ACT ARC Recommendation 23-1

Simulation Training Devices Suitable for Spatial Disorientation Training

I. Submission

The recommendation(s) below were submitted by the Spatial Disorientation Training Workgroup (SDT WG) for consideration by the Air Carrier Training Aviation Rulemaking Committee (ACT ARC) Steering Committee at F2F-27, January 25-26, 2023. The ACT ARC Steering Committee adopted the recommendations, and they are submitted to the Federal Aviation Administration (FAA) as ACT ARC 23-1.

II. Definitions

Flight Simulation Training Device (FSTD) means full flight simulator (FFS) or a flight training device (FTD).

Maneuver-Based Training (MBT) means training that focuses on a single event or maneuver in isolation.

Scenario-Based Training (SBT) means training that incorporates maneuvers into real-world experiences to cultivate practical flying skills in an operational environment.

Somatosensory Stimuli means those stimuli perceived as sensations of touch, pressure, pain, temperature, position, movement, and vibration through receptors located within the body tissue and musculoskeletal organs.

Spatial Disorientation is a term used to describe a variety of incidents occurring in flight in which pilots fail to sense correctly the position, motion or attitude of the aircraft or of themselves within the fixed coordinate system provided by the surface of the Earth and the gravitational vertical.[1]

Transfer of Training means the ability of a trainee to apply knowledge, skills, and behavior acquired in one learning environment (*e.g.*, a classroom, an FSTD) to another environment (*e.g.*, flight). In this context, “negative transfer of training” refers to the inappropriate generalization of knowledge or skills learned in training to line operations.

Undesired Aircraft States are characterized by divergences from parameters normally experienced during operations (*e.g.*, aircraft position or speed deviations, configuration of flight controls, or incorrect systems configuration) associated with a reduction in margins of safety. Often considered at the cusp of becoming an incident or accident, undesired aircraft states must be managed by flight crews.

Vestibular stimuli means those stimuli induced by movement of receptor organs in the structures of the inner ear, in response to accelerations in or about one or more axes.

Visual stimuli means those stimuli perceived through the sense of sight.

[1] Benson, A., “Spatial Disorientation – General Aspects”. In J. Ernsting & P. King (Eds.), *Aviation Medicine* (1988) (pp.277-296).

III. Statement of the Issue

In its report on a January 26, 2020, fatal accident in Calabasas, California involving a Sikorsky S–76B helicopter, the National Transportation Safety Board (NTSB) issued the following recommendation:

> **NTSB Recommendation A-21-6**
> *Convene a multidisciplinary panel of aircraft performance, human factors, and aircraft operations specialists to evaluate spatial disorientation simulation technologies to determine which applications are most effective for training pilots to recognize the onset of spatial disorientation and successfully mitigate it, and make public a report on the committee's findings.*

The ACT ARC formed the SDT WG, in part, to address Recommendation A-21-6.

Recommendation A-21-6 calls for the FAA "to evaluate spatial disorientation simulation technologies to determine which applications are most effective for training pilots to recognize the onset of spatial disorientation and successfully mitigate it […]". After studying existing devices and emerging technologies, the SDT WG concluded that a determination of effectiveness must consider the context of the training taking place—including factors such as the level of training, the type of aircraft, the pilot certification or qualification objective, the structure of the overall training program, the physical training environment, and the operational environment for which the pilot is being trained.

The SDT WG then examined existing requirements for SD training and checking and found that well defined training requirements do not exist at any level. For example, while unusual attitude recovery, and recovery from Inadvertent Instrument Meteorological Conditions (IIMC) are required events per the Part 135 Checking Module,[2] there is no explicit reference to SD. Additionally, SD is rarely mentioned[3] in the airplane Airman Certification Standards (ACS) and rotorcraft-helicopter Practical Test Standards (PTS).

The SDT WG resolved that SD training needs to be foundational at all levels of certification during a pilot's career. Furthermore, the WG determined that there are four key elements to an effective SD training program:

- Theoretical training
- Practical training
- Frequent training
- Operationally relevant training

[2] FAA Order 8900.1, Volume 3, Chapter 19, Section 7, Table 3-71)

[3] The group's research showed that the commercial pilot airplane Airman Certification Standards (ACS) mentions spatial disorientation once (I. Preflight Preparation, Knowledge CA.I.H.K1d, "The applicant demonstrates understanding of spatial disorientation"), and contains four references (all the same) to disorientation (*e.g.*, V. Performance and Ground Reference Maneuvers, Risk Management CA.V.A.R4, "The applicant demonstrates the ability to identify, assess and mitigate risks, encompassing distractions, improper task management, loss of situational awareness, or disorientation"). The commercial pilot Practical Test Standards (PTS) for rotorcraft (helicopter and gyroplane) only lists spatial disorientation once (I. Preflight Preparation, Task H: Aeromedical Factors). The helicopter instrument PTS does list SD as an FAA special emphasis item out of concern for pilots who "have attempted to control and maneuver their aircraft in clouds with inoperative primary flight instruments (gyroscopic heading and/or attitude indicators) or loss of the primary electronic flight instruments display."

IV. ACT ARC Recommendations

The ACT ARC has identified numerous devices and technologies used to train pilots to recognize and avoid, or recover from, spatial disorientation. The tables contained in Appendix A to this recommendation set forth the ACT ARC's assessment of devices and technologies with respect to achieving specific objectives associated with such training. The ACT ARC recommends the FAA consider incorporating these assessment materials into guidance for certificate holders and others responsible for the training of air carrier pilots.

The ACT ARC further recommends the FAA consider issuing guidance to operators and other training providers on designing training and selecting training devices and technologies that will deliver the most effective spatial disorientation training. This guidance should emphasize the foundational importance of SD training and include the four elements that make up an effective spatial disorientation training program: theoretical training, practical training, frequent training, and operationally relevant training.

