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Survey of Quantitative Research Metrics to Assess Pilot Performance in Upset Recovery

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Nomenclature

ADI	Attitude Direction Indicators
AFM	Aircraft Flight Manual
CAST	Commercial Aviation Safety Team
CRM	Crew Resource Management
FAA	Federal Aviation Administration
HUD	Head-Up Display
IMC	Instrument Meteorological Conditions
JSAT	Joint Safety Analysis Teams
JSIT	Joint Safety Implementation Teams
LOC	Loss of Control
LOC-I	Loss of Control – In Flight
POH	Pilot Operating Handbooks
PFR	Primary Flight Reference
SE	Safety Enhancement
UAR	Unusual Attitude Recovery
UPRT	Upset Prevention Recovery Training
USAF	United States Air Force
VMC	Visual Meteorological Conditions

Abstract

Accidents attributable to in-flight loss of control are the primary cause for fatal commercial jet accidents worldwide. The National Aeronautics and Space Administration (NASA) conducted a literature review to determine and identify the quantitative standards for assessing upset recovery performance. This review contains current recovery procedures for both military and commercial aviation and includes the metrics researchers use to assess aircraft recovery performance. Metrics include time to first input, recognition time and recovery time and whether that input was correct or incorrect. Other metrics included are: the state of the autopilot and autothrottle, control wheel/sidestick movement resulting in pitch and roll, and inputs to the throttle and rudder. In addition, airplane state measures, such as roll reversals, altitude loss/gain, maximum vertical speed, maximum/minimum air speed, maximum bank angle and maximum g loading are reviewed as well.

1. Introduction

Accidents attributable to Loss of Control – In Flight (LOC-I) continue to be the primary cause for fatal commercial jet accidents worldwide (Figure 1). In the years between 2004 and 2013, 22 percent of the fatal accidents were attributed to LOC-I. These 16 accidents accounted for nearly 40 percent of the total aviation fatalities. [1]

