SYSTEMS TECHNOLOGY, INC.
13766 Hawthorne Boulevard, Hawthorne, California 90250-7083, Phone (310) 679-2281, Fax (310) 644-3887

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David H. Klyde
Amanda K. Lampton, Ph.D.
P. Chase Schulze
Systems Technology, Inc.

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Development of Spatial Disorientation Demonstration Scenarios for Commercial Pilot Training

David H. Klyde*
Amanda K. Lampton, Ph.D.†
P. Chase Schulze ‡
Systems Technology, Inc., Hawthorne, CA, 90250

A study of world-wide commercial jet transport accidents by The Boeing Company found the most common events to be loss of control associated with an inability of pilots to recover from upsets and unusual attitudes. A key component in some of these events was pilot spatial disorientation. In terms of non-visual illusion cases, the spatial disorientation most commonly took the form of somatogravic and/or somatogyral illusions. Somatogravic illusions are those associated with the false sensation of body tilt, while somatogyral illusions are those associated with the inability of the human to perceive extended rotations. Improved pilot training in these abnormal flight conditions, including the ability of commercial pilot training simulators to replicate spatial disorientation, is needed to reduce loss of control accidents. A Federal Aviation Association-sponsored program led by Systems Technology, Inc. is currently developing spatial disorientation demonstration training scenarios using the B747-400 flight simulator at NASA Ames Research Center. Scenarios for a missed approach/go around and a steep bank, constant altitude turn have evolved from evaluations in the simulator conducted over several weeks. Evolutions in the scenarios included selection of out-of-the-cockpit visual conditions that effectively diminished a discernible horizon and adaptations of the hexapod motion system response to create the spatial disorientation sensations. Limited results from guest pilot evaluations are presented to illustrate the potential effectiveness of the approach.

I. Introduction

Spatial orientation (SO) refers to the ability to determine and maintain body orientation in relation to the surrounding environment. For the pilot, this means he or she must accurately sense the attitude, altitude, and direction of motion of the aircraft. Spatial disorientation (SD), on the other hand, refers to the inability of the pilot to retain SO. It is beyond the scope of this paper to summarize in detail the significant work in the area of SD. A key guide to SD as it relates to aviation is the book[1] by Previc and Ercoline. Past work conducted by Systems Technology, Inc. (STI) includes a study[2] of the dynamics of the vestibular system as it relates to the perception of motion including SD. Both of these works have been key references for the work described herein.

SD in pilots usually occurs when flying in weather conditions with little to no visibility, night-time flight, instrument failure, and conditions with high pilot visual load.[3] Humans evolved with a set of systems to sense the body's orientation at rest and during motion, including the visual system, vestibular system, and somatosensory system. These systems provide visual, vestibular, and proprioceptive sensory stimuli of various magnitudes, directions, and frequencies that must all be integrated and interpreted accurately to provide good spatial orientation. However, these systems are tailored to ground-based movement and do not perform as well in a three-dimensional flight environment. As such, there can be mismatching stimuli between the senses that can lead to sensory illusions and, ultimately, SD.

Systems Technology, Inc. (STI) is now conducting a Phase II Small Business Innovation Research (SBIR) program for the Federal Aviation Administration (FAA) to develop spatial disorientation simulator scenarios for commercial pilot training. The focus of the Phase II program is on the non-visual SD illusions, specifically the somatogravic and somatogyral illusions. Somatogravic illusions[1] are those associated with the false sensation of

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[*] VP Research & Engineering Services, AIAA Associate Fellow.
[†] Senior Research Engineer, AIAA Member.
[‡] Senior Research Engineer, AIAA Senior Member.

body tilt that results from perceiving the direction of a non-vertical gravitoinertial force as being vertical. Somatogyral illusions result from the inadequacies of the semicircular canals to correctly perceive extended rotations. The semicircular canals act as a heavily damped angular accelerometer that responds to angular accelerations in their own plane and results in sensations of angular rate.[2]

The purpose of this paper is to describe the development of training scenarios selected to represent elements of the cases identified from a commercial transport loss of control accident database of which spatial disorientation is an important subset. A key aspect in the scenario development process is the limitation of hexapod-based flight training simulators to generate sustained linear and angular accelerations. Using The NASA Ames Boeing 747-400 simulator, which is representative of a FAA Level D Certified flight training device, the SD scenarios evolved over two week-long simulator entries. Ultimately, the SD scenarios that emerged were successfully demonstrated using two guest pilots, each with significant commercial transport experience.

II. Background

A. Types of SD Illusions

1. *Visual Illusions*

Visual illusions are those caused by distorted ambient vision, absent ambient vision, and displays as described in Chapter 3 of Previc and Ercoline[1]. Because visual illusions are not the focus of this work, the following list is offered only as a summary of these types of events. The definitions and general descriptions of these illusions can be found in Reference 1 and Wynbrandt [4].

- **Distorted Ambient Vision**
    - False Horizons
    - False Surface Planes
    - Inversion/Luminance
    - Vertical/Optical Flow
    - Misjudgment of Terrain Features

- **Absent Ambient Vision**
    - Day IMC
    - Nighttime Landings
    - Illusory Motion of Fixed Targets

- **Display Related SD**
    - Refractive
    - Collimated Flight Displays
    - Night-vision Goggles

2. *Non-Visual or Vestibular Illusions*

The vestibular system, the human motion sensing apparatus, is usually relied on most heavily in the absence of the visual system. Unfortunately, this system is only reliable in detecting transient movement. Steady-state movement such as a constant banked turn cannot be detected by this system once the transient response fades. Thus, illusions associated with this system are the most likely to lead to spatial disorientation. The definitions and general descriptions of these illusions provided below were derived from Previc and Ercoline[1], Peters[2], Antunano[5], and Heinle and Ercoline[6].

- **Somatogravic Illusions:** Somatogravic illusions[1] are those associated with the false sensation of body tilt that results from perceiving the direction of a non-vertical gravitoinertial force as being vertical.
    - **False Perception of Attitude during Turns:** For a coordinated turn, the gravitoinertial force aligns with the pilot's spine yielding a sensation of sitting erect. The SD effect is determined by the angle of bank. When the turn is uncoordinated (e.g., a flat turn), the motion can produce an illusion that the roll is in the opposite direction.
    - **Sensation of Climbing in a Turn:** In a coordinated turn when the horizontal turn and bank are not perceived by the pilot, the increased G force in the turn results in the sensation of climbing (nose high attitude). To counteract, the pilot tends to push the stick forward.
    - **Sensation of Diving when recovering from a Turn:** The decreased G force when recovering from a turn gives the sensation of a dive (nose down attitude). To counteract the pilot tends to pull the stick back.

