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Review Article

Glare as a Mechanism of the Motion of an Aircraft Through the MIRCE Functionability Field

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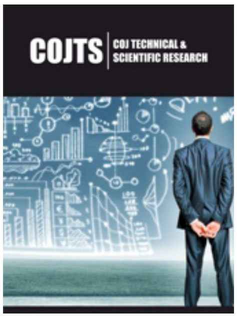
Abstract

MIRCE Mechanics is the discipline of MIRCE Science that focuses on the scientific understanding and description of the phenomena that govern the motion of functionable system types though the MIRCE Functionability Field [1]. A full understanding of the mechanisms that generate the motion is essential for the accurate predictions of the functionability performance of functionable system type. According to the 2nd Axiom of MIRCE Science the motion of a functionable system type through MIRCE Space is a result of imposed natural phenomena or human activities, which are jointly called functionability actions. Thus, the main objective of this paper is to address glare as an observed physical phenomenon in aviation that can contribute to fatigue, due to the frequency with which the pilot's eyes must adapt from cockpit to exterior, from near too far, from dark to light. Although it is not a frequently manifested catastrophic event, direct or reflected glare is a physically observable phenomenon, which has been attributed to impact directly on the performance of humans involved in flying aircraft and operating them on the ground. The paper also presents a set of possible preventions and management actions that could be taken to reduce the consequences of glare on the safety of flying.



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Introduction

MIRCE Mechanics is the discipline of MIRCE Science that focuses on the scientific understanding and description of the physical phenomena and human rules that govern the motion of functionable system type[1] though the MIRCE Functionability Field[2] . A full understanding of the mechanisms that generate this motion is essential for the accurate predictions of the functionability performance of a functionable system type using the mathematical scheme of MIRCE Science [1]. Nakagawara et al. [2] searched 25,226 accidents[3] in the USA National Transportation and Safety Board's (NTSB)'s database for terms including "sun," "glare," "vision," "blinded" and "reflections." They found 130 accidents in which direct or reflected glare was a contributing factor. Of those, 110 occurred during optimal visual and atmospheric conditions, since glare is hardly a risk factor on a cloudy day. Even further, 107 occurrences took place during the daytime hours rather than early morning or evening when the sun is lower in the sky. Further analysis shown that 72 of the accidents considered were associated with landing or departure phases, and of those 52 resulted in a collision with an object or terrain. Finally, 39 of the collisions were due to under or over-shooting the runway or failing to maintain alignment with the runway. Eight glare related events occurred during taxiing. Glare was also cited as a contributing factor in seven midair collisions. The study concluded that, "Exposure to glare from natural sunlight has contributed to aviation accidents, primarily under otherwise optimal visual conditions at low altitude in congested airspace" [3]. Ground and Air Traffic Control (ATC) personnel can also be affected by glare. A tragic example of this occurred on Feb. 1, 1991, at Los Angeles International Airport (LAX). An USAir Boeing 737 had been cleared to land, but the pilots were unaware that a Sky West Metroliner was holding on the same runway awaiting takeoff clearance. The Boeing landed on top of the commuter and 34 people died as a result. The NTSB's findings

[1]Functionable system type is a well-defined set of physical entities whose purpose of existence is to do a functionable work in accordance to natural laws and human rules.

[2] MIRCE Functionability Field is an infinite two-dimensional set of discrete functionability points, each representing a possible functionability state that a functionable system type could be found at any instant of the calendar time [1]. It is defined as: $MFF_S(t) = \{PFS_S^{i-1}(t), NFS_S^{i}(t), i = 1,2,..,\infty, t \geq 0\}$

[3]The NTSB database is the official repository of aviation accident data, causal factors, and selected incident data, whereas the FAA Accident/Incident Data System contains accident and incident data records for all categories of civil aviation.

included the following statement: "The ability of the Los Angeles Air Traffic Control tower personnel to distinguish aircraft on the runways and other airport traffic movement areas, including the accident site, was complicated by some of the Terminal II apron lights, which produced glare" [3]. It is worth pointed out that in many instances the accident report noted that the glare effects were intensified by inadequately maintained windscreens. Dirt, scratches and pitting on the windscreen, scattered the sunlight and further reducing the pilot's ability to see the external environment clearly. The main objective of this paper is to address the glare as a physical mechanism of the motion of an aircraft through the MIRCE Functionability Field and to presents a set of possible prevention and management actions that can be taken by humans in an attempt to minimize the impact to a functionable system from glare and thus continue with the scheduled flights.

