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"The goal of a scientist is to uncover new ideas, concepts and tools, practical or theoretical, that extend our understanding of the world around us and enable us to do new things. One must believe in what one is doing and stay the course. Now of course, in science one can ultimately prove the correctness of one's work by appeal to experiment and established theory. But even with this buttressing of one's ideas, acceptance can be a long and difficult road."

Richard F.W. Bader (1931 – 2012)

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Mirce Science in brief

During the history of human race, needs for transportation, communication, navigation and any others have been satisfied by human created machines, like: trains, aircraft, cars, computers, telephones, radars, radios satellites and so forth. They are constructed by assembling a well-defined number of parts in a pre-determined way. As they are functioning in a linear chains of cause and effect, governed by the well understood mechanisms of natural phenomena, their design-in performance, measured through speed, acceleration, power, range, energy usage, capacity and similar, could be accurately predicted by making use of Newton's and Hamilton's equations of mechanical motion, Coulomb's law of solid friction, Hook's law of stress and strain, Maxwell's equations of electrodynamics, Boltzmann's equations of thermodynamics, to name a few. All of them are based on the physical processes at the scales that are characterised by: certainty, continuity, reversibility, separability and independence of time, location and humans.

However, experience teaches us that in-service performance of machines, measured by the work done during a stated period of in-service time, like: hours flown in a year, electricity produced per month and similar get discontinued by phenomena like fatigue, operator induced errors, corrosion, creep, foreign object damage, a faulty weld, bird strike, perished rubber, shark bites, carburettor icing, space radiation, to name just a few. These phenomena are resulting from energy exchanges between machines and their in-service reality, causing the loss of need satisfying function(s). Consequently, infusion of energy into machines through actions like: like: repairs, replacements, modifications, diagnostics, "cannibalisation", change of operational location/mode, and so forth, is needed for a machine to continue performing a measurable function (s).

Finally, the cumulative amount of "satisfied needs", measured by work done by a machine and work done on it, becomes known through post-service statistical analysis of data collected, usually presented by histograms and pie-charts. As the design-in and in-service performance of a machine are important for the users the accurate predictions of both must be done concurrently during their creation. While existing scientific equations and engineering methods existed for the prediction of in-service performance of a machine, in mid 1970s Dr Knezevic realised that there was nothing similar for the corresponding prediction of in-service performance. Thus, he systematically studied in-service behaviour of machines to:

- *Physically observe the motion of machines through in-service reality over time and to measure their in-service performance*
- *Mathematically define a framework for describing the motion of machine through in-service reality to enable quantitative prediction of in-service performance*
- *Scientifically understand mechanisms that cause the motion of a machine through in-service reality to subject them to the predictive mathematical framework.*

The outcomes of the research lead to the conclusions that the motion of machine through in-service reality is characterised by uncertainty, discontinuity, irreversibility, separability and dependence of time, location and humans. This lead to the establishment of the Mirce science, a new discipline that was defined by Dr Knezevic as,

"The theory for predicting the irreversible motion of machines through in-service reality, by subjecting mechanisms of causing actions to Mirce mechanics equations."

Content

Mirce Science: Impact of Bed Bugs Infestations on Functionability Performance of Commercial Aircraft

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Abstract

Flights cancellations caused by bed bug infestations of commercial aircraft have significant impact of their functionability performance. Thus, this paper addresses bed bugs infestation as an observed phenomenon from the Mirce Science point of view, which means that it is considered as a mechanism that generates negative functionability events, which compels the affected aircraft out of scheduled service. The paper briefly examines the bed bug species to understand their physiological characteristics and life cycle phases, as a natural functionability action that could generate undesirable negative consequences to the travelling public and financial losses to the airlines due to the withdrawal from service of the affected aircraft. Several methods for eradicating bed bugs from infected commercial aircraft surfaces are briefly presented in the paper, as the potential positive functionability action, performed to return them to scheduled working processes.

Key words: Mirce Science, functionability actions, bed bugs, commercial aviation, eradications methods

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1. Introduction

The philosophy of Mirce Science is based on the premise that the purpose of existence of any working process is delivery of functionability[1] through time. It is quantified by the measures of the motion, like miles travelled, units produced, energy supplied and similar. However, experience teaches us that at any instant of operational process there is a probability of work being interrupted by occurrences of negative functionability events, resulting from failures of consisting components, natural causes, human actions or their interactions. As every action generates reaction, for the working process to resume functionability it is necessary for humans to undertake appropriate positive functionability actions, like: completion of required maintenance tasks, change the mode or location of operation and so forth. Thus, a working process could be considered as the time evolution through functionability states, compelled by imposing natural of human actions. [1]

The New York Times [2] reported that in March 2024 a passenger on Turkish Airlines flight from Johannesburg to Istanbul noticed a small bug crawling on her seat when she got up to use the restroom. She photographed the bug on her seat and called over the flight attendant, who disposed of the bug. However, her complaints to Turkish Airlines were met with denials, despite her photographic evidence! The same source stated that on 5th October 2024, passengers who were flying from Istanbul to San Francisco had seen bed bugs falling from the ceiling of the aircraft onto the seats and the passengers. Multiple passengers were asking to move seats after discovering the bugs, and one of them was even relocated to the flight attendant jump seat. Only three weeks later, a science teacher found bed bugs on the 10-hour flight from Washington Dulles to Istanbul. She documented 13 bite marks across her body after the flight.

By no means are appearances of bed bugs related to Turkish Airline alone. For example, during the 2018 flight between New York and Mumbai, one business class passenger even tweeted out pictures of bedbugs onboard, leading to the temporary grounding of two Air India planes[2]. Furthermore, in 2017 customers on a British Airways flight reported seeing bed bugs creep out of their seatback screens like a scene from a horror movie[3].

The first recorded observation of insect infestation in air transport was reported by Kisluik[4], who inspected the German airship Graf Zeppelin that landed in New Jersey in October 1928. He found 10 species of insect pests onboard, including one “bug”.

Commercial aircraft are cleaned and inspected regularly, and airlines take measures to prevent and address bed bug infestations. The process typically takes two to five days and can cost airlines between 75,000 and 125,000, USD, when accounting for lost revenue and treatment expenses. Sometimes, the aircraft pulled out of scheduled service requires a spare aircraft that is suitable for long-distance routes, which causes additional pressure to airlines, particularly when passengers report infestations during the flight.

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[1] Functionability is the ability of a working process to deliver measurable function(s) with expected performance and required attributes. [1]

[2] https://www.bbc.co.uk/news/world-asia-india-4496423

[3] https://www.independent.co.uk/travel/news-and-advice/british-airways-passengers-bedbug-bites-covered-apology-vancouver-london-flight-heather-szilagyi-a8010536.html#:~:text=British%20Airways%20has%20apologised%20after,seat%20in%20front%20of%20her.

[4] https://www.cabidigitallibrary.org/doi/full/10.5555/19290501301

The main objective of this paper is to expose the commercial aircraft design community to the observed phenomena of the infestation of commercial aircraft by bed bugs, as one of many in-service negative functionability actions that shape their functionability trajectory and work done. Therefore, this paper briefly examines the bed bugs species to understand their characteristics and impacts on the travelling public as mechanisms that could generate undesirable negative consequences to the in-service life of commercial aviation. The method for protecting the travelling public from bed bugs was examined in the paper together with their economic and scheduled impacts of airlines affected.

2. The Brief Overview of Mirce Science

In accordance to Mirce Science philosophy, [1] from a functionability point of view, working processes could be in one of the following two states:

- Positive Functionability State (PFS) – functionability is being delivered
- Negative Functionability State (NFS), functionability is not being delivered, for any reason whatsoever.

The motion of working processes through functionability states is a physical manifestation of the impacts of compelling natural and human actions, which in Mirce Science are classified as following:

- Positive Functionability Action (PFA), a generic name for any natural process or human activity that compels a given functionability process type to move to a PFS
- Negative Functionability Action (NFA), a generic name for any natural process or human activity that compels a functionability process to move to a NFS.

The motion of working process through the functionability states is manifested through the occurrences of functionability events which, according to Mirce Science philosophy, are classified as following:

- Positive Functionability Event (PFE), a generic name for any physically observable occurrence that signifies transition from a NFS to a PFS,
- Negative Functionability Event (NFE), a generic name for any physically observable occurrence that signifies the transition from a PFS to a NFS.

Consequently, the functionability performance through time is directly determined by the duration of times that working processes spent in functionability states. The pattern generated by the motion of functionability process through functionability states, in respect to the passage of time, forms the functionability trajectory, which is uniquely described by Mirce Functionability Equation [1]

The remaining part of the paper focuses on the bed bugs as one of many negative functionability actions generated by the natural or human actions that directly impact the motion of functionability of working processes of a commercial aircraft.

3. Cimex Lectularius (Common bed bug)

Bed bugs are small wingless insects that feed solely upon the blood of warm-blooded animals. They are sometimes mistaken for ticks or cockroaches. Bed bugs are sometimes called "red coats," "chinches," or "mahogany flats."

Human bed bugs were virtually eradicated from the developed world in the middle of the 20th century. However, as of the first decade of the 21st century, bed bugs are back and spreading. Bed bug infestations have been reported from all over the US and Europe. Together with bat bugs, swallow bugs, and poultry bugs, they belong to the family Cimicidae in the suborder Heteroptera or true bugs (order Hemiptera). They comprise less than 100 described species worldwide, but their notorious habits as temporary ectoparasites of birds and mammals, including humans, and the unusual mode of reproduction known as traumatic insemination[5] have made this small group of true bugs infamous.

3.1 Morphology and relationships to other bugs

Bed bugs are small to medium-sized, 4-10 mm, ovate, squashed-looking from top to bottom and of brownish coloration. Their wings are represented by short, non-functional wing pads and they cannot fly. They have sucking mouth parts, and metathoracic and abdominal scent glands that produce a characteristic smell. The mouthparts comprise the labium[6] and pairs of maxillary and mandibular stylets that form the salivary and food canals. Bed bugs have several specialised features in common with some closely related groups, such as loss of simple eyes known as ocelli[7].

Bed bugs are closely related to the blood-feeding, bat bugs and predatory minute pirate bugs (family Anthocoridae). The Cimicidae are divided into 22 genera, with 12 being exclusively associated with bats, 9 with birds, and only the genus Cimex containing a mixture of bird and mammal ectoparasites. Only three species may be associated with humans, Cimex lectularius in temperate and subtropical regions worldwide, Leptocimex boueti in certain areas of West Africa and Cimex hemipterus in the tropics.

3.2 Natural history

Bed bugs belong to one of only three lineages within Heteroptera that are obligate blood feeders. Similar to other obligate blood-feeding insects, cimicids have microbial symbionts in specialised organs that are presumably important for supplementing the blood diet. The human bed bug subsequently spread with its new host around the world as people migrated with their belongings.

Due to the inability to fly, bed bugs are reduced to passive transportation by their host to spread. Thus, they may “hitchhike” in suitcases, used furniture, and clothing. Even more, an adult bed bug can survive for more than a year without a blood meal. Upon arriving at a new location, the prodigious fecundity of an undetected bug, 200-500 eggs per adult female, ensures a rapid increase in their numbers.

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[5] Traumatic insemination, also known as hypodermic insemination, is the mating practice in some species of invertebrates in which the male pierces the female's abdomen with his aedeagus and injects his sperm through the wound into her abdominal cavity (hemocoel).
[6] externally visible part of the “beak”
[7] https://cisr.ucr.edu/invasive-species/bed-bugs

Bed bugs are nocturnally active with peak feeding activity occurring after midnight. They feed on blood about once every 1-2 weeks, while the host is inactive or sleeping.
Feeding requires about 5-10 minutes to complete and generally occurs on areas of the body that are exposed while sleeping, such as the face, neck, arms, and hands. Bites may itch and a rash may develop around the bite. Bed bugs locate a host by orienting toward cues including heat, CO_2, and host odours.

While not feeding, bed bugs are generally concealed in cracks and crevices in their environment, including bed frames, head boards and mattresses. Their affinity to move away from light (negative phototaxis) and they ability to respond positively to tight spaces (positive thigmotaxis) makes them very difficult to locate during daytime hours when they are hiding.

At resting places, bed bugs usually form aggregations of adults and immature stages that are maintained by aggregation pheromones and mechanical cues. When bugs are disturbed, substances emitted from scent glands function as alarm pheromones that drive dispersal and aggregations break up as bed bugs flee danger.

Apart from obligate blood feeding and host interactions, their unusual reproductive behaviour has stimulated considerable research on bed bugs. Reproductive biology of Cimicidae is characterised by traumatic insemination, where sperm is not injected into the genital tract, but rather introduced into the female bed bug after the male pierces the female's body wall with his reproductive organ. Traumatic insemination systems show tremendous species specific differences ranging from absent or simple to very complex and the study of reproductive structures used in this type of mating may provide insights into the evolution of this unusual mating strategy in the Cimicidae. Immature bed bugs (nymphs) release a chemical signal or pheromone to communicate their non-reproductive status to males, thereby protecting them from male mating attempts which might otherwise be very damaging.

While some viruses have been shown to persist within bed bugs for several weeks, their role in the transmission of human pathogens appears to be negligible. However, bed bugs are serious nuisance pests. Infestation rates of human dwellings with bed bugs may reach 100% in some temperate regions and as many 5,000 bugs may infest a single bed!

They are mainly nocturnal and reach peak activity before dawn. They rest and lay their eggs in crevices and behind wallpaper. When seen on a wall, they resemble mobile brown lentils. Although flightless, bed-bugs can run extremely fast, particularly in warm weather.

4. Bed Bugs, Humans and Infestation Management

The long and disturbing shared history of humans and bed bugs is reflected in language and legend. All Indo-European, African, and Oriental languages have names for bed bugs and these unpopular companions are mentioned in ancient Greek literature as well as the Talmud and the New Testament. Human sensitivity to the bite of a bed bug ranges from insensitive to severe immune reactions, and depends in part on the level of past exposure. Many people will develop hypersensitivity to bed bug bites following repeated feeding by bed bugs. [3, 4]

An infestation of bed bugs is usually identified by finding the bugs or their dark coloured fecal stains in the seams of mattresses and box springs, behind headboards and peeling wallpaper, or in other cracks and crevasses near a sleeping area. The use of a strong flashlight will help in their detection because their strong aversion to light results in considerable movement. Heavy infestations are sometimes associated with a “sweet” odour. Trained dogs provide a very efficient means to detect bed bug infestations, especially when abundance is low, because the dogs can quickly determine by smell whether bed bugs are present in a room. Bed bug traps using CO_2 and heat to attract the bugs may also be useful to identify infestations when bed bug abundance is low.

Management of bed bugs within an infested premise is typically achieved using insecticides, though methods such as targeted vacuuming and heat treatment may also be utilised. The recently discovered pheromone which protects immature bed bugs from mating attempts by males has generated some interest as a possible control mechanism. Application of this pheromone to bed bug aggregation sites within an infested home may reduce male mating even with mature females and this could cause populations to collapse.

5. Bed Bugs Eradication Systems

Substantial analysis of the bed bugs eradication methods and experimental trails related to their effectiveness are presented in [5]. A very brief summary of this extensive research is presented here. Thus:

- Methyl bromide fumigation was the benchmark that all treatment systems were measured against. The closed nature of aircraft favour a fumigation based approach and the non-corrosive, non-flammable properties made this system well accepted. According to Juson (2014) this is only treatment strategy that achieved 100% eradication in a single treatment. However, as methyl bromide depletes the ozone layer, many countries in the world have phased out its production and consumption.

- Chemical treatment replaced the band methyl bromide approach to aircraft fumigation. However, the complex nature of aircraft seating products and the restrictions on dismantling seats does not allow the technician access to properly apply a pesticide. Chemicals require multiple applications over an extended period of time and present health concerns and allergy risks to passengers and crew. [8] None of these other treatments will effectively sanitise the aircraft for viruses, allergens, and bacteria.

- Freezing can be also used to treat bed bugs, with a significant drawbacks or risks. It is contact-based system, which means, if the equipment does not touch the bugs they will survive. Hence, according to Romero et al., (2007) it is unlikely that this method will achieve the levels of control needed for the travelling passengers of commercial aircraft.

- Heat treatment has many supporters in the aviation industry, as it is an environmental manipulation technique. [7] The levels of control achieved are the closest to methyl bromide fumigation. If carried out correctly it has no deleterious effects on the aircraft. However, close attention needs to be paid to temperature monitoring to ensure safe treatment and the desired level of control. In one recirculating system treatment overheating of the environment resulted in warping of plastic components in seating products and cabin side walls. The need to use either fluid transfer or electric filament heaters within the aircraft raised further objections to recirculating heat treatments due to the risk of fire or flood. As only ducted hot air enter the aircraft and the more controllable nature of a forced air systems this has become the favoured eradication system. The increased air turbulence in a forced air treatment capsule results in greater energy transfer to the treatment substrate and consequently a greater reduction in population.

- Scent detection dogs could be used for the accurate and time efficient method for bed bugs detection and control. [6]. However, the complex nature of aircraft seating and regulatory constraints limit drastically reduced the practicality of this method.

6. Thermal Eradication of Bed Bugs in Commercial Aircraft

Thermal eradication is a single-treatment disinsection method for commercial aircraft that eradicates bed bug infestation and sanitises the aircraft at the same time. It has been developed and implemented by Dr Michael R. Linford[8], who designed the equipment for a complete bed bug heat treatment, without sacrificing safety, quality and capability.

Thermal aircraft insect eradication utilises no toxic chemicals, and is both discreet and FAA compliant. Heated air molecules transfer their energy into every surface of the aircraft and cargo hold, allowing all the furnishings and contents of the aircraft to reach a minimum of 60°C. As the equipment used maintains this temperature, bed bugs are successfully exterminated, at all stages of their life cycle. This, extremely effective positive functionability action, regarding eradication of bed bugs in commercial aviation, is completed in hours, when all resources are available.

Treating aircraft for bed bugs by heat, according to the GreenTech Heat solutions technology[9], has the following benefits:

- There is no need to remove soft goods such as cushions, carpet, and bedding for separate treatment
- At the end of the treatment there is no residues of dangerous chemicals
- Extended treatment times at lower temperatures will not damage electronics or avionics
- Return to service immediately following cool down after treatment
- Hypoallergenic
- Bed bugs will be killed at all life cycle states (from eggs through adults)
- Destroys all microbes, viruses, bacteria, allergens, moulds
- Everything can be treated: cabin linings, cockpit, galley, and cargo areas
- Exceeds FAA guidelines for thermal aircraft disinsection
- It will kill any other insects or spiders in your aircraft
- It will reduce or eliminate odours from food, smoking, animals, urine, and bacteria in the aircraft treated.

[8] GreenTech Heat, https://greentechheat.com/about-greentech-heat.php
[9] https://greentechheat.com/aircraft.php#:~:text=Thermal%20aircraft%20insect%20eradication%20utilizes,%2C%20its%20furnishings%2C%20and%20contents

7. Financial Considerations of Eradication of Bed Bugs in Commercial Aircraft

The cost of bed bug management on aircraft is quite variable depending on how the aircraft is employed. Private aircraft, commercial aircraft and military aircraft have very few financial restrictions with regards to the cost of bed bug control. This is because the cost of bed bug management in these aircraft is minimal when compared to the expense associated with even a short flight delay, or even worse flight cancelations. However, domestic medical aviation is often charitably funded and, as a result, very cost conscious. Air ambulance infestations are not common, but they are among the most time-consuming and costly to resolve. This is due to the complex interior structure of the aircraft, which is designed to house medical equipment.

The complex architecture of the aircraft interior limits both visual inspection and treatment ability. In many cases it is not possible to access deep intrusion on the airframe without dismantling the aircraft interior. The widespread use of light honeycomb structures in both aircraft seating and cabin construction allows bed bugs to hide in protected microclimates that are in close proximity to the hosts. These inaccessible surfaces enable infestations to go unnoticed for lone periods of time[10] and make treatment efforts very difficult and costly.

Further obstacles for aircraft disinfestations are the commercial aviation regulations that stipulate that any work carried out on board the aircraft, including pest control, must be overseen by a licensed aircraft engineer. Hence, engineers must be present during the strip-down and re-cover of passenger seating before and after chemical treatment. Engineers also must be present for the removal and reinstatement of heat-sensitive items, such as life vests and emergency exit slides, during thermal disinsection (heat treatment). Needleless to say that these legal requirements increase the cost of bed bug eradiation processes, on one hand, and put further pressure on the pest management crew to complete their treatment as quickly as possible.

In summary, in majority of cases, only the monetary component of a treatment's cost is considered. However, inconvenience, lost reputation, collateral toxicity, time out of service, and length of treatment should all be considered when calculating a total cost.

8. Conclusions

The main objective of this paper is to expose the commercial aircraft design community to the observed phenomena of the infestation of commercial aircraft by bed bugs, as one of many in-service negative functionability actions that shape their functionability trajectory and work done.

Bed bugs on commercial aircraft are a part of daily reality of their working processes and as such they are impacting the functionability performance. Most of the airlines have a reactive approach to bed bug management, relying on passenger complaints to initiate the treatment. As the bed bug issue is a global phenomenon the move from reactive bed bug control to proactive management is inevitable

The severity and spread of bed bug activity is obviously directly correlated with duration since the inoculating event. Once established within the aircraft cabin, infestations develop

[10] It is worth pointed out that bed bugs can survive more than 500 days between feedings!

very quickly due to the stability of the environment, extensive harbourage close to the host and the abundance of feeding opportunities. Those airlines that were engaged in a process of proactive detection averaged 80% fewer seats infested and 69% fewer insects in the heaviest seat, when compared with infestations detected by passengers. As preventing the inoculation is not possible, the early detection of infestations is vital particularly in view of reduced efficacy of eradication systems. In view of an aircrafts' likely exposure to bed bugs further research is needed to study passenger boarding behaviour with a view of reducing the rate of inoculation. Seating product design could also be vastly improved to reduce rates of establishment following inoculation and subsequent spread throughout the cabin environment.

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MIRCE Science: Orbital Debris Reentry Hazards

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Abstract

The aim of this paper is to present the approach to identify orbital debris reentry hazards through six historical orbital debris reentry events in chronological order. The orbital debris reentry disaster events were chosen by the type of their impact on the ground. In chronological order, these reentry events are: suborbital reentry of navigational satellite Transit 5BN-3 SNAP-9A (radioactive contamination) 21 April, 1964; reentry of non-operational spacecraft Cosmos 954 (radioactive contamination) 24 January, 1978; reentry of Skylab space station (debris impact) 11 July, 1979; reentry of Salyut 7 space station (debris impact) 7 February, 1991; SpaceX Crew Dragon trunk section reentry in Australia (debris impact) 9 July, 2022 and reentry of nickel-hydrogen batteries from the International Space Station (ISS) (debris impact) 8 March, 2024. Disaster happens when a hazard impacts vulnerable population or area and causes damage, causalities and disruption. This paper will present the hazards of orbital debris reentry and possible disasters that such an event can produce by examining the past events of interest through MIRCE Science philosophy approach.

Key words: orbital debris, hazards, disaster, reentry

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1. Introduction

Orbital debris is the term for any object in Earth orbit that no longer serves a useful function. These objects include non-operational spacecraft, derelict launch vehicle stages-rocket bodies, mission-related debris and fragmentation debris. Space debris encompasses both natural meteoroid and artificial (human-made) orbital debris. This paper will present the MIRCE Science approach in identifying causes of the six orbital debris reentry disasters that occurred from 1964 to 2024. Summary of each event will be shortly described inside the blue marked polygons. Each of the presented historical reentry events can be used as a lesson learned for the future engineering and management of orbital debris reentry scenarios that can potentially lead to disasters.

2. The Philosophy of MIRCE Science

MIRCE Science is a theory for determining the mechanics of the motion of working systems in time by subjecting causing mechanisms to mathematics.
The philosophy of MIRCE Science is based on the premise that the purpose of the existence of any functionability process is to do a work. The work is considered to be done when the expected measurable function(s) is performed through time. The functionability process is a sequence of actions compelled by natural and human actions performed to deliver expected performance during a given interval of time.
MIRCE Science focuses on the scientific understanding and mathematical description of the natural and human actions that govern behaviour of functionability processes. Each physical process that leads to failure has its own shape of probability function. The flow of the failure events follows the laws of probability, but probability itself propagates in accordance with the laws of physical causality. According to the MIRCE Science, system failures are events at which functionability process moves from positive to negative functionability state due to some of the following functionability actions, or combinations of them [1]:

- Built-in design errors (incorrect selection of materials, stresses shapes, etc).
- Production problems (human errors, material and process deficiencies).
- Irreversible changes in the condition of components with time due to wear, fatigue, creep, corrosion, and similar degradation processes due to impact of atomic oxygen, solar ultraviolet (UV) radiation, charged particle ionizing radiation, plasma, spacecraft charging and arcing, temperature extremes and thermal cycling.
- Imposition of external overstress mechanisms resulting from collisions, harsh landings, extreme weather conditions, solar storms, MMOD micrometeoroid and orbital debris impact, orbital debris collisions, direct-ascent anti-satellite (ASAT) missile tests, South Atlantic Anomaly impact radiation, etc.
- Human errors in execution of maintenance tasks.
- Human errors in execution of in-service support tasks.