  - **Sensation of Opposite Tilt in a Skid:** If an aircraft skids during a turn, the centripetal acceleration producing the skid also acts on the pilot. The resultant G vector is no longer perpendicular to the traverse or lateral axis of the aircraft. It appears to the pilot that the aircraft is banked in the opposite direction of the true bank.
  - **False Sensation of Pitch:** A false sensation of pitch can occur when the aircraft accelerates in a level plane due to the resultant G force. When accelerating there can be a pitch up illusion, while decelerating can produce a pitch down illusion. The nose high attitude sensation during rapid acceleration can cause the pilot to correct by pushing the stick forward and can result with the aircraft impacting the ground. The nose down attitude sensation during rapid deceleration can cause the pilot to correct by pulling back on the stick, which can eventually lead to stall. The accelerations produced in the pitch up maneuver would tend to inhibit the illusion.
  - **Inversion Illusion:** This illusion involves a steep ascent (forward linear acceleration) in a high-performance aircraft followed by a sudden return to level flight. When the pilot levels off, the aircraft's speed is relatively higher. This combination of accelerations produces an illusion that the aircraft is in inverted flight. The pilot's response to this illusion is to lower the nose of the aircraft (push forward on the stick) which results in intensifying the illusion.
  - **Elevator Illusion:** This illusion is associated with changing magnitude of the gravity vector. As the magnitude of the gravity vector increases, an image in the dark that is stationary relative to the pilot appears to rise. For a decreasing gravity vector magnitude, the target image appears to fall.
  - **Linear Translation:** The linear translation illusion is associated with rotorcraft, which are capable of rotary accelerations and linear accelerations along all axes in a controlled hover. In these conditions the vestibular system can be stimulated above its thresholds
  - **G-Excess Effect:** This illusion results in a false perception of aircraft attitude from an excessive effect of gravity force. The illusion produces an exaggerated sensation of body tilt under sustained gravity load.
- **Somatogyral Illusions:** Somatogyral illusions result from the inadequacies of the semicircular canals in the inner ear to correctly perceive extended rotations. The semicircular canals act as a heavily damped angular accelerometer that responds to angular accelerations in their own plane and results in sensations of angular rate.[2]
  - **Graveyard Spin:** This illusion can occur when a pilot either intentionally or unintentionally enters a spin about the vertical axis. When the pilot enters the spin, he or she will have a sensation of spinning in the same direction. As the spin continues, if the rate of the spin does not change, the fluid in the ear canals will settle into an equilibrium state and the sensation of spinning will fade. When the pilot stops the spin, there will be a sensation of spinning in the opposite direction. If the pilot believes the airplane is now spinning in the opposite direction, they may respond by initiating a spin in the original direction in an attempt to counteract the sensation and return to the perceived correct vertical posture. However, the pilot has unknowingly re-entered the spin. The problem of spin recovery is complicated by the inappropriate compensatory eye movements that accompany prolonged spins[7]. More drastic disorientation can occur in inverted spins. Checking the instrument panel would show that the aircraft is in a spin, but this will contradict the sensations the pilot feels creating a sensory conflict. If the pilot believes the physiological sensations rather than the instruments, the spin will continue and can result in impact with terrain.
  - **Gillingham (Postroll) Illusion:** The Gillingham postroll illusion can result from a rotation about the longitudinal axis. Here, after concluding a sustained roll, the pilot will inadvertently increase the bank angle in the direction of the previous roll.
- **Coriolis Illusion:** This illusion is characterized by the sensation of tumbling in space and is caused by the stimulation of the semicircular canals. It results from a sudden tilting of the pilot's head while the aircraft is turning. This can occur when the pilot lowers his or her head to look at a map or turns his head around to change instrument settings. When the pilot moves his or her head about an axis not aligned with the turn, he or she may experience sensation of rotation and tilt about a third axis which is approximately orthogonal the turning and head tilt axes. This experience can be extremely strong, producing postural disorientation, strong visual effects, and nausea.
- **Illusions Involving Semicircular Canals and Otoliths:** As described in Peters[2], the semicircular canals are the tubular canals in the inner ear that are responsible for motion sensing, while the otoliths are membrane structures in the inner ear that are sensitive to gravity and linear acceleration.

  - **Leans:** This illusion is the one most commonly experienced by pilots. It can result from a sudden return to level flight following an unnoticed gradual and prolonged turn. Pilots are unaware of such a gradual turn because physiologically the semicircular canals of the ear cannot detect rotational accelerations of 2 deg/s^2 or lower. The canals essentially remain in a state of equilibrium during the gradual turn and are jolted out of equilibrium with an abrupt return to level flight. This deviation from equilibrium with the return to level flight may cause the illusion that the aircraft is banking in the opposite direction, e.g., gradual right bank followed by abrupt return to level flight causes the illusion that the aircraft is now banking to the left. In response, the pilot may intentionally bank right in an attempt to achieve the perceived correct vertical posture. The sensation may persist even though the instrumentation will tell the pilot that he or she is flying straight and level. The leans are commonly experienced in turbulence.
  - **Underestimating the Degree of Bank:** If the rolling acceleration upon entering a turn is below the pilot's threshold of perception, the achieved bank angle is underestimated by the pilot. This causes the pilot to bank too much going into the turn and to overcorrect when recovering from the turn. This results in a bank in the opposite direction.
  - **Graveyard Spiral:** This illusion results from a return to level flight after an intentional or unintentional banked turn. Much like the previously discussed illusions, this one is caused by the fluid in the ears settling to equilibrium whilst in the prolonged banked turn. Returning to level flight causes a disturbance in the fluid in the canals, which leads to the sensation of a banked turn in the opposite direction. To counteract the sensation the pilot initiates a turn in the original direction. If the illusion is not recognized, the spiral will continue and altitude will be lost until the aircraft impacts the terrain. A novice pilot, noting the decrease in altitude, may attempt to correct for it by pulling back on the stick and adding power which in turn worsens the situation by tightening the spiral. This illusion is more common than the graveyard spin, because a pilot is more likely to initiate a banked turn rather than a spin.
- **Illusions Contributed by the Somatosensory System:** The somatosensory system is a series of complex receptors associated with the sense of touch. Illusions associated with this system can produce sensation of motion without a corresponding vestibular sensation.
- **Incapacitating Illusions:** Incapacitating illusions[1] include the giant hand, vestibule-ocular disorganization, and g-vector induced positional vertigo. The giant hand illusion is the perception by the pilot that the controls are being held in an extreme position against the pilot's efforts to move them as desired. Vestibular-ocular disorganization results from a misleading vestibular signal following rotation that cannot be corrected by visual fixation. G-vector induced positional vertigo results from exposure to negative g and possibly off axis g-levels and can persist long after landing.

B. Exploring a Loss of Control Database

STI has been participating in a review of a loss of control accident database that includes 275 events over a 15 year period from 1996 – 2010. The database[8] features only transport category or commuter category events, but these are the events that are of interest to this program. The selected events were collected from ten different databases (i.e., Aircraft Accident Report DVD, Australian Transport Safety Bureau, Aviation Safety Network, Canadian Transportation Safety Board, Flightglobal, French Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile, German Bundesstelle für Flugunfalluntersuchung, International Civil Aviation Organization, Irish Air Accident Investigation Unit, and the National Transportation Safety Board). The database identifies each event in terms of the following items:

- Event Descriptors (date, location, aircraft type, operator, flight number, souls on board, injuries, fatalities, etc.);
- Accident Description and Probable Cause; and
- References.

In summary, the database features accidents involving the following aircraft classifications: 38 wide-body, 96 narrow-body, 42 business jets, 44 turboprops, 5 piston engine, and 50 commuter airplanes. Of the 275 accidents in the loss of control database, 38 were identified by various descriptors or flags to have a potential spatial disorientation component. These 38 events are identified in Table 1. The table includes the flight identification, aircraft type, and, if available, a brief description of the SD component of the accident.

Table 1: Potential Spatial Disorientation (SD) Events from a LOC Database[8]

No.	Flight ID	Aircraft	SD Description
1	FOS 55	SF-340B	Somatogravic/somatogyral, false perception of attitude during turns and/or postroll tendency to roll back into a turn.
2	TIA 261	A-310-200	Somatogravic, false sensation of pitch (no details).
3	THY 5904	B-737-400	SA issue, no direct SD evidence.
4	LAK 6316	MD-11F	SA issue, no direct SD evidence.
5	TEJ 725	DC-9-30	Somatogravic, false sensation of pitch (no details).
6	KAL 8509	B-747-2B5F	Somatogravic, false perception of attitude during turns.
7	SWR 498	SF-340B	Somatogravic/somatogyral, false perception of attitude during turns and/or postroll tendency to roll back into a turn leading to a graveyard spin.
8	DAL 106	B-767-332	No discernible horizon led to somatogravic, false perception of attitude during turns.
9	GFA 72	A-320-312	Somatogravic, false sensation of pitch.
10	ETA4 1000	SA-226TC	SA issue, visual SD possible.
11	JEK PF	BE-200	Not a conclusive SD event.
12	N405PC	CE-501	Possible visual SD event.
13	VLK 352	Tu-154M	Somatogravic/somatogyral, false perception of attitude during turns and/or postroll tendency to roll back into a turn.
14	AJI TW	LR-25	Somatogravic, false sensation of pitch.
15	SKK 621	BE-1900C	Somatogravic, false sensation of pitch (no details).
16	FLT 101	SA-226-AT	Not a conclusive SD event.
17	EGU 220	CE-560	Possible Somatogravic, false sensation of pitch (no details).
18	ICE 662	B-757-200	Not a conclusive SD event.
19	9XRRB	Let-410-UVP	Not a conclusive SD event.
20	AFN 642	CV-580F	Not a conclusive SD event.
21	FLS 604	B-737	Somatogravic/somatogyral, false perception of attitude during turns and/or postroll tendency to roll back into a turn leading to a graveyard spiral following bank angle recovery.
22	N280AT	IAI-1124	Not a conclusive SD event.
23	MEP 490	MD-90-200	Not a conclusive SD event.
24	AHY 217	An-140-100	Possible visual SD event.
25	RNV 967	A-320-211	Somatogravic, false sensation of pitch.
26	DHI 574	B-737-4Q8	Somatogravic, false perception of attitude during turns.
27	KQA 507	B-737-8AL	Somatogravic/somatogyral, false perception of attitude during turns and/or postroll tendency to roll back into a turn leading to a graveyard spin.
28	DJQ BP	CE-550	Not a conclusive SD event.
29	VHOZA	SA-227-AC	Not a conclusive SD event.
30	AFL 821	B-737-505	Visual SD leading to somatogravic, false perception of attitude during turns leading to a graveyard spin.
31	CFS 8284	ATR-42-320	Not a conclusive SD event.
32	AOE 301	CE-650	Possible Somatogravic/somatogyral roll event.
33	AFR 447	A-330-203	Not a conclusive SD event.
34	IYE 626	A330-324	Possible visual SD event.
35	ETH 409	B-737-8AS	Possible visual SD event.
36	TIE 039C	CE-550B	Possible visual SD event.
37	AAW 771	A-330-202	Somatogravic, false sensation of pitch.
38	AFR 006	A-380-860	Somatogravic, false sensation of pitch.

