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Operations

ORIENTATION IN AVIATION

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This pamphlet implements AFPD 11-4, *Aviation Service*, and AFI 11-403, *Aerospace Physiological Training Program*. It provides all aircrew with a source of reference for information and techniques in spatial disorientation (SD) prevention and recognition and covers basic physiology of orientation threats in-flight. It describes the body's orientation systems, explains how to prevent SD, the factors that increase and decrease SD risk, and countermeasures to avoid SD. This pamphlet applies to all aircrew. Refer recommended changes and questions about this publication to the Office of Primary Responsibility (OPR) using the AF Form 847, *Recommendation for Change of Publication*; route AF Form 847s from the field through the appropriate functional chain of command. Ensure that all records created as a result of processes prescribed in this publication are maintained in accordance with AFMAN 33-363, *Management of Records*, and disposed of in accordance with Air Force Records Information Management System (AFRIMS) Records Disposition Schedule (RDS) located at **https://www.my.af.mil/afrims/afrims/afrims/rims.cfm**.

Chapter 1

SD INCIDENCE AND RISKS TO AIRCREW

1.1. Introduction. Spatial orientation is the correct perception of one's location and orientation within an environment. Aspects of accurate perception in flight include recognition of the location of the ground, changing terrain, and the horizon, as well as correct orientation of yourself and your aircraft relative to known natural and man-made objects in the immediate environment. Spatial orientation must account for the 3-dimensions of forward-aft, up-down, and left-right, as well as the concept of time.

1.1.1. In contrast to spatial orientation, SD is an incorrect perception of one's linear and angular position and motion relative to the plane of the earth's surface. Specifically in the flight environment, SD is an erroneous percept of any of the parameters displayed by aircraft control and performance flight instruments. Regardless of a pilot's experience or proficiency, sensory illusions can lead to differences between instrument indications and what the pilot "feels" the aircraft is doing. **Disoriented pilots frequently are not aware of their orientation error and upon recognizing a conflict exists, often believe an instrument to be in error.** Many crashes occur when pilots fail to recognize that SD is happening or when there is not enough time to recover once a conflict has been properly diagnosed. In general, unrecognized SD tends to occur during task-intensive portions of the mission, while recognized SD occurs during attitude changing maneuvers. As researchers[1] have stated, "Accidents do not occur because people gamble and lose, they occur because people do not believe that the accident about to occur is at all possible."

1.1.2. Another description of SD by Benson is that SD occurs when "the pilot fails to sense correctly the position, motion, or attitude of his aircraft or of himself within the fixed coordinate system provided by the surface of the Earth and the gravitational vertical."[2] Later in this publication, different types of SD misperceptions and illusions are described. It is rare to experience a single isolated and easily categorized misperception. Often confusing visual and vestibular cues combine to induce SD in a pilot. For instance, many vestibular illusions would not occur if adequate visual cues (terrain, horizon) were present. And furthermore, when a confusing vestibular sensation results from extreme maneuvering in a high-performance aircraft, it is a mixture of linear and angular accelerations and consequently a misinterpretation of linear and angular false sensations.

1.2. SD Mishap Statistics. SD mishap statistics are presented in this document to provide trend information and show the influence of training and mitigation strategies over many years of aircraft operations; these data originated from USAF Safety Center presentations and other published or formally presented findings. As one researcher found, mishap statistics can significantly vary depending on the definitions used by the mishap board or investigator or by the search terms used in data gathering from a centralized databank.[3] For more recent statistics on SD mishap rates, consult the centralized safety reporting database or the AF Safety Center website.

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[1] (Gibb, 2007)
[2] (Benson, 1988)
[3] (Previc and Ercoline, 2004)

1.3. SD Incidence. SD is an important issue for concern due to the high percentage of fatalities in accidents attributed to SD. According to NATO's SD Working Group, "across all aircraft categories, the percentage of aircraft accidents with fatalities was 2.2 fold higher in SD accidents compared with non-SD accidents."[4] From FY1993 to FY2010, there were 62 USAF Class A mishaps with SD as causal or contributory costing 86 fatalities and $2.0B.[5] An examination of USAF mishap data, shown in Table 1.1, found that from FY2003 to FY2011, SD had an estimated causal or contributory role in 33 mishaps (13%) resulting in 30 fatalities (41%) and costing $1.1B. Consequently, not only is the problem still plaguing modern-day USAF aviation, it may be getting worse. USAF Safety Center data clearly shows the overall Class A mishap rate (accidents per 100,000 flying hours) has gone down significantly over the past few decades, yet the SD mishap rate has remained constant in those same decades. **Figure 1.1** depicts the FY2007 to FY2011 data with a decreasing overall mishap rate, yet steady, if not increasing SD contributions.

Table 1.1. USAF Cost of Spatial Disorientation.

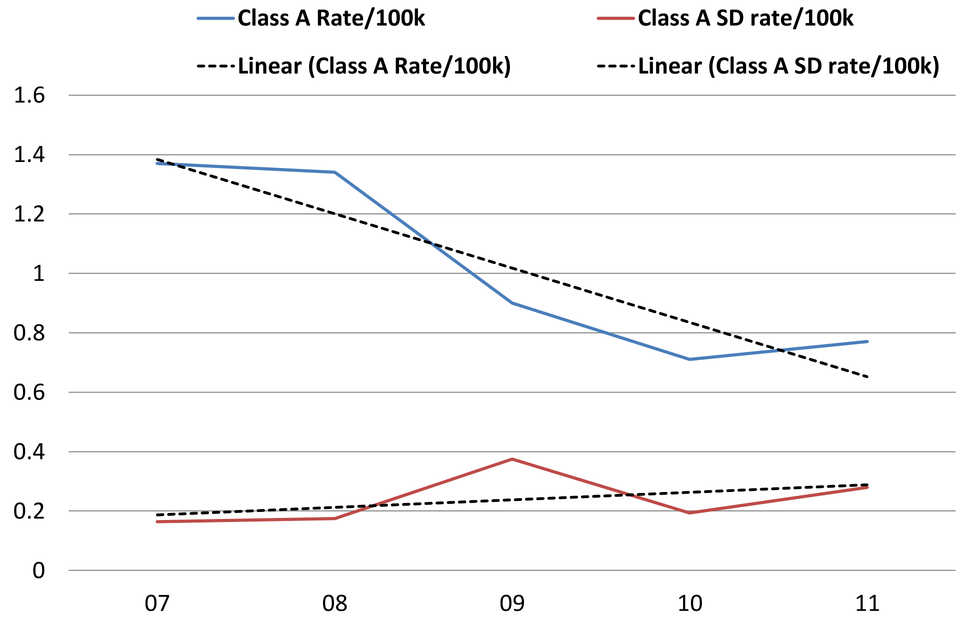
	Fiscal Years	Dollars	Mishaps	Fatalities
Class A	FY2003 – 11	$5.9B	245	73
SD Contribution		$1.1B (19%)	33 (13%)	30 (41%)

1.3.1. Historically, the rate of SD has remained relatively constant according to one study examining accident rates between 1958-1971 to 1972-1992 (0.32 and 0.35, respectively); however, a near 10% increase in accidents being caused by SD was noted.[6] In 2012, SD mishap data from FY03 to FY11 showed a surprising reduction in Class A mishaps per 100K flying hours, but mishaps attributable to SD increased from 0.2 back to the 0.3 seen in the previous studies of 1950s data.[7]

1.3.2. Lack of improvement in SD mishap trends may be caused by aircrew under-appreciation, under-estimation, poorly understood operational definition of SD, inaccuracy of SD contributions in mishap investigations, and failing to respect certain mission-phase vulnerabilities to SD. Additionally, engineering limitations within the design phase negatively affect a thorough analysis of operator workload and cognition. USAF aircrews are facing increasingly complex missions in more challenging environments. The cognitive demands of advanced avionics systems, head/helmet mounted displays, night vision devices, and night/all-weather environments are putting aircrew in situations with high risk for SD.

[4] (TR-HFM-118, 2008)
[5] (Hancock, 2011)
[6] (Ercoline, DeVilbiss, Lyons, 1994)
[7] (Musselman, 2012)

Figure 1.1. Class A Aviation Flight and SD Mishaps (FY 07-11)[8].



1.4. Susceptibility. Sensory illusions occur regardless of pilot experience or proficiency; no one is immune to SD. All pilots are susceptible to illusions while flying at night, in various weather conditions, during extreme maneuvers, and even in visual meteorological conditions (VMC). In other words, SD may happen at just about any time. The previous study examining SD mishaps from FY2003 to FY2011 also examined total flying hours of the pilots involved in Class A SD mishaps.[9] The study found that total hours of the pilots involved in Class A SD mishaps ranged from 500 to 4,000 flying hours, with an average of 2,000 total hours. The study also found that a pilot with fewer than 1,000 flying hours in a particular aircraft increased the odds of an SD mishap, regardless of total flying hours. Other factors which increase the risk of aircrew developing SD include: night flight (2.1 fold), instrument meteorological conditions (IMC, 2.7 fold), poor backdrop (3.2 fold), and adverse Crew or Cockpit Resource Management, (CRM, 3.8 fold).[10] In USAF flight operations, the primary factor cited as leading to disorientation is inattention (50%); in the majority (85%) of these cases, the aircrew's disorientation remained unrecognized.[11]

1.5. Coping with SD. In order to assist aircrew who face a higher risk of disorientation, NATO's SD working group recommends training in multi-task, high workload simulations to demonstrate SD susceptibility, using scenarios such as low-level abort into weather, maneuvering over water in haze, tanker rejoin at night, or cockpit distraction while on NVGs.

[8] (Musselman, 2012)
[9] (Musselman, 2012)
[10] (TR-HFM-118, 2008)
[11] (TR-HFM-118, 2008)

Improving the aircrew's understanding of the sensory systems, physiological mechanisms of various illusions, and conditions of flight where these illusions may be expected can help to successfully prevent or cope with SD. Training is important to counter susceptibility to SD since often SD occurs with other contributing factors such as fatigue, impoverished visual conditions, and cognitively demanding tasks (intense mission phases of flying). Because of these contributing factors, NATO recommends training on high-risk scenarios during advanced flying training, operational flying training units, upgrade to flight lead or instructor, conversion to a new aircraft, standardization/evaluation check rides, and annually.[12] High fidelity trainers and simulators can be used to practice instrument crosscheck and effective CRM in realistic situations typically resulting in SD. One study of pilots trained in SD simulator training showed the aircrew in the "SD Trained Group coped significantly better in terms of maintaining situational awareness and crew resource management than the control group" and were rated more prepared for the unexpected, resulting in fewer near controlled flight into terrain (CFIT) or crashes than an untrained control group.[13] Hence, through training a pilot could learn to recognize environmental cues and risk-assess situations in which SD is more likely to occur.

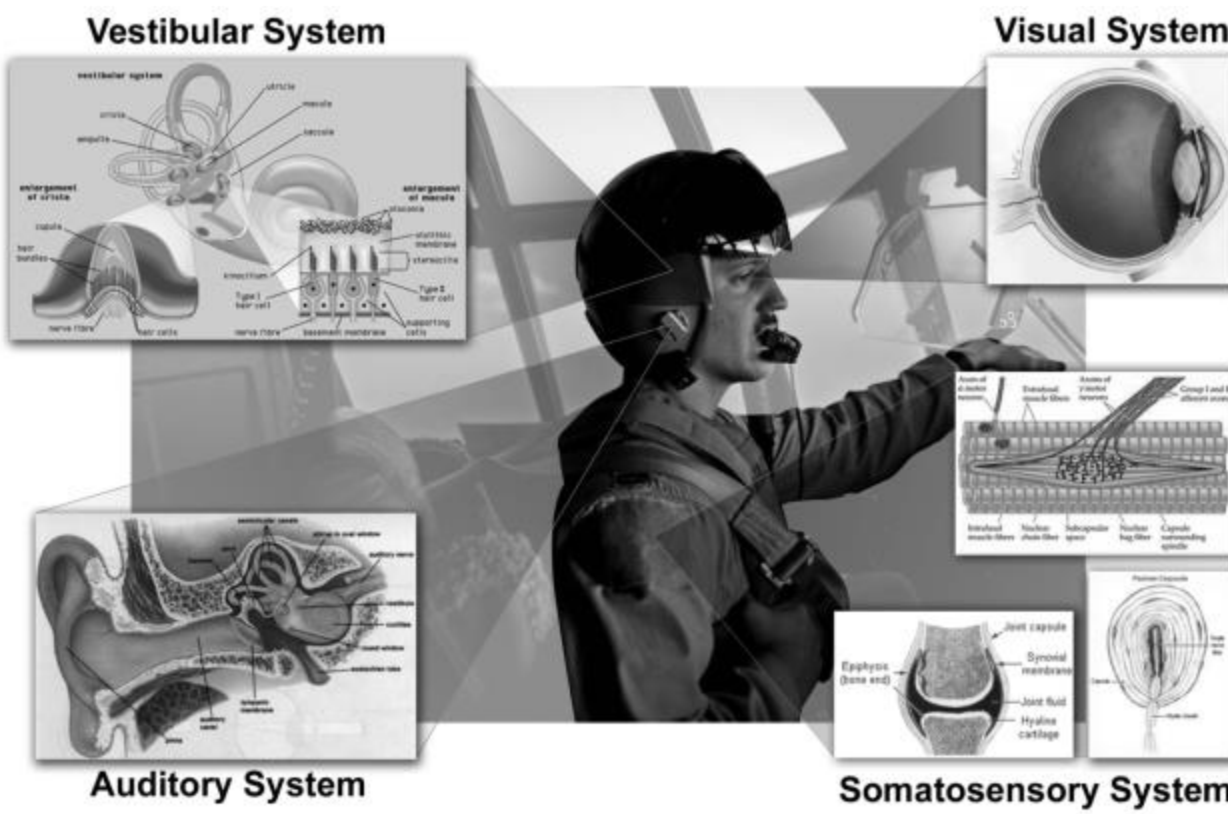
[12] (TR-HFM-118, 2008)
[13] (TR-HFM-118, 2008)

Chapter 2

MECHANISMS OF VISION & ORIENTATION SYSTEMS

2.1. A person's perception of spatial orientation develops from the interpretation of sensory input by the conscious and subconscious aspects of the brain. The subconscious mind uses sensory information from the ambient (or peripheral) visual system, the vestibular system and the somatosensory system to maintain orientation and equilibrium, as well as auditory inputs. This information is processed automatically at very high rates and without conscious effort. When walking on the ground, with a known horizon and constant G-force, our visual, vestibular, and somatosensory processes work exceptionally well in maintaining our spatial orientation. The conscious mind employs central (focal) vision to determine spatial orientation by comparing sensory inputs to known experiences. In contrast to the speedy processes of the subconscious, information processed in the conscious mind is relatively slow, requiring active thought, but is normally very accurate. For earthbound activities, our subconscious orientation system receives adequate information from the sensory systems. Four systems are used for spatial orientation: visual, vestibular, somatosensory, and auditory (**Figure 2.1**).

Figure 2.1. Four Orientation Systems.



2.2. However, when a person is subjected to the flight environment, these sensory systems are no longer adapted to the environment and the conscious and subconscious mind may misinterpret information from the sensory systems regarding orientation in space. When a pilot can easily see his/her flying environment by looking out the window/glare-shield, the process of spatial orientation is direct and seemingly effortless, because much of it is accomplished by unconscious processes. Any confusing vestibular inputs are ignored because of visual dominance. Within the flying domain, vision accounts for nearly 80% of a pilot's orientation. In contrast, when flying in IMC or without reliable external attitude or motion cues, only the conscious mind can correctly determine true orientation, through the use of focal vision and attention to flight instruments. With an 80 % loss of orientation due to impoverished visual conditions, it is very difficult to ignore the 20% of confusing vestibular input. Even though it is possible to indirectly establish spatial orientation through aircraft instrumentation and displays, orientation comes at a high cognitive demand. This high cognitive and attention demand of the pilot competes with other mission-specific demands such as in-flight mission planning, decision making, and risk assessment of different courses of actions.

2.3. Visual System. Vision is by far the most important sensory system for providing true spatial orientation during flight. In the absence of vision, orientation would be derived solely from the less accurate vestibular or somatosensory systems, and these systems do not provide reliable motion and position cues in the flight environment.

2.3.1. Visual Dominance. To minimize the effects of SD, aircrew must understand visual perception, by experiencing the concepts of visual dominance and vestibular suppression. We rely heavily on the visual system to successfully function within our normal everyday environment. This visual system must dominate the other sensory inputs. Consequently, we must learn to suppress the vestibular input experienced in the unique flight environment. Vestibular suppression is the ability to suppress unwanted vestibular sensations and reflexes. A pilot's ability to accomplish vestibular suppression comes from practice or exposure to the motion of the flight environment. An experienced pilot is more likely to suppress vestibular signals than an inexperienced pilot.

2.3.2. Ambient and Focal Vision. The visual system is actually composed of two separate visual systems providing different visual functions.

2.3.2.1. The ambient (mainly peripheral) visual system is primarily concerned with the question of "where," thus providing us an important piece of the spatial orientation mental "picture." Because ambient vision is monitored at the subconscious level, the information is processed automatically at very high rates and without conscious effort. The ambient visual system is most sensitive to motion and works well in low light conditions. It has very poor acuity, meaning object recognition does not usually occur without bringing the object into focal vision (see below). The ambient visual system is what allows you to perceive a change in attitude relative to the horizon without consciously being aware that you noticed a change in attitude. The ambient visual system is what allows pilots to orient themselves within their environment.

2.3.2.2. The focal (or central) visual system is primarily concerned with the question of "what," providing fine detail for recognition. For spatial orientation, focal vision provides visual cues for judgment about distance and depth, color, and relative size. Focal vision orients objects in an environment relative to the pilot. The focal vision system is what allows you to accurately read your flight instruments and displays. While focal vision operates with great precision and accuracy allowing you to discriminate detail (20/20 vision), it is processed in the conscious mind relatively slowly, requiring active thought. Also, focal vision is extremely slow to adapt to low-light conditions, requiring 20-30 minutes of adaptation, and even then your visual acuity is dangerously poor (20/200 to 20/400).[14] This slow adaptation is further hindered by the fovea, an area of cones located in the central visual field. Because this area has no rods, it becomes a night blind spot.

2.3.3. Visual Conditions in Flight. During flight, the utility of external visual references varies with the quality of available visual information. Because of the dynamic relationship between visual information available and mission requirements, all aviators should be aware that SD is possible under a wide variety of visual and varying workload conditions.

2.3.3.1. Adequate External Vision. SD can occur on a clear day as a result of extreme linear and/or angular accelerations, unusual aircraft attitudes, or lack of attention to the environment. Under such circumstances, reference to a distinct horizon in combination with flight instruments should allow the pilot to maintain visual dominance and naturally suppress false vestibular and somatosensory orientation cues. There are however particular visual environments, addressed later in this chapter, that can cause a pilot to misperceive the terrain, sky, horizon, and approach and landing environments even when adequate visual cues appear to be seen.

2.3.3.2. Degraded Visual and Instrument Conditions. At night, in IMC, or in marginal VMC (i.e., when adequate external visual references are not available), the pilot must maintain spatial orientation and a state of visual dominance solely by reference to aircraft instruments, especially the attitude display. This is the indirect perception of spatial orientation. The key to success in instrument flying is to develop an effective instrument crosscheck, which provides a continuous source of accurate information related to aircraft attitude, motion, and position. A proficient pilot with an effective crosscheck will have less difficulty in maintaining visual dominance and ignoring other, potentially disorienting, sensory data. The pilot should be aware that what is seen outside the aircraft may be confusing and may lead to visual illusions and sensory conflicts. During times when the aircraft instruments are the sole source of accurate information, pilots can count on becoming disoriented unless they direct their attention to see, correctly interpret, process, and believe the information provided by the instruments – and ultimately “make the instruments read right” regardless of the sensations felt. However, in certain situations this can be extremely difficult and cognitively demanding on the pilot.

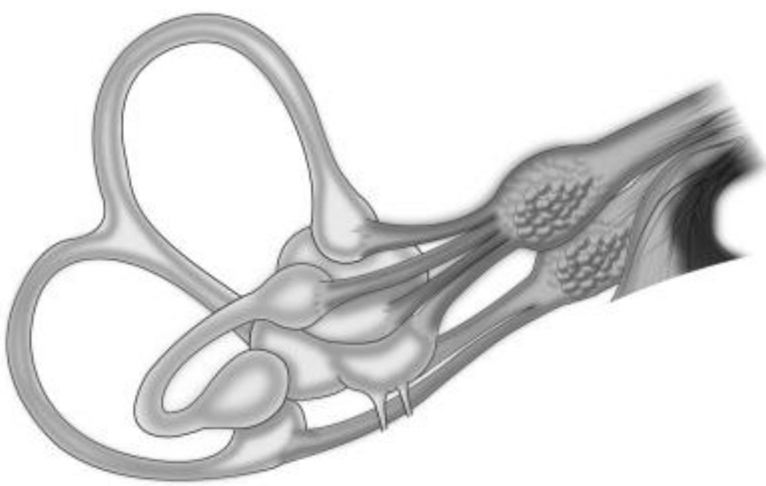
2.4. Vestibular System. The vestibular system contains the primary organs of equilibrium of balance and thus plays a major role in the sensation of motion and spatial orientation. It aids vision by providing angular and linear acceleration information to stabilize the eyes when motion of the head and body would otherwise result in blurred vision. On the ground, the vestibular system provides reasonably accurate perception of position and motion. In flight, the ability to sustain motion in the aircraft results in a mismatch between the vestibular input of the inner ear and the actual aircraft motion. When walking around in everyday life, our senses provide continuous input regarding which way is up and which way is down. Perceptual adaptation is the body’s capability to come to a state of equilibrium in preparation for the next sensory change. This perceptual characteristic however greatly complicates spatial orientation in the extreme sensory environment of flight because in aviation the pilot may still be maneuvering but the

[14] (AFRL-SA-WP-SR-2011-0003, 2011)

vestibular system may have returned to a state of equilibrium. Consequently, when the maneuvering is ceased, the vestibular system detects change and a false sensory input of vestibular acceleration is perceived, confusing the pilot if visual cues are not available. To understand how this vestibular information can be erroneous, one must look at its two sensors: the semicircular canals and the otolith organs of the inner ear.

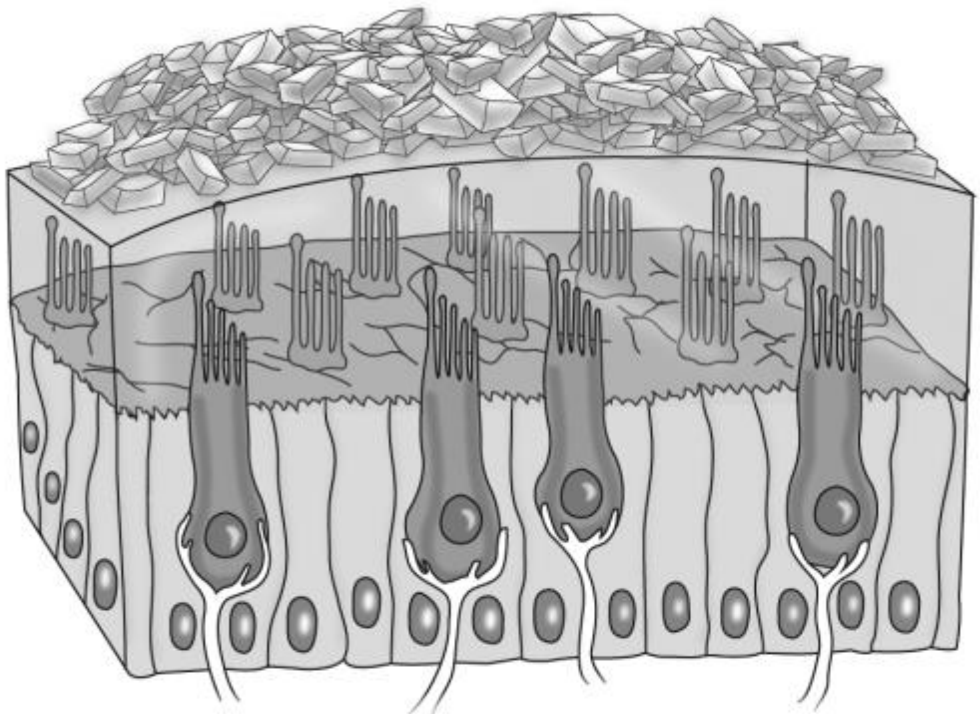
2.4.1. Semicircular Canals. The three semicircular canals on each side of the head approximate right angles to each other so that angular accelerations in any spatial plane (pitch, roll, or yaw) can be detected (**Figure 2.2**). The fluid within the semicircular canals moves relative to the canal walls when angular accelerations are applied to the head. This fluid movement bends sensory hair filaments in specialized portions of the canals, which sends nerve impulses to the brain resulting in the perception of rotary motion in the plane of the canal stimulated. Again, since the response characteristics of the semicircular canal system evolved for our ground-based environment of sudden stop-and-go movements, peculiar errors may be induced during sustained motion in flight. For example, a very small or short-lived angular acceleration may not be perceived accurately, and the resulting sustained angular velocity may not be perceived at all, either one resulting in a large change in actual attitude awareness over a short period of time. Additionally, angular accelerations experienced in flight can be quite different from those experienced on the ground. Hence, we often erroneously interpret the sensations produced by the fluid movement in the semicircular canal.

Figure 2.2. Semicircular Canals.



2.4.2. Otolith Organs. In the presence of linear acceleration or gravity, the relative movements of the otolithic membranes (**Figure 2.3**) bend the sensory hairs that penetrate the otolithic membranes over the underlying structures (the result of a shearing force). Without any linear acceleration, shearing force due to gravity is transformed into nerve impulses to the brain, which convey information about head position relative to true vertical. With linear acceleration, a resultant shearing force is generated and the signals to the brain are the same as those produced by a shift in the direction of gravity. During flight, inertial forces are combined with the force of gravity and act upon the otolithic membranes to produce a net combined force. The direction of this combined or resultant force is almost never in the direction of the true vertical. Hence, it is almost impossible to correctly determine the true direction of "down" from the otolith organs.

Figure 2.3. Otolith Organs.



2.5. Somatosensory System. Buried in many body structures, including the skin, joints, and muscles, the somatosensory receptors provide important equilibrium information as they respond to pressure and stretch, also called the proprioceptive system. The sensations they elicit are the deep pressure feelings that you experience when you sit or the sensations that enable you to know the relative positions of your arms, legs, and body. This system is commonly called the "seat-of-the-pants" sense because some early pilots believed they could determine which way was down by analyzing which portions of their bodies were subject to the greatest amount of pressure. The "seat-of-the-pants" sense is completely unreliable as an attitude indicator when moving in the aerial environment.