The Concept of Functionability is defined as "an emergence property of a functionability process generated by the complex interactions between:

- given structure of a system
- given construction of a system

- given operational concepts and rules given environmental conditions

in respect to time". [1]

Thus, the ability of being functional through time, known as functionability, is an essential property of functionability processes.

In accordance to MIRCE Science philosophy a functionability process type could be in one of the following two working states, at any instant of time:
- Positive Functionability State (PFS), a generic name for a state in which a functionability process type is able to deliver a measurable function(s)
- Negative Functionability State (NFS), a generic name for a state in which a functionability process type is unable to deliver a measurable function(s), resulting from any reason whatsoever.

Being in one of these two functionability is a physical manifestation of the motion of a functionability process through functionability states. This motion is caused by compelling natural and human actions, which in MIRCE Science are classified as following:
- Positive Functionability Action (PFA), a generic name for any natural process or human activity that compels a given functionability process type to move to a PFS
- Negative Functionability Action (NFA), a generic name for any natural process or human activity that compels a functionability process to move to a NFS.

The motion of a functionability process type through the functionability states is manifested through the occurrences of functionability events which, according to MIRCE Science philosophy, are classified as following:
- Positive Functionability Event (PFE), a generic name for any physically observable occurrence during a functionability process that signifies transition from a NFS to a PFS,
- Negative Functionability Event (NFE), a generic name for any physically observable occurrence during a functionability process that signifies the transition from a PFS to a NFS.

Consequently, the performance of a functionability process is directly determined by its motion through functionability states in time. The pattern generated by the motion of functionability process through functionability states, in respect to the passage of time, forms the MIRCE Functionability trajectory. Research studies conducted at MIRCE Akademy by staff and students had shown that any serious studies of the mechanisms of functionability actions have to be based between the following two boundaries:
- the “bottom end” of the physical world, which is at the level of the atoms and molecules that exists in the region of 10^{-10} of a metre.
- the “top end” of the physical world, which is at the level of the solar system that reaches the physical scale around 10^{+10} of a metre.

This range is the minimum sufficient “physical scale” which enables scientific understandings of mechanisms of natural and human actions that govern the behaviour of given functionability processes and their functionability performances. [2]

3. Reentry Events

3.1 Transit 5BN-3 SNAP-9A (radioactive contamination) 21 April, 1964

On April 21, 1964, a Transit navigational satellite carrying a SNAP-9A (Systems for Nuclear
Auxiliary Power) generator was launched aboard a Thor Able Star rocket from Vandenberg Air Force Base in California. The generator contained about 1 kg of plutonium-238 (Pu-238), equal to 17 kilocuries (kCi) of radioactivity. Unfortunately, the rocket failed to reach orbit, and the satellite reentered Earth's atmosphere over the Indian Ocean near Madagascar.
The SNAP-9A, which was designed to generate electricity from Pu-238 heat, was not built to survive reentry. This was the third and final launch of the Transit 5BN satellite series. The two earlier missions had launched successfully on September 28 and December 5, 1963 [3]. Stratospheric measurements later confirmed that the generator disintegrated around 46 km altitude, spreading fine Pu-238 particles into the upper atmosphere. By 1970, only a small portion (under one kilocurie kCi) remained above 12 km altitude. Unlike nuclear weapons fallout, the Pu-238 from SNAP-9A had a distinct global distribution - around 75% of it settled in the Southern Hemisphere, compared to only 20% from weapons testing. In contrast, 85% of Pu-238 in the Southern Hemisphere and 34% in the Northern Hemisphere were attributed to the SNAP-9A release.
This single accident in April 1964 nearly tripled the global inventory of atmospheric Pu-238 by 1970 [4].

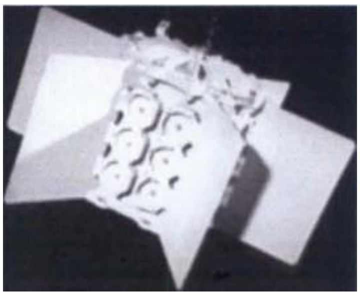

Figure 1. SNAP-9A Radioisotope Thermoelectric Generator (RTG). [3]

MIRCE Science event summary
1. MIRCE Science mechanism of negative functionability event: □ Rocket failure to deliver satellite into orbital flight. [Possible **Built-in design errors** and **Production problems**] 2. Disaster: Environmental pollution of air and soil by Pu-238 reentry ablation remnants over the whole Southern Hemisphere.

3.2 Reentry of non-operational spacecraft Cosmos 954 (radioactive contamination) 24 January, 1978

On 24 January, 1978, Cosmos 954, a Soviet nuclear-powered surveillance satellite, crashed in the Northwest Territories. Radioactive material (U-235) spread across a 124,000 km^2 area in north Canada, from Great Slave Lake to northern Alberta and Saskatchewan, as a result of the crash. The recovery operation named 'Operation Morning Light' was a coordinated event between the United States and Canada. The operation continued into October 1978 and resulted in the estimated recovery of about 0.1 % of Cosmos 954 power source. [5] Investigators found that some of the located fragments proved to be of lethal radioactivity. Canada and the USSR claimed different versions of the facts of the accident. The USSR blamed the fall of Cosmos 954 as a result of space collision. Academician L.I.Sedov explained that: “On 6 January, 1978, for reasons that as yet remain unclear, sudden depressurization of the satellite took place outside the visibility zone of our facilities for tracking space objects. Judging from the fact that the depressurization process was very rapid, it can be assumed that the satellite collided in flight with some other body of natural or artificial origin. As a result, the satellite on board systems went out of commission, it lost orientation, and began an uncontrollable descent.” Canada, in contrast, stated that the fall of the satellite was caused by faulty motor. The USSR admitted that Cosmos 954 had malfunctioned, and that it was not possible to lift the satellite into higher orbit because of failure of a rocket system, as had been planned in case of an emergency. [6]

Figure 2. The Cosmos 954 debris recovery area covered by Operation Morning Light. [7] (Image credit: Charlie Conway)

Figure 3. Operation Morning Light. Team members dressed in specially designed arctic clothing searching the area with hand-held radiation detectors. The majority of the Cosmos 954 debris fell as radioactive particles approximately the size of pepper grains, which were impossible to detect without specialized equipment. [7] (Image credit: US DOE)

MIRCE Science event summary
MIRCE Science mechanism of negative functionability event: • Sudden depressurization of the satellite. • Faulty motor. • Uncontrollable descent of satellite. [Possible **Imposition of external overstress mechanisms** resulting from MMOD micrometeoroid and orbital debris impact] Disaster: Radioactive contamination of 124,000 km^2 area in Canada Northwest Territories. Extreme Arctic climate prevented the normal decontamination procedures. Language barriers for many northern residents and uncertainties surrounding radiation detection and mistrust of government communication efforts fueled concerns about contamination and the effectiveness of debris recovery. Increased environmental impact on Indigenous communities and their well-being.

3.3 Reentry of Skylab space station (debris impact) 11 July, 1979

Before leaving the Skylab space station on 8 February 1974, the final astronaut crew boosted its orbit, hoping it would remain in space long enough to be visited again by a future Space Shuttle. However, increased solar activity caused the Earth's atmosphere to expand, which in turn increased atmospheric drag and made Skylab's orbit decay faster than expected.

In 1978, NASA ground controllers reactivated Skylab and adjusted its orientation to minimize drag and extend its time in orbit. But delays in Space Shuttle development meant it couldn't reach Skylab in time. As a result, Skylab reentered Earth's atmosphere on 11 July 1979, with debris falling across the Indian Ocean and parts of Western Australia.

When the Skylab 4 crew left, the station was orbiting between 432 km and 455 km. The day after their departure, NASA ran final systems checks, oriented Skylab into gravity gradient attitude (where the heavier part faced Earth), vented its internal atmosphere, and powered it down. Scientists initially predicted that Skylab would stay in orbit until March 1983, based on solar activity forecasts. However, the solar cycle turned out to be the second most intense in a century. The resulting atmospheric disturbances pulled Skylab out of its stable orientation, increasing drag even further.

On the day of reentry, ground controllers placed Skylab into a slow tumble at 149 km altitude, aiming for it to break up over the Indian Ocean. However, Skylab did not burn up in the atmosphere as fast as NASA predicted, and its debris landed 3,942 km farther east, affecting populated areas of Western Australia. [8]

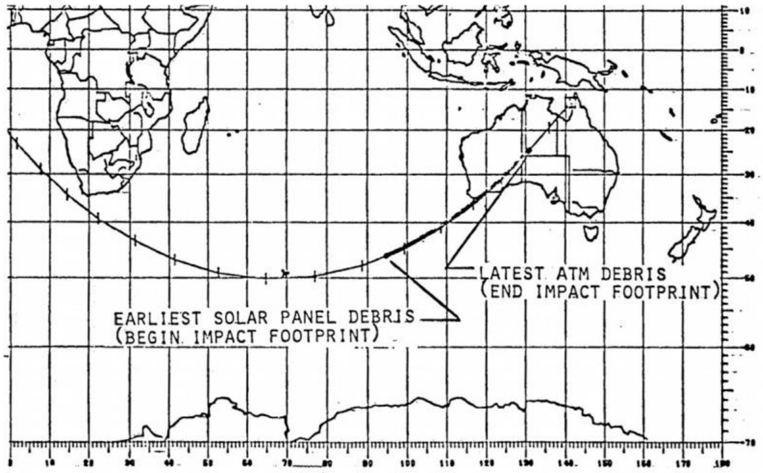

Figure 4. Ground track of Skylab final orbit and the debris footprint in the Indian Ocean and Australia. [8]

Figure 5. An overhead view of the Skylab photographed by final Skylab 4 Command and Service Modules (CSM) crew upon its departure. (Image credit: Crew of Skylab 4-NASA)

Figure 6. Skylab reentry path over Western Australia, showing locations of recovered debris. [8]

MIRCE Science event summary
MIRCE Science mechanism of negative functionability event: • The Earth atmosphere expanded because of higher solar activity, which increased. atmospheric drag on the Skylab and caused its orbit to decay faster than expected. • Delays in the space shuttle development leads to abandonment of Skylab orbit boost option. • Skylab broke apart at an altitude of 16 km lower than expected. [**Imposition of external overstress mechanisms** resulting from increased solar cycle and atmospheric drag which reduce Skylab altitude] Disaster: Skylab reentry sonic boom and debris scattered across the populated Western Australia from the coastal town of Esperance to the town of Balladonia.

3.4 Reentry of Salyut 7 space station (debris impact) 7 February, 1991

The Salyut 7–Cosmos 1686 complex made an uncontrolled reentry over Argentina on 7 February 1991. It weighed 40.13 tones, about half the mass of Skylab. While previous Salyut stations were safely deorbited over the Pacific Ocean, this one was different—mission control lost contact with Salyut 7 more than two years before reentry. The last crew to occupy the complex left in June 1986. A few months later, in August 1986, the engines on the Cosmos 1686 module raised its orbit by 135 km to 474.75 km, aiming for a reentry around 1994.

At one point, there were even plans to retrieve the station using the Buran space shuttle, but those plans were cancelled. The last communication with the station happened in December 1989. Like Skylab, increased solar activity in the late 1980s caused the station to lose altitude faster than expected.
Initially, the station settled into a gravity gradient attitude, with the heavier Cosmos 1686 pointing toward Earth. But as it entered denser layers of the atmosphere in January 1991, this orientation degraded. On 5 February, ground teams attempted to rotate the station to a nosefirst attitude to reduce drag and direct reentry over less populated areas, but due to low

fuel, they couldn't finish the maneuver. Atmospheric drag caused the vehicle to spin off course, and it eventually made an uncontrolled reentry on 7 February 1991, crashing over the town of Capitán Bermúdez in Argentina—missing its intended reentry zone over the uninhabited South Pacific Ocean.[8]

Cosmos 1686 was a modification of the cancelled TKS manned ferry that docked with the Salyut 7 space station. All landing systems were removed from the VA reentry capsule and replaced with military optical sensor experiments (infrared telescope and Ozon spectrometer). It burned up in the atmosphere and together with the Salyut 7 station over Argentina on February 7, 1991 04:00 GMT. It reentered with unused 3 m diameter recoverable capsule of 2- 3,000 kg mass, solid rocket motors, and cesium sensors. [9]

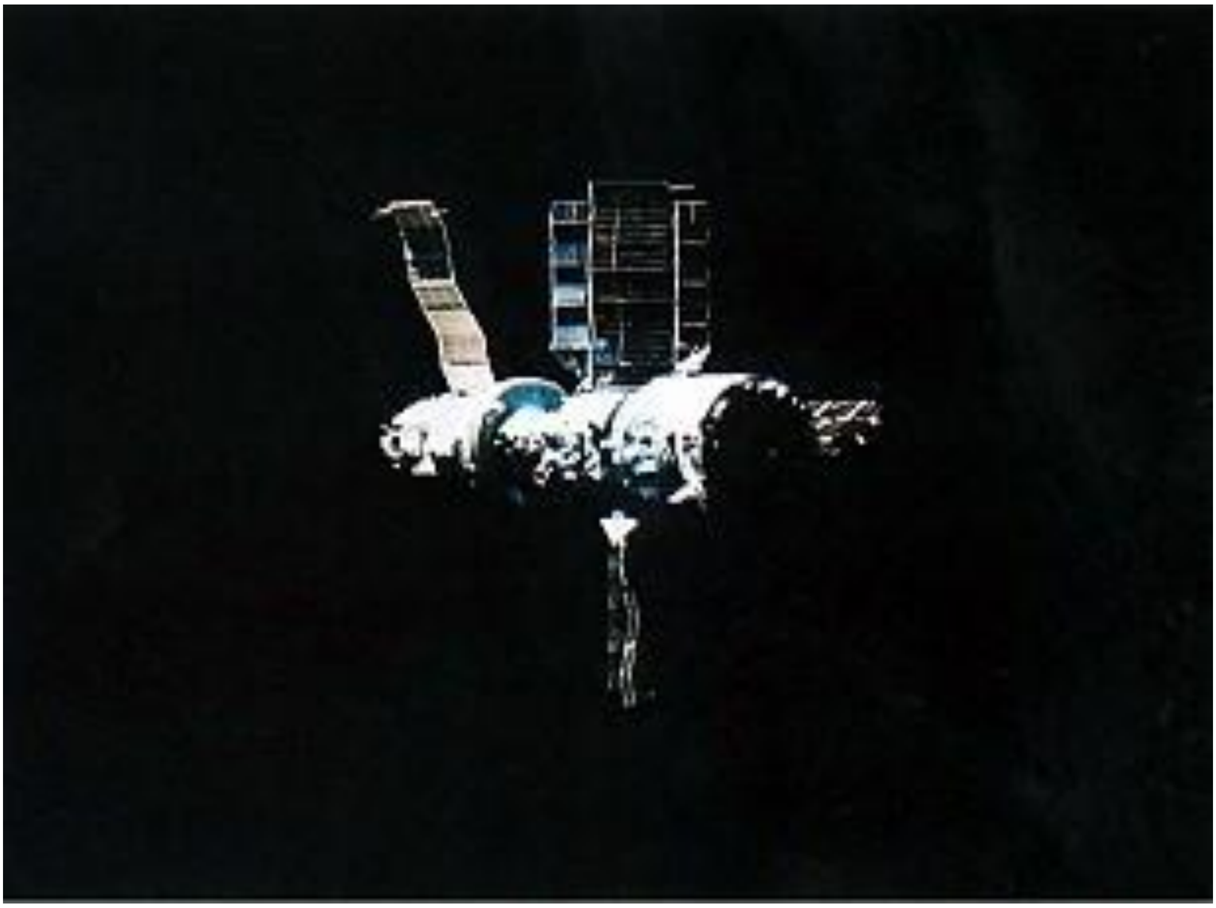

Figure 7. A view of the deactivated Soviet space station Salyut 7 and docked Cosmos 1686 (TKS-4) during the Soyuz T-15 crew departure. [10]

Figure 8. Piece of Salyut 7 recovered debris in Argentina. (Image credit: Carlos Zelayeta)

MIRCE Science event summary
MIRCE Science mechanism of negative functionability event: • The Earth atmosphere expanded because of higher solar activity, which increased atmospheric drag on the Skylab and caused its orbit to decay faster than expected in the late 1980s. • Cancellation of Buran space shuttle leads to abandonment of Salyut 7 retrieval option. • Fuel depletion did not allow completion of the maneuver to an orbit that overflew less populated areas. [**Imposition of external overstress mechanisms** resulting from increased solar cycle and atmospheric drag which reduce Salyut 7 altitude] Disaster: Salyut 7 debris scattered across the densely populated town of Capitán Bermúdez in Argentina.

3.5 SpaceX Crew Dragon trunk section reentry in Australia (debris impact) 9 July, 2022

Large pieces of debris from a SpaceX mission were discovered in a sheep paddock in southern
New South Wales, Australia, following a sonic boom heard across the Snowy Mountains on 9 July 2022. The boom was caused by the reentry of the SpaceX Crew Dragon trunk section, which had launched in November 2020. One of the debris fragments, estimated to be about 3 meters long, was found embedded deep in the ground. Another piece found in Numbla Vale, near the town of Jindabyne, had visible serial numbers linking it to the spacecraft. [11][12]

Figure 9. Survived orbital debris found in Moonbah, New South Wales Snowy Mountains, Australia. (Image credit: Nick Lodge) [11]

The debris was identified as part of the Crew Dragon trunk, an unpressurized service module that supports the spacecraft. The Crew Dragon itself consists of two primary components: the capsule, which carries astronauts and pressurized cargo, and the trunk, which houses solar arrays and radiators. The trunk also provides the structural interface between the capsule and Falcon 9 during launch. While in orbit, the trunk powers and cools the spacecraft, but it is jettisoned prior to reentry and typically burns up in the atmosphere; though in this case, some components survived reentry and reached the ground. [13]

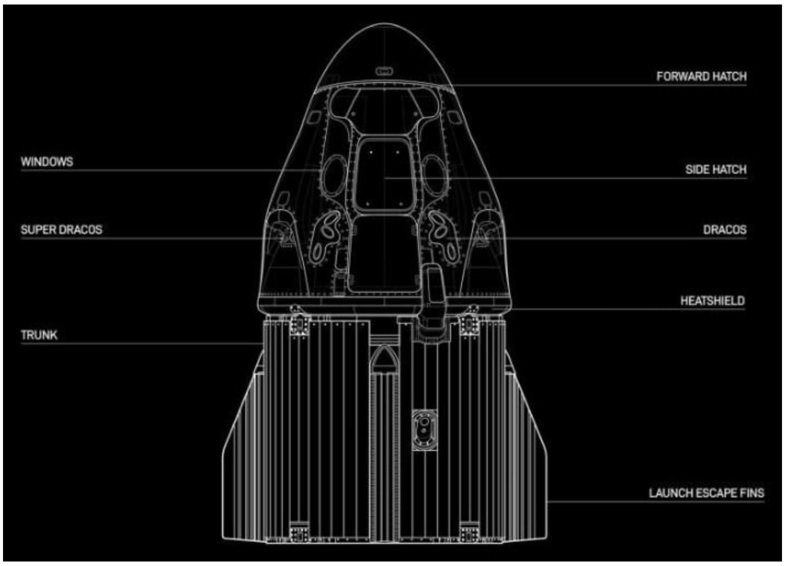

Figure 10. SpaceX Crew Dragon parts. [13]

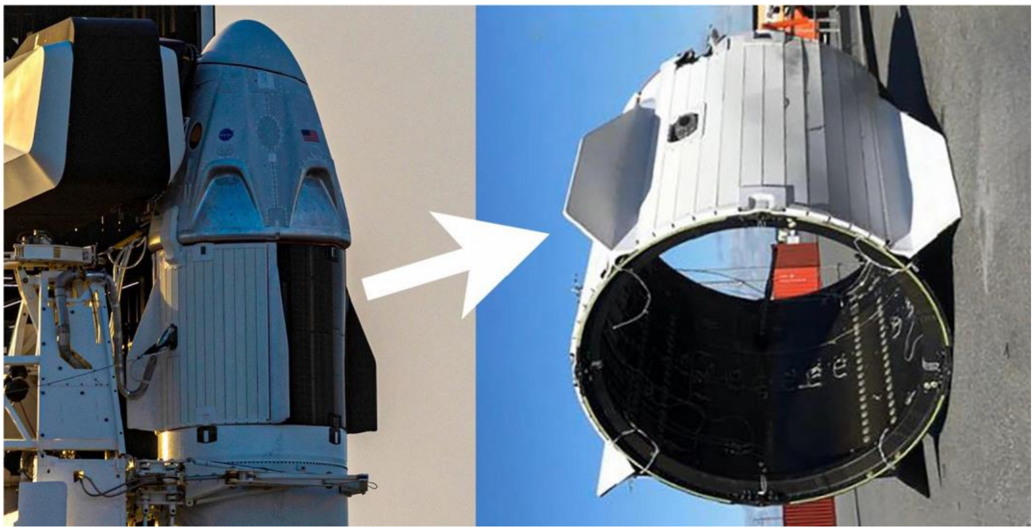

Figure 11. SpaceX Crew Dragon and its trunk section.
(Image credit: Richard Angle, SpaceX) [14]

MIRCE Science event summary
MIRCE Science mechanism of negative functionability event: - Jettison of Crew Dragon trunk shortly before reentry. [Possible **Built-in design errors** resulting from incorrect design and material selection of SpaceX Crew Dragon trunk section which leads to higher probability that some parts will not completely burn during the reentry process] Disaster: Sonic boom during the reentry of SpaceX Crew Dragon trunk section and survived debris impact on New South Wales, Snowy Mountains near the Jyndabine town.

3.6 Reentry of nickel-hydrogen batteries from the International Space Station (ISS) (debris impact) 8 March, 2024.

The International Space Station (ISS) electric power system (EPS) employs nickel-hydrogen (Ni-H_2) batteries as part of its power system to store electrical energy. The batteries are charged during insolation and discharged, providing station power, during eclipse. The batteries are designed to operate at a maximum 35 % depth of discharge during normal operation. 38 individual pressure vessel Ni-H_2 battery cells are series-connected and packaged in an orbital replacement unit (ORU), and two ORUs are series-connected, using a total of 76 cells, to form one battery. The ISS electrical power system had a total of 24 batteries (48 ORUs) on-orbit. The ISS is the first application for low-Earth-orbit cycling of this quantity of series-connected cells.

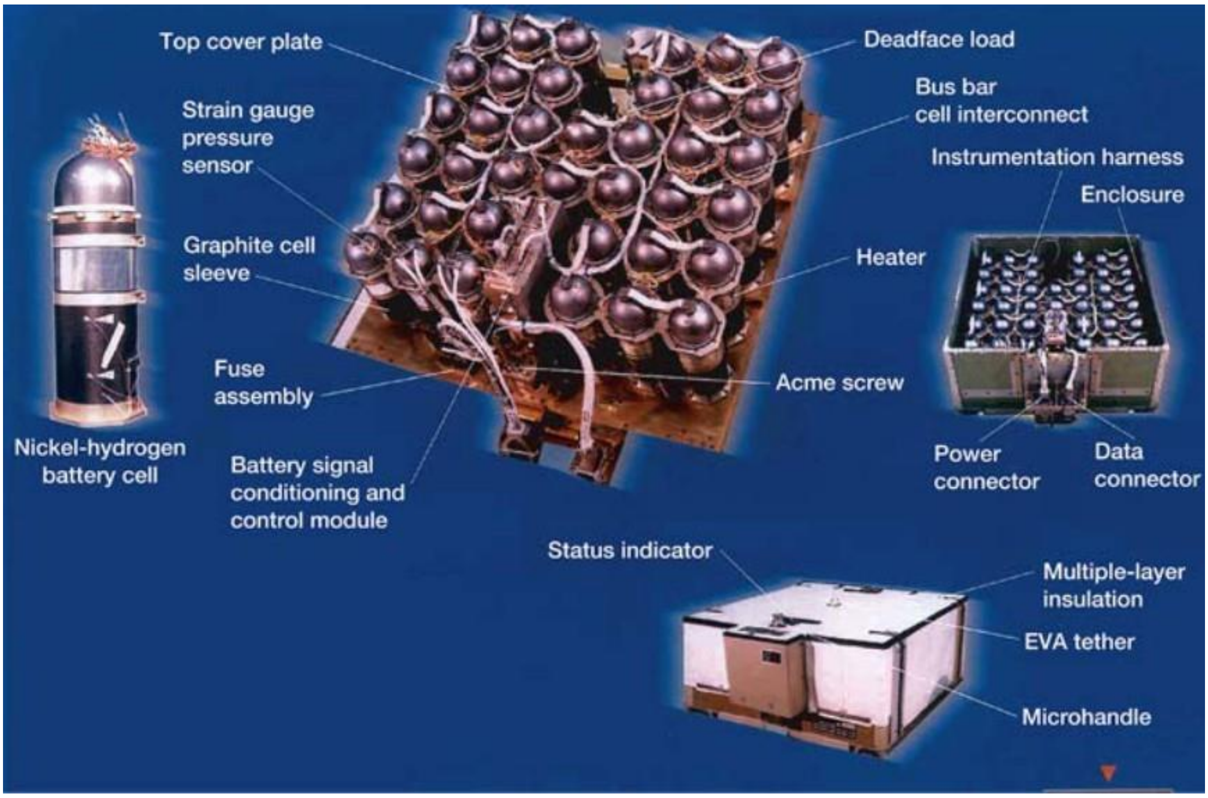

Figure 12. ISS battery sub assembly orbital replacement unit (ORU).

