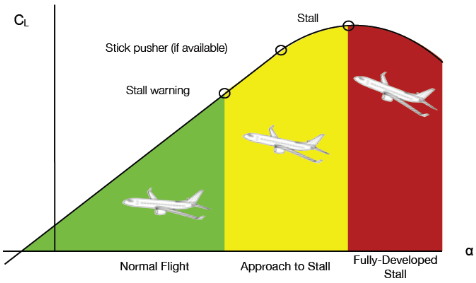
Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

Executive summary

Upset Prevention and Recovery Training in Flight Simulators



Problem area
Loss of Control – In Flight (LOC-I) is the number one cause of fatal accidents in the aviation industry. It is therefore a primary concern for the international industry and is being addressed by regulators, operators, training organisations and manufacturers alike. The risk of LOC-I accidents can be significantly mitigated through the development of “Upset Prevention and Recovery Training” (UPRT). Flight Simulators can play a major role in UPRT, but may require some further development and enhancement. These additional requirements need to be defined.

Description of work
In 2009 the Royal Aeronautical Society established the international working group: International Committee for Aviation Training in Extended Envelopes (ICATEE). The committee consists of stakeholders from throughout the aviation industry. This group is tasked with defining the training requirements, and the technical facilities required for training to enable UPRT.
ICATEE is currently finalising the initial training analysis and simulation requirements for application in the industry. These requirements will eventually be reviewed by ICAO for inclusion in the ICAO guidance material for Flight Crew Training, and Flight Simulation standards.

The work that is being carried out by ICATEE covers several areas of the aviation industry:
- Training requirements
- Flight simulation standards
- Research requirements
- Regulatory modifications
- Flight Crew Licensing
- Initial & Recurrent training

The current focus of the group is on defining the training requirements,

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This report is based on a presentation held at the AIAA Modelling & Simulation Technologies Conference, Portland, OR, USA, 8-11 August, 2011.

and the associated requirements for the training environment – including aircraft as well as flight simulators.

Results and conclusions

The training strategy being proposed by ICATEE is described as upset prevention & recovery training, which consists of three levels:

- Awareness
- Prevention (Recognition & Avoidance)
- Recovery

The training is balanced between academic knowledge as required for a basis to understand the practical elements of the training. These training requirements are detailed in a training matrix, that is being used by the sub-groups of ICATEE to work through the different aspects of the training requirements development. It is not the intention of ICATEE to define a detailed training syllabus, rather to define areas that should be included in the broad training of flight crew – across the different licences and training.

Parallel to this the ICATEE group is working to define the training environment that is required for UPRT. It is agreed that the current training environment is not sufficient for full UPRT, so enhancements are required. This has also included defining training exercises that are carried out on advanced training aircraft.

Given the wide application of Flight Simulation Training Devices within the industry, the ICATEE group is working on defining the enhancements that are required for FSTDs:

- Aerodynamic modeling
- Instructor feedback
- Scenario development
- Control authority
- Buffet motion
- Motion feedback
- Upset forcing function

These enhancements are being defined for inclusion in the Simulator Standards for UPRT.

Applicability

The research that is being carried out by ICATEE is applicable to all synthetic training devices used for flight crew training – including Flight Training Devices (FTD) and Full Flight Simulators (FFS). The ICATEE conclusions will be presented via the Royal Aeronautical Society and ICAO.

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Upset Prevention and Recovery Training in Flight Simulators

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This report is based on a presentation held at the AIAA Modelling & Simulation Technologies Conference, Portland, OR, USA, 8-11 August, 2011.

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Contents

Upset Prevention and Recovery Training in Flight Simulators

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Loss of Control in Flight (LOC-I), which is currently the number-one cause of aviation fatalities, can be mitigated through integrated upset prevention and recovery training. The means by which this training is conducted needs to be systematically defined to include both practical and academic training. To determine the training requirements as well as acceptable technical solutions, the Royal Aeronautical Society formed the International Committee for Aviation Training in Extended Envelopes (ICATEE). This working group is defining the operational training objectives, the training needs (shortcomings), and the training means (or media) that are acceptable for addressing the threat of LOC-I upsets. The improvements to flight simulators recommended by ICATEE include better incorporation of the surprise factor, enhancing mathematical model fidelity in simulation, improving the realism of upset onsets, and improving motion cueing. The role of the instructor in providing properly executed training is also key to ensuring a high training standard. The paper examines the training requirements and technical solutions considered by ICATEE.

Nomenclature

AURTA	=	Airplane Upset Recovery Training Aid
EASA	=	European Aviation Safety Agency
EGPWS	=	Enhanced Ground Proximity Warning System
FAA	=	Federal Aviation Administration
IATA	=	International Air Transport Association
ICAO	=	International Civil Aviation Organization
ICATEE	=	International Committee for Aviation Training in Extended Envelopes
IOS	=	Instructor Operator Station
LOC-I	=	Loss-of-Control In Flight
V_{ne}	=	Never-exceed airspeed

I. Introduction

LOSS-OF-CONTROL In-Flight (LOC-I) has become the primary cause of fatal commercial aviation fatalities, overtaking the prior leading cause, which was Controlled Flight Into Terrain (CFIT). Unlike CFIT, which was resolved primarily through the widespread introduction of Enhanced Ground Proximity Warning System (EGPWS), there appears to be no immediate, single technical solution for reducing or eliminating LOC-I. Hence, a systematic approach to analyzing the problem and developing feasible solutions is needed. LOC-I events are primarily the result of stalls, icing, flight control system failures, spatial disorientation, and atmospheric disturbances. They usually involve the actions by the pilot. In a broad context, these events can cause an aircraft to enter into an upset, which is "an airplane in flight unintentionally exceeding the parameters normally experienced in line operations or training" [1].

