mass less than 700 g, volume for IR LED and photodiode 10 cm$^3$ and volume of the remaining components 60 cm$^3$.

8. CALIBRATION OF THE SENSOR SYSTEM

As mentioned, the sensor system shall be calibrated for a nominal operation, taking into account the absorptive coefficient of the transparent pipe, the full range of air flow rates and the directivity effects. Another factor that should be taken into account in calibrating the sensor is the moisture present in the nominal air flow.
A substantial amount of moisture may be present as a result of the breathing process and perspiration from the crew member (due to strenuous activity). This moisture present in the air conduits needs to be accounted for while measuring the presence of leaked water. Not doing so would lead to an over estimation of the leaked water presence and generate a faulty warning. The calibration of the sensors for nominal operation must hence take into account the full range of moisture presence as well, which dictates the limit on water permissible in the air lines. Optimally, the sensors upstream of water separator may have a higher tolerance for water and sensors downstream, a lower tolerance.

Further tests need to be carried out in order to determine if the calibration of the sensor is sufficient to account for this presence of moisture. Design changes may be made accordingly.

9. TEST PROGRAM

The capability and proof of concept shall first be done on ground using the sensor system as detailed in the preceding sections. Due to the presence of gravity, the water would not take a spherical form. To counter this problem, a spherical thin hollow glass shell (of known absorption coefficient) can be filled with water and introduced into the sensor system. The response of the sensor can be observed and the sensor can be validated. This operation is shown in Fig. 10. Once the sensor has been demonstrated on the ground, it can then be flown to the ISS for the system qualification.

If the sensor system concept clears all other qualification tests (as the case may be for each electronic component as per the necessary guidelines) and is to be installed on the existing EMU’s, during the checkout of an EMU prior to launching it to the ISS, the sensors shall undergo the ground testing and calibration (for each sensor to follow the same requirement for maximum allowable intensity drop) described above. The installation of the sensor system on the suits will require replacing the existing ventilation line with several smaller ones in order to accommodate the sensors and joined by pneumatic fittings, as shown in Fig. 3.

10. OTHER APPLICATIONS OF THIS SENSOR CONCEPT

The concept discussed in this paper can be extended to other applications as well. One example is to use a spectrometer (in place of the photodiode) and a light source of applicable wavelength(s) in order to detect the presence of certain gases or liquids like Carbon Dioxide. This would detect the presence of these molecules by analyzing their absorption spectrum. A similar approach to detect water, fluids or gases can be used in fluid lines which form part of the Environmental Control and Life Support Systems of a manned spacecraft or space station.

11. SUMMARY

A high risk operation like the EVA needs the safest possible systems. The sensor concept detailed in this paper acts as a safety feature that detects the presence of leaked water in air lines in an Extravehicular Activity space suit, preventing the failure mode from being catastrophic. This design accomplishes that goal at very little additional cost, weight and lead time.

12. REFERENCES

ABSTRACT

Based on a comprehensive analysis of all major manned space projects (capsule types – Mercury, Soyuz, Gemini and Apollo – and winged type – Space Shuttle, Buran and Hermes) and taking into account the advantages and drawbacks of both types, a new concept for a manned reusable spacecraft has been proposed and justified in detail. The concept, which is patented, combines the features of both the types, hence the name, hybrid.

1. CONCEPT

The basic concept is that the wings of the hybrid spacecraft are folded and protected by a front heat shield during ascent and descent phases when flying through the atmosphere with the front heat shield first (similar to a capsule). After atmospheric braking, the front heat shielding is jettisoned, the wings are deployed, and the spacecraft lands on a conventional runway. In contrast with the winged spacecraft (as well as of a lifting body type) the thermal insulation could be made using high temperature alloys (not tiles) with the exception of the front heat shield protected by ablative insulation.

An additional advantage of the hybrid spacecraft is control that is achieved during atmospheric descent by rotating in roll, similar to a capsule. This very effective concept is realized by using quite small reactive control engines rather than large, massive aerodynamic control surfaces with powerful actuators to produce high rotating moments. As a whole, this unique concept could result in a spacecraft that will combine a number of attractive features of both types: the capsule type (compact launch configuration, compatibility with an escape system, quite effective protection during the atmospheric flight, the same direction of overloads on cosmonauts and astronauts during descent and ascent); and the winged type (additional maneuverability during approach and landing on a runway).

Both the concept of foldable wings (on aircraft and proposed spacecraft conceptual designs) and the use of front heat shields on spacecraft are well known and widely used. However only in this combination are they able to ensure an effective way to bring a spacecraft back to Earth from space orbit.

As an example, a 7.5-ton option of the hybrid spacecraft, to be launched by the Soyuz launcher, is conceptually designed and considered in more detail to demonstrate the basic idea and show its potential. For this initial option, it is also proposed to use the Soyuz Service Module and other components to a maximum extent.

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To improve approach and landing maneuverability, a small air-breathing engine is added. In order to increase safety, the spacecraft is equipped with an escape system also of the Soyuz type; thus, the whole crew compartment could be separated on a launch pad, or in flight, and land using a backup parachute system.

In principle, the same method could also be applied to other spacecraft: the Shenzhou of China, for example, in order to turn it into a reusable space vehicle capable of landing on a runway, as well as to the European and Japanese cargo transfer vehicles: ATV and HTV.

2. ADVANTAGES

An advantage of the concept proposed is that a similar approach could be used when designing an interplanetary manned probe. A recovery module would eventually bring
Figure 2: Orbital configuration

Orbital operation window
DM doors
Front heat shield
Solar panels
Tail RCS
Service module
Nose RCS
Crew cabin
Docking module DM
Tail module
Pilot windows
Docking unit
Nose section
RCS
Flight direction
Escape parachute
Conical fairing
Front shield

Figure 2: Orbital configuration
Figure 3: Landing configuration

Figure 4: Spacecraft composition
its crew back to Earth landing on wings on a runway. This feature seems rather attractive in connection with the new American space initiative, in designing the CEV. An important advantage of the concept is also the fact that it would require new technology, greatly reducing the risk of future projects. This would greatly save time, effort, and resources during phase A of development (advanced studies) and B (project definition), and later as well.

3. CONCLUSION

The proposed concept seemingly brings the times closer when spacecraft will return to Earth quite similar to conventional aircraft. This would provide an opportunity to well-developed, as well as developing and ambitious countries to have access to outer space and to increase the number of nations participating in space exploration.

EDITOR’S NOTE

This is an article by Vladimir Syromyatnikov (1934-2006) that is published posthumously by the JSSE.