Figure 12. illustrate nickel-hydrogen battery cell, top cover plate, strain gauge pressure sensor, graphite cell sleeve, fuse assembly, battery signal conditioning and control module, acme screw, heater, bus bar cell interconnect, dead face load, instrumentation harness with power connector and data connector, and status indicator, multiple layer insulation, EVA tether, and micro-handle. [16]

In March 2021, NASA ground controllers used the International Space Station (ISS) robotic arm to release a cargo pallet containing old nickel-hydrogen batteries, after they had been replaced with new lithium-ion batteries during a power upgrade (Figure 14). The total mass of the released hardware was approximately 2,630.83 kg. It was expected to completely burn up during atmospheric reentry on 8 March, 2024.

However, part of the hardware survived reentry and struck a home in Naples, Florida. NASA retrieved the object and conducted an analysis, comparing its size and features with the released equipment and performing a materials assessment. They confirmed that the debris was a stanchion from the flight support equipment used to mount the batteries on the pallet. The object was made of Inconel, a metal alloy, and measured 10.16 cm tall by 4.06 cm in diameter, weighing 0.72 kg (Figure 13.).

Figure 13. Recovered stanchion from the NASA flight support equipment used to mount International Space Station (ISS) batteries on a cargo pallet. The stanchion survived reentry through Earth atmosphere on 8 March, 2024 and impacted a home in Naples, Florida. [15]

Figure 14. An external pallet packed with old nickel-hydrogen batteries is pictured shortly after mission controllers in Houston commanded the Canadarm2 robotic arm to release it into space on 11 March, 2021. [17]

MIRCE Science event summary

MIRCE Science mechanism of negative functionability event:

- Soyuz launch failure in 2018 which disrupted the sequence of battery spacewalks replacement.
- No new HTV cargo spacecrafts coming to the station to retrieve and dispose of the final cargo pallet, because of Japan withdrawal of the first HTV design, and development of a next generation cargo spacecraft known as the HTV-X. [18]
- Lack of possibility that battery pallets can be retrieved via Progress, Cygnus or SpaceX Dragon cargo spacecrafts.

[**Human errors in execution of maintenance tasks** resulting from Soyuz launch failure in 2018 which disrupted the sequence of battery spacewalks replacement sending one HTV cargo ship to Earth without battery pallet on it and **Built-in design errors** of battery pallets resulting in lack of possibility that battery pallets can be retrieved via other cargo spacecrafts]

Disaster: During the uncontrolled reentry one piece of nickel-hydrogen batteries external pallet survived reentry process and impacted a home in Naples, Florida. The object was made of the metal alloy “Inconel”, 0.72 kg, 10.16 cm in height and 4.06 cm in diameter.

4. Conclusion

Orbital debris can be presented as man-made/technological hazard and thus all disaster risk reduction techniques that are applied in the case of other natural and man-made/technological hazards can be also applied in the case of orbital debris reentry hazard. One of the techniques is the examination of the past disaster events and forming of historical disaster database, in this case orbital debris reentry disaster database to investigate the causing mechanism of the orbital debris reentries disasters. Orbital debris reentry hazards can be divided into three main parts: risk from surviving fragments on the ground, risk to people being hit on the ground and risk of aircraft being hit by surviving fragments. Some of the major properties of orbital debris reentry breakup are: environmental pollution, surviving debris spread over long thin ground footprint, 10 to 40% of the orbital debris mass survives reentry and impacts the Earth surface posing hazard to people and property on the ground which is largely determined by the kinetic energy of the debris. In most cases, people are unsheltered and unprepared for a hazard of this type. Further research must be focused on hazards from SpaceX Crew Dragon trunk orbital reentries and from unsuccessful rocket launches on suborbital reentry path.

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Mirce Science: Impact of Windscreen Damage on Functionability Performance of Commercial Aircraft

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Abstract

Flights cancellations or diversions of flights of commercial aircraft caused by windscreen damage have significant impact on their functionability performance. Thus, this paper addresses windscreen damage as an observed phenomenon from the Mirce science point of view, which means that it is considered as a mechanism that generates negative functionability events, which compels the affected aircraft out of scheduled service. The paper briefly examines the types of damage experienced in the past to understand their physical manifestations, as a negative functionability action that could generate undesirable consequences to the travelling public and financial losses to the airlines due to the withdrawal from service of the affected aircraft. Several design and operational methods for reducing the probability of windscreen damage are briefly presented in the paper, as the potential positive functionability actions to be taken to return them to scheduled service.

Key words: functionability performance, commercial aircraft, windscreen damage, windscreen delamination, windscreen design methods, windscreen protection and maintenance methods

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1. Introduction

Mirce science philosophy is based on the premise that the purpose of the existence of any working system is to do work. The work is considered to be done when the functionability [2] is maintained through time like miles travelled per hour, units produced per a shift, KW of energy supplied per month and so forth.

From the functionability point of view, at any instant of time a working system can be in one of the following two functionability states:

- Positive Functionability State, PFS, which is the state of being able to deliver a measurable function(s)
- Negative Functionability State, NFS, which is the state of not being able to deliver a measurable function(s)

According to the second axiom of Mirce science [1], a working system stays in a given functionability state until compelled to change it by any causing action whatsoever. Consequently, in respect to the state to which systems moves, all causing actions in Mirce science are classified as following:

- Negative Functionability Action (NFA), is a generic name for any natural process or human activity that compels a working system to move to a NFS. Typical examples are: thermal ageing, actinic degradation, acid reaction, bird strike, warping, abrasive wear, suncups formation on the blue ice runway, fatigue, pitting, thermal buckling, photo-oxidation, production errors, strong wind, maintenance error, hail, lightening strike, COVID-19, quality problems, tsunami, hard landing, sand storm and so forth.

- Positive Functionability Action (PFA), is a generic name for any natural process or human activity that compels a working system to move to a PFS. Typical examples are: servicing, lubrication, visual inspection, repair, replacement, final repair, examination, partial restoration, inspection, storage, modification, sparing, cannibalisation, health monitoring, packaging, diagnostics, as well as, proactive actions like change of operational[3] pattern, location, timing and similar.

Scientific understating of mechanisms of the imposing functionability actions requires analysis within the physical scale between: 10^{-10} metre (atomic/molecular phenomena) and 10^{+10} metre (space and environmental phenomena). Although it is a huge range, from an engineering point of view, it is the smallest physical range that must be studied and understood in order to understand the mechanisms which shape the functionability trajectory of working systems.

According to Knezevic [1] the expected amount of the scheduled work to be done by a working system type during a given interval of calendar time *T*, *PW(T)*, measured in calendar hours, Hr, can be calculated by making use of the following equation:

[2] In Mirce science, the ability of working system to deliver measurable function(s) at any instant of time is named functionability, during the period considered. [1]

[3] In January 2005 United Airlines had to operate 26 flights on less than optimum polar routes due to, solar activity, which resulted in Chicago to Hong Kong flight stopping in Anchorage for 4 consecutive days.

$$PW_{ws}(T) = \int_0^T \varphi(t)dt \qquad [Hr] \tag{1}$$

In the above expression, $\varphi(t)$ represents the proportion of working systems of the type considered delivering functionability at instant of time t, which is predictable by making use of Mirce Functionability Equation [2].

In commercial aviation, the expected measurable work to be done by any aircraft is to safely transport passengers and cargo from one location to another, through working life. Although they come in many different shapes and sizes, depending on the missions they are expected complete, all commercial aircraft are doing expected work only when they are safely in the air, with passengers/cargo. Hence, the main objective of any airline/user is to keep them in the air in accordance to the published scheduled.

Irrespective of the type of aircraft fuselage is common for all of them. It houses passengers, cargo and fuel, on one hand and holds together all other parts, like: wings, stabilizer, flaps spoilers and engines, on the other. The pilots, who sit in the cockpit at the front of the fuselage, are separated by the windscreen from the unbreathable thin air outside (at -56°C). Besides pressure, temperature control, and foreign object damage, the aircraft windscreen has to withstand chemical resistance to substances like hydraulic fluid or jet fuel as well as abrasion actions caused by dust, snow, rain erosion and the most dangerous, static electrical discharge (lightening).

- On 10th June 1990 when, a British Airways BAC1-11 aircraft[4], was climbing at 17,300 ft on route from Birmingham International airport to Malaga, Spain, the cockpit window was blown out under the effects of cabin pressure when it overcame the retention of securing bolts. The windscreen separated from the aircraft, which was flying at 400 mph, causing an explosive decompression that sucked the captain partially out of the window, leaving his upper body pinned against the exterior of the plane. The flight attendants, who came to his aid, held onto his ankles for 20 minutes, until the aircraft safely landed at Southampton Airport. The captain survived with frostbite, fractures, and severe shock but no fatal injuries. A UK government investigation into the incident later revealed that the 84 bolts out of 90, were smaller than the design diameter were used to install the blown-out windscreen, which had been replaced during routine maintenance 27 hours before the flight took off. The injured pilot returned to the flight deck just months later!

- On 15th January 2013 a Cessna Citation 750 was en route from Samoa to Sydney the message, WSHLD HEAT INOP L (windscreen heat inoperative left) was displayed on the EICAS[5]. Approximately 2 minutes later, the left windscreen's outer ply shattered with a loud bang. The crew put on oxygen masks and started an immediate descent toward Nadi International Airport at Fiji, deployed the passenger oxygen masks, and declared MAYDAY[6] to Nadi Radio. Concurrently, the pilot not flying ensured the passengers were on

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[4] https://assets.publishing.service.gov.uk/media/5422faa7e5274a131400078d/1-1992_G-BJRT.pdf

[5] EICAS stands for Engine Indicating and Crew Alerting System. It's an aircraft system that displays engine parameters and alerts the flight crew to potential issues or system failures.

[6] "Mayday" signifies an immediate life-threatening emergency and requires immediate assistance and silence on the radio frequency.

oxygen and briefed them on the situation, which included preparing for a possible ditching and donning life vests. The pilot flying reported that the windscreen crack did not grow any further and the cabin did not depressurise. The flight crew subsequently downgraded to a Pan-Pan[7] and landed safely at Nadi airport, with no injuries to the passengers or crew. At the time of the failure the windscreen had accumulated approximately 3,200 flight hours and 2,050 flight cycles. Failure analyse determined that wear of the seal at the top of the windscreen allowed moisture ingress to the bus bar and led to degradation of the electrical connection between the bus bar and the heating film. Eventually, the heating film began to burn out causing arcing that damaged the outer non-structural face ply of glass and finally compelling the flying aircraft to negative functionability state. [3]

- On 31st May 2012, during cruise flight at FL220, the LH flight deck windscreen cracked in a Cessna 560. Worried about failure of the window, the flight crew made an immediate descent for diversion. Subsequent engineering inspection identified a damaged seal that had let water in and then frozen during flight. Crews were warned to pay attention to seal condition during preflight checks. [3]
- On 27th October 2008, a Boeing 737 was climbing when it encountered pressurisation warnings and a loud vibration noise from a recently replaced windscreen. The aircraft descended and returned to the departure airport. The Civil Aviation Authority investigation revealed that there had been insufficient time for the sealant to cure on the eyebrow windows, which caused them to leak. [3]

- On 5th May 2008, the flight crew of a DHC8 heard a loud bang behind the first officer during approach. The cabin pressure indicator showed a rate of descent of approximately 2,000 fpm. A section of the weather seal was observed to have blown back from the rear of the co-pilot’s window. A normal approach and landing was carried out. [3]

Aircraft windscreens are designed under the “fail safe” concept, which means that the malfunction of a single component does not cause a catastrophic failure of the working systems. Hence, windscreens on a commercial aircraft are constructed of multiple layers to withstand the immense thermal, aerodynamic and mechanical stresses.

The main objective of this paper is to apply methods of Mirce science [1] to the motion of commercial aircraft through functionability states in time caused windscreen damage and to examine the consequences on their occurrences on scheduled operations of commercial airlines. The design actions that could be taken to reduce the probability of their occurrences are analysed and presented in the paper, together with recommended maintenance actions that should be taken to prevent occurrences related negative functionability events.

[7] "Pan Pan" indicates an urgent situation but not an immediate threat to life, but requires assistance.

2. The Commercial Aircraft Windscreens

The main function of an aircraft windscreen is to provide protection and visibility for the flight crew. They, also contribute to the structural integrity of the aircraft by balancing pressure differences between the interior and exterior. The other functions of windscreens are briefly listed below:

- Protection: the windscreens are designed to withstand the impact of rain, snow, hail, and even bird strikes, preventing damage to the cockpit and the flight crew.
- Visibility: the windscreens provide a clear field of vision for the pilots, during all stages of the flights.
- Structural integrity: windscreens are crucial for maintaining the aircraft's pressure differential, ensuring the integrity of the cabin and the aircraft's overall structure.
- Aerodynamic considerations: the windscreens are shaped and designed to minimise drag and provide efficient airflow around the aircraft.
- Safety: the strength and integrity of windscreens are critical for ensuring the safety of the aircraft and its occupants, especially during adverse working and weather conditions.
- De-icing and anti-icing: some aircraft windscreens utilise systems like electrically heated windscreens or hot bleed air to maintain clear visibility and prevent ice build-up.

2.1 Windscreens design and materials

Commercial aircraft windscreens typically comprise a laminated structure consisting of layers of glass, acrylic or polycarbonate plastics, or their combinations, bonded together by interlayers of polymeric bonding material. Such laminated structure provides high strength at reduces weight of aircraft. The environment to which such laminated windscreens are exposed is severe and the outer surface, known as the face ply, is often damaged due to particulate impacts, scratching or bond delaminations at inter-layer interfaces and/or electrical faults in anti-icing heater coatings caused by cyclical thermally and mechanically induced stresses, moisture ingress and bond deterioration. These types of negative functionability actions are the main causes for replacement of windscreens, and almost invariably occur at the inner surface of the outermost ply and/or within the interlayer adjacent thereto. Irrespective of the size of aircraft the windscreen thickness is the same, on average four times thicker than a car windscreen which is 5 mm thick. The flight deck windscreens are made with glass-faced acrylic, an outer layer of glass bonded to stretched acrylic, with a layer between them, made of urethane. Each has anti-ice and anti-fog system. [4]

Multilayer plastic construction of windscreens is most frequently used in the commercial aviation. Two relatively thick layers of acrylic or a similar hard plastic are typically sandwiched around a thinner layer of a soft material such as polyvinyl butyral (PVB) which provides thermal stress relief. The hard plastic layers are typically about 10 to 12.5 mm thick and the soft inner layer about 1.25 mm thick. Scratches in aircraft windscreens are typically removed by polishing during routine maintenance, after which thickness measurement is required to ensure that windscreen thickness has not been reduced below a specified minimum. Additionally, producers need to measure the soft PVB middle layer to ensure that it is within a specified thickness.

2.2 Windscreen fasteners

Some aircraft windscreens are fastened with bolts, while others use a clamping system. Both methods are equally reliable. The Airbus A320 and A340 are clamped-in production, without bolt holes, whereas Boeing aircraft are typically bolted-in during the manufacturing process. If the window is to be an integral part of the aircraft structure, then a bolted in method is necessary, because it transmits the aircraft loads right through the window, which becomes a structural part of the front of the fuselage. The alternative is to isolate the window from any possible loads being transmitted by the aircraft, by a heavy metal fuselage build-up, or frame, around the window to isolate it. When windows are damaged, they have to be replaced, except in certain cases of very minor damage, light scratches or scuffs, which could be repaired by qualified mechanic. The expected working life of a flight deck window is ten years, less than half of the rated service life of most aircraft, which is around 25 years.

2.3 Windscreen seal

Windscreen seals are part of the pressure system of the aircraft. The ability of the aircraft to maintain pressure is measured and inspected during a variety of maintenance activities, schedules, etc. When an aircraft's exterior windscreen seal deteriorates due to erosion rain and by wind, moisture creeps into the window assembly, causing a negative functionability event, observed as window cracking. Proper inspection and maintenance of the aerodynamic seal are critical to prevent moisture ingress, which in turn directly contributes to extending windscreen service life.

The service and repair manual, of each type of aircraft, contains the recommended visual inspection of the seal for erosion, cuts, nicks and overall condition. Other abnormalities, like cloudy areas in corners of a window or around the window periphery in the interlayer indicate moisture ingress and should be brought to the attention of the aircraft's maintenance technician. Burn marks, bubbles and moisture stains are other indications that a window may be reaching an unserviceable condition.

3. Types of Aircraft Wndscreens Negative Functionability Actions

Transitions of a commercial aircraft from PFS to NFS caused by windscreens related functionability actions could be categorised as following:

- Environmental elements and factors may cause NFA. For example, hail can crack the windscreens, or volcanic ash[8] lingering in the upper atmosphere, can cause abrasions to the windscreen's surface.

- Bubbles between layers may occur between the laminated windscreens layers, as result of anomalies during the manufacturing process. The amount and placement of the bubbles may be within allowable limits. However, if the

[8] The volcanic eruption of Eyjafjallajökull in Iceland in April 2010 led to widespread chaos in commercial aviation across Europe due to the ash cloud it produced. The eruption sent a massive ash cloud into the atmosphere, prompting airspace closures and safety concerns for aircraft.

bubbles exceed the limits, the windscreens must not be installed.

- Bird strikes may cause considerable damage to aircraft windscreens, and even cause fatal accidents. The extent of the damage depends on the size of the bird. Generally speaking, bird strikes happen during take-off and landing phases of flight, although it could take place while the aircraft is at a low altitude. [5, 6]

- Interlayer heat systems in aircraft windscreens may cause a cracking in the windscreens' outer layer. A heating system, installed to prevent icing on the glass during flight, should be switched on during the whole flight, as turning it on while in flight to combat icing leading to thermal shock. [3] The drastic temperature changes may result in the windscreens cracking or delaminating. In the events of the heating system short circuits, the consequential uneven temperature distribution could result in cracking of the windscreen.

- Moisture between layers may enter between laminated layers if there are gaps along the window edges. Trapped moisture could turn to ice while flying in geographical regions with colder temperatures, where the moisture could turn to ice, which expansion will cause the windscreens to delaminate or crack. Inspections of windscreens edges and "hump seals" for cracks or gaps could prevent moisture getting between the layers. [3]

- Use of unapproved cleaning products, such as paper towels or shop rags, can scratch the surface of the windscreens. Manufacturer's guidelines regarding the use of cleaning products for windscreens must be applied. [3]

3.1 Windscreen crack identification and procedures

In all the cases in which a crack appears on the windscreen, it is imperative to determine if it is on the inside or outside panel of glass. If it is determined to be the outside panel it is safe to continue the flight, but it must be reported after the landing. In case of windscreen damage/crack due to the impact of a foreign object or electrical arcing of the window heating system, the visual clues are not sufficient to assess the structural integrity of the windscreen. The flight crew must do a physical check of the inner ply of the windscreen as required by the cockpit windscreen/ window cracked procedure in the QRH [9] / FCOM [10] / Ops manual [11] and apply the requested/recommended procedure accordingly.
After touching the crack with a pen or with fingernail, the following action should be taken [5]:

- If there is no crack on the cockpit side, structural integrity is not affected and there is no limitation. The inner pane is still strong enough to maintain differential pressure up to the maximum flight level assuring safe flight to the

[9] Quick Reference Handbook, which contains all the procedures applicable for abnormal and emergency conditions in an easy-to-use format. In addition, performance data corrections are also provided for specific conditions.
[10] Flight Crew Operating Manual, which is issued by Airbus Helicopters as a guideline for operators to develop their own Standard Operating Procedures, in accordance with applicable requirements.
[11] Operations Manual (Ops Manual) is a foundational document that provides detailed guidelines, procedures, and information for safe and efficient aircraft operations.

destination airport. The pilot flying should be on the non damaged side of the windscreen.

- If the crack is on the cockpit side, structural integrity may be altered and limitations on cabin altitude, differential pressure, flight level, and speed must be obeyed as prescribed in the operations manual. The pilot should initiate the descent to 23000 ft or below to reduce the differential pressure between the cockpit and the outside air pressure to reduce the risk of further damage which could lead to cabin depressurisation. It is recommended to find the next suitable airport to land, as at lower levels the fuel flow is significantly higher and unexpected turbulence could damage the windscreen even more.

- If both windscreens are damaged the visibility could be severely reduced, which requires an auto land landing at the next suitable airport. In case auto land is not available and the visibility is so severely reduced on both windows, the pilot flying shall open the side window to get a better view of the runway for the visual approach.

4. Windscreen Delamination

In commercial aviation windscreen delamination, which is also known as glazing delamination, refers to the separation of layers within a laminated windscreen. It typically occurs when the polyvinyl butyral (PVB) interlayer between the two glass layers starts to degrade or separate. It can lead to cloudy, milky-white, or hazy patches on the windscreen, especially around the edges. Moisture may enter between laminated layers if there are gaps along the window edges. Trapped moisture could turn to ice while flying in colder temperatures. If the moisture turns to ice, it will expand, causing the windscreens to delaminate or crack.

4.1 Causes of windscreen delamination

Several factors can contribute to windscreen delamination, thus:

- Exposure to UV Rays: Prolonged exposure to sunlight and UV rays can cause the PVB layer to deteriorate over time, leading to delamination.
- Extreme Temperatures: Frequent exposure to extreme heat or cold can weaken the bond between the glass layers and the PVB, making the windscreen more susceptible to delamination.
- Physical Impact: A significant impact or collision can damage the windscreen, compromising the integrity of the PVB layer and leading to delamination.
- Chemical Damage: Certain chemicals, such as harsh cleaning agents or solvents, can react with the PVB layer and cause it to degrade.

4.2 Preventing windscreen delamination

While windscreen delamination can occur over time due to various causes, there are preventing actions that could/should be taken to reduce the probability its occurrence. Hence,

- Regular cleaning and maintenance of windscreen by using mild, non-abrasive cleaners.

- Protective windscreen covers could/should be used to cover a windscreen to reduce the probability of the exposure to direct sunlight and UV rays.
- Garage parking, could/should be used to shield windscreen from extreme temperatures.
- Repair of chips and cracks could/should be attempted to prevent further damage and potential delamination of windscreens.
- Inspections could/should be implemented on a scheduled basis by fully trained mechanics to identify any signs of delamination or other issues that may require attention.

5. Drone Strike on Windscreen

In recent years there has been increasing collisions of drones colliding, either accidentally or deliberately, with aircraft. The risk is particularly high at airports where aircraft are ascending or descending at low altitudes while taking off or landing. There have already been a number of incidents in which airports have been closed due to the close proximity of drones. Hence, it is reasonable to express concerns regarding the risk of that happening and the amount of damage a drone could do to an aircraft. As it has been a difficult question to answer the Aerospace Research Centre at the National Research Council Canada (NRCC) published a report in 2020 describing a series of ground tests in which a commercial drone was fired at an aircraft windscreen and wing leading edge. [8]

The windscreen tests conducted were done with a windscreen being mechanically fastened onto a steel plate and then sandwiched between two square frames. The drone used was a commercial quadcopter fitted with an external camera.

The first test was conducted on the left windscreen at a speed of 140 kt (72 m/s) followed by a second test on the right windscreen at a speed of 250 kt (128.6 m/s). The intent with the second test was to simulate an impact on the front windscreen. Each windscreen was composed of three layers: a non-structural protective outer glass pane, a structural vinyl interlayer and a structural inner glass pane. Urethane adhesive interlayers are used between the main plies for bonding purposes. The structural inner glass represents the main load bearing pane whereas the vinyl interlayer is structural for bird impact resistance and fail-safe pressure loads in case of failure of the structural inner glass pane. This windscreen design would be expected to withstand a 2 kg bird impact at 350 kt (180 m/s) with no damage.

Although the drone did not penetrate through all the layers, windscreens were severely damaged, in both tests. The external and internal layers of the windscreens both failed during each test run and only the plastic (vinyl) interlayers were left holding the shattered fragments together after the impacts. In both tests the windscreen would be unlikely to be able to support pressure loads due to the fracture of the inner glass ply. It was also likely that the optics through the impacted windscreen would be lost and an emergency landing be required.

In addition, the drone impacts generated clouds of glass fragments that were observed above the windscreens immediately after impact. The damage was especially severe for the high-speed test. In an aircraft in flight, a cloud of glass fragments would be released into the cockpit moving with a velocity which "would have posed a penetration and inhalation hazard to the operator located directly behind". [8]

The report concluded that: "One can notice the severity of the damage to both windscreens and only surmise the possible consequences of such impacts would have, especially at high speed where both the internal and external glass layers of the windscreen broke in the vicinity of the impact location and disintegrated into fragments." The report also comments that the severity of the damage resulting from the drone impact is more significant than those from bird impact tests performed at the NRC over the last 40 years on similar windscreen types.

The report notes that the Canadian tests do not agree with the findings from US simulations of drone/windscreen impacts conducted under the FAA-ASSURE (UAS Airborne Collision Severity) evaluation which concluded that a collision with a quadcopter drone would not result in significant damage to the windscreen in cases where a significant fraction of the deformation due to the impact is absorbed by the drone. Based on the results of the NRC's impact tests, the report recommends the development of a separate damage level category for windscreens, as the failure of the structural glass pane may cause a direct threat to the pilots.

