Technical Challenges of Upset Recovery Training: Simulating the Element of Surprise

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Abstract

This invited paper is written in the context of a concerted effort by the aviation industry and regulators to reduce the occurrence of Loss of Control (LOC) accidents. LOC accidents have taken the lead among fatal airplane accidents, recently outpacing Controlled Flight into Terrain. The community is pursuing different avenues that all have potential for leading towards that goal. These include technical solutions such as preventing or automatically correcting uncontrollable airplane states or providing pilots with flight deck warnings and advisories; managerial solutions such as optimizing procedures and checklists to prevent narrowing of attention and reversal to primal responses; or instructional solutions enhancing pilots' knowledge, skills, and aptitudes via academics, ground-based procedure and flight training, and in-flight demonstrations and practice. This paper addresses ground-based training in a Flight Simulation Training Device (FSTD). In particular, it examines whether an FSTD is an adequate tool to first *simulate* a situation where flight crews may be too distracted to become aware of the danger of losing control of the airplane and to subsequently *stimulate* the confusion and panic that would be triggered during an actual LOC, where the crew's and passengers' lives are at stake. It first discusses the psychological obstacles interfering with anticipation, recognition, and appropriate responses to LOC. It then lays out the training goals that need to be reached in successful upset recovery training, and briefly discusses the training strategies that might be applicable to different types of training goals. Finally, it examines the different methods that may be applied to overcome a potential drawback, but also a major advantage of training appropriate responses to LOC in an FSTD: that it is safe.

I. Background

This paper is written in the context of a concerted effort by the aviation industry and regulators to reduce the occurrence of Loss of Control (LOC) accidents. LOC accidents recently have taken the lead among fatal airplane accidents, outpacing even Controlled Flight into Terrain.[1] The community is pursuing different avenues that all have potential for leading towards that goal. These include technical solutions such as preventing or automatically correcting uncontrollable airplane states or providing pilots with flight deck warnings and advisories; managerial solutions such as optimizing procedures and checklists to prevent narrowing of attention and reversal to primal responses; or instructional solutions enhancing pilots' knowledge, skills, and aptitudes via academics, ground-based procedure and flight training, and in-flight demonstrations and practice. This paper addresses ground-based training in a Flight Simulation Training Device (FSTD). In particular, it examines whether an FSTD is an adequate tool to first *simulate* a situation where flight crews may be too distracted to become aware of the danger of losing control of the airplane and to subsequently *stimulate* the confusion and panic that would be triggered during an actual LOC, where the crew's and passengers' lives are at stake. It first discusses the psychological obstacles interfering with anticipation, recognition, and appropriate responses to LOC. It then lays out the training goals that need to be reached in successful upset recovery training, including a brief discussion of the training strategies applicable to different types of training goals. Finally, it will propose several methods of enhancing surprise stimulation and thus upset-recovery training in an FSTD. It will favor general principles of setting a situation rather than working out specific scenarios. For the latter, several efforts are underway in the framework of the US Federal Aviation Administration FAA-Industry Stall/Stick Pusher Working Group and the International Committee on Aviation Training in Extended Envelopes (ICATEE), in particular the Training Subcommittee and the Research and Technology Subcommittee's Surprise Stimulation Team led by the author (see Ref 2 presented at this conference and Acknowledgments).

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II. Psychological Obstacles to Anticipation, Recognition and Recovery from LOC