Fatalities by CICTT Aviation Occurrence Categories

Fatal Accidents | Worldwide Commercial Jet Fleet | 2004 through 2013

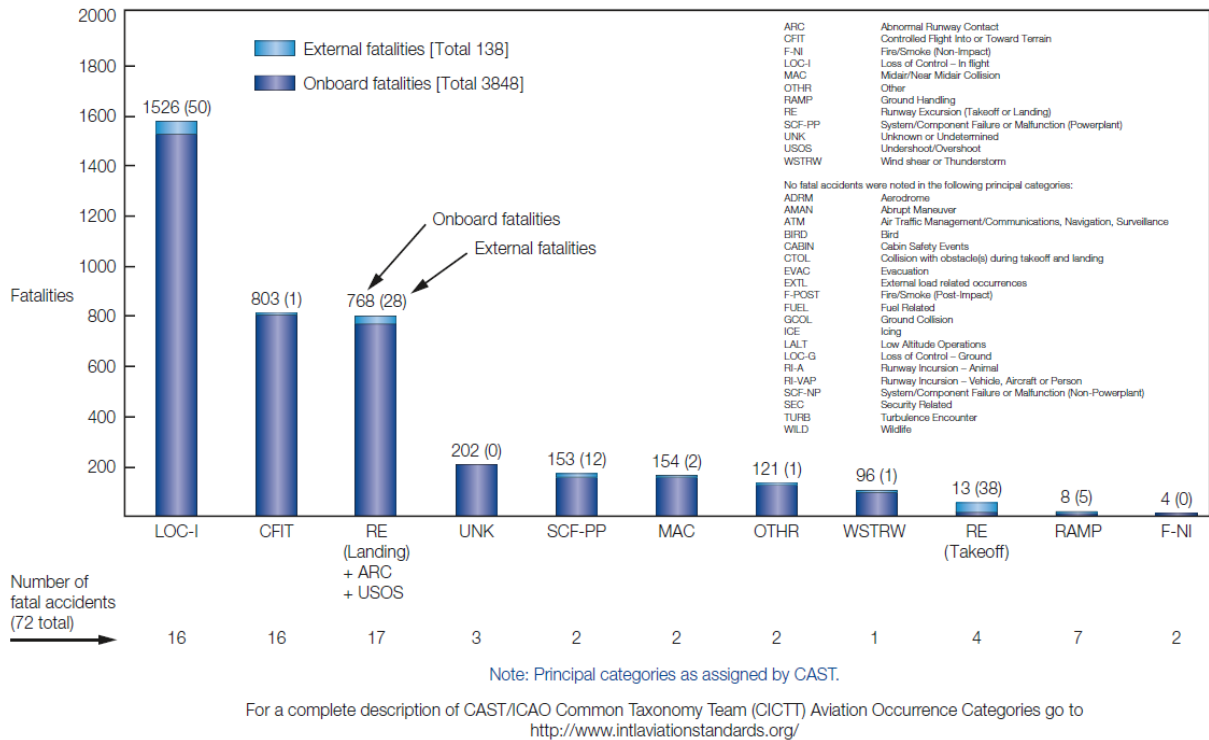


Figure 1: Aircraft Accident Statistics for Worldwide Commercial Fleet 2003-2012 [2]

The Commercial Aviation Safety Team (CAST) works to reduce the number of commercial aviation fatalities within the United States. Their mission includes current and future risk identification, developing mitigation strategies and monitoring those implemented strategies for overall effectiveness. CAST continues to work on identifying potential safety threats before any accidents result. This is done using the Joint Safety Analysis Teams (JSATs) working group to perform in-depth data analysis of accident categories to identify strategies to reduce contributing factors. These intervention strategies are then evaluated by the Joint Safety Implementation Teams (JSITs) to develop a detailed plan of action to be recommended for implementation by the government and industry as a Safety Enhancement (SE). [3]

A study of 18 loss-of-control (LOC) events by CAST focused on an aircrew's loss of attitude and energy state awareness. [2] Of its conclusions and recommendations, CAST issued SE 207, which recommends "research into flight deck technologies that have potential to mitigate the problems and contributing factors that lead to flight crew loss of airplane state awareness." Within this SE is the recommendation to identify quantitative standards to assess pilot recovery performance. Identifying these quantitative standards of performance allows for a uniform way to gauge the relative benefits of different technologies and countermeasures that may potentially aid in the mitigation of LOC events. To date, various performance and airplane measures have been collected and analyzed by researchers during technology testing or aircraft upset recovery testing and training. As such, there are no recovery performance standards to guide CAST research or uniform measures of merit by which to assess technology development and certification. [2]

This memorandum documents a literature review toward SE 207, which represents a compilation of the measures used in the past as well as recommendations for a standardized list to use in current research into aircraft upset recovery.

2. Background

In commercial aviation, the following criteria have been generally agreed as defining an airplane upset situation [4]:

- Pitch attitude greater than 25 degrees, nose up;
- Pitch attitude greater than 10 degrees, nose down;
- Bank angle greater than 45 degrees;
- Within the above parameters, but flying at airspeeds inappropriate for the conditions. [4]

These upset situations can be brought about by the environment, equipment and/or pilots. The upset involves attitude and energy state awareness.

Upset conditions are analogous, but not identical, to the term "unusual attitude conditions." In the United States Air Force (USAF), unusual attitudes are defined as "an aircraft attitude occurring inadvertently. It may result from one factor or a combination of several factors such as turbulence, channelized attention, instrument failure, inattention, spatial disorientation, lost wingman, or transition from visual meteorological conditions (VMC) to instrument meteorological conditions (IMC). [5] The key elements to prevent an upset or unusual attitude scenario progressing into a LOC-I accident are:

1. Recognition: This happens in one of two ways, either because of the picture on the attitude direction indicator (ADI) or an abnormal presentation of the performance instruments. Recognition is vital to a successful recovery.
2. Verification: Compare the control and performance instruments and use additional attitude sources to verify the attitude prior to initiating recovery.
3. Recovery: The pilot executes a recovery using their primary flight references.