6. Conclusion

The main objective of this paper is to expose the commercial aircraft design community to the observed phenomena of windscreen damage, as one of many in-service negative functionability actions that shape their functionability performance, quantified by the work done, measure through number of scheduled flights safely completed during a given interval of time (weeks, months or years), which are the most frequently used statistics by the travelling public and financial losses of the airlines affected due to withdrawals from service of the affected aircraft.

In accordance to the methods used in Mirce science, the paper briefly examines the types of damages experienced in the past to understand their physical manifestations, in the first part. Having addressed the types of windscreen structure, the second part of the paper examined several design and operational methods that could be used to reduce the probability of their occurrences in service, together with the potential positive functionability actions that should be taken to return them to and keep them in scheduled passenger service. It is necessary to stress that the impact of each of these methods could be quantitatively predicted for comparative purpose at the early stages of aircraft design by making use of Eq. (1), which is the bedrock of Mirce science.

7. Addendum

On the day this paper was to be sent to the publisher, 23rd April 2025, an Atlas Air Boeing 747 cargo aircraft en route from Jiangsu Province, China, to Anchorage, Alaska, experienced a crack in the cockpit window. The flight crew decided to divert and made an emergency landing at New Chitose Airport in Chitose, Hokkaido, Japan. As part of precautionary procedure for the safe landing gallons of fuel were jettisoned over the ocean. All four crew members on board were uninjured. The Japan Civil Aviation Bureau confirmed that an inspection of the aircraft was conducted to determine the cause of the windshield damage.

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Optical Observations of CZ-2C R/B 28222 and KSLV-II R/B 56750 Derelict Launch Vehicle Stages-Rocket Bodies

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Abstract

The main objective of this research paper is to present the first results of the optical observations of CZ-2C R/B (COSPAR ID: 2004-012C, SATCAT: 28222) in further text CZ-2C R/B 28222 and KSLV-II R/B (COSPAR ID: 2023-072H, SATCAT: 56750) in further text KSLV-II R/B 56750 derelict launch vehicle stages-rocket bodies. CZ-2C R/B 28222 rocket body was observed from 7 February, 2025 to 19 April, 2025 and KSLV-II R/B 56750 was observed from 9 February, 2025 to 20 March, 2025. All work is done by applying methods of MIRCE Science in all of the activities and procedures during the CZ-2C R/B 28222 and KSLV-II R/B 56750 observations. The most significant results of these observations were the recording of the overpass intersection of CZ-2C R/B 28222 and KSLV-II R/B 56750, first time observations of South Korean derelict launch vehicle stage-rocket body, validating the overpass prediction accuracy of two-line element set (TLE) data of each rocket body and overpass behaviour. No changes in brightness that can be attributed to tumbling were noticed.

Key words: orbital debris, rocket body, observations, reentry

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1. Introduction

The main objective of this research paper is to present the first results of the optical observations of CZ-2C R/B (COSPAR ID: 2004-012C, SATCAT: 28222) in further text CZ-2C R/B 28222 and KSLV-II R/B (COSPAR ID: 2023-072H, SATCAT: 56750) in further text KSLV-II R/B 56750 derelict launch vehicle stages-rocket bodies. CZ-2C R/B 28222 rocket body was observed from 7 February, 2025 to 19 April, 2025 and KSLV-II R/B 56750 was observed from 9 February, 2025 to 20 March, 2025.

1.1 CZ-2C R/B 28222 Data

The CZ-2C R/B 28222 rocket body is a part of the Long March 2C (LM-2C), also known as the Chang Zheng 2C (CZ-2C), Chinese orbital launch vehicle, part of the Long March 2 rocket family. It was launched on 18 April, 2024 with payloads: Shiyan 1 (China's first experimental digital imaging system) and Naxing 1 (China's first micro-satellite). [1]

The Long March 2C (LM-2C) is developed and manufactured by the China Academy of Launch Vehicle Technology (CALT). The Long March 2C made its first launch on 9 September 1982. It is a two-stage launch vehicle with storable propellants, consisting of nitrogen tetroxide and unsymmetrical dimethylhydrazine. The launch vehicle was derived from the DF-5 ICBM. [2]

First stage – height 25.72 m, diameter 3.35 m
Second stage – height 7.75 m diameter 3.35 m
Third stage (optional) – height 1.50 m, diameter 2.70 m [2]

Figure 1. CZ-2C (Shiyan 1 and Naxing 1) launch. [1]

1.2 KSLV-II R/B 56750 Data

The KSLV-II R/B 56750 rocket body is a part of the Nuri (KSLV-2) South Korean orbital rocket class. It was launched on 25 May, 2023 with the following payloads: NEXTSat 2, SNIPE 1-2-3-4, Lumir T1, KSAT3U and JLC-101-v1-2. [3]

The Nuri (KSLV-2) is a South Korean orbital rocket. Contrary to the Naro-1 (KSLV-1) it is completely indigenously developed at the Korea Aerospace Research Institute (KARI). Stage 1 of KSLV is 3.30 m in diameter and features four kerosene and LOX fueled KRE-075 engines. Stage two is 2.60 m in diameter, it uses the same fuel and oxidizer and is powered by a single KRE-075 engine. Stage three is also 2.60 m in diameter and is powered by a KRE-007 engine. The KSLV-2 is capable of hosting up to 1500 kg payload into a 700 km sun-synchronous orbit. Component tests was performed on the KSLV-2-TLV test launch in October 2018. The maiden flight of the complete KSLV-2 took place on 21 October 2021 from Naro, but failed to reach orbit due to early shut down of stage 3. [3]

First stage – height 21.60 m, diameter 3.50 m
Second stage – diameter 2.60 m
Third stage – height 3.50 m, diameter 2.60 m [4]

Figure 2. Nuri (KSLV-2) launch. [3]

2. Orbital Debris Observations

Complete observations were made from non-permanent (temporary) observatory located at Novi Sad metropolitan area, Serbia. The images were taken using the custom made Full-spectrum Nikon D7000 camera with 50 mm lens. [5] All work is done by applying methods of MIRCE Science in all of the activities and procedures during the CZ-2C R/B 28222 and KSLV-II R/B 56750 observations. [6] [7] The images presented in this paper are one part of continuous optical observations of orbital debris on uncontrolled reentry path. [8]

2.1 CZ-2C R/B 28222 Observations

Observation dates:
7 February 2025. image
9 February 2025. image
10 February 2025. image
20 February 2025. image
21 February 2025. image
3 March 2025. image
5 March 2025. image
8 March 2025. image
11 March 2025. image
18 March 2025. image
19 April 2025. image

Figure 3. Enhanced image of CZ-2C R/B 28222 rocket body overpass on 7 February, 2025. Time 6:27 PM CET. Elevation: ~67°. Overpass direction from south to north. Altitude (Perigee: 432.87 km, Apogee: 467.93 km). Camera pointed to the east with exposure of 15 seconds.

Figure 4. Enhanced image of CZ-2C R/B 28222 rocket body overpass on 9 February, 2025. Time 6:51 PM CET. Elevation: ~55°. Overpass direction from south to north. Altitude (Perigee: 432.7 km, Apogee: 467.43 km). Camera pointed to the southwest with exposure of 30 seconds.

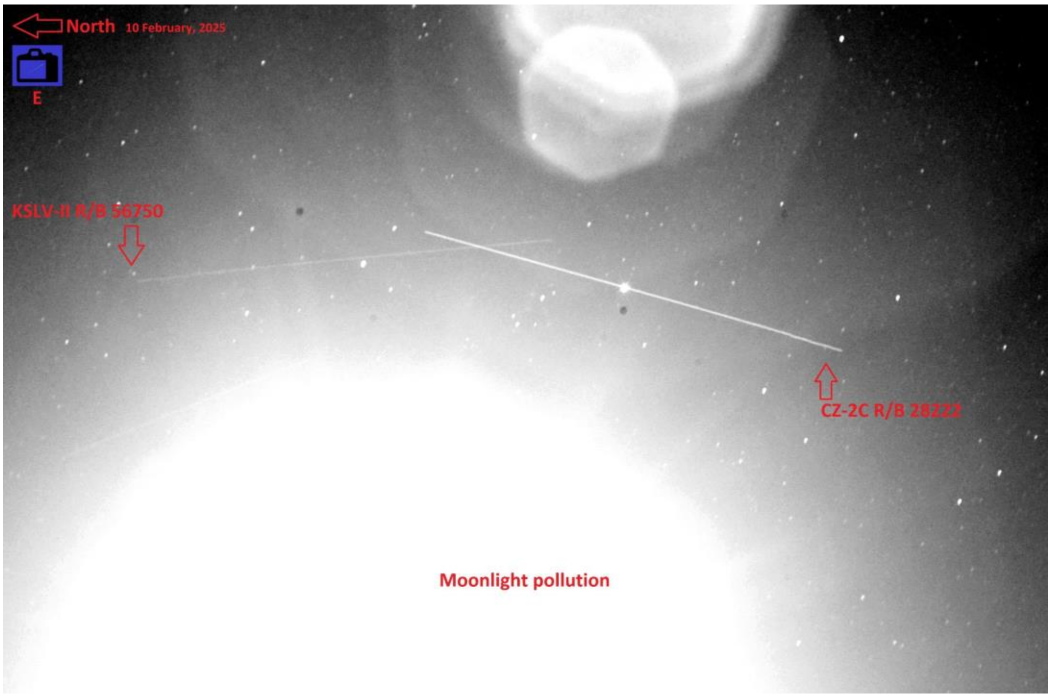

Figure 5. Infrared image of CZ-2C R/B 28222 and KSLV-II R/B 56750 rocket body overpass on 10 February, 2025. Time 6:17 PM CET. Elevation: ~48°. Overpass direction from south to north with moonlight pollution from Full Moon phase. CZ-2C R/B 28222 altitude (Perigee: 432.58 km, Apogee: 467.23 km). Camera pointed to the east with exposure of 15 seconds.

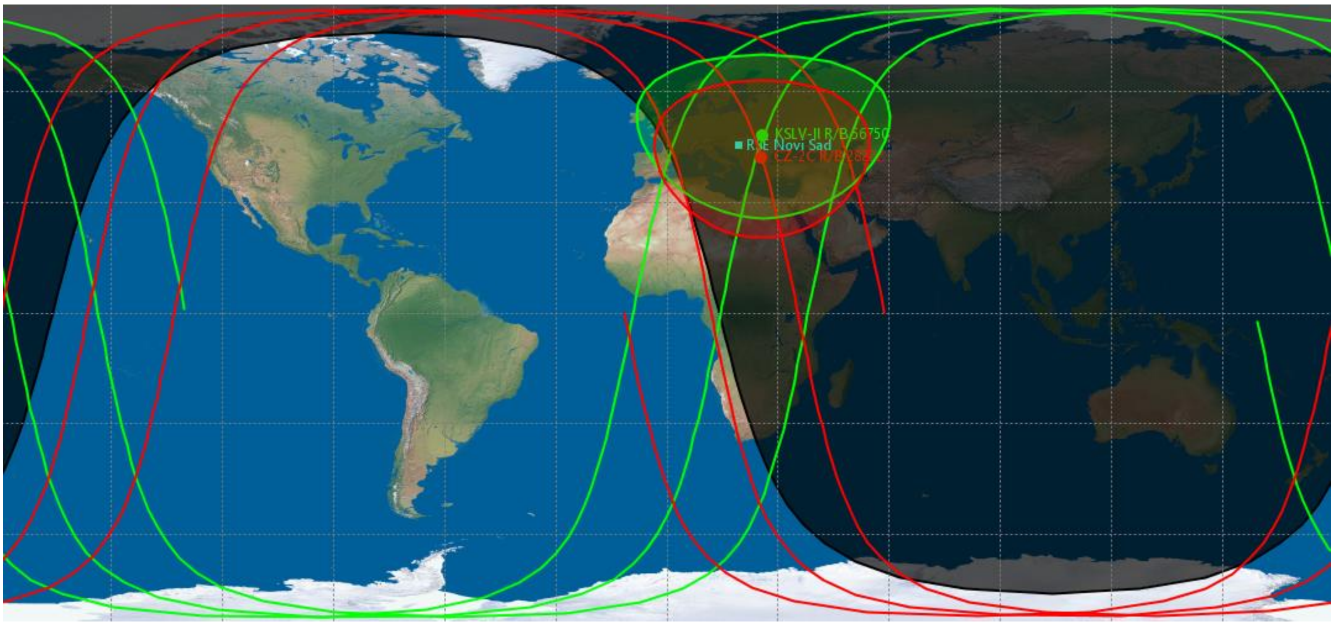

Figure 6. CZ-2C R/B 28222 and KSLV-II R/B 56750 ground tracks simulation in JSatTrak satellite tracking program for overpass on 10 February, 2025. Intersected overpass tracks of two rocket bodies on uncontrolled reentry path with altitude difference of 40.96 km at the closest point of intersection.

Figure 7. 3D View of CZ-2C R/B 28222 and KSLV-II R/B 56750 rocket body overpass on 10 February, 2025.

Figure 8. Original non-enhanced image of CZ-2C R/B 28222 rocket body overpass on 20 February, 2025. Time 6:45 PM CET. Elevation: ~75°. Overpass direction from south to north. Altitude (Perigee: 431.15 km, Apogee: 465.54 km). Camera pointed to the south with exposure of 20 seconds.

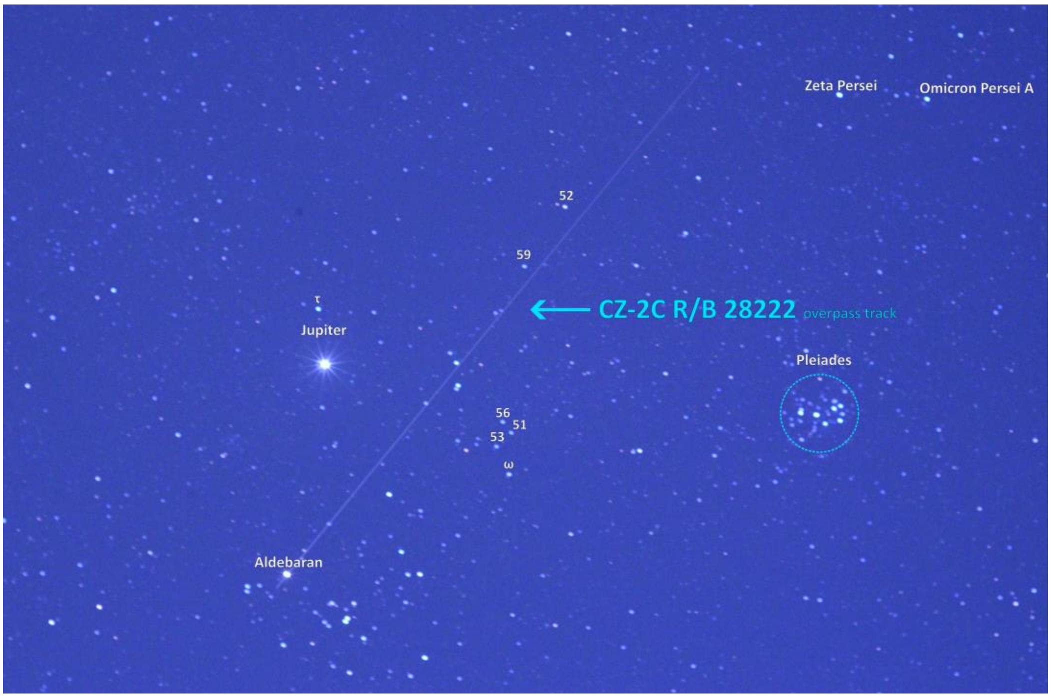

Figure 9. Original non-enhanced image of CZ-2C R/B 28222 rocket body overpass on 20 February, 2025. Time 6:46 PM CET with astronomical analysis using Stellarium Web. Camera pointed to the southwest with exposure of 20 seconds. Taurus constellation stars are: Aldebaran, 51, 52, 53, 56, 59, τ and ω.

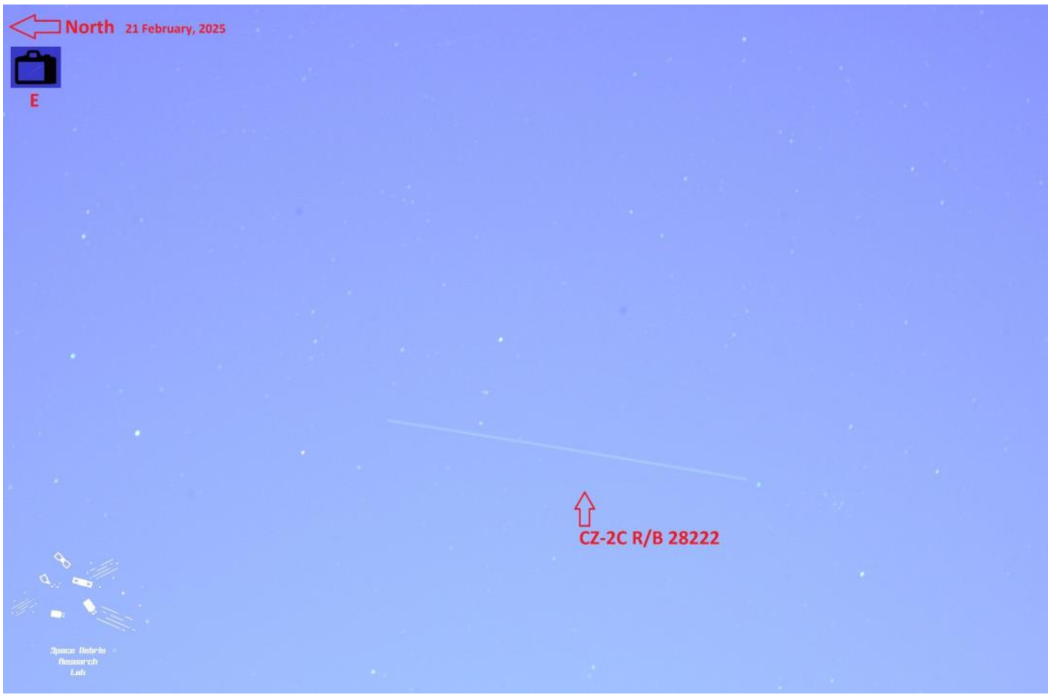

Figure 10. Original non-enhanced image of CZ-2C R/B 28222 rocket body overpass on 21 February, 2025. Time 6:11 PM CET. Elevation: ~37°. Overpass direction from south to north. Altitude (Perigee: 430.95 km, Apogee: 465.38 km). Camera pointed to the east with exposure of 15 seconds.

Figure 11. Original non-enhanced image of CZ-2C R/B 28222 rocket body overpass on 3 March, 2025. Time 6:33 PM CET. Elevation: ~67°. Overpass direction from south to north. Altitude (Perigee: 428.82 km, Apogee: 464.05 km). Camera pointed to the south with exposure of 15 seconds.

Figure 12. Original non-enhanced image of CZ-2C R/B 28222 rocket body overpass on 5 March, 2025. Time 6:56 PM CET. Elevation: ~61°. Overpass direction from south to north. Altitude (Perigee: 428.41 km, Apogee: 463.89 km). Camera pointed to the south with exposure of 20 seconds.

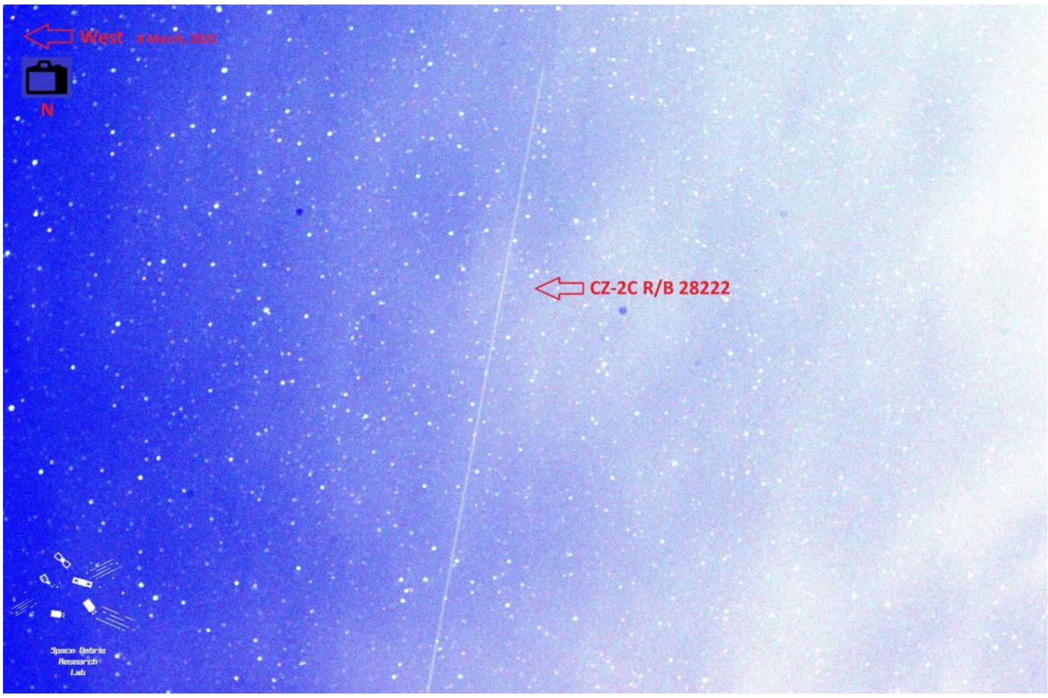

Figure 13. Enhanced image of CZ-2C R/B 28222 rocket body overpass on 8 March, 2025. Time 6:44 PM CET. Elevation: ~85°. Overpass direction from south to north. Altitude (Perigee: 427.82 km, Apogee: 463.66 km). Camera pointed to the north with exposure of 20 seconds.

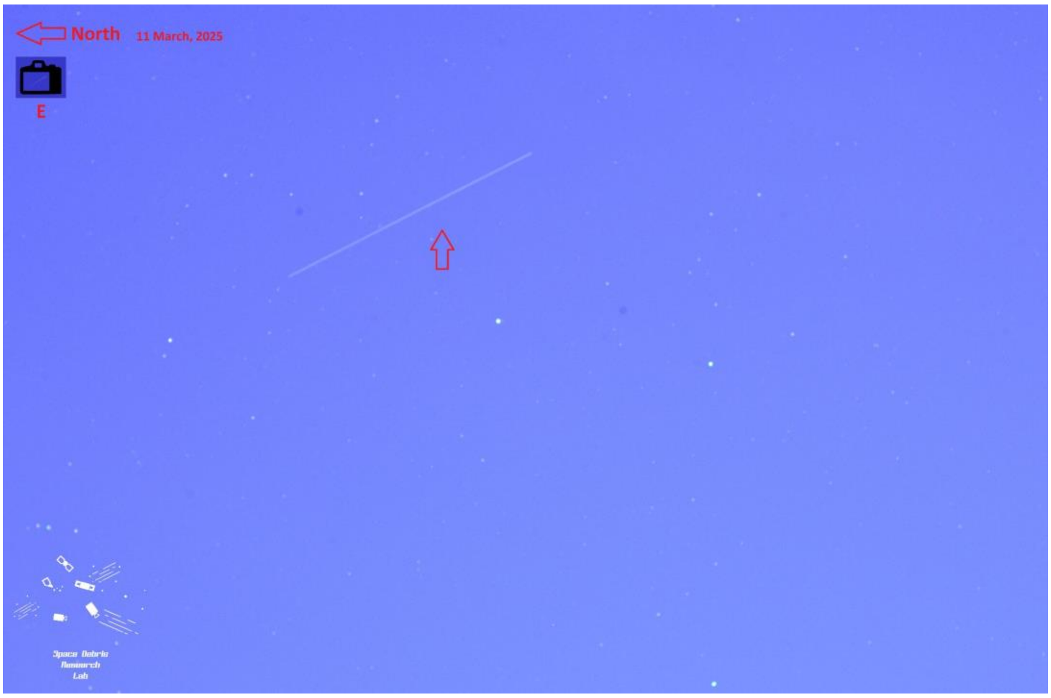

Figure 14. Original non-enhanced image of CZ-2C R/B 28222 rocket body overpass on 11 March, 2025. Time 6:30 PM CET. Elevation: ~54°. Overpass direction from south to north. Altitude (Perigee: 427.19 km, Apogee: 463.37 km). Camera pointed to the east with exposure of 10 seconds.