The descriptions were based on a review of the summary material available for these cases. Of these 38 cases, 21 were found to be inconclusive or possible SD events given the information available. These cases are highlighted in gray in the table. Thus, 17 events or 6.2% of the 275 total cases were found to have strong evidence of a SD component. These 17 events are characterized as follows:

- Somatogravic illusion resulting in a false sensation of pitch (8 cases);
- Somatogravic illusion resulting in a false perception of attitude during turns (2 cases)
- Somatogravic/somatogyral illusions resulting in a false perception of attitude during turns and/or postroll tendency to roll back into a turn (5 cases); and
- Visual SD leading to somatogravic/somatogyral illusions resulting in a false perception of attitude during turns and/or postroll tendency to roll back into a turn (2 cases).

Four of the roll axis somatogravic/somatogyral illusions led to either a Graveyard Spin (3 cases) or a Graveyard Spiral (1 case). Based on the accident database analysis, a missed approach was selected as a candidate pitch axis scenario and a sustained steep turn was selected as a candidate roll axis scenario.

III. Evolution of the Training Scenarios

The Boeing 747-400 Simulator facility at the NASA Ames Research Center's Crew-Vehicle Systems Research Facility (CVSRF) that is part of the SimLabs network served as the scenario development simulator for this program. The pitch and roll axis training scenarios were evolved over two weeks in this facility. The first week was conducted in November 2014 and the second week was conducted in February 2015.

A. Selected Flight Simulator Description

The Boeing 747-400 simulator is configured to United Airlines Tail #RT612 and is representative of a FAA certified Level D simulator and Level II International Qualification Standards as established by the International Civil Aviation Organization (ICAO). The purpose of this simulator is to support human factors research and airspace operations research, and as such, users have "the ability to modify the flight displays and other flight crew interfaces, enhanced control over external effects, and the capability for powerful but flexible data collection and performance measurement."[9]

An external view of the simulator cab in motion is shown in Figure 1a. An interior view of the simulator is shown in Figure 1b, which includes a cockpit flight deck, observer seats, an experimenter operator control station, and an engineering terminal. Key features of the simulator include a fully programmable visual system and integrated display system, a digital control loading and motion system, a weather radar system simulation, a traffic alert and collision avoidance system, advanced aircraft avionics, and a digital sound/aural cues system.

The visual system displays out the window views in day, night, dawn, or dusk with a field-of-view range of 36° vertical and 88° horizontal. Visual modeling of terrain, customized and generic airport scenes, weather fronts, thunderstorms, rain, lightning, hail, snow, and fog is available. Visibility, runway, ambient lighting, and ground and air traffic can also be controlled and customized.

a) Simulator cab b) Simulator cockpit

Figure 1: NASA Ames SimLabs Boeing 747-400 simulator.

The advanced digital control loading and six degree-of-freedom motion system[9] consists of a CAE 600 series motion hydraulic unit comprised of two motor pump units feeding into the six servoactuator assemblies and control loading actuators. The ranges of motion for this platform are listed in Table 2.

The host computer that drives the simulator interfaces with it through the digital control electronics. Control surface models are computed at a rate greater than 500 Hz, and control loading and motion servo loops are computed at an iteration rate of greater than 2 kHz. The physical sensations that can be induced by the motion system include the onset of an acceleration followed by low-level acceleration washout, sustained longitudinal and lateral acceleration cues created by exploiting earth's gravity vector, pitch and roll tilts, flap and gear buffets, stall buffets, high speed buffets, spoiler buffets, thrust reversers, engine vibrations, ground reaction forces, and weather effects such as turbulence thunderstorms, and windshears.

Table 2: CAE 600 Series Motion System Capabilities

Motion	Value
Stroke Length	54 in
Max Load	22000 lb
Vertical Acceleration	±1 g
Lateral Acceleration	±0.7 g
Longitudinal Acceleration	±0.7 g
Pitch Axis Excursion	-37.5 deg to +32.5 deg
Roll Axis Excursion	±32 deg
Yaw Axis Excursion	±37.5 deg
Pitch Rate	±30 deg/s
Roll Rate	±32 deg/s
Yaw Rate	±32 deg/s
Angular Acceleration (All)	±250 deg/s^2

B. The Missed Approach/Go-Around

1. Overview

Scenario development for the pitch axis was a relatively straightforward affair in which the desired somatogravic illusion was a false sensation of pitch that can accompany longitudinal acceleration changes. Development began with testing variations of the tilt gain applied to the motion command path of the simulator. The baseline missed approach task was then assessed and refined. The task was designed to be representative of the training scenarios used by US airlines that fly twin aisle transports. Weather and visibility options were explored to create the out-the-window scene for the SD illusion scenario. Finally, the full task was then examined to tune the motion and out-the-window scene to illicit the desired response and feel of the simulated SD illusion.

2. Baseline Task Definition

Initial runs were focused on the missed approach/go around task definition and out-the-window visibility settings, items that were addressed with the motion system off. The checkout pilot verified that, for the most part, the candidate task from the test plan was well-defined. There was a question concerning the requirement to maintain a 2,000 fpm climb rate throughout the climb, but upon further checking by the Ames pilot, including discussions with a subject matter expert commercial pilot, it was determined that the requirement to hold climb rate only applies to the first 800 feet. For most of the simulator runs, final approach flaps were set to 30°, except for one run, which featured a 25° final flap setting. The baseline out-of-the-window scene was a nighttime approach into SFO with no clouds and 200 nautical mile visibility.

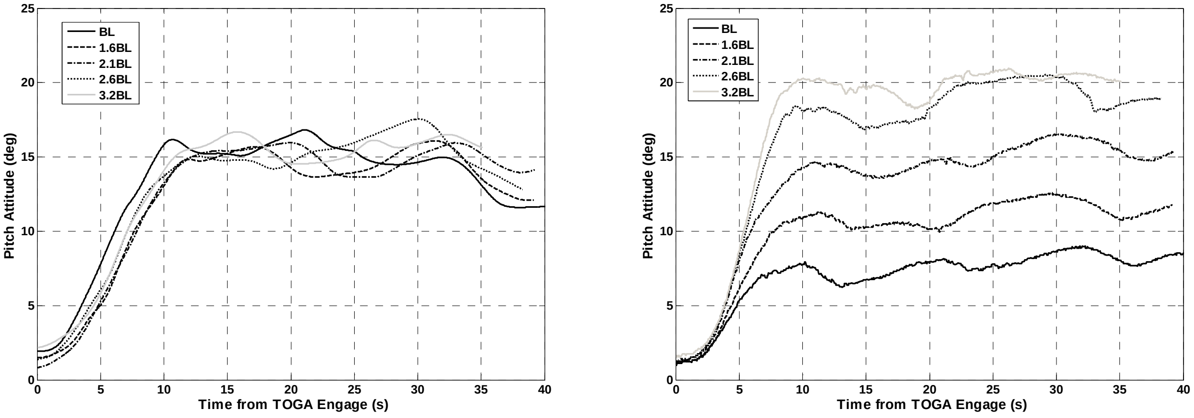
Over the two evaluation weeks, subtle changes were made to the baseline scenario. These changes include use of the 25° final approach flap setting and a lower landing weight. The lower landing weight allowed for greater motion in the go-around. A complete description of the final scenario is provided in the Appendix to this paper.