Vladimir Syromyatnikov was the Russian designer of one of the most successful piece of space hardware, the docking system Androgynous Peripheral Assembly System (APAS). It was used in the Apollo-Soyuz Test Project in 1975, successful in more than 200 dockings of Soviet/Russian, on the Shuttle and on the International Space Station. The International Docking System Standard (IDSS), as global docking mechanism standard, is based on the heritage of the APAS system. Also the Chinese Shenzhou spacecraft is equipped with a docking system based on the APAS. Vladimir Syromyatnikov graduated with a degree in engineering from the Bauman Moscow High Technical University and the School of Mechanics at the Moscow State University. In 1956 he went to work for the S.P. Korolev Rocket and Space Corporation Energia as an engineer, where he helped design the first piloted spacecraft that cosmonaut Yuri Gagarin rode in 1961. He then rose through the ranks to become a department head in 1977, helping design and overseeing the development of docking systems, onboard manipulators, and reusable solar arrays. Syromyatnikov was a Professor and head of the Technical Cybernetics Department at Moscow State University, an Invited Professor at the International Space University, and an Academician of the International Academy of Astronautics. His awards included the Lenin Prize, Honorable Scientific Worker of Russia, and the Friendship Order.
ABSTRACT

Pre-dawn sightings of a fireball over Spain on November 3, 2015, and the subsequent discovery of three composite overwrap pressure vessel (COPV) spheres and other suspected space debris, pointed to a re-entry as the cause. The resource of record for re-entries is the USSTRATCOM (U.S. Strategic Command); however, its Space Track web site reported neither predictions nor historical data that correlated with the events in Spain. The mystery was solved by estimating the orbital elements from the fireball sightings and positions of the debris, and finding a matching object in the orbital data of independent sources. The re-entering object was the Centaur upper stage with the international designation 2008-010B, and the USSTRATCOM catalogue number 32707.

1. INTRODUCTION

Verifying that a fireball sighting was due to a re-entry from orbit, and identifying the object, normally is a simple matter of visiting USSTRATCOM's Space Track website and running a query. With a sufficient number of reliable sighting reports, a preliminary identification takes about ten minutes. Identifying the source of suspected debris is almost as easy, provided the date of impact can be narrowed sufficiently.

News of the Spanish re-entry of November 3, 2015 reached the author two days later. About all that was known was that a COPV sphere had been found between Mula and Calasparra (Murcia). The date of impact was not initially clear, but it seemed to have been recent. There were no obvious candidates in the Space Track database, but there was too little data from the field to draw conclusions.

On November 9, came news of the discovery of another sphere in the same area as the first. A reasonably detailed news report on the sighting of a fireball on the day the first sphere was discovered, appeared on November 10. The discovery of a metal strip near Elda (Alicante) was reported on November 11. The following day brought news of a large object found near Pozorrubio de Santiago (Cuenca). Word of the discovery of the third sphere came on November 15.

By then it was clear that a re-entry occurred just before dawn on November 3, that some debris had survived, and that Space Track had neither predicted nor acknowledged a re-entry that could explain these events. News reports quickly converged on the space debris hypothesis, but the identity of the object that re-entered was a mystery. Fortunately, there were sufficient pieces of the puzzle to enable an independent solution.

Section 2 documents existing reports on the fireball sightings and the recovered debris, which form much of the evidence of the case. Section 3 explains how the description of the fireball sightings, and especially the locations of the suspected debris, led to the 2008-010B re-entry hypothesis. The independent sources of orbital data, essential to solving the case are described. The agreement in number, size and type of the discovered spheres with those aboard 2008-010B is documented.

Section 4 reports the orbital decay analyses that demonstrated the spatial and temporal correlation between the re-entry of 2008-010B and the fireball sightings and debris locations. The resulting trajectory is compared with the debris locations and one of the fireball sightings. Section 5 states the conclusions. Section 6 acknowledges those who assisted this study.

2. FIREBALL SIGHTINGS AND DEBRIS

The fireball sightings and recovered debris formed much of the evidence of the case.

2.1 Fireball sightings

Re-entry fireballs look similar to meteoritic ones. Their key distinguishing characteristics are their much slower speed, and nearly horizontal flight. Meteors seldom are observed to break up, but this is almost always a feature of re-entries. Observers see a swarm of bright lights, each with a meteor-like tail, moving along the same path. The key information for analysis is the time of the sighting and the direction of travel.

The fireball suspected to have been the source of the debris occurred in bright morning twilight, so it was not
as prominent as it would have been in a dark sky, which probably explains the scarcity of reports.

2.1.1 Las Cumbres (Murcia)

The earliest reports of fireball sightings came from the vicinity of Calasparra, where three COPV spheres subsequently were found. Several newspaper articles mentioned the sighting of 7-8 fireballs early on the morning of Tuesday, November 3 - the same day that the first sphere was discovered.

The sighting was at about 7 AM CET (6 UTC), from Las Cumbres. The witnesses reported that the fireball headed toward Los Llanos del Cagitán, less than 10 km to their southeast, where the first sphere was discovered. After they lost sight of it, they heard a “roar like thunder” (“estruendo”) [1], consistent with a known phenomenon of re-entries, resulting from sonic booms of fragments below about 50 km altitude. Knowing the duration of the delay before this sound was heard, would help to decide whether it was a sonic boom. [2]

2.1.2 Almería

In Almería, amateur astronomer José Luis Ruiz Gomez had just completed an observing session. As he prepared to return indoors, at about 7:03 AM CET (6:03 UTC), he spotted a fireball. He watched it for about 30 s, during which it fragmented three times. He spotted it low in the north, traveling "somewhat approximate northwest-west to southeast-east." [3]

Ruiz Gomez attempted to photograph the fireball, but it faded from view before he could steady his camera. He took several photographs, the first of which is of special significance because it defines the latest possible time that he observed the fireball. Ruiz Gomez calibrated his camera’s clock after the fact, by comparing it with an accurate time source. He measured the clock error every day or so, during the period Nov 20-Dec 9. The author correlated the resulting 18 measurements with the clock time, by means of a linear regression analysis, and used the regression line to correct the time of the first photograph. The result was 06:03:40 UTC, accurate to +/-5 s, to 95 percent confidence.

2.1.3 Almansa (Alicante)

Ximo Alvarez made a cell phone video from a highway in Almansa (Alicante). The reported time of the sighting was 2015 Nov 03 at 7 AM CET (6 UTC). It is a bit dark, but adjusting the brightness reveals a string of several lights moving from right to left, seen between clouds in the morning twilight. [4]

2.2 Suspected debris

Tab. 1 lists the locations of the five suspected pieces of debris that have been reported to-date.

<table>
<thead>
<tr>
<th>Object</th>
<th>Location</th>
<th>Co-ordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sphere 1</td>
<td>Los Llanos del Cagitán (Murcia)</td>
<td>38.17 N, 1.59 W</td>
</tr>
<tr>
<td>Pipe or duct elbow</td>
<td>near Pozorrubio de Santiago (Cuenca)</td>
<td>39.81 N, 2.90 W</td>
</tr>
<tr>
<td>Sphere 2</td>
<td>Villa Vieja (Murcia)</td>
<td>38.25 N, 1.69 W</td>
</tr>
<tr>
<td>Metal strip</td>
<td>Las Barrancadas (Alicante)</td>
<td>38.47 N, 0.85 W</td>
</tr>
<tr>
<td>Sphere 3</td>
<td>near Sierra del Molino (Murcia)</td>
<td>38.23 N, 1.64 W</td>
</tr>
</tbody>
</table>

The co-ordinates are of places reported by the news media to have been proximate to the debris, probably accurate to within a few kilometres.