All of these factors contribute to the speed and efficiency of the aircraft recovery. Techniques for recovery vary considerably and, therefore, influence the aircraft performance standards. The recovery techniques should be compatible with the severity of the unusual attitude, the characteristics of the aircraft, and the altitude available for the recovery. These factors are reviewed in the following. [5] [6]

2.1 Recovery Techniques

Both the military and the commercial aviation community have general upset recovery procedures for use in unusual attitude/upset situations.

The military's AFMAN11-217V1 outlines the techniques for recovery from unusual attitudes for military aircraft if the manual does not include recovery procedures. It states that the recovery techniques used should match the severity of the unusual attitude event, the altitude available for recovery and the airplane characteristics. It is also noted that quick recognition is vital to a successful recovery. The recovery procedures for an unusual attitude recovery (UAR) are as follows [5]:

- If diving, use power and bank to aid in pitch control to get to level flight, refraining from back pressure until the bank angle is less than 90 degrees.
- If climbing use bank and power to aid in pitch control while avoiding negative g forces. Adjust power, pitch and bank to reestablish level flight. Avoid excessive bank limitations when recovering from a steep climb.
- Bank angle and power should be matched with pitch attitude and airspeed to avoid extremely low or high airspeeds and must be within aircraft limitations.

Recovery is considered complete “when the evaluation pilot has maintained straight and level flight, within 10 degrees of bank angle and 5 degrees of flight path angle, for 5 seconds measured from when the aircraft enters the position criteria for the first time.” [7] Variations of this set of recovery criteria were used in several of the studies included in this literature review.

For non-military aircraft, most Pilot Operating Handbooks (POH) or Aircraft Flight Manuals (AFM) will include recommended recovery procedures. If not, recovery should be made in reference to the altimeter, airspeed indicator, turn coordinator, and vertical speed indicator. [8]

The Airplane Upset Recovery Training Aid (2008) discusses several different airplane upset situations for commercial air transport to include: nose high or nose low coupled with high or low airspeed with wings level, and high bank angles with nose high or nose low. They have summarized the two basic airplane upset recovery techniques into nose high and nose low. [4]

- Nose high Recovery:
 - Recognize and confirm the situation
 - Disengage autopilot and autothrottle
 - Apply as much as full nose-down elevator

- Use appropriate techniques:
 - Roll (adjust bank angle) to obtain a nose-down pitch rate.
 - Reduce thrust (underwing-mounted engines).
- Complete the recovery
 - Approaching the horizon, roll to wings level.
 - Check airspeed, adjust thrust.
 - Establish pitch attitude
- Nose-low recovery:
 - Recognize and confirm the situation
 - Recover from stall, if necessary
 - Roll in the shortest direction to wings level - bank angle more than 90 degrees, unload and roll
 - Recover to level flight:
 - Apply nose-up elevator
 - Apply stabilizer trim, if necessary
 - Adjust thrust and drag as necessary

Using the correct recovery measures depends on the correct understanding of the situation and correct application of the procedures. Integrating academic training of the key concepts, simulator training for specific procedure training and airborne training to bring in real world experience, and development of the critical skills needed, can help prepare a pilot to successfully recover from an upset situation, avoiding loss of control. [9]

2.2 Training and Standards Development Considerations

One of the few opportunities available today to assess aircraft recovery performance – outside of research or equipment/technology development - is during training. Pilots have the opportunity to experience upset situations and practice their skills with many companies doing upset prevention recovery training (UPRT) in simulators and full flight. However, using the pilot’s simulator performance to predict their flight performance during emergency procedures has proven difficult. [10] The reality that most pilots may never encounter an actual airplane upset, other than in UPRT, is what makes that training so vital. UPRT teaches primary and alternate control strategies containing the knowledge, skills, techniques and procedures to safely recover from an upset situation in a measured and timely way. [11] Some of these skills cannot be mastered by academics alone. Classroom learning used in conjunction with cockpit training has specific benefits in the comprehension and retention of UPRT. Recurrent training may be necessary because recovery skills are perishable by nature and learning to recover from an upset situation requires developing the skills to appropriately and correctly respond to the psycho/physiological reactions that naturally occur in an aircraft upset situation. [11] These cannot be experienced or conquered except in actual flight. For the training to be complete, pilots should experience the full flight envelope from which a recovery can occur. Based on the analysis of 6 LOC-I accidents, the critical window for corrective response when an airplane upset occurs is under 7.6 seconds. [11] Because of the number of variables in upset situations, they often don't lend themselves naturally to