2.6. Auditory System. The auditory response in flight is unique in that it is an acquired skill. Pilots learn early in Undergraduate Pilot Training (UPT) that when the aircraft is going fast, there is more airframe/canopy wind noise, and when the aircraft is going slow, the noise level decreases. Thus, the pilot is able to grossly discern airspeed by the noise level in the cockpit. For some pilots, the first clue that they are disoriented is a mismatch between the sounds they expect to hear, based upon their perceived attitude, and the actual "wind" noise present. Although this is not a very precise method, it is often a first clue that something may be out of sync. A quick look at the flight instruments is needed to correctly confirm a possible misperception. However, some aircraft fail to provide this sensory feedback mechanism, in that the aerodynamic control feel and auditory feedback may not provide sufficient cues for aircraft speed and attitude.

2.7. Types of Spatial Disorientation. There are three distinct types of spatial disorientation. Type I is unrecognized spatial disorientation; the pilot is unaware that anything is wrong and controls the aircraft in response to the false sensations of attitude and motion. Type II is recognized disorientation; the pilot is aware that something is wrong, but may not realize that the source of the problem is spatial disorientation. The pilot usually suspects an instrument malfunction, and in a few cases it has been reported that the pilot will "tap" on the display glass to see if it is stuck, even with Cathode Ray Tubes (CRTs). Type III is incapacitating spatial disorientation; the pilot knows something is wrong, but the physiological or emotional responses to the disorientation are so great that the pilot is unable to recover the aircraft. This may result from the pilot's inability to obtain visual information due to blurring of vision (nystagmus). However, there have been several reports of this occurring during air refueling or flying fingertip. An example of each type of disorientation follows:

2.7.1. Example of Type I SD. The last of four aircraft took off on a daytime sortie in the weather, intending to follow the other three in a radar in-trail departure. Because of a navigational error shortly after takeoff, the pilot was unable to acquire the other aircraft on radar. Frustrated, the pilot elected to intercept the other aircraft knowing they would be on the arc of the Standard Instrument Departure. The pilot proceeded directly to that point, scanning the radar diligently for the blips that should be appearing at any time. Meanwhile, after climbing to 4,000 feet above ground level, the pilot entered a 2,000- 3,000 foot per minute descent as the result of an unrecognized, 3-degree nose-low attitude. After receiving requested position information from another member of the flight, the mishap pilot suddenly made a steeply banked turn, either to avoid a perceived threat of collision or to join up with the rest of the flight. Unfortunately, the pilot had already descended far below the other aircraft and was going too fast to avoid the ground. This mishap resulted from unrecognized, or Type I, disorientation. The specific illusion responsible was the somatogravic illusion created by the forward acceleration of the aircraft during takeoff and climb-out. Preoccupation with the radar scanning compromised the pilot's instrument crosscheck to the point where the false vestibular cues were able to dominate orientation information processing. Having accepted this inaccurate spatial orientation "feeling," the pilot controlled the aircraft accordingly until it was too late to recover. Also, the lack of reliable visual cues outside of the aircraft had the pilot juggling multiple tasks and spending time allocating attention to indirect spatial orientation via the aircraft instruments and displays.

2.7.2. Example of Type II SD. On a clear day with unlimited visibility and a distinct horizon, the pilot was flying a two-on-two air combat training mission over water. After a series of roll reversals during the engagement, the pilot thought the aircraft was straight and level when the pilot acquired the bandits slightly low and to the right. In reality, the pilot was in a 90-degree left bank looking up at the other aircraft. To ensure a successful separation, the pilot rolled to the left and pulled to raise the nose slightly. Actually, the pilot had rolled almost inverted and pulled down. What alerted the pilot to being disoriented was that the aircraft sounded as if it was going very fast (this is the beginning of Type II—the pilot suspects something to be wrong, in this case it was an aural cue). When the pilot looked inside and checked, the instruments showed the pilot was in an inverted 60-70 degree dive accelerating through Mach. The recovery was all instinct-- roll to the nearest horizon and pull. The pilot pulled 12.5 G during the recovery and bottomed out at 2,000 feet above the water. This incident of recognized, or Type II SD, occurred because of channelized attention on the second bandit, a breakdown of crosscheck, and subsequent loss of attitude awareness. Type II SD happens more often than mishap reporting would indicate and is a known hazard associated with employing an aircraft as a weapons platform.

2.7.3. Because incapacitating or Type III SD results from overwhelming, incapacitating physiological response to physical or emotional stimuli, it can be difficult to prove during mishap investigation given the perishable nature of investigative evidence. Unfortunately, any mishap occurring that had the pilot failing to eject and/or losing situational awareness could be an example of a Type III SD. One common reference describes an F-15E pilot who was engaged with two other F-15s on a clear day. He initiated a hard left turn at 17,000 feet AGL and began an estimated 150 to 180 degree/sec left roll for an undetermined reason. The pilot communicated "out-of-control auto-roll" and executed at least one successful attempt to stop the roll, resulting in momentary cessation at 8,000 feet AGL. Unfortunately, the aircraft began to roll again. Within 40 seconds of the roll start, the pilot attempted ejection and was fatally injured. Investigators could not establish if the roll was induced by a mechanical malfunction or by the pilot who may have experienced a vestibulocular illusion.[15] Investigators may have a limited understanding what the pilot sensed and perceived is which contributes to the challenge of accident investigation and determination of exact causal factors.

2.8. Causes of Spatial Disorientation. There are a number of conditions or factors that will increase the potential for spatial disorientation. Some of these situations are related to human factors (i.e. physiological or psychological) while others are external factors related to the environment in which the pilot must operate. Awareness on the part of the pilot is required to reduce the risks associated with these situations and factors. Although SD episodes are found throughout the experience range of pilots, it is most commonly noticed within the first 500 – 1,000 hours of learning to fly an aircraft new to the pilot, regardless of total experience.[16]

2.8.1. Personal Factors. Mental stress, fatigue, hypoxia, various medicines, G-stress, temperature stresses, and emotional problems can reduce the pilot's ability to resist spatial disorientation. A pilot who is proficient at accomplishing and prioritizing mission tasks (with an efficient instrument crosscheck), is mentally alert, and is physically and emotionally qualified to fly will have significantly less difficulty maintaining orientation. On the other hand, a pilot who becomes easily task-saturated, fails to properly prioritize tasks, is mentally stressed, is preoccupied with personal problems, is fatigued, is ill or taking non-prescribed medication, is at increased risk of becoming disoriented.

2.8.2. Workload. A pilot's performance on instruments and formation flying is decreased when he or she is busy manipulating cockpit controls and either anxious, mentally stressed, or fatigued. When the pilot is distracted from crosschecking the instruments during task intensive phases of flight in marginal weather or reduced visibility conditions, the pilot's ability to recognize and resist SD is severely diminished.

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15 (Fundamentals of Aerospace Medicine 4th ed, 2008)

16 (NATO, 2008)

2.8.3. Fatigue. Although mentioned above with personal factors, fatigue is such a major contributor to degraded cognitive functioning it needs to be singled-out as a cause of SD. As presented in this discussion on SD, it takes conscious processing to indirectly ascertain spatial orientation when visual cues are removed. A symptom of fatigue is difficulty concentrating and focusing on cognitive tasks.

2.8.4. Inexperience. Inexperienced pilots with little instrument time are particularly vulnerable to spatial disorientation. It takes time and experience to "feel" comfortable in a new aircraft system and develop a solid, effective instrument crosscheck. A pilot who must still search for switches, knobs, and controls in the cockpit has less time to concentrate on flight instruments and may be distracted during a critical phase of instrument flight. The cockpit workload associated with complex aircraft is particularly significant for the recent pilot graduate or pilots new to these systems. A second crewmember is not always available to change radio channels, set up navigation aids, and share other cockpit chores. Therefore, it is essential for an effective instrument crosscheck to be developed early and established during all phases of flight. Other cockpit duties, like radio changes, radar operation, etc., must not be allowed to distract the pilot from basic instrument flying. Also, pilots who are less experienced in a particular airframe and its mission may find themselves in novel situations and quickly become disoriented. In contrast, pilots who are familiar with an aircraft and mission can experience similar maneuvering and situations but can more easily maintain their orientation; due to training and experience, the situations are not as novel for experienced aviators.

2.8.5. Proficiency. Total flying time does not protect an experienced pilot from spatial disorientation. Proficiency and total number of flying hours or sorties in the past 30 days is more important. Aircraft mishaps due to SD generally involve a pilot who has had limited flying experience in the past 30 days. Flying proficiency begins to deteriorate rapidly after 3 or 4 weeks out of the cockpit. Vulnerability to SD is high for the first few flights following a significant break in flying duties.

2.8.6. Instrument Time. Pilots with less instrument time are more susceptible to SD than more experienced pilots. Many SD incidents have been reported during the penetration turn, final approach, climb-out after takeoff, trail departures, and while performing high-performance flight maneuvers. This is when the vestibular illusions are the most devastating. Other very critical times are at night and during weather formation flights, when the wingman loses sight of the lead, or when a pilot flying in VMC suddenly enters IMC.

2.8.7. Phases of Flight. Although distraction, channelized attention, and task saturation are not the same as spatial disorientation, they precipitate it by keeping the pilot from maintaining an effective instrument crosscheck. SD incidents have occurred during all phases of flight. During the following critical phases pilots are particularly susceptible to becoming spatially disoriented because of the extra potential for distraction, channelized attention, and task saturation.

2.8.7.1. Takeoff and Landing. The takeoff and landing phases of flight occur in dynamic and demanding environments. Aircraft acceleration, speed, trim requirements, rate of climb or descent, and rate of turn are all undergoing frequent changes. The aircraft may pass between VMC and IMC. At night, ground lights may add confusion. Radio channel or IFF/SIF changes may be directed during a critical phase of flight while close to the ground. Unexpected changes in climb-out or approach clearance may increase workload and interrupt an efficient instrument crosscheck. An unexpected or poorly planned/briefed missed approach or circling approach at night or in IMC is particularly demanding. Also, a field with poor lighting can quickly become a highly demanding approach and landing at night or in IMC. Finally, the configuration changes of the aircraft during these phases of flight, along with degraded visual cues, may result in misperception of acceleration and pitch. Extending the gear and flaps during an approach may cause deceleration to be perceived as a nose-down attitude.

2.8.7.2. Air-to-Ground & Air-to-Air. Another critical phase of flight, with a high potential for spatial disorientation, is the maneuvering associated with air-to-ground ordnance deliveries during impoverished visual conditions and air combat maneuvers. Again, under such conditions the only completely reliable information related to aircraft attitude is provided to the pilot by the flight instruments. Because of the nature of the mission, the pilot's attention is directed outside the cockpit. Potential for distraction is great. What the pilot sees outside the cockpit may be misleading or the pilot may fail to scan an important instrument parameter (such as attitude, airspeed, altitude, or vertical velocity) during a critical phase of the weapons delivery. These factors easily can lead to an unrecognized SD or "lack of attitude awareness" in which the pilot inadvertently places the aircraft in a position from which recovery is impossible. Recently mishaps have occurred during high angle strafing maneuvers while the pilot was flying in low illumination night conditions wearing NVGs; other factors were mountainous terrain and fatigue. Pre-mission planning and risk assessment is vital for safe and effective mission accomplishment. Again, NVG use can reduce acuity, contrast, and ambient visual cues and orientation processing, thus strict adherence to procedures is required.

2.8.7.3. Formation Flying. Night or weather formation flights are demanding situations with a high potential for creating SD. Formation flying presents special problems to the pilot in maintaining spatial orientation. First and most important, pilots flying on the wing cannot maintain appropriate visual dominance. They are deprived of any reliable visual information concerning aircraft attitude related to the earth's surface. They cannot see the true horizon and have little or no time to scan their own instruments. Under these conditions, it becomes difficult to suppress information provided by unreliable sources such as the vestibular system. Illusions of various kinds are almost inevitable. A pilot's concentration on maintaining proper wing position may be compromised by what the pilot "feels" the aircraft attitude to be. Lack of confidence in lead will increase tension and anxiety. An inexperienced flight lead will most certainly aggravate the situation due to abrupt control inputs. Also, poor in-flight communications and the lack of specific properly briefed procedures to help recover a disoriented wingman will increase the potential for an aircraft mishap. Consequently, direct communication inputs from lead or other pilots to the SD pilot/aircrew can help recovery.

Chapter 3

ILLUSIONS AND MISPERCEPTIONS

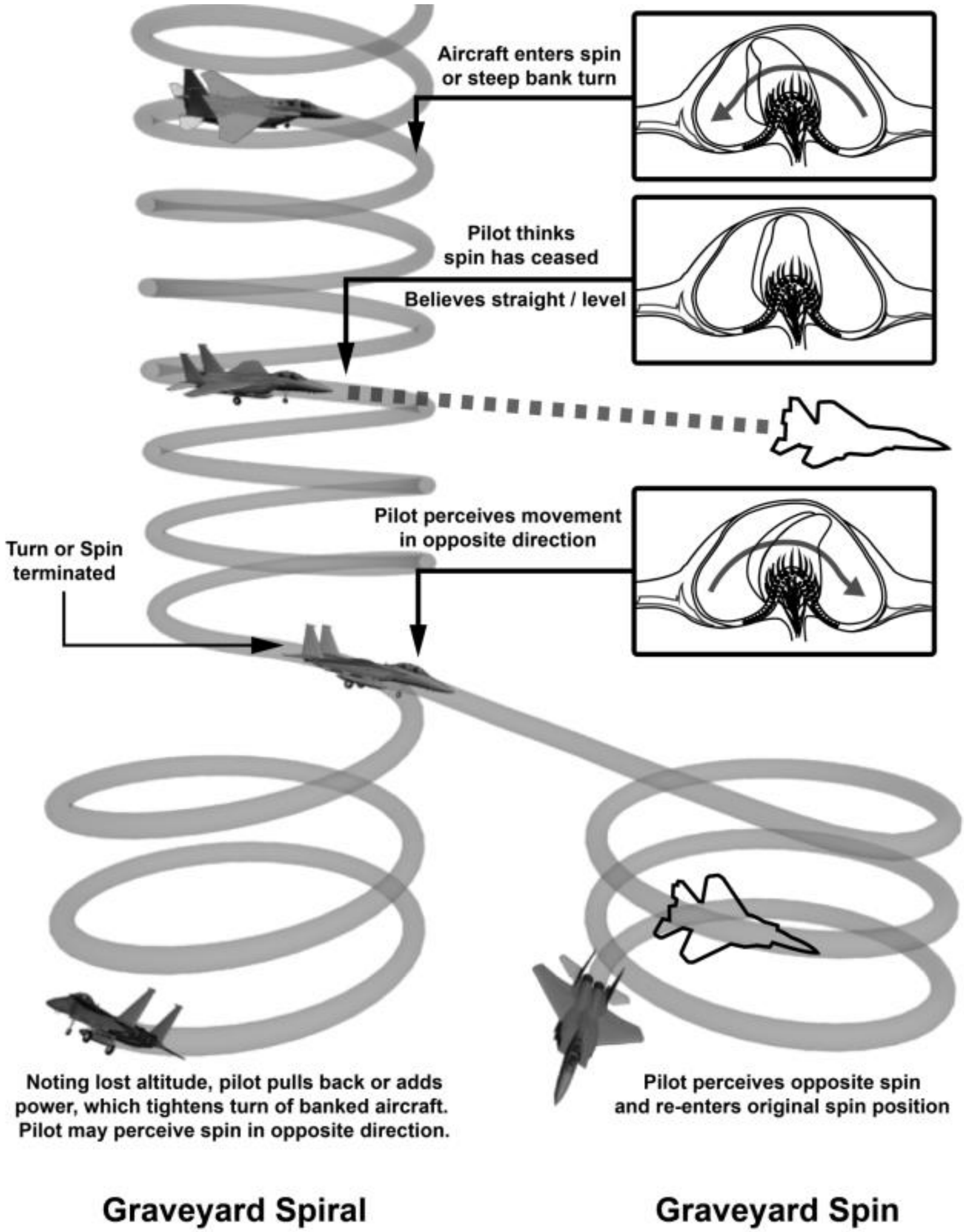
3.1. Vestibular Illusions. In the absence of adequate visual orientation cues, the inadequacies of the vestibular and somatosensory systems can, and generally do, result in orientation illusions. It is customary to discuss vestibular illusions in relation to the two components that generate the illusions--the semicircular canals and the otolith organs. However, as mentioned previously, a pilot will rarely have a sensation of only one of the two different vestibular systems. A combination of sensory inputs is often perceived by the pilot, but for the presentation of the information they are presented individually.

3.2. Somatogyral Illusions. This set of illusions result from the semicircular canals' inability to register accurately a prolonged rotation, i.e., sustained angular velocity.

3.2.1. Graveyard Spin (**Figure 3.1**). This situation begins with the pilot intentionally or unintentionally entering a spin. The pilot's first impression is accurate; that is, a spin is perceived. After about 10 to 20 seconds of constant rotation (no angular acceleration), the fluid in the canals comes to rest with respect to the canal walls and the sensory hairs return to the upright, resting position (equilibrium and perceptual adaptation). The sensation is that of no rotational motion despite the fact that the spin continues. If the spin is then terminated, the angular deceleration produced causes a relative motion between the fluid and the canal walls deflecting the sensory hairs in the opposite direction. The pilot erroneously perceives spinning in the opposite direction. If the pilot does not recognize the illusion and acts to correct this false impression, he or she will put the aircraft back into the original spin.

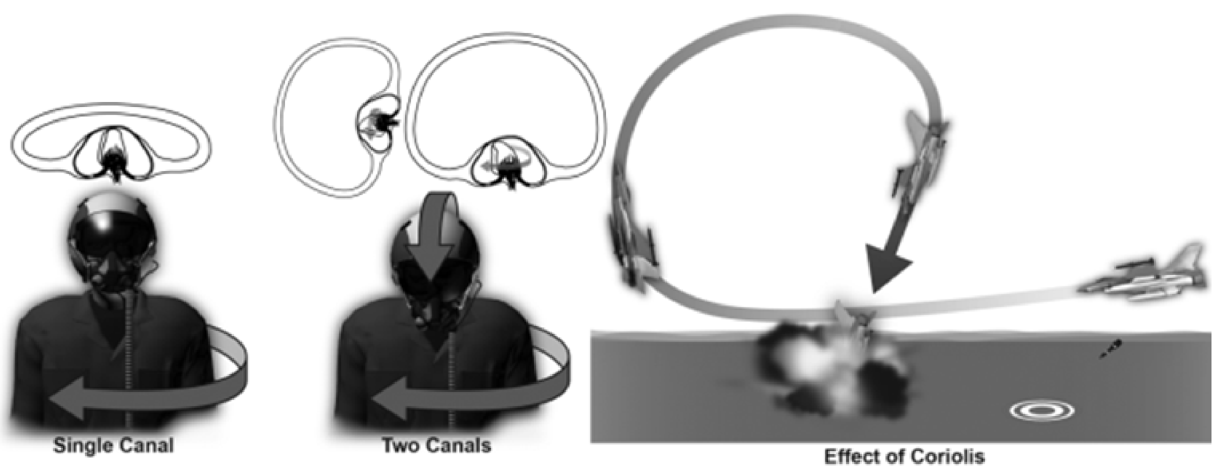
3.2.2. Graveyard Spiral (**Figure 3.1**). In this maneuver the pilot has intentionally or unintentionally put the aircraft into a prolonged turn with a moderate or steep bank. The constant rate of turn causes the pilot to lose the sensation of turning after a period of time. Noting a loss of altitude, the pilot may pull back on the controls or perhaps add power in an attempt to regain the lost altitude without checking that an increase in bank has occurred. Unless the incorrectly perceived bank attitude is corrected, such actions only serve to tighten a downward spiral. Once the spiral has been established, the pilot sometimes experiences the illusion of turning in the opposite direction after the turning motion of the aircraft has stopped. Under these circumstances, if the pilot fails to suppress all sensory data except the visual, vestibular illusions may cause inappropriate inputs, resulting in re-establishment of the spiral.

Figure 3.1. Graveyard Spin/Spiral.



3.2.3. Coriolis Illusion (**Figure 3.2**). During high turn rates, abrupt head movements may cause pilots to perceive motions they are not actually doing. When the body is in a prolonged turn in one plane, the fluid in those canals stimulated by the onset of the turn eventually comes up to speed with the canal walls. If the head is then tilted in another plane, the angular momentum of the fluid causes it to move again relative to the canal walls. The resulting sensation is one of rotation in a third plane. This has also been called a "cross-coupling" sensation and may provide a feeling of tumbling. If pilots try to correct for the illusion without referencing their flight instruments, they may put the aircraft in a dangerous attitude. Research has attempted to further understand the Coriolis illusion but given the multiple aircraft forces and maneuvers (G-forces and bank) combined with pilot initial head position and subsequent head movements it is difficult to truly isolate and quantify. Research has also examined rotary versus fixed-wing effects of this illusion in terms of the G-excess issues of fixed-wing and high yaw rates of rotary-wing. Regardless of the airframe and on-set conditions, this illusion can be extremely difficult to ignore and incapacitating to an unsuspecting pilot.

Figure 3.2. Coriolis Illusion.



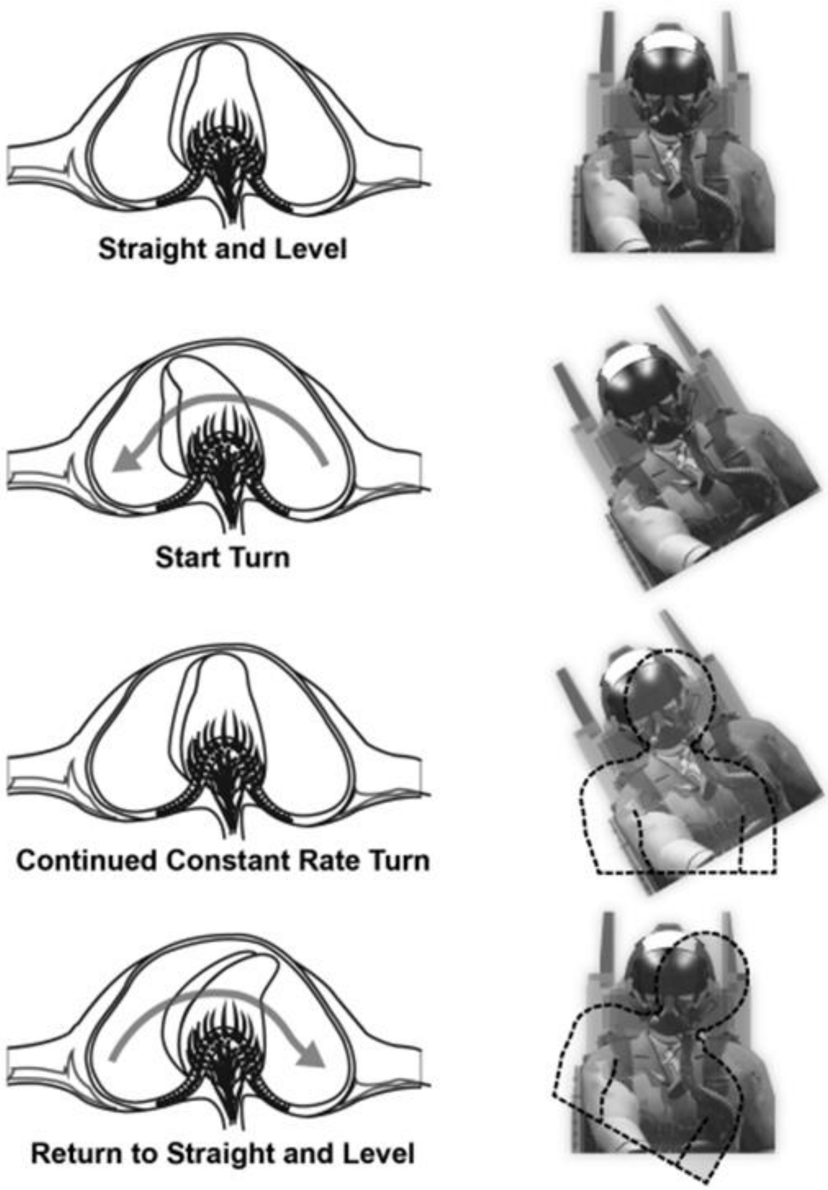
The illustration on the far left shows fluid movement within the semicircular canals during a simple aircraft bank (turn). The center illustration shows movement in two semicircular canals during a climbing turn. When two or more semicircular canals are stimulated, the Coriolis Effect results, causing aircrew members to have an overwhelming tumbling sensation. A potentially catastrophic result of Coriolis when the sensation of tumbling limits the aircrew's ability to recover the low-flying aircraft is shown on the far right.

3.2.4. The Leans (**Figure 3.3**). This is the most common vestibular illusion and is caused by rolling or banking the aircraft after the pilot has a false impression of the true vertical. Surveys of rotary wing naval flyers and one division of Canadian Forces pilots respectively indicate a 91% rate of experiencing the leans and 50% with disorientation experience, primarily the leans.[17] After a prolonged turn has ceased, the pilot may perceive the roll to wings level as a bank and turn in the opposite direction. The effect causes pilots to lean in an attempt to assume what feels like a vertical posture. Alternatively, if they establish a very slow roll to the left that does not stimulate the vestibular apparatus and then roll rapidly to

[17] (Previc and Ercoline; 2004, 260)

the right to level flight, they may generate the false impression of only having rolled to the right; again, the leans may result. The leans are most commonly felt when flying formation on the wing in and out of the weather or at night. Since the wingman's attention is on the flight lead and not on the attitude display, it becomes easy for the vestibular or somatosensory system to provide false orientation cues, often reinforced by false ambient visual cues. These false orientation cues can quickly convince the wingman of being in an "unusual" attitude and cause a strong case of the leans. To minimize the effects of the leans while on the wing, it is important for the wingman to occasionally cross-reference the attitude display, without making a head movement if possible. Thus, the pilot must use focal vision to overcome the false cues and to acquire accurate spatial orientation information. Often pilots fail to believe that 'the leans' could actually contribute to a mishap, but a 2007 F-16 mishap occurred due to this illusion as one fairly recent example.

Figure 3.3. The Leans.