3. Visuals for the SD Scenario

As part of the scenario development, the team also took the opportunity to experiment with the visual display options of the simulator, which were used as a tool to degrade the out-of-the-window visual cues in a manner representative of conditions where SD illusions can occur. Most of the SD related accidents discussed earlier in this paper occurred at night with no discernible horizon available to the pilots. Weather options available in the B747-400 simulator include clouds, visibility, and fog. It was decided that clouds would be the primary weather condition with the secondary being visibility as it is often reduced below a solid cloud layer. Following a number of runs that involved various visibility conditions, the final scenario features a 1.5 nautical mile visibility with a cloud layer between 400 and 1,000 feet.

4. Motion System

To assess the impact of tilt gain variations, a series of missed approach runs were undertaken as the gain was increased beginning with its baseline (BL) value. Figure 2 shows the pitch attitude of the aircraft model and the pitch attitude of the motion system as the tilt gain increased. The runs were aligned by the time of the TOGA switch engage, so that comparisons in the resulting responses could be easily made. The Ames pilot supporting the development of this task was asked to not respond to the altered motion cues and fly the task as close to nominal as possible. There are minor differences (not shown here) in the first 150 seconds before the TOGA call and injection of the altered tilt gain that can be attributed to normal variances of flying any given task.



a) Aircraft model b) Motion platform

Figure 2: Motion system pitch axis tilt gain survey.

After the TOGA call, when the aircraft transitions to the climb, the aircraft model input and response for each run is very similar. The differences appear as the simulator platform responds to the altered tilt gains. The baseline tilt gain yields a peak motion platform pitch attitude of approximately 7.5 degrees, half of the value generated by the model. These baseline gains were "tuned" to provide the best possible pitch response for a full range of piloting tasks. It is therefore important to note that for this more aggressive task, the baseline gain only produces half of the pitch attitude motion that would be experienced in the actual airplane. The tilt gain of 2.1 times the baseline yields a pitch attitude that effectively replicates that of the model. Given the aircraft configuration used for these runs (i.e., aircraft weight of 540,000 lbs with CG at 22% MAC), it was not until the tilt gain values exceeded 2.1 times the baseline that the perceived pitch attitude exceed the model response. Finally, the tilt gain of 3.2 times the baseline caused the motion platform to ride near or on the motion system soft stops, while the tilt gain of 2.6 times the baseline merely approached the stops.

With the tilt gain sensitivity well understood, the next step in the missed approach scenario development consisted of final tuning of the tilt gain and the trigger altitude for ramp out of the gain change. With the tilt gain set to 2.67 times the baseline, a ramp out duration of either 30 or 15 seconds with a ramp out trigger at either 1,500 feet or 1,200 feet were explored. The 15 second ramp out was found to be too aggressive, and there was some unnerving excess movement with the ramp out trigger at 1,500 feet likely due to some coupling with the flap setting change that is usually called at approximately the same altitude. A gain of 3.2 times the baseline was also tested, but this setting was again found to be too aggressive.

It was also noted by the team in the cab that there were a number of accelerations throughout the TOGA maneuver as the aircraft climbed from 200 feet to level off at 3,000 feet that were associated primarily with the flap retraction schedule, and if the tilt gain was ramped out at 1,200 feet, some of the pitch up illusion would be missed. Thus, a number of runs were conducted with the tilt gain triggered with the TOGA and held throughout the climb out, which was found to work well.

One additional change was to decrease the aircraft weight from 540,000 pounds to a lighter landing weight of 450,000 pounds to see if this would impact the motion perceived in the cab. A new set of runs was then undertaken to tune the tilt gain for this lighter landing weight condition. Ultimately, a final missed approach/go around scenario was defined that featured the reduced landing weight configuration, a tilt gain of 2.44 times the baseline that was triggered with the TOGA, and, following the first guest pilot evaluation discussed below, a reduction in the pitch filter damping.

C. The Steep Turn

1. Overview

After the initial transient associated with a bank angle capture, the vestibular system of the inner ear adjusts such that the human perceives the gravity vector with the angle of bank when in a sustained, steady turn. Upon the return to wings level flight, the human can perceive a continuation of the rolling sensation and may counter this sensation by turning the airplane back into the direction of the turn that was just exited. As expected, scenario development for this situation proved to be a challenge as there is no simple motion system change that can be used to achieve the desired results for the somatogravic/somatogyral illusion of interest (i.e., the false sensation of attitude). Development began with an assessment of a baseline roll axis maneuver, a constant altitude turn. Weather and visibility options were then explored to create the out the window scene often associated with SD incidents. Since manipulating the tilt gain proved so effective in pitch, it was tested in the roll axis as well. This did not create the desired effect, so other methods to manipulate motion and create the desired SD illusion were examined.

2. Baseline Task Definition and Visuals for the SD Scenario

All of the runs during development of this scenario were flown at 10,000 feet altitude and an initial speed of 280 KIAS (autothrottle off) with 200 nautical mile nighttime visibility when not in clouds. Testing began with a baseline roll task that consisted of a constant altitude turn with and without a solid cloud bank introduced to reduce visibility. The initial scenario featured a nominal 30° banked turn, but pilot workload was found to be too low. Therefore, the task was redefined as a steep turn, i.e., a 45° banked turn, which proved more demanding for the pilot as constant back pressure on the column was required to maintain altitude. A solid cloud layer was selected to achieve the visibility effect, i.e., the lack of a discernible horizon that was desired for demonstrating the roll axis SD illusion.

To more thoroughly develop the basic steep turn, the aggressiveness of the pilot as he rolled out of the turn back to straight and level flight was investigated. For the scenario development, 180° and 360° turns were used. During initial testing of the task to set clouds and visibility, the pilot began rolling out of the turn with about approximately 15° of heading change remaining, which resulted in a smooth, slow, gentle transition out of the turn at the designated heading. Qualitatively, the pilot indicated that an attempted rollout with 5° of heading change remaining was near peak aggressiveness. After numerous runs, a rollout back to wings level with approximately 10° of heading change remaining was found to consistently achieve the desired level of aggressiveness.

A complete description of the final scenario is provided in the Appendix to this paper. For the formal evaluations, the airspeed for the turn was reduced to 250 KIAS to adhere to standard transport practice that requires maximum airspeeds to remain at or below 250 KIAS at altitudes of 10,000 feet or lower.

3. Motion System

With task aggressiveness and visuals set, the next step in the development of the steep turn SD task was to explore candidate methods of generating additional movement in the simulator platform that could be used to demonstrate the desired SD illusion. Several methods for inserting a ramped roll attitude command were investigated. To generate the desired roll effect, a step roll rate command was added to the angular motion. The step command was found to be too abrupt, so a ramped roll rate command was explored next. The command was ramped to full amplitude over two seconds and then held. Gain variations on the roll rate command were explored through wings level flight. With the pilot holding attitude and zero angle of bank, the roll rate command was inserted and assessed by the team in the cab until several candidate commands were identified.

With an established roll command, triggering the ramp then became the critical issue. To provide a sustained rolling sensation, the motion system needed to continue rolling beyond wings level at a rate that approximated the pilot's correction from the steep turn. This requirement tied the trigger to the angle of bank. That is, the trigger needed to initiate as the bank angle returned to wings level from the 45° steep turn. After a number of trials, a trigger was established with the angle of bank of 10° as the pilot returned the aircraft to wings level flight. To insure repeatability of the scenario, the steep turns were always performed as right turns.