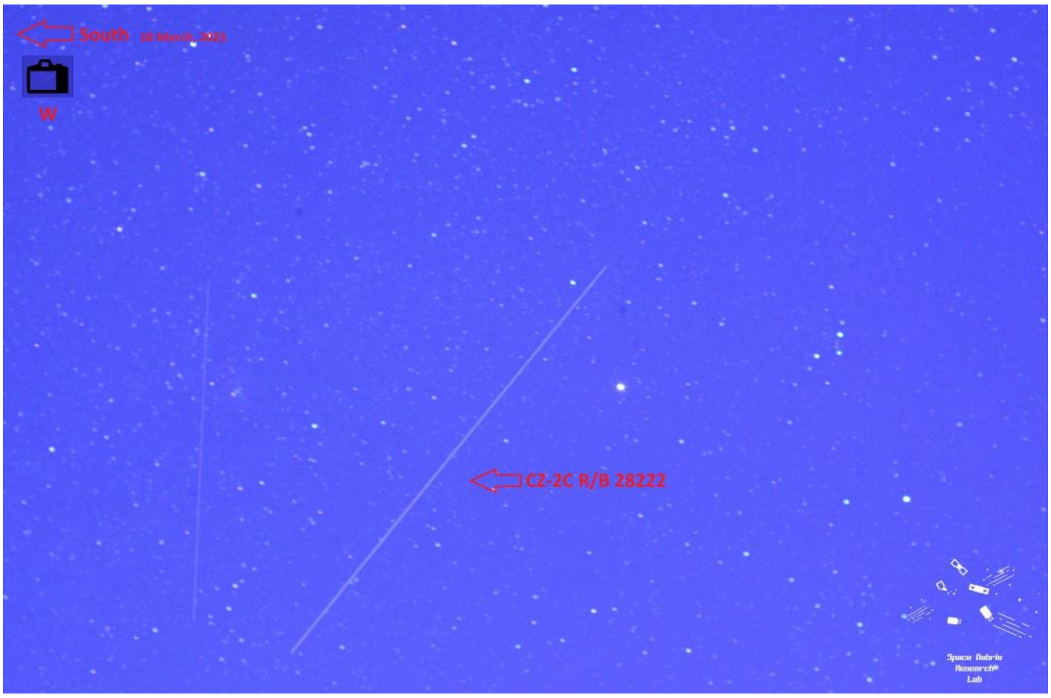

Figure 15. Original non-enhanced image of CZ-2C R/B 28222 rocket body overpass on 18 March, 2025. Time 6:58 PM CET. Elevation: ~65°. Overpass direction from south to north. Altitude (Perigee: 425.44 km, Apogee: 462.33 km). Camera pointed to the west with exposure of 20 seconds.

Figure 16. Enhanced image of CZ-2C R/B 28222 rocket body overpass on 19 April, 2025. Time 8:19 PM CEST. Elevation: ~42°. Overpass direction from south to north. Altitude (Perigee: 419.98 km, Apogee: 454.83 km). Camera pointed to the west with exposure of 13 seconds.

2.2 KSLV-II R/B 56750 Observations

Observation dates:
9 February 2025. image
10 February 2025. image
21 February 2025. image
5 March 2025. image
20 March 2025. image

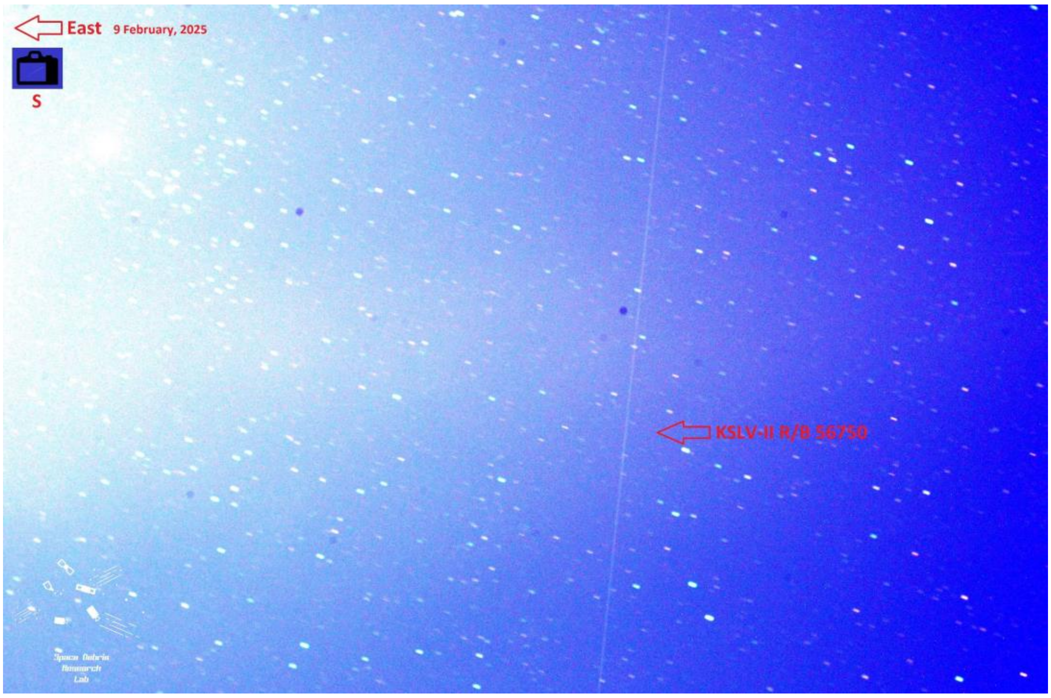

Figure 17. Enhanced image of KSLV-II R/B 56750 rocket body overpass on 9 February, 2025. Time 6:41 PM CET. Elevation: ~83°. Overpass direction from north to south. Altitude (Perigee: 466.11 km, Apogee: 505.6 km). Camera pointed to the south with exposure of 30 seconds.

Figure 18. Infrared image of KSLV-II R/B 56750 overpass on 10 February, 2025. Time 6:17 PM CET. Elevation: ~47°. Overpass direction from north to south with moonlight pollution from Full Moon phase. Altitude (Perigee: 466.05 km, Apogee: 505.53 km). Camera pointed to the east with exposure of 15 seconds.

Figure 19. Enhanced image of KSLV-II R/B 56750 rocket body overpass on 21 February, 2025. Time 6:44 PM CET. Elevation: ~82°. Overpass direction from north to south. Altitude (Perigee: 465.20 km, Apogee: 504.68 km). Camera pointed to the south with exposure of 30 seconds.

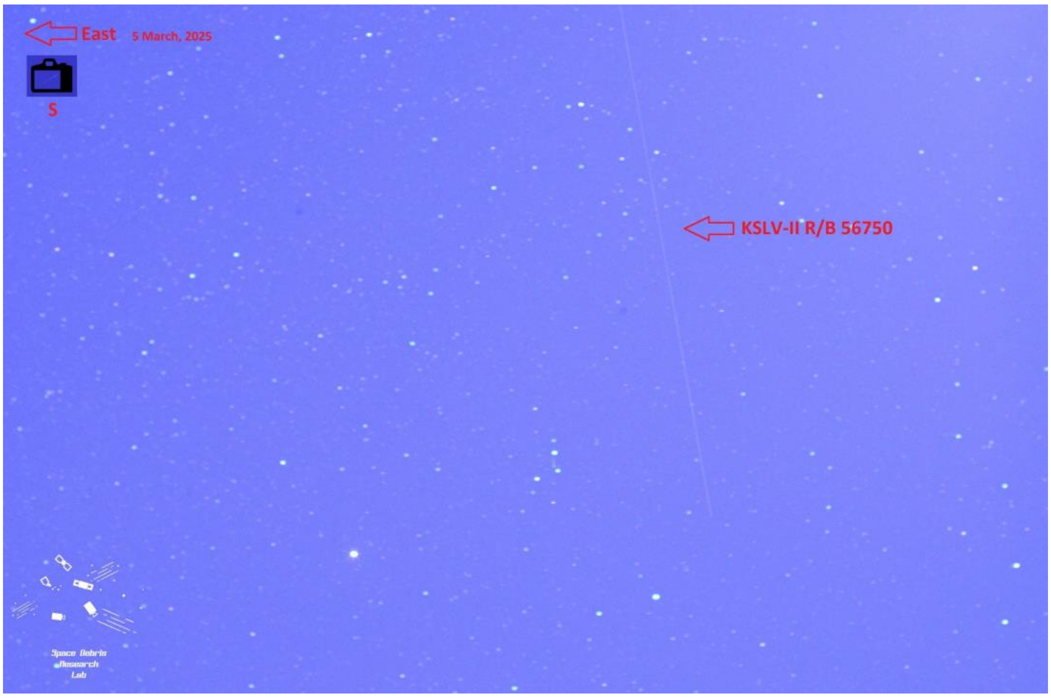

Figure 20. Original non-enhanced image of KSLV-II R/B 56750 overpass on 5 March, 2025. Time 6:42 PM CET. Elevation: ~86°. Overpass direction from north to south. Altitude (Perigee: 463.85 km, Apogee: 504.08 km). Camera pointed to the south with exposure of 20 seconds.

Figure 21. Enhanced image of KSLV-II R/B 56750 overpass on 20 March, 2025. Time 6:59 PM CET. Elevation: ~55°. Overpass direction from north to south. Altitude (Perigee: 462.1 km, Apogee: 503.29 km). Camera pointed to the south with exposure of 15 seconds.

Satellite altitude data was obtained from Kayhan Space Satcat. [9]
According to NASA Guidelines and Assessment Procedures for Limiting Orbital Debris [10], we predicted that CZ-2C R/B 28222 will be in orbit for at least one year and KSLV-II R/B 56750 for at least three years, without taking into account the corrective measures by calculating real area-to-mass ratio A/m and sun activity impact.

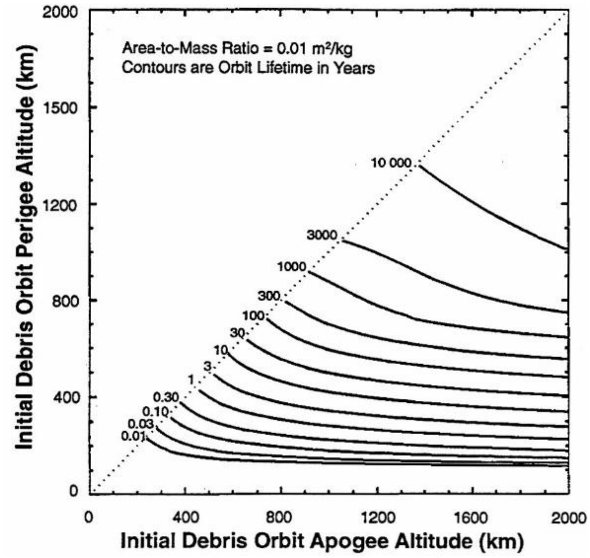

Figure 22. Orbit lifetimes for debris released in low altitude, low eccentricity orbits. Radiation pressure effects neglected in orbit lifetime calculations. [10]

3. Conclusion

The observations of CZ-2C R/B 28222 and KSLV-II R/B 56750 were successful during different time of the day and impact of moonlight on some of the images. All work is done by applying methods of MIRCE Science in all of the activities and procedures during the CZ-2C R/B 28222 and KSLV-II R/B 56750 observations. The most significant results of these observations were the recording of the overpass intersection of CZ-2C R/B 28222 and KSLV-II R/B 56750, first time observations of South Korean derelict launch vehicle stage-rocket body, validating the overpass prediction accuracy of two-line element set (TLE) data of each rocket body and overpass behaviour. No changes in brightness that can be attributed to tumbling were noticed. Although the two rocket bodies were at a distance of more than 40 km at the closest point, it demonstrates us how the Earth's orbital environment is fragile to the risk of direct collisions of the two large derelict launch vehicle stages without any ability to maneuver. An event of this kind would be a complete disaster with a great impact on the safe and peaceful use of our orbital environment. To advance this research, AGI's Systems Tool Kit (STK) can be used for high-fidelity simulation and orbital behaviour modelling. STK enables precise analysis of satellite trajectories using TLE data, dynamic visualisation of conjunction scenarios, and tools for assessing orbital decay and atmospheric drag under changing space weather conditions. Its integration would improve overpass prediction, collision risk analysis, and the development of long-term orbital debris mitigation strategies.

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[2] Wikipedia – Long March 2C. https://en.wikipedia.org/wiki/Long_March_2C (accessed 14.05.2025)

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[10] NASA Safety Standard, Guidelines and Assessment Procedures for Limiting Orbital Debris, NSS_1740.14, August 1995.

Mirce Science: Impact of Bees on Aircraft Functionability

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Abstract

Impacts of bees on aircraft could have significant consequences on flight delays and cancellations. Hence, it is considered as one of the many mechanisms that generate negative functionability events, from the Mirce Science point of view, which compels the affected aircraft out of scheduled service. At the beginning of the paper several examples of encounters of bees and aircraft are briefly described as an observed functionability phenomenon, on all five populated continents. The second part of the paper briefly examines the bees species to understand their physiological characteristics and life cycle phases, as a natural functionability mechanism that could generate undesirable negative consequences to the travelling public and financial losses to the airlines due to the withdrawal from service of the affected aircraft, or mission rejection in public services. Methods for dealing with bees from infected aircraft surfaces are briefly presented at the end of the paper, as the potential positive functionability action, performed to return them to a positive functionability state.

Key words: Mirce Science, functionability actions, impact of bees, commercial aviation, military missions, eradications methods

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0. Preface

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The research conducted and presented in this is paper has been initiated by the correspondents between Benedeicte Diallo and the author through LinkedIn. Part of it is presented in the Appendix 1. The author is thankful for the first-hand information obtained in the "real-life laboratory", Wau, South Sudan.

1. Introduction

The philosophy of Mirce Science is based on the premise that the purpose of conducting any working process is delivery of work, which is considered to be done when expected functionability[2] is delivered through time. It is quantified by the relevant measures of the motion, like: miles travelled, units produced, quantity of energy supplied and similar. However, experience teaches us that at any instant of the working process there is a probability of work being interrupted by occurrence of negative functionability events, resulting from failures of consisting components, natural causes, human actions or their interactions. As every action generates reaction, for the working process to be returned to positive functionability state it is necessary to implement appropriate positive functionability actions, like: completion of required maintenance tasks, change of the mode or location of operation and so forth. Thus, a working process could be considered as the time evolution of functionability compelled by imposing mechanisms (natural of human). [1]

The main objective of this paper is to expose the aircraft design community to the observed phenomena of the potential impacts of bees, as one of many negative functionability actions, which shape the motion of functionability in time and the quantity of the work done. Therefore, this paper briefly examines the bee species to understand their characteristics and impacts on the working processes of aircraft as mechanisms that could generate undesirable negative consequences. Methods for dealing with removal of bees, in a safe manner to the bees, environment and humans, were examined in the paper together with their impacts on scheduled flights.

2. The Brief Overview of Mirce Science

In accordance to Mirce Science philosophy [1], from a functionability point of view, working processes could be in one of the following two states:

- Positive Functionability State (PFS) – work is being done
- Negative Functionability State (NFS) – work is not being done.

The motion of working processes through functionability states is a physical manifestation of the impacts of compelling mechanisms (natural and human actions), which in Mirce Science are classified as following:

- Positive Functionability Action (PFA), a generic name for any natural process or human activity that compels a working process type to move to a PFS
- Negative Functionability Action (NFA), a generic name for any natural process or human activity that compels a working process to move to a NFS.

[2] Functionability is the ability of a working process to deliver measurable function(s) with expected performance and required attributes at the unit of time [1]

The motion of working process through the functionability states is manifested through the occurrences of functionability events which, according to Mirce Science philosophy, are classified as following:

- Positive Functionability Event (PFE), a generic name for any physically observable occurrence that signifies transition from a NFS to a PFS,
- Negative Functionability Event (NFE), a generic name for any physically observable occurrence that signifies the transition from a PFS to a NFS.

Consequently, the functionability performance through time is directly determined by the duration of times that working processes spent in functionability states. The pattern generated by the motion of working process through functionability states, forms the functionability trajectory, which is uniquely described by Mirce Functionability Equation [1]

The remaining part of the paper focuses on the impact of bees as one of many negative functionability mechanisms that directly impact the motion of functionability of working processes of aircraft and work done.

3. Selected Examples of Interactions Between Bees and Aircraft

Experience teaches as that aircraft flights, commercial and military, can be grounded for numerous reasons, ranging from poor weather to technological issues and government-issued groundings. Some of the mechanisms are described in papers published by the author [2,3,4,5,6,7,8,9]

A few examples of encounters between bees and aircraft are briefly presented in this part of the paper. To illustrate the world wide spread of this phenomenon, examples are taken from each continent.

3.1 Greater Natal Airport (Brazil): 24th January 2024, Swarm of bees covered the wing of the aircraft

Passengers on board of Voepass Airlines that just landed at a Greater Natal airport were left stranded on the tarmac for more than an hour[3]. As they were waiting to disembark, via a set of external stairs onto the runway, a buzzing sound outside the plane compelled the crew to send them back into their seats. The swarm had started landing on the plane’s windows. As the bees refused to budge, the pilot eventually had to call in the fire department for help. While waiting for help, some of the bees settled on one of the plane’s wings, while the rest continued flying above the aircraft.

After “quite a while,” the fire-fighters sprayed the aircraft with liquid which knocked them to the ground. After the removal of the bees, all passengers disembarked safely, the aircraft underwent maintenance, which cleared it for the next flight.

[3] https://nypost.com/2024/01/24/lifestyle/bees-swarm-plane-on-tarmac-leaving-passengers-trapped-inside-aircraft/

3.2 Houston-Bush airport (USA): 3rd May 2023, Group of bees landed on the winglet of the aircraft

A Delta Airlines flight, 1682 from Houston-Bush to Atlanta, encountered a delay after a friendly group of bees landed on the winglet of the aircraft. The delay, that lasted 3 hours, affected 92 passengers. The flight was held up as staff considered a solution that wouldn't harm the bees and also wouldn't contaminate the surfaces of the plane.
Eventually, the bees left on their own, as the plane was moved to a taxi position. Afterward, the passengers boarded and completed their flight; no bee stings were reported.

3.3 Khon Kaen Airport (Thailand): 10th May 2023, Cloud of angry bees descended on the right engine

As the Thai Smile flight FD3260 parked at the gate a cloud of angry bees descended on the right engine at the Khon Kaen Airport. The passengers were safely unloaded, but their luggage could not be retrieved due to the territorial colony dive-bombing anyone who approached. Six members of ground staff were injured by bee stings as they tried to get rid of the bees by blasting them with water and blowing air into the plane's exhaust pipe.

Although this operation was successful, the bees then attacked a second plane later the same day, causing flight WE045 heading to the Suvarnabhumi International Airport (BKK) to be delayed by 40 minutes. Inspections of the tarmac and jet bridges were conducted to find the remaining insects, which were killed with insecticide.

No other flight was disrupted on that day. According to airport management team "It was the first time such an incident happened at the airport. The bees may have become disoriented or migrated due to the recent storm"[4].

3.4 Kolkata (India): 15th September 2019, swarm of honeybees clamped themselves onto the window of the flight deck

A regional, 60 minute Air India, flight 743 from Kolkata to Agartala was delayed by two and a half hours after a swarm of honeybees clamped themselves onto the window of the flight deck[5]. The swarm took up residence on the left hand window panes, obstructing the pilots' vision. Windscreen wipers failed to remove the bees. The swarm was only cleared when the airport fire crew were recruited to use water cannons to disperse the bees.

The plane had already been delayed by 90 minutes due to a technical fault, before the bee attack added an extra hour's delay. There were 136 passengers on board.

The airport staff had carried out checks for bees in the wake of the incident. As they did not find any beehives on any structures inside the airport, they concluded, "that the bees came from outside the airport premises."

3.5 Durban (South Africa): 26 September 2012, Bees flew into aircraft

At the main airport in South Africa's coastal city of Durban a swarm of bees flew into the engine of a Mango Airlines plane, forcing a delay in flights. Bee experts were called in and

[4] https://www.newsflare.com/video/561743/bees-attack-plane-injuring-six-people-when-it-lands-in-thailand
[5] https://edition.cnn.com/travel/article/bees-delay-flight-air-india-kolkata

they safely removed the estimated 20,000 bees from the engine.

The incident was extremely unusual, and the bees were probably resting before planning to fly on, as it was unlikely they intended to make a "smelly" engine their home. The bees populated the engine in less than 25 minutes.

3.6 Vnukovo airport (Russia): 7th July 2015, Russian plane attacked by bees

At Vnukovo airport, Russiya airways, Airbus 319 was getting ready to perform the flight from Moscow to St. Petersburg, when a group of honey bees “attacked” it. As passengers were frightened by the bees, two ambulances were called.

The plane was soon cleared of the bees and the flight was only delayed by one hour. According to a Russian news source[6], a local agriculture scientist and bee expert said, “Bees were swarming from some suburban apiary and were migrating through the airport.”

3.7 Bournemouth International Airport (United Kingdom): 4th May 2007, Bees sucked into aircarft engine causing 11-hour delay

A swarm of bees, some 20,000 strong, were sucked into the engine of a Palmair B737 which had departed Bournemouth International Airport on the Southern English coast enroute to Faro, Portugal, with 90 passengers aboard[7]. The pilot reported an engine surge about one hour into the journey and returned on just one engine.

According to reports, the pilot reassured his frightened passengers that the rattling noises they were hearing from the plane's engine area was a simple case of "carburettor trouble."

When the aircraft was checked by maintenance workers, the engine "looked as if someone had shaken 1,000 cans of coke and sprayed them onto it." The bees got so far into the B737 that it took two attempts to clean the engine. "This was not life-threatening, because the bees came out of the back of the engine”. According to experienced mechanic, “Bees flying into an aircraft's engine was an extremely rare event and that the engines were designed to cope with bird strikes”.

3.8 Joint Base Langley-Eustis, Virginia (USA): 11th June 2016, A swarm of honey bees found hanging from the exhaust nozzle of an F-22 Raptor stealth jet’s engine

On 11 June 2016, 192nd Fighter Wing Aircraft Maintainers found a swarm of honey bees hanging from the exhaust nozzle of an F-22 Raptor. Since this had never happened on the flight line before, the on-base entomologist was called to assess the situation. He immediately knew that he did not have the means to relocate the bees, so he referred to a local honey bee keeper in Hampton, Virginia.

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[6] https://badbeekeepingblog.com/2015/07/08/russian-plane-attacked-by-bees/
[7] https://www.aero-news.net/annticker.cfm?do=main.textpost&id=8F011E9D-B91D-4DBE-B25F-8F6600D25AA8

When the local bee keeper arrived to base, he commented, "The swarm was one of the largest he had ever seen". He was escorted to the aircraft and used vacuum hoses to safely corral the honey bees off of the aircraft into large buckets. He then took the bees home and found that, as a hive, they weighed eight pounds which calculates to almost 20,000 bees!

4. Cimex Lectularius (Common bees)

Bees are insects with complex biology, living in colonies with specialized roles, while others are solitary. Understanding bee biology is crucial for appreciating their ecological importance, particularly their role in pollination that is essential for many plants, including crops, which is vital for maintaining biodiversity and food security.

Bees exhibit a holometabolous development, also known as a complete metamorphosis, which is characteristic of all endopterygote insects. Hence, the main stages are:

- Egg**:** The bee life cycle begins with the egg, which is typically laid in a cell within the hive.
- Larva: After hatching from the egg, the larva emerges. This stage is characterized by active feeding and growth, as the larva consumes food provided by worker bees.
- Pupa: The pupa is a transitional stage where the larva undergoes significant internal and external changes, transforming into an adult bee.
- Adult (Imago): The final stage is the adult bee, which emerges from the pupal case and can perform various tasks, such as foraging, caring for young, or defending the hive.

The specific duration of each stage can vary depending on factors like the bee's caste (queen, worker, or drone), the time of year, and the availability of resources. For example, the honeybee (*Apis mellifera*) egg can hatch in 28-144 hours, depending on temperature.

Honeybees, like social bees, live in colonies with a queen, drones (males), and numerous worker bees (females). In social bees, there is a division of labour based on caste, with the queen focused on reproduction, drones on mating, and workers on various tasks like foraging, nest building, and caring for the young.

Bees communicate through various means, including dances (like the waggle dance[8] used by honeybees to indicate food sources) and chemical signals (pheromones).

There are two honeybee sexes, male and female, and two female castes. The two female castes are known as workers, which are females that do not attain sexual maturity, and queens, females that are larger than the workers. The males, or drones, are larger than the workers and are present only in early summer. The workers and queens have stingers, whereas the drones are stingless.

Queen honeybees store sperm in a structure known as the spermatheca, which allows them to control the fertilization of their eggs. Thus, queens can lay eggs that are either unfertilized or fertilized. Unfertilized eggs develop into drones, whereas fertilized eggs

[8] Honeybee perform a waggling movement at the hive or nest, to indicate to other bees the direction and distance of a source of food

develop into females, which may be either workers or virgin queens. Eggs, predetermined to become queens, are deposited in queen cells, which are vertical cells in the honeycomb that are larger than normal.

After hatching, the virgin queens are fed royal jelly, a substance produced by the salivary glands of the workers. When not fed, a diet consisting solely of royal jelly, virgin queens will develop into workers. During the swarming season, in the presence of a weak queen or in the absence of a queen, workers may lay unfertilized eggs, which give rise to drones.

4.1 Swarming of bee hives

Bee hives are constantly growing and they eventually become overcrowded. Hence, when a honeybee colony outgrows its current hive, it will swarm. From a swarm's resting place, around 100 bees will take off to look for a safe controlled environment, which instinctively satisfies their needs. Any enclosed structure, the cracks in stucco, openings in wood siding, chimneys, and flashing around chimneys, will provide access for bees that has opening, between 35 – 65 cm. Scout bees, while looking for new hive locations, can occasionally land on aircraft temporarily while they assess the area. However, if the new location is not suitable or if the bees are disturbed, they will quickly relocate.

Once a location is found, they return to the swarm and lead them to the new location. Within an hour after arriving, the swarm will be inside the new location. The bees will start building their hive (putting up their wax structure) within 26 to 30 hours of their arrival. This could require removal of the beehive to prevent property damage.