V. Rationale and Discussion

In developing a response to NTSB Recommendation A-21-6, the SDT WG sought to identify relevant devices currently used to intentionally induce spatial disorientation in connection with pilot training, as well as devices and technologies the SDT WG expects may, or could be used for such purposes as they continue to mature. The SDT WG also identified functions, features, characteristics, and capabilities that can provide effective training with respect to spatial disorientation training, and assessed whether each identified device, type of device, or technology possessed such functions, features, characteristics or capabilities.

While assessing various devices and technologies, the SDT WG considered numerous factors, including each device's ability to effectively induce or simulate various illusions or conditions for the purpose of training recognition, avoidance, and recovery from spatial disorientation, in addition to their ability to accurately simulate the operation of specific aircraft. Appendix A to this recommendation contains detailed definitions of the characteristics the SDT WG assessed, and additional criteria the WG employed in making its assessment.

The SDT WG relied on information such as manufacturers' representations and the experiential knowledge of subject matter experts in summarizing the capabilities of the devices assessed. The SDT WG did not systematically test or measure the performance of any devices, but was able to experience a demonstration of several representative devices.

While evaluating devices, the SDT WG grouped them into three main categories: in-aircraft, ground-based, and emerging technologies. In assessing the ability of in-aircraft systems or technologies to effectively induce or simulate an illusion or condition, the SDT WG considered whether each system or technology eliminates or degrades outside visual references to a degree necessary to induce or simulate the illusion or condition in question. The SDT WG also gave consideration to whether inducement or simulation of an illusion or condition can be safely achieved in aircraft of different types and with differing characteristics. The SDT WG identified the potential for increased risk during SD practical training using in-aircraft devices when compared to ground-based simulation devices. Possible hazards involve instructor disorientation, instructor distraction while operating the training device, absent or delayed instructor intervention during an upset caused by SD, and temporary incapacitation of the trainee due to fully developed SD. Left unmitigated, some of these hazards could result in consequences as severe as aircraft damage or catastrophic loss of aircraft control.

Safe and effective in-aircraft SD training can be conducted if risks are carefully assessed and mitigated. These risks should be mitigated through fail safe features inherent in system design, features that reduce instructor workload, and supplemental instructor training for providing timely and appropriate intervention techniques.

In assessing ground-based devices used to effectively induce or simulate illusions and conditions, the SDT WG considered whether a pilot experiencing a given illusion or condition would experience sensations similar enough to those during an in-flight encounter with the illusion or condition to offer a meaningful training opportunity.

The WG also noted that ground-based training devices are not without their own hazards and potential for negative consequences. While the risks of injury or damage to equipment are almost non-existent in ground-based SD training devices, there are still hazards that must be identified.

No matter what category of device is used, it is vitally important that instructors are knowledgeable of the subject matter and the limitations of the training device chosen to conduct SD training in order to avoid negative transfer of training. Instructors must have a clear understanding of each scenario and the specific effects intended. The examples below are provided to illustrate potential instances of negative transfer of training:

- A Barany Chair is a device used to generate rotational vestibular stimuli by rotating a seated, blindfolded subject around the vertical axis. Barany Chairs can be an effective way to demonstrate vestibular illusions, which are associated with the limitations of the human sensory system. Their value is in reinforcing to pilots that human sensory systems are not infallible. However, the lack of “pilot in the loop” capability precludes their use for scenario-based training events.
- Purpose-built ground-based SD simulation devices are designed specifically to generate human sensory stimuli (visual, vestibular, and somatosensory) which closely reproduce the SD generating conditions encountered in actual flight. Current generation SD simulation devices are equipped with flight simulation capabilities, allowing the pilot to be in the loop, actively controlling a simulated flight in an environment that is designed to accentuate the conditions leading to SD. Devices with only generic “pilot in the loop” capability may not accurately represent any specific cockpit, which could detract from the realism of the training event. However, these devices can be built with cockpits that are representative of category or class of aircraft and are capable of providing a much higher fidelity simulation of the sensory stimuli that result from aircraft motion.
- Level C/D FSTDs’ motion capabilities motion capabilities cannot fully excite a human’s motion sensors like that of an actual aircraft. While FFSs are limited in their ability to recreate vestibular illusions, and better tools/simulation should always be the goal, training programs and knowledgeable instructors make level C/D FFSs an effective, viable tool to expose pilots to at least some disorienting sensations.

It cannot be emphasized enough that training developers and instructors properly balance risks and limitations when designing and conducting SD training.

Spatial Disorientation Training Philosophy

The ACT ARC notes Recommendation A-21-6 calls for a determination of "which applications are most effective for training pilots to recognize the onset of spatial disorientation and successfully mitigate it[.]" The ACT ARC believes such a determination must be made in the context of the training taking place, including the level of training, the type of aircraft, the pilot certification or qualification objective, the structure of the overall training program, the physical training environment, and the operational environment for which the pilot is being trained. Furthermore, while not directly related to effectiveness, the cost and availability of different devices and technologies will certainly have an impact on which devices operators and training providers are able to incorporate into a training program.

The SDT WG members discussed and reached concurrence on a general philosophy for comprehensive spatial disorientation training, to include incorporation of training devices presented in this report. Given that approximately 80 percent of all aviation accidents involve human factors,[4] the ACT ARC firmly believes that increased emphasis on SD training beyond what is contained in current guidelines is needed. Although training related to human factors is difficult to design and administer—especially for SD training—the ACT ARC supports a comprehensive approach for SD training programs through incorporation of theoretical, ground-based, and in-flight elements to the maximum extent possible.

In arriving at this philosophy, the SDT WG identified a number of aspects essential to effective recognition and avoidance of conditions that could lead to spatial disorientation, as well as techniques to assist in recovery from SD should a pilot experience it. First, the ACT ARC regards SD training to be foundational. That is, pilots should complete SD training at the earliest opportunity, ideally at the primary flight training level, and at every level of licensing thereafter.