checklists of procedural solutions that crews normally would follow in the event of a problem. [11] Some crews may even misdiagnose an upset event and apply the incorrect recovery procedures, albeit correctly, thereby leading to an unsuccessful recovery and further loss of control. “A pilot’s singular ability to recognize a unique problem, develop what may be a novel strategy, and apply it to the recovery process may be the only means available to avoid an accident”. [9] Furthermore, because UPRT is done individually, there are few instances of crew resource management (CRM) training that include pilot communications during upset situations such as verbal diagnosis of the perceived issue or even the typical "I've got the plane. You've got the plane" transfer of control during emergencies. [11] Since upset situations typically surprise, startle and/or disorient pilots, smooth coordination between crewmembers is essential.

3. Upset Recovery Performance Measures

Researchers are looking for ways to measure a pilot’s performance to better train all pilots in UPRT as well as gauge the relative benefits of new and different technologies/countermeasures to spatial disorientation and loss of energy state awareness (SD/LESA). As described below, many studies using quantitative measures of pilot recovery performance have been conducted. Pilot performance has been measured in many ways, through many avenues. Some of these include pilot control inputs, airplane state measures, and measures taken using video and human observation. Some researchers state the exact measures used and how they are determined while others only allude to the measures collected and analyzed. The following is a breakdown of each parameter measured over the breadth of this research.

3.1 Recognition Time

One of the measurements used when collecting pilot performance data during trials containing recovery from unusual attitude is recognition time. To measure recognition time adequately, there needs to be a defined event start time. This event start time can be characterized by a specific condition, such as, a specific bank angle, tone or verbal notification. [10] Recognition time has been previously defined using time, to the nearest tenth of a second, from the beginning of the event to when the pilot recognizes there is an issue and either verbalizes it or it is marked in some other way. [12] MIL-STD 1787C defines the parameters of recognition and recovery from an unusual attitude as one where the pilot initiates recovery within 1 second towards the correct horizon, with minimal loss of altitude and airspeed, and less than 10 percent errors because of roll reversals. [7] [13] It further states that attitude recognition on the primary flight reference (PFR) should be immediately understandable and should present adequate indications to aid in the pilot’s ability to maintain full-time attitude awareness while minimizing the likelihood of spatial disorientation. [7] AC25-11 recommends using permanent ground-sky horizon, chevrons and pointers on displays to aid in accurate interpretations of the unusual attitude situations and as an aid in manual recovery from these conditions. [14]

Other researchers used the time from the start of the event until the pilot announced the problem. This method measured recognition time using the video recording transcript and time stamps to the nearest one hundredth of a second. [10] Pilots in another study

were instructed to verbalize their diagnosis of the airplane state as well as the recovery action. However, most pilots were so focused on the recovery that they did not verbalize either the diagnosis of the airplane state or the intended recovery procedure. After further training, this effect lessened and the pilots became more verbal during recovery. [9] Another researcher, using the term “intervention time” defined it as the time between notification and first action. [15] Without the parameters listed above, recognition can be difficult to measure.

Recognition can be further broken down into “correct recognition” where there is initiation of recovery coupled with the correct use of a control input towards that recovery as shown below.

3.2 Control Inputs

Researchers need a way to quantify recognition time, initiation of recovery (i.e., first response), and the speed and correctness of the recovery. Control inputs can be measured and used to determine all of the above as well as any subsequent actions in a recovery. This allows researchers to quantify the recovery and measure it to determine the quality of the recovery. The published recovery procedures can be used to identify a list of control inputs which should be measured. These measurements should also quantify the force, or deflection (in inches or degrees of movement) made to the controls. In addition to the measures of primary control inputs, measures were also taken of the state of the airplane, whether or not the autopilot or autothrottle was on or off, and the maximum excursions of the aircraft. Some of the measures taken were based on where the airplane was in space, at a certain time in the recovery, compared to where it started. These measures were often indicators of whether the recovery was successful or not. Researchers also scored the recovery based on the briefed recovery procedures and the direction of the control inputs (i.e., correct or incorrect) in accordance with those procedures. Participants were also briefed on the scoring parameters that would be used. The correctness of the inputs were determined by comparing the recovery criteria with the time history of the control inputs from the event start time. Throttle handle displacement and wheel/column pitch and roll deflection were deemed intentional/significant if they exceeded the agreed upon threshold values. Time and direction were also noted. [16]