In an attempt to address this problem, an industry/government team published the Airplane Upset Recovery Training Aid (AURTA) for educating pilots and recommending effective methods of recovery from upsets in large transport aircraft. Its use has been encouraged by the regulatory bodies like the FAA; however, it has not been mandated. Consequently, its use varies widely across the industry. The AURTA is also specifically aimed for pilots of large transport aircraft (100-plus seats, and with swept wings) [1].

In recognition of the problem and the need for a harmonized solution, the Flight Simulation Group of the Royal Aeronautical Society formed the International Committee for Aviation Training in Extended Envelopes (ICATEE).

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Membership in ICATEE includes operators, airframe manufacturers, trainers, simulator manufacturers, researchers, and regulators.

The main problem with Loss-of-Control Incidents is that the causes are widespread. The prevention of and recovery from upsets requires the proper application of rule-based, knowledge-based, and skill-based behaviour. The mitigation proposed by ICATEE is to provide training through the following levels:

I - Awareness

II - Prevention (consisting of Recognition and Avoidance of upsets)

III - Recovery

Combined, this area of training is now referred to as "upset prevention and recovery training", or UPRT.

The following sections of this paper review the current status of the ICATEE working group, particularly highlighting the requirements of the simulator-related training to prevent and recover from upsets. Section II reviews the background to the problem and training requirements developed within ICATEE, and the impact on the simulator facilities, is discussed in Section III. The integrated approach to UPRT is brought forward in Section IV. Methods of improving current flight simulators to enhance their contributions to upset recovery training are suggested in Section V, as well as the main technical challenges associated with these possible improvements. While several training improvements will be realized through ICATEE's initial recommendations to ICAO in 2012, there are many issues that will require additional research. These are discussed in Section VI. Open issues and conclusions are reported in Section VII.

II. Background on the Problem

Today, of the limited number of accidents to commercial transport airplanes LOC-I is identified as the most common accident category. Lambregts et. al.,[2] categorize seventy-five airplane upset incidents between 1993 and 2007 and identify common trends. Their conclusion is that 27 incidents (36%) were due to stalls induced by contaminated airfoils or the autopilot. Secondly, flight-control system or autopilot failures of malfunctions caused 16 (21%) of the incidents. Spatial disorientation and contaminated airfoils (excluding the stall related ones mentioned above) contributed to a further 11% each, while atmospheric disturbances and other (including unknown) events cause the remaining 21%.

Operationally, pilots are rarely exposed to any parts of the flight envelope beyond the normal "centre" of that envelope. Typically, it has been estimated that a pilot will perform approximately two minutes of manual flying during any given flight in a transport category airliner. In long-range operations, the manual flight accrued per year may be as little as 30 minutes per pilot. At altitude, pilots are rarely exposed to the rather critical flight envelope, and the actual effects of approaching the airplane's aerodynamic and performance limits. An example is the limited maneuverability at high altitude due to the stall speed equalling the critical Mach number - "coffin corner". At or near this altitude, the aircraft becomes more difficult to stabilize. Since most manual flying is performed at low altitude, manual operation including stall recovery at higher altitude appears from the accident statistics to be challenging.

Basic flight training has moved away from extensively teaching stall and spin recovery. Pilots are asked to demonstrate "minimum altitude loss" during a stall, by maintaining a relatively high angle-of-attack and applying power. While this may work successfully and repeatedly in a docile single-engine piston training airplane, large aircraft are likely to have different characteristics that require immediate reduction of angle-of-attack. Airplanes with low, wing-mounted engines may require delayed application of power until the airflow is re-attached (by reducing the angle of attack) and airspeed is gained to avoid the nose-up pitching moment from further aggravating the stall. Hence, there may be a gap in the transferability of the skills gained during basic training to the air transport category operation.

Spin training has been abandoned for several years due to safety concerns. While large transport aircraft may have significant difficulty recovering from a spin (usually considered an "unrecoverable upset"), performing a spin and recovery during initial training may be beneficial for demonstration purposes. In fact, learning the recovery skills related to spins can be beneficial towards avoidance as well.

Current commercial pilot training and checking in simulators focuses on areas such as stall prevention by teaching recoveries from approach-to-stall condition. Yet, the data indicate that prevention is not foolproof, and the inability to recover from entry into the actual stall condition is clearly a significant problem. In many cases, pilots have applied incorrect control inputs, worsening the situation, and even ignoring or fighting the envelope-protection systems of their aircraft. The following recent examples support this finding:

1. Colgan Air flight 3407, pilots continued to apply control back pressure even though Q-400 was stalled.
2. USAir 427 accident, where the crew also applied continued back pressure until impact.
3. West Caribbean 967, stalled at high altitude and crashed
4. Pinnacle Air 3701, stalled at high altitude and crashed
5. Turkish Airlines 1951, stalled on approach and crashed
6. USAF C-5 Galaxy, stalled on approach to Diego Garcia and recovered

The Colgan accident led the National Transportation and Safety Board to issue several new recommendations relevant to the upset recovery problem, particularly those that are stall-induced.[3] These are:

> Require 14 Code of Federal Regulations Part 121, 135, and 91K operators and 14 Code of Federal Regulations Part 142 training centers to develop and conduct training that incorporates stalls that are fully developed; are unexpected; involve autopilot disengagement; and include airplane-specific features, such as a reference speeds switch. (A-10-22)

> Define and codify minimum simulator model fidelity requirements to support an expanded set of stall recovery training requirements, including recovery from stalls that are fully developed. These simulator fidelity requirements should address areas such as required angle-of-attack and sideslip angle ranges, motion cueing, proof-of-match with post-stall flight test data, and warnings to indicate when the simulator flight envelope has been exceeded. (A-10-24)

Training based on awareness and prevention alone appears to be insufficient. Carbaugh et. al.,[4] indicate that variable situations and outcomes, a lack of training, and the fact that crews became startled by rare events are three major reasons why there have been so many accidents. It was also found that crews used improper recovery techniques in many cases, indicating that training left them unprepared to respond properly in these situations. The most remarkable finding was that most of these situations were recoverable, but successful recoveries were not commonplace. Their work went further and reported that simulator-based training, coupled with involvement from an instructor, specifically trained to provide upset recovery training, showed a significant improvement to successful recovery techniques as well as higher consistency.