The three spheres found in Murcia (Fig. 1), weigh about 23 kg, and are about 65 cm in diameter. [5]

Figure 1: Three spheres in laboratory. Source: Centro de Referencia Nacional de Formación Profesional de Cartagena/SEFCARM

On November 7, 2015, a large object was found by a farmer in Monte Bajo, about 3.5 km from Pozorrubio de Santiago (Cuenca). Fig. 2 is one of several photographs that depict what appears to be a pipe or duct elbow, with an irregular break on one end, and a flange on the other. The news media reported mass 20 kg and size 3 m [6], but scaling from the cigarette pack in a different photo reveals a pipe diameter of 40 cm. The largest dimension appears to be less than 1 m.
The metal strip found in Alicante (Fig. 3) reportedly had been deformed by heating and was 4 m long and 0.2 m wide. [7] No other physical data was available.

The fireball and debris evidence proved essential to identifying the prime re-entry suspect.

3. PRIME SUSPECT IS 2008-010B

None of the objects reported by USSTRATCOM to have decayed on or near November 3 were in orbits that could have matched the time of the fireball sightings and the locations of the debris. They were also too small to account for the size and mass of the debris. It quickly became clear that the debris and fireball sightings would be key to solving the case.

3.1 Debris locations reveal orbital inclination

Debris footprints commonly are hundreds of kilometres long, but only about 30 km wide. Their narrowness is a useful property, that enables the trajectory of objects that have re-entered to be deduced from the locations of their debris on the ground.

Fig. 4 shows the approximate locations where debris was discovered, and the implied re-entry ground tracks.

The red line passes within a few kilometres of four of the five pieces of debris. Its orientation is consistent with re-entry from an orbit inclined approximately 64 deg, travelling from northwest to southeast. The metal strip was found about 70 km from this line, which probably is too far for it to have been carried there by the upper atmosphere wind.

The blue line connects a different subset of four pieces of debris, that includes the metal strip. Its orientation is consistent with re-entry from an orbit inclined approximately 44 deg, travelling from west-southwest to east-northeast. The large metal object found near Pozorrubio de Santia-go was about 200 km from this line, which is too far for it to have been carried there by the upper atmosphere wind.

Since the fireball was observed to be travelling substantially southward - "southeast-east," according to Ruiz Gomez in Almería, the red line seemed the more likely of the two. Therefore, the object that re-entered, probably...
was in approximately a 64 deg inclination, that would have been coplanar with the debris locations on 2015 Nov 03 at about 06:00 UTC, heading southeast. That is a very well constrained search orbit.

3.2 Search for decaying objects in matching orbits

The most likely possible explanations for the lack of any warning of the re-entry by USSTRATCOM, or acknowledgment after the fact, are as follows:

1. The object had been lost, perhaps never catalogued.

2. Orbital and re-entry data had been withheld, because the object was a military payload or related rocket body.

A thorough check for large objects recently lost by USSTRATCOM, revealed no likely candidates for the re-entry in question. That left only the military satellite hypothesis. The approximately 64 deg inclination implied by the debris locations and fireball sightings, suggested an object in a Molniya orbit, which is highly elliptical, typically inclined between 62 and 64 deg. Independent sources were consulted to check this possibility.

The author is a member of a small, informal group of amateur astronomers, who specialize in finding, tracking and identifying satellites in unpublished orbits. They share their observations and analyses of several hundred such objects via the SeeSat-L mailing list. On October 15, Scott Tilley observed a satellite that he could not immediately identify. Mike McCants identified it as a Centaur upper stage, which had the international designation 2008-010B, and the USSTRATCOM catalogue number 32707. It had last been knowingly observed by Kevin Fetter, on March 3 [8], in a 237 X 38111 km, 63.3 deg orbit [9]. McCants fit an approximate orbit to Tilley’s new observations, which revealed that it had lost more than half of its altitude since it was last observed, and was decaying rapidly. [10]

This Centaur had flown on Atlas-V number AV-006, on March 13, 2008, from Vandenberg AFB, carrying the NROL-28 payload for the National Reconnaissance Office. The Centaur had been discarded in a Molniya orbit. Its rapidly decaying, 63 deg inclination orbit, matched the general description of the suspect sought in the investigation of the re-entry over Spain. The hobbyists did not observe 2008-010B after October 15. To learn its fate, the investigation turned to another independent source of orbital data.

Russia’s International Space Observation Network (ISON) conducts scientific research into high altitude orbital debris. Its global network of telescopes has detected thousands of small debris fragments that are potentially hazardous to spacecraft. Cameras that can see faint debris, inevitably detect satellites and rocket bodies. ISON’s data analysis partner, JSC Vimpel, distributes orbital data on 1,700 newly detected objects, via its web-based portal.

The majority of those orbits are not found in USSTRATCOM’s public database. The data had not been correlated with known objects; however, the author and his colleagues had previously identified a number of U.S. military objects of interest to them. One of them was a large object that ISON discovered in August 2013, and assigned the identifier 68101. The author identified it as 2008-010B in October 2014, by propagating its current orbital elements back to a time shortly after launch. This was accomplished using McCants’ int2 program, which includes the luni-solar perturbations that strongly affect highly elliptical orbits. The results were compared against the elements of 2008-010B’s payload, which had been tracked by the group. Their orbital planes were within 2.5 deg. Argument of perigee agreed to within 1 deg. The eccentricity agreed to within 0.15 percent; mean motion within 0.6 percent. These small differences are believed to have been due mostly to the evasive maneuver performed by 2008-010B immediately after payload separation. There was also close agreement with the partial orbital elements of 2008-010B registered by the U.S. with the United Nations. Inclination agreed to within 0.1 deg, orbital period to within 0.03 percent, and eccentricity to within 1.5 X 10⁻⁶ percent. ISON observed 2008-010B frequently during 2015, and its data confirmed that by October it had been rapidly approaching decay.

At the start of 2015, 2008-010B was in a 63.4 deg orbit, with perigee of 276 km and apogee of 38211 km. Due to the high apogee, which extended one tenth the distance to the moon, the orbit was strongly perturbed by lunar, and to a lesser degree, solar gravity. As a result of these luni-solar perturbations, the eccentricity slowly oscillated, causing the apogee and perigee to rise and fall. Eventually, the perturbations forced the perigee into the dense layers of the upper atmosphere, which greatly increased the rate of decay.

The onset of rapid decay in early June, coincided with the descent of the perigee below 150 km. The rate of decay was fairly constant from June through September, during which the apogee was reduced by about 15,000 km. The perigee had remained fairly constant during this period. In late September, luni-solar perturbations forced it to descend further into the upper atmosphere, greatly increasing drag, which completed the destruction of the orbit in five weeks. As this is written, the latest known ISON observation was about November 1.
On November 14, the author alerted his colleagues via SeeSat-L to the results of a quick analysis that showed a possible correlation between the re-entry of 2008-010B and the recent events in Spain.

Before proceeding with a detailed decay analysis, research was undertaken to determine whether any of the recovered debris matched known components of the Centaur in question.

3.3 Recovered spheres consistent with those of Atlas-V Centaur stage

The Centaur stage of Atlas-V has undergone design changes since its first launch in 2002. The original version, called the Common Centaur, was used on Atlas IIIB, as well as on Atlas-V. Jonathan McDowell's satellite catalogue lists the Atlas V in question as AV-006, which means that it was the sixth one built; therefore, it probably was the Common Centaur version.