Accident reviews show several psychological factors preventing pilots from anticipating, recognizing, and responding appropriately to LOC situations, namely stress and distraction, surprise, startle, and spatial disorientation. Stress and distraction in the cockpit arises from having to manage too many contemporaneous tasks, such as dealing with air-traffic-control, company, and cabin-crew communications and interruptions, checklists, and automation, in addition to the primary tasks of aviating and navigating. Stress can also stem from external factors such as weather, traffic, and delays edging a crew towards the limits of their allowable duty times (so-called "press-on-itis," see Ref 3). Distraction can also occur when workload is too low, e.g., when automated systems relieve pilots from actively flying the airplane, leaving them free to become absorbed in activities unrelated to flying the airplane (like when two pilots overshot their destination airport by over 100 miles ignoring all ATC queries while immersed in conversation).[4] Physiologically, stress triggers sweating, raises heart and respiratory rates, increases blood pressure and stress-hormone secretion, changes galvanic skin pressure, and causes narrowing of peripheral vision by dilating the pupils. Cognitively, stress may lead to the inability to absorb, comprehend, remember, and analyze the full spectrum of relevant information; to loss of situation awareness through narrowing of attention; and to forgetting of the applicable standard operating procedures and aerodynamic theory. Behaviorally, it may lead to delayed, inappropriate, or lack of response (so called "freezing," which often may be better than an inappropriate response especially in airplanes with automation intended to prevent LOC, see, e.g., the National Transportation Safety Board's report[5] on the Colgan accident in 2009). [5]

Surprise is aroused by the presence of an unexpected but also by the absence of an expected event (e.g., when a crew ready for takeoff sees an airplane on final and expects to be delayed, but then is cleared for takeoff anyway).[6] Some examples for surprises in aviation are events that deprive pilots of information, such as flight instruments and sensor malfunctions, or events that directly disturb the flight path, such as weather, wake vortex, power and or control system failures. Precursor cues are often ignored because of inadequate crew resource management, insufficient arousal (Chas Harral's "white" state, as described in Ref 7), distraction, or because of an inadequate anticipatory model of potential emergency situations.[8] The strength of the surprise depends on the severity, frequency, expectedness, and degree of prior experience with the event.[9] The physiological and cognitive responses to surprise are similar to the ones to stress, but proportionally stronger. The ultimate surprise event is startle, which results in instantaneous and uncontrollable motor responses,. Dependent on pilots' anticipation, the same events can merely surprise or they may startle; however, unexpected events involving intense stimulation of one or more senses usually do startle (e.g., compressor stalls, tire bursts, bird strikes, intense wakes).

An especially insidious type of surprise or even startle event arises from unrecognized spatial disorientation. Vestibular illusions enhanced by kinesthetic sensations occur when pilots perceive an erroneous gravity vector from sustained acceleration leading them to mistaken perceptions of their position and motion relative to earth. Such illusions build up slowly from the combined effects of gravity and sustained accelerations bending the hair cells in the otolith organs so that they signal to the brain that the head is tilted. If no visual information is available out-the-window and if pilots trust their "feel" rather than the instruments, they may find themselves in a situation where they are confused on which way is up. For obvious reasons, inducing vestibular spatial disorientation may go beyond the capabilities of a ground-based FSTD, even if it is a Full Flight Simulator with motion qualified for air-carrier-pilot zero-flight-time training. However, even a fixed-based FSTD with only visual cues may be able to simulate scenarios where pilots fly themselves into a situation that produces unrecognized visual spatial disorientation. Several such scenarios intended to be presented in a non-motion simulator are described in Ref. 10, such as an inadvertent shift from Visual Meteorological Conditions to Instrument Meteorological Conditions coupled with erroneous ATC instructions.

Given the psychological and perceptual or even psychophysical obstacles to timely recognition and appropriate response to stalls, unusual attitudes, and disorientation, the next section considers the overall training goals for attempting to stimulate stress, surprise, startle, and confusion in a ground-based device.

III. FSTD Training Goals and Strategies

The first and foremost training goal in LOC accident prevention is early recognition of a developing LOC situation. This may involve the detection of mechanical failures (e.g., engine failures), awareness of atmospheric phenomena (icing, turbulence, or wakes), or recognition of the potential for spatial disorientation. Early recognition is supported by an effective instrument scan, heads-up out-the-window observations, listening for abnormal engine and warning sounds, awareness of airplane handling qualities, or direct and indirect (party line) communications from the flight or cabin crew, company, or air traffic control. The most important factors for successful recognition are crew and cockpit resource and task management skills that support effective acquisition and integration of the relevant information available from vision, audition, touch, and smell. As Chas Harral might put it, a cockpit seat should not ever be confused with a recliner in front of the fireplace (the "white" zone), but pilots should be in "a relaxed state of self-awareness at which nothing goes by you" (the "yellow" zone as reported in Ref. 7). There is a reason why professional pilots have duty-time restrictions.[11] General-aviation pilots need to use their own judgment, which, in a NextGen environment with mixed traffic and increasing automation in and out of the cockpit, may no longer be good enough.