4. Adding a "Startle" Effect

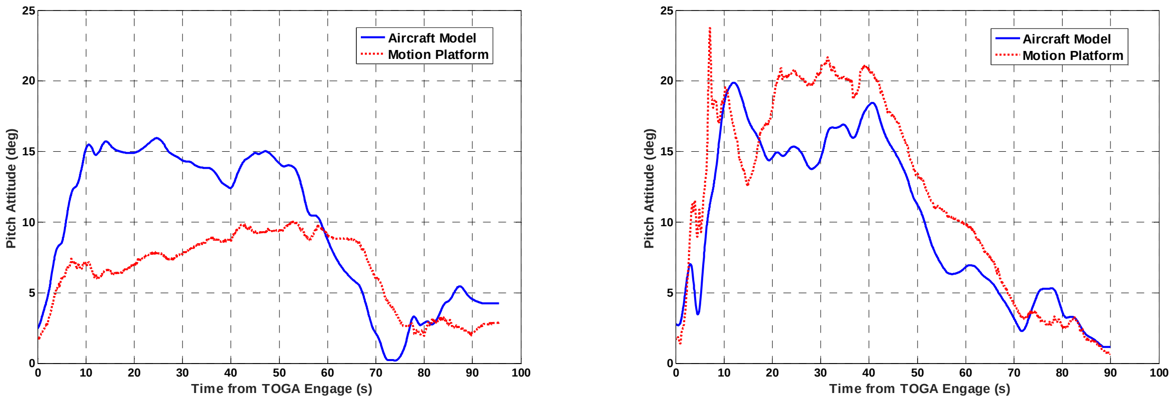
A number of the roll axis SD accidents from the database described earlier in this paper involved a failure, confusing cockpit warnings, display failures, etc. These incidents can distract the pilots and exasperate the SD effects. In a simulator setting, a "startle" effect is often needed to create a similar level of distraction. In the roll scenario developed herein, this startle effect was created by "failing" the pilot flying's primary flight display just as the aircraft is returning to wings level. This forces the pilot to assess the problem and scan to another display as the rolling sensation is ramped into the motion system. With the failed display, the disorientation sensations are enhanced as the pilot flying must move his or her head to scan right as the added motion is rolling the cab to the left.

IV. Guest Pilot Simulation Results

Toward the end of the second scenario development week in February 2015, two guest pilots were invited to "fly" the pitch and roll scenarios herein referred to as Pilot 1 and Pilot 2. Pilot 1 was a commercial transport pilot for a major US airline, while Pilot 2 was a long time NASA Ames test pilot. Like the formal evaluations to follow, the pilots were told that they would be reviewing two degraded visual environment scenarios. It was not until the test scenarios were complete that spatial disorientation was discussed.

A. The Missed Approach/Go-Around

When Pilot 1 flew the missed approach/go around with the enhanced motion, the enhance motion was noted in his debrief comments, but it was not as effective as desired. It was at this point that the reduced damping described above was added to the scenario. Figure 3 shows pitch attitude comparison plots for the Pilot 2 runs that featured the increased motion platform tilt gain and reduced damping for the SD case. For these plots the zero time signal coincides with the TOGA button select by the pilot. In Figure 3a, the pitch attitude of the aircraft model is compared with that of the motion platform for the baseline case. As was noted earlier in the paper for the baseline case, the motion platform only produces approximately half of the pitch attitude on the TOGA onset as achieved by the aircraft model and these differences continue throughout most of the climb. In contrast, the motion platform produces motion that not only matches, but also exceeds the aircraft model pitch attitude in the SD scenario as shown in Figure 3b. As will be seen, these differences produced a strong reaction from the pilot.

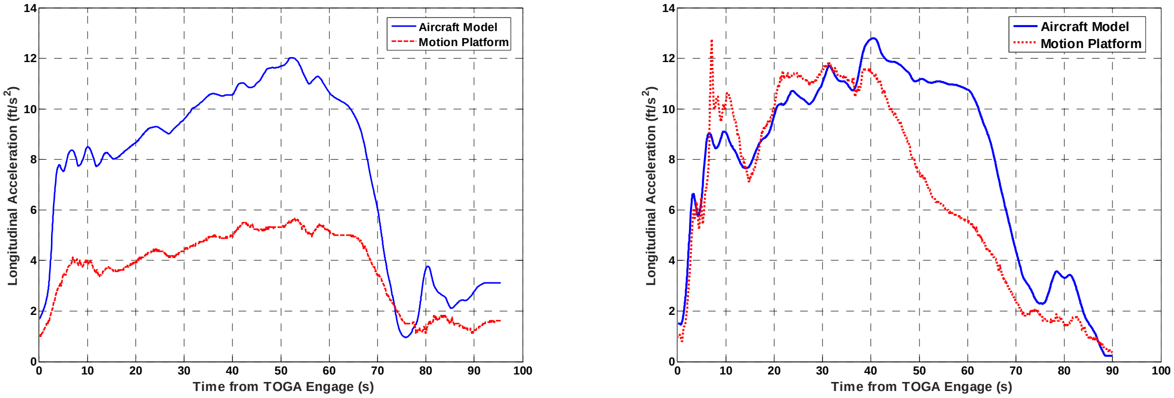


a) Baseline case with nominal tilt gain and damping ratio

b) SD demonstration case with increased tilt gain and reduced damping ratio

Figure 3: Pitch attitude comparison for missed approach/go around scenario.

Figure 4 compares the longitudinal acceleration responses for the Pilot 2 baseline and SD cases. Similar to the pitch attitude plot discussed above, the motion platform produces significantly less longitudinal acceleration than indicated by the aircraft model for the Figure 4a baseline case. For the SD case, the platform matches the acceleration of the model for nearly the first forty seconds post TOGA. There are also significant transients in the platform motion that exceed that of the model. As the maneuver continues, the motion platform acceleration washes out much quicker than that of the model, but by this time the pitch up sensation has been effectively demonstration.

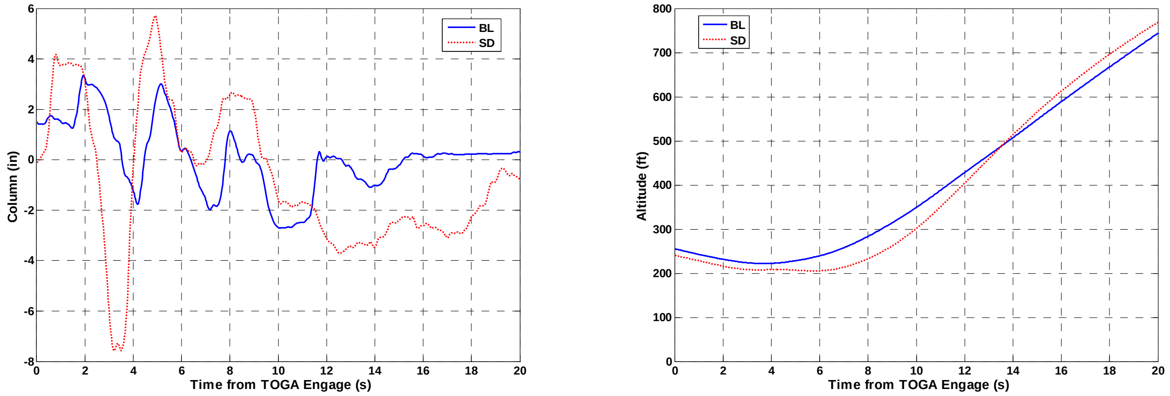


a) Baseline case with nominal tilt gain and damping ratio

b) SD demonstration case with increased tilt gain and reduced damping ratio

Figure 4: Longitudinal acceleration comparison for missed approach/go around scenario.