For short-coast missions (25 min.), the helium supply system employed three 66.0 cm helium storage spheres (Fig. 5), which consisted of a graphite overwrapped 301 CRES (Corrosion Resistant Steel) metallic liner. For longer coast duration missions, an additional helium bottle could be installed. [11]

Figure 5: The first Common Centaur (AVC-001) in final assembly in the clean room in Denver. Source: ULA.

A fourth helium tank could be added for missions that required the Centaur to make manoeuvres later than about two hours after launch. Jonathan McDowell expressed confidence that this Centaur made only two burns; therefore, was the 3-tank version. The author's pre-launch analysis estimated that the second Centaur burn was expected about 43 min. after launch, well within the known capability of the standard 3-tank configuration. [12]

The discovery in Spain of COPV spheres identical in number, size and construction to those of 2008-010B, strongly supported the circumstantial case that it was their source. The final test of this hypothesis was to verify its temporal and spatial correlation with the fireball sightings and the locations where the suspected debris was found.

4. ORBITAL DECAY ANALYSIS OF 2008-010B

4.1 Satevo decay propagation analysis

An object decaying over the region where the fireball was seen and the spheres fell, on Nov 3 at 06 UTC, from a 63 deg orbit, southeast-bound, would have had an approximate theoretical RAAN (right-ascension of ascending node) of 334 deg.

For 2008-010B to correlate with the re-entry, its orbit must have been expected to decay near Nov 3 at 06 UTC, and its RAAN at the time of decay, must have been close to that of the above theoretical orbit.

Cees Bassa de-osculated the final three ISON orbital element sets to produce mean elements compliant with SGP4 (Simplified General Perturbations), shown in Tab. 2 in the standard units of TLEs (2-line orbital element sets).

<table>
<thead>
<tr>
<th>Date</th>
<th>2015 Oct 19</th>
<th>2015 Oct 26</th>
<th>2015 Nov 02</th>
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<tbody>
<tr>
<td>Epoch</td>
<td>15292.947094</td>
<td>15299.967639</td>
<td>15306.963703</td>
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<td>ndot/2</td>
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The elements were propagated to decay using Alan Pickup's Satevo program. It is based on the published research of Dr. Desmond King-Hele, who was among the leading investigators into the mathematics and physics of Earth satellite orbits during the first three decades of the space age. Satevo estimates the date and time of decay of a TLE, and generates propagated TLEs for each revolution up to the final ascending node prior to decay.

The propagated date of decay ranged between Nov 2 and Nov 4 UTC, close to the actual date of Nov 3 UTC. The absolute error ranged between approximately 6 and 18 percent of the time remaining to decay, which was within the typical re-entry prediction uncertainty of 20 percent. [13]
The RAAN at decay was estimated by adjusting the rate of decay to cause the time of decay to match the reported time of the fireball. In each case, the resulting RAAN was 334.7 deg, close to the theoretical value of 334 deg. The difference can be explained at least in part, by the imprecision with which the time of the fireball sightings and locations of the debris are known.

4.2 GMAT propagation

The re-entry trajectory has been estimated using GMAT R2014a (General Mission Analysis Tool), developed by a team of NASA, private industry, public, and private contributors.

The analysis was performed using GMAT’s Dormand-Prince 78 numerical integrator, with a 90 degree, 90 order gravity field, MSISE90 atmosphere model, and space weather data entered manually. Orbital elements in TLE format were converted for GMAT propagation using TLE Analyzer 2.12.

The rate of decay is determined by the co-efficient of drag (Cd) and the area to mass ratio (A/m). The former was taken to be 2.2. A/m was estimated from the known physical properties of the Common Centaur, which was more than 12 m long overall, including the engine bell. Its main body was 3.05 m in diameter and about 9 m long. The combustion chamber and engine bell were significantly narrower. Its inert mass was 2,086 kg. The estimated average A/m is about 0.012 m$^2$/kg.

Of the three ISON orbital element sets available, the one from Oct 19 (Tab. 2) has so far proven best to work with, probably because it had been extrapolated only one day beyond the latest observation to that point. The Oct 26 elements were based on 6 day old observations; therefore, they probably had some error due to the inevitable difference between the actual rate of decay and that of the elements. The Nov 2 elements were extrapolated one day beyond the latest observation, but since the object was close to decay, it is probable that there was considerable error due to the difference between actual and propagated rate of decay.

The results of propagating the Oct 19 elements over 14 days proved extremely sensitive to the accuracy of the initial orbit, and the atmospheric model. For example, due to the ultra-low perigee height, the rate of decay was highly sensitive to small errors in the eccentricity, which are unavoidable. The approach taken was to make small adjustments in the eccentricity, by trial and error, that enabled propagation to decay close to the observed time of the fireball, using a reasonable value of A/m.

The analysis began with $C_d = 2.2$ and $A/m = 0.012 m^2/kg$, which caused GMAT to propagate the orbit to decay far too early. Using an unrealistically low A/m yielded decay on Nov 3, but about one rev too early.

Of the many combinations of A/m and eccentricity tried, the best result was obtained with A/m about 0.006288 m$^2$/kg, and an SGP4 mean eccentricity of 0.05450405, that raised the perigee about 2 km over that of the reference orbit. GMAT propagated the orbit to decay over Spain within about 5 min. of the fireball sightings. The RAAN of a TLE computed from the GMAT state vector at 100 km altitude was 0.4 deg east of the theoretical orbit. The trajectory passes the region of the fireball sightings and debris about 5 min. early and somewhat to the east.

The high altitude wind on the morning of the re-entry was predominantly from the SW; therefore, the debris probably fell on the east side of the ground track. Delaying the time of passage 340 s, and taking into account Earth’s rotation, was sufficient to place the trajectory just west of the debris zone at about 06:01:45 UTC. News media reports put the time of the fireball sighting at 06:00 UTC. The best available estimate of the latest possible time of the fireball, is that of the Ruiz Gomez photograph taken at 06:03:40 +/-5 s UTC, which was a failed attempt to image it. He concluded that it had faded by the time he steadied the camera sufficiently to attempt the photo. He believes that he had spotted the fireball by 06:03 UTC. (Section 2.1.2). The 1.25 min. difference between the trajectory analysis and Ruiz Gomez is excellent agreement, considering the uncertainties affecting both.

4.3 2008-010B correlates with debris locations

The estimated 2008-010B re-entry trajectory would have passed close to the locations where the suspected debris fell, and within visual range of all three places where fireball sightings were reported, shortly after 06:01 UTC (7:01 AM CET), moving from NW to SE, depicted by the line in Fig. 6. The alternating red and white segments span 5 seconds of flight.

![Figure 6: Approximate re-entry track of 2008-010B relative debris locations.](image-url)
The estimated ground track is about 12 km SW of the large object found in Cuenca, and between 4 km and 7 km SW of the three spheres that fell in Murcia. It passed 80 km SW of the 4 m long metal strip found in Alicante (Fig. 3), which seems to be near the empirical limit of cross-track dispersion of re-entry debris. About 97 percent of the recovered debris of space shuttle Columbia was found within 5 NM (9 km) of its re-entry ground track. This consisted primarily of the lowest A/m objects. The remaining 3 percent was dispersed up to about 80 km from the ground track. [14] A study into the risk posed by re-entry debris to aircraft, assumed that the width of the airspace potentially including re-entry debris is 35 km on either side of the ground track. [15] These facts call into question the relationship between the metal strip and the re-entry of 2008-010B. Expert analysis based on the object’s ballistic and aerodynamic properties, and local wind velocity would help resolve the question. Determining whether the object was a unique component of 2008-010B would be decisive. The ground track is remarkably similar to the hand-drawn theoretical one, depicted by the red line in Fig. 4, that informed the investigation that lead to the identification of 2008-010B as the prime suspect.