MIRCE Science Fundamentals

According to the 2nd Axiom of MIRCE Science[4] the motion of a functionable system type through the MIRCE Functionability Field is a result of imposed natural phenomena or human activities, which are jointly called functionability actions [1]. At any instant of calendar time, a given functionable system type could be in one of the following two observable functionability states:

a. Positive Functionability State (PFS), a generic name for a state in which a functionable system type is able to deliver the expected measurable function(s),

b. Negative Functionability State (NFS), a generic name for a state in which a functionable system type is unable to deliver the expected measurable function(s), resulting from any reasons whatsoever.

The sequential motion of a functionable system type through the functionability states in the direction of calendar time is generated by functionability actions, which are classified as:

a. Positive Functionability Action (PFA), a generic name for any natural process or human activity that compels a system to move to a PFS,

b. Negative Functionability Action (NFA), a generic name for any natural process or human activity that compels a system to move to an NFS.

To scientifically understand the mechanisms that generate functionability events, positive and negative, analysis of the in-service behaviour of several thousands of components, modules and assemblies of functionable systems in defence, aerospace, nuclear, transportation, motorsport, communication and other industries have been conducted at MIRCE Akademy, by members of staff, students and science fellows.

In MIRCE Science all negative functionability actions are categorized as following [1].

Component-internal actions that consist of

a. Inherent actions that are introduced into components prior to their introduction into service through the activities associated with the design, manufacturing, handling, transportation, maintenance, storage and similar processes.

b. Cumulative continuous actions that are an inevitable part of the components in-service life resulting from natural decay processes such as: corrosion, fatigue, creep, wear and similar.

Component-external actions, which are originated by

a. Environmental phenomena that cause discrete overload, like foreign object damage; birds strike (domestic and wild animals), weather (hail, rain, snow, lightening, solar radiation, etc.,) and so forth.

Human activities

a. Errors that are related to phenomena that cause overload, for example use and abuse by operators, (pilots, driver and other users), maintainers (maintenance induced errors) and logistics support personnel (bogus parts, shelf life, etc.)

b. Rules that are related to organizational policies, legal requirements, national and international, best practices or any other human imposed functionability related actions (scheduled and condition-based maintenance tasks).

c. System-internal actions: resulting from processes that are taking place within a system, like a change from passive to active state for certain components and modules, a change in functionability states of some of its constituent components that impact the functionability of the system.

System-external actions: which are generated by

a. Discrete environmental phenomena related to weather (hail, rain, snow, lightening, volcanic eruptions, wind, fog, solar radiation, etc.) and other causes that impact on the functionability of a functionable system type.

Human activities

a. Errors, which are related to the phenomena of use and abuse by: operators, maintainers or supply chain personnel.

b. Rules, which are related to organizational policies, legal requirements, national and international, best practices or any other human imposed functionability actions that cause the occurrence of NFEs for the functionable systems.

This paper discusses the glare, as one of many external functionability actions generated mechanisms that govern a motion of an aircraft from PFS to ma NFS of the MIRCE Functionability Field.

The Mechanics of Human Vision

Human eyes need light[5] to work, and it is essential for colour vision. Light reflects off the objects and it is this reflected light

[4]MIRCE Science comprises axioms, laws, mathematical equations and calculation methods that enable accurate predictions of the functionability performance of a given "future" system to be calculated [1].

[5]According to quantum theory a light is a type of energy. It is a form of electromagnetic radiation of a wavelength which can be detected by the human eye. It consists of discrete packets of energy called photons.

that we observe and interpret as an image of the world. Different objects reflect different amounts and frequency of light. Reflected light entering eyes is collected by retina, which is located at the back of the eye. It is a light-sensitive layer of cells, which are of the following type:

a. Cone cells, which are concentrated in the center of retina where the light is focused by the cornea and lens. This area is called the macula. Cone cells give detailed vision that is used when reading, watching and looking at people's faces. They are also responsible for most of colour vision.

b. Rod cells, which are concentrated around the edge of retina. They help to see things that aren't directly in front of a person giving a rough idea of what is around. They help with mobility and getting around by not bumping into things. They also enable to see things in dim light and to see movement.