One possible way of preventing upsets is through effective flight envelope protection. Maintaining the aircraft state within acceptable structural and aerodynamic limits can be achieved by these systems. However, even in such aircraft, significant incidents have been reported. These are often due to (a) the crew being unaware that the disturbance was due to an external event, (b) failure of an aircraft system, or (c) mismanagement of the systems (e.g., A320, Perpignan, November 2008[5]). This suggests that even in these aircraft it would be beneficial for crew to be prepared to handle upset incidents.

Based on accident data, enhanced stall prevention and recovery training is considered a major goal of ICATEE. By developing the required skill sets, pilots can be taught to respond properly to stalls in most situations well in advance of them becoming safety critical. In providing the tools for training or for demonstrations, a satisfactory representation of the flight vehicle is warranted. Academics and in-flight training of stalls are also supported.

III. Requirements For Upset Prevention and Recovery Training

The upset prevention and recovery training objective is to maintain situational awareness in normal flight (in order to prevent upsets), and in the event of an upset, to apply the correct action. In some cases, applying corrective action preemptively when the aircraft is not upset can also lead to undesirable consequences. A key requirement is to avoid *negative* training, as this could lead to inappropriate reactions during flight. History has proven that negative simulator training can propagate to fatal consequences due to an incorrect learning process[6]. Because UPRT cannot take place in a single medium that is fully representative of the actual aircraft environment, there are benefits as well as potential negative training aspects to each of the training media or elements.

If one employs simulators that lack sufficient fidelity outside the normal envelope for upset training applications, this could in turn teach an inappropriate and unsafe recovery technique. For example, if training of recoveries in the simulator leads to over stressing the simulated aircraft model beyond its physical limits, this could be considered an inappropriate and counter-productive use of simulation. One example is American Airlines flight 587, which experienced a structural failure due to the pilot applying excessive rudder input in the presence of wake turbulence[6]. Inappropriate simulator training was blamed as one of the causes of the incident. In this case, the lack of fidelity in a simulator to portray lateral accelerations meant that the pilot was not able to "feel" these significant forces in the training device when applying full and reversed rudder inputs. This could have been a compelling demonstration on the "power" of the rudder, and the inappropriateness of full and reverse rudder flight control inputs. Note that the AURTA provides a good demonstration of this phenomenon, and explains how this can be performed in current Level D simulators at the current level of fidelity. The key challenge here is not a technical one alone, but involves making the correlation of the danger associated with rudder reversal to the pilots in training. The instructor plays a key role in the AURTA to mitigate the risk of negative training.

In addition, this lack of acceleration fidelity would inhibit the instructor pilot from identifying the misuse of this flight control if such a control input was used by a pilot. The benign accelerations represented in a simulator commonly led to excessive flight control inputs by pilots. There are no negative consequences for the aircraft in the simulator, as it cannot be "over stressed". Additionally, there is a lack of standardized knowledge in the instructor pilot ranks on the limitations of simulators in representing excursions into the extended envelope and the negative training that can result from such excursions in training exercises.

Acquiring data that are suited to the potential extreme flight conditions of upsets is a challenge however. The required level of accuracy and coverage is a big question, as incorrect data could also lead to erroneous interpretations. Additionally, there would be a potential danger and cost associated with collecting real flight data to model the extended envelope sufficiently in simulation. For this reason, many researchers resort to alternatives, such as the use of computational fluid dynamics of unsteady flows.

Beyond the technical challenge, there is a demographic one. In civil aviation, we have now transitioned away from the military supplying 80-90% of professional pilots to the inverse, 10-20% of professional pilots. This demographic change has resulted in the vast majority of incoming pilots into the airline inventory having little-to-no actual exposure to "all-attitude" aircraft training, nor an emphasis on upset aerodynamic academics. In examining the upset accident literature, it is not uncommon now for the pilots involved in these accidents to have had no actual exposure to a real aerodynamic stall and or pitch/roll excursions in an actual aircraft beyond the normal envelope (e.g., Q400, Buffalo, February 2009).[3]

IV. ICATEE Approach to Integrated UPRT

ICATEE consists of a team of specialists representing over 40 organizations from seven categories (airframe manufacturers, regulatory bodies, training providers, simulator providers, industry bodies, airline operators and research agencies/academia). The ICATEE team is organized into two main streams, namely, Training & Regulations, and Research & Technology.

Since June 2009, ICATEE has concluded that the provision of comprehensive UPRT requires a balanced combination of the following three training elements:

A - Academic knowledge (familiarity with aerodynamics, stalls, recognition of upsets).

B - In-flight exposure and training in an all-attitude/all-envelope environment in aerobatic-capable airplanes

C - Simulator-based training, specific to UPRT

The training requirements developed by ICATEE have culminated into a detailed training matrix, identifying the required skills and knowledge for each mitigation level and event within. This has helped identify the specifications for each of the training elements. It must be emphasized though that to prepare a pilot for all the levels of mitigation (awareness, prevention and recovery), exposure to the three training elements is required.