4.4 2008-010B correlates with fireball sighting

From Almería, Ruiz Gomez briefly observed what he later realized must have been the re-entry fireball. He used the author’s kml file of the trajectory to help reconstruct from memory the events of his sighting.

Seeing the trajectory in Google Earth, immediately reminded him of the beginning of his sighting, and confirmed for him that this was the event he had seen.

He spotted the fireball at a very low elevation, west of north, just above the Sierra de Gádor mountains. Its color was dark orange, easily distinguished against the lighter sky. The color slowly lightened as it rose and moved toward the east. He noted at least two breakup events, before it faded in the bright morning twilight. He originally reported the sighting duration as 30 s, but it may have been as long as 45 s. [16]

5. CONCLUSIONS

Virtually all identifications of suspected sightings of re-entry fireballs and debris recoveries are circumstantial. Authoritative records of known re-entries are consulted to identify potential suspects. Their final orbital elements before re-entry reveal whether they happened to be passing within range of the sightings or close to the location of any debris at the relevant time, and whether they might have descended low enough to have been burning and breaking up. Even with accurate orbital data, it is seldom possible to precisely estimate the time and place of the final descent. Confidence in the circumstantial case depends on the quantity and quality of the sighting and debris reports, and the strength of correlation with the trajectory.

Bright twilight reduced the Spanish fireball of November 3, 2015 to a fraction of its normal brilliance. Had it occurred half an hour earlier, there would have been hundreds of sightings and numerous cell phone videos on YouTube. Fortunately, the known sightings agreed closely on what appears to be the correct approximate time of the event, and the substantially southbound trajectory.

The locations of the recovered debris provided by far the strongest evidence of the orbital inclination.

The time, place, inclination and direction of travel of the re-entry fireball defined a very well constrained search orbit, that enabled easy detection of the 2008-010B Centaur as the prime suspect, among the respective orbital data of the hobbyists and ISON.

The three spheres found near Calasparra matched the number, size and construction of the helium pressurant spheres carried by the Centaur stage.

Additional information is sought, that could further test the circumstantial case, including:

- authoritative physical data on each piece of suspected debris
- the precise location of discovery of each piece of suspected debris
- additional fireball sighting reports

Section 3.3 reported that the Centaur's helium spheres had a metal liner made of 301 CRES. Metallurgical tests to confirm this would further test the 2008-010B hypothesis. If the large object found near Pozorrubio de Santiago is confirmed to have come from 2008-010B, then it will help to better define the actual debris footprint, and may help experts to verify existing re-entry debris survival analyses of the Common Centaur.

5.1 What's next for the debris?

If history repeats, then despite the air of secrecy, the U.S. will eventually repatriate its debris.

On 2010 Feb 19, near 03:32 UTC, pieces of the second stage of the Delta II rocket that launched the USAF’s STSS Demo 1 and 2 satellites (2009-052C / 35939), landed in Mongolia. This object was from a military mission, so its orbit was secret, but Russell Eberst discovered it on
2009 Nov 23 UTC, a couple of months after launch. Hobbyists successfully tracked it to within hours of re-entry, resulting in the sole public history of precise orbital information on this object.

USSTRATCOM had not issued any decay predictions, but it took less than a week for the source of the recovered debris to be reported by the Mongol News. How this came to be known in Mongolia is unknown.

In August 2011, the USAF sent a 15 person crew to Mongolia to retrieve its debris, and openly published an article about the operation [17]. The precise source of the debris was not stated, but a photo gallery includes a photo that clearly identifies the actual launch and payload [18]. Yet, to this day USSTRATCOM has not acknowledged that this object has decayed from orbit.

6. ACKNOWLEDGMENTS

Vicente-Juan Ballester Olmos was among the first to inform me of this case, and he has spared no effort in pursuing and analyzing the evidence. Among his many contributions are the co-ordinates of the reported places where debris was found, most of which are not known to Google Earth.

Cees Bassa de-osculated ISON's orbital elements to produce SGP4-compliant 2-line elements sets.

José Luis Ruiz Gomez calibrated his camera's clock to accurately determine the time it was taken.

The International Space Observation Network (ISON), via its partner JSC Vimpel, provided the orbital data on 2008-010B, that was essential to solving the case.

Marco Langbroek brought to my attention the fireball sighting of Ruiz Gomez, located upper altitude wind data from Murcia, and provided helpful advice.

Jonathan McDowell's satellite catalogue and launch history table were indispensable.

Jon Mikel assisted in the effort to contact authoritative sources of information on the debris.

Allen and Zaida Thomson provided the English translation of the relevant portions of reference [1] and Ruiz Gomez's discussion of his reconstruction of his sighting of the fireball, summarized in Section 4.4.

7. REFERENCES

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10. Private correspondence between McCants, Tilley and author, October 18, 2015.
18. STSS Demo launch photo: http://www.march.afrc.af.mil/shared/media/photos/110830-F-EQ386-001.JPG
ABSTRACT

Norway has a long tradition as a space nation, in no small measure due to its northern position on the globe. Kristian Birkeland’s famous Terrella experiment in 1896 in which he created synthetic northern lights can be seen as the start of modern space activities. The Sun Earth connection – studying the Sun and the effects on the Earth system is one of the central scientific topics in Norway. In modern time the focus has indeed shifted more to the use of space for the benefit of our society. The Norwegian use of space is born out of nature’s challenges. A harsh climate, vulnerable nature and areas rich in resources must be managed in the High North. Our land and sea areas equal half the size of the EU. Being less than 5 million people, we have to explore the most efficient ways of managing our resources.

1. HISTORIC PERSPECTIVES

The early aurora and solar research led to the establishment of the rocket range on the island of Andøya in North Norway, where the first Norwegian research rocket was launched in 1962. Researchers from numerous countries now utilize this rocket range in their studies of the northern lights and the Earth’s atmosphere and the facility is NASA’s most important launch facility for sounding rockets outside USA. More than 1000 rockets have been launched since 1962, the biggest being NASA’s 15 meter long Black Brant XII, with an apogee of up to 1500 km.

Much of the science focus was on the Sun-Earth connection – the heritage from Birkeland. Thus a strong solar physics community also grew and Norwegian scientists were early involved in all major space based observatories starting with Skylab.

2. SOLAR RESEARCH

Norwegian scientists participated in the solar telescope HRTS (High Resolution Telescope and Spectrograph) that flew on the space shuttle Challenger in 1985. More recently they played a central role in the successful SOHO mission - a large satellite based solar observatory including 12 different telescopes and instruments launched in 1995. This was a collaboration between the European Space Agency and NASA in which Norwegian industry provided equipment and services to the tune of 80 million Norwegian kroner. For six years, a Norwegian (the author) served as deputy project leader of this mission. Also, Norway is currently involved in the Japanese solar satellite Hinode.