The key word in information acquisition, of course, is "relevant." The development of the ability to distinguish relevant from irrelevant individual or combinations of bits of information must start long before a crew enters the FSTD, during basic flight training and study of aerodynamics, airplane systems, and procedures in ground school. During these phases, pilots should develop an anticipatory model of what events or combination of events may develop into an uncontrollable situation. Ideally, a variety of preprogrammed scenarios would be available to instructors in the simulator, which, combined with the variability generated by individual crew responses, would serve the purpose of helping crews reinforce and preserve the flexibility of their models. This would occur by training novel situations requiring the recognition and integration of perceptual cues that were at the fringes or even outside of crew's earlier models of potential risks (as will be suggested by ICATEE, see Ref. 2).

Once a crew has failed to recognize the relevant cues of a developing situation and is surprised by a stall, overbank, upset, spin, or spiral dive, it may have little time to assess the situation and make an informed decision on the most appropriate course of action. In fact, often pilots appear to yield to an instinctual desire to increase their distance to the ground by pulling back on the control column or stick, as the Captain of the Colgan flight appears to have done.[5,12] The key goal is thus to train pilots to refrain from such primal responses.

After that, it gets more complicated, and the question is how pilots (and their passengers) are best served, by drilling them in an "All-Attitude Upset Recovery Strategy"[13] such as "push-power-rudder-roll-climb" or by teaching them to discriminate situations and apply the most efficient tactic to regain control. The former may be the most appropriate method for recreational pilots with limited or no recurrent training opportunities. A one-fits-many strategy may better maximize their chances of survival than an unsustainable effort to teach them the complexities of different types of extended envelope events and their associated recovery actions. For pilots that are responsible for the lives of the flying public, however, such a simplified strategy would be unacceptable, and they must be taught to consider not only what to do, but also metacognitive aspects such as recognizing the degree of their mental impairment and reminding themselves to "slow down, make sure you know what you need to know, then decide." So an effective response to an upset or stall may involve first assessing the time available to take action dependent on distance from terrain and/or traffic. If there is but very little time, the best course of action might be to revert to the "All-Attitude Upset Recovery Strategy." If there is time, pilots should go through a minimal memory checklist containing only the two items of first discriminating between the two crudest categories of LOC, namely stalls and all else. If there is enough time, they should pull the appropriate paper checklist and follow it as far down as time permits. If there is not enough time for the paper checklist and they are dealing with a stall, the next action would be reduction of angle of attack. Next, they need to remind themselves which airplane they are flying, especially if there is a danger of negative training transfer from training in an earlier type. If they are dealing with an event other than stall, they need to consider what type of event it is, whether the nose is low or high, whether they are already beyond the critical angle of attack, etc., and try to remember the appropriate actions. In all cases, they should aim at maintaining the mental flexibility to deal with any unexpected compounding event.

The difficulty from a training point of view is that training strategies differ dependent on whether you are aiming for a rote response relying on implicit or procedural memory, where error-free drills may be most effective, or for a more differentiated response relying on explicit memory, which is best trained using a trial and error strategy (see, e.g., Ref. 14). The latter requires exposure to complex scenarios honing effective information acquisition and decision-making skills as well as cognitive flexibility. Regardless of what the desired response and the appropriate training strategy are, the environment in the simulator must approximate the situation in the airplane closely enough to induce the same psychological responses that so often lead to inappropriate responses to LOC events in the airplane. Instructors require training to support an environment that helps pilots to 1) develop an anticipatory model for effective information acquisition and recall; and 2) acquire effective cockpit resource management, analysis and decision skills that remain intact should the unexpected happen.