Second, effective SD training should include a combination of theoretical and practical training as detailed below. Similar to other areas of training where effective habit patterns should be introduced—such as instrument flight training—effective SD training should build progressively on the foundations established at the primary level. Participating in a comprehensive training program that incorporates solid ground academics along with ground-based and in-flight simulation, further adds to the effectiveness of spatial disorientation training.

- Theoretical Training – Training that consists of ground school in the physiological systems and structures involved, and the mechanisms by which pilots experience spatial disorientation.[5] Appendix A to Recommendation 23-2 contains sample syllabi including theoretical spatial disorientation training elements.
- Practical Training – Training that consists of exposure, in an aircraft or suitable ground-based training device, to stimuli likely to produce spatial disorientation.[6] Such exposure allows the pilot to correlate sensations and perceptions

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[4] Ch. 13, Helicopter Flying Handbook (FAA-H-8083-21B), Federal Aviation Administration, 2019.

[5] Theoretical training is the only element of spatial disorientation training currently included in pilot certification standards and training requirements.

[6] It is noted that exposure to a given stimulus does not guarantee that the pilot exposed to it will experience the intended illusion, or any illusion at all.

experienced during spatial disorientation with the knowledge obtained from theoretical training.

Theoretical training establishes the foundation from which situational awareness, insight, knowledge, and skills are developed, and therefore must be accomplished prior to practical training of the associated flight events. To ensure sufficient retention, practical training should occur within a reasonable time after theoretical training.

Finally, SD training should be both frequent and operationally relevant.

- Frequent Training – Frequency of training signifies the incorporation of spatial disorientation training into each level of pilot certification and qualification, including initial and recurrent training cycles at the air carrier level.
- Operationally Relevant Training – Operationally relevant training describes the use of safety data to identify and emphasize illusions most frequently involved in accidents and incidents related to an organization's operational environment. The SDT WG expressed operationally relevant training by assigning priorities to the illusions considered when assessing devices and technologies in the column labeled "Training Priority" in Appendix A, Table A-2. The information is intended to guide operators and training providers as they consider selection of training devices and design training programs. Such data could include, for example, accident and incident reports, Safety Management System (SMS) data, and Aviation Safety Action Program (ASAP) or other safety reports.

The ACT ARC is cognizant that cost and availability will also be factors in device selection. For example, in-aircraft view limiting devices may offer lower cost ways to effectively expose student pilots to spatial disorientation at the primary training level, where lower operating costs permit in-aircraft training, while at the air carrier level, where in-aircraft training is often cost-prohibitive, the use of more expensive ground-based devices at fixed locations may be justified.

VI. Background Information

Recommendation 23-1 addresses item 1.a in the SDT WG Scope of Work and ACT ARC Initiative #46 (see below):

SDT WG Scope of Work:

1. Generate a report in the form of a recommendation on simulation training devices[7] suitable for use in training air carrier pilots to recognize the onset of spatial disorientation and successfully mitigate it. The report should include—
    a. A discussion of training device functions, features, and characteristics that are necessary or desirable for effective training of spatial disorientation recognition and response. This discussion should differentiate between those functions, features, and characteristics of particular importance to training pilots of airplanes and helicopters.
    b. A description of training devices potentially suitable for spatial disorientation recognition and response, including an assessment of the extent to which each such device possesses or performs the functions, features, and characteristics discussed in 1.a.
    c. A discussion of the present and anticipated availability of the devices described in 1.b. for air carrier pilot training.

ACT ARC Initiatives:

- Initiative #46: Evaluate spatial disorientation simulation technologies to determine which applications are most effective for training pilots to recognize the onset of spatial disorientation and successfully mitigate it.

Source Reports

National Transportation Safety Board (NTSB) Report AAR-21/01

Attachments

Appendix A – Assessment of Devices & Technologies

[7] While the training devices considered may include flight simulation training devices (FSTD) qualified in accordance with Title 14 Code of Federal Regulations (14 CFR) part 60, the SDT WG may consider simulation devices other than FSTD.

Appendix A – Assessment of Devices & Technologies

General Definitions

Tables A-1 and A-3 contain descriptive and qualitative information about the devices and technologies the SDT WG assessed, including manufacturer, date of first use, number in use, and, for ground-based simulators, locations. The following definitions may be instructive in understanding the SDT WG's findings.

In aircraft systems refers to devices that limit the trainee pilot's view of external references. Simple devices such as hoods, foggles, and view limiting curtain systems have been in use for flight training for many years. More recently, manufacturers have marketed more sophisticated view-limiting devices that allow an instructor or safety pilot to change visibility conditions using a controllable Smart Film. View limiting devices allowing the inducement of conditions conducive to visual illusions. When using such devices, the in-aircraft flight environment produces conditions required for additional illusions including vestibular and proprioceptive[8] illusions.

Ground based Simulators means ground based devices used to expose pilots to stimuli intended to induce spatial disorientation illusions. Ground based simulators is a broad category, and includes flight simulation training devices (FSTD) qualified for use in air carrier flight training under 14 CFR part 60; other devices used for flight training that incorporate a simulated visual environment and a motion platform; dedicated devices used strictly for spatial disorientation training; devices and hardware/software combinations meeting the requirements for basic aviation training devices (BATD) or advanced aviation training devices (AATD); and specialized devices used to train specific aspects of spatial disorientation, such as Bárány chairs.

Emerging Technologies consists of devices and technologies with capabilities that are continuing to evolve, but offer significant potential for future spatial disorientation training applications. Examples of emerging technologies include VR, AR, and MR (Collectively known as Extended Reality or XR) applications and devices (see sub-definitions, below), as well as mass market flight simulation software (*e.g.*, Microsoft Flight Simulator, X-Plane) and associated hardware. The SDT WG contemplated emerging technologies, but did not assign Y/N values because they represent broad categories of devices with continually changing and expanding capabilities and features. However, the WG believes it is necessary to include these devices because they hold significant potential for future use in spatial disorientation training, particularly at the basic flight training level.