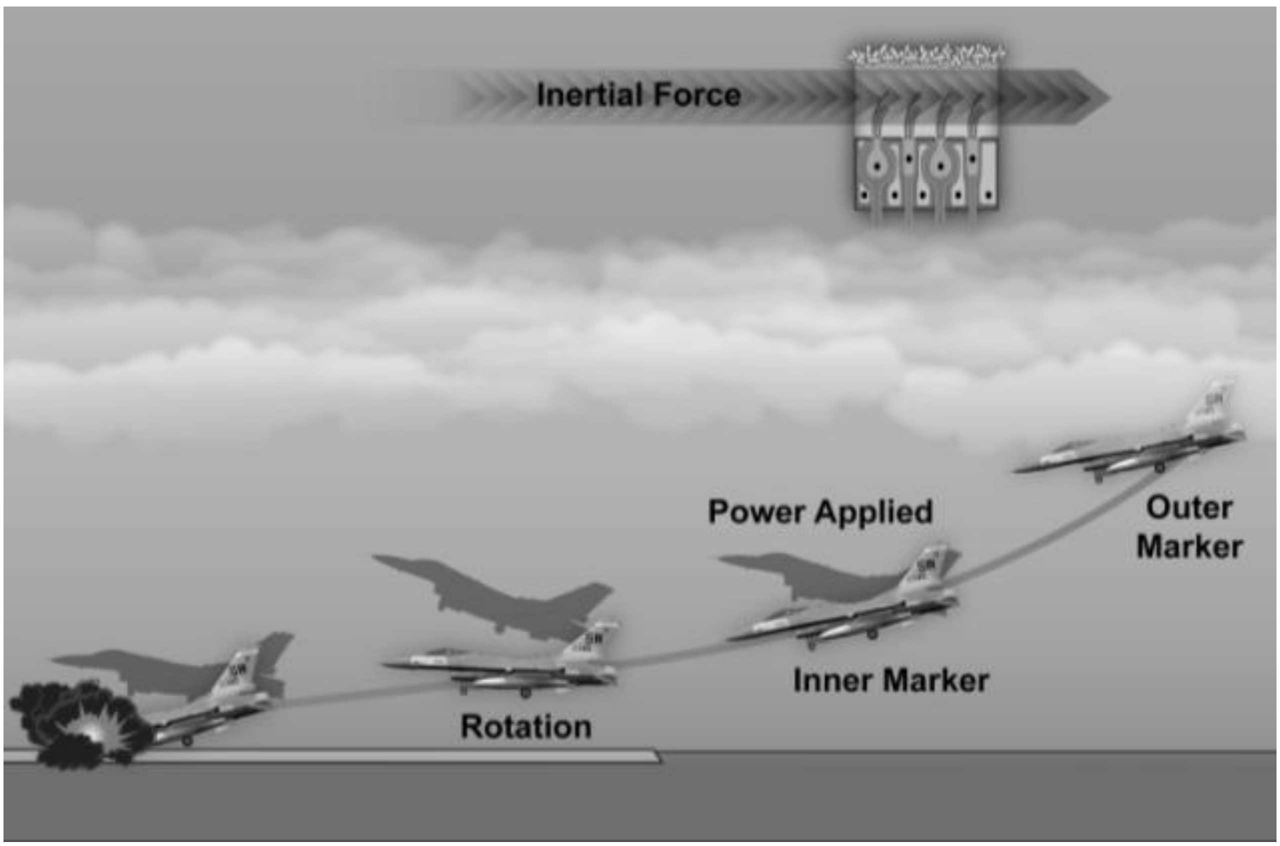
The illustrations on the left show fluid movement within the semicircular canals during aircraft bank (turn). The illustration series in the right column illustrate the aircraft's actual position and the individual's feeling of position in dashed lines.

3.2.5. Gillingham (post-roll) Illusion. This illusion occurs after completing a roll about the longitudinal axis. What happens in this illusion is that in the absence of a horizon to provide ambient visual cues, the vestibular system induces the perception of adding further roll after the completion of a roll to counter the misperception of roll-reversal or decrease in bank. For instance, a pilot rolls left with 45 degrees of bank, stops the roll, but then has the sensation to add additional left bank. This illusion was specifically cited in a 2008 F-16 mishap.

3.3. Somatogravic Illusions. The otolith organs are responsible for a set of illusions known as somatogravic illusions. This type of illusion is the sensation of change in attitude when the otolith organs are stimulated by linear acceleration.

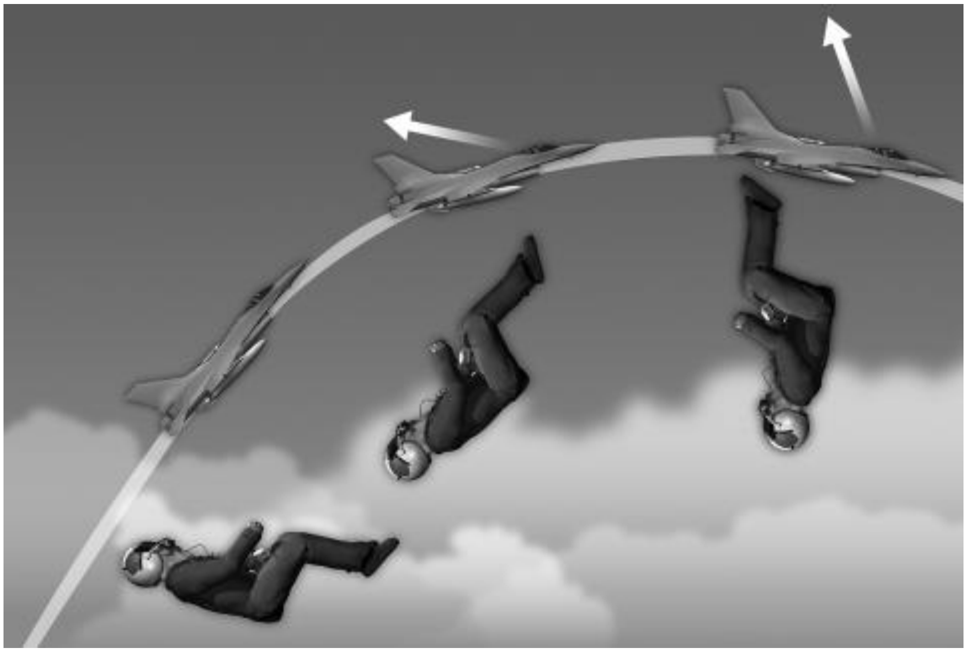
3.3.1. Pitch Illusions (**Figure 3.4**). Also called a pitch-up or pitch-down illusion and sometimes called a dark-night take-off illusion. This illusion is often noted in the US Navy during aircraft carrier launch operations, but it has also been attributed to commercial airline and General Aviation accidents during take-offs at night. A false nose high sensation can occur when an aircraft accelerates forward in level flight. This somatogravic illusion may be unrecognized during an IMC takeoff or missed approach acceleration if the pilot is not concentrating on flying via instruments, while in impoverished visual conditions. Correcting for this illusion during climb-out could cause the pilot to push over/dive the aircraft toward the ground as seen in **Figure 3.4**. A false nose-down sensation can occur as a result of rapid deceleration in the weather.

Figure 3.4. Pitch-up Illusion.



3.3.2. Inversion illusion. (**Figure 3.5**) A variant of somatogravic illusion is the inversion illusion, in which G forces act on the otolith organs to give the pilot transitioning from an upright position to one of feeling upside down. Although the inversion illusion is of greatest magnitude in high-performance aircraft, it can occur in any aircraft abruptly leveling after a steep climb. The pilot can overcome the illusion by paying attention to valid external visual references or to aircraft attitude instruments.

Figure 3.5. Inversion Illusion.



3.3.3. Elevator Illusion. A quick reduction in descent is misperceived to be a climb, due to the translational motion after effect, and induce an unwarranted pitch-down by the pilot. The opposite can also occur after an abrupt reduction in ascent, this may create a false sensation of a dive and induce an unwarranted pitch-up by the confused pilot.

3.3.4. G-excess Illusion. The G-excess illusion depends on otolith-organ mechanisms. When a pilot's head is facing forward in a G-pulling turn, the G-excess effect causes a false perception that the aircraft has tilted backwards (pitched up). In the absence of overriding visual cues, the pilot can make dangerous attitude control errors to correct for the G-excess illusion. If the pilot is looking at the "9 o'clock level" position while in a left turn, the G-excess effect would create the illusion the pilot's direction of gaze is above the actual direction; i.e., the aircraft is in less of a bank than is actually the case. The pilot would compensate for the illusion by overbanking. Because of the G-excess illusion, the pilot may be in a bank somewhat greater than the perceived bank angle, and feel comfortable in it. Even though the initial perceptual error may be small, the accumulation of erroneous compensatory control input can result in a rapidly developing severe overbank and the accompanying earthward velocity vector. Remember, the prime time for the G-excess illusion to happen is during any turning and looking maneuver.

3.4. Nystagmus. During and immediately after maneuvers resulting from particularly violent angular accelerations, such as spins and rapid aileron rolls, the vestibular system can fail to stabilize vision. The eyes can exhibit an uncontrollable oscillatory movement called nystagmus. This eye movement generally results in an inability to focus on either flight instruments or outside visual references. Rolling maneuvers are especially likely to result in visual blurring because of nystagmus. Normally, nystagmus ceases several seconds after termination of angular acceleration. Under conditions of vestibular dominance and high task loading, nystagmus and blurring of vision can persist much longer, even long enough to prevent recovery. This is another example of the merging between the vestibular and visual systems for orientation.

3.5. Visual Illusions. A wide variety of visual misperceptions are known to occur during flight, and the most common illusions are described here. When flying with NVGs, pilots should be aware that they are susceptible to the same visual illusions listed below but with additional variations. The image intensification process of the goggles can intensify the illusion as well as the ambient light. Reference Chapter 4 of this publication for further academic discussion; operational use is detailed in 11-2MDS and tactical guidance for each MDS. Many of the following illusions involve the loss of visual cues such as the horizon and terrain, or the visual environment is such that accurate depth and distance estimation is not possible.

3.5.1. Decreased Visibility: Night & Weather. This first listed illusion is not so much a specific illusion, but an environmental condition that leads to various forms of SD. The condition of decreased visibility or impoverished visual cues, whether due to night conditions or IMC, relates to most of the other illusions both visual and vestibular. Pilots are over-confident in their visual capabilities and this often sets them up for failure. A majority of mishaps occur at night, and it should not be surprising to learn that SD results within 60 seconds when attempting to fly straight and level with no visual cues.

3.5.2. Blending of Earth and Sky. At night with both aided and unaided vision, pilots may confuse ground lights with stars. In doing so, the possibility exists of flying into the ground because the perceived horizon is below the actual horizon. Pilots may also confuse unlighted areas of the earth with an overcast night sky. If pilots erroneously perceive ground features (such as the seashore) as the horizon, they are in danger of flying into the unlighted water or terrain above it.

3.5.3. False Vertical and Horizontal Cues. Flying over sloping cloud decks or land that slopes gradually upward into mountainous terrain often compels pilots to fly with their wings parallel to the slope, rather than wings-level, or to climb or descend with the slope. A related phenomenon is the disorientation caused by the aurora borealis in which false vertical and horizontal cues generated by the aurora result in attitude confusion in pilots trying to fly formation or refuel at night in northern regions. This illusion has been called the visual form of the leans. The other form of the leans is primarily the result of semicircular canal stimulation.

3.5.4. Formation Flying Problems. This situation is especially hazardous during night formation flights when the only outside reference is the lights of the lead aircraft. Frequent cockpit instrument scans, to include altitude, are essential when taking “spacing.” Keeping the leader’s lights in the same relative position on the windscreen does not ensure adequate horizontal or vertical spacing, nor does it ensure adequate height above the terrain. Especially during deceleration, when aircraft pitch attitude increases, keeping lead in the same position on the windscreen can cause a substantial loss of altitude. Night intercepts are especially dangerous without frequent instrument crosschecks. An overshoot and subsequent pullback toward lead can be confusing if you think that you are below the lights when in reality you are level (altitude-wise) with the lights but in a 90-degree bank. A maneuver to offset your aircraft to one side or the other, or below, could have disastrous results. When displacement is behind and below the lead aircraft, the misperception of actual altitude has been termed the Dip Illusion.

3.5.5. Inadvertent Flight into IMC. A leading cause of mishaps in General Aviation, this still can be a dangerous situation to USAF aircrew if they do not immediately transition to their instruments. Often inadvertent flight into visibility reducing weather results in an unusual attitude, and results in SD requiring unusual attitude recognition and recovery procedures.

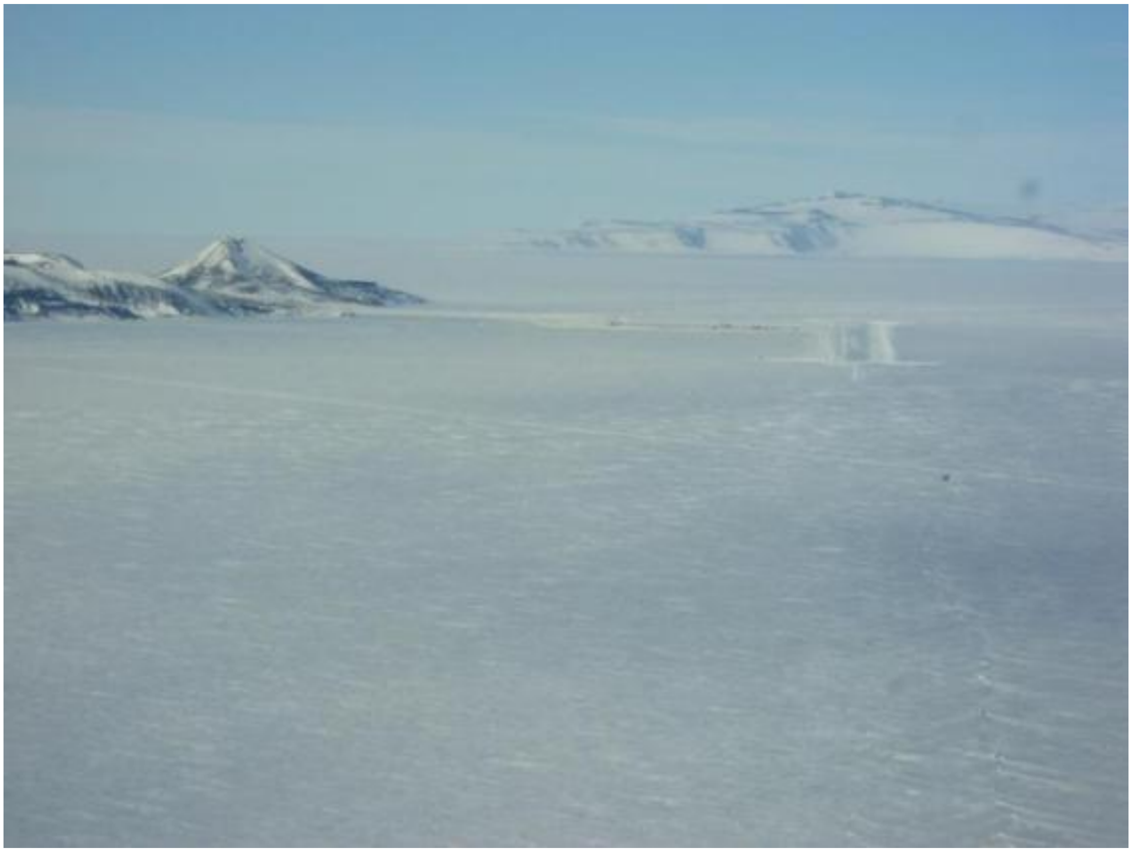
3.5.6. Vection Illusions. A sensation of self-motion induced by relative movement of viewed objects is called vection. Such sensations are frequently illusory, and can be of linear (translational) or angular (rotational) movement. An example of a linear vection illusion is that of an adjacent automobile creeping forward at a stoplight and creating the sensation that one's own vehicle is creeping backwards. In formation flying, such illusions are common. An example of an angular vection illusion is the feeling of rotation one can experience when the revolving reflection of a rotating anti-collision light is viewed in fog or clouds. Induced motion illusion is the perceived motion to move the attitude indicator to the proper attitude. Induced motion is most vivid with indiscernible backgrounds such as "black hole" conditions. Some pilots have reported that they used their fingertips or knees to move the controls to minimize the illusion of objects that are not actually moving, when other objects are physically moving instead

3.5.7. Visual Autokinesis. A stationary light stared at for 6 to 12 seconds in the dark will appear to move. This phenomenon can cause considerable confusion in pilots flying formation or rejoining on a tanker at night. To minimize or overcome this phenomenon: (a) shift your gaze frequently to avoid prolonged fixation on the light, (b) view the target beside or through, and in reference to, a relatively stationary structure such as a canopy bow, (c) make eye, head, and body movements to try to destroy the illusion, and (d) as always, monitor the flight instruments to prevent or resolve any perceptual conflict. Increasing the brilliance, size, and number of lights, or causing the lights to flash, will diminish the effect of the autokinesis phenomenon.

3.5.8. Flicker Vertigo. Individuals can be susceptible to flickering lights, and can experience unusual sensations or a false sense of motion caused by the passage of light through propellers or rotor blades or by flashing strobe lights. Light that flickers at frequencies from 4 to 20 times per second can produce nausea, dizziness, convulsions, and even unconsciousness in susceptible individuals.

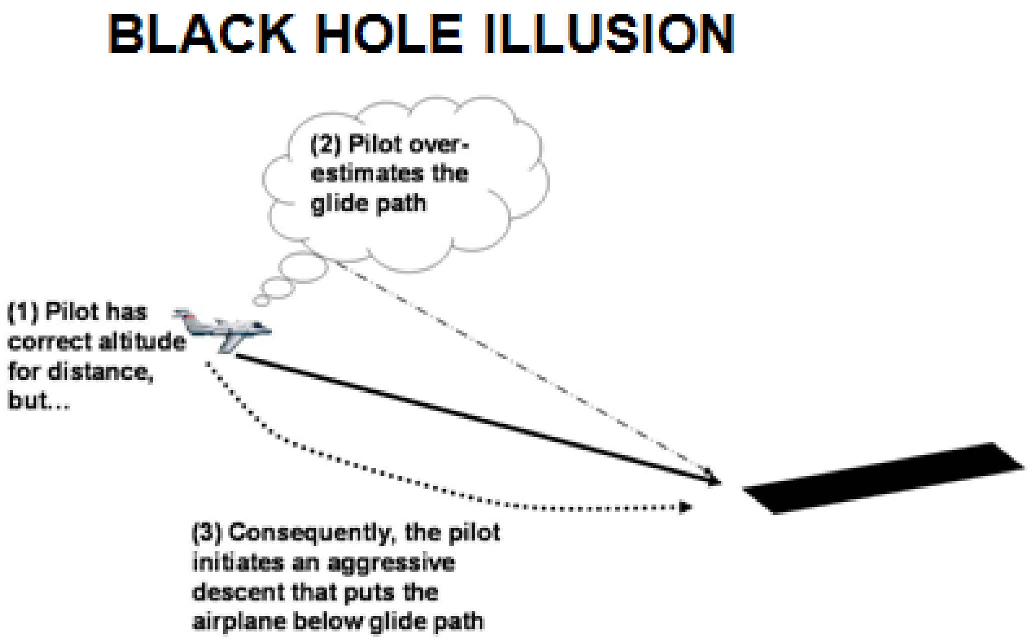
3.5.9. Featureless Terrain (Figure 3.6). These illusions are a more general category of visual illusions that consist of an environment that is lacking in both focal and ambient vision cues. A featureless terrain environment (like a desert, large areas of snow, or a large body of water) does not have or, due to night conditions the pilot is unable to see, any terrain cues for depth and distance estimation. What happens in this condition is that the pilot eventually finds themselves flying dangerously low to the ground because the pilot had perceived their altitude higher than actual. Flying low-level over featureless terrain often leads a pilot below their planned altitude if the pilot fails to maintain their cross-check on their radar altimeter. This illusion often contributes to mishaps, but can be sufficiently addressed during pre-flight planning and risk assessment of known environmental conditions.

Figure 3.6. Example of Featureless Terrain (Detail Covered by Snow).



3.5.10. Black Hole Illusion (Figure 3.7). The Black Hole Illusion is a sub-set of the featureless terrain illusion and pertains specifically to an approach and landing. Conditions are encountered over a featureless environment such as when flying on a dark night over water or unlighted terrain with an indiscernible horizon toward a runway. Poor peripheral cues or even a lack of focal vision cues for relative size estimation and depth/distance information create the false perception in the pilot that they are too steep relative the normal 3 degree glide-path. The pilot, incorrectly feeling steep, initiates an unwarranted descent below the desired glide-path and consequently puts the aircraft in a dangerously low position relative to the terrain prior to the runway. Situations may occur that the approach glide-path is so shallow the pilot "lands short" of the runway. It can even occur if flying to a runway with approach lights and runway glide-path indications. Often, the pilot's preference to fly "visual" and not back-up the approach with instruments induces a pilot into an unsafe and shallow glide-path to the runway. Consequently, it is highly recommended to always back-up your visual approach if flown during night or over featureless terrain.

Figure 3.7. Black Hole Illusion[18].



3.5.11. White-out/Brown-out (**Figure 3.8**). This condition has become an increasing problem, especially with helicopter operations in desert or snow-covered environments. The brown-out results from an inability to properly perceive the environment when the downwash from the rotary blades kick-up debris to the point of completely obscuring vision. There is some illusion of self-motion due to the swirling dust/snow that creates the false sensation that the helicopter is moving more than it actually is. In this situation, pilots and aircrew are unaware of their position relative to the ground prior to landing. They also are unable to monitor lateral drift, and although they may maintain safe altitude above the ground, they may drift to the side significantly while in the cloud and collide with a natural or man-made obstacle. The removal of environmental visual cues results in the pilots and aircrew not being able to perceive their movement in any direction.

[18] (Gibb, 2007)

Figure 3.8. Brown-out Resulting From Rotor Downwash into Sand.

3.5.12. Oculogyral Illusion. This visual "illusion" is experienced while trying to stay oriented with a fixed visual field or target during movement stimulating the semi-circular canals. It occurs as a result of the failure of the static visual image to achieve visual dominance over the motion experienced.[19] These illusions can reinforce the sense of motion, as the apparent movement is typically in the direction of the angular acceleration experienced.[20]

3.5.13. Terrain Illusions. Differing terrain texture and terrain geography can result in misperception of altitude in pilots. Similar to the featureless terrain illusions, often pilots flying over various terrain features adapt to obstacles of one relative size and then misperceive other terrain objects, with the result of flying too low or possibly be induced into flying higher than desired depending upon the changing terrain. This is called a size-constancy illusion in terms of visual perception. For instance, a pilot may keep a certain distance above the ground by relying on clearance over large trees. However, as the low-level navigation route continues, terrain changes and the large trees are replaced by smaller shrubs resulting in the pilot keeping that same altitude over shrubs significantly shorter than the trees. The end result is flying at a much lower altitude relative to the terrain.

3.6. Runway Illusions (Figures 3. 9 & 3.10). Flying towards different runways of various shapes and sizes can induce steep or shallow visual approaches if the runway is significantly different from what a pilot is familiar with. Also, the terrain surrounding a runway can often trick pilots into flying dangerously shallow approaches or flying dangerously steep approaches. These illusions often occur despite rich viewing environments.

3.6.1. Runway Ratio. The length and width of a runway (length/width equals ratio), if significantly different from what a pilot is accustomed to, can induce four different scenarios.

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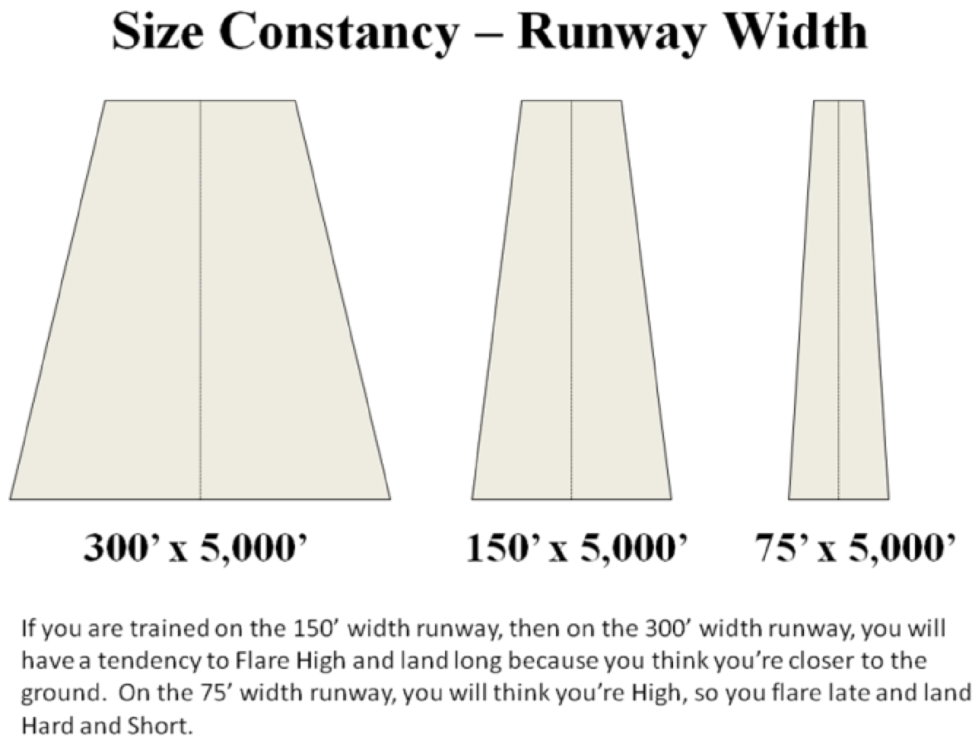
19 (Previc and Ercoline, 2004)

20 (AFRL-SA-WP-SR-2011-0003, 2011)

Figure 3.9. Runway Illusions.



3.6.1.1. High Ratio Approach and Landing. A high ratio runway is long and narrow, compared to the pilot’s usual landing runway ratio. The pilot may perceive the runway as farther away than it truly is due to its smaller visual image and may choose to descend at a higher than appropriate rate. This illusion occurs because the visual picture of long and narrow runway usually only occurs when the aircraft is still a great distance away in the pilot’s experience approaching his usual runway. As the pilot gets closer to the high ratio runway, he or she may realize the descent rate is too quick and the aircraft approach is now too shallow and/or too low relative their distance to the runway. A hard landing often results from this type of mistaken approach to a higher ratio runway. This is similar to the black hole illusion.