A few researchers were very detailed in their descriptions of what constitutes a control input for their study. One such study [16] used a tone to indicate that the pilot should initiate the recovery; this tone also served as the marker for the event start time. After the tone sounded, the wheel and column’s pitch and roll deflection, as well as the displacement of the throttle handle, were recorded and analyzed. Only the first control input was recorded and they were only deemed significant if they were over the threshold values as determined by the researcher. Determining and using a threshold value cut down the amount of unintentional inputs being counted as intentional. These threshold values were:

- 0.30 in. of pitch controller deflections,
- 2 degrees of roll, and
- 2 degrees of throttle handle displacement from trim.

The full scale deflections were also listed at +/-5 inches for pitch, +/-90 degrees for roll, and +80 to +29 for throttle. The rationale used in choosing the thresholds above were not described. [16]

While the Federal Aviation Administration (FAA) has defined the maximum control forces permitted to be applied to the control wheel or rudder pedals for roll, pitch and yaw in CFR 25.143, aircraft manufacturers may choose the actual values for each control up to that maximum value. [17] Commonly, a ratio of 1:2:4 is accepted as the ratio for the control forces of roll, pitch and yaw and falls in line with CFR 25.143. The minimum control forces needed to move the control inputs out of the null position is known as breakout force. The breakout force is designed to prevent unintentional control inputs. [18] Therefore, researchers may use breakout force as a way to define intentional movement. The differences between aircrafts and control inceptors make it difficult to have a single standard, however it is believed that the force threshold should be above two percent, but less than five percent, of the total pounds of force, degrees and/or inches of deflection needed for aircraft movement. [19]

The pitch, roll and throttle control reaction times were measured as the time it took for the control input to exceed the threshold values above. [10] The shortest reaction time (whether correct or incorrect) and shortest correct reaction time and type of control input were also measured in a study. [16] Another study used the magnitude and direction of lateral force applied within the first 3 seconds after the pilot assumed control of the airplane. A force greater than 0.5 pounds was needed for it to be considered a purposeful input, whereas one between 0 and 0.5 pounds did not cause a significant enough bank response. [20]

Many control inputs are measured from the start time of the event to the first control input to the nearest one hundredth of a second. Autopilot and autothrottle disconnect were measured to within one hundredth of a second from the event start time to when the button was pressed. Any throttle input was measured when the thrust delta was greater than 100 pounds. [10] Many of the other researchers did not indicate whether these measures were recorded, though it is mentioned in the recovery procedures above. Some researchers counted the number of control input errors the pilot made during recovery. [15] Others measured the first response in the wrong direction, primary control-input reversals, as well as any subsequent control inputs in the wrong direction. [21] Additionally, researchers used the first throttle response or roll response to the nearest hundredth of a second. [22] [23]

Stick deflection from center was used to measure elevator (pitch) and ailerons (roll). [15] Definitive aileron inputs were defined by any lateral stick force greater than 10 pounds. In other aircraft, the position of the wheel column was measured in inches for pitch inputs and degrees for roll inputs. [10] During one study, the use of ailerons for roll control authority was measured to the nearest hundredth of a degree of yoke rotation. [22] The maximum rate of the correct change in roll of the airplane during recovery was also measured. [15]

Incorrect roll control inputs, or roll reversals, were another common measure. If the initial wheel response, in an unusual attitude recovery, was at least 5 degrees bank in the wrong direction, it counted as a roll reversal. The duration of the roll reversal was also measured, in seconds, from the beginning of the incorrect roll control input until the beginning of the correct control input. [12]