> *Virtual Reality* means the computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors.
>
> *Augmented Reality* means technology that superimposes a computer-generated image on a user's view of the real world, thus providing a composite view.
>
> *Mixed Reality* means a medium consisting of immersive computer-generated environments in which elements of a physical and virtual environment are combined.

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[8] *Proprioceptive* senses describe what is commonly referred to as "seat-of-the-pants" flying. These senses are derived from receptors located in the skin, muscles, tendons, and joints. In a flight environment, these stimuli can vary in magnitude, direction, and frequency, resulting in a "sensory mismatch" that can produce illusions leading to spatial disorientation.

Table A-1 – Device Information

Device Information	Manufacturer	Date In Service	Number In Service	Locations	SD Recognition	SD Avoidance	SD Recovery	NVG Training Capable	Device Category	ICAO 9625 FSTD Qual	Aircraft and Instrument Similarity	Complexity/ Trainer Proficiency	NOTES
In Aircraft Systems													
ICARUS Device	**ICARUS**	**2020**	**203**	**Portable System**	**Y**	**Y**	**Y**	**Y**	**N/A**	**N/A**	**S**	**1**	Instrument Conditions Awareness Recognition and Understanding System, ICARUS, is a Smart View Limiting Device for UIMC, DVE, IFR, and weather decision making training * The system consists of a lightweight visor, small power control unit and iOS or Android app
ATS Device	**AT Systems**	**2020**	**50**	**Portable System**	**Y**	**Y**	**Y**	**Y**	**N/A**	**N/A**	**S**	**1**	In-aircraft training device that trains pilots for degraded visual environments (DVE), such as IIMC and brown/white out * Controlled wirelessly through a tablet application * Regularly updated accident scenarios replicate real-world historical accident conditions * Able to simulate DVE conditions while incorporating available resources such as NVG's, HUD or synthetic vision * Visibility can be set between 0 to 6 miles in ¼ mile increments and ceilings set to any altitude in 100ft increments
Hood/Foggles	**Numerous**	**1929**	**Many**	**Portable System**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**S**	**1**	Creates and instrument-only environment by obscuring vision outside the aircraft * A traditional method of creating an in-flight simulated instrument flight environment
Cockpit Curtains	**Numerous**	**Unknown**	**Many**	**Aircraft Specific**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**S**	**1**	Creates and instrument-only environment by obscuring vision outside the aircraft * A traditional method of creating an in-flight simulated instrument flight environment
Ground Based Simulators													
Level C/D Flight Simulator	**Numerous**	**Circa 1980**	**>1200**	**Multiple Locations**	**Y**	**Y**	**Y**	**Y**	**N/A**	**Level C/D (ICAO Type VII FSTD)**	**S**	**3**	ICAO equivalent is Type VII FSTD * Aircraft and Instrument fidelity is specific on these devices * Features that are considered representative are motion, sound, etc.
GAT-II Fixed Wing SD Trainer	**ETC**	**1980s**	**~20**	**FAA-CAMI** (Oklahoma City, OK) **Flight Schools** (Multiple Locations) **Foreign Air Forces** (Multiple Locations)	**Y**	**Y**	**Y**	**N**	**2**	**None**	**G/R**	**2**	3DOF (Degrees of Freedom) with a continuous 360° Yaw turntable - Simultaneous multi-axes motion cueing and motion sensation stimulation * Light fixed wing trainer cockpit (C-172 analog gauge type) with pilot-controlled flight simulation * Programmable training profiles with visual and vestibular SD stimulation * Used routinely for general aviation and military SD training * Meets USAF and NATO SD training standards
GAT-II Helo Rotary Wing SD Trainer	**ETC**	**1990s**	**1**	**FAA-CAMI** (Oklahoma City, OK)	**Y**	**Y**	**Y**	**N**	**2**	**None**	**G/R**	**2**	3DOF with a continuous 360° Yaw turntable - Simultaneous multi-axes motion cueing and motion sensation stimulation * Light helicopter cockpit with pilot-controlled flight simulation * Programmable training profiles with visual and vestibular SD stimulation * Used for general aviation SD training
GAT-III Fixed Wing SD Trainer	**ETC**	**~2017**	**2**	**Univ of N Dakota** (Grand Forks, ND) **Foreign Air Force** **Manufactured at Southampton, PA**	**Y**	**Y**	**Y**	**N**	**2**	**None**	**G/R**	**2**	3DOF with a continuous 360° Yaw turntable - Simultaneous multi-axes motion cueing and motion sensation stimulation * Light fixed wing trainer cockpit (C-172 G1000 type) with pilot-controlled flight simulation (including motion flight replay) * Programmable training profiles with visual and vestibular SD stimulation * Used routinely for general aviation and military SD training * Meets USAF and NATO SD training standards * Built to AATD specifications
GAT-HELO Rotary Wing SD Trainer	**ETC**	**~2017**	**4**	**US Army** (Ft Rucker, AL) **Foreign Air Forces** (Multiple Locations) **Manufactured at Southampton, PA**	**Y**	**Y**	**Y**	**Y**	**2**	**None**	**G/R**	**2**	3DOF with a continuous 360° Yaw turntable - Simultaneous multi-axes motion cueing and motion sensation stimulation * Light helicopter cockpit with pilot-controlled flight simulation (including motion flight replay) * Wide field of view, dome projection visual system * Programmable training profiles with visual and vestibular SD stimulation * Used routinely for general aviation and military SD training * Meets US Army and NATO SD training standards
GYRO IPT-II SD Trainer	**ETC**	**1990s**	**10-20**	**US Air Force** (Multiple Locations) **Foreign Air Forces** (Multiple Locations) **Manufactured at Southampton, PA**	**Y**	**Y**	**Y**	**Y**	**2**	**None**	**G/R**	**2**	4DOF (Roll / Pitch / Yaw / Heave) with a continuous 360° Yaw turntable - Simultaneous multi-axes motion cueing and motion sensation stimulation * Active pilot-controlled flight simulation or passive flight capable (including motion flight replay) * Interchangeable fixed wing (fighter, trainer, transport) and rotary wing (helicopter) cockpit * Wide field of view, dome projection visual system * Programmable training profiles with visual and vestibular SD stimulation * Used routinely for military SD training * Meets USAF and NATO SD training standards