4.2 Encounters between queen bees and aircraft

Around springtime, the bees will make a new queen. Approximately, a half of the hive will be transported the new location, already identified by scouts, to build a hive for their queen. However, queen bees, which typically fly with eggs to lie at the new hive, would not have eaten for up to 10 days before leaving to start a new colony. As a result, the queen is often malnourished for the journey. Consequently, in very rare occasions a swarm of bees would land on parked aircraft, where one out of two following things will happen:

- the queen will rest, gain energy and the swarm will continue its journey in the morning,
- the swarm will "decide" that the aircraft is a great place to build a hive and they would stay!

5. Potential Impacts of Bees on Aircraft

Speed and altitude are critical parameters for autopilot functionality. Autopilots use these inputs, along with other data, to maintain desired flight paths and control the aircraft. Specifically, altitude hold mode maintains a specific altitude by adjusting throttle and pitch, while speed control ensures the aircraft maintains a desired airspeed

In the earlier part of the paper, several encounters between bees and parked aircraft have been described, at the world wide scale. Although bees have been found on many different parts of aircraft, the most damaging impact is on the pitot tube, which can cause significant consequences for aircraft and travelling public, due to inaccurate speed readings, potentially causing rejected takeoffs or other flight safety hazards.

5.1 Bernoulli equations

In the 1700s, Daniel Bernoulli[9] investigated the forces present in a moving fluid, which was defined by Bernoulli's equation. The equation states that the static pressure, p_s, in the flow plus one half of the density times the velocity squared, V^2, is equal to the total pressure p_t, which is equal to a constant throughout the flow, thus:

$$p_s + \frac{\rho \times V^2}{2} = p_t \quad \Rightarrow \quad V^2 = \frac{2(p_t - p_s)}{\rho} \qquad (1)$$

where: ρ is the local value of air density. Thus, by determining the difference in pressures measured and knowing the local value of air density, from pressure and temperature measurements, it is possible to determine the velocity of the object studied.

5.2 Pitot tube

A pitot[10] (or pitot-static) tube is a standard instrument for measuring air speed on an aircraft. In its simplest form, a pitot tube has two holes for pressure measurement: one at the end of the tube perpendicular to the oncoming flow, and one on the tube's side. At the base of the tube, a differential transducer compares the pressures (total and static, respectively) obtained at the two holes and Bernoulli's principle is used to determine the velocity. More complex probes may have several holes at the tip to allow determination of the local angles of attack and sideslip.

Pitot tubes must be mounted forward of a fuselage on an aircraft pointing into the airflow. This mounting arrangement exposes them to precipitation, ice, dirt and insects, all of which can enter the pressure tubing and disrupt measurements, leading to aborted takeoffs and manual cleaning to remove the blocking object.

6. Bees Deterring Methods

In order to reduce the probability of the encounters between travelling bees and parked aircraft, some, or all, of the following human actions are required:

- removing attractants,
- sealing potential nesting sites,
- using repellents.

Each of the possible deterring actions will be briefly describe below.

[9] Daniel Bernoulli (1700-1782) FRS was a Swiss-French mathematician and physicist and was one of the many prominent mathematicians in the Bernoulli family from Basel. He is particularly remembered for his applications of mathematics to mechanics, especially fluid mechanics, and for his pioneering work in probability and statistics.
[10] The Pitot tube was invented by the French engineer Henri Pitot in the early 18th century, which was modified to its modern form in the mid-19th century by French scientist Henry Darcy.

6.1 Removing attractants

The main objective of these actions is removal of natural or human material that attracts bees to surrounding areas of parked aircraft. Thus:

- As bees are attracted to water sources it is essential to remove any puddles or standing water near the aircraft.
- Keep any food or sugary drinks covered and away from the aircraft to prevent attracting bees.
- Reduce the presence of flowering plants near the aircraft, as they attract bees.

6.2 Use bee repellents

As bees are sensitive to certain scents it is worth considering using natural repellents near potential nesting sites. Thus,

- Applying, essential oils like peppermint, citronella, and tea tree oil can be diluted and sprayed in affected areas to deter bees
- Spraying a vinegar solution can also help repel bees
- Using mothballs, but with caution due to their strong odor and potential toxicity.
- Smoke can be used to discourage bees from nesting in an area

6.3 Relocate existing nests

Bees play a vital role in pollination, so consider relocating them if possible, rather than killing them. Thus,

- If bees have already established a nest, it's best to contact a professional pest control service or a beekeeper for safe removal.
- While removing the nest it is necessary to be cautious. It is recommended to use soapy water or smoke to encourage the bees to relocate.

7. Preventative Measures

Regular inspections of aircraft for signs of bee activity could be an effective preventive action taken by airport staff, before nests become established.

It is necessary to mention that improper removal methods could damage the aircraft or create further issues, thus:

- Unless directed by a professional, avoid using strong insecticides as they can harm the bees and potentially damage the aircraft.
- Don't block the entrance, as that will only make the bees more agitated and likely to find a new way in.
- Bee removal may take time, especially if the hive is large or the bees are agitated, so be patient!

8. Use of Professional Beekeepers

The most effective method of removing bees nesting on aircraft, is to contact a professional beekeeper or pest control service that handles bee removal. They have the expertise and equipment to safely relocate the bees without harming them or damaging the aircraft.

Bees can be defensive when their hive is disturbed. Professionals have the proper protective clothing and techniques to avoid stings and potential allergic reactions.

Professional bee keepers can safely remove the entire hive and relocate it to a more suitable environment.

9. Conclusions

The main objective of this paper is to expose the aircraft design community to the observed encounters of bees and aircraft, from the Mirce Science point of view. Thus, it is considered as one of many mechanisms that generate negative functionability events, which compels the affected aircraft out of scheduled service.

Real life examples of encounters between bees and aircraft are briefly presented in the first part of the paper, together with the consequences on the travelling public and financial losses to the airlines due to the withdrawal from service of the affected aircraft, or mission cancellation in public services. To illustrate the world wide spread of this phenomenon, examples are taken from all populated continents. The second part of the paper briefly examines the bee species to understand their physiological characteristics and life cycle phases, as a necessary precursor for understanding their natural functionability mechanism that could generate undesirable negative consequences. Methods for dealing with bees from infected aircraft surfaces are briefly presented in the paper, as the potential positive functionability action, performed to return them to expected working processes.

The author sincerely hopes that the examples from the “real life laboratory” related to the impact of bees on aircraft will find a place in the “educational and university laboratories” of the future aircraft design community for the benefit of the flying passengers, on one hand, and the protection of bees and their role in pollination that is vital for maintaining global biodiversity and food security, on the other.

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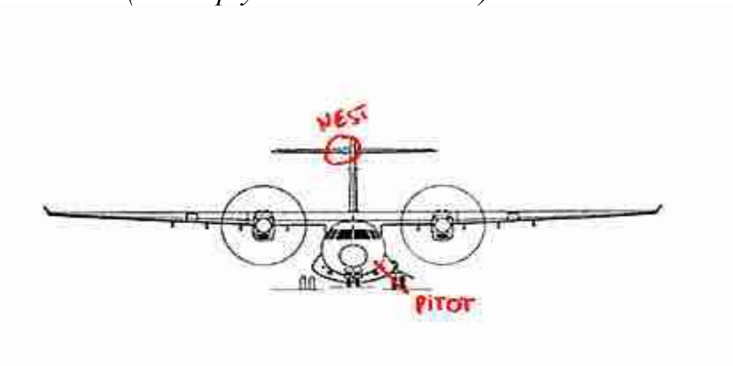
Appendix 1: Extract for the author's correspondence with Benedicte Diallo

"Swiftair was operating some flights for the UN in different missions, including Sudan. In 2010, we opened a new base in Wau, South Sudan, where we operated an ATR72. The flights were always scheduled to depart early in the morning and return before sunset due to airport closure.

In 2010, the runway, taxiways, and the parking area were still unpaved and made of red soil, often muddy, surrounded by dense vegetation. South Sudan has a tropical climate, unlike the arid North one and we were not used to it yet.

The first event happened one morning. During a visual inspection of the aircraft, we noticed a large wasp's nest located on the fuselage between the tail and the horizontal stabilizer (as simply illustrated below).



I called the firefighters to remove the nest as safely as possible, for the team around the aircraft but also without damaging the fuselage. I immediately reported the incident to the UN chief of mission, requesting to take preventive action immediately for the oncoming operations. However, due to a lack of aviation safety knowledge, nothing was done.

Everything remained unchanged until the second incident happened a few days later, when the plane aborted its take-off (accelerate-stop) due to a default in the speed indicators from the captain side and had to get back to the parking area. After investigation, it was determined that a bee was stuck in the le: pitot-tube. The mechanics had to purge the system with pressure nitrogen. It took around two hours before resuming safely our operations.

We never fully understood how that bee, or whatever wasp, could have entered the tube, as the pitot and the statics are always covered upon arrivals and covers are removed just before flights, as per mandatory procedures.

Nevertheless, this incident had prevented a serious accident that day, which eventually led the UN chief of mission to understand the severity of the situation. So, from that time, to mitigate the risks, it was decided to spray some insecticide or repellent all over the area and on all the aircraft: based in Wau (fixed and rotary wings) on a regular basis.

I am sorry, I can't be more accurate as it occurred 15 years ago, and we don't keep the records as long.

As a conclusion, I might say that:

- *The schedule, climate, and environment were favorable to the wasps nesting.*
- *Only one night was sufficient to build a nest.*
- *The lack of understanding of aviation safety from people outside the field and the "no action politic" led to these repeated incidents (we were not the only ones).*
- *We had to be even more cautious in that new environment (new base).*
- *The measures taken, efficiently helped to mitigate potential future risks*

Mirce Science: Maintenance Actions at the Distance of 592 Million Kilometres from Earth on NASA's Juno Spacecraft

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Abstract

The main objective of the paper is to draw attention of the space community to another innovative approach to maintenance at distance, conceived and implemented by the mission Team of the NASA's Jupiter-orbiting Juno spacecraft. In December 2023 they executed a "deep-space move" to repair its JunoCam imager to capture photos of the Jovian moon Io, without trained maintenance personnel and with no existing maintenance manual, tools or equipment. At that time NASA's spacecraft Juno has been orbiting planet Jupiter at the distance of $597x10^6$ km from Earth. The paper is analysing the maintenance task at the distance through the prism of Mirce Science and draws conclusions that could be useful during the planning of the future space working processes. It is essential to stress that the opportunities to executed maintenance action at the distance are only possible if they are envisaged at the design stages of the future spacecraft and conditions created during their working processes. It that context the paper briefly defined the planet Jupiter and it physical characteristics as a "host" of the Juno mission, followed by the brief description of the Juno spacecraft design and finally, the details of positive and negative functionability actions taken on JunoCam, based on the information thus available.

Key words: functionability, NASA Juno mission, maintenance action at distance

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1. Introduction

The philosophy of Mirce Science [1] is based on the premise that the purpose of existence of any working process is to deliver expected measurable work during intended time duration, like: miles travelled during one flight, units produced in one shift, energy supplied during 24 hrs and similar.

However, experience teaches us that at any instant of time there is a probability of a working process being interrupted by occurrences of disruptive events, compelled by failures of consisting components, natural causes, human actions or their interactions. As every action generates reaction, for the working process to resume work it is necessary for appropriate actions to take place, like: completion of required maintenance tasks, change of the mode or location of operation and so forth.

It is well known that maintenance tasks are performed by trained personnel in well designated locations, like workshops, hangars, dry docks, garages, airport gates and similar. Other resources, like: manuals, tools, equipment and so forth are used for the successful completion of maintenance tasks. Thus, it could be safely concluded that maintenance tasks are mainly performed by trained maintenance personnel in situ using required maintenance resources.

However, in [2] Knezevic concluded that space weather could have harmful impacts on the reliability and safety of future autonomously working systems. The research presented in the paper has shown that the maintenance of autonomously working systems against potential failures of the sensors located in Earth orbiting satellites from the impact of continuously generating space weather in the Sun, could be served the best if the satellites are temporarily moved from the trajectory of incoming harmful space weather generating particles. This is an equivalent of the well known preventive maintenance policy commonly applied to safety critical systems on Earth. However, for this solution to work it is necessary to provide real time observations and predictions of space weather, equivalent to the 24/7 produced forecasts for the Earth weather.

Consequently, the main objective of this paper is to draw attention of the space community to another innovative approach to maintenance, conceived and implemented by the mission Team of the NASA’s Jupiter-orbiting Juno spacecraft. In December 2023 they executed a “deep-space move” to repair its JunoCam imager to capture photos of the Jovian moon Io, without trained maintenance personnel and with no existing maintenance manual, tools or equipment. At that time NASA’s spacecraft Juno has been orbiting planet Jupiter at the distance of 597×10^6 km from Earth. [3]

The paper is analysing the distance, maintenance task through the prism of Mirce Science and draws conclusions that could be useful during the planning of the future space working processes. It is essential to stress that benefits from the successfully executed maintenance action taken by the NASA operational Team, are only possible if they are envisaged at the design stages of the future spacecraft and conditions created that could facilitate maintenance at distance during their working processes. In that context the paper will briefly define the planet Jupiter and its physical characteristics as a “host” of the Juno mission, followed by a brief description of the design of Juno spacecraft and finally the details of maintenance actions taken on JunoCam will be described, based on the information thus available.

2. The Brief Overview of Mirce Science

In order to completely address the working processes in their natural and human environments, it is necessary to normalise operational, maintenance and support actions, together with the resources needed for their executions, the concept of functionability[2] has been created by Knezevic [4]. Hence, this clearly delineates the concept of functionality that is a property of working systems and functionability which is a property of working processes. It is necessary to stress that despite the fact that they verbally sound similar; they are totally different physical properties, which are defined by totally different measures. [1]

In accordance to Mirce Science, [1] from a functionability point of view, working processes could be in one of the following two states:

- Positive Functionability State (PFS) – functionability is being delivered
- Negative Functionability State (NFS), functionability is not being delivered, for any reason whatsoever.

The motion of working processes through functionability states is a physical manifestation of the impacts of compelling natural and human actions, which in Mirce Science are classified as following:

- Positive Functionability Action (PFA), a generic name for any natural process or human activity that compels a given functionability process type to move to a PFS
- Negative Functionability Action (NFA), a generic name for any natural process or human activity that compels a functionability process to move to a NFS.

The motion of the working process through the functionability states is manifested through the occurrences of functionability events which, according to the Mirce Science philosophy, are classified as following:

- Positive Functionability Event (PFE), a generic name for any physically observable occurrence that signifies transition from a NFS to a PFS,
- Negative Functionability Event (NFE), a generic name for any physically observable occurrence that signifies the transition from a PFS to a NFS.

Based on the above, the functionability mechanics describes the pattern of the motion of working processes through functionability states, in respect to the passage of time. The trajectory of this motion is uniquely defined by Mirce Functionability Equations[3]. [5]

3. Planet Jupiter

[2] Functionability is the ability of a working process to deliver measurable function(s) with expected performance and required attributes in a unit of time.
[3] The MIRCE Functionability Equation is not a single formula but a set of equations and computational methods within MIRCE Science, developed by Dr. Jezdimir Knezevic, to quantify and predict the expected work of a working processes over a given period of time.

Jupiter was the first of the Sun's planets to form. It is the largest and most massive planet[4]. It orbits the Sun at a distance of about $7.8x10^8$ km. Jupiter spins extremely fast, with a single rotation taking less than ten hours, which contributes to its flattened, oblate spheroid shape and banded atmosphere.

Jupiter is one of the brightest objects in the night sky that can be seen every 13 months from Earth, due to its orbital period, 11.9 years and the position of the Earth in space.

As Jupiter does not have a solid surface, the "surface" temperature refers to a specific atmospheric pressure level. It varies significantly with altitude; the average cloud-top temperature is around -110°C, but temperatures increase dramatically with depth, reaching thousands of degrees Celsius in its interior. The Great Red Spot is also much hotter than the surrounding atmosphere, reaching temperatures around 1,300°C.

Jupiter's core is extremely hot, estimated at around 24,000°C, which is even hotter than the surface of the Sun.

3.1 Jupiter's atmosphere

The atmosphere of Jupiter is the largest planetary atmosphere in the Solar System. It is primarily composed of hydrogen (90%) and helium, with trace amounts of ammonia, water vapour, and methane.

Deep within the atmosphere, intense pressure compresses the hydrogen into a liquid state, creating a large metallic hydrogen ocean that generates the planet's strong magnetic field. This turbulent, fast-spinning atmosphere features multiple cloud layers and high-speed winds, a result of the planet's powerful internal heat and rapid rotation. The following three distinct cloud layers exist:

- the uppermost layer is likely to be ammonia ice,
- the middle layer probably contains ammonium hydrosulphide crystals,
- the lowest layer consists of water ice and vapour.

As pressure and temperature increase with depth, hydrogen gas is compressed into a liquid. Further down, it becomes metallic hydrogen, an electrically conductive fluid that is crucial for Jupiter's powerful magnetic field, which is 15 times more powerful than Earth's magnetic field, and in some places, more than 50 times more intense. It rotates with Jupiter and sweeps up charged particles, accelerating them to very high energies and creating intense radiation that bombards anything passing near the planet.

The most recognisable features are the colourful latitudinal bands, which are alternating belts of high and low pressure. This long-lived storm, larger than Earth, is located at the boundary of two opposing wind currents.

4. The NASA Juno Mission Objectives

"Italian astronomer Galileo Galilei, in January 1610, saw four points of light near Jupiter; which did not traverse the sky like other stars, they stayed close to the planet. He

[4] The planet Jupiter has a diameter 11 times that of the Earth and a mass (more than 300 times that of the Earth) which is greater than twice the sum of all the other planets.

concluded that they are moons, the first discovered beyond Earth." [6]

"In June 2016 as it approached Jupiter, NASA's Juno spacecraft enjoyed the same orbital view that Galileo witnessed, and captured a unique time-lapse movie of the Galilean moons in motion around the planet." [6]

The principal goal of NASA's Juno mission was to understand the origin and evolution of Jupiter. Underneath its dense cloud cover, lies the answer to the fundamental processes and conditions that likely governed our solar system as it formed. This knowledge can also help further understandings of planetary systems being discovered around other stars. [6]

For many of Juno's instruments to do their job, the spacecraft had to orbit closer to Jupiter than in any previous mission. Thus, to avoid the highest levels of radiation in the belts surrounding Jupiter, Juno's trajectory is long looping orbits that approach it from the north. Over the north pole it dives between the radiation belts and the planet, at times descending to $3.5x10^3$ km above the cloud tops. Juno traverses the planet and exits over the south pole, then zooms far away, even beyond the orbit of the Jovian moon Callisto in order for Jupiter's gravity to pull the spacecraft back for another pass. [6]

5 The NASA Juno Spacecraft

Lockheed Martin is a part of the NASA Team that has developed the Juno spacecraft. It is the first solar-powered spacecraft designed by NASA to operate at such a great distance from the Sun. As Jupiter's orbit is five times farther from the Sun than Earth's, it receives only 4% of the sunlight that Earth does.

To generate adequate power for the spacecraft's computer, instruments and heaters, Juno's solar arrays needed to be quite large; each of its three solar arrays extends 9 meters from the main body. In total, arrays contain 18,698 individual solar cells covering an area of almost 50 m^2. At Earth, the arrays would be capable of generating over 14 kilowatts, yet will provide only about 500 W at Jupiter. However, each expansive array was built as multiple hinged segments, so the panels could fold up before launch, and the spacecraft could fit into the payload fairing of its rocket.

Thus, Juno spacecraft has a distinctive silhouette, like a three-bladed fan spinning through space. Its hexagonal main body measures about 3.5 m high and wide with solar arrays that give it an overall width of 20 meters. [7]

Juno's rotation keeps it stable in flight, the way a spinning top or gyroscope remains steady, as the spacecraft spins twice per minute for science operations, which it increased to five rotations per minute when it performed main-engine manoeuvres.

To protect the sensitive spacecraft electronics, from Jupiter's extreme radioactive environment Juno has a unique titanium vault mounted between the spacecraft main structure and high gain antenna. The vault acts as shielding to protect the critical spacecraft computers and instrument computers from the high energy particles excepted to encounter when the orbit brings it close to the planet. [7]

5.1 Juno's instruments

To map Jupiter's magnetic field and gravity, measure the abundance of water and ammonia in its deep atmosphere and study its aurora, Juno spacecraft caries a suite of instruments capable of observations from radio and microwave through infrared, visible and ultraviolet frequencies. Thus, in addition to particle sensors and magnetometers the following instruments are in Juno's tool box[5]:

- Microwave Radiometer (MWR): To measure the abundance of water and ammonia in the deep layers of Jupiter's atmosphere, obtain a temperature profile of the atmosphere, and make surface and subsurface observations of Jupiter's moons
- Jovian Auroral Distributions Experiment (JADE): To measure aspects of ions and electrons at low energy present in the auroras of Jupiter, and in the vicinity of Jupiter's moons
- Jovian Energetic Particle Detector Instrument (JEDI): To measure aspects of ions and electrons at high energy present in the auroras of Jupiter, and in the vicinity of Jupiter's moons
- Jovian Infrared Auroral Mapper (JIRAM): A spectrometer to provide images of auroras in Jupiter's upper atmosphere, and observations of the composition and temperature of the surface of Jupiter's moons. This was a contribution of the Italian Space Agency (ASI)
- Magnetometer (MAG): To map Jupiter's magnetic field and determine the dynamics of the planet's interior, and map the magnetic field in the vicinity of Jupiter's moons
- Gravity Science (GS): To map the distribution of mass inside Jupiter by measuring its effect on the spacecraft's radio signals to and from Earth
- Radio and Plasma Wave Sensor (Waves): To identify the regions of auroral currents that define Jovian radio emissions and acceleration of the auroral particles, and make similar observations around Jupiter's moons
- Ultraviolet Spectrograph (UVS): To provide spectral images of the ultraviolet auroral emissions in the planet's polar magnetosphere, as well as measure ultraviolet auroral emissions from Ganymede
- Stellar Reference Unit (SRU): This engineering camera is used to help orient Juno in space by taking images of the stars, but has also been employed to take low-light images used to gather information on Jupiter's radiation, atmosphere and lightning, dust rings, and the surfaces of Jupiter's moons

All instruments are fixed, so the rotating spacecraft gives each of them regular turns at their targets during close passes over Jupiter, a trip that takes about two hours from pole to pole.

5.2 JunoCam

JunoCam is a colour, visible-light camera designed to capture pictures of Jupiter's cloud tops. It was included on the spacecraft specifically for purposes of public engagement;

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5 https://www.google.com/search?q=The+instruments+Juno+carries+in+its+toolbox%3A&oq=The+instruments+Juno+carries+in+its+toolbox%3A&aqs=chrome..69i57j33i160l3.2107j0j4&sourceid=chrome&ie=UTF-8 (23.09.2025)

although its images have been helpful to the science Team, it is not considered one of the mission's science instruments. The design specification required a camera to operate in Jupiter's high-energy particle environment for at least seven orbits.

Part of its expected mission was to provide close up views of Jupiter's polar region and lower-latitude cloud belts, and at Juno's intended orbit the camera is able to take images at up to 15 km per pixel resolution. In addition to visible light filters, it also has a near infrared filter to help detect clouds; a methane filter in addition to the visible colour filters.

The camera is a "push-broom" type imager, generating an image as the spacecraft turns moving the sensor in sweeping motion over the observation area. As one of the constraints for JunoCam hardware was mass, the optics of the camera is of limited size. [6]

6. The NASA Juno Mission

On the 5th of August 2011, NASA's Juno spacecraft started a 5-year journey to Jupiter from a Cape Canaveral Air Force Station in Florida, USA.

Juno arrived at Jupiter on 4th July 2016, covering $2{,}9 \times 10^9$ km. On the 5th July 2016, the NASA Juno spacecraft successfully entered a highly elliptical, polar orbit around Jupiter to study the planet's origins, interior, atmosphere, and magnetosphere.

During the first 35 orbits around Jupiter, Juno collected more than 3 TB of science data providing unprecedented views of its satellites. All of this information was available to citizen scientists, which is NASA's first-ever camera dedicated to public outreach.

Juno's microwave radiometer allows scientists to see beneath Jupiter's clouds, revealing information about the planet's deep atmosphere, including the structure and depth of its storms. [6]

The JunoCam physical and electronic interfaces are largely based on the MARDI instrument for the Mars Science Laboratory. However, the housing and some aspects of the camera's inner mechanism have been modified to provide stable operation in Jupiter's intense radiation environment and magnetic fields.

The Juno Team originally expected the craft would make 33 orbits required to compile a full map of the planet. Hence, it was planned to complete all science objectives by October 2017 and then it would be steered it into the planet, to burn up in the atmosphere. [6]

7. Functionability Events Related to Juno Spacecraft

Based on the publically available information, the author could not find any functionability significant event that took place during the Juno mission till December 2022. In the remaining part of the paper a sequence of functionability related events, positive and negative, will be highlighted, which challenged the NASA operational Team during working processes of Juno spacecraft.

7.1 First negative functionability event

On 14th December 2022 NASA's Juno spacecraft completed its 47th close pass of Jupiter.

Afterward, as the solar-powered orbiter was downloading its science data to mission controllers from its onboard computer, the downlink was disrupted.

The issue was an inability to directly access the spacecraft memory that is storing the science data collected during the flyby. The most likely NFA that caused this negative functionability event was a radiation spike as Juno flew through a radiation-intensive portion of Jupiter's magnetosphere.

7.2 First positive functionability actions

On 17th December 2022 mission controllers at NASA's Jet Propulsion Laboratory and its mission partners successfully implemented the first positive functionability action, which was rebooting the computer and putting the spacecraft into safe mode, as a precautionary status in which only essential systems operate.