In some studies, the maximum bank angle was measured. The measurement was recorded when the maximum bank angle was achieved by the airplane after the start of an unusual attitude, but prior to when recovery was reached. [12] Another way that maximum bank angle was measured was done during a study on attitude perception where the pilot had to stabilize the airplane at a 45 degree bank. This measurement was the actual bank angle of the airplane that resulted from the pilot's stick input at task onset since the pilot was not required to recover the airplane in this study. [20]

Additional inputs may be recorded at the researcher's discretion and may include rudder, trim, airspeed and other inputs. The use of rudder for roll control (authority) was measured to the nearest hundredth of an inch of rudder pedal displacement. [22] One study ignored rudder pedal movements under one inch in an effort to rule out ambiguous pedal activation. [24]. Any force on the rudder pedal that was greater than 10 pounds was considered an unambiguous rudder input in another study. [10] When recorded, trim input was measured when the trim became greater than +5.0 degrees more than the trim at the start of the event. Elevator inputs were also measured as any longitudinal stick force greater than 10 pounds. [10] Trim was measured in one study when the trim increased by more than 5 degrees from what it was at the start of the event. [10] Maximum and minimum airspeed was measured during recovery as well as the airspeed at the start of the event. [10]

Measuring altitude loss is an important measure since other recovery procedures influence how much altitude is lost. [23] However, caution is needed as altitude loss should not be briefed to participants as a performance parameter for two reasons. First, altitude loss implies that maximum g-load is important during the recovery and as noted below, without a g-meter in the test (i.e., a simulation test), pilots may be using g-loading that is not realistic. [9] Second, the recovery may require significant attitude changes, especially when recovering from a stall, and according to the new upset recovery pitch guidance, the first requirement is to pitch in order to reduce the angle-of-attack. After the stall is broken, recovery with a minimum of altitude loss is advisable, but it is not the first-and-only requirement. [4]

Most researchers measured altitude loss as the difference between the altitude of the airplane when it entered the upset situation and the lowest airplane altitude reached prior to recovery of wings level. [12] [10] [15] There were also some instances where an altitude gain was measured. [22] [23] [16] Along with altitude loss or gain, maximum vertical speed during the recovery was measured. [15] This is the difference between the vertical speed at the start of the event and the highest value for vertical speed prior to a completed recovery. [12]

According to 14 CFR 25.333, keeping the airplane's maximum g-forces to less than 2.5 'g's is essential for air transport aircraft. [15] In cruise configuration, jet transport airplanes are currently certified to withstand normal vertical load factors from -1.0g to 2.5g. [4] Normal acceleration between 1.5 and 2.0g are expected during in flight recoveries. [16] Therefore, the maximum load factor maintained during recovery was measured. Measurements of the maximum g loading of the airplane needed to stay within the safety threshold put out by both the manufacturers and the FAA. This measurement of the maximum load factor is taken between the start of the event, where the load factor is close to 1.0 and the end of recovery, where the load factor should be close to 1.0 again. [12] This 1.0g is indicative of normal unaccelerated flight. During recovery, maintaining approximately 0.5g has resulted in the quickest acceleration as well as reduced wing loading. [25]

During a program development flight test for UPRT, a g-meter was added to the simulator because without vertical acceleration cues the pilots tended to make larger inputs to try to speed recovery which took the aircraft out of its acceptable flight envelope. During flight training however, they were initially timid in their pushing or pulling of the controls, as they appeared to be unwilling to use all the available performance for recovery in a full-cue environment. These actions could have put the recovery in jeopardy as it led to a rapid loss of energy. Adding a g-meter in this environment aided the pilots' techniques and willingness to use all of the aircraft's available recovery performance. Furthermore, having a g-meter during the full flight simulation part of the experiment, pilots were less likely to exceed the maximum load factor of the airplane. [9] Other researchers told participants that the time to recover would not be graded to avoid excessive 'g' during recovery. [16] Recordings and statistical analysis of both the maximum g-force sustained in the dive pullout and the minimum unload g-forces encountered during rolls were done, as well as the overall ratio of available to allowable g-forces. [10] [22] [23]