Table A-1 – Device Information (Cont'd)

Device Information	Manufacturer	Date In Service	Number In Service	Locations	SD Recognition	SD Avoidance	SD Recovery	NVG Training Capable	Device Category	ICAO 9625 FSTD Qual	Aircraft and Instrument Similarity	Complexity/ Trainer Proficiency	NOTES
Ground Based Simulators													
GYROLAB GL-4000 (and Variants) SD Trainer	**ETC**	**2000s**	**3**	**Foreign Air Forces** (Multiple Locations) **Manufactured at Southampton, PA**	**Y**	**Y**	**Y**	**Y**	**3**	**None**	**G/R**	**3**	4DOF (Continuous 360° Pitch / Roll / Yaw / Planetary) - Simultaneous multi-axes motion short-arm human centrifuge of up to 3G * Active pilot-controlled flight simulation or passive flight capable (including motion flight replay) * Configured as a fixed wing twin-jet transport cockpit * Wide field of view, projection visual systems * Programmable training profiles with visual and vestibular SD stimulation * Configured for civilian SD and Upset Prevention and Recovery Training
GYROLAB GL-6000 SD Research Device	**ETC**	**2015**	**1**	**US Navy** (Dayton, OH)	**Y**	**Y**	**Y**	**N***	**4**	**None**	**G/R**	**3**	4DOF (Continuous 360° Pitch / Roll / Yaw / Planetary) - Simultaneous multi-axes motion short-arm human centrifuge of up to 6G * Active pilot-controlled flight simulation or passive flight capable (including motion flight replay) * Configurable fixed wing (fighter, trainer, transport) and rotary wing (helicopter) cockpit * Wide field of view, dome projection visual system * Programmable training profiles with visual and vestibular SD stimulation * Used routinely for military SD training * Meets USAF and NATO SD training standards
ATFS-400 Series Human Centrifuge	**ETC**	**2004**	**8**	**US Air Force** (Dayton, OH) **Foreign Air Forces** (Multiple Locations) **Manufactured at Southampton, PA**	**Y**	**Y**	**Y**	**N***	**N/A**	**N/A**	**G/R**	**3**	6DOF (Continuous 360° Roll / Pitch / Yaw / Planetary with Heave / Surge / Sway) - Simultaneous multi-axes motion human centrifuge of up to 3G * Configurable (multiple types) cockpit with pilot-controlled flight simulation * Programmable profiles with visual and vestibular SD stimulation * Used for advanced research in the US Navy
Night Vision Training System (NVTS)	**ETC**	**1980s**	**20-30**	**Foreign Air Forces** (Multiple Locations) **Manufactured at Southampton, PA**	**Partial** (Visual)	**Partial** (Visual)	**Partial** (Visual)	**N**	**N/A**	**N/A**	**G**	**2**	3DOF (Continuous 360° Roll / Pitch / Planetary) - Simultaneous multi-axes motion human centrifuge of up to 9G (manned) * Configurable (fighter, trainer) cockpit with pilot-controlled flight simulation * Programmable profiles capable of both high-G training and visual / vestibular SD stimulation * Continuous planetary motion used in lieu of continuous yaw motion (similar to actual aircraft)
Night Vision Goggles Training System (NVGTS)	**ETC**	**2000s**	**10-20**	**Foreign Air Forces** (Multiple Locations) **Manufactured at Southampton, PA**	**Partial** (Visual)	**Partial** (Visual)	**Partial** (Visual)	**Y**	**N/A**	**N/A**	**G**	**2**	Classroom based Night Vision Training * Night vision flight imagery projected on classroom screen * Flyable cockpit (fixed wing / rotary wing) placed within the classroom * Allows trainee to conduct free flight and be exposed to situations predisposing to night visual SD
DESDEMONA	**AMST**	**2007**	**1**	**Soesterberg, NL**	**Y**	**Y**	**Y**	**N**	**4**	**N**	**R/S**	**3**	Classroom based Night Vision Goggles Training * NVG compatible night vision flight imagery projected on classroom screen * Flyable cockpit (fixed wing / rotary wing) placed within the classroom * Allows trainee to conduct free flight and be exposed to situations predisposing to NVG related night visual SD
AIRFOX	**AMST**	**1990s**	**22**	**Multiple Locations**	**Y**	**Y**	**Y**	**Y**	**2**	**FNPT II possible**	**G**	**2**	Based on 6 DoF centrifuge design, hardware by AMST GmbH, disorientation courseware and motion cueing by multiSIM BV and Desdemona BV
StarSpot	**JFJ GmbH**	**2022**	**1**	**Burgkirchen, AT**	**Y**	**Y**	**Y**	**Y**	**2**	**UNK**	**R/S**	**2**	New device with hexapod and full yaw capabilities, comparable to a Level C/D simulator with full yaw
Barany Chair	**Numerous**	**Circa 1914**	**Many**	**Multiple Locations**	**N**	**N**	**N**	**N/A**	**1**	**N/A**	**N/A**	**1**	
AATD/BATD	**Numerous**	**2008**	**1000**	**Multiple Locations**	**Partial** (Visual)	**Partial** (Visual)	**Partial** (Visual)	**N**	**N/A**	**N/A**	**G/R**	**2**	Reference AC 61-136B for detailed information regarding AATD/BATD
Emerging Technologies													
VR/MR Simulators	**Numerous**	**1960s**	**Few**	**Multiple Locations**	**Partial** (Visual)	**Partial** (Visual)	**Partial** (Visual)	**TBD**	**N/A**	**FTD**	**R/S**	**2/3**	Data listed is an estimation of the capabilities of these devices
Mass Market Simulator Software/Hardware	**Numerous**	**1980s**	**Many**	**Multiple Locations**	**Partial** (Visual)	**Partial** (Visual)	**Partial** (Visual)	**N/A**	**N/A**	**N/A**	**R**	**2**	Some systems support VR/MR

Table A-1 contains the SDT WG's assessment of the of the following capabilities, qualities, and characteristics for each device or technology evaluated:

SD Recognition means the ability to expose pilots to realistic illusions or physical sensations of disorientation.