Photons passing through the iris are focused by the lens and collected by the retina, which converts them into electrical signals that are send by the optic nerve to the brain. Finally, the brain processes these signals and enables a person to "see" the world around. Although light is an essential part of this process, sometimes it can have a negative impact on human vision. For example, there are times when the amount of light or the quality of that light can affect our ability to see. Many people with impaired vision need more light than is typical to read. However, too much light can cause problems with glare[6] . Some eye conditions can exacerbate glare, including ocular albinism, cataract, macular degeneration, uveitis and some conditions which affect the front surface of the eye such as conjunctivitis, dry eye or corneal problems. There are also some other conditions such as meningitis which cause light to be very painful quite quickly.

Glare as a Physical Phenomenon

Glare is usually defined as a temporary sensation produced by luminance within the visual field that is significantly greater than that to which the eyes can readily respond to and is not associated with biological damage. It is a vision impairment produced by intense light, and it can occur either directly or by reflection. It occurs whenever there is a high contrast between a light source and the object(s) a person is trying to focus on. Unified Glare Rating (UGR) is a unit of measurement of glare in accordance to the International Commission on Illumination (CIE). The UGR is a ratio of light source illuminance and background luminance and can take values from 5 to 40. Glare becomes more drastic as the UGR rises. It's necessary to stress that there is a range of light sensitivity among humans, as some are just more sensitive to light than others. Also, as human grow older they can become more sensitive to light; this is because the eye changes even though there is no underlying eye condition.

Types of glare

Glare can be divided into three types:

a. Blinding or Reflected Glare can be described as glare that is caused by, for example, staring directly into the sun. While reflected glare can be described as light which is reflected off surfaces which are smooth and shiny such as sand, snow and water.

b. Disability Glare can be best described as being blinded by surrounding light sources. Similar to blinding glare, disability glare also has the ability to block vision or a significant reduction in vision capabilities. This is due to a reduction in contrast. For example, driving under the rain in a two-way street causes the light from cars coming in the opposite direction to get scattered by raindrops, impairing vision. In this scenario glare interferes with the task at hand, but without reaching the point of causing pain or physical discomfort.

c. Discomfort Glare can be best described as a sensation that humans are unable to tolerate it and instinctively look away. A drastic example of discomfort glare would be the experience if a High-intensity discharge lamp is turned on and pointed directly at eyes from only a few meters away. The same thing happens whenever humans look directly at the sun by accident. Light sources capable of causing discomfort glare are normally also able to damage human eyes, hence the instinctive reaction to look away.

Sources of glare

Although essential to life on Earth, sunlight could cause a problem for those humans who traverse the skies above Earth. Sunlight is a portion of the electromagnetic radiation given off by the Sun, in particular infrared, visible, and ultraviolet light. On Earth, sunlight is filtered through Earth's atmosphere, and is obvious as daylight when the Sun is above the horizon. When the direct solar radiation is not blocked by clouds, it is experienced as sunshine, a combination of bright light and radiant heat. When it is blocked by clouds or reflects off other objects, it is experienced as diffused light. Flash-blindness is a visual interference effect that persists even after the source of illumination has been removed. After image occurs when a transient image is left in the visual field after exposure to a bright light. These can temporarily impair vision as the spots appear to be burned into one's vision. Even if the spots are small and not in the center of the eye, they can still be distracting. Glare affects the ability to maintain visual awareness and therefore can impair flight safety and is a frequent factor in all air operations. Glare can come directly from the light source or can take the form of veiling glare, reflected from crazing or dirt on the windscreen. The visual phenomenon affects a pilot's ability to accurately detect objects, especially when they are in the same direction as the glare. For example, Air Traffic Control (ATC) issues a traffic alert for an aircraft straight ahead and it happens to be flying with the sun in that same direction. Hawkins [4] states that when the source of the glare is only 5 deg. away from the direction of view, the loss of visual effectiveness is an astounding 84%. When glare is 40 deg. from the line of sight, the loss of visual effectiveness drops 42%.