The comparisons of the pitch attitude and longitudinal acceleration responses illustrate the effectiveness of the SD scenario creation, but how did the pilot react to these enhanced sensations? Figure 5 shows the pilot column inputs and aircraft altitude response for the baseline and SD cases. In response to the added pitch motion in the SD case, the pilot has a significant push on the column between 2 and 4 seconds that creates a significant delay in the climb out as seen in the altitude response. Following this initial push, several large column inputs follow that indicate a level of aggressiveness that significantly exceeds that seen in the baseline case. For the baseline pitch scenarios, Pilot 2 displayed a light touch on the column, mostly making inputs with his left hand. There was a startle effect to the enhanced motion in the SD scenario that resulted in a two hand on the wheel technique that may have contributed to the more aggressive inputs.



a) Control column input

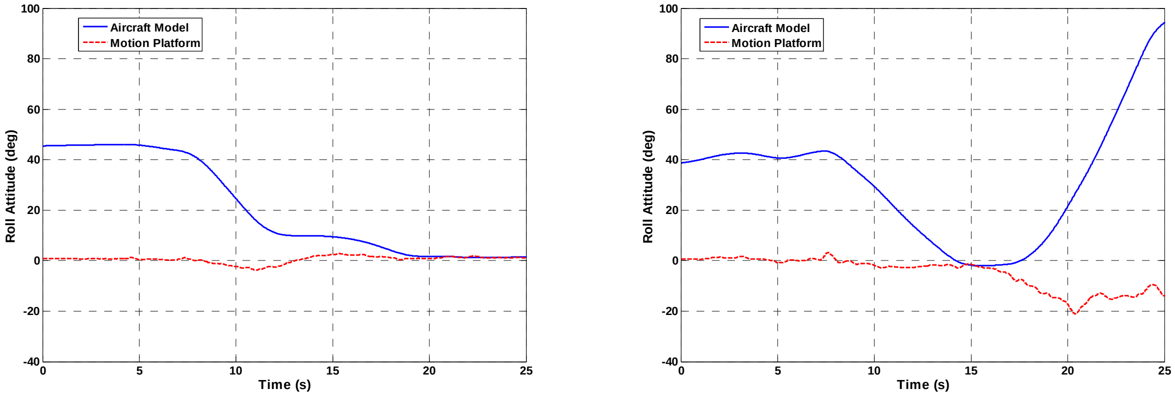
b) Altitude

Figure 5: Pilot input and altitude response for missed approach/go around scenario.

B. The Steep Turn

In this section, a baseline steep turn run is compared with the SD scenario for Pilot 1. When Pilot 2 flew the roll scenario, he stopped flying when his primary flight display failed believing that there was a simulator issue. This was not surprising given his years of piloted simulation experience. The team used this result as a lesson learned to improve the briefing procedures going into the formal evaluations.

Figure 6 compares the roll attitude response of the aircraft model with that of the motion platform for the baseline and SD runs. The time axis has been zeroed to a time in the steady turn. Note that for both runs the roll motion of the platform washes out in the steady turn. The roll attitude for aircraft model for both cases illustrates the steep turn and rollout back to wings level. Note that for the baseline case, the pilot slows his rollout and holds 10° of bank for several seconds before recovering to wings level. The rollout back to wings level was much more consistent in the SD case. This was also an important lesson learned for the team leading to formal test procedures that included allowances for as many baseline runs as was needed for the evaluation pilots to achieve consistent rollouts at the desired level of aggressiveness. The significant result here, however, is the very large roll seen in the aircraft response back into the right turn in response to the sensed rolling left motion of the platform between 15 and 20 seconds.

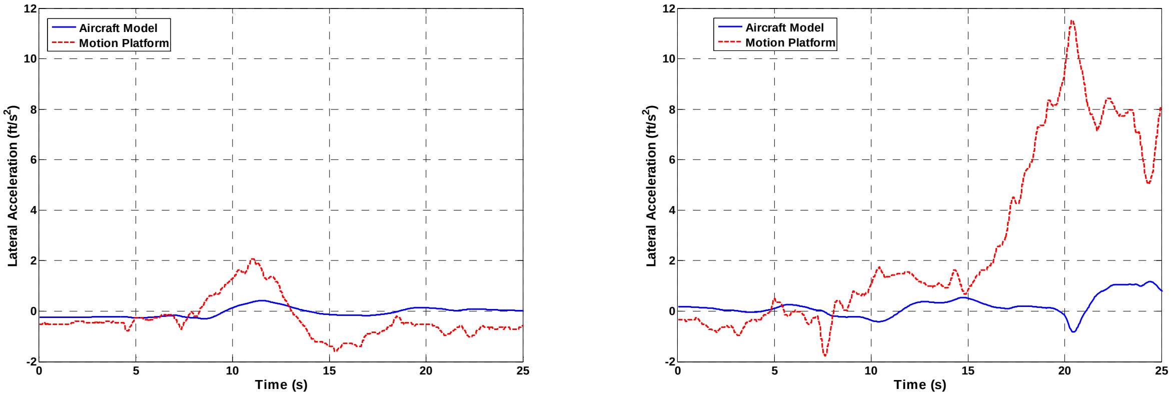


a) Baseline case

b) SD demonstration case

Figure 6: Roll attitude comparison for steep turn scenario.

Figure 7 compares the lateral acceleration response of the aircraft model and motion platform for the baseline and SD cases. Note that the lateral acceleration of the motion platform exceeds that of the aircraft model for the baseline case by a significant amount during the correction back to wings level. For the SD case, there is a large lateral acceleration associated with the injected motion system command that is, of course, not reflected in the aircraft model response.

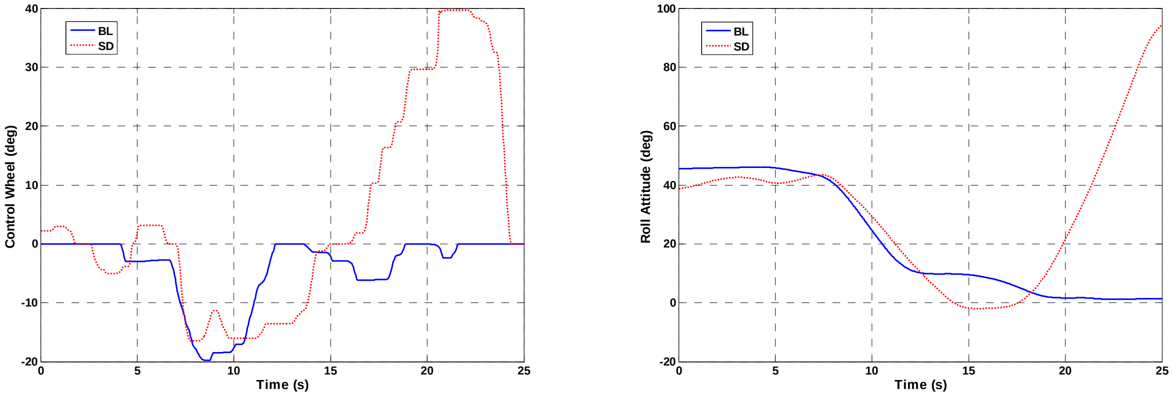


a) Baseline case

b) SD demonstration case

Figure 7: Lateral acceleration comparison for steep turn scenario.

Finally, Figure 8 provides a comparison of the pilot's control wheel response and the resulting bank angle for the baseline and SD cases. The control wheel input shows the halting of the correction back to wings level at approximately 12 seconds before continuing the correction back to zero bank angle. For the SD case, the obvious difference is the large control wheel input in response to the sensed roll motion from the platform. As seen in the bank angle comparison, this results in a roll from the established wings level attitude to over 80° back into the right hand turn. In the post simulation debrief, the pilot's response to the SD illusion disclosure included the exclamations, "That was great! That was perfect!" He also commented about scanning the other instruments after the display failure, but he did not believe the bank angle indications in the presence of the strong motion cues.



a) Control wheel input

b) Bank Angle

Figure 8: Pilot input and bank angle response for steep turn scenario.

V. Conclusions

Over the course of two weeks in the NASA Ames SimLabs Boeing 747-400 simulator, the development of two spatial disorientation (SD) simulation scenarios was completed and the resulting scenarios were successfully demonstrated with two guest pilots. The final SD scenarios and lessons learned from the guest pilot evaluations are summarized as follows.