SD Avoidance means the ability to support realistic and scenario-based training focused on avoiding the conditions conducive to causing spatial disorientation, through increased situational awareness and sound decision making. (*e.g.*, degraded visual environment, deteriorating weather, flat light, whiteout, brownout.

SD Recovery means the ability to allow pilots to recover from spatial disorientation through active, pilot in the loop, recovery techniques.

Device Category refers to the categorizations of SD devices according to North Atlantic Treaty Organization (NATO) Research and Technology Organization (RTO) Air Standardization Coordinating Committee (ASCC) Air Standard 61/117/14:

- Device Category 1 - A device capable of yaw rotation only (*e.g.*, the Barany Chair)
- Device Category 2 - A device capable of yaw rotation and limited roll, pitch and/or heave that has full/partial close looped subject control
- Device Category 3 - Devices with a 4 Degree-of-Freedom (DoF) motion base (pitch, roll, yaw, and planetary), which provides 2 – 3 Gs sustained acceleration
- Device Category 4 - Centrifuge devices having 6 DoFs such as roll, pitch, yaw, heave, surge, and sway with 2 – 3 G capability for sustained acceleration.

ICAO 9625 FSTD Qual refers to the qualification level of any Flight Simulation Training Devices (FSTD) found in International Civil Aviation Organization (ICAO) Manual 9625, Manual of Criteria for the Qualification of Flight Simulation Training Devices. The manual addresses the use of FSTDs representing airplanes (Volume I) and helicopters (Volume II). The methods, procedures and testing standards contained in the manual are the result of the experience and expertise provided by Civil Aviation Authorities (CAA) and airplane and FSTD operators and manufacturers.

Aircraft and Instrument Similarity refers to the cockpit fidelity of the specific device being used for training (*e.g.*, since in aircraft visibility simulation systems use the actual aircraft, the table listing is S - Specific). Note: Although similar to ICAO Doc 9625 references, only the Level C/D device is outlined in Doc 9625:

- (N) - None
- (G) - Generic
- (R) - Representative
- (S) – Specific

Complexity/Trainer Proficiency represents the relative complexity of setting up and operating the various devices listed:

- 1 SIMPLE - Relatively simple to use and maintain, with no significant training requirements on how to operate or maintain the equipment
- 2 MODERATE - Moderate levels of maintenance requirements or basic level of training requirements on how to operate the equipment
- 3 COMPLEX - Elevated levels of maintenance requirements or elevated level of training requirements on how to operate the equipment

Table A-2 – Device Capability

DEVICE CAPABILITY	Applicability & Priority		In Aircraft Systems				Ground Based Simulators																Emerging Technologies	
Refer to Tab Instructions for Notes, Definitions, and References	Predominate Applicability	Training Priority	ATS Device	ICARUS Device	Hood/Foggles	Cockpit Curtain	Level C/D Flight Simulator	GAT-II FW SD Trainer	GAT-II-Helo RW SD Trainer	GAT-III FW SD Trainer	GAT-HELO RW SD Trainer	GYRO IPT-II SD Trainer	GYROLAB GL-4000 (and Variants) SD Trainer	GYROLAB GL-6000 SD Research Device	ATFS-400 Human Centrifuge	Night Vision Training System	Night Vision Goggles Training System	DESDEMONA	AIRFOX	StarSpot	AATD/BATD	Barany Chair	VR/MR	Mass Market Simulator Software/Hardware
VISUAL ILLUSIONS/CONDITIONS																								
Brownout	H	A	Y	Y	N	N	Y	N/A	Y	N/A	Y	Y	Y	Y	N/A	Y	Y	Y	Y	Y	N	N	I	I
Whiteout	H	A	Y	Y	N	N	Y	N/A	Y	N/A	Y	Y	Y	Y	N/A	Y	Y	Y	Y	Y	N	N	I	I
Blackhole Approach	B	A	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	I	I
Size Constancy (Runway Width)	B	B	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	I	I
Shape Constancy (Runway Slope)	B	B	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	I	I
Terrain Height Perception (Terrain Slope)	B	B	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	I	I
Vection Illusion	B	B	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	I	I
Flat Light	B	B	Y	Y	N	N	Y	N	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	N	I	I
Low Contrast	B	B	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	I	I
Flicker Vertigo	B	B	Y	Y	N	N	Y	N	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	I	I
False Horizon Day	B	B	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y	N	I	I
False Horizon Night	B	B	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	I	I
Autokinesis	B	B	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	N	I	I
GYRAL VESTIBULAR ILLUSIONS																								
Coriolis Illusion	B	B	Y	Y	L	L	L	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	N	Y	I	N
Somatogyral Illusion	B	B	Y	Y	L	L	L	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	N	Y	I	N
Oculogyral Illusion	B	B	Y	Y	L	L	L	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	N	Y	I	N
Erroneous Sensation of Rotation	B	B	Y	Y	L	L	L	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	N	Y	I	N
Graveyard Spin	F	B	Y	Y	L	L	N	Y	Y	Y	Y	Y	Y	Y	N	N	N	Y	Y	Y	N	N	I	N
Nystagmus	B	C	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	N	Y	I	N
GRAVIC VESTIBULAR ILLUSIONS																								
Dark Takeoff	F	A	Y	Y	L	L	L	L	L	L	L	L	Y	Y	Y	N	N	Y	L	L	N	N	I	N
Somatogravic Illusion	B	A	Y	Y	L	L	L	L	L	L	L	L	Y	Y	Y	N	N	Y	L	L	N	N	I	N
Oculogravic Illusion	B	B	Y	Y	L	L	N	L	L	L	L	L	Y	Y	Y	N	N	Y	N	N	N	N	I	N
Elevator Illusion	B	B	Y	Y	L	L	N	L	L	L	L	L	Y	Y	Y	N	N	Y	N	N	N	N	I	N
Inversion Illusion	B	C	Y	Y	L	L	N	L	L	L	L	L	Y	Y	Y	N	N	Y	N	N	N	N	I	N
MIXED VESTIBULAR ILLUSIONS																								
Graveyard Spiral	B	A	Y	Y	L	L	N	L	L	L	L	L	Y	Y	Y	N	N	Y	N	L	N	N	I	N
Leans	B	A	Y	Y	L	L	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y	N	N	I	N
G-Excess	F	C	Y	Y	L	L	N	N	N	N	N	N	Y	Y	Y	N	N	Y	N	N	N	N	I	N