Figure 1. The data from HINODE is downloaded to Svalbard and Troll (T. Abrahamsen).

Data from the satellite are downloaded at the Svalbard archipelago and a European data centre at the University of Oslo is processing the raw material making it accessible for the entire European science community. In addition Norwegian scientist are involved in NASA’s Solar Dynamics Observatory (SDO) launched in 2010. SDO is a super-telescope taking images with four times higher resolution than HD-TV quality every 10 seconds, transmitting 1500 Gb of data every single day. The NASA solar mission IRIS (Interface Region Imaging Spectrograph) was launched in June 2013 with a significant Norwegian contribution in modelling of the solar atmosphere as well as providing downlink of data via the Svalbard Satellite Station.

These activities has been part of a long term plan since early 80’s and today Norway has one of the largest and strongest solar research groups in the world.
3. AURORA RESEARCH

The Norwegian scientist Kristian Birkeland, 1867-1917 was the first to explain the real cause – that particles from the Sun were sparking the Northern lights. To prove his theory—which is still valid today—he built his own world in a glass box, electrified his model earth with its own magnetic field and showed how particles from the sun could ignite auroras. The particles were captured by the earth’s magnetic field and channeled down towards the polar regions. Birkeland, his Terella-experiment, and many facts about the Northern Lights are pictured on the Norwegian 200 kr bill.

But despite the importance of this work in retrospect, many of Birkeland’s ideas were not confirmed until the Space Age. Since then, we have solved many of the aurora’s secrets.

Figure 2. Kjell Henriksen Observatory at Svalbard was opened in 2008 (KHO/UNIS)

Today we study the northern lights from both ground and space. A large number of all-sky cameras and instruments study the phenomenon from many northern countries. These surveys include incoherent scatter radars, such as the large EISCAT antennas on Svalbard, a Norwegian cluster of islands nearly as far north as Greenland’s northernmost shore. Also on Svalbard sits the new Kjell Henriksen Observatory, opened in 2008 and the largest aurora observatory of its kind, with 30 dome-topped instrument rooms. Here, scientists around the world can remotely operate their instruments from their home institution. What makes Svalbard special is that during daytime it is located right under the northern polar cusp. Here solar wind particles can enter directly into the atmosphere without being routed via the magnetic tail as is the case for particle precipitation on the night side.

Sounding rockets are also used to study the aurora. Launched from Fairbanks in Alaska, Svalbard, and Andoya (off mainland Norway) they spear the aurora and can actually measure its physical properties. And from even higher up, satellites provide a global view of the auroral oval, the ring of light circling each geomagnetic pole.

4. SPACE WEATHER ACTIVITIES

The response of the space environment particularly around the Earth to the constantly changing Sun is known as ‘space weather’. Most of the time space weather is of little concern in our everyday lives. However, when the space environment is disturbed by the variable outputs of the Sun, technologies that we depend on can be affected.

The increasing deployment of radiation-, current-, and field-sensitive technological systems over the last few decades and the increasing presence of complex systems in space, combine to make society more vulnerable to solar-terrestrial disturbances. This has been demonstrated by the large number of problems associated with the severe magnetic storms the last two decades.

Our society depends on satellites for weather information, communications, navigation, exploration, search and rescue, research, and defense systems. Thus, the impact of satellite system failures is more far-reaching than ever before, and the trend will almost certainly continue at an increasing rate. Furthermore safe operation of the International Space Station depends on timely warnings of eruptions on the Sun.

Space weather will affect radio communication in the high north and degrade navigation systems. Systems such as LORAN are adversely affected when solar activity disrupts their radio wavelengths. It also introduces position errors and decreases the accuracy and reliability of the Global Positioning System (GPS). This can cause problems for operators depending on high accuracy positioning such as dynamical positioning in the off shore industry. One example is to keep a supply vessel steady close to a oil platform with an accuracy of 10-15 cm.

Thus, the Norwegian Mapping Authorities (NMA) is monitoring the ionosphere using geodetic GPS reference stations to allow for correction for solar induced errors in the GPS signal. Norway will be especially interested in the rapid ionospheric changes affecting navigation accuracy over the large ocean areas in the Norwegian Sea and the Barents Sea. In fact Norway has responsibility for issuing navigation accuracy warnings to seafarers in these areas.

Another example is variations in the Earth’s magnetic field during geomagnetic storms. Tromso Geophysical
Observatory (TGO), is a small unit under the Faculty of Science and Technology at UiT – the Arctic University of Norway. They operate a network of 15 magnetometers in mainland Norway and Norwegian areas in the Arctic. TGO has for many years supported the oil industry with real-time magnetometer data during directional drilling operations on the Norwegian continental shelf. The drill-operators are using the Earth's magnetic field as one way of navigating while drilling. When the magnetic field is fluctuating large errors in the drill-directions can be very costly – and the operators are receiving real-time date from TGO to correct or stop the drilling during space weather disturbances.

For Norway a better understanding and operational monitoring of the Sun and Space Weather is important for many reasons. Power grid companies, dynamic positioning of oil drilling ships/platforms, directional drilling, radio communication, and helicopter operations in the polar night have especially strong needs for space weather information.

In light of the above and the increasing awareness of space weather in non-scientific areas as well as the increasing commercial activity in the auroral zone/Barents Sea, the Norwegian Center for Space Weather (NOSWE) was established as a unit under TGO during summer of 2014.

The main purpose of NOSWE is to act as a tool to enhancing Norwegian abilities to participate in the ESA SSA program, to be a national source for information and knowledge about space weather hazards and to provide means towards mitigation of these. An important aim of NOSWE is to establish contact with national directorates, industries and other activities that are vulnerable to or dependent on space weather, ranging from search and rescue and offshore drilling operations to the tourist industry and the amateur radio community.

5. ACCESS TO SATELLITE DATA

Norway has since the early 1980 been active in development of satellite based services for Marine situational awareness including oil spill, - ship and ice detection. The services are primarily based on data from polar orbiting radar satellites. This near real time operational services is used world-wide among others by the European Maritime Safety Agency. The services are being developed through various national initiatives and offered commercially by Kongsberg Satellite Services (KSAT). KSAT also owns and operates the world's largest station for satellites in polar orbits (KSAT SvalSat) located at Svalbard Norway. Combined with the other KSAT ground stations daily contacts are made to about 100 satellites using more than 70 antennas. Important Norwegian antenna installations are also located in Tromsø and at the Troll Station (TrollSat) in Antarctica. All the major space agencies are using Norwegian ground stations, including ESA, NASA and JAXA science missions and ensures easy access to high quality science data for Norwegian scientists.
AIS is a ship information system used by most European coastal states to monitor the whereabouts of ships over 300 gross tons. Combining these two methods it is possible for KSAT to identify a possible source of the oil spill discovered on the satellite picture. The information systems are able to detect oil spills and ships independently of clouds and light conditions.

In 2007 KSAT was awarded a contract by the European Maritime Safety Agency (EMSA) to provide a satellite based system for oil spill monitoring in all European sea-waters.

6. SHIP DETECTION FROM SPACE

In July 2010 Norway’s first satellite for ship traffic monitoring was launched. AISSat-1 has been a big success, and a copy AISSat-2 is being launched in 2013. A Norwegian built AIS receiver has also been placed on the ISS and is being used for anti-piracy operations in the Indian Ocean. Combined with the oil spill detection from radar satellites, the space based AIS system is a unique system to detect and identify illegal release of oil or illegal fishing and even support monitoring of pirates.