Nighttime glare

For pilots operating an aircraft at night preservation of optimal night vision is of vital importance. When the eyes have adapted to

[6]Light Sensitivity (photophobia), Eye Conditions Fact Sheets, Royal National Institute of Blond People, London, UK, 2016, pp. 11.

low-light levels, exposure to bright light can result in temporary visual impairment due to glare, flash-blindness, and afterimages. Nakagawara et al. [4,5] also examined the role of glare at night. Their study revealed that the eye is much more sensitive to light at night because it relies primarily on the rods for night vision. In order for eyes to adapt to low light they undergo a chemical reaction using photoreceptor pigments. Intense light decomposes the photoreceptor pigments reducing sensitivity to dim light. Regeneration of the photo pigment occurs during night adaptation. The regeneration of these pigments can take 30 to 60 minutes after exposure to bright light. This is a serious problem in flight for obvious reasons. Pilots commented that they lost depth perception after experiencing glare or from being flash blinded by approach or runway lights, which caused them to land long or short, resulting in a collision with terrain.

The FAA study cited an incident in which a pilot asked the control tower to turn up the intensity of the approach lights to aid visually acquiring the runway on approach but then reported experiencing excessive glare in contact lenses on short-final. Consequently, that resulted in a collision with the approach light structure. Pilots also reported visual difficulties when their landing lights reflected back into the cockpit due to dust, fog, rain, snow or ice. Other sources of glare were taxiway/apron lighting, aircraft lights, lasers and emergency vehicles, among other things. Ineffective lighting configurations in the airport environment appear to be the root cause of these visual difficulties while taxiing. The majority of the taxiing incidents involved pilots straying off ramps, taxiways, runways, hitting obstacles or other aircraft. Undoubtedly, many pilots have experienced the problem with poorly positioned ramp or apron lighting that hampers the ability to distinguish runway markings or to determine exactly where the taxi surface begins and ends. Coincident with these conditions were inadequate taxiway markings. The study's authors highlight the increased risk of runway incursions, collisions and excursions from aircraft movement areas when pilots cannot adapt to the dark [6,7].

Human made glare

Solar power is a growing source of "clean" energy for many communities. While solar power panels provide a useful means to generate revenue and to provide energy locally, nobody expected that it will pose a potential hazard in the form of glare. Airplane pilots reported that they were blinded by the intense sunlight reflecting off some of the 340,000 mirrors at the Ivanpah Solar Electric Generating System on the California-Nevada border. The Ivanpah power plant is about 40 miles from the Las Vegas airport [8]. The mirrors, called heliostats, focus the sun on 140 metre towers that contain water-filled boilers. The concentrated sunlight boils the water to create steam, driving turbines that generate 377MW of carbon-free electricity. The heat is so blistering that it has melted the feathers of birds in mid-flight [6]. Planes fly far too high to be affected by the heat, but not by the light[7] . According to Air traffic controller at a Federal Aviation Administration (FAA) center that monitors the airspace in southern California Daily, during the late morning and early afternoon hours there are numerous reports from pilots[8] of aircraft flying from the northeast to the southwest about the brightness of this solar farm.

In USA the Aviation Safety Reporting System (ASRS), receives more than 1,300 reports weekly from pilots, air traffic controllers and other aviation personnel, according to the organization's website. If the reports identify a hazardous situation, the ASRS issues an alert to the appropriate government agency in USA [8]. Aviation officials have long been concerned about the impact of huge solar power plants, and in recent years the US military has vetoed the construction of projects near bases in the California and Nevada deserts.

Impact of Glare on Pilots Vision

The most significant feature of glare encountered in flight is its variable nature. It is variable in intensity and in direction, and while the pilot may be subjected to these variations very quickly within the space of seconds, she/he may on the other hand be exposed to glare from one direction for a period of several hours. Also, the frequency, with which the pilot's eyes must alternate from cockpit to exterior, from near too far, from dark to light, combines with all these factors to produce a visual environment that most readily results in fatigue and difficulty in seeing. When operating below clouds, and at lower altitudes, the light comes from above. However, at high altitude there is a reversal of light distribution, particularly when flying above a layer of clouds. Once an aircraft climbs above a cloud deck most of the light reflected back into the aircraft comes from the cloud layer below. It is estimated the clouds underneath effectively reflect 80% of the sunlight. Some light does come from the sky above, but the amount of scattered light that comes from the sky becomes progressively less as the aircraft flies at higher altitudes. This altered light distribution results in more light reaching the upper part of the cockpit and in less reaching the lower part, which is therefore darker than it would be at a lower altitude.