IV. Fostering the Correct FSTD Training Environment

To effectively train pilots to handle LOC events and to refrain from primal or inappropriate responses it is important to effectively evoke at least some of the physiological, psychological, and behavioral responses associated with in-flight startle or surprise events. For this it is critical to reduce the so-called "simulator mindset" and compensate for the lack of real-life risk. This is done by creating an in-flight atmosphere, stressing pilots with realistic tasks and distractions, and, once they are fully immersed into the scenario, present them with startle, surprise, or spatial-disorientation inducing events (see Ref. 2 for ICATEE's suggestion of a scenario toolbox containing such events).

Line Operational Simulations are the best way of creating an immersive in-flight atmosphere in an FSTD. The FSTD must realistically simulate all the visuals, sounds, force-feedback, instruments, and automation including stick pusher, envelope protections, and stall warnings. For training within the envelope the author's research has not shown an operationally relevant benefit of the kind of motion provided by the type of hexapod platforms currently available to airlines, at least on quasi-transfer of training (see, e.g., Ref. 15 presented at this conference). The physical limitations of such systems make it unlikely that a training benefit for extended envelopes would emerge from these systems as they are to date, but it has been suggested that it may be possible to provide "special-effects" vestibular and/or proprioceptive cueing to improve the realism of simulated upset events.

The difficulty of providing realistic communications, including air-traffic-control voice and data-link communications as well as communications with the company dispatchers, may be one of the biggest obstacles to reducing the simulator-mindset syndrome. This has been succinctly put by an instructor participating in Ref. 16: "How can we expect crews to 'treat the sim[ulator] like the[aircraft]' when the audio environment belies the condition so often?" Currently, instructors have to impersonate all voice communications themselves, and very few have time to go beyond communications to the trainee's airplane itself ("you have to split your brain between presenting and evaluating"). This reduces pilot workload and distractions. Pilots don't need to redial frequencies or to listen for their own call sign. They also don't have the opportunity to hone their situation awareness skills by experiencing the benefit of hearing, via the so-called party line, about a heavy airplane with wake potential in front of them, or potentially upset-inducing weather phenomena experienced by other aircraft in the same airspace. The need for interruption management is also reduced by instructors waiting with radio communications until the crew finishes, e.g., programming the Flight Management System.

An often-held misconception is that when training difficult tasks (as which recoveries from extended envelopes would qualify), it is better to start with a part-task environment, because the full task including realistic radio communication would be "too much of an overload during training," as one of our study participants put it. However, an extensive multi-institution research effort by the Defense Advanced Research Project Agency has shown that training the whole task, while shifting attention between aspects of the task, may lead to development of general skills that transfer better to real flight, as described in Ref. 16.

Finally, another apparently simple but sometimes neglected aspect of creating an in-flight atmosphere conducive to effective training in the simulator is an overall attitude of professionalism. Treat the simulator like the real airplane, as the instructor quoted earlier put it. That means, don't do anything that you wouldn't do in the airplane. Keep the sound at the volume that corresponds to the airplane noise (even if it is tempting to reduce it for increased comfort), wear headsets, seat harness, maybe even a uniform, as it is required in the military and at some airlines and flight schools. As D.P. Davies puts it,[17] don't do anything that "destroy[s] the image that [you] want to create." Freeze and reset the simulator only if absolutely necessary; never use increased speeds to get the "airplane" where you want it to be; don't open the simulator door during a flight; don't interrupt the scenario with non-scenario related activities such as snacking, taking cell phone calls, etc. Any violation of these "don'ts" can sabotage a pilot's full immersion into the scenario.

V. Conclusions

Although it may admittedly be impossible to recreate, in the safety of a simulator, exactly the same physiological and psychological reactions that a trainee would experience in an upset airplane, there are many ways that the realism of emergency scenarios generally, and particularly extended-envelope-recovery scenarios, can be improved in the simulator. Especially with emergency training there is an important trade-off that needs to be considered when comparing the training effectiveness of the airplane with the training effectiveness of an FSTD. As John Rolfe put it, when praising manifold benefits from training in the simulator, "[i]t has been a long-time since I lost a buddy in training accident."[18]

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