Aeroplane Upset Recovery Training

History, Core Concepts & Mitigation

A Specialist Paper by the Royal Aeronautical Society
October 2010

Royal Aeronautical Society
Flight Operations Group

The Flight Operations Group (FOG) committee consists of 41 members and ten Consultants from both the civilian airline and military transport & flying training sectors, with Flight Safety and the Quality of Training throughout the Public Transport Industry being its primary objectives. The FOG is a discussion group that focuses on issues which primarily concern civil aviation, although it touches upon aviation safety in the armed forces, specifically where the safety issues could also be applicable to civilian operations. Its membership is highly respected within the civil aviation operations area and brings together a team with many years of experience in the field of aviation.

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This Paper represents the views of the Specialist Group of the Society. It has not been discussed outside the Learned Society Board and, as such, it does not necessarily represent the views of the Society as a whole, or any other Specialist Group or Committee.

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A Specialist Paper developed by
The Flight Operations Group (FOG)
FOG Watch Publications
Editorial team

From an original paper by Captain John M. Cox, FRAeS (SOS Inc)

THE REASON WHY

Flight upsets have become the number one cause of fatal aircraft accidents, now that CFIT accidents have been reduced, through installation of Ground Proximity Warning Systems, improved navigation displays with higher navigational accuracy, Constant Angle Non Precision Approach Procedures and finally Enhanced GPWS giving visual display of terrain on the navigation displays.

This Specialist Document is an introduction to Loss of Control in Flight (LOC-I), to use in preparation for the day you face an impending or actual loss of control during flight. It is a brief reference manual to be read and remembered. It gathers advice offered elsewhere and is intended to give pilots more background to add to their experiences in abnormal flight conditions and recovery, whether from impending stalls or fully developed upsets. It also serves as an introduction to the FAA Airplane Upset Recovery Training Aid, compiled with the assistance of the Flight Safety Foundation (FSF), Boeing and Airbus contributors. This Aid should be considered as the 'Bible' on the subject of upsets and recovery therefrom.

Additionally, some material has been included in this FOG publication, as a refresher on the relevant aerodynamics and as an offering on how best to recognise any approach to an aeroplane upset condition, generally referred to as an 'upset' in this document. Recovery from a full upset is also addressed. Aeroplane upsets are referred to in a number of ways in the industry, such as jet upset, or flight upset, et al. In the context of this Specialist Document, LOC-I means 'upset' in this document only, as the term LOC-I in other documents will include other forms of loss of control not covered here.

As ever, staying out of trouble is the primary advice offered. Monitor your instruments at all times and remain focused on the operation, without becoming distracted with peripheral activities that have nothing to do with the flight. Know your power settings and the aircraft attitude you need for the various phases of flight you encounter. Trust your instruments, not your physical reactions to what you think is happening, when you find yourself in an unusual condition.

The intent of this compilation is to make it self-sufficient. Fly to your SOP but remember how to apply what is recommended to get you out of trouble when things go wrong. The content as offered makes this manual a one-stop source of relevant data that should be of interest to pilots of whatever sized aircraft, but do not let that stop you from reading more on the subject. It may save your life.

If you are upside down, at night and with airspeed increasing … but now read on.

Captain Ralph Kohn, FRAeS
FOG Watchkeeper Publications

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Boeing B-52H 61/0026 Stratofortress — Fairchild AFB. Low level stall upset crash, 24 June 1994. *From Wikipedia, the free website encyclopaedia.*

The B-52 on its final steeply banked 360° turn, round the control tower, with flaps and spoilers deployed. *From Wikipedia, the free website encyclopaedia.*

PREAMBLE

This specialist document represents the views of the Flight Operations Group of the Royal Aeronautical Society. It has not been discussed beyond the Learned Society Board and hence it does not represent the views of the Society as a whole. It reflects selectively, guidance contained in the documents listed in Appendix 2 — Bibliography and is a brief introduction to the various sources of upset and their recovery.