Introduction

Table A-2 contains information on the extent to which the different devices the SDT WG assessed are capable of producing specific illusions, which are defined or described here.

The SDT WG used the following designators in assessing the capabilities of devices and technologies to induce the specified illusions:

- *Y (Yes)* means the device is capable of producing sensory stimuli intended to induce the specified illusion.
- *L (Limited)* means the device is capable of producing SOME sensory stimuli intended to induce the specified illusion, but with reduced duration or magnitude.
- *N (No)* means the device is not able to induce the specified illusion.
- *E (Emerging)* means the device designation describes a broad category of devices with evolving capabilities.
- *N/A (Not Applicable)* means not applicable to the device based on its application. (For example, helicopter-specific illusions are not applicable to fixed-wing simulation devices.)

Illusions

Sourcing Information

Many of the definitions or descriptions below are drawn from existing reference publications. The source for these definitions and descriptions is indicated by a superscript following the name of the illusion, referencing the following list:

a– Aeronautical Information Manual, Chapter 8 (Subsection 8-1-5)
b – Fundamentals of Aerospace Medicine, Davis *et al*
c – USAF Handbook of Aerospace and Operational Physiology, 2nd Ed (2016)
d – Ernsting's Aviation Medicine, 45h Ed (2006)
e – USAF Pamphlet 11-417 Orientation in Aviation

Italicized notes following a definition or description are not contained in the referenced source material.

Visual Illusions

Visual illusions are spatial disorientation Illusions that are derived primarily from erroneous visual perception and can occur independently from vestibular inputs.

Size Constancy (Runway Width)[a]

A narrower-than-usual runway can create the illusion that the aircraft is at a higher altitude than it actually is. The pilot who does not recognize the illusion will fly a lower approach, with the risk of striking objects along the approach path or landing short. A wider-than-usual runway can have the opposite effect, with the risk of leveling out high and landing hard or overshooting the runway.

Shape Constancy (Runway Slope) [a]

An upsloping runway, upsloping terrain, or both, can create the illusion that the aircraft is at a higher altitude than it actually is. The pilot who does not recognize this illusion will fly a lower approach. A downsloping runway, downsloping approach terrain, or both, can have the opposite effect.

Terrain Height Perception (Terrain Slope)[a]
An upsloping runway, upsloping terrain, or both, can create the illusion that the aircraft is at a higher altitude than it actually is. The pilot who does not recognize this illusion will fly a lower approach. A downsloping runway, downsloping approach terrain, or both, can have the opposite effect.

Vection Illusion[b]
Vection is the visually introduced perception of self-motion in a spatial environment and can be a sensation of linear motion (linear vection) or angular motion (angular vection).

Brownout[b]
Visibility is restricted drastically by sand driven into the air by the propeller or rotor wash of the affected aircraft.

Whiteout[b]
Visibility is restricted drastically by snowflakes driven into the air by the propeller or rotor wash of the affected aircraft.

Flat Light
Flat light occurs when the sky is overcast, especially over snow-covered terrain and large bodies of water. In flat light conditions, no shadows are cast and terrain features and other visual cues are masked, making it difficult for pilots operating under visual flight rules (VFR) to perceive depth, distance, or altitude.

Low Contrast
Environments where a pilot lacks the ability to distinguish between the surface of the earth and the background sky. Flights over deserts and water as well flight into the rising or setting sun or moon can produce low contrast flight environments.

Flicker Vertigo[d]
Aircrew have described a number of sensory disturbances that can be attributed to a flickering visual stimulus. Such problems are more common in rotary wing aircraft, where the shadow cast by the main rotor blades passes across the cockpit several times a second. Difficulties have also been experienced when light from a rotating anti-collision beacon illuminates the cockpit, either directly or by reflection from cloud or smoke. The principal complaint is irritation and distraction. Less frequently, there is a true disorientation in which the visual stimulus gives rise to vection illusion characterized by a sensation of angular motion of the aircraft in the opposite direction to that of the moving shadow.

False Horizon Day[a]
Sloping cloud formations, an obscured horizon, a dark scene spread with ground lights and stars, and certain geometric patterns of ground light can create illusions of not being aligned correctly with the actual horizon. The disoriented pilot will place the aircraft in a dangerous attitude.

False Horizon Night[a]
Sloping cloud formations, an obscured horizon, a dark scene spread with ground lights and stars, and certain geometric patterns of ground light can create illusions of not being aligned correctly with the actual horizon. The disoriented pilot will place the aircraft in a dangerous attitude.

Blackhole Approach[b]
A blackhole approach is one that is made on a dark night over water or unlighted terrain to a runway beyond which the horizon is indiscernible, the worst case being when only the runway lights are visible. Without peripheral visual cues to help provide orientation relative to the Earth, the pilot tends to feel that the aircraft is stable and situated appropriately but that the runway itself moves about or remains malpositioned (is downsloping, for example).

Autokinesis[a]
In the dark, a static light will appear to move about when stared at for many seconds. The disoriented pilot will lose control of the aircraft in attempting to align it with the light.

Gyral Illusions
Gyral illusions are spatial disorientation illusions that are derived primarily from erroneous perception of the semicircular canals, typically (but not exclusively) in the absence of reliable visual inputs.