By 22 December 2022, steps to recover the flyby data yielded the first positive functionability event**,** which meant that the Team was able to successfully download the science data. There is no indication that the science data was adversely affected through the time of closest approach to Jupiter, or from the spacecraft's flyby of Jupiter's moon Io.

On 29th December 2022, Juno returned to nominal PFS. As expected, the majority of the science data collected during the flyby was successfully received and only a small portion was corrupted by the experienced anomaly (NFA).

7.3 Second is negative functionability event

On 19th January 2023, data received from Juno after the 47th flyby, showed that JunoCam experienced a second NFE, which was manifested through the fact that the first four, out of 90, images taken by the spacecraft's JunoCam were degraded. Two of them were unusable and two had a high level of image noise. [3]

The JunoCam Team believes the NFA that caused the loss of these images was an unexpected temperature rise that occurred when the camera power was turned on in preparation for the flyby.

7.4 Second positive functionability actions

As images taken after the instrument returned to normal temperatures were not degraded, the NASA Team decided to take a PFA, which was to change existing rules of the working process and leave the instrument turned on after the next flyby instead of powering it off and then on again before the 49th flyby. [3]

7.5 Third is negative functionability event

According to [3], by orbit 56, nearly all images from the camera were degraded, featuring noise, streaks, and reduced dynamic range. JunoCam's primary problem was radiation, which caused corrupted images.

As the Juno spacecraft was at 592×10^6 km, from the Earth, this was a serious problem for the NASA Team. Clearly a maintenance action was needed urgently, if the camera was to be used to capture high-quality images of Jupiter's moon Io, which was rapidly approaching.

7.6 Third positive functionability actions

The part of the NASA Team that designed and operated the JunoCam knew that NFA are caused by Jupiter's high radiation, but diagnosing the damaged caused was extremely difficult. All indications led to a malfunctioning of the voltage regulator, which is vital to JunoCam's power supply. With few options for recovery, the Team turned to a process known as annealing[6], on the Earth. They knew that this PFA could alter a material like silicon at a microscopic level but didn't know if this would fix the damaged camera. Although not sure that this maintenance action would reduce defects in the material they had to act. The decision was made and their "commanded JunoCam's one heater to raise the camera's temperature to 77 degrees Fahrenheit, much warmer than typical for JunoCam, and waited with bated breath to see the results." [3]

7.7 Third positive functionability event

After a "long-distance microscopic repair" was performed, where JunoCam's internal heater was used to raise the camera's temperature in order to reduce defects at a microscopic level, the test images sent back to Earth during the annealing showed little improvement. However, as the Juno was approaching Io, the images began to improve dramatically.

On 30 December 2023, the spacecraft came within 1500 km of the volcanic moon's surface; when the NASA Team confirmed that "the images received were almost as good as the day the camera launched". [3]

7.8 Baking the card

NASA's unconventional attempt to fix damage caused by radiation to Juno's JunoCam, may have some resemblance to the practices used by those who had a problem with a Graphics Processing Unit, (GPU), which is a specialised electronic circuit designed to rapidly process and render images and video on a computer or other device.

According to Lotz [8] the act of "baking the card" is well known technique to "anybody who has had a faulty graphics card". The thermal treatment of GPU requires taking it apart, removing components that could melt and putting the card itself in the oven. The logic behind this action is that the heat allows the solder to flow bridging any breaks that may have happened over time. It's a technique that may not be well accepted, but it's based on the concept of annealing. It has a huge recognition and approval rate from the relevant portion of the web community[7].

8. Current functionability state of Juno mission process

As of May 2025, the solar-powered spacecraft had orbited Jupiter 74 times. Recently, the image noise returned during Juno's 74th orbit, due to the intense radiation environment

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6 Annealing is a heat treatment process for materials like metals and glass, where affected parts are heated to a specific temperature, for sometime, and then slowly cooled in order to alter their microscopic properties.
7 https://www.youtube.com/watch?v=8Xanr4jkmEc

around Jupiter, which caused microscopic defects in the camera's electronics, particularly its voltage regulator. [3]

However, it is necessary to stress that JunoCam, a visible-light camera on the Juno spacecraft, was designed to last only seven orbits but survived much longer. According to NASA the spacecraft will continue its exploration of Jupiter, its ring system and moons through September 2025, when it will enter its final negative functionability state. The Juno's orbit will degrade naturally and Jupiter's gravity will pull the spacecraft in to be consumed in the atmosphere. [6]

9. Conclusions

The maintenance task at the distance conducted by NASA's Team in charge of Juno spacecraft at the distance of 592×10^9 km from the Earth was analysed through the prism of Mirce Science to draws attention of the future space missions that might benefit from this action. Even further, the Juno Team has successfully applied derivations of this annealing technique on several Juno instruments and engineering subsystems. [3]

It is essential to stress that the opportunities to execute maintenance actions at a distance are only possible if they are envisaged at the design stages of the future spacecraft and conditions created during their working processes, which is main focus of functionability engineering and management professionals within any design Team. [9]

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Mirce Science: Metals Aerosol from Spacecraft Re-entry as a Functionability Mechanism in Human Modifying Stratosphere

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Abstract

The main objective of this paper is to draw the attention of humans on Earth on changes in the natural properties of the atmosphere by re-entries of spent rocket bodies and defunct satellites that generate metal vapours, which condense into aerosol particles and descend into the stratosphere. While majority of models of spacecraft re-entry have focused on the hazard generated by objects that survive to the surface of the Earth rather than the fate of the metals that vaporise are totally neglected. Latest research studies show that vaporised metals traces during spacecraft re-entries can be clearly measured in stratospheric sulphuric acid particles. Over 20 elements from re-entry were detected and traced to alloys used for spacecraft production. As the number of low earth orbit satellites is rapidly increasing it could be expected that within the next few decades nearly half of stratospheric sulphuric acid particles will contain metals from their re-entries. From the Mirce science point of view, it is realistic to assume that the metallic content in stratospheric aerosol will become a human generated functionability action that will shape the working processes of spacecraft in that portion of atmosphere and as such it has to be understood and adequately addressed by all parties concerned.

Key words: functionability, metal particles from re-entry spacecraft, stratospheric aerosol

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1. Introduction

The philosophy of Mirce Science [1] is based on the premise that the main objective of any working process is to deliver expected measurable work during intended time duration, like: miles travelled during one flight, units produced in one shift, energy supplied during 24 hrs and so forth.

Experience teaches us that at any instant of time there is a probability of a working process being interrupted by occurrences of disruptive events, compelled by failures of consisting components, natural causes, human actions or their interactions. For example, on the 25th December 1996, Reuters published an article on a Chinese passenger plane that made an emergency landing due to cracking of the exterior glass of the cockpit window by an unidentified flying object at an altitude of 31,500 feet according to the Yangchen Evening News. The shiny object that fractured the windscreen of the Boeing aircraft could have been a bit of debris from a human made space object (such as a satellite or launch vehicle upper stage) that survived re-entry. As this incident occurred in a location where an airport was available for an emergency landing it had a happy ending.

Fast forward, on the 16th October 2025, United Airlines flight UA1093, carrying 140 passengers and crew, from Denver to Los Angeles, was cruising at 36,000 feet approximately 200 miles southeast of Salt Lake City when the crew reported a cracked windscreen. The captain reportedly stated that he saw an object coming at the last moment and that it appeared to him to be “space debris.” The captain’s claim that the aircraft was “hit by a falling object at FL360” represents an extraordinary statement that, if confirmed, would mark an unprecedented event in commercial aviation history. The crew initially descended to 26,000 feet before ultimately diverting to Salt Lake City, where the B737 MAX 8 landed safely. Investigators will also examine whether any tracking systems detected space debris or satellite fragments in the aircraft’s path at the time of the incident.

It is necessary to stress that irrespective of the results of ongoing investigation there is already proof that the metal particles from re-entry parts of spacecraft/satellites are detected in the stratosphere and by being there could be a mechanism that generates future negative functionability events for working processes of all aviation processes in the future.

However, as of today, there is no international document, agreement or law that addresses the already observed physical reality of human space objects capable of producing hazardous debris impacts from reentering the Earth's atmosphere in an uncontrolled manner. More specifically, any debris from a satellite that survives an uncontrolled re-entry poses a potential collision hazard to aircraft flying between the latitudes under the orbital inclination of the satellite. As human made and managed objects that randomly re-enter the atmosphere are designed with survive re-entry in mind, intense heating loads and aerodynamic forces typically disintegrate each object into fragments of debris that are spread over a vast areas. Some analyses indicate that about 10-40 % of the pre-re-entry dry mass of each large human made space object (800 Kg or greater) typically survives re-entry and constitute debris large enough to be a hazard to people and property [4]. There are currently no standard practices for issuing warnings in areas where debris from a random re-entry or natural meteor falls.
Consequently, the main objective of this paper is to examine the current state of the knowledge related to the existence of metallic particles that are modifying, thus far naturally control and managed, stratosphere by human functionability related actions. As

services provided by spacecraft during their working processes are in the interest of humans, mitigating the problem of space debris should be in the interest of humans too. Thus, as a global problem can only be solved by the global understanding is cooperation; it is the author's firm believe that Mirce science will be a part of mitigating solution.

2. The Brief Overview of Mirce Science

In order to completely address the working processes in their natural and human environments, it is necessary to normalise operational, maintenance and support actions, together with the resources needed for their executions, the concept of functionability[2] has been created by Knezevic [1].

In accordance to Mirce Science, [1] from a functionability point of view, working processes could be in one of the following two states:

- Positive Functionability State (PFS) – functionability is being delivered
- Negative Functionability State (NFS), functionability is not being delivered, for any reason whatsoever.

The motion of working processes through functionability states is a physical manifestation of the impacts of compelling natural and human actions, which in Mirce Science are classified as following:

- Positive Functionability Action (PFA), a generic name for any natural process or human activity that compels a given functionability process type to move to a PFS
- Negative Functionability Action (NFA), a generic name for any natural process or human activity that compels a functionability process to move to a NFS.

The motion of the working process through the functionability states is manifested through the occurrences of functionability events which, according to the Mirce Science philosophy, are classified as following:

- Positive Functionability Event (PFE), a generic name for any physically observable occurrence that signifies transition from a NFS to a PFS,
- Negative Functionability Event (NFE), a generic name for any physically observable occurrence that signifies the transition from a PFS to a NFS.

Based on the above, it is clear that the functionability actions are the governing forces of the motion of working processes in time. The trajectory of this motion is predictable by subjecting them to Mirce Functionability Equations[3]. However, the accuracy of these predictions is directly proportional to the level of awareness and understanding of mechanisms of compelling action.

[2] Functionability is a measure of the motion of working processes through functionability states, caused by functionability actions and observed by occurrences of functionability events [1]

[3] Mirce Functionability Equation is a set of convolution integrals that quantitatively predict the expected work to be done by a given working process over a given period of time. [2]

3. The Atmosphere

"We live submerged at the bottom of an ocean of the element air, which by unquestioned experiments is known to have weight, and so much, indeed, that near the surface of the Earth where it is most dense, it weighs (volume for volume) about the four-hundredth part of the weight of water ..... whereas… on the tops of high mountains it begins to be distinctly rare and of much less weight."
E. Torricelli (1608-47)

The atmosphere of the Earth is a thin spherical layer composed of a mixture of gases compelled by gravitational attraction, 90% of its total mass is found below 40km.

Today, the atmosphere is composed of 13 gases, of which two dominate: oxygen (21%) and inert nitrogen (78%). The other important gases are trace gases, such as: argon (0.9%), carbon dioxide (0.04%) neon (0.001818 %) hydrogen (0.00055), methane (0.00018%) and helium (0.000524%). Ozone makes up a very small percentage of the atmosphere, with the average concentration being about 0.00006%. Finally, radon, krypton, xenon and nitrous oxide, adds up to nearly 0.000004% of the atmosphere.

Ozone, O_3, is created in the stratosphere through a two-step process initiated by ultraviolet (UV) radiation from the sun. First, UV light with wavelengths less than 240 nm breaks apart oxygen molecules O_2 into two individual oxygen atoms (2O).
Second, these highly reactive single oxygen atoms combine with other oxygen molecules to form ozone.

The lowest layer of the atmosphere, the one in which humans live, is named the troposphere. The Greek word tropos means turning; turbulent air motion results in continual mixing, and the troposphere is host to much of what is called weather.

The temperature drops linearly in the troposphere-that is, the decrease in temperature with altitude follows a straight line. The cooling of the air with increasing distance from sea level is about -6.5°C per 100 km.

The troposphere extends to about 11 km, and at its upper edge (tropopause) there is a shift in the behaviour of the temperature. Beyond the stratosphere is the cold stratosphere where the temperature remains a constant –56 °C for about 9 km.

The troposphere undergoes vertical air movement, for example, convection, an upward motion of air due to heating. This effect may alter the lapse rate and cause instability. The rising air gets colder. Once the moisture in the air reaches saturation at the dew-point temperature, it condenses on the huge number of aerosols, dust particles, salts, ions, and so forth, present in the air. The resulting movements of clouds, thunderstorms, and precipitation are part of the origin of local weather.

3.1 Stratosphere

The stratosphere is the second layer of Earth's atmosphere, situated above the troposphere and below the mesosphere. It extends from 6-20 km above the Earth's surface to around 50 km and contains nitrogen (78%) and oxygen (21%).

Around 90% of the planet's ozone is located in the stratosphere, forming the ozone layer, which protects the Earth from harmful ultraviolet (UV) radiation. The remaining 10% is in the troposphere, closer to the Earth's surface, where it is considered a pollutant.

The temperature in the stratosphere increases with height. Causing heat is produced in the process of the formation of ozone4, which is responsible for temperature increases, from an average -51°C at tropopause to a maximum of about -15°C at the top of the stratosphere. Hence, a stable stratified region with very little turbulence or weather.

3.2 Aviation portion of the atmosphere

The composition of the air in aviation atmosphere is gases, listed earlier, water vapour, together with solid particles such as dust, sand and carbon (smoke).

The stratosphere is also the altitude limit of jets and weather balloons, as air is roughly a thousand times thinner there than at the troposphere. Working processes of commercial airliners are typically located at altitudes of 9–12 km, which is in the lower reaches of the stratosphere in temperate latitudes. Flying at this altitude provides the following advantages:

- Being above most weather avoids storms and clouds.
- Improved fuel efficiency, as the thinner air at high altitudes reduces drag, which means less fuel is needed for the same speed.
- Less air traffic, providing more space for large aircraft.

3.3 Meteorological aviation hazards

Meteorological aviation hazards now vie in importance with those based on engineering and therefore their significance cannot be overplayed. The hazards include:

- Wake turbulence
- Mountain Waves
- Rotor Streaming
- Low level wind shear
- Clear air turbulence
- Cumulonimbus-thunderstorms
- Tornadoes
- Tropical cyclones

Further information about aviation hazards can be found in the literature [3].

The above listed aviation hazards have been known to the flying community well before the spacecraft and satellites were created and deployed. Hence, in the remaining part of the paper the human generated aviation hazards will be considered.

4. Human Modification of Stratosphere

The current state of the stratosphere, as a part of the atmosphere, is the result of over 4.5

[4] Ozone, O_3 is created in the stratosphere through a two-step process initiated by ultraviolet (UV) radiation from the sun. First, UV light with wavelengths less than 240 nm breaks apart oxygen molecules O_2 into two individual oxygen atoms (2 O). Second, these highly reactive single oxygen atoms combine with other oxygen molecules to form ozone

billion years of the natural evolution of the planet Earth within the solar system. In contrast, modern humans (Homo sapiens) first appeared in Africa around 300,000 years ago.

Earth has had some form of atmosphere since its formation around 4.6 billion years ago, but its composition has changed dramatically over time. The early atmosphere was very different, consisting mainly of gases from volcanic activity like carbon dioxide and methane, with little to no oxygen. The current oxygen-rich atmosphere is a result of a gradual process that began with the appearance of early life forms, such as cyanobacteria, which produced oxygen through photosynthesis.

Atmosphere as an essential part of life on Earth has been rather of the constant composition over hundreds of millions of years. This is particularly important regarding the ratios oxygen and nitrogen. If the oxygen concentration reaches 25%, all land vegetation, from Arctic to equator would burst into flame, causing a planetary fire. In contrast, if nitrogen levels fell to 75%, the climate would spiral into a deep freeze from which Earth would never recover. [5]

The first human-made satellite, Sputnik 1 was launched on 4th October1957, with the first orbit of the Earth taking 98 minute. That was the beginning of the Space Age.

Today, there are a large number of human made and managed satellites that orbit
Earth whose working processes deliver functions like: communication (TV, phone, internet), Earth observation (weather, natural disasters), scientific research, navigation (GPS) and so forth. They are launched via rockets and stay in orbit by balancing their forward speed with Earth's gravity.

A working process of a satellite in space depends on its mission, design and location, ranging from a few years to decades. They are design to be moved to a higher "graveyard" orbit or get deorbit to burn up in the atmosphere, through a control and managed manner, at the end of the working process. However, some satellites move to NFS unexpectedly and become "space junk", which means that they continue floating through space for an indefinite period of time. The most frequent factors that determine the length of the working process of a satellite are: fuel supply, technological obsolescence or mechanical failure.

It could be said that, that at the early stages of the space age, neither the space sector nor the astrophysics community considered burning up satellites on re-entry to be a serious environmental threat, to the atmosphere, at least. After all, the number of spacecraft and satellite particles released is small when compared with 440 tonnes of meteoroids that enter the atmosphere daily, along with volcanic ash and human-made pollution from industrial processes on Earth.

Fast forward, there is evidence that the atmospheric composition is changing because of human activities. Metal particles generated by the re-entry of spacecraft and satellites burning up in the atmosphere are a part of "space debris". As the number of satellites grows, this problem is expected to increase significantly; scientists have started studying the unknown impact these newly formed metallic aerosols could have on the stratospheric ozone layer, Earth's climate and aviation safety.

5. Formation of Particles from Spacecraft Re-entry

"Metals from spacecraft re-entry don't simply vaporize and vanish. Scientists found them in the stratosphere."[5]

Engineers combine different types of metals to build each component of a spacecraft to perform required function(s). When Murphy and his team analysed data from the 2023 mission [6], together with the data from previous research projects available to them, they discovered the presence of elements such as niobium and hafnium. To the best of their knowledge these two elements have never been found in any type of meteor. Thus, they started seeking their origin. "Eureka," they have found that niobium and hafnium have been used for the production of rocket engine nozzles. However, their analysis has shown that the particles are neither intact bits of melted material nor ablation of the rocket nozzle by hot gases during ascent. Even further, the tanks, structures and rocket engines may have ablated at different times during the re-entry. However, elements from each of them are found in the same stratospheric particles. This suggests mixing or coagulation in the cold far-field re-entry plume.

A re-entry plume is the visible trail of gas and aerosols created when an object like a spacecraft, rocket stage, or meteor enters Earth's atmosphere at high speed. It is a combination of vaporised material from the object and compressed, superheated air, which is able to form glowing, high-temperature gas and particulate matter, like aluminum oxide particles. For spacecraft, these plumes also include exhaust gases from retro-rockets fired for deceleration. [8]
The data obtained, also showed that more than 20 elements from spacecraft re-entry had the same combinations as those used by designers of spacecraft. Even further, it has been found that there are more lithium, aluminium, copper and lead from spacecraft re-entry than from meteorites.

Murhpy and associated researchers [6] also found that particles with silver often also contained tin and lead and especially high copper content, which made them to make "an educated guess" that silver, may be a marker for electronics that are relatively more common in satellites than in spent rocket stages. It appears that diffusion and coagulation are fast enough for some mixing within a given re-entry event but not extensive enough to mix the components of different space re-entry events into the same particles. [6]

There are some significant differences between the ablation of meteors and spacecraft. Most of the meteoric mass is deposited at altitudes between 75 and 110 km by a very large number of sub-millimetre meteoroids. Reentering spacecraft, which are larger and moving more slowly, ablate between 40 and 70 km over a 300 km long footprint. [9]

Almost all of the stratospheric particles with spacecraft metals also contain meteoric metals. The geographically isolated spacecraft particles mix with the global background of meteoric smoke particles as both are taken up in the atmospheric circulation. We may expect that the metals from reentering spacecraft mix with and condense on meteoric smoke particles that are coming from above, followed by more coagulation during descent into the stratosphere. [10]

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[5] Citation: Herring, M. (2023), Spacecraft are sprinkling the stratosphere with metal, Eos, 104, https://doi.org/10.1029/2023EO230444 . Published on 22nd November 2023.

6. Conclusions

"We would like to understand these things before we put all these satellites into orbit, and not after." Murphy [6]

During the last 60 years, Homo sapiens have also been expanding their communications, meteorological forecasting and navigational capabilities through working processes conducted by orbiting spacecraft and satellites around Earth. However, as thousands of satellites burn up during re-entry, scientists are discovering that metals and soot, accumulating high above Earth, look more and more as if it is "an accidental geoengineering experiment"[6] that is modifying the planet's stratosphere.

The latest concern is not related to the spacecraft that orbit the Earth, but from the consequences of their fall back down, as they are injecting metals and exotic alloys into the upper atmosphere. Each of them has a limited duration of being in a positive functionability state, which for most satellites is around five years. The final functionability action taken by humans is to deliberately steer them into the atmosphere to avoid contributing to space debris. When they burn up, the consisting components release clouds of aluminium, titanium, nickel, copper and exotic alloys, along with soot and reactive gases, into the mesosphere and stratosphere. It is estimated that about 900 tonnes of spacecraft material now vaporise in the upper atmosphere every year, which is equivalent to roughly 5% of the mass naturally injected by meteoroids. Hence, humans are introducing materials into parts of the atmosphere where they have never been, with unknown long-term chemical consequences.

Satellite burn-up also produces black carbon (soot), which absorbs sunlight and warms the air around it. While the total amount is small compared with ground-based pollution, these particles form much higher up, where rain cannot wash them out.
Once trapped in the mesosphere (between 50 and 80 kilometres up), they can persist for years, gradually descending into the stratosphere, where most of the planet's protective ozone resides with cascading effects on ozone stability, cloud formation, and temperature gradients.

In summary, this paper is introducing the "re-entry pollution" that reaches from low Earth orbit to the edge of the stratosphere as a new negative functionability action introduced by human managed working processes in space, as an integral part of the application of Mirce science to spacecraft design as an entirely new kind of pollution that could outlast the satellites themselves. Hence, the following words of wisdom, by Professor Eloise Marais[7], should be taken on board, for the benefit of humanity.
"We've treated space as an endless frontier. Now we're learning that what happens up there doesn't stay up there."

7. Addendum

By the time this paper has been completed the mystery of the "falling object" that hit the windscreen of a United Airlines plane, referred to in the introduction of this paper, appears to have been solved. Not long after the National Transportation Safety Board in the USA started investigation Windborne Systems, a California company, quickly concluded

[6] https://aerospaceglobalnews.com/news/space-debris-dead-satellites-atmosphere-pollution/
[7] The new danger of space debris Dead satellites is polluting Earth's upper atmosphere, J Menon, 26.10. 2025

that the B737 Max very likely ran into one of theirs weather balloons, despite the company's best efforts to prevent such collisions. It has not yet been confirmed officially, either way!

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Mirce Science: Moon Night as a Mechanism of the Motion of Space Machines through In-service Reality

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Abstract

The main objective of this paper is to draw attention to the fact that the motion of space machines through in-service time is not only driven by their own capabilities, but also by the actions generated by the natural phenomena of their in-service reality. Hence, this paper addresses the clockwork sequence of occurrences of the day-night cycle on the Moon. This specific phenomenon is a well known property of Moon's physical existence and its position within the Solar system. Consequently, the paper examines the impact of temperatures that go even two hundred degrees below zero during the 14 Earth days long Moon night. This is a permanent challenge for any human mission to the Moon and even bigger for using it as a launch pad for the missions to Mars and beyond. Although these are long term ambitions for the human race, they need solutions. Part of that solution is Mirce Science which provides a framework for predicting the in-service behaviour of space machines by subjecting mechanisms of causing actions to the Mirce functionability equation. This enables designers to compare mission options quantitatively and choose the configuration with the highest probability of success related to the future human ambitions related to inhabiting and exploiting the Moon and space beyond. In the paper, Radioisotope Heater Units, Nuclear Reactors, Solar Arrays and Lithium-ion Batteries, are briefly examined as the primary source of electrical power during the lunar day, together with their generic functionability trajectories.

Key words: space machines, Moon-night, extremely low temperature, Mirce functionability equation, power generating sources

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1. Introduction

"The machine does not isolate man from the great problems of nature, but plunges him more deeply into them." A. de Saint Exupery[2]

The philosophy of Mirce Science [1] is based on the premise that the main objective of existence of any machine is to do work, which is considered done when measurable functions, like miles travelled during one flight, units produced in one shift, energy supplied during one calendar year and so forth, are performed in existing physical reality.

However, experience teaches us that at any instant of time there is a probability of the in-service working process being interrupted by occurrences of compelling actions, caused by failures of consisting components, natural phenomena, human actions or their interactions.

The Moon is one of the most recognisable objects in the Solar system. Due to its proximity to Earth humans have given it immeasurable cultural, scientific and technological significance. Thus, the Moon has been in the main focus of the space explorations driven by human curiosities. Numerous missions have been undertaken to reach and study the Moon, some of them successfully and some less successfully.