Table 1 shows the differences between the existing curriculum and the recommended additions for the academic component of stall training. Note that in addition to the expansion of the curricula, ICATEE is also recommending further qualification of instructors to provide the in-depth know-how in UPRT.

Table 1. Curriculum enhancements for academic stall training

STALL - ACADEMIC ELEMENTS	Existing Curriculum	Recommended Additional Curriculum (further instructor qualification required)
High AOA Performance		X
Pre-Stall	X	
High AOA Instability		X
Stall Buffet	X	
Stick Shaker/Pusher Familiarization, operation, recovery	X	X
Aircraft-specific characteristics	X	
Accelerated Stall	X	
Nose below Horizon Stall		X
High altitude stall		X
Stall with yaw present		X
Stall break	X	
Incipient spin		X
Developed spin		X
Managing g-loading		X
Tailplane icing		X

A significant portion of ICATEE's recommendations relates to practical training and checking. Currently, most manual flying skills are developed at the basic level, and the limited exposure to the "edges" of the flight envelope are also taught here. In looking toward long-term implementation of the ICATEE principles of integrated academics and practical training, a new recommendation is to require exposure to an all-attitude full-envelope environment in aerobatic aircraft at the commercial licensing level. This would mandate that all new-hire pilots aiming for a career in commercial transport flight operations be exposed to these conditions.

The existing pilot fleet would be required to perform training and checking in flight simulators only, since the economics of teaching these skills to this large population are preclusive, and several of today's pilots do have exposure through prior military careers.

Table 2 illustrates the practical skills enhancements associated with the ICATEE recommendations for airplane stalls, based on the use of aerobatic-capable aircraft and UPRT-certified flight instructors. The capabilities of full flight simulators (current and enhanced) are also shown in this table concerning stall training needs.

Table 2. Practical skills development for stalls, through simulators and aerobatic-capable aircraft, compared to current means

PRACTICAL SKILLS DEVELOPMENT; SIMULATOR VS AIRCRAFT	FFS (existing resources)	Existing normal-category training aircraft	Aerobatic-Capable Aircraft allowing all-attitude all-envelope instruction
G-orientation & exposure		X (limited)	X
Unusual attitudes	X	X	X
All-Attitude exposure			X
High AOA performance	X	X	X
Pre-Stall	X	X	X
High AOA instability			X
Stall buffet	X (limited)*	X	X
Stick Shaker/Pusher familiarization, operation, recovery	X		
A/C specific characteristics	X		
Accelerated stall		X	X
Nose below horizon stall	X	X	X
High altitude stall	X		
Stall with yaw present		X (limited)	X
Stall break	X (limited)*	X	X
Incipient spin		X (limited)	X
Developed spin			X
Managing g-loading		X (limited)	X
Airframe, wing, tailplane icing	X (limited)*		

* improvements being recommended by ICATEE

V. Simulator Requirements and Possible Solutions

Simulation technology has matured over the past several decades to a point where they are an acceptable surrogate to in-flight training and checking for most conditions and events. Simulator qualification documents define the levels of fidelity pertaining to specific types and levels of training,[7] while other documents define the testing procedures to meet these qualification requirements.[8]

However, upset prevention and recovery training requires the preparation of pilots for unexpected situations, where the training focuses on introducing the crew to realistic scenarios that, if encountered in real life, would require immediate and corrective action, and the information that indicates the onset of these conditions in order that they are acutely avoided. Are there any reasons to believe then that simulators today can satisfactorily meet these requirements?

Today, simulators are used in UPRT, even though their data may not be accurate for some of these situations. It should be noted that most upsets do not occur outside the validated envelope: A roll excursion can accumulate by a long-term roll rate at very low angles of attack and sideslip. Recovery in real life, however, may lead to high aerodynamic angles, or high loads on the airframe. A concern shared within ICATEE is whether some simulations and training exercises actually lead to negative training.

From the above, four primary objectives are derived:

a) Ensure the simulator model, where necessary, is representative of the aircraft for the training purpose
b) Allow realistic introduction of the upsets to the simulation
c) Allow the instructor to interject numerous safety-critical and realistic scenarios.
d) Provide feedback to the candidate regarding the status of the aircraft with respect to the allowable operating envelope

A. Representative stall model (and training need)

A prinicpal aim of the ICATEE working group was to evaluate and define the potential extension to the simulated flight envelope that is required to train upset prevention and recovery effectively. A public law now exists within the United States applicable to simulator training to (A) recognize and avoid a stall of an aircraft or, if not avoided, to recover from the stall; and (B) to recognize and avoid an upset of an aircraft or, if not avoided, to execute such techniques as available data indicate are appropriate to recover from the upset in a given make, model, and series of aircraft. [9] According to the US Law, the term ‘‘stall’‘ is defined as an aerodynamic loss of lift caused by exceeding the critical angle of attack. In order to train full stall recovery, the aerodynamic envelope that is required to support a “representative model” is currently undefined.

The training objectives that are identified for the stall recovery that affect the aerodynamic stall model are:

- Pre-stall characteristics and awareness cues
- Effect on control effectiveness prior to stall
- Reduced lateral stability
- Stall warning systems (including stick pusher)
- Effect of icing (on aerodynamics and stall warning systems)
- High altitude stall considerations
- Effect of thrust

While the current aerodynamic models support many of these objectives, there are some objectives that are only partially, or not, supported. The intention of the development of a representative stall model is intended to address these. The ICATEE group has assessed the existing aerodynamic models that are available, identifying three zones within the stall maneuver (see Figure 1).