- Missed Approach/Go Around Pitch Axis Scenario:
    - For best results, a lower landing weight configuration was ultimately selected;
    - The final Degraded Visual Environment consisted of 1.5 nautical mile visibility with a cloud layer from 400 to 1,000 feet;
    - A final pitch tilt cue gain of 2.44 times the baseline gain was selected, which yielded a response in pitch attitude on the TOGA that included an added “pitch up” beyond that of the aircraft model;
    - The motion platform pitch filter damping ratio was reduced from an over damped value to a slightly underdamped value, which yielded a slightly more oscillatory response, as expected, and an improved “pitch up” sensation on the TOGA; and
    - The trigger for the tilt gain change was the selection of the TOGA, while the damping ratio change was in place throughout the SD scenario run.
- Steep Turn:
    - The final Degraded Visual Environment consisted of full immersion in the clouds;
    - A roll rate command was injected into the motion system response that ramped in over two seconds and then held, thereby generating an increasing left bank motion system response;
    - The roll rate command was triggered during the correction back to wings level as the bank angle passed through 10 degrees; and
    - To enhance the SD scenario, a PFD display failure was introduced at the same triggering point, which was designed forced the pilot flying from the left seat to change his or her scan to other available attitude indicators.
- Lessons learned from the guest pilot demonstrations:
    - While the pitch scenario produced the desired results with the first guest pilot, the impact was considered too subtle, so the reduced pitch filter damping ratio was added;
    - With the second guest pilot, the improved pitch scenario produced a much more dramatic result with a significant column push following the TOGA that resulted in a delayed climb out;

- The roll scenario that included the introduction of the failed PFD worked beyond expectations with the first guest pilot resulting in a significant roll command back in the direction of the steep turn; and
- The second guest pilot treated the PFD failure as a simulator issue and simply stopped flying, thus indicated that the pilots must be briefed to continue flying through failures until instructed to terminate the task.

The results described in this paper provided the confidence necessary to proceed to the formal evaluations of the pitch and roll scenarios with a pool of commercial pilot test subjects. These evaluations were conducted with 14 pilots over two weeks in the simulator, the results of which will be the subject of a later paper.

Acknowledgements

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References

1. Previc, F. H., and W. R. Ercoline, "Spatial Disorientation in Aviation," *Progress in Aeronautics and Astronautics Series*, Volume 203, AIAA, Reston, VA, 2004.
2. Peters, R. A., *Dynamics of the Vestibular System and their Relation to Motion Perception, Spatial Disorientation, and Illusions*, NASA CR-1309, Feb. 1968.
3. Collins. H. L. and G. Harrison, "Spatial Disorientation Episodes among F-15-C Pilots during Operation Desert Storm," *Journal of Vestibular Research*, November/December, 1995, Vol. 5, No. 6, pp. 405-410.
4. Wynbrandt, J., "Spatial Disorientation: Confusion that Kills," *Safety Advisory: Physiology*, AOPA Air Safety Foundation , No. 1, 2004.
5. Antunano, M. J., "Spatial Disorientation," AM-400-03/1, Prepared by FAA Civil Aerospace Medical Institute Aerospace Medical Education Division, Oklahoma City, OK.
6. Heinle, T. E. and W. R. Ercoline, "Spatial Disorientation: Cause, Consequences, and Countermeasure for the USAF," in *Proceedings of the RTO Human Factors and Medicine Panel (HFM) Symposium*, La Coruna, Spain, 15-17 April 2002.
7. Jones, G. M., "Vestibulo-ocular Disorganization in the Aerodynamic Spin," *Aerospace Med.*, vol. 36, no. 10, Oct. 1965, pp. 976-983
8. Belcastro, C. M., R. L. Newman, D. A. Crider, L. Groff, J. V. foster, D. H. Klyde, and A. M. Houston, "Preliminary Analysis of Aircraft Loss of Control Accidents: Worst Case Precursor Combinations and Temporal Sequencing," AIAA 2014-0612 presented at the *Science and Technology Forum and Exposition 2014: AIAA Guidance, Navigation, and Control Conference*, National Harbor, Maryland, January 13-17, 2014.
9. Sullivan, B. T., and P. A. Soukup, "The NASA 747-400 Flight Simulator – A National resource for Aviation safety Research," AIAA Paper No. 96-3517 presented at the *Flight Simulation Technologies Conference*, San Diego, CA, 29-31 July 1996.

Appendix – Scenario Descriptions

Readers should note that the following scenarios were written as maneuver descriptions for the subject pilots. Thus, to preserve a "startle" effect, no mention of spatial disorientation is made. Instead, the inference is that the pilots will be evaluating maneuver performance under degraded visual environment conditions, IMC or worse.

A. Missed Approach/Go Around

Overview

Variations of the missed approach maneuver described below are used both in training and as standard procedure in the event of an actual missed approach event in operation. As originally derived from representative airline training procedures, the primary objective of this maneuver task is to train pilots to properly execute a missed approach/go around with four engines operating in a B747-400. During the simulation evaluation, the maneuver will be conducted in baseline nighttime VMC conditions and a degraded visual environment (DVE) condition featuring reduced visibility and low clouds.

Objectives

- Evaluate missed approach task performance under degraded visual conditions.
- Characterize pilot assessment of the DVE demonstration via comments and targeted debrief questionnaires.

Baseline Missed Approach

Environmental Conditions

- Night
- Clear
- 200 mi visibility

Pre-Task Setup

- Approach plates: clipped on yoke
- Gross Weight / CG: 450,000 lbs / 21% MAC
- Position/Altitude: (2,000 ft MSL) 8nm final at KSFO-ILS RWY28R
- Airspeed: 160 KIAS

Pre-Task Brief

- Max flap during approach: 25
- Approach speed (Vref + 5 @ 25Flaps): 138 KIAS
- Decision Height: 200 ft AGL
- Missed-Approach: Climb and maintain 3,000 ft MSL

Aircraft Configuration

- Flaps: 10
- Gear Lever: UP/OFF
- Speed Brake: ARMED
- Autopilot: OFF
- Flight Director: (APPR mode engaged) ON
- Auto-Throttle: SPD

Description

As is standard procedure with an approach and landing, the pilots should brief the approach plan assuming an uneventful instrument approach before engaging the simulation. *(Note: The Pilot Flying (PF) will be the subject pilot, while the Pilot Monitoring (PM) will be a pilot confederate aiding the testing process.)*

This task is driven by the standard procedure for a missed approach. When executing the missed approach, PF announces "going around, flaps 20," then pushes the TOGA switch while the PM selects flaps 20. PF announces "check thrust." PF and PM set and verify thrust by checking that the autothrottles advance throttles to go-around thrust. *(Note: Maximum thrust can be engaged by pushing the TOGA switch again and verifying that autothrottles advance to maximum go-around. For these evaluations, only a single TOGA switch selection is to be used.)* Throttles can also be manually advanced, but for these evaluations the TOGA switch should be engaged and then the throttles can be advanced manually as well. With TOGA the aircraft should maintain existing track and rotate at the higher of the existing airspeed or speed set in IAS/MACH indicator until reaching 2,000 fpm climb. Maintain 2,000 fpm climb at existing airspeed through 800 ft. Announce and confirm "positive rate." PF announces gear up, and PM raises landing gear. PF announces "check missed approach altitude," and PM sets and verifies missed approach altitude of 3,000 ft. PF or PM selects roll mode by engaging LNAV or HDG SEL at 400 ft. PF or PM selects pitch mode and speed by engaging VNAV or FLCH at 800 ft and selects desired speed. PF or PM retract flaps on schedule. PF levels off the aircraft at 3000 ft, and PM goes through the after takeoff checklist. (See Figure 9 for an example profile.)

Desired Performance

- ±1/2 dot deviation in ILS G/S and LOC during the approach (for reference see Figure 10).
- Maintain wings level, ±2.5° through the climb.
- ±2° heading deviation through the climb.
- ±50 ft of level off altitude at 3000 ft.

Adequate Performance

- ±1 dot deviation in ILS G/S and LOC during the approach (for reference see Figure 10).
- Maintain wings level, ±5° through the climb.
- ±5° heading deviation through the climb.
- ±100 ft of level off altitude at 3000 ft.