Mirce science based analysis of all missions to the Moon, conducted by the author, have shown that despite the fact that the very different public and private organisations from five very different countries have completed their missions, concluded that in-service activities of their space machines never exceeded 14 days. By no means that was a chosen duration of all those missions; it was an un-unintentional, but expected, ending of their missions caused by the in-service reality on the Moon. Due to the clockwork of planetary mechanics of the Solar system that is governed by the Sun's gravitational pull and Earth-Moon space positioning, the lunar night lasts 14 Earth days. During this period of time, removed from the reach of the solar energy the temperature on the Moon surface plummet down up to -230°C and stays there in total darkness for 336 hours.

Consequently, the main objective of this paper, from Mirce science point of view, is the focus on the impacts of the in-service reality on the Moon, manifested through extremely low temperatures during a 14 Earth day long Moon night, on the design, technology, performance and management of space vehicles in respect to the functionability performances of their missions. Thus, the governing mechanism of the motion of space vehicles on the Moon is driven by the mechanics of the motion of the Moon within the Solar system. This means that all human design space machines must be conceived to complete their missions within the duration of the Moon's day or fined the new solutions that will enable successful missions beyond 14 Earth days! The only successful solution thus far are multiple Chinese landers that have used radioisotope power systems, known as nuclear batteries, to keep space vehicles and infrastructure warm during the in-service reality of lunar nights, which will be briefly described in the paper below.

[2] Wind, Sand and Stars, Penguin Modern Classics, translated from the French, 25 May 2000.

2. The Brief Overview of Mirce Science

In order to completely address the motion of machines through in-service reality it is essential to define the measure of the motion in time, the concept of functionability[3] has been created by Knezevic [1].

In accordance to Mirce Science, from a functionability point of view, at instant of in-service time a machine could be in one of the following two states:

- Positive Functionability State (PFS) – functionability is being delivered
- Negative Functionability State (NFS), functionability is not being delivered, for any reason whatsoever.

The motion of machines through functionability states in time is caused by the compelling natural and human actions, which in Mirce Science are classified as following:

- Positive Functionability Action (PFA), a generic name for any natural process or human activity that compels a given functionability process type to move to a PFS
- Negative Functionability Action (NFA), a generic name for any natural process or human activity that compels a functionability process to move to a NFS.

The motion of machines through the functionability states is physically manifested through the occurrences of functionability events which, according to the Mirce Science philosophy, are classified as following:

- Positive Functionability Event (PFE), a generic name for any physically observable occurrence that signifies transition from a NFS to a PFS,
- Negative Functionability Event (NFE), a generic name for any physically observable occurrence that signifies the transition from a PFS to a NFS.

Based on the above, it is clear that the functionability actions are the governing forces of the motion of machines through in-service reality. The trajectory of this motion is predictable by subjecting the mechanisms of their actions Mirce Functionability Equations[4]. However, it is necessary to stress that the accuracy of these predictions is directly proportional to the level of scientific understanding of the mechanisms of compelling action.

The first example of connection between the Mirce Science and the Moon environment related to the motion of machines through in-service reality was addressed in [7]. It examines the functionability focused design of the Moon handheld cameras and the accumulation of lunar dust as a mechanism of the motion of working systems in MIRCE Space. Short overview of Moon dust environment and set of recommendations were given for the future Handheld Universal Lunar Camera (HULC) in order to complete their in-service mission.

[3] Functionability is a measure of the motion of machines through in-service reality caused by functionability actions and physically manifested by the occurrence of functionability event(s). [1]
[4] Mirce Functionability Equation is a set of convolution integrals that quantitatively predict the expected work to be done by a given working process over a given period of time. [2]

3. The Moon

The Moon is the only natural satellite[5] that orbits the planet Earth. While Mercury and Venus have none. The number of natural satellites that orbit other planets is as follows: Mars (2), Jupiter (95), Saturn (274), Uranus (28) and Neptune (16).

There is a generally accepted theory that the Moon had been formed from the debris of a giant impact event that occurred 4.5 billion years ago when an object of the size of Mars struck the Earth. The body that the Earth collided with has been named Theia. It is proposed that the collision led to rock and dust being ejected into Earth's orbit. This rock and dust likely then coalesced to form the Moon, in a similar way to how the dust and gaseous material of the Solar Nebula formed the planets of the solar system.

The Moon is located approximately 384,633 km away from Earth, and has a diameter that is just 1/81 of Earth's diameter. Although the ratio looks small, it makes it the largest moon in the solar system relative to the size of the planet that it orbits.

For a long time, scientists thought that there was no atmosphere on the Moon, but recent studies have confirmed that there is one. The very thin atmosphere, known as an exosphere, contains helium, argon, neon, ammonia, methane and carbon dioxide. It also contains sodium and potassium, which aren't usually found as gases in the atmospheres of Earth, Venus or Mars. [3]

The origin of the atmosphere on the Moon is still not known. Some theories suggest that the solar winds and high energy particles are stripping material from the surface of the Moon. Others propose that evaporation of surface material might be involved or even meteor impacts. However, it could also be a combination of all of these effects.

The Moon offers a unique laboratory for studying geology, conducting astronomical observations without Earth's atmospheric interference, and testing technologies for future missions

3.1 A synodic day on the Moon

The Moon orbits Earth at a speed of 1.022k m/s at the distance 357,000 and 407,000 kilometres, as its orbit is not perfectly circular. At that speed it takes Moon to orbit Earth approximately every 27.3 Earth days. However, it takes exactly the same amount of time for the Moon to rotate once on its axis.
A synodic day on the Moon, also known as a lunar day, is the time it takes for the Sun to return to the same position in the lunar sky, which is approximately 29.5 Earth days. The extra 2.2 days is the time it takes for the Moon to catch up on its rotation and allow the Sun to return to the same position in the Moon's sky, much like a synodic day on Earth.

As the Moon is orbiting Earth at the same rate at which it rotates itself, the same side of the Moon always faces the Earth. This is known as synchronous rotation that led some people to call it the 'dark side' of the Moon. However, this is very misleading; as the Moon orbits the Earth most of its surface is exposed to sunlight at some point, although the far side of the Moon never faces Earth.

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[5] A satellite is any object that orbits a larger celestial body. A "natural satellite" is one that is not human-made.

3.2 Temperature of the Moon

Due to almost no existing atmosphere on the Moon, in full sunshine, temperatures on the Moon reach 127°C, way above boiling point. However, during Moon night time the temperature drops to around -133° C at night on the equator, but can get much colder. Night temperature in permanently shadowed craters near the poles can fall below -246° C, at the Hermite Crater (North Pole).

Natural mechanisms that cause extreme temperatures are:

- Lack of sufficient atmosphere to trap heat or moderate temperatures, facilitates rapid and extreme swings between day and night,
- No heat redistribution due to the luck of air to enable movements to spread heat.
- Heat radiates to space very quickly during the long Moon night

Due to its tilt, some parts of the Moon's surface never see sunlight, allowing water ice to survive in some of its craters. When India's Chandrayaan-1 lunar orbiter passed over the north pole of the Moon in 2009 it found more than 40 craters thought to contain water ice. This confirmed a finding from the previous year that found water ice on the southern pole.

4. Human Missions to the Moon

As of March 2025, there were a total of 27 successful or partially successful human missions that landed softly on the Moon, namely:

- United States: 13 (6 manned and 7 unmanned) successful landings
- Soviet Union: 8 successful unmanned landings
- China: 4 successful unmanned landings
- India: 1 unmanned successful landing
- Japan: 1 unmanned partially successful landing

A very brief review of some of the mission is give below.

4.1 Unmanned missions

The first Moon mission: Luna 9, Soviet Union's unmanned space machine, was the first to reach the Moon. In fact, it was first survivable landing on a celestial body ever made by human race. It was launched on 31st January 1966 and the historic landing took place on the 3rd February. In-service process started immediately and Luna 9 spacecraft sent the first photo ever of the Moon to the Earth. However, after 3 days in-service the mission came to the end, as the batteries ran out of power.
The last Moon mission: Blue Ghost Mission 1, named "Ghost Riders in the Sky", is a robotic Moon landing mission led by Firefly Aerospace, a US Company, marking a major milestone by being the first commercial company to successfully land on the Moon. It was launched on 15th January 2025 and landed on the Moon on 2nd March 2025, in the Mare Crisium basin. Hence, it had approximately 60 days of operations, including 45 days in transit to the Moon and only 14 days and 5 hours of in-service activities on the lunar surface. During that time it: successfully collected science data and transmitted it back to Earth, captured high-definition images of a total lunar eclipse and a lunar sunset.

Also, it successfully tracked Global Navigation Satellite System (GNSS) signals for the first time in lunar orbit and on the surface.

4.2 Manned missions

US National Aeronautics Space Administration (NASA) conducted a series of six successful Apollo missions that landed astronauts on the Moon between 1969 and 1972. Starting with the historic Apollo 11 mission, astronauts walked on the lunar surface, collected samples, and returned safely to Earth, with a total of twelve astronauts landing on the Moon before the program ended. The primary goal was to win the space race with the Soviet Union, but the missions also significantly advanced scientific knowledge about the Moon.

The longest human mission on the Moon was NASA's Apollo 17, which lasted 12 days and 14 hours. This mission was conducted from 7th to 19th December 1972. Also, it delivered the longest time spent on the lunar surface 74 hr, 59 min, 38 sec and the longest total duration on lunar surface extravehicular activities of 22 hr and 4 min. That was the last human visit to the Moon, thus far.

During the design of all Apollo missions the lunar phases had been taken into careful consideration, especially the planning of the Apollo Moon landings. All the landings took place soon after local sunrise because the lunar surface was cool, and the long shadows thrown by the terrain made navigation easier.

4.3 Chinese Chang'e Moon mission

Chang'e-4 is a Chinese lunar mission which was the very first spacecraft to successfully land on the far side of the Moon. The launch was in December 2018 and touched down in early January 2019. This was very challenging as it was constantly facing away from Earth, making any direct communication with a space machine impossible. The Chang'e-4 mission solved that problem by using a relay satellite in lunar orbit to send data back to Earth. The mission also included a lunar rover named the Yutu-2.

The mission's goals of Chang'e-4 were: radar study of the moon's geology, radio astronomy observation, including an attempt to grow plants on the lunar surface.

The Chang'e-4 mission uses a combination of solar panels for power during the lunar day and Radioisotope Thermoelectric Generators[6] (RTGs) for continuous power supply during the cold lunar nights. Solar Panels: Provide electrical power to the lander and rover during the daytime. The lander and the Yutu-2 rover are both equipped with this dual system to survive and operate continuously through in-service reality.

Chang'e-4 has been continuously operating for more than five years on the far side of the Moon

[6] RTGs generate heat from the decay of radioactive material, which is then converted into electricity.

5. Power Supply for the Future Moon Related Missions

Physical evidence has shown that the only Moon missions that continued to operate through in-service reality of the Moon night are the space machines from Chang'e family. Hence, it is to be expected the same type of power generators will be used in the future Moon missions.

5.1 Radioisotope thermoelectric generators

RTGs are nuclear batteries that convert heat from radioactive decay into electricity. The heat comes from the natural radioactive decay of a small pellet of plutonium dioxide, which consists mostly of Pu^{238}. This heat is used to create a temperature difference across a series of thermocouples, which are solid-state devices that convert the heat difference into an electrical voltage through the Seebeck [7] effect, which is the direct conversion of temperature differences to electric voltage. This heat can be transferred directly to spacecraft structures, systems, and instruments, without the need for moving parts or intervening electronic components.

As there are no moving parts in RTGs they are highly reliable for long-duration missions in extreme conditions where solar power is not a viable option. Thus, they can provide a stable power output for many decades.

5.2 The Seebeck effect

In a conductor, heat causes electrons to gain kinetic energy and move more vigorously. Hence, when one part of a material is heated, electrons at the hot end move more, while electrons at the cold end are less mobile. This creates a "jiggle" or spread-out effect at the hot end, resulting in a lower concentration of electrons. The cold end, conversely, has a higher concentration of electrons. The imbalance of electrons created generates an electrical potential difference, or voltage, between the two ends. The end with more electrons becomes negatively charged, and the end with fewer becomes positively charged. This phenomenon is amplified when two different metals are joined into a loop. As each metal responds differently to temperature changes, the differing voltage drops create a net current in the circuit.

The full applications of these natural actions are utilised in thermoelectric generators (TEGs), which convert waste heat into electrical energy and are used to power spacecraft with radioisotope thermoelectric generators (RTGs).

6. Mirce functionability equation

According to Knezevic [1] the Mirce Functionality Equation quantifies the motion of the in-service machine through in-service time through the probability of the event *{working process is being in a PFS at instance of time t}*, denoted as $\varphi(t)$, thus [6]:

$$\varphi(t) = P\left(PFS_{md}, t\right) = \sum_{i=1}^{\infty}\left[O_{md}^{i-1}(t) - F_{mn}^{i}(t)\right], \quad t \geq 0 \qquad 1.$$

[7] Thomas Johann Seebeck (1770-1831) was a German physicist who discovered this natural effect.

where: $O_{md}^{i-1}(t) = P(TPE_{md}^{i-1} \le t)$, is a cumulative probability function of the sequential occurrence of TPE^i, which in this case is the Mood day (*md*), and $F_{mn}^{i}(t) = P(TNE_{mn}^{i} \le t)$, a cumulative probability of the opposite phenomena, which is this case is a Moon night (*mn*). It is necessary to point out that $O_{md}^{0}(0) = 1$, in accordance to the 1st axiom of Mirce science [1]. It is necessary to stress that in this case both functions, $O^i(t)$ and $F^i(t)$ are single event discrete step functions due to regularity of occurrences of day-night cycles on the Moon.

Eq.1 describes the pattern of the motion of space machines through in-service reality of the Moon driven only by its perpetually occurring day-night cycle, as this is the specific objective of this paper. Consequently, the pattern of the motion is determined by the design concept of the space machine and the mission objectives in respect to the survival of the equipment in the space machine during Moon nights.

6.1 Space machine without ability to survive Moon night

Assuming that the space machine does not have the ability to cope with the ferociously low temperatures during the nights on the Moon, the corresponding trajectory of that mission, calculated by Eq. 1 will be as shown in Fig. 1. In this example, it was assumed that the space machine entered the in-service mission on the 5th Earth day of the Moon day, purely for illustrative purposes.

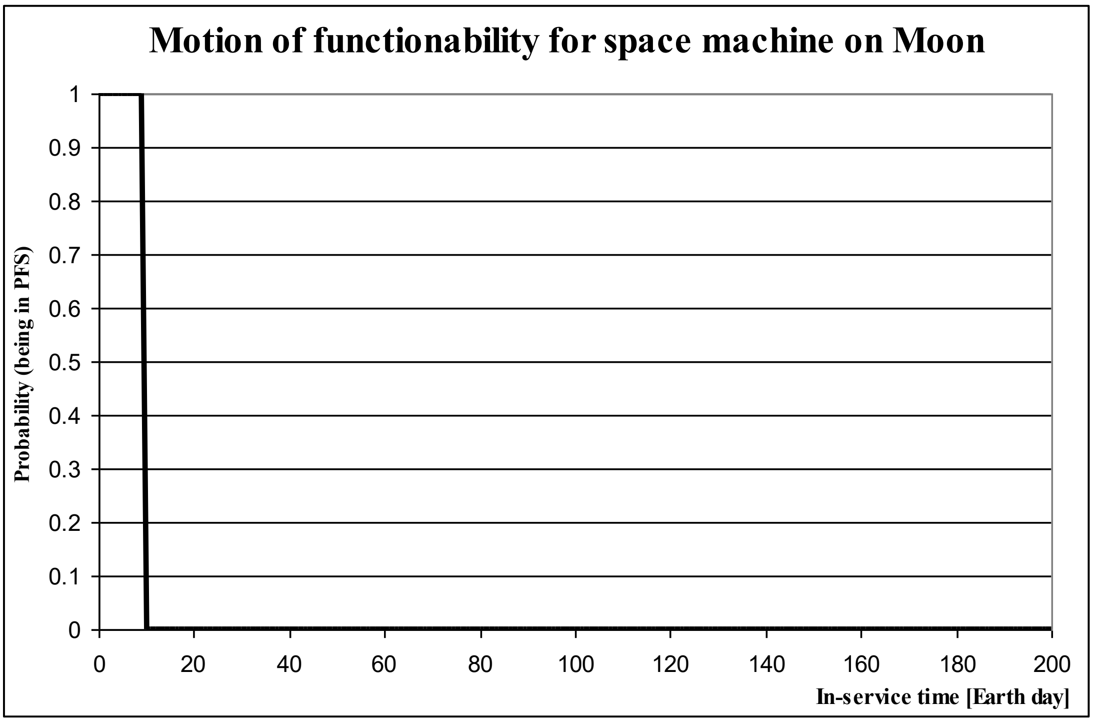

Figure 1: Mirce functionability equation applied to the motion of a space machine without ability to survive the first Moon night.

This example applies to the space machines which are using the following types of power sources, during the in-service reality of the Moon day:

- Solar Arrays: The primary source of electrical power during the lunar day, converting sunlight directly into electricity.
- Lithium-ion Batteries: Used for energy storage to provide continuous power when solar energy is unavailable, and to support high-power operations like driving.

6.2 Space machine with ability to survive Moon night

Assuming that the space machine does have the ability to cope with the ferociously low temperatures during the nights on the Moon, the corresponding trajectory of that mission, calculated by Eq. 1 will be as shown in Fig. 2. In this example, it was assumed that the space machine entered the in-service mission on the 5th Earth day of the Moon day, purely for illustrative purposes.

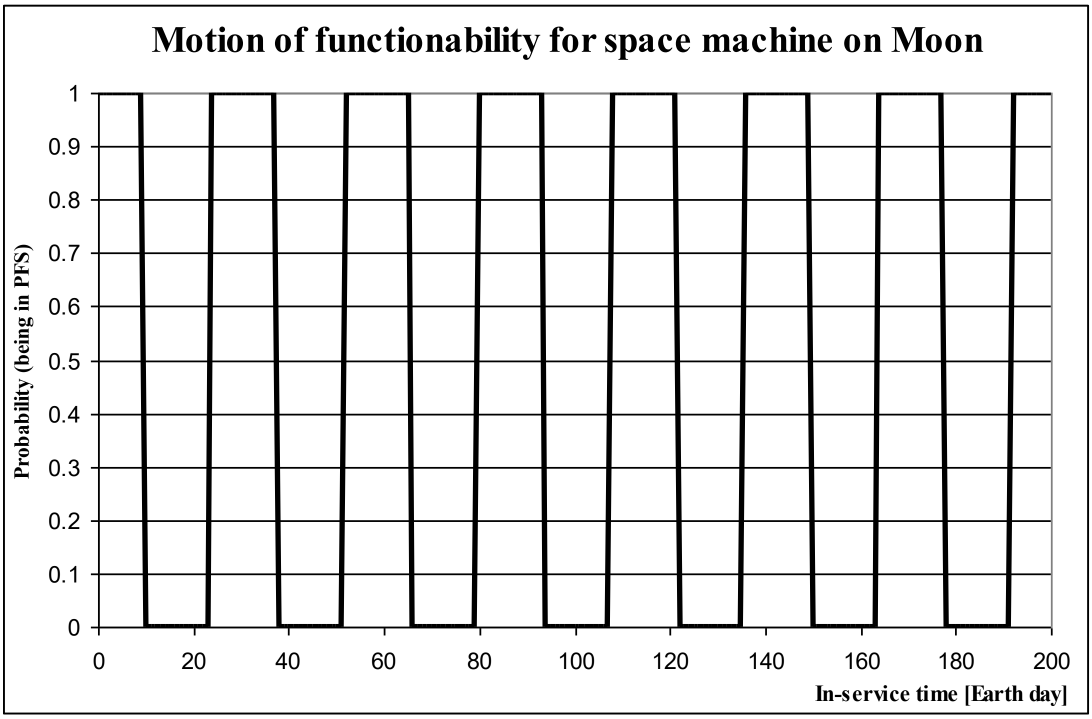

Figure 2: Mirce functionability equation applied to the motion of a space machine with ability to survive Moon nights.

This example applies to the space machines which are using the Radioisotope Heater Units (RHUs), for the provision of the heat to keep instruments and systems warm and prevent damage during the extremely cold lunar nights, not electric power for the equipment required for the mission.

6.3 Space machine with ability of continuing operation during Moon night

Assuming that the space machine does not have ability to cope with the ferociously low temperatures during the nights on the Moon, the corresponding trajectory of that mission, calculated by Eq. 1, will be as shown in Fig. 1. In this example, it was assumed that the space machine entered the in-service mission on the 5th Earth day of the Moon day, purely for illustrative purposes.

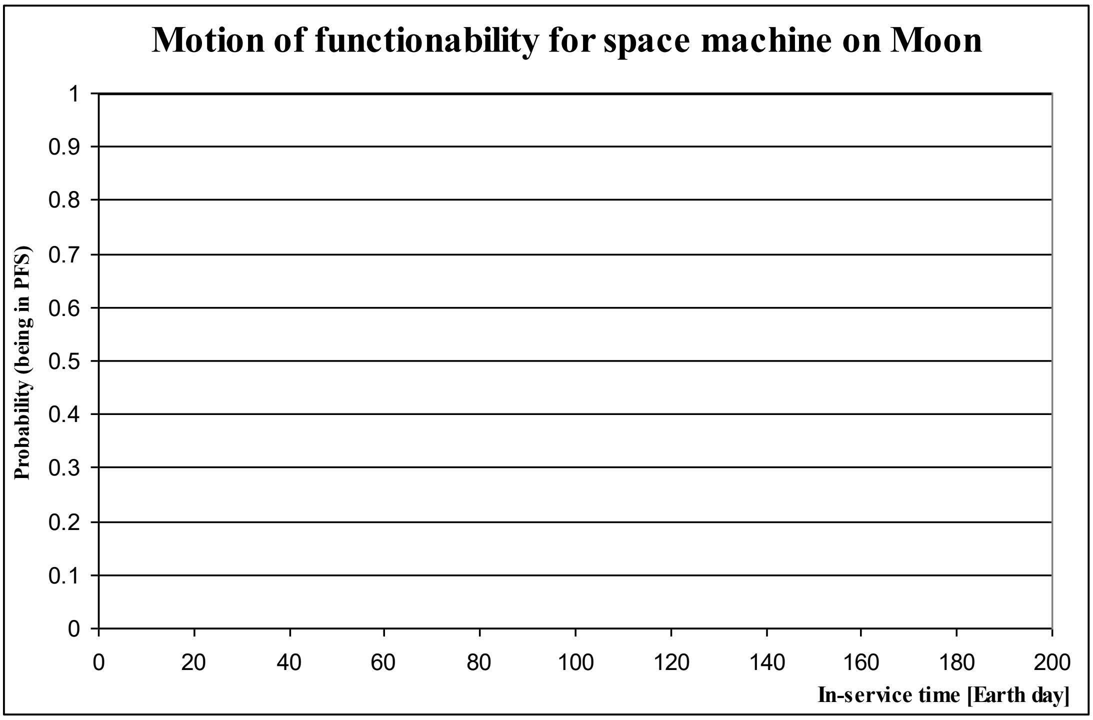

Figure 3: Mirce functionability equation applied to the motion of a space machine with ability to survive Moon nights.

This example applies to the space machines which are using the Nuclear Reactors, which are developments for future, long-term lunar base operations to provide a continuous and reliable power source independent of the day/night in-service time.

7. Conclusions

The Moon is one of the most recognisable objects in the Solar system. Due to its proximity to Earth, humans have given it immeasurable cultural, scientific and technological significance. Thus, the Moon has been in the main focus of the space explorations driven by human curiosities. Numerous missions have been undertaken to reach and study the Moon, some of them successfully and some less successfully.

Thus far, the biggest challenge for humans to stay and research the Moon is the duration of the night there. Due to space mechanics each lunar “night” lasts roughly 14 Earth days. With the sun out of view, temperatures plunge below -200° C, causing solar panels stop generating power, batteries drain and electronics freeze. In 2024 and 2025, the United States made its return to the moon with three commercial landers sponsored by the USA government and industry. Each completed its primary mission but lacked the thermal and power systems required to survive the lunar night, dying within two weeks. However, Chinese landers equipped with nuclear power systems have remained and have been operational for more than 2,400 Earth days.

Consequently, the main objective of this paper is to draw attention to the fact that the motion of space machines through in-service time is not always driven by their own capabilities, but also by the actions that are generated by the natural phenomena of their in-service reality. Hence, the clockwork sequence of occurrences of the day-night cycle on the Moon and its impacts on the in-service performances of the space machine on its surface.

Thus, the paper examines the current options for power supply for space machine in respect to their survivability during the extremely low temperatures during the 336 hours long night on the Moon. This is a permanent challenge for any human missions to the Moon and even bigger for staying there and launching missions to Mars and beyond. In the paper the Radioisotope Heater Units, Nuclear Reactors, Solar Arrays and Lithium-ion Batteries, are briefly examined as the primary source of electrical power during the lunar day, together with their generic functionability trajectories.

As these are long term ambitions for the human race, which will exist as long as humans exist it is in our interest to address it. It is the author's firm believe that Mirce science could assist in the selection of the design solution for the space machines that will have the highest probability of success for the future human ambitions related to inhabiting and exploiting the Moon.

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