The green zone represents the pre-stall warning region where the training is currently focused, simulator qualification standards are fully defined, and models are available across the industry – the normal flight envelope. The yellow zone represents the area between the initial stall warning activation, and the aerodynamic stall point. In this zone the current data available are more limited, and there are fewer specific requirements for the aerodynamic model. In the red zone, aerodynamic stall, there is currently no requirement to train in this region, and there is only limited flight test data available for many aircraft, if at all.

As an illustration to identify the bounds of the regions, for a commercial transport with flaps down, the angle of attack for CL_{max} is around 20 degrees, with the Stick Shaker occurring at around 15 deg AOA. With flaps up, the associated alpha for CL_{max} is about 14-15 deg, and Stick Shaker at 10-11 deg.

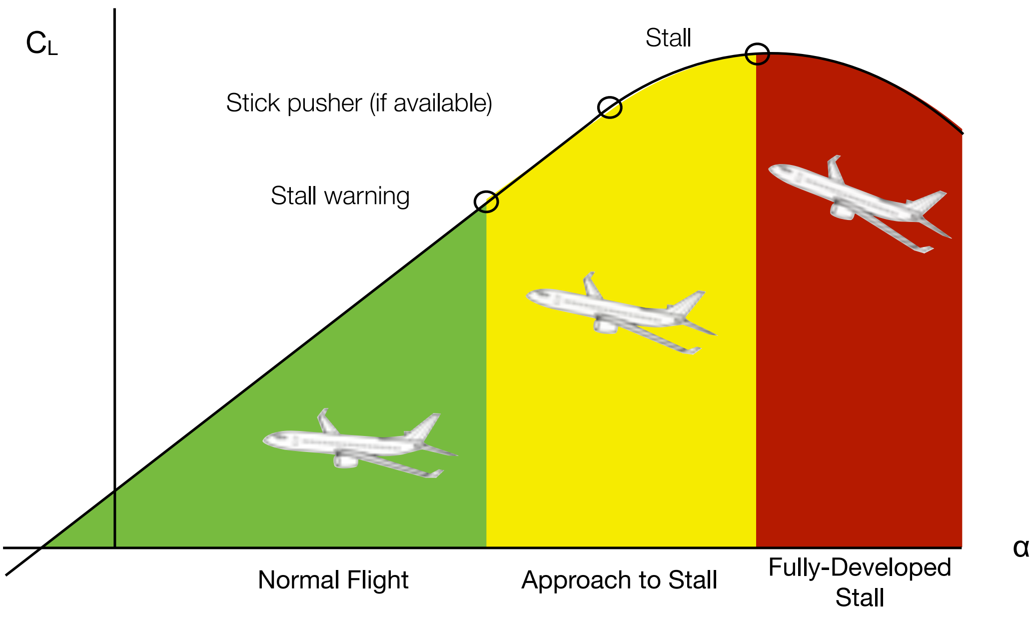

Figure 1. Regions of stall models

The training objectives that have been identified emphasize the *familiarization* element of training stall recovery. The aim of the training is to prepare pilots for the situation that they may encounter, while recognizing that the behaviour of the aircraft in this region is highly dependent on a number of factors, and therefore not easy to predict. It has therefore been recognized that a representative model is appropriate for this region (rather than a specific aerodynamic model). This is also in part due to the limitations of flight test data and modeling that affect the production of a specific model for each aircraft type and model. ICATEE is therefore working to define a guideline that will enable representative models to be used, and qualified on FSTD's. This standard will consist of both subjective and objective assessment.

The main outcome of the ICATEE analysis is that current simulator technology and the associated qualification guidelines need improvement to provide acceptable value for the simulation of upsets for the training of awareness, prevention and recovery. The salient points will be reviewed in the Discussion section of this paper.

Table 3. Stall flight regimes and training objectives

	Flight Regime Training Objectives		
Training value	**Normal Flight**	**Approach-to-stall**	**Stalled**
Longitudinal control	Awareness or flight envelope, recognition of stall warnings, avoidance of stall	Recognition, avoidance and recovery by reducing AOA	Recovery by immediate reduction of AOA
Lateral control	Awareness of effects of maneuvering on stall speeds	Avoidance of excessive lateral control inputs	Awareness of potentially complex lateral handling during recovery; g-break
Power	Little impact on upset prevention	Depending on aircraft class, may further increase AoA	
Current Simulator Capabilities			
Math Model	Available	Generally available	Requires additional development
Buffet Model	Available; emphasis on high-amplitude buffets	Aircraft could demonstrate subtle pre-stall buffet cues (could be missing in simulator)	Requires development
Motion cues	Present, but subjectively tuned.	Due to subjective tuning, may lack appropriate correlation with aircraft dynamics	Subjective; may be inappropriate for training

B. Instructor Operator Station

Transferring knowledge to candidate pilots requires a high standard for instructors that teach and check pilots operating in the regimes of upsets and similar challenging flight conditions. Current flight simulators limit the instructor's knowledge of what the actual airplane would have encountered in an upset situation. Additional feedback is required for the following:

a) Where the simulated aircraft is within the validated flight envelope, and if it is in an unvalidated region.
b) Feedback of the normal load factor during the maneuver (Illustrated in Figure 2 by a V-n envelope diagram as an example).
c) Control inputs exercised by the pilot, which should occur in a timely and non-abrupt manner, with avoidance of large excursions with reversals (such as rudder input)
d) The state of the aircraft (through the flight instruments).

The information could be displayed to the instructor, and played back during briefing/de-briefing sessions, to give the pilot better insight into the upset onset and recovery. Figure 2 shows a proposed display format, with each screen providing the feedback to items a), b), c) and d) above, respectively.