3.3 Recovery Time

Recovery time is typically the time, to the nearest tenth or one hundredth of a second, from when the pilot enters the event and when the aircraft is stabilized into straight and level flight as defined by each research team. [10] [22] [23] [12] In one study the procedures used to recover the aircraft were also measured in addition to the time it took to recover the aircraft, though the pilots were told that the recovery time was not graded so that the pilots avoided excessive g forces. The procedures were documented using a video recording of the pilot's actions from the start of the event to the completion of the recovery. [10] There are many ways to define a recovery, and among most researchers there is no agreed upon standard. Some researchers use the military's definition of a recovery from an upset situation, found in MIL-STD 1787C, as the metric as listed in the previous section. [26] MIL-STD 1787C defines the symbology requirements for new primary flight reference (PFR) across multiple airplane types for the military. It describes the minimum simulation and flight testing evaluations required for such systems. One such simulation and/or flight test assesses compliance with attitude awareness/recognition. In this task the pilot is required to quickly and accurately recover

from a series of unusual attitude events. Within the UAR testing, a recovery is considered successful and complete when “the pilot has maintained straight and level flight within 10 degrees of bank angle and 5 degrees of flight path angle, for 5 seconds, measured from when the aircraft enters the position criteria for the first time”. [7] Researchers have also used other recovery definitions and time frames. In between maneuvers to determine the effect of windscreen bows and HUD pitchladder on pilot performance, pilots were put into a preprogrammed unusual attitude from which they needed to recover. The recovery time was computed based on the following criteria: altitude greater than 0 feet, airspeed greater than 130 knots, bank angle of less than 30 degrees, pitch angle between +/-10 degrees, and vertical velocity between -100 and 1200 feet/minute. [27] Hughes, Hassoun, & Barnaba (1992) considered the recovery complete for their study once the airplane was within +/- 5 degrees pitch and +/-8 degrees roll for 5 seconds. [28] Gawron, Bailey, & Randall (2009) considered a recovery complete for their study when the airplane was wings level, +/-5 degrees for 5 seconds. [16] Beringer, Ball, Brennan & Taite (2005) considered the airplane recovery complete when it reached +/- 5 degrees of bank and +/-2.5 degrees of pitch and these values were maintained for 3 seconds. [21] Some researchers see recovery time as the period of time from when the pilot takes the first action to recover and when the aircraft is straight and level with no further phugoids or oscillations, without any defined flight parameters or time confines. [15] Others, while doing simulator training for procedures, just want the airplane returned to less than 30 degrees bank as soon as possible. [29] Researchers also collected data on time to recover without indicating in their papers what recovery criteria was used. [22] [23]

3.4 Successful Recovery

Defining a successful recovery is also necessary. Loosely defined, a successful recovery could be thought of as any action taken that kept the aircraft in the air, returned it as quickly as possible into the flight envelope and kept an accident from happening. However, many researchers further defined recoveries as being successful using additional criteria. MIL STD 1787C defines the parameters of recognition and recovery from an unusual attitude as one where the pilot initiates recovery within 1 second towards the correct horizon, with minimal loss of altitude and airspeed, less than 10 percent errors because of roll reversals and a 95 percent or higher correct response rate. [7] One study defined the successful recovery as one that was without verbal or physical assistance from the safety pilot. In addition it was considered a ‘good’ upset recovery when the pilot returned the airplane to straight and level flight, while respecting the operating limits, with a minimum loss of altitude. This minimum loss of altitude occurs when there is correct and prompt control of thrust, a high roll rate which orients the lift vector towards the sky, and the appropriate use of G forces during the recovery. [22] To qualify as a successful recovery in another study, the airplane must be returned safely to straight and level flight. The recovery also could not cause a safety-trip of the safety systems aboard the airplane that would end the trial, or, in the event a safety-trip occurred, the safety pilot had to have believed that the pilot’s control inputs would have ended in a successful recovery. [10]

Below (Table 1.) are the measures examined in this paper that could be considered when doing research in assessing pilot recovery performance, as these were the ones used in other studies:

Table 1. Quantitative measures to assess aircraft upset recovery performance.