At high altitudes the change in the light spectrum causes a visual illusion in the pilot's ability to see contrasting shades of colour. When a dark and a bright area are adjacent to each other, the bright area appears brighter and the dark area darker. Human anatomy plays an interesting role in accommodating this visual phenomenon. A light source below eye level can actually flood one's vision and cast a troublesome haze over the entire visual field. Sunglasses reduce the luminance of the outside scene, bringing it to a comfortable level, but they also reduce the luminance of

[7]From the pilot's seat of my aircraft the brightness was like looking into the sun," reported one pilot as his small plane climbed from 6,000 to 12,000 feet after taking off from the Boulder City, Nevada, airport. In a report he filed with the Aviation Safety Reporting System (ASRS), the pilot wrote that, "In my opinion the reflection from these mirrors was a hazard to flight because for a brief time I could not scan the sky in that direction to look for other aircraft [8].

[8]In my opinion the reflection from these mirrors was a hazard to flight because for a brief time I could not scan the sky in that direction to look for other aircraft [8].

the already dark interior of the cockpit. Humans have different tolerances for illumination from high intensity light sources. Age is one of significant factors. Older eyes have less tolerance for high-intensity light. In addition, eye pigment, which is the colour of retina, influences an individual's tolerance for glare and people with a lighter pigment have less tolerance than those with darker pigment. Abnormal eye conditions can also increase glare sensitivity as can contact lenses. Cataracts will cause a person to see halos around lights. While modern medical procedures such as lens implants, cataract surgery, radial keratotomy and laser refractive surgery offer visual sight improvement, they can result in discomfort or disability glare, according to abundant references cited in [2].

Glare Protecting Methods

When possible, pilots could consider alternative flight routes and takeoff and landing directions. However, as a practical matter, it may not be possible to choose a different route or an alternate runway to avoid glare. The FAA's "Natural Sunlight" study [2] recommends the following actions could have a positive impact on the poetical negative consequences of a glare effects on pilots and safety of flights, thus:

a. Enlisting a co-pilot or passenger to help read important instruments and/or printed flight documents including checklists and approach plates so the pilot-flying can focus attention on overcoming glare conditions.

b. The aircraft's sun visor or a brimmed hat can provide shielding to the pilot's eyes from glare.

c. Avoiding light-coloured clothing as it creates a reflection on the windscreen.

d. Light-coloured or reflective materials should not be place on the glare shield since they can reflect light off the windscreen.

e. Preventive maintenance on the windscreen is necessary when scratches or pits cause unacceptable light scatter.

f. Periodic windscreen polishing prevents additional light scatter as well.

g. Cleaning the windscreen thoroughly during the pre-flight check

h. Use of appropriate sunglasses can minimize the effects of glare by establishing a proper balance between visibility of objects inside and outside of the cockpit environment.

i. Use of larger lenses and wrap-around frame styles can prevent sunlight from entering peripherally and affect the wearer's vision[9].

Conclusion

The main objective of this paper was to address glare as a physical mechanism of the motion of an aircraft through the MIRCE Functionability Field [1]. Although it is not a frequently manifested catastrophic phenomenon, glare is a physically observable event, which has been attributed to impact directly on the performance of humans involved in flying aircraft and operating them on the ground [2-5]. Glare as a physical mechanism is briefly explained in the paper together with all three types of its manifestation, namely: blinding (or reflected), disability and discomfort, considering their main characteristics and potential impact on pilots and air traffic controller. These effects can result in prolonged visual impairment and be extremely hazardous to pilots in flight who require optimum vision all the time. Pilots are exposed to various meteorological conditions while in-flight that may increase glare and limit visibility and contrast. They are often subjected to direct and indirect sunlight, which can act as an intense source of glare.

Furthermore, while flying at high altitude pilots may be exposed to darkened skies above and bright reflected light from the clouds beneath. Physiologically the contours of the human face serve to protect the eyes from bright light coming from above, but not from below. It has been pointed out in the paper that in many instances the accident report concluded that the glare effects were intensified by inadequately maintained windscreens. Dirt, scratches and pitting in a windscreen scatter the sunlight and further reduce a pilot's ability to see the external environment clearly. While solar power panels provide a useful means to generate a "clean" energy for many communities nobody expected that it will pose a potential hazard in the form of glare to the aviation community. In USA the Aviation Safety Reporting System (ASRS), receives more than thousand reports weekly from pilots flying from the northeast to the southwest about the brightness of this solar farm, according to the organization's website. This paper clearly confirms that glare from natural sunlight and other sources has caused visual impairment of pilots while operating aircraft and has contributed to the transition of an aircraft from positive to negative functionability state, resulting in the reduction or potentially cessation of the functionability work done.

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