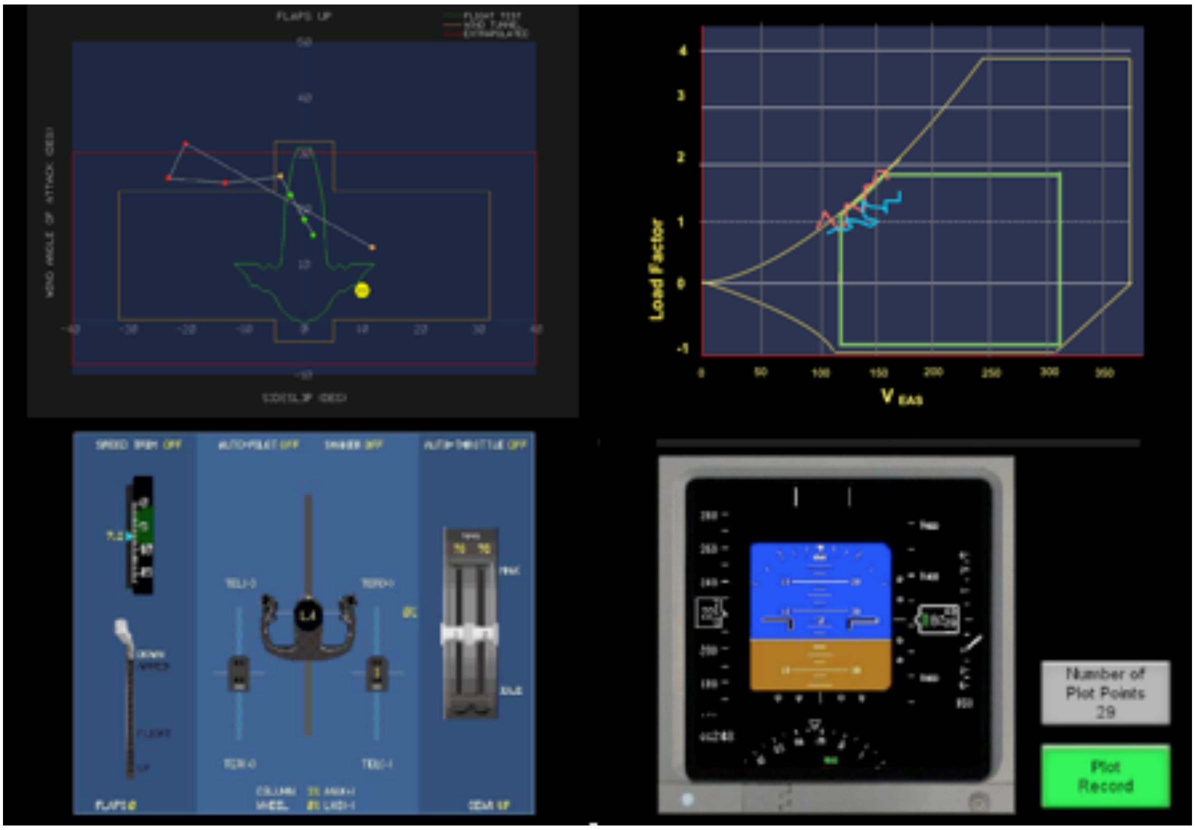

Figure 2. IOS feedback on simulation for validated or extended α-β envelope, aircraft V-n, flight control inputs, and aircraft state.

C. Scenarios and Startle

ICATEE was asked to identify methods for including the effect of surprise and startle within the training environment. Within Loss of Control – In Flight occurrences the unexpected nature of the event has often contributed to the challenge that crews faced in responding appropriately. These effects are often a combination of psychological and physiological factors. The investigation of these effects is described in Bürki-Cohen.[10]

As a result of this study, the working group within ICATEE created a number of scenarios where the intention was to include the surprise element. These scenarios are intended for application in existing training schemes using 6 DoF FSTDs, and are therefore focused on the cognitive elements of the surprise factor. The scenarios are based on the Line Oriented Flight Training (LOFT) concept, and are intended to form part of the LOFT training. In total 12 scenarios were created where an operational flight setting was combined with distracting factors in addition to an event that could result in an aircraft upset. These scenarios were implemented in the FAA's simulation facility in Oklahoma City for evaluation by the ICATEE pilot group.

The goal of creating surprise in the simulator is to indirectly train pilots to effectively handle LOC-I events, while primarily concentrating on the number-one task of flying the airplane. Much current upset training that is conducted in FSTDs is maneuver-based training which results in one pilot conducting pre-announced upset recovery training. The emphasis of scenario based training is presenting realistic upset scenarios in the context of how they might occur in normal line operations and compel the crew to apply crew resource management in the prevention and recovery. The intention is to effectively evoke the physiological, psychological and behavioural responses associated with in-flight surprise events, by reducing the "simulator mindset" and compensating for the absence of real-life risk. The latter can be achieved by creating an in-flight atmosphere (full adherence to procedures in the flight deck), stressing the pilots with tasks and distractions, and then presenting them with surprise-inducing events. A key goal in training is to prevent inappropriate responses, such as a primal reaction that exacerbates the situation or flight condition, not returning to a secondary activity (like FMS programming) when control is regained, fighting envelope protections, or applying control interventions that exceed the aircraft performance envelope.

The evaluation of the scenarios from the pilot group demonstrated that it was possible to include an element of surprise. While this was not a full evaluation experiment, it does demonstrate the potential for application in training. The response from the pilots was positive and illustrated that an element of surprise could be achieved in a simulation environment. Concerns were raised about the risk of a scenario being communicated to other pilots before their training. The aim would be to ensure that a large number of scenarios are available to the instructors. In this way, by applying the distracting factors in varying degrees, the unpredictability of the scenario can be maintained and pilots are required to assess each situation as it arises.