A version of the AIS-receiver was also installed on the International Space Station in 2010 – called The Norwegian Automatic Identification System (NORAIS-1). On a good day, approximately 400,000 ship position reports were received by NORAIS-1 from more than 26,000 different ships around the world. In 2015 NORAIS-1 was replaces with an upgraded and more sensitive NORAIS-2. The improvements were obvious after just a few months with an increase in number of ships tracked daily from roughly 26 000 to 33 000. A more detailed maritime picture enables better organized rescue operations, combat piracy and an ability to uncover illegal activities such as smuggling, oil dumping and illegal fishing.

Norway is now building a small satellite called NORSAT-1 to be launched in 2016. The payload will consist of a new generation Solar Total Irradiance monitor delivered by PMOC/WRC in Switzerland and will provide important data for the Sun-climate connection. In addition a Mini-Langmuir probe from the University of Oslo will provide space weather measurements while a new AIS receiver will be tested out.

7. EARTH OBSERVATION - COPERNICUS

A new era has begun for Earth Observation with the new Earth Observation Programme in Europe, Copernicus. This is an operational programme, which provides a new dimension to monitoring and management of the Arctic, and it will in the years to come give us a better and deeper understanding about the processes taking place in this vulnerable region.

The Copernicus programme contains a new observation fleet of satellites, called the Sentinels. There are six types of satellites, Sentinel-1 to Sentinel-6, each with different measurement properties. These satellites will cover the operational needs of the Copernicus programme. The programme will have a constellation of two identical satellites of each type in orbit at the same time to fulfil revisit and coverage requirements.

Norway’s participation in this program will not only provide new opportunities for users of the data, but also for business and industry. Norway has also been assigned primary responsibility for marine monitoring and forecasts in the Arctic. The Norwegian Meteorological Institute, in cooperation with the Nansen Environmental and Remote Sensing Center and the Institute of Marine Research, has been given responsibility for providing information about ocean and sea ice conditions, including plankton blooms, in the High North and the Arctic.
Full membership in Copernicus gives Norwegian public agencies and research institutes the possibility to tailor their use of Copernicus data, and it is guaranteed that the satellites will record over areas of interest to Norway.

Norway is Europe’s biggest user of satellite data in relation to its population size. Such data are used to monitor marine traffic, fishery resources and activity in maritime border areas, to detect oil spills from ships or offshore installations, and for mapping sea ice and icebergs in the waters around Svalbard.

8. SATELLITE NAVIGATION

The EU channels its satellite navigation investments into the EGNOS and Galileo programs, whose missions are to develop, operate and expand systems of the same names. EGNOS (European Geostationary Navigation Overlay Service) has been in operation since 2009. It verifies and corrects GPS signals (and eventually will do so for Galileo signals) so the signals are more reliable and precise. Galileo is to be an independent global satellite navigation system comparable to the American GPS, Russian GLONASS and future Chinese Beidou systems. Unlike the others, Galileo will be a purely civilian system.

When fully developed, Galileo will be a fully operational, global satellite navigation system consisting of 30 satellites and 20 or so ground stations.

One of the most important goals of Norwegian participation in the EU satellite navigation programs EGNOS and Galileo have been to make sure the programs are able to perform satisfactorily in the High North. Norway’s participation in Galileo’s early phase has helped ensure that the system will perform better in the High North than had originally been planned. The satellite ground operations at Jan Mayen Island and Svalbard are representative of Norway’s continuing involvement in the Arctic, to improve satellite navigation.

Norway is a large consumer of satellite data, and the new navigation system will therefore be important to Norwegian users in a wide range of sectors – primarily communication, transport and fisheries, but many other critical functions in society also need accurate time and positioning services.

The Galileo satellites are also to detect distress signals and transmit the information via ground stations to the nearest rescue coordination center. Ground stations equipped to receive such signals from Galileo have been built on Svalbard, on Cyprus, in France and in Spain.

9. SEARCH AND RESCUE

Norwegian mariners are sailing all over the world, and have for many years benefited from the use of emergency beacons, which can relay distress signals through satellites. Already in the 1980s Tromsø Satellite Station became an important station in the COSPAS/SARSAT satellite-based search & rescue system, and Norwegian industry has for many years had a leading role in the production of distress beacons for ships.

Later this year the search & rescue part of the European Galileo satellite navigation system will start its Initial Operations Phase. Also for the Galileo system Norwegian ground stations will play an important part. Improved radio communication is also important for all search and rescue operations in the High North.

Sometimes, all traffic in the northern part of the Arctic takes place in Norwegian waters, which means that Norway is responsible for search and rescue operations for a large number of vessels in demanding waters. Thus, it is quite natural that Norway should take the initiative and invest in a satellite-based communication system that will be useful in rescue operations, but could also...
support research, tourism, commercial and environmental activities in the Arctic.

10. COMMUNICATION IN THE ARCTIC

Interest in the Arctic areas is growing, and the High North is considered to be Norway’s most important foreign policy arena. The northern areas are rich in natural resources, they are active tourist destinations, important in a research and climate perspective, and may contain oil and gas fields for the future.

Existing satellite communication systems offer little or no coverage in the arctic. Geostationary satellites are the most widely used communication system at sea. However, since these satellites orbit above the equator their coverage doesn't extend as far north as the Arctic. The theoretical limit for coverage is 81.3 degrees north, but the signals can become unstable at latitudes as low as 70 degrees north.

Figure 9. Satellite communication is limited in the Arctic (Norwegian Space Centre)

About 700 vessels visit the European sector north of 72 degrees north each year. However, broadband access for ships in the High North is not sufficient to cover the increase in demand. The present broadband satellite performance gradually deteriorates from 72 degrees north, and from 75 degrees north, coverage is highly unstable and dependent on good weather and little wave activity. If you are on a ship north of Svalbard, you will not get a signal at all.

Ships are becoming as dependent on broadband as any other form of transport worldwide. Broadband access for ships will support on-board operations such as video transmission, Internet access, remotely controlled operations, telemedicine and access to real-time ice and weather maps.

That is why the Norwegian Space Centre has studied the benefits of launching a publicly funded communication satellite to cover this growth area. A satellite in highly elliptical orbit could provide broadband coverage in the High North for 16 hours a day with a capacity of 500 Mbit/s.

Public funding of this would help to pave the way for a second satellite, which could become commercially profitable for the operator, according to the analysis company Menon Business Analytics. Two satellites in highly elliptical orbits would provide 1 Gbit/s broadband with 24 hour coverage.

Figure 10. Two communications satellites in highly elliptical orbits can provide full coverage in the Arctic (Norwegian Space Centre)

A broadband network that could transmit large amounts of data over many channels would benefit the oil and gas industries, search-and-rescue operations and shipping traffic communications, among other things.

II. THE NORWEGIAN SPACE CENTRE

The Norwegian Space Centre (NSC) is the national space agency in Norway, organized as a government agency under the Ministry of Trade and Fisheries.
Within the last ten years, satellite observations have become an essential part of numerous activities, including weather forecasting, sea monitoring, monitoring of forest fires and deforestation, thematic mapping, and polar studies.