3.6.1.2. Low Ratio Approach and Landing. A low ratio runway is short and wide and may induce a feeling as of being too low, causing the pilot to delay descent. The result is often a steep approach to the normal landing point, and becomes a significant problem due to limited runway length. If the runway has a smaller ratio than the pilot usually experiences, visual point at which he or she usually begins landing will occur when the aircraft is still too high to safely initiate a flare. This occurs because a wide runway perspective is an image usually seen when just about to touch down during landing. However, if the runway is unusually wide, the normal peripheral visual cues may trigger the pilot to flare when in fact they are still well above the runway, even as much as 100 feet in the air.

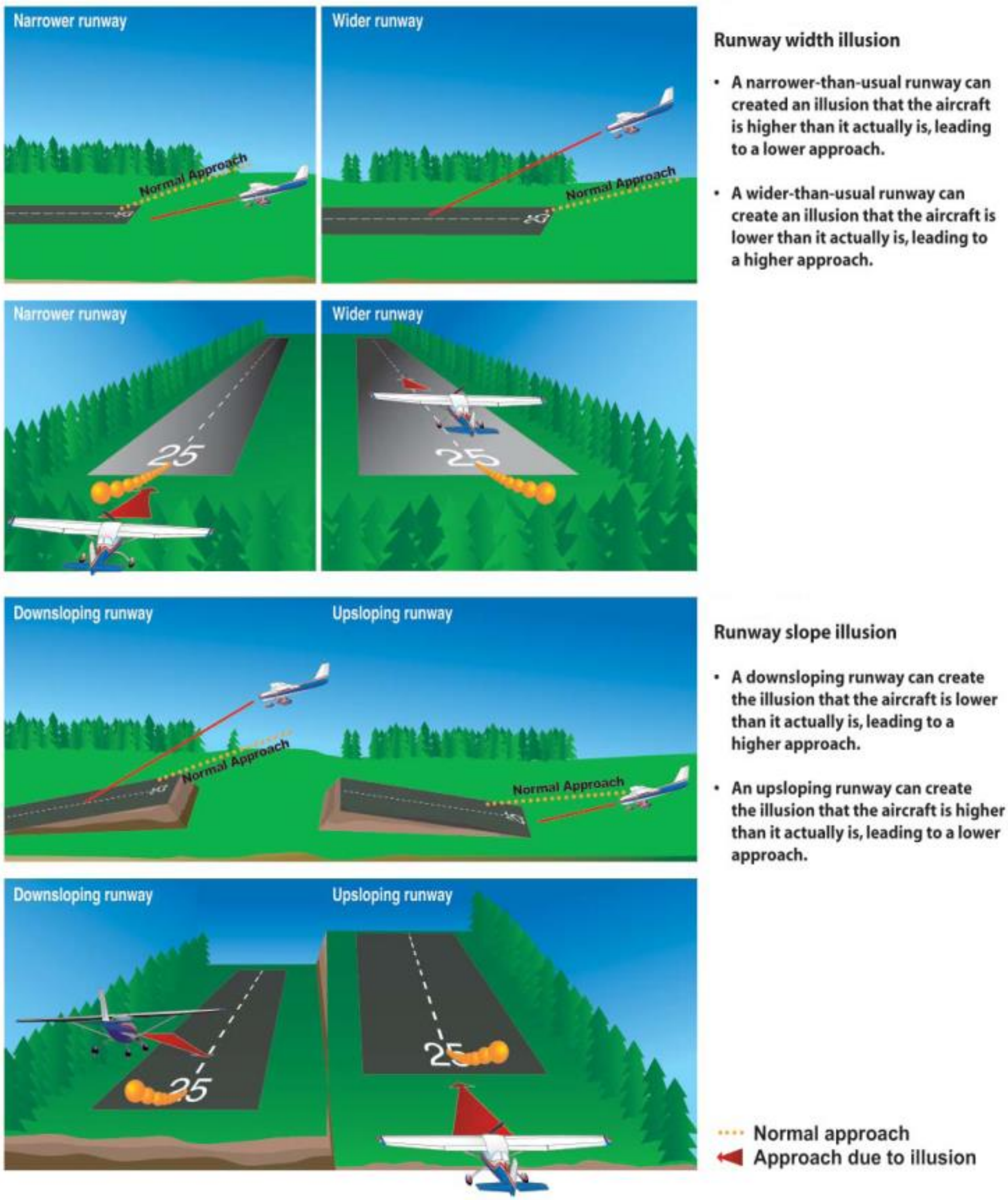
3.6.2. Up-Sloped Runway. If a runway is up-sloping and the pilot may fly too shallow of an approach. This is because the pilot may feel they are too steep relative to the flat terrain below their approach. Usually the perception of looking steep to a runway induces the unwarranted descent to an incorrect shallow approach angle to the aim-point, similar to a black hole illusion-type approach. This illusion can occur in rich viewing conditions or when combined with a black hole environment.

3.6.3. Down-Sloped Runway. If a runway has a slope in the downward direction, it can induce the perception in the pilot that they are flying too shallow toward their usual aim-point. To correct this false perception, the pilot incorrectly is induced into flying too steep of an approach. An influence in this situation is not only the down-sloped runway but the flat terrain beneath the pilot as they make their approach. The pilot assesses their altitude above the terrain to match their usual mental picture of their approach and over-corrects.

3.6.4. Rising Terrain Prior to the Runway. With up-sloping terrain to a flat runway, the pilot estimates their normal glide-path incorrectly relative to the terrain below prior to the runway, which puts the aircraft too shallow towards the runway.

3.6.5. Down Sloping Terrain prior to the Runway. With down sloping terrain prior to the runway, the pilot may fly too steep because the perception of the terrain being close to their current glide-path. This in turn induces a steep approach relative to their aim-point.

Figure 3.10. Runway Width and Slope Illusions[21].



3.7. Somatosensory Illusions.

21 (FAA, 2012)

3.7.1. The Seat-of-the-Pants Sense. Pilots can be deceived if they interpret the pressure sensations experienced during flight as meaning the same thing they would in an earth bound situation (i.e., pressure on the seat-of-the-pants indicates down). In flight, this pressure sensation is misleading because during coordinated flight, the force resulting from centripetal acceleration and gravity are always toward the floor of the aircraft. Thus, pilots can never tell through the pressure sensors which direction is the true vertical.

3.7.2. Giant Hand Illusion. The giant hand phenomenon is a subconscious reflex behavior, generated by vestibular or somatosensory inputs that interfere with the pilot's conscious control of the aircraft. This illusion gives the impression that some external force is pushing on the aircraft or holding it in a certain attitude. When disorientation is primarily about the roll axis, as with the leans or graveyard spiral, the pilot may see deviation from the desired attitude on the attitude indicator, apply the appropriate stick pressure to roll the aircraft to reduce the unwanted bank angle, and discover that efforts to roll the aircraft appear to be resisted. The aircraft either seems to not let the pilot roll or, once the airplane has been rolled to the proper attitude, it seems to roll back to the original attitude as if a giant hand were pushing a wing down. When the disorientation is about the pitch axis, as it is when a somatogravic illusion of pitch-up occurs during forward acceleration, the pilot may experience what feels as excessive nose down trim and the aircraft appears to resist efforts by the pilot to pull the nose up, as if a giant hand were pushing the nose down. There is little research relating to our understanding of the giant hand illusion. To date it has not been satisfactorily reproduced on the ground. It appears to be most commonly experienced during night air refueling operations.

3.7.2.1. Reflex Actions. The giant hand phenomenon is thought to occur as a result of pilot reflex actions during disorientation. Remember, our reflexes are geared to a ground-based environment and rely on vestibular and somatosensory inputs to determine orientation. During disorientation, the desired control input is in conflict with the reflex input, giving the illusion of some external force acting on the aircraft.

3.7.2.2. Overcoming the Giant Hand. To overcome the giant hand illusion, the pilot should momentarily remove his or her hand from the control stick to interrupt the reflex response. A positive effort must then be made on the controls to move the attitude indicator to the proper attitude. Some pilots have reported that they used their fingertips or knees to move the controls to keep the illusion dispelled. Upon transition back to holding the controls in the usual manner, the control anomaly returned. Clearly, the pilot must be sufficiently knowledgeable about the giant hand illusion to suspect it when the possibility of SD exists.

3.8. Other Sensory Phenomena. Fascination and resulting target hypnosis are often described as spatial disorientation, though these events are more correctly defined as anomalies of attention rather than alterations of perception.[22] Fascination occurs when the pilot's attention is focused on one aspect of his flying tasks to the exclusion of others, particularly when the focused aspect is new or particularly challenging, such as an in-flight emergency. Mishaps that result from fascination may be caused by target hypnosis, such as when a pilot is intently focused on NVG use without cross-referencing instruments to verify altitude or attitude. The concept of other sensory phenomena underscores the critical connections between orientation in flight and

[22] (USAFSAM-TR-85-31, 1985)

situational awareness. It is virtually impossible to discuss one topic in flight without understanding the impact of the other. In many cases, spatial disorientation and loss of situational awareness have been used as interchangeable concepts by mishap investigation boards. However, identification of a final cause in any mishap is critical to establishing effective prevention measures.

Chapter 4

AIDED NIGHT VISION IMPACTS TO ORIENTATION

4.1. Introduction. The most important sense used in flight is vision because it allows aircrew to quickly ascertain their position in space. Unfortunately, when transitioning to night operations, visual acuity decreases as the illumination levels are reduced. To compensate for this and improve the ability to operate in the night environment, the Air Force uses night vision devices (NVDs). NVDs permit aircrew to operate more effectively in the low-illumination environment, but NVDs have important limitations. Aircrew must recognize the limitations and exercise proper planning, good training, and sound judgment discussed in this chapter and in device-specific training, to effectively exploit the night using NVGs.

4.2. Dark Adaptation. Dark adaptation is the process by which your eyes increase their sensitivity to lower levels of illumination. People adapt to the dark in varying degrees and at different rates. For most people, the sensitivity of the eye increases roughly 10,000-fold during the first 30 minutes, with little increase after that time. One of the variables that determines the time for dark adaptation to take place is the length of exposure to bright light. If you have not been exposed to long periods of bright light, either through the use of sunglasses or spending the day indoors, you will likely dark adapt normally. On the other hand, if you are exposed to a large amount of unfiltered white light during the day, dark adaptation will take much longer. In extreme cases (snow-blindness or very reflective sand and water conditions), dark adaptation may not be possible for hours or even days. Under normal circumstances, complete dark adaptation is reached in approximately 30 minutes. If the dark-adapted eye is then exposed to a bright light, the sensitivity of that eye is temporarily impaired, with the amount of impairment depending on the intensity and duration of the exposure. Brief exposure to a bright light source can have minimal effect upon night vision because the pulses of energy are of such short duration. However, exposure to a bright light source (e.g., lightning or flares) for longer than one second can seriously impair your night vision. Depending on the intensity and duration of exposure, recovery to a previous level of dark adaptation can take anywhere between 5 and 45 minutes. The average image luminance in a night vision goggle (NVG) is not particularly bright, and your eyes will be in an intermediate state of dark adaptation when viewing scenes of typical uniformity. Once reaching this intermediate state and after discontinuing goggle use, it will take you approximately 5-10 minutes to regain full dark adaptation. Consequently, NVG use should be discontinued for a period of time prior to your requiring full dark adaptation (e.g., performing a landing without the use of NVGs).

4.3. Night Vision Device Systems. Two types of night vision systems will be discussed in this chapter, forward looking infrared (FLIR) technology and night vision goggles (NVGs).

4.3.1. FLIR technology is based on the fact that all objects warmer than absolute zero emit heat. FLIR can discriminate between objects with a temperature of less than one-degree difference, or of the same temperature if they emit heat at different rates. The rate of emission depends upon the composition of individual objects. FLIR sensors detect the differences in the thermal properties of these materials and create an image on either a head up or head down display. This process, called thermal imaging, is presented as a monochromatic image for the aircrew that can be gray or green depending on the display.

4.3.2. NVGs provide an intensified image of scenes illuminated by ambient energy in the night environment. Although they are a great aid to aviators conducting night operations, NVGs do not turn night into day. The image provided by NVGs places limitations on critical aspects of human visual performance, (i.e. visual acuity, field-of-view, contrast sensitivity, and motion/depth perception). These limitations combine to create a degraded visual environment, increase cognitive workload, and contribute to spatial disorientation. Proper training and extensive experience can help deal with these limitations and reduce the susceptibility to dangerous situations. Spatial orientation at night requires conscious, complex processing of data from cockpit instruments and displays. An aggressive NVG instrument crosscheck should be a part of all NVG operations regardless of illumination levels, flight altitudes or mission profiles. In addition, an effective NVG scan (using constant head movements) compensates for the reduced NVG field-of-view and increases the external field of regard of the aviator. By scanning the horizon during aggressive maneuvering, aircrew can minimize disorientation. Both the instrument crosscheck and an effective scanning technique require concentration and good habit patterns, which should be emphasized and developed during training. When employed under appropriate conditions, NVGs enhance orientation by providing an external visual scene where none is available without the goggles. However, NVG operations are inherently more demanding than comparable day missions and aircrew must fully understand the limitations on human physiology and aircraft systems.

4.3.3. Comparison of FLIR and NVG (Table 4.1). NVGs and FLIR systems are complementary sensors and can aid mission accomplishment through their integration.

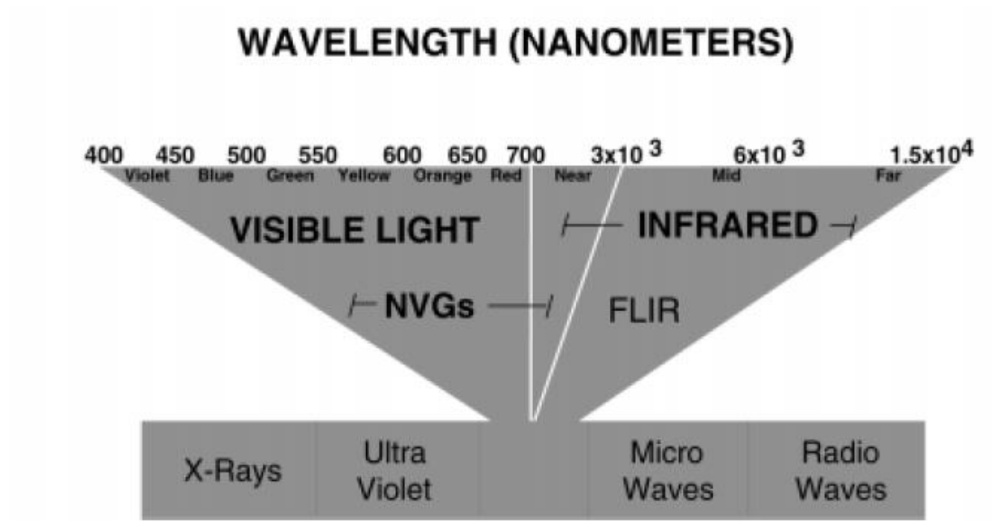
Table 4.1. NVG and FLIR Comparisons.

NVG	FLIR
Use reflected energy (visible light and near IR)	Use emitted energy (mid or far IR)
Images reflective contrast	Images thermal contrast
Requires at least some illumination	Totally independent of light
Penetrates moisture more effectively	Penetrates smoke
Attenuated by smoke, haze, and dust	Attenuated by moisture (humidity)

4.4. The Night Environment.

4.4.1. Electromagnetic Spectrum (see **Figure 4.1**). Areas on the electromagnetic spectrum represent both the light that stimulates the unaided eye and the energy intensified by NVGs. The human eye is sensitive to the visible spectrum (approximately 400 to 700 nm), which progresses from violet to blue, green, yellow, orange, then red. A substantial amount of near-infrared (IR) energy (approximately 700 nm to 900 nm) is present in the night sky, so NVGs were designed to be sensitive to both visible and near-IR wavelengths. Thermal imaging systems, such as forward- looking infrared (FLIR) devices, are sensitive to energy in the mid- and far-IR regions.

Figure 4.1. The Electromagnetic Spectrum.



4.4.2. **Terms**. The following terms are used to describe properties of light:

4.4.2.1. Illuminance. Illuminance (illumination) refers to the amount of light that strikes an object or surface at some distance from the source. An example is the amount of ambient light that strikes the ground from a light source.

4.4.2.2. Luminance. Luminance refers to the amount of light emitted or reflected from a surface area. An example is the apparent brightness of a surface that is illuminated by moonlight.

4.4.2.3. Albedo. Albedo is the ratio between luminance to illuminance, in other words, the ratio of reflected to incident electromagnetic radiation. Simply put, albedo is the fraction of light or other electromagnetic radiation reflected by a surface. For example, a mirror would have an albedo of near 1 or 100% while something that is very dark (black) would have an albedo near zero. Illumination from a light source may remain constant, but the luminance of different terrain features or objects will vary depending on their different albedos. The light source provides illumination, but what our eyes see, and what NVGs intensify, is the energy reflected from objects and terrain.

4.4.2.4. Contrast. Contrast is a measure of the luminance difference between two or more surfaces. In the night terrain environment, contrast is dependent upon differing albedo values for each type of terrain surface.

4.4.2.5. Nanometer (nm). The nanometer, (1 billionth meter) is a measurement of the wavelength of radiant energy.

4.5. Sources of Illumination. Many natural and artificial sources of energy, *described as environmental and cultural lighting*, combine to illuminate the night environment. Natural sources include the moon, stars, solar light and other atmospheric reactions, while artificial sources include city lights, fires, weapons discharge, searchlights and/or flares.

4.5.1. Moon. When present, the moon is the primary source of natural illumination in the night sky. The amount of moon illumination reaching the earth's surface is dependent on moon elevation above the horizon (moon angle) and the lunar phase.

4.5.1.1. Moon angle. Illumination from the moon is greatest when the moon is at its highest point (zenith) and at its lowest when the moon is just above the horizon. This effect is caused by absorption of energy as it travels through the atmosphere; at low moon angles there is more atmosphere for the energy to penetrate and hence more energy absorption occurs. Particulates in the atmosphere (e.g., fog, dust) will also increase this absorptive effect. An additional problem associated with a low angle moon concerns the adverse effect it has on the NVG image. The bright light source (moon) will degrade the image, making it difficult to see terrain detail such as ridgelines. In fact, flying towards a low angle moon results in problems similar to those experienced when flying towards a low angle sun. All these factors should be considered during mission planning. Mission planning tools often incorporate detailed US Naval Observatory data into reports; additional stand-alone resources can also be used to aid preparation.

4.5.1.2. Phases of the Moon. Illumination is also affected by the phases of the moon. There are four distinct phases in the lunar cycle: new moon, first quarter, full moon and third quarter. For a period of time during the new moon phase, the moon is in conjunction with the sun and the dark side of the moon faces earth. However, this phase, which lasts about 8 days, also includes periods when approximately one quarter of the moon's surface is illuminated. A relatively low light level is characteristic of the new moon phase. Following the new moon phase is the first quarter (waxing) moon phase. One quarter to three quarters of the moon disk is visible during this phase, which lasts approximately 7 days, and good illumination is provided. The full moon phase covers the period when more than three quarters of the moon disk is visible and lasts approximately 8 days. The third quarter (waning) moon is the last phase and lasts about 7 days. It covers the time period when three quarters to one quarter moon disk illumination is present. Good illumination is provided during this phase, though slightly less than during the first quarter due to the type of lunar surface (mountainous) being illuminated by the sun. The entire cycle is repeated each "lunar month," which lasts approximately 29 days. A quarter moon equals 50 percent illumination, which is optimal for current NVG technology.

4.5.1.3. Moon Shadows. Another characteristic of the changing moon position is shadowing. Moonlight creates shadows during nighttime just as sunlight does during the day. However, understanding what you cannot see in nighttime shadows is critical to NVG operations. Since they contain little or no energy (and some energy must be present for the NVGs to provide an image), shadows can completely hide obstructions such as ridgelines or towers, and may make it difficult to detect waypoints, targets, landing zones (LZ), drop zones (DZ), etc. The term foreshadowing refers to a particular shadowing situation in which near objects may be masked by the shadow created by a distant, higher object. Any of these effects can be a serious threat during low level flight.

4.5.2. Stars. The stars provide about 20 percent of the night sky illuminance on a moonless night. They contribute some visible light, but most of their contribution is in the form of near-IR energy. This means the majority of the energy is invisible to the human eye but is within the response range of NVG image intensifiers.

4.5.3. Solar Light. Sky-glow is ambient light from the sun that can adversely affect NVG operations up to 1 ½ hours after sunset and ½ hour prior to sunrise, depending on latitude and time of year. For example, in Alaska sky-glow will have a prolonged effect during the time of year when the sun does not travel far below the horizon. Sky-glow will affect the gain of the goggle and thus reduce image quality. The effect is similar to flying into a sunset and results in the loss of visual cues when looking either west (sunset) or east (sunrise). Mission planning should take sky-glow and its effects into consideration.

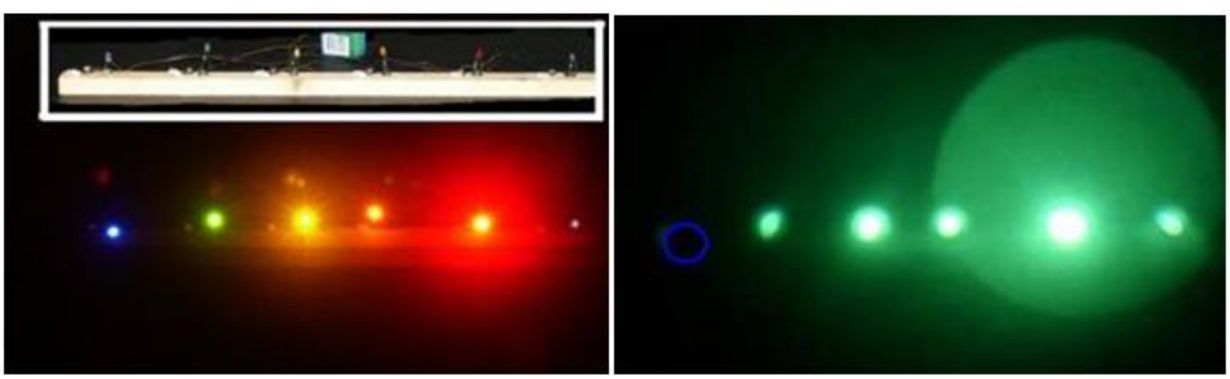
4.5.4. Other Background Illumination. The greater portion (approximately 40 percent) of energy in the night sky originates in the upper atmosphere and is produced by chemical reaction (ionization) processes. Other minor sources of night illumination are the aurora and zodiacal light caused by the scattering of sunlight from interplanetary particulate matter.

4.5.5. Artificial Sources. Lights from cities, industrial sites, and fires are also sources of illumination. Light from missile fly-out, weapon flashes, flares, and explosions can adversely affect NVG performance, but the effects are usually short lived due to the nature of the source (e.g., short 20mm/30mm bursts). In this case, the goggle image would return to normal as soon as the offending light source disappears.

4.5.6. Spectral Sensitivity (**Figure 4.2**). One of the concerns is the *difference in spectral sensitivity* between the unaided eye and the NVG. The display setup consists of five differently colored light emitting diodes, arranged according to the rainbow, from blue to green to yellow to orange to red. The NVG image is monochrome, showing all lights as green. The NVG is particularly sensitive to red light, also sensitive to near-IR light, and relatively insensitive to blue and green light.

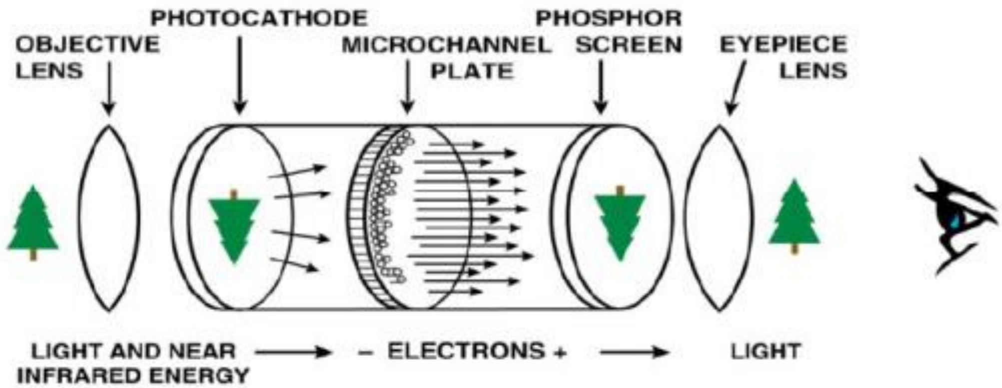
4.5.6.1. Some light-emitting diode (LED) lights do not produce high levels of near infrared energy, thus spectral sensitivity under NVG may change from incandescent lighting. For instance, a red incandescent position light can be seen by the NVG due to spectral "color" and near infrared energy being emitted. The same red position light as an LED may not produce the same level of intensity in the NVG. This potential decrease in intensity may render the LED light unperceivable under NVG's, and could pose a risk to the operator. This highlights one reason that a good visual scan is recommended to compliment the NVG scan.

Figure 4.2. Effect of Lights with Different Colors.



4.6. NVG Characteristics. The NVG is an advanced night vision system. The goggles chosen by most organizations in the Air Force are binocular-style, helmet mounted, image intensification devices that amplify visible and near-IR energy (Figure 4.3). This amplification is a passive process, meaning no emissions are created by the goggles themselves.

Figure 4.3. NVG Components and the Image Intensification Process.



4.6.1. Basic Components of the Image Intensifier Tubes. The most common NVG is a lightweight, fully adjustable binocular assembly consisting of two monoculars, one for each eye. Each monocular amplifies available ambient light and presents an intensified image to one eye. Each monocular is comprised of the following components.

4.6.1.1. Objective Lens. The objective lens of each monocular consists of a combination of optical elements which focus the incoming photons of light onto the photocathode of the intensifier tube. During this process the image is inverted.

4.6.1.2. Photocathode. The photocathode is the first element in an intensifier tube; it is a light- sensitive surface onto which the scene being viewed is focused by the objective lens of the monocular. It is similar to the film in a camera. It is made of gallium arsenide, and releases electrons when photons impact it, starting the intensification process. In the photocathode, light is converted into electrical energy, which allows for the amplification that follows.