D. Continuous Control Authority

A beneficial way of illustrating upsets is by replaying in the flight simulator time histories of known upsets from flight data recorder information. Commanding synchronized responses of the simulator instruments, controls, visual display and sound can be beneficial in providing informative feedback. However, additional learning takes place when pilots are also able to prevent such upsets from developing into the consequences to which a particular recorded historic event led. Therefore, in the case of replayed upset events, the simulation must be configured so that the pilot is able to recognize and to prevent the upset from building. While a demonstration alone, if desired, can also be a valuable learning exercise, interactive learning significantly reinforces the recognition and avoidance of upsets. If the simulator does *not* permit pilot response or if the controls are frozen to follow the model, the resulting inability of the pilot can be frustrating and limiting to an attitude of upset prevention.

E. Buffet

Current buffet models may not necessarily present accurately the subtle vibrations that may be present when a transport-category aircraft approaches a stall. The aerodynamic buffet associated with the pre-stall phases is an essential cue to the pilot of a potential upcoming stall. In some situations, such as severe wing icing, it is possible for this aerodynamic cue to be the first warning of a stall that the pilot receives for some aircraft. This is also an effect that can be, and is, included in the simulator for training. However, ICATEE's analyses have indicated that the buffets in simulators may manifest later than they would in the real-life situation. It has also been reported that, like stall models, there can be considerable variability in pre-stall buffets which may occur in some situations, and be completely lacking in others.

The FAA Advisory Circular providing guidance for conducting flight tests to certify a commercial transports (FAA AC25-7B)[11] notes a definition of initial buffet for the stall as +/- 0.05 G (e.g. 0.1G peak to peak). If this threshold is used as the first indication of buffet during a stall it would come too late since some flight test data shows that this level of buffet may not occur until well into the stall for some aircraft/configurations. However, since the human perception system is capable of detecting buffets of less than half that amplitude, ICATEE is recommending that simulation modelling of pre-stall buffets includes low-amplitude vibrations, particularly when they can be detected early and before the stall. An assessment of the available flight test data is being applied to define an appropriate lower peak-to-peak threshold for buffet onset.

In addition, ICATEE is examining the stall buffet qualification tests. While objective tests of the buffet are desirable for different flight conditions (e.g. cruise, climb, approach and landing), there is recognition that the current power spectral density (PSD) analysis method may not be the most appropriate for this dynamic flight condition. This is a potential area for further research to define an alternative method. It is recognized that the availability of flight test data – stall time history and accelerometer data for the PSD analysis – is a consideration for the feasibility of objective testing, since it may not be possible to produce data for older aircraft types.

F. Motion Feedback

Motion feedback assists a pilot in controlling a dynamic system due to the faster response time of the vestibular system compared to the visual system. In certain cases, an aircraft may demonstrate reduced stability in the region close to a stall, meaning the stability time constants and mental workload may increase. Furthermore, in some cases, there may be non-linear behaviour associated with the control inputs and vehicle response, particularly in roll. In such cases, the presence of motion feedback may lead to a response by the pilot that is representative of that achieved in the aircraft. This may help enhance the learning process, particularly with regards to avoidance of such conditions.

One particular learning element in the ICATEE training matrix where pilots should learn to avoid these areas of the flight regime is unloading the wing by reducing angle-of-attack. Maintaining the high angle-of-attack increases the workload and effort required. Realistic representation of these conditions can be beneficial in training avoidance. Through the vestibular system, the pilot can become aware of appropriate and inappropriate control inputs.

In the longitudinal degrees of freedom, pilots need to be aware of the angle-of-attack primarily, which is not necessarily coupled to the pitch attitude. In simulators, the motion drive algorithm and motion platform attempt to provide the pilot with feedback on the specific force, rather than the inertial accelerations. When properly configured, and in concert with the instrument and visual information, the simulator can provide an instructional benefit by presenting the pilot with potentially confusing signals that may lead to incorrect response to the pitch attitude, rather than the angle-of-attack. Again, the training objective it to get out of this area of the flight envelope by reducing the angle of attack.

It is important to note that all the above are dependent on the aircraft type, state, condition, and even configuration. What is most important for the training goals is that the simulator provides accurate feedback, without negative cueing. Instructor involvement in the feedback process can also be important in helping a pilot to avoid, for example, abrupt control inputs, or even use a control input that could lead to aggravation of the state during a particular condition.

Motion feedback often differs between simulator platforms, primarily because objective criteria are not used for the qualification and test of motion cueing systems. The motion drive algorithms, motion platform and the digital implementation in flight simulators introduces differences in both gain and phase with respect to the motion cues that would otherwise be perceived by pilot in the airplane. An alternative technique that was proposed[12] has been incorporated into the ICAO 9625 Manual, [8] and is expected to support the standardization of motion cueing systems across flight simulator platforms.

Figure 3. Transport airplane cockpit configuration of Desdemona continuous-G flight simulator. Image courtesy TNO.

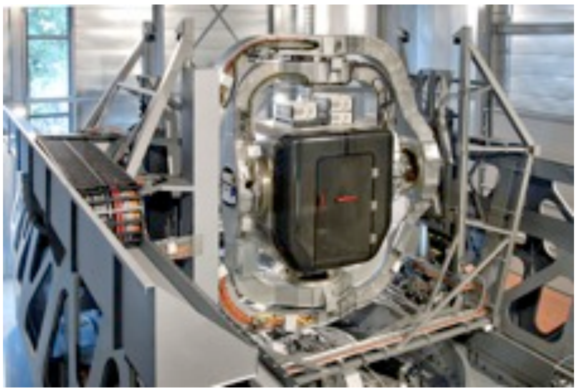

Figure 4. Six-degrees-of-freedom plus continuous-G motion system of Desdemona flight simulator. Image courtesy TNO.