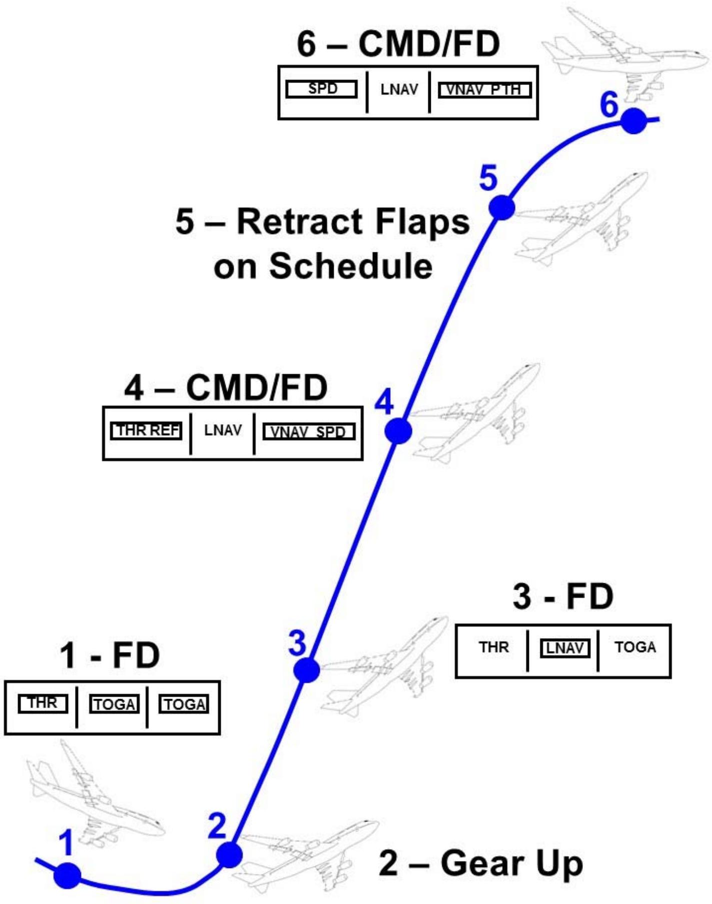
Missed Approach with DVE

Conditions

- Night
- Clouds 400-1,000 ft
- 1.5 nm visibility

Description

The missed approach with degraded visual environment task will be a night task with degraded visual environment for the out-the-window scene. The baseline case will be flown in nominal nighttime conditions with 200 mi visibility, whereby the runway lights, etc. are clearly visible. For the DVE case(s), clouds are added from 400-1000 ft with 1.5 nautical mile visibility out of the clouds, which creates a scene with no visible horizon for much of the approach forcing the pilot to rely on an instrument scan. Performance requirements are the same as defined above. Go around call may be given as the aircraft approaches the decision height.



6. Missed Approach Altitude
    - Level off
    - Set speed as required
    - Perform “After Takeoff” Checklist

5. Retract Flaps

4. Select VNAV or FLCH and desired speed at 800 feet

3. Select LNAV or HDG SEL at 400 feet RA

2. Climb Out
    - Positive Rate (based on barometric altimeter & VSI)
    - Gear up
    - Check missed approach altitude

1. Initiate Go Around
    - Push TOGA switch*
    - Set Flaps to 20
    - Verify throttles advance
    - Check thrust
    - Rotate to go-around attitude (~15° ANU)

* A second push of TOGA switch gives full go-around thrust and the THR REF annunciation

Figure 9: Missed approach/go-around profile.

Figure 10: NASA Ames B747-400 simulator primary flight display with ILS flight director.

B. Steep Turn

Variations of standard turn maneuvers and climbing/descending turn maneuvers are used both in training, as standard course correction maneuvers, and in more complex maneuvers such as the missed approach maneuver described above. The primary objective of this maneuver task is to compare task performance in nighttime VMC with DVE conditions, while performing a steep, constant altitude turn.

Objectives

- Evaluate step turn task performance under degraded visual conditions.
- Characterize pilot assessment of the DVE demonstration via comments and targeted debrief questionnaires.

Baseline Steep Turn

Environmental Conditions

- Night
- Clear
- 200 mi visibility

Pre-Task Setup

- Gross Weight / CG: 540,000 lbs / 22% MAC
- Altitude:10,000 ft MSL
- Airspeed: 250 KIAS

Aircraft Configuration

- Flaps: UP
- Gear Lever: UP/OFF
- Speed Brake: STOWED
- Autopilot: OFF
- Flight Director: N/A
- Auto-Throttle: OFF

Pre-Task Brief

- Altitude: Maintain level flight
- Bank angle to maintain turn: 45°AOB
- Heading change: Right 360°
- Initiate roll-out 10° prior to target heading capture

Description

The pilots will discuss task execution prior to engaging the simulation. *(Note: The Pilot Flying (PF) will be the subject pilot, while the Pilot Monitoring (PM) will be a pilot confederate aiding the testing process.)*

The steep turn standard maneuver consists of a 360 deg turn to the entry point heading with the maximum bank angle of 45 deg sustained throughout the steady turn as illustrated in Figure 11. The entry altitude and airspeed should be maintained throughout the maneuver. The initial conditions for the maneuver are straight and level flight at 250 KIAS, pitch at 3.0 ANU, and power at 1.00 EPR and 5,000 lbs FF per engine. During the turn, pitch attitude should be increased from 3 to 4 deg as necessary to maintain altitude as the aircraft rolls from 25 deg to 45 deg bank attitude.

Desired Performance

- 45° ± 2° bank angle throughout the turn and 0° ± 2° upon wings level capture.
- ±0.5° pitch attitude variation throughout the steady 45° bank.
- ±5 kts deviation in airspeed.
- ±2° of target heading upon rollout.
- ±50 ft altitude throughout the turn.

Adequate Performance

- 45° ± 5° bank angle throughout the turn and 0° ± 5° upon wings level capture.
- ±1° pitch attitude throughout the 45° bank.
- ±10 kts deviation in airspeed.
- ±5° of target heading upon rollout.
- ±100 ft altitude throughout the turn.

Steep Turn with DVE

Environmental Conditions

- Night
- Solid cloud layer

Description

The basic task will be a steep turn to 45 deg with a 360 deg heading change. The aircraft will begin in straight and level flight at 250 KIAS and 10,000 ft. Initiate a steep turn maneuver with the requirement that rollout not commence until within 10° of the target heading. For the DVE case(s), the aircraft and maneuver are completely ensconced in clouds, which creates an out-of-the-window scene with no visible horizon thereby forcing the pilot to rely on an instrument scan. Performance requirements are the same for both tasks.

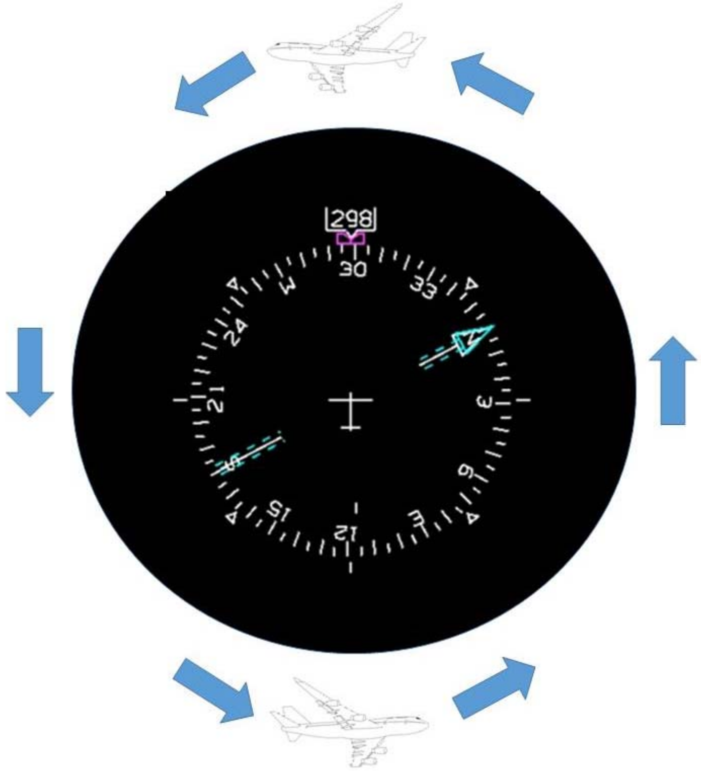


Figure 11: Constant altitude, 360 degree steep turn.