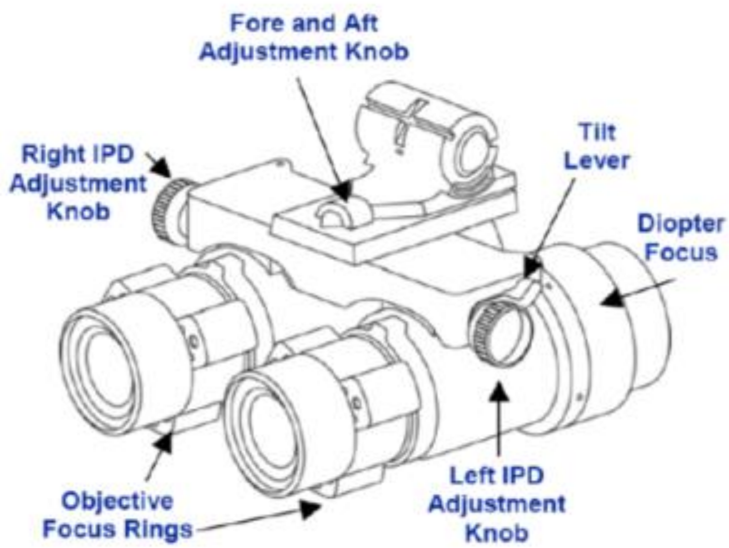
4.6.1.3. Micro-channel Plate. The micro-channel plate is the next element in an intensifier tube. It consists of a thin wafer containing millions of microscopic glass tubules that channel the electrons exiting the photocathode. The tube walls release multiple electrons when an electron impacts the wall. The tubules are tilted to ensure electron impact with the tubule wall. The result is a “cascade effect,” which is an essential part of the intensification process. As a result of this process, for every single electron that enters one of the tubules, over one thousand exit.

4.6.1.4. Phosphor Screen. The phosphor screen is the next successive element in an intensifier tube. The screen is located on the front surface of the fiber optic inverter, next to the rear (exit) surface of the micro-channel plate, and consists of a chemical that emits energy in the visible spectrum (light) when struck by electrons. Thus, as the electrons exiting the micro-channel plate strike the phosphor, an image is created. Due to the type of phosphor selected for NVGs, the resultant image is green.

4.6.1.5. Fiber Optic Inverter. The fiber optic inverter serves to convey the intensified image created on the phosphor screen to the output of the intensifier tube. The inverter reorients the image that was inverted by the objective lens.

4.6.1.6. Diopter (eyepiece) Lens. The diopter lens is the final optical component of the image intensifier tube. The lens is adjustable and focuses the image onto the retina.

Figure 4.4. Basic Night Vision Goggle Components.



4.6.2. **Procedures for adjusting and focusing NVGs (Figure 4 4).** Begin by cleaning all four lenses, setting the diopter adjustment ring settings to zero, and adjusting the tilt lever parallel with the tube housing.

4.6.2.1. Don the helmet and attach/lock the NVG assembly to the helmet mounted power transfer module (PTM, not pictured) in the up position.

4.6.2.2. Press the lock release button on PTM and lower the NVG assembly into the down position. Use the vertical adjustment knob on the PTM to raise or lower the goggle assembly to level with the eyes.

4.6.2.3. Adjust the horizontal eye relief creating one inch of space between your eyes and the diopter lenses (if done correctly a shaded circle with a silver ring lining can be viewed looking through both monocular tubes).

4.6.2.4. If necessary, adjust the Inter-Pupillary Distance (IPD) knobs moving the monocular tube toward the shaded area to aid in aligning your visual axis with the NVG optical axis thus aiding the evidence of a shaded circle with the silver ring lining.

4.6.2.5. At this point, the proper adjustments are made and the focusing procedures may be done using the ANV20/20 Hoffman Box. Ensure the Hoffman Box is adjusted to the proper height distance for the user. Prior to powering the NVG ensure the lights are out in the surrounding area.

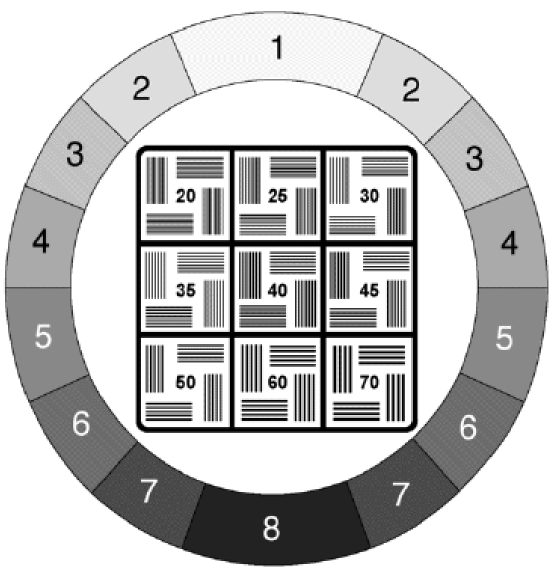
4.6.2.6. Cover one objective lens with a cap. Power on the Hoffman Box and while peering through the uncapped tube assess the image in the following manner:

4.6.2.6.1. Adjust the objective focus ring in either clockwise or counter clockwise direction until you can identify the orientation (vertical or horizontal) of the coarse lines only (fine lines will not be in complete focus at this point.)

4.6.2.6.2. Adjust the diopter focus ring counter clockwise until the image blurs, pause allowing time to let eye accommodate, then slowly turn the diopter focus ring in the clockwise position until you achieve a focused image (fine lines will be in focus at this point.)

4.6.2.7. IAW TO 12S10-2AVS9-2, using the Hoffman tester in the high light setting it is recommended that the user attain at a minimum 20/30 visual acuity. While pushing in and holding the low light function test button the user should attain a minimum of 20/35 visual acuity. See **Figure 4.5**. In effect, the low light button is used to establish the NVGs will perform acceptably under low illumination conditions. If there's a drastic drop off in VA, consider exchanging to another set of NVGs.

Figure 4.5. ANV- 20/20 Visual Acuity Box Image.



4.6.2.8. The only adjustments after this point in the focusing procedures are to be done with the objective lens.

4.6.2.9. Repeat steps 6-8 adjusting the focus rings of the other tube lenses allowing for image assessment.

4.6.3. **Assessment of Image**. The following image defects are typical deficiencies that can be either normal or defective in nature; see figure 4.6 for illustrations of defects described below. It is important to understand the difference to determine the proper course of action.

4.6.3.1. Shading. Shading is a condition encountered when a full image cannot be obtained and a dark area appears along the edge of the image. Attempt to eliminate shading by readjusting either the tilt or the IPD, or by shifting the helmet's position. Shading can also occur as a result of a shift in the micro-channel plate caused by the goggles being dropped or handled roughly. If shading cannot be corrected by readjustments or by repositioning the mounting bracket on the helmet, turn the goggles in for maintenance.

4.6.3.2. Edge glow. Edge glow appears as a bright area along the outer edge of the image. It can result from an incompatible light source outside the goggle FOV, a shift in the micro-channel plate due to mishandling, or a power supply problem within the tube assembly. If edge glow is noted, move your head or cup your hand around the periphery of the objective lens in an attempt to alleviate the condition. If the edge glow does not disappear, turn the goggles in for maintenance.

4.6.3.3. Honeycomb. At times of very high luminance, a hexagonal (honeycomb) pattern may be visible across the intensified field of view. This pattern is a result of the manufacturing process during which the fiber optic inverter is assembled within the tube. Normally it is faint in appearance and does not affect NVG performance. Should it appear as a bold outline or during low luminance conditions, turn the goggles in for maintenance.

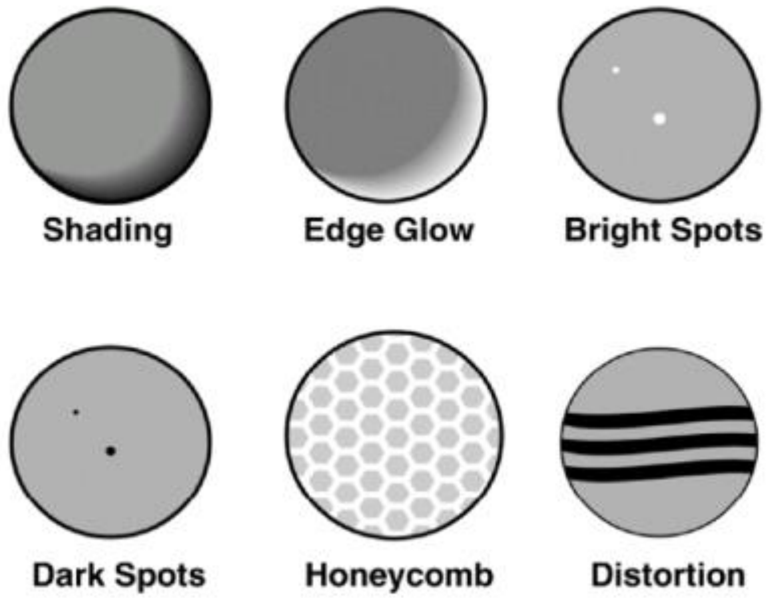
4.6.3.4. Bright spots. Bright spots are the result of irregular emission points on the photocathode, usually occurring during the manufacturing process. Because these spots are normally detected during the quality control process at the manufacturer, you will seldom see them. However, if an NVG has an excessive number of spots present in the image, or if the spots are distracting, turn the goggles in for maintenance.

4.6.3.5. Dark spots. Dark spots are simply the bright spots described above that have been corrected at the manufacturing facility. This correction is accomplished by exposing the light spots to laser energy and burning out that portion of the photocathode. Dark spots may also be caused by material allowed to enter the system during maintenance. NVG acquisition contracts usually include a specification that limits the number, size, and location of dark spots. Nevertheless, if you are distracted by the dark spots, even if the NVG is within specification, turn the goggles in for maintenance.

4.6.3.6. Distortion. The two most common types of distortion are bending and shear. Bending distortion results in the image having a wavy appearance, usually in a horizontal or vertical direction. Shear distortion results in a choppy appearance somewhere in the image. If distortion is present and likely to interfere with normal operations, turn the goggles in for maintenance. Flying with tube distortion can cause problems in distance and altitude estimations.

4.6.3.7. Scintillation. A sparkling effect normally occurs in the NVG image during low illumination conditions as a result of increased goggle gain and system noise. In flight, it can be an indication of decreasing illumination caused by such things as deteriorating weather conditions or flight into shadows.

Figure 4.6. NVG Image Defects.



4.7. NVG Performance Characteristics.

4.7.1. Gain. Gain refers to the ratio of output to input, or the amount of energy the intensification process produces relative to the amount that entered the intensification process. A NVG has circuitry that determines the amount of energy entering the intensification process, and this circuitry automatically controls the level of intensification needed to produce images of consistent brightness over a wide range of illumination levels. At some point, the ability of the intensifier to increase gain is reached and image brightness and quality begin to degrade. Image degradation caused by lowering light levels can be very insidious and leads to problems for the aircrew.

4.7.2. Image color. The NVG image appears in shades of green. Since there is only one color, the image is said to be monochromatic.

4.7.3. Visual performance. When compared to the human eye under daylight conditions, your vision is limited while utilizing NVGs—detection ranges increase and recognition of objects, terrain and targets can be severely limited. While NVGs can be vastly superior to the human eyes' performance under night conditions, NVGs DO NOT TURN NIGHT INTO DAY.

4.8. NVG Limitations. The following visual limitations are common to most NVGs. The limitations of NVG are not as obvious as the characteristics described above and must be learned.

4.8.1. Field of view. FOV refers to the total instantaneous area covered by the NVG image. Regardless of the type of NVG utilized, it is important to understand that the FOV it is able to provide is less than your eye's FOV, particularly in your peripheral vision. This loss of peripheral vision is often a contributing factor in the onset of spatial disorientation.

4.8.2. Resolution. Resolution refers to the capability of the goggle to present an image that makes clear and distinguishable the separate components of a scene or object. Though not technically accurate, it is easiest to discuss resolution in terms of Snellen visual acuity (the same system used for vision testing during flight physicals). Current NVGs have a resolution capability of 20/25 to 20/40 Snellen. The resolution achieved with the Hoffman tester is the best; during flying operations, resolution may be negatively impacted by transmissivity, weather, lighting, etc. Though quite an improvement for NVGs, the performance may still be less than 20/20, a standard accepted as "normal day vision." However, NVG performance far exceeds the eye's unaided visual performance at night, which is approximately 20/200 to 20/400. It should be noted that while NVGs have a rated acuity of 20/25 to 20/40 Snellen, this is the best an aircrew can expect to achieve under optimum conditions. There are many factors that affect NVG operations and degrade the expected acuity. These factors are discussed in the next section. NVGs will not correct for sight deficiencies such as myopia or astigmatism. If you wear glasses during the day, you will still have to wear them when flying with NVGs to see properly.

4.8.3. Depth Perception and Distance Estimation. Depth perception is the ability to determine where objects are located relative to each other, whereas distance estimation is the ability to determine the distance to something, such as the ground or a target. Depth and distance are discussed together because they use the same visual cues—binocular and monocular.

4.8.4. Binocular Cues. An aircrew's binocular cues are usually quite degraded due to the design of the goggle. Binocular cues are needed for tasks relatively close (within an arm's reach) and for tasks at distances up to approximately 200 feet. Binocular cues, by definition, require the use of both eyes functioning together and include stereopsis, vergence and accommodation.

4.8.5. Monocular Cues. Monocular cues appear to be most important for deriving distance information while flying. Monocular cues do not require the coordination of both eyes and are available beyond the distances at which binocular cues are. NVGs adversely affect monocular cues several ways. The decreased resolution of the NVG image results in a loss of sharp contrast and definition, both helpful for determining depth and distance. The limited FOV of the image diminishes depth and distance tasking by reducing the availability of cues. Also, anything adversely affecting the image (e.g., low illumination) will aggravate the problem. Examples of monocular cues used when flying include:

4.8.5.1. Size constancy. If two hangars are known to be equal in size, the one appearing smaller must be further away.

4.8.5.2. Motion parallax (optical flow). Nearer objects appear to be moving past more quickly than distant objects.

4.8.5.3. Linear perspective. The convergence of parallel lines at a distance.

4.9. Avoiding Depth and Distance Problems. Be aware that anything adversely affecting the NVG image will also adversely affect the assessment of depth and distance. Avoid the tendency to fly lower or closer in order to see more detail. Over a period of time, an aircrew member "learns" how to assess depth and distance when flying in the same area. However, the "learned" techniques may not transfer to a new area where terrain and objects might be completely different in size and perspective. In general, there is a tendency for aircrew to overestimate how well they can see when using NVGs.

4.9.1. Contrast. As with resolution, contrast in the NVG image is degraded relative to that perceived by the unaided eye during daytime. Also, any bright light source within or near the NVGs FOV will further reduce contrast by reducing gain, creating veiling glare across the image, or both. Additionally, there are differences in sensitivity to contrast among crewmembers, which may lead to differences in image interpretation.

4.9.2. Dynamic Visual Cues. Dynamic visual cues provide information that helps to determine direction, altitude and speed. The three primary dynamic cues are:

4.9.2.1. Static Cue Motion. Static cue motion is the summed effect of the change in one or more of the static cues caused by aircraft movement. Static cues include elevation, known size, and perspective. Central vision tracking is a method for seeing static cue motion and will be degraded when using NVGs.

4.9.2.2. Optical Flow. Optical flow is the angular rate and direction of movement of objects as a result of aircraft velocity measured relative to the aviator's eye point. This provides our visual system the information necessary to interpret speed and direction of motion. If there is no relative motion, there is no optical flow. We use central vision to obtain optical flow information. Since visual acuity is degraded with NVGs, the optical flow cues will be degraded when compared to daytime cues.

4.9.2.3. Peripheral Vision Motion. Peripheral vision motion is a subconscious method of detecting optical flow. It is dependent on a wide FOV and is the primary attitude sensory input. With the reduction in FOV due to NVGs, this cue is severely degraded and central vision tracking becomes the primary attitude detection means. This leads to one of the most insidious dangers when flying low altitude—flying at a lower than expected/allowed altitude. Just as in the day, visual acuity will improve as the aircraft gets closer to the ground. However, because of the reduction in peripheral vision motion, the ensuing "speed rush" that would indicate close proximity to the ground is degraded and controlled flight into terrain becomes a real danger.

4.9.3. NVG Scan. The reduction in FOV necessitates an active, aggressive scan on the part of the NVG wearer. By continually scanning, aircrew members increase their field of regard by increasing the mental image of the surrounding terrain, aircraft, and cultural features. This information can then be compared and added to the aircraft flight instruments. Aircrew members should establish a scan pattern that allows information from outside the cockpit to be merged with cockpit flight instrumentation. Fixating in one direction may be necessary for a short duration (e.g., identifying a waypoint), but the scan should be continued after just a few seconds. A crewmember's scan pattern may be disrupted during high cockpit workloads or when fatigued. Under these conditions, an extra emphasis needs to be given to the scan pattern, especially keeping the horizon in the field of regard.

4.9.4. Preflight Adjustment and Assessment. Following proper NVG adjustment procedures prior to each flight is imperative to ensure a safe and effective operational capability. Even a small error in goggle adjustment can significantly degrade NVG visual acuity. The problem is compounded by the fact that it is nearly impossible to measure a loss in visual acuity without a controlled test environment, which means you can lose visual performance and not realize it.

4.10. Factors Affecting NVG Operations.

4.10.1. Cockpit Lighting. NVG compatible cockpit lighting allows the crewmember to see cockpit instruments underneath the NVG while not measurably affecting NVG performance. Although NVG filters allow the use of cockpit lighting that will not adversely affect gain and image quality, unfiltered aircraft lighting is incompatible. If the lighting is not properly modified, it will emit wavelengths that affect NVG performance. There are aircraft in the inventory that have not been fully modified to be NVG compatible. The following points are provided for clarification:

4.10.1.1. Just because a light is green or blue does not mean it is compatible. When the filament in a light glows, it releases a significant amount of near-IR energy which will affect NVG gain and performance. Light bulbs and other energy sources in the cockpit must be modified in some manner to block the emission of all energy to which NVGs are sensitive in order to make them NVG compatible.

4.10.1.2. Turning down the brightness of incompatible cockpit lighting will not make them compatible because NVGs are also sensitive to the near-IR energy emitted by the lights. Attempting to turn down lighting to reduce the effect on goggles can be a two edged sword—the NVG image will still be degraded and vital instruments may not be readable with the unaided eye for several seconds.

4.10.1.3. An incompatible light does not have to be within the NVG FOV for it to have an effect on gain. MAJCOMs have specific lighting modification procedures if your aircraft cockpit lighting is not NVG compatible. When modifying your cockpit, remember that AFI 11- 202 Volume 3 requires you to always have primary flight instrumentation present and properly illuminated. It must provide full-time attitude, altitude, and airspeed information; an immediately discernible attitude recognition capability; an unusual attitude recovery capability; and complete fault indications.

4.10.2. Transparency Transmissivity. Another impact on NVG performance is the degradation caused by windscreens, canopies, or other transparencies through which aircrew must look. Some transparencies transmit visible wavelengths fairly well, but near-IR wavelengths very poorly. Since NVGs are sensitive to near-IR wavelengths, transparencies that "trap" much of that energy will degrade NVG performance. All transparencies absorb near-IR energy to some extent, so there will be some goggle degradation in your cockpit.

4.10.3. **Weather and Visibility Factors.** Any atmospheric condition which absorbs, scatters, or refracts illumination, either before or after it strikes the terrain, will effectively reduce the usable energy available to the NVG. This reduction, in turn, degrades our ability to see key features critical for flight. The exact amount of reduction is difficult to predict because a common factor cannot be applied to each condition.

4.10.3.1. Clouds. In general, NVGs easily "see" clouds that are dense but may not see clouds that are less dense. In the case of the more dense clouds, both visible and near-IR energy is reflected and the NVG can see the cloud (just as you can see the cloud unaided if there is enough light), especially if silhouetted against the night sky. However, dense clouds will reduce the amount of illumination striking the ground and therefore reduce the luminance available for NVG use. Thin (less dense) clouds have more space between their particles. Because the near-IR wavelength is slightly longer, it has a greater chance of passing through these type clouds than does the shorter visible wavelength. It is possible for the thin and wispy clouds (which may be seen with the naked eye during daytime) to be invisible when viewed through the NVG. This potential invisibility is possible given three conditions: The clouds are less dense and are low level, set in against the terrain rather than being silhouetted against the night sky, and ambient illumination is either very high or very low. NOTE: The invisibility of thin clouds can create a severe hazard for NVG operations. Even though a cloud is "invisible," you may not be able to see the terrain behind it because the cloud reduces luminance, which in turn reduces scene contrast and texture. This may, in turn, produce a false perception of distance, resulting in the pilot either not seeing the terrain or thinking it is farther away than it actually is. Additionally, the cloud may get progressively thicker, allowing the pilot to progress into the cloud without initially perceiving it or the terrain beyond. If a cloud is detected, the perception may be that it is at a distance.

4.10.3.2. Fog. Fog is another atmospheric condition of concern for the NVG operator. Its effects on goggles are similar to those of clouds, but there is a greater tendency for fog to be less dense and therefore more of a problem. It is important to know when and where fog may form in your flying area. Typically, coastal and mountainous areas are most susceptible.

4.10.3.3. Rain. Like clouds, the effect rain may have on goggle performance depends on the type of conditions encountered. Droplet size and density are key ingredients to its visibility or invisibility. Light rain or mist may not be seen with NVGs, but will affect contrast, distance estimation, and depth perception. Heavy rain is more easily perceived due to the large droplet size and energy attenuation.

4.10.3.4. Snow. Snow occurs in a wide range of particle sizes, shapes, and densities. Snow crystals, while small in size, are generally large in comparison to the wavelength of visible light and near-IR energy, and will easily block or scatter those wavelengths. As with clouds, rain, and fog, the more dense the airborne snow, the greater the effect on NVG performance. On the ground, snow has a mixed effect depending on terrain type and the illumination level. In mountainous terrain, snow may add contrast, especially if trees and rocks protrude through the snow. In flatter terrain, snow may cover high contrast areas, reducing them to areas of low contrast. On low illumination nights, snow may reflect the available energy better than the terrain it covers and thus increase the level of illumination.

4.10.3.5. Sand, Dust, Smoke and Similar Obscurants. The effect of sand, dust, smoke and similar obscurants is similar to that created by the weather factors. However, the individual particulates in these obscurants are usually far more dense, which means they can block energy even if less concentrated.

4.10.4. All the atmospheric conditions described above reduce illumination levels. Recognition of this reduction in the cockpit is very difficult. The change is often a very subtle reduction in contrast that is not easily perceived with NVGs. Cues can be very subtle and the crewmember will have to stay aware to catch their significance. Common cues to reductions in ambient illumination due to visibility restrictions include loss of celestial lights, loss of ground lights, reduced contrast, reduced depth perception or distance cues, reduced acuity or resolution, increased graininess or scintillation, and a more pronounced "halo" effect around incompatible light sources outside the aircraft.

4.10.5. Cockpit lighting, weather, transparency effects, the illumination level, and terrain type all have an effect on NVG performance. The visual acuity you achieve in the eye lane will usually not be what you get in the aircraft during the mission—it will usually be less. It is therefore imperative you maximize NVG performance before flight and avoid doing anything to the goggle during flight to disrupt it (e.g., readjust the diopter). Maximizing the NVGs performance will help offset the negative effects discussed.

4.11. Night Operations with NVGs. The NVG environment is always changing, so you must always be aware of what cues are presented and work to interpret them. Even then, beware of the potential misperceptions or illusions in any NVG scene. Many terrain characteristics influence our ability to see features or objects and distinguish differences. Due to the variability of the weather, the illumination level, and the moon angle, any given scene may look radically different on consecutive nights. A basic understanding of NVG operations requires the crewmember to blend the following considerations with an awareness of those changing conditions over different types of terrain.

4.11.1. Terrain Albedo (Reflectivity). Differences in terrain albedo, or reflectivity, will greatly influence luminance. For example, surfaces such as snow will reflect more energy than surfaces like asphalt or dark rock. Since NVGs intensify reflected energy, different albedos become critical in interpreting the NVG scene. Albedo will also vary with specific conditions of terrain even though the terrain type remains constant. For instance, dry sand is twice as reflective as wet sand.

4.11.2. Terrain Contrast. Terrain contrast is a measure of the difference between the reflectivity of two or more surfaces. The greater the differences in contrast, the more "normal" the scene appears in the NVG image, and the easier it becomes to pick out objects. Contrast generally improves with higher light levels, but there comes a point where there is actually too much light. This is usually noted when flying over low contrast terrain during high illumination conditions. Normally, however, as the ambient light level increases, overall definition is improved. Some examples of the effects of contrast in varying conditions are below.

4.11.3. Roads. The ability to detect roads with goggles depends primarily on the albedo difference between the road and the surrounding terrain. For example, the highly reflective surface of a concrete highway is easily identified in a grassy area during most illumination levels because of the difference in their albedos. However, asphalt roads are usually difficult to identify in heavily vegetated areas because both the asphalt road and the vegetation absorb available energy, and therefore have similar albedos. Conversely, in desert areas the reflective sand can make asphalt roads easily detectable.

4.11.4. Water. Still water, when seen with NVGs, normally looks dark when viewed at high angles from higher altitudes. Under low illumination, there is very little contrast between a vegetated landmass and a body of water. In desert areas, lakes and small bodies of water are normally detectable as a dark area in a light background. Lakes in a forested area are more difficult to detect due to the low reflectivity of the surrounding terrain. As light levels increase, land-water contrast increases. Due to the reflective nature of water, when over-flying large bodies of calm water, the stars appear to move across the surface as the angle of reflection is changed by the movement of the aircraft. This phenomenon may contribute to or induce the onset of spatial disorientation. Any action on the water caused by wind, such as white caps, may improve the contrast, aiding in surface identification. Over the ocean, the normal wave action breaks up reflections, thus reducing the problem. As in non-NVG flight, however, all night flight over open water is best performed with a heavier reliance on primary instruments.

4.11.5. Open fields. Contrast is usually very good over fields that are tended for crops. Various types of vegetation differ widely in their near-IR reflectance characteristics. For example, due to differences in the near-IR reflectance of chlorophyll, an oak tree will appear brighter than a pine tree. The same holds for crops. However, if flying over a large area of similar vegetation, contrast will be reduced. Additionally, the differences in the surface texture due to plowing are very apparent. A freshly plowed field may lack vegetation, but may produce a good NVG image when the coarse texture of the upturned soil contrasts well with the relatively undisturbed soil between the rows.

4.11.6. Desert. Open desert without vegetation can produce a washed-out NVG image. This is due to the high reflectivity of the sand and poor contrast offered by the lack of different albedos in the scene. Desert environments which have bushes, low trees, and cacti provide better contrast cues, allowing for more detail in the image. In general, flying over this type of terrain is similar to flying over water and is best accomplished with more reliance on your instruments.