	Measures	Standards	Reference #
Time	<i>Time is measured to the nearest one hundredth of a second.</i>		
	Time to first input	Time from the event start to the time when the pilot exceeds an agreed upon threshold value for control inputs (whether correct or incorrect).	[10] [16] [20]
	Recognition time	Time from the event start to the time when the pilot exceeds an agreed upon threshold value for a control input in the correct direction.	[10] [12] [15]
	Recovery time	Time from the event start to when the aircraft is recovered to straight and level for 5 seconds (within 10° bank and 5° flight path angle)	[7] [10] [12] [15] [16] [21] [22] [23] [26] [27] [28] [29]
Correctness	<i>These are determined by comparing the control inputs made after the event start time with the briefed recovery criteria.</i>		
	Correct inputs	Whether the first pilot input was correct.	[16] [21]
	Incorrect inputs	The number of incorrect inputs before the first correct input.	[15] [16] [21]
	Successful recovery	Measured as successful when the pilot returned the airplane to straight and level flight, while respecting the operating limits, with a minimum loss of altitude.	[7] [10] [22]
Control Inputs	<i>These are measured when the pilot exceeds an agreed upon threshold value for the input.</i>		
	Autopilot/Autothrottle disconnect	Measured from the event start time to when the button was pushed.	[10]
	Throttle movement	Measured if/when the pilot exceeds an agreed upon threshold value.	[10] [16] [22] [23]
	Control wheel/sidestick movement	Deflection from center is measured in pounds of force/degrees/inches if/when the pilot exceeds an agreed upon threshold value.	[10] [16] [20]

Pitch (Elevator) / Roll (Ailerons)	Measured in pounds of force for stick deflection and to the nearest hundredth of a degree for yoke rotation in wheel columns if/when the pilot exceeds an agreed upon threshold value.	[10][15] [16] [22] [23]
Rudder	Measured in inches of movement and pounds of force if/when the pilot exceeds an agreed upon threshold value.	[10] [22] [24]
Trim	Measured when the trim increased by more than 5 degrees from what it was at the start of the event.	[10]

Airplane State

Roll reversal	Measured as an incorrect roll input, i.e., in the wrong direction, greater than 5 degrees.	[12]
Altitude loss/gain	Measured as the difference between the altitude of the airplane when it entered the upset situation and the lowest airplane altitude reached prior to recovery.	[4] [9] [10] [12] [15] [16] [22] [23]
Maximum bank angle	Measured as the maximum bank angle achieved after the start of the upset situation.	[12] [20]
Maximum g loading	Measured between the start of the event and the end of recovery.	[9] [10] [12] [15] [22] [23]
Vertical Speed	Measured as the difference between the vertical speed at the event start and the highest value for vertical speed prior to the completed recovery.	[12] [15]
Maximum/Minimum Airspeed	Measured in knots as the maximum and minimum airspeed during the recovery.	[10]

4. Concluding Remarks

There are several metrics that researchers tend to use when assessing pilot recovery performance. Time is a metric that researchers use to measure time to first input, or initiation to recovery, recognition, and the length of the recovery itself. Pilot control inputs affecting the airplane state are measured in pounds of force, deflection in inches or degrees and even button pushes. Airplane state is measured to determine the maximum values of bank and pitch, and vertical speed as well as the maximum/minimum airspeed during the recovery. Altitude loss or gain and g forces are measured to determine where the aircraft started the recovery and where it ended. These metrics can be used together to determine whether the recovery was “successful”, meaning it was completed safely, promptly and using the correct procedures. All of these metrics above have proven useful in various aspects of research into upset recovery performance.

5. Recommendations

Studies on the goodness of the above measures were not found. Furthermore, there does not seem to be a consensus on a standard set of recovery metrics. Researchers tend to be vague in their descriptions of the standards used to measure recovery performance, only alluding to those measures in their data analysis. This may be because different aircraft and/or scenarios lend themselves to the measuring of different criteria in different ways. Also, the recovery metrics are not widely documented or shared, and this perpetuates the multitude of different metrics and their definitions. Research is needed to determine the best quantitative standards to assess pilot recovery performance from an upset situation.

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