Polar orbiting satellites, 800 – 1000 km above the Earth’s surface, are most valuable to Norway. The reason is that their orbits converge at the poles and therefore provide more coverage at our latitudes than they do closer to the equator.

An ambitious vision of the Norwegian Space Center is that Norway shall be the country that benefits most from space. We are not there yet, but we are definitely on our way.

12. AN ARCTIC SPACE NATION

Because Norway is located so far north we have the possibility to utilize space better than most other countries. Polar orbiting satellites are the ones collecting the most detailed information about the Earth. This means that the Norwegian territory will be observed much more frequent than most other countries. The geographic advantages of Norway’s northern latitude for space activities is important, both to meet national needs and to provide services for international clients.

This means that services from space will become increasingly important for all Norwegians, even if they are not aware of it yet. Not before GPS fails, the TV screen goes blank during the Super Bowl, or your bank machine loses contact with the satellite that synchronizes your code, or the weather satellite no longer spots the storm coming from the sea will we notice how vital a role space plays in our everyday lives.

Arctic can be seen as a new space arena. Space technology is perfect for use in the Arctic since satellites can cover vast areas with relatively small amount of infrastructure and without harming the environment.

In recent years, Norway has established itself as an active space nation that is also building up its own fleet of small satellites. We expect to have five public satellites orbiting under the Norwegian flag in a few years’ time. Their most important task will be to improve safety for shipping in the rough waters for which Norway is responsible.

Space infrastructure has practical implications on the ground. Norway’s small national satellites open up for cooperation with other, larger space nations. There is thus a foreign policy aspect to the use and utilization of space. But even if Norway were to have a considerable number of national satellites in the future, we are a small country that will always need to cooperate with others in space. For Norway, membership in the European Space Agency (ESA) is the most important tool in this respect. For further reading we refer to [1], [2], and our web pages at www.romsenter.no

13. REFERENCES


EDUCATIONAL VIDEOS ON THE THREAT OF COSMIC HAZARDS FOR SCHOOLS, MUSEUMS AND THE GENERAL PUBLIC

Firooz Allahdadi

Air Force Space Safety Directorate (retired)

Recently, the Handbook on Cosmic Hazards and Planetary Defense was published by Springer Press. This was a two-year project sponsored by the International Association for the Advancement of Space Safety (IAASS), the International Space University (ISU), the Clarke Foundation and the International Institute of Space Commerce (IISC). This 1,600 page, two-volume reference Handbook is quite comprehensive in its scope. The Handbook is a valuable resource for technical and scientific researchers; however, because of its esoteric nature, only a small number of people around the world will read and utilize this Handbook.

The Clarke Foundation and the International Institute of Space Commerce have undertaken an ambitious effort to bring this information to a wider audience. The goal of this undertaking is to introduce the public to the broad range of cosmic hazards in readily accessible language. Among the hazards described are asteroid and comet impacts, extreme solar flares and coronal mass ejections and disruptive man-made, earth-orbiting space debris.

Three videos of varying lengths are now available on YouTube. These videos feature prominent experts in space sciences including Astronauts Rusty Schwieckart and Ed Lu of the B612 Foundation, Donald Kessler, known for the “Kessler Syndrome phenomenon,” Isabelle Rongier, President of the IAASS, James Green of NASA, Bill Ailor of the Aerospace Corporation and Joseph Pelton, co-editor of the Handbook and former Dean of the International Space University. It is my hope that these readily available educational videos will receive the broadest dissemination.

These professionally produced educational videos are:

1. *If There Were a Day without Satellite* (3:58 minutes) https://www.youtube.com/watch?v=5sgM7YC8Zv4
   This video is to be featured in a new space gallery at the National Electronics Museum in the Washington, D.C./Baltimore, MD. Area.

2. *Cosmic Hazards* (short version, 5:50 minutes) https://www.youtube.com/watch?v=IJDGD73aD9s
   This video serves as short introduction to the Handbook of Cosmic Hazards.

   This video is designed to be shown on public access channels or on television shows and is available for free release by its producer Dr. Joseph N. Pelton and the Arthur C. Clarke Foundation. https://www.youtube.com/watch?v=RwRdyag2dxA

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Cosmic Hazards. Credits: Dr. Joseph N. Pelton and the Arthur C. Clarke Foundation.
The 8th IAASS International Space Safety Conference “Safety First, Safety for All”, will be held in Melbourne - Florida (USA) in the period 18-20 May 2016. The IAASS conference is the premiere international forum dedicated to the discussion of a wide variety of space safety topics.

The conference offers a unique opportunity to meet top U.S. and international experts in space safety and related engineering fields, from industry, academia and agencies. An occasion for exchanging views and establishing new professional bonds, towards the common goal of forging and a global space safety culture.

The online registration is open. You can access the online registration form at http://iaassconference2016.space-safety.org/registration/ or directly by clicking the red tab at the bottom of this page. Early Birds registration ends 14 March 2016.

TIMETABLE OF CONFERENCE EVENTS

<table>
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<tr>
<th>Date</th>
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<tr>
<td>30 December 2015</td>
<td>Deadline for abstracts submission</td>
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<tr>
<td>29 January 2016</td>
<td>Notification to authors</td>
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<tr>
<td>15 February 2016</td>
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<tr>
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At the occasion of the Conference Gala Dinner on May 19, 2016 the IAASS will assign three awards:

- Jerome Lederer Space Safety Pioneer Award
- Vladimir Syromyatnikov Safety-by-Design Award
- Joseph Loftus Space Sustainability Award

These prestigious awards are a means to honor and recognize safety professionals and systems designers and engineers who have made outstanding contributions towards space safety.
**Safety Design for Space Systems**

*Elsevier 2009*

Progress in space safety lies in the acceptance of safety design and engineering as an integral part of the design and implementation process for new space systems. Safety must be seen as the principle design driver of utmost importance from the outset of the design process, which is only achieved through a culture change that moves all stakeholders toward front-end loaded safety concepts. Superb quality information for engineers, programme managers, suppliers and aerospace technologists.

**Safety Design for Space Systems, Chinese Edition**

*Elsevier 2011*

Progress in space safety lies in the acceptance of safety design and engineering as an integral part of the design and implementation process for new space systems. Safety must be seen as the principle design driver of utmost importance from the outset of the design process, which is only achieved through a culture change that moves all stakeholders toward front-end loaded safety concepts. Superb quality information for engineers, programme managers, suppliers and aerospace technologists.

**Space Safety Regulations and Standards**

*Elsevier 2011*

Space Safety Regulations and Standards is the definitive book on regulatory initiatives involving space safety, new space safety standards, and safety related to new space technologies under development. More than 30 world experts come together in this book to share their detailed knowledge of regulatory and standard making processes in the area, combining otherwise disparate information into one essential reference and providing case studies to illustrate applications throughout space programs internationally.

**Safety Design for Space Operations**

*Elsevier 2013*

Safety Design for Space Operations provides the practical how-to guidance and knowledge base needed to facilitate safe and effective operations safety in line with current regulations. With information on space operations safety design currently disparate and difficult to find in one place, this unique reference brings together essential material on: safety design practices, advanced analysis methods, and implementation procedures.