4.11.7. Mountain Ranges. Normally, mountain ranges can easily be identified by contrast between the lower reflectivity of the mountains with a lighter, more reflective desert floor. However, if ridges between your aircraft and a distant ridge have similar albedos, the intermediate ridges can for all practical purposes be “invisible.” Low, rolling terrain with the same reflectivity as the surrounding terrain can also blend together and be difficult to distinguish. These effects are more pronounced in low-light situations, but can occur under any conditions.

4.11.8. Forested areas. Heavily forested areas do not reflect energy efficiently, and solid canopied forests or jungles look like a dark mass at night. Excellent contrast does exist between deciduous (leafy) and coniferous (pines, firs, etc.) trees as well as between open fields, exposed rocks, and surrounding forest areas.

4.11.9. Snow. Fresh, wet snow reflects approximately 85 percent of the energy reaching it, thus providing the best natural reflectivity of any terrain surface. Under high illumination, this can provide excessive light which can, in turn, lower intensifier tube output and decrease resolution. During periods of predicted low illumination conditions, snow may add to the illumination level. Snow on the ground can also be a factor for flight planning; landmark recognition may be difficult if deep snow obscures prominent terrain features.

4.11.10. Terrain Shadows. Shadows form at night just as they do during the day, and anything blocking moonlight will create a shadow. The amount of terrain obscuration within a shaded area is dependent on the amount of ambient illumination and relative position of the moon. The smaller the moon disc, the darker the shadowed area and the more difficult to see detail. However, never plan on seeing any terrain features within shadows, regardless of the moon disc size.

4.12. NVG Misperceptions and Illusions. While most misperceptions and illusions encountered during NVG operations are simply a carryover of those experienced during daytime flight, others are specific to the NVGs themselves. Reduced resolution, limited field of view, and susceptibility to obscurants can intensify misperceptions and illusions. The most common NVG misperceptions and illusions are discussed below.

4.12.1. Depth Perception and Distance Estimation Errors. A common belief is that depth perception (DP) and distance estimation (DE) capabilities do not exist when using NVGs. It is true that these abilities are degraded by environmental conditions and goggle limitations, but techniques can be developed to assess depth and distance. The most helpful depth and distance cues are those with which the aircrew is most familiar. Flying over familiar terrain and culture features can reduce DP and DE errors. When flying over different terrain with unfamiliar features, serious errors in DP and DE can develop. For example, if someone normally flies over terrain with 30 foot trees, but is then deployed to an area populated with 5 foot shrubs, aircrew may fly lower than normal trying to make the scene look as it normally does. Using visual information alone, that person would likely think they were higher than they actually were. In this situation, bringing a radar altimeter into the cross-check would help minimize the effects of the illusion. Overall, the best way to train for the lack of DP and DE cueing is through proper planning, training, and a good discussion of differences between the deployed location and the normal area of operations. Training over a wide variety of terrain, features, and illumination levels can build the experience level of the aircrew to handle varying situations. Additionally, a thorough pre-brief should be incorporated to familiarize aircrew with the cues expected in the area of NVG operations. Be aware that a light source's halo intensity is not an accurate representation of its distance from the aircraft. The various wavelengths of light affect halo size significantly. When viewing light sources with NVGs, a technique that may help DP and DE is to look at the source with unaided vision. By looking underneath or around the goggles, not only can colors be determined, but the halo effect produced by the NVGs is eliminated. This additional information can be combined with the information presented in the NVG scene to improve the accuracy of your assessments.

4.12.2. Terrain Contour Misperceptions. Terrain contour misperceptions are exaggerated by anything that degrades the NVG image. The following are a few techniques to aid the aircrew in correct terrain perception.

4.12.2.1. Discriminating Between Near and Distant Terrain. One way to discriminate between near and distant terrain that contain little contrast difference is being attentive to motion parallax between the two. For example, a hidden ridgeline close to you may be highlighted by noting its movement relative to a distant, higher mountain.

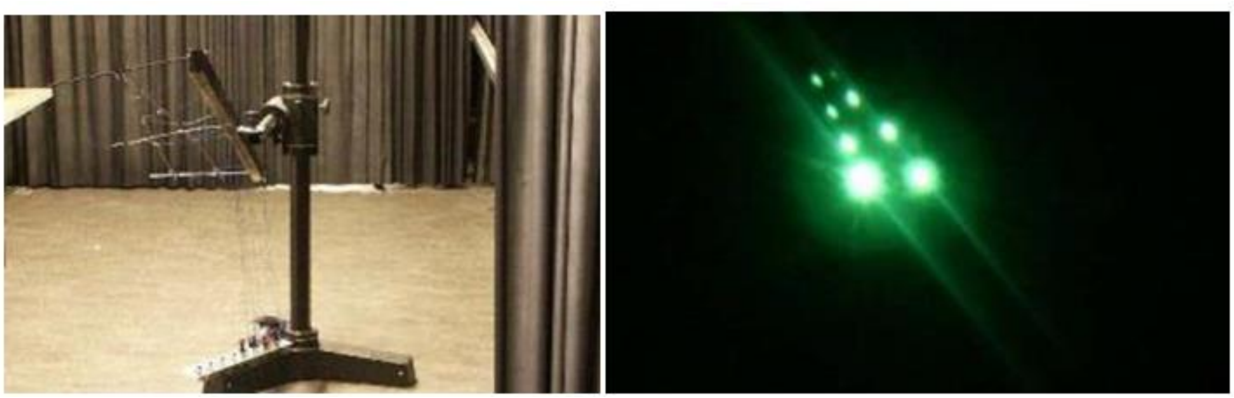
4.12.2.2. Gradual Changes in Terrain Elevation. Gradually rising or descending terrain can be very difficult to assess when the terrain is low contrast. It becomes even more difficult when there are few cultural features available for comparison. To aid in detection of the gradual changes, an aggressive NVG scan must be maintained. By scanning aggressively, indicators of changes in terrain elevation may be picked up in areas other than directly in line with the flight path. Also, an aggressive instrument scan—when altitude, mission, and terrain type allow—can provide additional inputs to the developing situation.

4.12.2.3. Maintaining Scene Detail. If for any reason scene detail is reduced, there may be a tendency to fly lower in an attempt to regain the lost detail. In the worst case, this can lead to ground impact. Examples of when scene detail can be reduced include transitioning from an area of high contrast to one of low contrast, or when transitioning from an area of high illumination to an area of low illumination.

4.12.2.4. Undetected or Illusory Motion. Motion illusions experienced by aircrews are usually due to flights over areas of reduced contrast, or a sudden loss of contrast and flow cues. This can result from the lack of perceived "flow" information in the NVG image and may create the illusion that the aircraft has slowed down or stopped. This situation can induce spatial disorientation, especially if coupled with other factors such as loss of the horizon. An increased instrument scan will help alleviate the problem. Another insidious aspect of undetected motion is when an aircrew perceives they are motionless. Helicopter crews hovering over low contrast terrain, whether a large field or over open water, can actually be moving at fairly high speeds without knowing it. Without cues to provide stimulus to the visual system, this movement can go undetected and is very dangerous. Again, this is a known problem even during daytime, but the decreased resolution and FOV of the NVG image can accentuate the effects.

4.12.2.5. False Perspective. Halos and the dominance of light sources can cause a dramatically distorted NVG depth perception. This can be shown by a wire frame to which several light sources have been attached (**Figure 4.7**). With the naked eye the correct geometry is apparent, but with the NVG the perceived geometry flips. When the observer moves sideways it appears as if the construction becomes fluid: the geometry distorts. The correct perspective does not re-appear as is usually the case with geometrical illusions. This demonstration is particularly powerful because the viewer cannot overcome the illusion even when he or she is aware of the correct geometry.

Figure 4.7. Line of Sight.



4.12.3. NVG Flight Over Water. Flight over water is particularly dangerous with NVGs due to the significantly reduced contrast, absence of features, and lack of motion cues in the NVG image. Also, a frequent cause of SD with NVGs has been the reflection of stars by water surfaces. Hazy conditions over water can cause disorientation and force almost total reliance on flight instruments. Therefore, NVG flight over water must be conducted with an increased reliance on instruments as if the aircraft were in IMC. Because of the number of illusions that can occur, extraordinary vigilance must be maintained in the aircrew's crosscheck between outside visual references and instrument references to prevent misinterpretation of the NVG scene.

4.12.4. Inadvertent Flight into IMC with NVGs. A particularly hazardous regime exists when flying with NVGs in weather conditions conducive to the formation of thin clouds or fog. NVGs are primarily sensitive to near infrared energy, which is poorly reflected by moisture. Aircrew using NVGs will be able to detect dense clouds or fog, especially clouds silhouetted against a clear sky. However, thin clouds or light fog may not be perceived. It is possible to enter IMC without ever detecting its presence while utilizing NVGs. To combat this phenomenon, NVG aircrew must be aware of the increase in scintillation in the NVG image, indicating a decrease in the level of brightness of the NVG image. As the illumination level decreases with the increasing cloud cover, the automatic brightness control in the goggle adjusts to maintain constant image luminance. However, as illumination conditions worsen, NVG image luminance can gradually decrease. The NVG user may continuously adapt to decreases in image luminance and fail to notice the subtle changes in scene brightness. In these conditions the NVG aircrew must interpret the increase in scintillation in the NVG image as the primary warning that environmental conditions may be deteriorating.

4.12.5. **Recommendations.** Susceptibility to illusions and misperceptions can be lessened by maximizing visual acuity. The best way to accomplish this is through effective training as well as proper preflight adjustment and assessment of the goggles to ensure the best NVG image. In-flight attentiveness is another building block to ensure NVG effectiveness. As stated earlier, reliance solely on visual cues will nearly always result in a flight path that is lower, closer, or steeper than intended, so the aircraft instruments must be readable and included in your cross-check. Use all information available to you, not just one piece of the puzzle. By using the entire picture, you lessen the likelihood of relying too much on NVGs. As usual, an aggressive scan is required to maintain situational awareness and spatial orientation.

4.13. Emergency Situations. In general, consider the type of emergency and what actions might be required from the pilot or the crew. If the NVGs will not be useful during emergency procedures, consider removing them. However, if you can still gain valuable information from the NVGs, aircrews may continue to use them.

4.13.1. Ejection. Ejection seat aircrew members must remove the NVGs prior to ejection unless they are ejection seat compatible. During the ejection sequence, with the NVGs in place on the helmet, fatal neck injuries or skull fractures can occur due to the forward center of gravity and weight of the goggles. For this reason, aircrew should not leave their NVGs in a raised position during emergencies that may lead to an ejection. It is probable they will forget they are wearing them as they manage this highly stressful situation.

4.13.2. Inadvertent IMC. One of the most dangerous situations that can be experienced with NVGs is flight into undetected meteorological conditions. The inability of the NVGs to see various areas of moisture can lull the aircrew to continue further into instrument meteorological conditions (IMC) to a point where there is virtually no visual information. This can result in a gradual loss of scene detail and place the aircrew in an area of heavy moisture and, in the low- level environment, place the aircrew in a potential conflict with masked terrain. The following NVG cues will help alert you to impending IMC:

4.13.2.1. Halos surrounding incompatible light sources outside the cockpit (e.g., external lights from another aircraft) may change in appearance. Normally sharp edges to the halos can become less distinct and the halo may appear larger due to energy dispersion from the moisture.

4.13.2.2. A gradual loss of scene detail, visual acuity, or terrain contrast.

4.13.2.3. Partial or complete obscuration of the moon and stars.

4.13.2.4. An increase in scintillation.

4.13.2.5. The glow or flash from your aircraft external lights/strobes/landing lights/searchlights may become visible or intensify.

4.13.2.6. Looking underneath or around the NVGs with the unaided eye can aid in detecting IMC, but be aware that you can be in precipitation without seeing it in the NVG image. Use all the cues available to you.

4.14. Spatial Disorientation. Spatial disorientation can occur at any time during flight. Although NVGs usually improve situational awareness and reduce the possibility of spatial disorientation, they can also enhance momentary disorientation. This is due to the limited field of view and lower resolution. Maintaining spatial orientation at night requires complex conscious processing of data from various instruments, displays, and references. The task of maintaining spatial orientation competes with the usual tasking of navigation, terrain masking, threat avoidance, etc. Add to this the fact that fatigue occurs more frequently at night and it is easy to understand why the incidence of spatial disorientation in this environment appears to be logarithmic as variables are added. Constant vigilance and a good scan pattern, both inside and outside the cockpit, must be maintained to help prevent spatial disorientation. Keeping the horizon in the NVG scan can help avoid spatial disorientation. If you feel disoriented, react in exactly the same way as if you were on a non-NVG flight. NOTE: Refer to AFMAN 11-217, Volume 1 Instrument Flight Procedures, for a discussion on preventing aircraft mishaps due to spatial disorientation.

4.15. Overconfidence in NVGs. It is important aircrew not become over confident in the capabilities of NVGs. Goggles are only one tool used during night flight, and many situations can degrade or eliminate their effectiveness. Aircrews need to be cognizant of NVG limitations and prepared to transition to other flight aids, primarily aircraft instrumentation. Remember that NVGs do not turn night into day. After your initial NVG flying experience, there may be a natural tendency to be overly confident in your abilities. While, over time, there will undoubtedly be an increase in your skill level, it is not enough to compensate for the multiple variables in the night environment. The complacent mind-set could be a setup for a mishap.

Chapter 5

SD IN RPA AIRCREW

5.1. Historical Perspective: Remotely Piloted Aircraft (RPA). What is now known as aviation is vastly different from what it was in the past. Just a few decades ago, in-flight refueling, high altitude air delivery, and stealth technology, were at the forefront of advanced aviation. However, the development and effectiveness of Unmanned Aerial Systems (UAS) has driven both political and military leadership to reconsider national defense strategies, aviation capability, research and development initiatives, and even budgetary allotments. In 2010, Admiral Michael Mullen stated, "We're at a real time of transition here in terms of future aviation. What's going to be manned? What's going to be unmanned? There are those who see [the JSF] as the last manned fighter/bomber. And I'm one that's inclined to believe it—whether it's right or not."[23]

5.1.1. This new age of flying was forecast, maybe even prophesied, by General Henry "Hap" Arnold when at the end of World War II he stated, "We have just won a war with a lot of heroes flying around in planes. The next war may be fought by airplanes with no men in them at all… Take everything you've learned about aviation in war, throw it out of the window, and let's go to work on tomorrow's aviation; it will be different from anything the world has ever seen".[24] General Arnold's assessment was correct; the world has never seen aviation the way that the unmanned community delivers it. However, alongside this new and exciting technology are new and unique safety challenges. With the human operator no longer on the flight deck, the atmospheric, physiological, and physical limitations are removed from the equation. However, the operator is still integral to the system and creates significant human factors challenges.

5.2. RPA Human Factors Challenges. A study by Tvaryanas and Thompson suggests the validity of previous human factors data may be called into question when technology changes rapidly or new and radical designs are introduced, as with the advent of RPAs.[25] Tvaryanas also suggests that RPAs are the engineering control for traditional aeromedical physical hazards as hypobaria, hypoxia, acceleration, vibration, thermal stress, and those forms of spatial disorientation associated with acceleration.[26] However, the human factor is forever pertinent and ever-present. Furthermore, the human operator is, and will continue to be the weak link in any operation, to include unmanned flight. Additionally, spatial awareness, and a lack thereof, is directly attributable to other human factor challenges, specifically loss of situational awareness (LSA), visual illusions and disturbances, mental exhaustion and fatigue, and attention management. Although slightly different from manned aircrew, RPA aircrews also face orientation challenges.

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[23] (www.thune.senate.gov/public/index.cfm/press-releases?ID=0203f6f8-a260-413a-96dc-5938367a2967)
[24] (www.history.net)
[25] (Tvaryanas and Thompson, n.d.)
[26] (Tvaryanas, 2006)

5.3. SD and RPA Mishaps. According to the FAA, "unmanned aircraft (UA) have suffered a disproportionately large number of mishaps relative to manned aircraft."[27] In 1996, the Air Force Scientific Advisory Board (AFSAB) identified the human/system interface as the greatest deficiency in current UA designs.[28] Yet, surprising to many, a relatively recent 10-year review of Class A accident statistics for military MQ-1s and MQ-9s show that the mishap rate is normalizing when compared to that of the F-16 Fighting Falcon (see Figure 5.1.). A disturbing data point was discovered during reports analysis; the human factors trends in MQ-1s and MQ-9s remained the same. This was especially true as it pertained to spatial disorientation and other misperception factors. Overall, when observing ten years of USAF safety data the U.S. Air Force has lost an estimated 80 MQ-1s (see **Figure 5.2**). Additionally, over a six-year period the USAF has lost an estimated 11 MQ-9s (see **Figure 5.3**). As with most aircraft mishaps, there are typically two causes: a mechanical failure or human error; the latter falls into a category known as human factors. One of the subcategories of human factors is the study of the visual system, and how aviators orient themselves, to include avoiding other aircraft. The ability to avoid mid-air collisions with other aircraft is an oft discussed concern at all levels of aviation. The FAA issued this statement concerning this topic: "Decisions being made about [RPA] airworthiness and operational requirements must fully address safety implications of [RPA] flying in the same airspace as manned aircraft, and perhaps more importantly, aircraft with passengers. Overcoming these [human factor] challenges associated with the differences between manned and unmanned aircraft while simultaneously transitioning to Next-Gen further amplifies the need for extensive cooperation between the FAA, other government agencies, and industry."[29] As discussed in **paragraph 1.2**, Air Force Safety Center resources should be used for more recent mishap statistics.

[27] (Williams K, 2004)
[28] (Worch et al, 1996)
[29] (UAS Factsheet, 2011)

Figure 5.1. Class A USAF MQ-1 and MQ-9 Lifetime Mishap Rates[30].

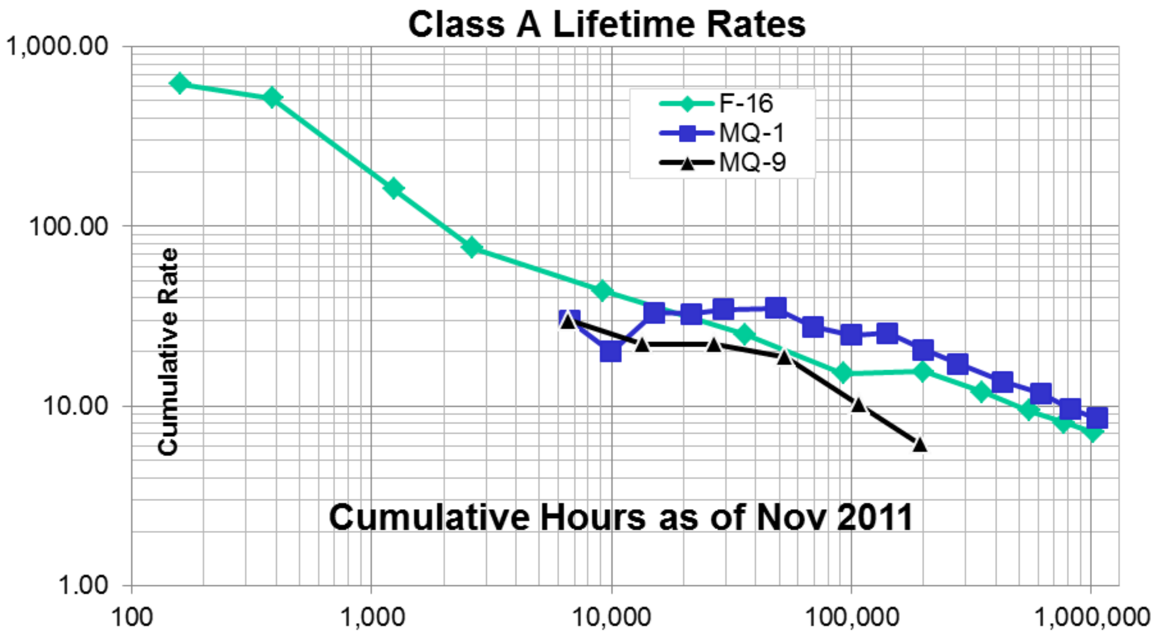
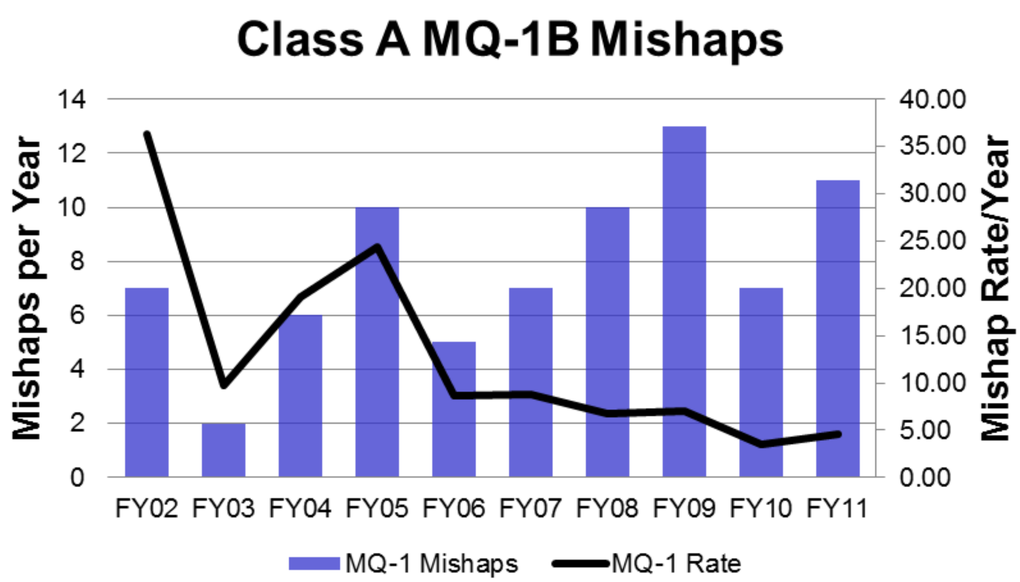
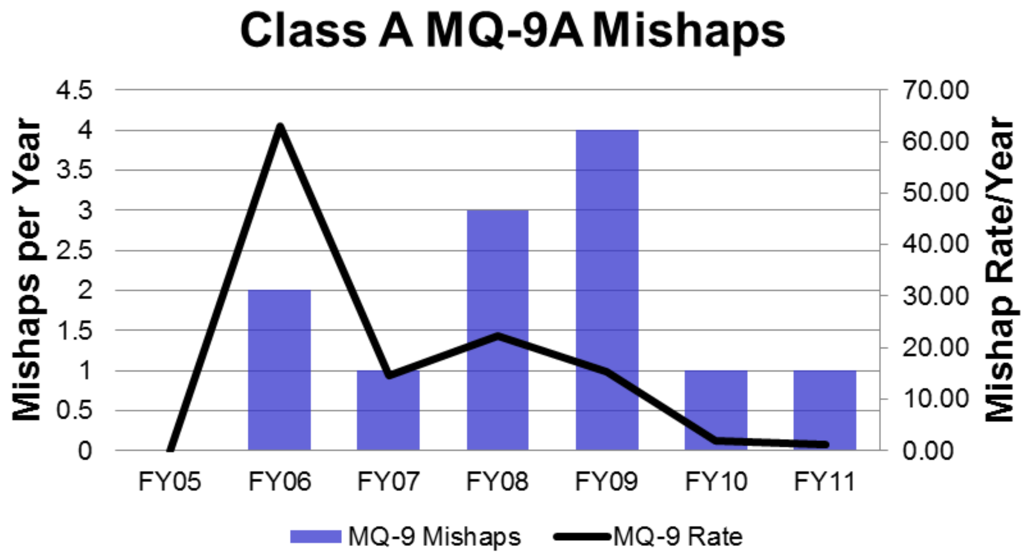


Figure 5.2. Class A USAF MQ-1 Nine-Year Look Back[31].



[30] (USAF Safety Center, 2012)
[31] (USAF Safety Center, 2012)

Figure 5.3. Class A USAF MQ-9 Six-Year Look Back[32].



5.3.1. Spatial disorientation is the major cause in 32% of military aviation mishaps. The United States Air Force loses on average five aircraft each year due to spatial disorientation.[33] This problem has been present since the first flight at Kitty Hawk and has been well researched with the manned paradigm in mind.[34] [35] [36] [37] Therefore, the majority of spatial orientation research suggests that pilots receive feedback from vestibular and kinesthetic receptors, stimulated by angular and linear accelerations, which are phase advanced on the velocity and displacement of visual cues. Yet, there is very little emphasis on the impact of operating an aircraft solely on visual cues totally devoid of traditional auditory, vestibular, or proprioceptive cues. In 2012, the Air Force Safety Center published data which cited human factors as either causal or contributory in 100% of mishaps in 2012.[38] Of those factors, some type of spatial disorientation or visual misperception was cited 74% of the time. Additionally, RPA SD incidents are certainly higher than published due to the amount of near-misses that go unreported every year.

5.3.2. **SD in the RPA Community.** Spatial disorientation (SD) has long been associated with inverted flying, the leans, centrifugal forces, and other physically-centric scenarios. However, with the employment of highly advanced remotely piloted aircraft (RPA) it is necessary to redefine, or at least research spatial orientation challenges as they pertain to unmanned flight. For various reasons, the RPA's limited see-and-avoid capability and its absence of traditional motion and sensitivity cues are the primary threats to spatial

32 (USAF Safety Center, 2012)

34 (deHavilland, 1913)
35 (Jones, 1917)
36 (O'Reilly and Mackechnie, 1920)
37 (Benson, 1973)
38 (Greenwood and Lee, 2011)

orientation. Additionally, the see-and-avoid problem is not only relevant to spatial awareness as it pertains to the earth's surface, but also to the location of other aircraft.

5.4. RPA Spatial Orientation and Orientation Limitations.

5.4.1. **RPA Orientation.** Aviators orient themselves in many ways; by touch or feel, auditory and visual cues, and by the inner ear which responds to both linear and angular acceleration. It is also known, that of these orientation mechanisms, the visual system is the most trustworthy. Vision is by far the most important sensory input to spatial orientation, especially so in moving vehicles such as aircraft.[39] In current RPA platforms such as the MQ-1 and the MQ-9, crews are forced to orient themselves solely through the visual system. This is akin to a non-motion flight simulator; only a real aircraft is being flown.

Figure 5.4. Examples of RPA Ground Control Station (GCS).

Figure 5.5. Examples of RPA Ground Control Station (GCS).