A generally-accepted consideration is that the lack of g-cues in hexapod-type simulators limits their benefit during a recovery phase. Even abrupt maneuvering for which the specific forces and angular accelerations cannot be accurately presented in a motion base (without the presence of significant false cues). Reduction of motion amplitudes is one alternative, however little research has been performed to support a proper conclusion.

The ICATEE training matrix has proposed that for teaching g-orientation (reduced, negative, increased), managing g-loading, for spatial disorientation during recoveries, and high bank-angle recoveries, continuous-g devices may be employed. These systems could provide a ground-based alternative to in-flight training for some parts of the flight envelope, while also offering a representative civil transport cockpit environment. Figure 3 shows the interior of the Desdemona simulator, Figure 4, which has a continuous-g capability (up to 3 g) as well as six degrees of freedom motion. The generic transport cockpit is part of the SUPRA European project[13], taking place currently.

G. Upset Forcing Function

The creation of upsets in flight simulation is a subject of contention. In current training practices, several methods exist. In some cases, one pilot brings the aircraft into an upset, while the other is then required to recover. In other cases, the instructor introduces an upset through the IOS. There are also cases where the instructor fully prepares a pilot for an upset and guides them through the situation before asking them to recover.

ICATEE has recommended that an upset be created in a realistic manner. From an analysis of accident investigations, upsets have often occurred when the pilots were distracted, loaded with non-flying tasks, inattentive, or during conditions where it was not expected. Hence, an externally-generated stimulus could be created. Conceptually, the aircraft "flies" into a zone where an external forcing function introduces an artificial roll rate to the airplane, for example, upon the command of the instructor operator. The pilots, if aware of the situation, can respond to it in a constructive manner and exercise the proper avoidance or, if necessary, recovery techniques.

VI. Discussion

Simulator modelling and fidelity specifically aimed at improving feedback to the pilot in flight regimes corresponding to extended envelopes have been discussed so far. The key issue that needs to be understood is the effort required to achieve these goals, the true training benefit of going beyond what is available today (including the dangers of negative training), and the ability to consistently apply the results on a broad scale.

The main areas requiring further development in flight simulation are outlined in Table 4. Areas identified by "Enhancements Necessary" are areas of near-term development. The inclusion of enhanced stall models and icing effects is an area of longer-term developments.

Table 4. Recommended enhancements in flight simulation to support UPRT

FFS TRAINING ELEMENT / ENHANCEMENT REQUIRED?		Are Today's FFS Models Capable?	Enhancements: Improved Instructor Training	IOS Information Mods	IOS URT Scenarios	Upset Drivers	Improved Icing Model	Stick Pusher Calibration	Improved Stall Buffet	Improved Stall Model
Awareness / Academics		Yes	EN	-	-	-	-	-	-	-
Prevention (Recognition & Avoidance)		Many	EN	-	-	-	EN	-	EN	-
Recovery	Unusual Attitude Recovery Training	Yes	EN	EN	EN	-	-	-	OK	-
Recovery	Train to Stick Shaker / Stick Pusher	Most	EN	-	-	-	OK	EN	OK	-
Recovery	LOFT Upsets	Most	EN	OK	-	EN	OK	-	OK	OK
Recovery	Icing / Upsets	Some	EN	OK	-	OK	EN (Many)	-	EN	OK
Recovery	Full Stall & Recovery	No (TBV)	EN	OK	-	OK	-	N/A	EN	EN (TBV)

Legend:	
EN	Enhancement Needed
-	No FFS Enhancement Needed
OK	May be helpful
TBV	To be verified

For the levels of mitigation, one of the main improvements required in training awareness skills is not the simulator but the instructor. For prevention, where the first indications of an upset may occur, icing models and stall buffet enhancements are recommended.

The area of recovery training in simulators is one that will also require enhancements to IOS feedback, the implementation of scenario-based training and methods of externally driving the upsets. Calibration of stick pushers, if available, are also recommended. The main technical challenge is in the improvement of stall models.

For all the above, technical development supported by research that considers also the benefits of these enhancements is necessary. For the majority of the developments, solutions are fairly accessible. The enhanced modeling of stalls will require long-term research and development.

VII. Conclusions & Future Work

Given that LOC-I is the main cause of fatalities in commercial aviation,[14] coupled with the lack of systematic training to prevent upsets that lead to the associated accidents in this area, it is valuable to consider how simulation technology can contribute to improving the safety record. Pilot awareness of the causes of upsets, recognition of the initial indications and corrective avoidance are the first and foremost steps. Sometimes, corrective action can include taking no action, by recognizing that the aircraft may on its own perform the required corrective action through the automated flight control system. In the rare event of an upset, pilots should be equipped with the skills to effectively, safely and reliably recover from these situations.

Upset prevention and recovery training requires a comprehensive approach involving academics, in-flight training, and flight simulator exposure. Simulation is the closest representation of the cockpit environment, and provides the pilot with exposure to the instrument conditions associated with upsets. In most cases, the motion cues are restricted due to the limited motion envelope of the hexapod.

The main areas of improvement to flight simulation technologies that ICATEE recommends are:

- Improved modeling of the fully-developed stall regime, including a representative model of the airplane
- Improved buffet modeling to provide accurate awareness cueing
- A standardized motion cueing criterion
- An upset training IOS
- Scenarios that induce surprise
- An external aircraft upset forcing function

In the long term, additional issues need to be considered. Stall model fidelity and modeling techniques, as well as icing effects are of primary concern.

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