Nystagmus[c]
Nystagmus is the term used to describe a sweeping motion of the eyes in a direction that is opposite of an imposed angular acceleration and followed by a quick return of the eyes to the center position. *Note: Nystagmus requires a continuous yaw turntable or planetary motion.*

Coriolis Illusion[a]
An abrupt head movement in a prolonged constant-rate turn that has ceased stimulating the motion sensing system can create the illusion of rotation or movement in an entirely different axis. The disoriented pilot will maneuver the aircraft into a dangerous attitude in an attempt to stop rotation. This most overwhelming of all illusions in flight may be prevented by not making sudden, extreme head movements, particularly while making prolonged constant-rate

turns under IFR condition. *Note: A Coriolis illusion requires a continuous yaw turntable or planetary motion, although it may be possible to induce mild effects*

Somatogyral Illusion[b]
False sensation of rotation, or absence of rotation, which results from misperceiving the magnitude or direction of an actual rotation. *Note: The somatogyral illusion requires a continuous yaw turntable or planetary motion.*

Oculogyral Illusion[c]
Apparent relative motion of an object in an individual's foveal field-of-view while both the person and object are subjected to angular acceleration. *Note: The oculogyral illusion requires a continuous yaw turntable or planetary motion.*

Erroneous Sensation of Rotation
Disorientation that occurs as a result of combination of vestibular sensation that are perceived while the aircraft in a turning motion. *Note: When attempting to induce an erroneous sensation of rotation, best effects are achieved with a continuous yaw turntable or planetary motion.*

Graveyard Spin[a]
A proper recovery from a spin that has ceased stimulating the motion sensing system can create the illusion of spinning in the opposite direction. The disoriented pilot will return the aircraft to its original spin. *Note: A graveyard spin requires a continuous yaw turntable.*

Gravic Vestibular Illusions
Gravic vestibular illusions are spatial disorientation illusions that are derived primarily from erroneous perception of the otolith organs, typically (but not exclusively) in the absence of reliable visual inputs.

Dark Takeoff[a]
A rapid acceleration during takeoff can create the illusion of being in a nose up attitude. The disoriented pilot will push the aircraft into a nose low, or dive attitude. A rapid deceleration by a quick reduction of the throttles can have the opposite effect, with the disoriented pilot pulling the aircraft into a nose up, or stall attitude. *Note: True G effects require a resultant force of greater than 1 g, generated by planetary motion. Simulated G derived from excess pitch is limited to a resultant force of 1 g.*

Somatogravic Illusion[a]
A rapid acceleration during takeoff can create the illusion of being in a nose up attitude. The disoriented pilot will push the aircraft into a nose low, or dive attitude. A rapid deceleration by a quick reduction of the throttles can have the opposite effect, with the disoriented pilot pulling the aircraft into a nose up, or stall attitude. *Note: True G effect requires a resultant force of greater than 1 g,*

generated by planetary motion. Simulated G derived from excess pitch is limited to a resultant force of 1 g.

Inversion Illusion[a]
An abrupt change from climb to straight and level flight can create the illusion of tumbling backwards. The disoriented pilot will push the aircraft abruptly into a nose low attitude, possibly intensifying this illusion. *Note: An effective inversion illusion uses a combination of a resultant force of greater than 1 g and a high pitch attitude (possibly greater than 45° nose-up) to re-create a realistic sensation of inversion.*

Oculogravic Illusion[d]
A visual component of the somatogravic illusion. Apparent upward movement and displacement of objects within the visual field during forward acceleration. Conversely, downward movement in deceleration. *Note: The oculogravic illusion will be difficult to create in the absence of sustained acceleration force (planetary) because the otolith organs may not receive the stimuli required.*

Elevator Illusion[a]
An abrupt upward vertical acceleration, usually by an updraft, can create the illusion of being in a climb. The disoriented pilot will push the aircraft into a nose low attitude. An abrupt downward vertical acceleration, usually by a downdraft, has the opposite effect, with the disoriented pilot pulling the aircraft into a nose up attitude.

Mixed Vestibular Illusions
Mixed vestibular illusions are spatial disorientation illusions that are derived from a combination of vestibular inputs (semicircular canals and otoliths organs) typically associated with sustained aircraft turns where both turning motion and change in resultant G forces influence spatial orientation.

Graveyard Spiral[a]
An observed loss of altitude during a coordinated constant-rate turn that has ceased stimulating the motion sensing system can create the illusion of being in a descent with the wings level. The disoriented pilot will pull back on the controls, tightening the spiral and increasing the loss of altitude. *Note: When attempting to induce a graveyard spiral, best effects will be achieved by planetary motion since a resultant force of greater than 1 g is produced during a constant turn which influences the vestibular stimuli.*

G-Excess[b]
The G-excess effect is a false or exaggerated sensation of body tilt that can occur when the G environment is sustained at greater than 1 g. *The G-excess illusion requires a continuous yaw turntable or planetary motion.*

Leans[a]
An abrupt correction of a banked attitude, which has been entered too slowly to

stimulate the motion sensing system in the inner ear, can create the illusion of banking in the opposite direction. The disoriented pilot will roll the aircraft back into its original dangerous attitude, or if level flight is maintained, will feel compelled to lean in the perceived vertical plane until this illusion subsides.

Other Information

For each illusion in Table A-2, the SDT WG identified the following information, in addition to assessing the devices' and technologies' capability of inducing or simulating the illusion:

Predominate Applicability

Illusions were classified based on the aircraft class with which they are most commonly associated:

- F – Predominately Fixed Wing Aircraft
- H – Predominately Helicopters
- B – Both equally

Training Priority

Illusions were assessed based on likelihood of occurrence in order to set a Training Priority as indicated below. Priorities should be adjusted based on specific threats and errors that may present themselves based on each operation's specific operating environment:

- A – Highest Priority
- B – Secondary Priority
- C – Tertiary Priority