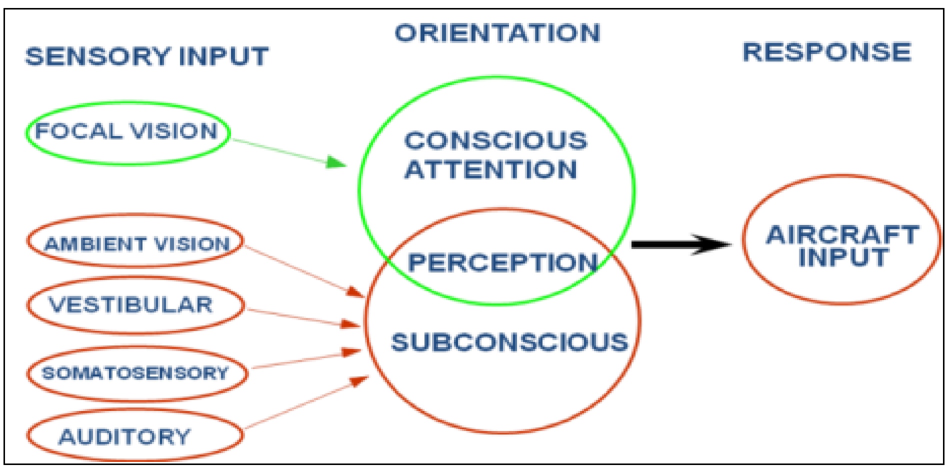
5.4.2. **Vision.** There are two visual orientation systems and they have two distinct functions: focal vision for object recognition and ambient vision for spatial orientation. Additionally, visual and vestibular orientation information is effectively integrated at very basic

[39] (DeHart and Davis, 2002)

(subconscious) neural levels.[40] For aviators, this integration is vital to spatial orientation. Regrettably, in most RPAs, the visual system is the single physiologic orientation mechanism available to RPA crews. In retrospect, it would seem plausible that flying on visual cues only would reduce RPA crews' susceptibility to spatial disorientation. However, none of these cues are designed to be used as a stand-alone orientation system.

5.4.3. **RPA Orientation Limitations.** By removing the other physiologic, traditional, feeling-based systems from the equation, RPA pilots may not experience the traditional spatial disorientation illusions. However, removing these factors from the environment ironically creates a hyper-susceptibility to other orientation challenges. One example of such a challenge is a myriad of visual illusions due to the pilot's inability to validate what he or she perceives to be true. Furthermore, even though the visual system is the most reliable sense of orientation, it is severely limited in flight. Another orientation limitation for RPA crews is information overload due to the high degree of RPA automation. This overload is expected with the advent of new technology however, the true danger rests in the resultant attention management threats. In current RPAs, much of the information provided to crews is written using engineer-logic rather than pilot-logic. In other words, critical information is often buried behind keystrokes, M-keys, Variable Information Tables (VIT), figures of merit, and other engineering-centric software/hardware rather than dials, obvious gauges, and other pilot-centric cockpit sensors. Furthermore, the lack of alternative orientation systems available to RPA crews places higher workloads on the conscious-focal system, and places no demand on the ambient-subconscious system (see **Figure 5.6**). Processing information using the conscious-focal system often leaves crews distracted and mentally exhausted. Research shows a positive correlation between mental exhaustion and task-performance. In addition to the aforementioned challenges, there are other RPA-centric challenges to orientation which are discussed over the next few sections.

Figure 5.6. Cognitive Processing Diagram.



5.5. Visual Challenges.

5.5.1. ***Arx Tantum Visio*** **(Only Focal Vision).** Due to the focal vision's "what" function, it can contribute to orientation by processing information from judgments of constancy,

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[40] (DeHart and Davis, 2002)

distances, shapes, sizes, depths, and motion parallax. However, focal vision only utilizes a narrow range because the retina loses resolution by an order of magnitude with just 15^{o} off axis.[41] Focal vision is not designed as a stand-alone mechanism for environmental orientation; peripheral information is also very important. In the manned community, black-hole and whiteout conditions are types of scenarios where the focal system is forced to operate in a similar manner. RPA aircrew deal with these factors each flight, especially during the Launch and Recovery Element (LRE) phase. Therefore, it can be said that RPA crews spend the majority of their flight time in black hole and/or whiteout conditions due to an absence of ambient cues.

5.5.2. **Judgment Difficulties.** Without the assistance of the ambient visual system, and the absence of peripheral cues to help provide orientation in relation to the earth, RPA crews often misperceive heights, distances, velocity, and depth perception.

5.5.2.1. **Depth Perception Challenges.** Depth perception, the ability of the brain to determine relative distance from visual cues, is compromised by any atmospheric conditions that interfere with light transmission.[42] This truth is even more compelling within the limited visibility parameters of most RPAs. Unlike traditional manned aviation where aviators see a three dimensional picture, RPAs only offer a two dimensional sight picture from what are basically television screens located in a Ground Control Station or GCS (see **Figure 5.7**). The depth perception issue is best mitigated in manned aircraft by relying on aircraft instruments, but some RPAs, like the MQ-1, are not IMC aircraft. The MQ-1 is outfitted with a pressure altimeter but not with a radar altimeter. Additionally, the MQ-1 is equipped with a GPS Landing System (GLS) which creates an artificial Instrument Landing System (ILS). However, according to T.O. 1Q-1(M)B-1, "Localizer and Glide Slope on the GLS are calculated from the GPS data. Erroneous GPS data could result in inaccurate localizer and/or glide slope indications. A corrupted GLS data file could also result in erroneous indications."[43] Consequently, the GLS is not fail-safe, nor is it certified for use in IMC conditions. Unlike other manned aircraft, MQ-1 pilots cannot fully trust their instruments. This fact is a major departure from traditional SD awareness literature. **Note:** The MQ-9 is outfitted with a radar altimeter and also a weight on wheels switch. These two engineering fixes have reduced the number of landing mishaps for MQ-9s. However, the Reaper's landing mishap rates are still significantly higher than manned platforms because of the inherent visual problems associated with RPA flying. RPA type and capability heavily influence the total effect of reliance on visual cues only; some systems can be landed during visual observation by the pilot or using auto-land systems.

5.5.2.1.1. The depth perception challenge has resulted in extremely high mishap numbers due to hard landings, nose first landings, and premature release of back stick pressure. One example occurred when the mishap pilot became focused on GLS commands, resulting in a shallow approach. Because of his limited depth perception resulting from a 45 degree field of view and no somatosensory cues, the mishap pilot failed to recognize his close proximity to the ground and did not make appropriate

[41] (Previc and Ercoline, 2004)
[42] (Reinhart, 1996)
[43] T.O. 1Q-1(M)B-1(p.2-46)

control inputs to avoid landing short. The lack of 3D visual cues and absence of other orientation cues creates another key judgment difficulty as it pertains to depth perception or depth sensation. Other than using all available orientation cues, one technique RPA crews have devised is to use the current pressure altimeter reading and compare it to the field elevation. Subsequently, the sensor operator can verbalize 200 feet down to 50 feet calls during the landing phase.

Figure 5.7. MQ-1 GCS.

5.5.2.2. **Camera Variance/s.** Because RPA crews primarily use cameras for orientation and awareness, many of their visual perception issues begin and end with the type of camera that is installed on the aircraft.

5.5.2.2.1. In certain instances, one level of technology is better suited than others based on certain environmental and electromagnetic factors. An example of this is that the MQ-9's Multi-Spectral Targeting System (MTS) Ball is a moveable camera and therefore poses a vection illusion threat should it rotate upward during the landing phase, or downward during the departure phase. However, it is also gyroscopically engineered and offers better fidelity than the other two cameras (the nose camera and the IR nose camera). Therefore, many pilots accept the illusion risk and land utilizing the MTS ball. This topic is germane to the judgment discussion in that the three cameras offer three different pictures. This is mainly due their placement on the aircraft itself. Example: The MQ-1/MQ-9 nose camera is physically higher on the aircraft and therefore presents a steeper gaze angle. This can present a "too high" perception resulting in a nose over input, increased rate of vertical velocity, and nose first landing or PIO. Additionally, the MTS ball is lower on the aircraft and offers a shallower gaze angle and can present a "too low" perception resulting in the potential for longer and more exaggerated flare distances, or overshoots (See **Figure 5.8-5.9**). **Note:** There are also other human factors engineering issues that exacerbate this phenomenon such as flying approaches with nose low trim set and then failing to pull the stick back far enough to compensate during the flare.

5.5.2.2.2. Depending on RPA type and mission phase, additional sensors, such as a digital moving map display or digital horizon, may provide valuable orientation information. Also, visual sightings of the RPA can be used to ensure effective flight orientation.

Figure 5.8. MQ-1 Camera Variance Illustrations.

Figure 5.9. MQ-1 Camera Variance Illustrations.

5.5.2.3. **Field of View Limitations.** When the source of camera-fed pictures is obscured or distorted there are few visual, physical, or auditory cues by which RPA pilots can identify the ground, inhibiting their ability to orient themselves. The normal field of view for the human visual system is 180° (140° for depth perception) yet the primary sensors for both MQ-1 and MQ-9 aircrews are the Multi-Spectral Targeting System (45° by 34°), an Infrared Nose Camera (36° by 27°), or the Nose Camera (30° by 23°). RPA crew cannot effectively utilize the combination of focal and peripheral vision for simple tasks such as traffic deconfliction. Furthermore, crews are limited to looking at one thing at a time leaving them virtually blind to both insidious and sudden peripheral dangers (See **Figure 5.7**).

Figure 5.10. Examples of Soda Straw/Focal Vision with no ambient cues.

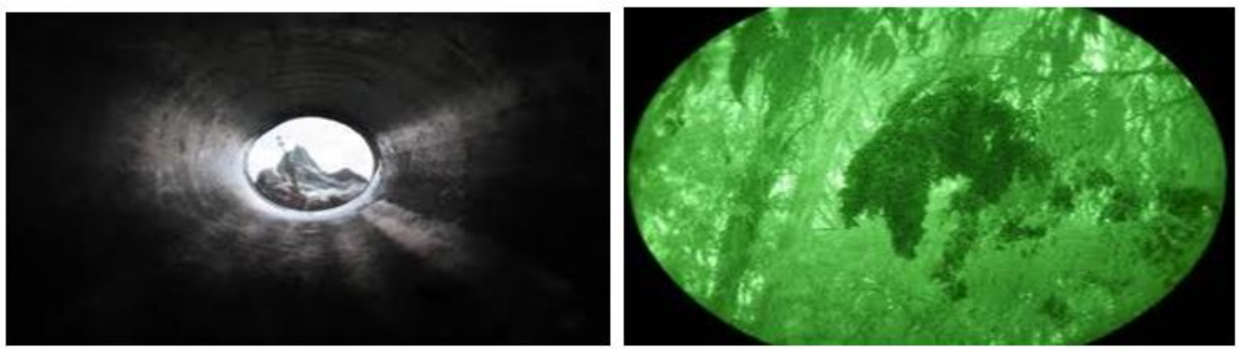
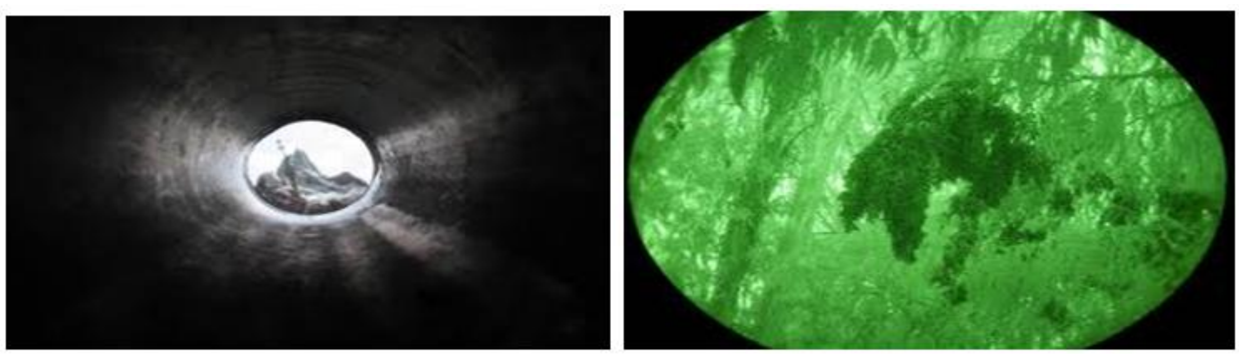


Figure 5.11. Examples of Soda Straw/Focal Vision with no ambient cues.



5.6. Environmental Factors. Manned pilots view the environment through a glass canopy or windshield, while RPA crews view the environment through sensors and the lens of cameras. Just as rain, clouds, debris, etc. obscure manned crews' sight pictures, the same applies to RPA crews (See **Figures 5.12-5.14**). The exception is that unmanned crews view these factors from an outside-in perspective, rather than an inside-out perspective. Therefore, RPA crews are not only limited by ophthalmic factors such as short and near sightedness, but they are also limited by technology. Engineering weather radars and panoramic cameras into future RPA platforms will go a long way to preserve combat assets and prevent aircraft mishaps.

Figure 5.12. MQ-1 Low Visibility Approach.

Figure 5.13. MQ-1 Low Visibility During Landing.

Figure 5.14. MQ-1 Night Landing (Black hole Example).

5.7. Electromagnetic Factors. In addition to environmental factors such as weather, RPA crews also face signal strength issues, poor picture quality, and degradation of picture due to some other electromagnetic limitations. Video cameras and television screens project the environmental factors the aircraft is experiencing; therefore, if a camera feed is weak or intermittent, RPA crews are not receiving the most accurate visual information (See Figure 5.15.). The result is an unavoidable demand to make in some cases a life or death decision based on poor visual cues. The same can be said based on the quality of the screen, or even the lighting in the GCS itself. These types of issues are commonplace amongst RPA crews. When these factors are encountered during a critical phase of flight, they have proven to be a key contributor to landing mishaps and incidents.

Figure 5.15. MQ-1 on Approach with a Poor Signal.

5.7.1. For some RPA crews, the beginnings of an intermittent picture are akin to a manned crew unknowingly flying into some sort of weather phenomena which severely hinders their visual picture. One of their mitigation tactics is to send the aircraft lost link to accomplish its emergency mission until a positive visual picture, control, telemetry data, etc. is restored. Other frequent issues with picture can be a choppy picture, a frozen picture, or video ghosting.

5.8. RPA Specific Visual Illusions.

5.8.1. **Video Ghosting**. Video ghosting can occur during certain scenarios which could present another aircraft's video and telemetry to the pilot and crew. More information on this phenomenon is detailed in a 2012 MQ-9 mishap.

5.8.2. **Vection Illusion.** As previously mentioned in **Chapter 3**, a vection illusion is a sensation of self-motion induced by relative movement of viewed objects. Such sensations are frequently illusory, and can be of linear (translational) or angular (rotational) movement. After depth perception illusions, Vection Illusions are the second most common types of illusions encountered. There are two subsets of this illusion in remote aviation: (1) Unintentional and (2) Intentional (Operator Induced). An Unintentional Vection Illusion occurs when RPA crews fly off of the Multi-Targeting Spectral System or the "MTS ball", and the ball suddenly moves. An Intentional Vection Illusion occurs when an input by an RPA crew member moves the ball while the pilot is using it as the primary visual source. It should be noted that vection illusions are not a primary factor when RPA crews fly off of fixed cameras.

5.8.2.1. **Vection During Critical Phases of Flight.** The most dangerous scenario is when the camera insidiously moves upward, perfectly mimicking an aircraft climb during a critical phase of flight. This insidious movement gives the pilot a nose-rising visual cue. The pilot's reaction is to push the nose over sending the RPA into a Pilot Induced Oscillation (PIO). To overcome this illusion, a pilot must be aware that when using the MTS ball as a primary visual flight reference, it could mechanically fail and rotate upward to the stow position due to a Gimbal-Drive Assembly failure. When this is experienced, the pilot must fight the urge to push the nose over. This is a difficult task because the RPA pilot has no other cues to validate or reject the visual cues. One factor that helps crews overcome this illusion is the speed in which the Gimbal-Drive assembly fails. In other words, a more sudden and quick uncommanded movement can help mitigate the illusion and cue the crew that the ball is moving and not the aircraft.

5.8.2.1.1. **On Takeoff Roll and Climb-out.** Uncommanded MTS movement on takeoff roll or climb-out can cause pilots and crews to perceive that their attitude is abnormally high resulting in a nose over input. Aircrew should use known power settings and/or HUD pitch references while cross-checking sensor operator video display for aircraft attitude to help counter vection illusions.

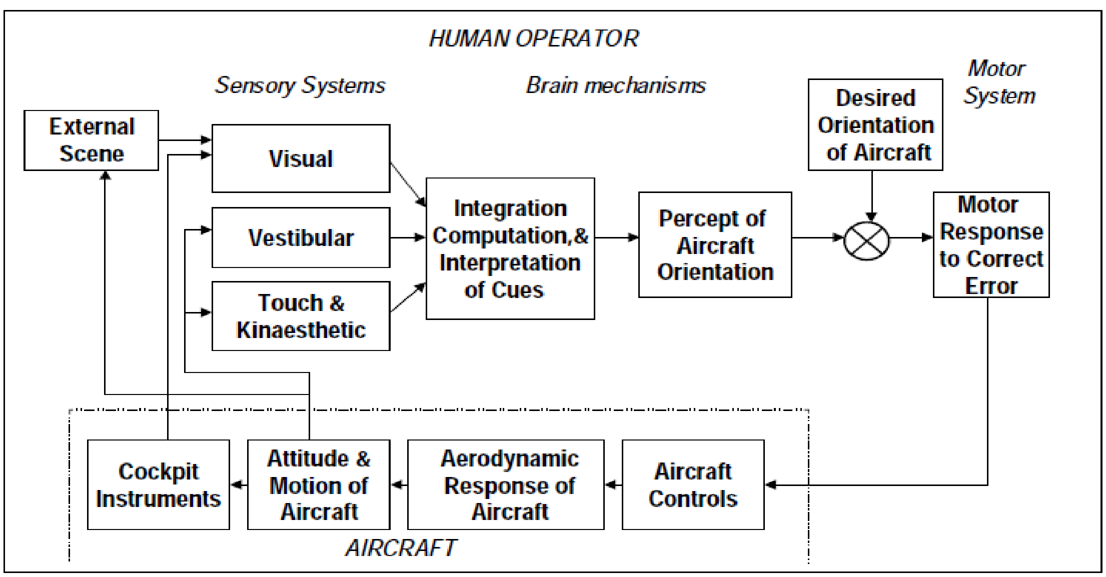
5.8.2.1.2. **On Approach and Landing.** Uncommanded MTS movement can also occur on approach and landing, resulting in pilots and crews to perceive that their attitude is abnormally high resulting in a nose over input. Aircrew should use known power settings and/or HUD pitch references while cross-checking sensor operator video display for aircraft attitude will help counter vection illusions.

5.8.2.2. **Intentional (Operator Induced).** An Intentional Vection Illusion occurs when an input by an RPA crew member moves the MTS ball while the pilot is using it as the primary visual source. This will be seen when the sensor operator is tracking targets, scanning the aircraft, looking for weather, etc. This movement of the MTS ball is disorienting and requires the pilot to focus on the HUD graphics (instruments) thereby ignoring the visual picture. Communication and crew coordination are the keys to preventing intentional vection illusions. As previously mentioned, this can cause disorientation and confusion for unsuspecting crewmembers. This is especially true during pattern work, or on departures and landings. Good CRM and pre-briefed contract should be established requesting sensor operators to notify pilots prior to moving the MTS ball. This can and should prepare the pilot for the sudden picture swings and sight adjustments.

5.9. Cognitive Processing and Information Management Limitations.

5.9.1. A human being's limited ability to consciously process multiple levels of information simultaneously challenges RPA crews along with the field-of-view and picture challenges already discussed. As previously mentioned, focal vision is the RPA pilot's most used orientation tool and requires constant conscious attention which after time can cause focal (visual) fatigue, focus trapping (a form of channelized attention tied to a single instrument or sensor), and even empty field myopia, when lack of visual stimulus causes loss of mental focus on the task at hand. It is important to follow with an illustration of how that information is used, particularly in the challenges in processing several inputs effectively. The diagram below illustrates how the human operator receives information and how that information results in either a correct, or incorrect motor response (see **Figure 5.16**).

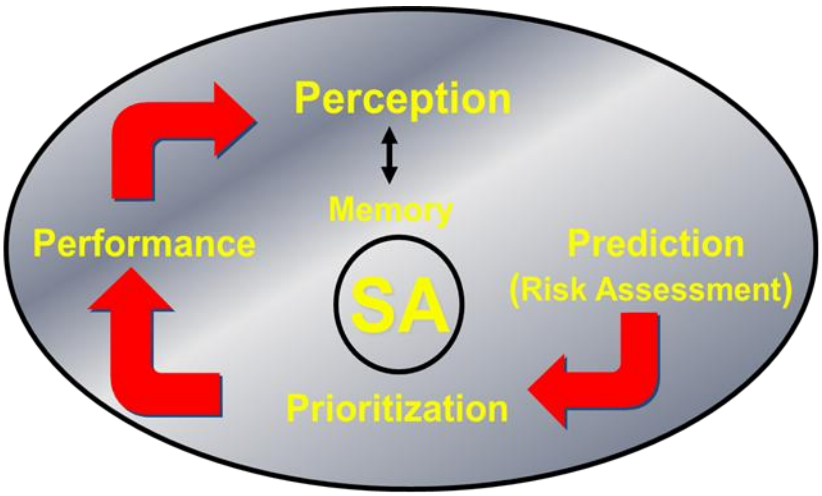
Figure 5.16. Human Operator Sensory, Brain, and Motor System Diagram.



5.9.2. **Cognitive Exhaustion.** Due to abnormally high reliance on focal-information, RPA pilots are forced to maintain approximately 6-8 hours of conscious attention in order to recognize aircraft output and aircraft orientation (spatial awareness). This submission is also true of a shorter time period and a more intense workload. Conscious attention is especially key during the landing and departure phases of flight. Yet, conscious attention, both for a short or long period of time, requires a high mental workload and can mentally exhaust the operator.

5.9.2.1. This type of exhaustion can lead to boredom, complacency, fatigue, and a high-susceptibility to visual misperception resulting in a myriad of safety of flight issues. Subsequently, once fatigued, cognitive processing speeds become slower. This is especially true after high-density workloads over an extended period (3-4 hours) when primarily using focal vision. Subsequently, RPA pilots will inevitably revert to subconscious processing. Once an individual settles on the subconscious processor, decisions become automatic without the utilization of risk assessment, forecasting, prioritization, and mitigation strategies (see **Figure 5.17**).

Figure 5.17. Situational- Decision Making Diagram.



5.10. Attention Anomalies. As previously discussed, the subconscious processor will by-pass any risk evaluation altogether and rely solely on memory and experience as the blueprint for performance. This is a dangerous methodology and leads to boredom proneness and other attention anomalies that can lead to a loss of spatial awareness and potentially disorientation. The common RPA attention threats are:

5.10.1. *Complacency.* The complacency risk is ever-present in the RPA community due to a Groundhog Day phenomena, shift work, and being physically separated from the actual aircraft. Complacency has led to a plethora of mishaps and is evident by incomplete or incorrectly completed checklists, a lack of procedural knowledge, and poor responses to in-flight emergencies and other in-flight incidents.

5.10.2. *Boredom.* Oftentimes RPA crews find certain tasks such as constant reconnaissance or pattern of life missions to be boring. A recent studyfound that task boredom (or boredom proneness) was most present at the 4-6 hour point of the sortie for RPA crews. [44] Additionally, it was found that sensor operators became bored more quickly than pilots.

5.10.3. *Task Saturation*. Task saturation is seen when individuals have too much to attend to at one time, thus possibly missing important cues or higher priority tasks. This is especially true of RPA crews who frequently go from extreme boredom, to extreme excitement due to a

[44] (Tvaryanas, 2006)

sudden mission change. For example, an RPA crew will often sit for hours at a time with little to no mental arousal; however, just before shift change an order to go kinetic will be given. The sudden change can overwhelm RPA crews with information. Other factors contributing to task saturation are stress (internal/external), a lack of proficiency and/or currency (knowledge), and poor task management skills.

5.10.4. *Excessive Professional Deference.* In the case of excessive professional deference, junior or less qualified crewmembers are hesitant to call attention to deficient performance in others, particularly if they are senior. Therefore, even when one crewmember points out performance which is outside of established parameters, it is typically done with vague corrective instructions.

5.10.5. *Passenger Syndrome.* Lack of assertiveness is an issue in most multi-place aircraft. However, in RPAs it can be more evident because most sensor operators are brand new to the Air Force or cross-train from other non-aviation career fields. The issue is compounded by the fact that the career field is relatively new with very little history or precedent. It is widely believed that this issue will be a challenge until the community matures and the overall experience level of the community increases. There are many Class A mishaps where the sensor operator could have prevented the accident but failed to speak up after perceiving that his or her pilot had it “under control.”

5.10.6. *Loss of Situational Awareness.* Situational Awareness (SA) can be defined as the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future. However, SA is often dependent on the amount of available continuous information available to the individual. For RPA crews, this information is saturated at the focal-conscious level and requires conscious attention. Additionally, the lack of subconscious, vestibular, and other lower level cues exacerbates the human inability to manage multiple scenarios for too long. This makes RPA crews vulnerable to a loss of SA and inevitably a loss of spatial orientation.

5.11. Training Issues. USAF aviation training must include preparation for all aircraft operations, manned and unmanned. It must begin with introducing new thoughts on SD beyond inner-ear fluid, otolith organs, and cilia to include concepts like cognitive processing, focally driven awareness, and other visually induced illusions. In an effort to prevent accidents, incidents, and even loss of life, more research must be conducted. Until then, every effort must be made to educate RPA crews on orientation limitations, resultant illusions, and mitigation tactics. Current RPA centric courses (activities) which include SD awareness for RPAs are AFI 11-403 Aerospace Physiology curriculum/training, RPA-Instrument Refresher Course, flight safety meetings and councils, Standardization/Evaluation Review Boards (SERBs), shop visits, AFSAS data extraction, trending, and reporting of RPA mishaps.

5.12. SD Impact. SD is an erroneous percept of any of the parameters displayed by aircraft control and performance flight instruments. As more cameras, sensors, radars, etc. are added to these aircraft there are greater chances of disorientation episodes, not only from a visual perspective but from a cognitive one as well. In most accidents, there are several opportunities to prevent the mishap from occurring.

Chapter 6

SD CASE STUDIES

6.1. Case studies illustrate aircrew susceptibility to SD because they demonstrate that SD can happen to any aviator at any time. Aircrews should review risk factors and maintain awareness via regular SD briefs during recurrent safety meetings, in addition to required training events.

6.2. Case Study 1 – Fighter Aircraft. The following mishap occurred just a few years ago and highlights many aspects presented in this chapter on SD, such as any pilot being susceptible to SD, interplay between visual and vestibular systems, impoverished visual conditions, and NVG limitations. An F-16 pilot with over 2,600 total flying hours maneuvering at night wearing NVGs became spatially disoriented but safely ejected from his aircraft. The $20M aircraft however, impacted the water 120+ miles off the coast and was destroyed. The pilot at the time was executing a hard, 90-degree left turn and began to descend, but he lost sight of the horizon and became disoriented. The Accident Investigation Board (AIB) concluded that the cause of the mishap was: "The pilot's failure to recognize and recover from SD in a timely manner due to inadequate instrument cross check. Additionally, sufficient evidence indicates that the nighttime over-water environment, use of NVGs [night vision goggles], and weather conditions limited the visible horizon, substantially contributing to the mishap." Furthermore, the AIB detailed ten contributing factors to the mishap:

6.2.1. Complacency. The visible horizon to the northeast may have created a false sense of security or comfort to the pilot as he maneuvered at night while wearing night vision goggles.

6.2.2. Restricted vision. When flying at night, the pilot became spatially disoriented when he maneuvered to the west, the darker section of the night's skyline. Also, a cloud deck was at 6,000 ft [1.8 km] and may have presented a false horizon.

6.2.3. Breakdown in visual scan. The pilot failed to execute practiced internal and external crosschecks during maneuvers.

6.2.4. Vestibular Illusion. During the execution of a 18-second 65-degree nose low turn, any head movement can induce a vestibular illusion.

6.2.5. Instrument and Sensory feedback systems. The night vision goggles limited the pilot's field of view and resolution; the attitude indicator may have provided inadequate situational awareness due to technical limitations.

6.2.6. Habituation: during daylight hours an abeam maneuver is performed at 60 degrees nose low and may have led to the pilot performing the maneuver at night at nearly the same attitude.

6.2.7. Elevator Illusion: this illusion occurs when a reduction in descent is perceived as a climb; thus the pilot believes that he has arrested and reversed the aircraft's vertical movement when in fact it is still descending, just at a lesser rate. It was during this descent that the pilot's unrecognized SD was recognized and a recovery was attempted.

6.2.8. Misinterpreted Instruments. Correct information was displayed to the pilot but it was not interpreted as such. The pilot failed to differentiate the attitude displays of ground and sky due to the extreme nose-low attitude.

6.2.9. Gillingham Illusion. Pilots with restricted visual references try to recover from excessive roll maneuvers by inadvertently inducing more roll while perceiving a constant bank angle. Although the pilot recognized his SD condition, due to the lack of visual references available (dark westerly direction of the night's sky), the board determined disorientation became incapacitating at this time.

6.2.10. Temporal Distortion. The pilot recalled detailed events within the entire scenario as he attempted to recognize and recover from his disorientation. The pilot initiated an 8.75 G pull to recover. However, he was inverted and the pull only worsened his position. The pilot ejected 3 seconds prior to the aircraft hitting the water.

6.3. Case Study #2 – Heavy Aircraft. A C-130E pilot/co-pilot with a combined 1271 hours of C-130 total flying time along with a competent aircrew failed to recognize their landing picture due to a fog bank, with reference to the runway, and to transition to a normal visual glide path for landing. The three prior sorties were accomplished without incident between Al Salem AB, Kuwait City International (KCIA) and Al Jaber AB. There were no reported aircraft problems and fatigue was ruled out. The mishap aircraft's final sortie departed with 86 passengers and 6 crewmembers from KCIA and was bound for Al Jaber AB. Approximately 4.5 miles (2 minutes) from the approach end of the runway; the pilot/crew initiated a visual approach and began with a 3-degree glide slope, at about 640-fpm rate of descent. It was soon transitioned to a 6 to 7 degree glide slope with a 1600-1700 fpm rate of descent for the remainder of the approach. At about 125 feet AGL, descending at 28 feet per second, the aircraft entered a fog bank. The flight engineer called "Go Around" one to two seconds after entering the fog bank (70 to 100 feet AGL). The pilot complied and initiated the go-around procedure (full power and nose up) about a second after the flight engineer's call. The aircraft was too low (approximately 50 feet AGL) to break its descent rate and start a climb. As a result, it impacted the ground 2890 feet short of the runway threshold causing three fatalities, seven injuries (two serious) and damages worth approximately $3.8 million. The Accident Investigation Board (AIB) concluded that cause of the mishap was, "Crew's failure to follow governing directives and complacency in flight operations. As a result, the crew suffered spatial disorientation at a critical phase of flight; thereby, resulting in the crew's loss of situational awareness and failing to recognize an unsafe descent." Furthermore, the AIB detailed the following contributing factors to the mishap:

6.3.1. Lack of pilot leadership and discipline – In this case, the pilot was an inexperienced brand new aircraft commander with 51.7 hours pilot-in-command experience at the time of the mishap. According to the AIB, he failed to set the tone in the flight deck and allowed the crew to become complacent in their duties.

6.3.2. Lack of support from the Co-pilot, Navigator and Flight Engineer – it is apparent from the narrative that the crew became complacent and lost situational awareness. The co-pilot made all their radio calls but failed to recognize the steep approach and perceived the approach to be 3-degree glide slope. The navigator was scanning the outside environment for other aircraft and failed to do cross-checks or provide information on recommended glide path, wind drift, distances and clearances. The flight engineer was also scanning the outside environment and noticed the bank but failed to inform the crew because he felt that the aircraft would over fly the fog.

6.3.3. Lack of sound judgment by the flight deck crew – The crew displayed a lack of judgment throughout the sortie especially during crew planning phases and failed to implement/adhere to Air Force and Department of Defense instructions. The pilot deviated from AF directives when he did not wear his glasses to fly. The crew failed to contact the base tower to check weather prior to beginning the descent. The crew elected to fly a published approach despite the weather required for the approach being below the required minimums. Approximately five minutes after takeoff, the crew maneuvered the aircraft for the final approach by flying to a point northwest of the field versus flying directly over the navigational aid. This caused the crew to rush through the checklists and possibly put them behind. As a result, the aircraft was too high and too close to the runway for a normal descent profile. The pilots also failed to monitor their flight instruments during night conditions on the approach.

6.3.4. The above mentioned contributing factors created a chain of events that led to a loss of situational awareness by the aircrew and spatial disorientation for the pilot. First, certain preconditions such as a lack of ambient visual orientation cues due to minimal surrounding light sources around the runway and the fog bank already existed. Second, the crew's lack of communication, complacency, cross-check, and rush to complete checklists created a dangerous situation. This may have contributed to the pilot's failure to recognize his transition point to the normal glide scope and resulted in Type I (unrecognized) spatial disorientation. According to the DoD HFACS guide - Spatial Disorientation is a failure to correctly sense a position, motion or attitude of the aircraft or of oneself within the fixed coordinate system provided by the surface of the earth and the gravitational vertical. Spatial Disorientation (Type 1) Unrecognized is a factor when a person's cognitive awareness of one or more of the following varies from reality: attitude; position; velocity; direction of motion or acceleration. Proper control inputs are not made because the need is unknown.

6.4. Case Study #3 – RPA (MQ-1). During initial climb-out after a touch and go, the Mishap Aircraft (MA) Multi-Spectral Targeting System (MTS) moved from Position Mode upward without any input from the Mishap Sensor Operator (MSO) or commands from Pilot/Sensor Operator (PSO) Control Station 2. The Mishap Student Pilot (MSP) misidentified the upward movement of the MTS as an increase in the MA's pitch attitude and commanded approximately 10° nose down pitch. The MSP failed to identify the uncommanded movement of the MTS as a malfunction and failed to crosscheck the nose camera displayed on the MSO's monitor, prior to commanding nose down pitch. The nose gear impacted the runway at 2.68 G-force with the MA in a 6° nose-low attitude and a subsequent nose-high bounce Pilot Induced Oscillation (PIO). During this time, the Mishap Evaluator Pilot (MEP) crosschecked the nose camera display on the MSO's monitor and identified the bounce and PIO. The MEP took control of the MA PSO Control Station 1 control stick and commanded approximately 20° nose up pitch. The MA nose gear impacted the runway a second time with the MA in a 12° nose-low attitude. The MA bounced again reaching approximately 25° nose high causing the tail and propeller to strike the runway at 4.88 G-force. The tail and propeller strike caused one of the propeller blades to depart the MA's propeller assembly, catastrophic engine damage, and engine fire. Following the tail strike, the MA oscillated between 10-20° nose-up with full power commanded for approximately eight seconds. The MA impacted the runway a third and final time with 12° left bank and approximately a zero pitch level attitude. The final impact registered the maximum reportable value of 5.0 G-force. With the nose gear and both main landing gear collapsed, the MA slid approximately 300 feet coming to rest along the asphalt edge and dirt on the south side of the runway. The MA stopped with the MTS resting on the nose gear strut and the engine on fire.

6.4.1. MSP Human Factors Analysis: The MSP was relatively new to LR operations having just successfully completed his MQ1LR evaluation earlier in the MS. After the MEP flew two patterns to a touch and go for his currency, the MSP returned to the controls to conduct additional approaches to increase proficiency. During the climb-out phase of the touch and go, the uncommanded upward movement of the MTS caused the visual illusion that the MA was reaching an excessively nose high attitude. The MSP's attention became channelized on this unexpected perceived nose high condition. The visual illusion caused spatial disorientation which was unrecognized by the MSP. In response to the perceived nose high attitude, the MSP commanded approximately 10° nose down pitch. This pitch command resulted in a PIO, two nose gear impacts, and the tail and propeller strike on the runway. The tail and propeller strike caused the propeller to depart the MA propeller assembly and additional catastrophic engine damage. Conclusion: The SIB determined the actions of the MSP were a causal factor in this mishap.

6.4.2. MEP Human Factors Analysis: After recognizing the uncommanded upward movement of the MTS, the MEP crosschecked the nose camera on the MSO's monitor. The MEP recognized the MA was beginning to pitch down and directed the MSP to command "nose up." The MSP had to process the directed "nose up" command and determine if that meant the MA's nose was pitching up or that the MEP wanted him to command the MA's nose up. Use of the standard "go-around" call by the MEP may have conveyed a clearer message to the MSP and allowed him to immediately rely on previous training and experience to command aft stick with full power. If the MSP commanded aft stick earlier in the sequence, the amount of damage resulting from the second nose gear impact may have been reduced. The MEP took appropriate action by taking control of the stick to command nose-up pitch. Conclusion: The SIB concluded the actions of the MEP were not a factor in this mishap, but could contribute to future mishaps.

6.4.3. Technical Order (T.O.) Publications: The SIB also determined two WARNINGs for "possible uncommanded MTS movement while in Position Mode" should be added to the Takeoff procedures (page 2-31) and the Before Landing checklist (page 2-46) in T.O. 1Q-1(M)B-1. This WARNING should be added following paragraph 5 of the Takeoff section: *While conducting takeoffs using the MTS cameras, crews must be aware of possible uncommanded MTS movement while in Position Mode. In the event of uncommanded MTS movement during takeoff roll, consider initiating an "ABORT". If continuing the takeoff, use HUD pitch references while crosschecking Sensor Operator video display for aircraft attitude.* This WARNING should be added to Step 4 of the Before Landing checklist: *While conducting approaches and landings on MTS cameras, crews must be aware of possible uncommanded MTS movement while in Position Mode. In the event of uncommanded MTS movement during landing, consider initiating a "GO-AROUND" using HUD pitch references while crosschecking Sensor Operator video display for aircraft attitude.* Conclusion: The SIB concluded T.O. Publications were not a factor in this mishap, but could contribute to future mishaps. Note: These recommendations were non-concurred at the MAJCOM level due to feeling that this was a “basic airmanship issue”. This exact incident has happened five additional times since, and is further proof of how difficult it is to implement HF RPA mitigation tactics. It is well known that due to the RPA's relative newness, much of the USAF is unaware of the degree of difficulty associated with operating an aircraft without the use of traditional motion and sensitivity cues. For now, RPA crews should be aware of this recommendation as a "technique only" until effectively implemented into the T.O.s.

6.4.4. The Multi-Spectral Targeting System (MTS): Position Mode is described as follows by **paragraph 4.2.6.3** of T.O. 1Q-1(M)B-1: "Selecting position mode places the turret at 0° azimuth and 0° elevation, or forward caged position, relative to the aircraft longitudinal axis. While in position mode, the turret will respond to input commands from the control stick in azimuth (±180°) and elevation (60° to -105°), but will return to the caged position when the control stick is returned to the neutral position. When position mode is selected the AN/AAS-52 HUD graphics display POS in the gimbals' status line. The select position mode via the HUD toolbar, select the POS button." The MA's MTS moved upward from Position Mode without any inputs from the MSO or commands from PSO2. In addition, no associated GIM DIS errors were displayed. The MTS manufacturer and maintenance have identified that this movement may have been associated with a "non-coded" GIM DIS equipment safety function IAW T.O. 1Q-1(M)B-1 **paragraph 4.3.2**: "Occasionally conditions may exist (mechanical, electrical, etc.) which cause the turret gimbals to lock. This is a built-in safety feature designed to prevent damage to the gimbal drive motors." The SIB conducted an informal survey of MQ-1B and MQ-9A Mission Control Element (MCE) and LRE aircrew members to determine if uncommanded movement of the MTS while in Position Mode had been observed in all phases of flight. 47 of 141 survey participants (33%) indicated they had observed uncommanded movement of the MTS while in Position Mode. Conclusion: The SIB determined the uncommanded movement of the MTS was a causal factor in this mishap. Summary: This mishap is a prime example of RPA SD. The impact of SD in RPA operations is an ever growing, but widely unknown threat. While the vestibular aspects of SD are expectedly absent, the visual factors are present and are a safety of flight issue.

Chapter 7

RECOGNITION AND PREVENTION OF SD MISHAPS

7.1. The pilot's role in preventing mishaps due to SD essentially involves three things: training, good flight planning, and knowledge of procedures. The key to success in instrument flying is an efficient instrument crosscheck. The flight instruments provide the only reliable aircraft orientation information, at night or in IMC. Any situation or factor that interferes with this flow of information, directly or indirectly, increases the potential for disorientation.

7.2. Training. The training and education of the pilot about the dangers of SD begin with the information in this chapter. Additional information is provided by flight surgeons, aerospace and operational physiologists, IRC instructors, and flying safety officers through lectures, slide presentations, films, videos, and safety journals. Experienced pilots can pass on valuable information to new crewmembers in flight briefings and squadron meetings. Finally, training can ensure pilots recognize SD-inducing situations and make risk assessment decisions related to maintain their orientation and situational awareness.

7.2.1. Basic Knowledge. The effects of SD can be minimized through an understanding of the physiological mechanisms that cause various illusions, the phases of flight where the illusions can be expected, and a plan of action (procedure) to follow in dealing with sensory conflicts once they occur.

7.2.2. Flight Simulators and Trainers to Prevent SD. Aircraft simulators are excellent training devices for learning instrument flight procedures. A pilot who experiences demanding situations during impoverished visual conditions creates a knowledge base for maintaining awareness and orientation. Also, simulators can provide pilots with recognition of cues that may enhance risk assessment processes regarding scenarios that may lead to SD. Thus, simulators enhance instrument flight procedures and scanning techniques during cognitively demanding tasks.

7.2.3. Aircraft Flight. Regular and frequent instrument flight in the aircraft either under the hood (if available), at night, or in actual weather conditions is necessary to provide the pilot the experience and confidence needed to fly safely in instrument conditions.

7.3. Flight Planning. Thorough preflight planning is important in reducing the potential for SD incidents, particularly in fighter-type aircraft. It is difficult for a pilot to fly the airplane and maintain an effective instrument crosscheck while searching for information in the IFR supplement.

7.3.1. General information. Before takeoff acquire all of the information needed to safely complete an instrument flight. This is particularly important for cross-country flights to strange fields in night weather conditions. The remarks section of the IFR Supplement Airport/Facility Directory and FLIP AP/l should be checked for known approach illusions. Attention should be directed during flight planning to events that may be unexpected. What are the missed approach procedures? What is the circling minimum descent altitude? What type of runway lighting system is installed at the alternate airfield?

7.3.2. Specific situation. If available at the base of intended landing, pilots flying single-seat aircraft should plan to make a single frequency, en route descent to a radar monitored, precision approach during night or IMC.

7.3.3. Risk Management. In line with flight planning is the knowledge of the type of mission to be flown, the conditions encountered, the weather forecast, illumination, and threat level combined with the knowledge of the pilots' currency and proficiency for that particular mission and the individual pilot's assessment of their skill-level for that day/night. All of these factors play a role with how susceptible a pilot may be for an SD episode on one day compared to another day. Training and experience may help a pilot recognize environmental cues and resulting scenarios that may lead to problems (SD and/or successful mission accomplishment). Risk assessment involves amending activities and taking action to reduce risk by removing or eliminating hazards. For example, a night NVG flight in mountainous terrain ought to have extensive risk assessment applied prior to takeoff to ensure success.

7.4. Procedures. It is important that aviators have an established set of recommended procedures to follow in the event they experience spatial disorientation. The general procedures put forth here may differ depending on type of aircraft (such as single-seat, dual-seat, or crew-type aircraft) or type of mission (formation flight or NVG flight). Additionally, commands normally establish specific procedures for aircraft under their control.

7.4.1. General Principles. Any pilot who does not continually monitor the flight instruments during IMC, night, and other conditions of reduced visibility has a significantly increased risk of developing SD, perhaps in a matter of seconds. This disorientation could occur in several ways. The pilot may divert attention from the instruments just long enough to study an approach plate, look for a wingman, or assess the effect of a weapons drop, and feel perfectly comfortable as he/she develops Type I disorientation. The pilot may fly the aircraft into the ground without realizing the error or check the instruments and regain orientation, but too late to prevent a mishap. Alternatively the pilot may develop Type II disorientation and struggle with a sensory conflict to maintain control of the aircraft. The general procedure for dealing with SD is the same for all aircraft. Start with the basics: Aviate, Navigate, and Communicate. This mantra, learned from Day-1 in pilot training, prioritizes flying the airplane (altitude, airspeed, and heading) as the most important task. Similar to recovering from an unusual attitude, "aviate" would include to Recognize, Confirm, and Recover. Often a pilot may not recognize their own SD, increasing the need to prevent it from ever developing. The following paragraphs further expand upon the steps to prevent, mitigate, and/or recover from SD.

7.4.2. Recognize Problem. If a pilot begins to feel disoriented, the key is to recognize and confirm the problem early. Then take immediate corrective actions before aircraft control is compromised.

7.4.3. Reestablish Visual Dominance. The pilot must reestablish accurate visual dominance. To do this, keep the head in the cockpit, defer all cockpit chores that are not essential, and concentrate solely on flying basic instruments. Keeping the head in the cockpit means to focus on the instruments and not to look outside. The external visual environment may be the cause of SD, and flying via instruments will most quickly establish proper orientation. Make frequent reference to the attitude display that is the primary reference needed to establish and maintain visual dominance. Apply the necessary control inputs to make the attitude indicator display the desired orientation and adjust that display to make the other flight parameters fall into line.

7.4.4. Beware of Persistent Symptoms. If the symptoms do not improve immediately, or if they get worse, the pilot should bring the aircraft to straight and level flight using the attitude display. Maintain straight-and-level flight until the symptoms abate. Declare an emergency if necessary, and advise ATC of the problem.

7.4.5. Resolve Sensory Conflict. If action is not taken early, the pilot may not be able to resolve the sensory conflict. It is possible for SD to proceed to a point (a true state of panic) where the pilot is unable to see, interpret, or process information from the flight instruments. Further, it may not be possible to hear or respond to verbal instructions. Aircraft control in such a situation may be impossible. The pilot must admit that physiological limits have been exceeded and the only alternative may be to abandon the aircraft.

7.4.6. Transfer Aircraft Control. If the pilot experiences SD to a degree that it interferes with maintaining aircraft control, then control of the aircraft should be transferred to the second crewmember, if qualified. If an autopilot is available, consideration should be given to using it to control the aircraft.

7.4.6.1. Single-Seat/Solo Aircraft. A pilot alone in an aircraft is more limited in applying these general principles to deal with spatial disorientation. In this situation, the pilot obviously does not have the option to transfer aircraft control, except possibly to the autopilot.

7.4.6.2. Dual-Seat Aircraft. The same general principles stated above apply to a dual-seat aircraft. However, a second crewmember is generally available to share the cockpit workload.

7.4.6.2.1. Division of Workload. The other crewmember can assist the pilot by copying clearances, changing radio/IFF channels, and acquiring information from flight information publications. The division of workload between the crewmembers should be clearly understood and covered in the preflight briefing.

7.4.6.2.2. Critical Phases. During departures, penetrations/en route descents, or critical phases of flight, the second crewmember should closely monitor and call out altimeter settings, altitudes, airspeeds, and other appropriate information.

7.4.6.3. Crew Aircraft. The same general principles apply to crew-type aircraft. Although additional crewmembers are available to reduce pilot workload, illusions and sensory conflicts are possible and do occur. Illusions experienced here are more likely to be visual in origin than vestibular. Specific procedures concerning division of workload and crew coordination should be clearly understood and covered in the preflight briefing.

7.4.7. Flying Formation. All of the general principles for dealing with SD apply to formation flights. Additional procedures are necessary since the potential for SD is greatest for formation flights during night or weather conditions.

7.4.7.1. Proficiency. Pilots scheduled for formation flights in night/IMC should be current and proficient in instrument, night, and formation flying. Particular attention should be directed to the number of sorties and flying hours in the past 30 days.

Remember, all pilots are susceptible to SD regardless of total experience and pilots in a new airframe are especially susceptible as they learn the new mission and aircraft.

7.4.7.2. Safe Formation Flight. There are two essential requirements for safe formation flight. First, the flight leader must be experienced, competent, and smooth. Second, the wingman must be proficient in formation flying. The wingman must have total confidence in lead and concentrate primarily on maintaining a proper wing position.

7.4.7.3. Night Join-ups. Night join-ups are inherently difficult, particularly when conducted at low altitude over water or dark terrain. Alternative profiles, such as a trail departure and climb-out, should be considered.

7.4.7.4. Deteriorating Weather. If the weather encountered during a formation flight is either too dense or turbulent to ensure safe flight, the flight leader should separate the aircraft under controlled conditions. This may be better than having a wingman initiate lost wingman procedures at a time that may be dangerous or, worse yet, when the wingman is severely disoriented.

7.4.7.5. Disoriented Wingman. In the preflight briefing, the flight leader should cover specific procedures to manage a disoriented wingman. NOTE: Lost wingman procedures are designed to ensure safe separation between aircraft in a flight when a wingman loses sight of lead. Lost wingman procedures are not designed to recover a wingman with severe spatial disorientation. Precise execution is required to perform lost wingman procedures; a severely disoriented pilot may not be able to accomplish this.

7.4.7.6. Communication. The flight lead should encourage a wingman to verbalize a feeling of disorientation. A few words from lead may reassure the wingman and may help form a mental picture of the flight's position in space. For example: "Two, we are level at 20,000 feet in a 30 degree left bank at 300 knots."

7.4.7.7. Wingman with Persistent SD. If the wingman continues to have problems, the lead should bring the flight to straight-and-level and advise the wingman. If possible, maintain straight-and-level for at least 30 seconds and up to 60 seconds. Generally, the wingman's symptoms will subside in 30 to 60 seconds. Advise ATC if an amended clearance is necessary.

7.4.7.8. Lead Transfer. If the above procedures are not effective, then lead should consider transferring the flight lead position to the wingman while straight-and-level. NOTE: Once assuming lead, maintain straight-and-level flight for 60 seconds before initiating turns, climbs, or descents. The objective is for the disoriented pilot to reestablish visual dominance as quickly as possible. Again, a wingman that is severely disoriented should normally not elect or be directed to execute lost wingman procedures. At this point, consideration should be given to terminating the mission and recovering the flight by the simplest and safest means possible. Under exceptional circumstances, such as if the above procedures are ineffective and the disoriented wingman cannot continue to fly formation safely, the lost wingman procedure and single ship recovery are a viable last resort.

7.4.7.9. Lost Wingman. SD may not be experienced until the pilot executes lost wingman procedures. Sudden vestibular and other erroneous sensory inputs may not agree with instrument indications. It is most important at that moment for the pilot to believe and trust the attitude display and to make the attitude display reflect the desired aircraft orientation. It is paramount that a pilot who has just gone lost wingman immediately advise flight lead if he/she is experiencing any effects of SD. The flight lead should advise current flight parameters, ensure that flight member has transitioned to instruments, and clear an altitude block if necessary. For example, in 2011, an A-10 pilot flying as wing on a 2-ship vector in the weather for an instrument approach went lost wingman and became spatially disoriented but safely ejected. It is not unusual for SD to occur after intently trying to fly formation for an extended period of time and then quickly being thrust into flying instruments. The SD symptoms should subside within 30-60 seconds with a concentrated effort on basic aircraft control with the attitude display as the primary reference.

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Attachment 1

GLOSSARY OF REFERENCES AND SUPPORTING INFORMATION

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AF Form 847, *Recommendation for Change of Publication*

Abbreviations and Acronyms

AP—Aerospace Physiology

AETC—Air Education and Training Command

AFI—Air Force Instruction

AFMS—Air Force Medical Service

AFPD—Air Force Policy Directive

AFRL—Air Force Research Laboratory

AIB—Accident Investigation Board

AGL—Above Ground Level

ANG—Air National Guard

AOP—Aerospace and Operational Physiology

AOPTU—Aerospace and Operational Physiology Training Unit

ARC—Air Reserve Component

CC—Commander

CFIT—Controlled Flight into Terrain

CONOPS—Concept of Operations

CRM—Crew/Cockpit Resource Management

DNIF—Duty Not Involving Flying

DV—Distinguished Visitor

ETCA—Education and Training Course Announcement

FLIR—Forward Looking Infrared

FOV—Field of View

FS—Flight Surgeon

FTU—Formal Training Unit

GCS—Ground Control Station

HQ—Headquarters

HUD—Head up Display

IFF—Identification Friend/Foe

IPD—Inter-pupillary Distance

IMC—Instrument Meteorological Conditions

MAJCOM—Major Command

MDA—Minimum Descent Altitude

MDS—Mission Design Series

MTS—Multi-Spectral Targeting System

NVG—Night Vision Goggles

OG—Operations Group

OPR—Office of Primary Responsibility

PCS—Permanent Change of Station

RPA—Remotely Piloted Aircraft

SA—Situational Awareness

SD—Spatial Disorientation

TO—Technical Order

UAS—Unmanned Aerial System

UFT—Undergraduate Flying Training

UPT—Undergraduate Pilot Training

VMC—Visual Meteorological Conditions

WG—Wing