This paper has not been endorsed by Airbus. Pilots of all Airbus aircraft should refer to 'The Airplane Upset Recovery Training Aid, Rev 2' (URTA) *and* Airbus Flight Crew Manuals *for background information and detailed procedures applicable to Airbus aircraft. The URTA is available from many sources including the websites of the FAA and Flight Safety Foundation. Employment of techniques other than those specifically approved by Airbus for use on its aircraft may lead to loss of control, or structural failure.*

This is not a training manual. It is a general document where the intention is to raise the awareness of pilots to the threat posed by aircraft upsets and to motivate them to study the characteristics of and the procedures appropriate to their aircraft type. These procedures will be found in their appropriate type specific Flight Manual or Flying Manual of the aircraft that they fly.

The operator of any particular aircraft type will have a preferred Standard Operating Procedure (SOP) for managing the recovery from departures from controlled flight, so as to ensure standardisation across all the crews. In such cases, company SOPs have primacy. Overall, this publication should be seen as indicative rather than prescriptive. Its intent is to offer pilots an idea on what to look for in the event of an upset and be knowledgeable on a recovery procedure, irrespective of the type of aircraft flown.

It must be emphasised that a developing upset will define how prompt or forceful the required control inputs will be to recover from the event. In all cases, the pilot response to an upset must be appropriate to arrest and recover the condition. Up to full-scale control deflections may be necessary; however, initiating recovery with arbitrary full-scale control deflections could actually aggravate the situation. An excessive or inappropriate control input that overshoots the desired response can startle the pilot and cause one upset to lead to another. Pilots must also be reminded that opposite lateral control inputs potentially exacerbate the situation, with increased drag and flow separation (Q400 accident Buffalo — 2009) so these inputs and lateral departure from controlled flight, must also be avoided. Structural damage with Secondary upsets and stalls could be induced, resulting in unrecoverable events.

Where 'Upset Recovery Training' is mentioned in this document, it is recommended that any such training should be according to manufacturers' drills and the Airplane Upset Recovery Training Aid (URTA) guidance, addressing all three phases of the upset scenario: Avoidance, Recognition and Recovery (see Appendix 2 — Bibliography for details of the URTA guide).

Note on Sources: Except where specifically cited, this document with its graphics and diagrams, generally reflects work contained in the document captioned Airplane Upset Recovery Training Aid (URTA) as revised.

Guidance in this RAeS Flight Operations Group Upset Recovery document is consistent with the content and recommendations of the URTA, in addition to industry best practice standards. The Training Aid was created at the request of the FAA. It is a Flight Safety Foundation (FSF) product, prepared by the Upset Recovery Industry Team of representatives from the FSF, Airbus and The Boeing Company which may be downloaded from both the FAA and the FSF websites as indicated in Appendix 2 — Bibliography.

PART ONE: HOW SIGNIFICANT IS THE IN-FLIGHT LOSS OF CONTROL THREAT?

1.1 INTRODUCTION AND HISTORY

Aeroplane manufacturers, airlines, pilot associations, flight training organisations, and regulatory agencies are increasingly concerned with the incidence of loss of control events. Accidents resulting from loss of aeroplane control (referred to as an 'upset' in this document) have, and continue to be, major contributors to fatalities in the commercial aviation industry. In fact, since the decline of Controlled Flight into Terrain (CFIT) accidents due to technological breakthroughs, Loss of Control — In flight (LOC-I) has become the number one cause of hull losses and fatalities in worldwide Commercial Air Transport.

1.2 LOSS OF CONTROL (LOC-I) EVENTS

Aircraft upsets are sometimes unavoidable but they are most often recoverable by use of appropriate and correct piloting techniques. These incidents may well be prevented by Upset Recovery Training. Unfortunately, some accidents now classified as LOC-I, such as structural or system failures, may not be prevented by Upset Recovery Training but it is hoped that such training will reduce and ultimately eliminate LOC-I events.

1.2.1 Prevention and Recovery

A fundamental requirement of LOC-I prevention consists of sound crew knowledge, good operating procedures and crew monitoring discipline. However, because not all upsets can be avoided, upset recovery training is essential, It is hoped that this document may help with the setting-up of upset recovery and LOC-I prevention programs.

To illustrate, the aim in the current 'Airplane Upset Recovery Training Aid' manual, is to prevent 'upsets' especially at high altitude, besides training for an 'upset' recovery, should this prevention not succeed.

Suitable Crew Resources Management (CRM) procedures and proper monitoring are essential from all on the flight deck, to prevent LOC-I and CFIT events from happening.

1.2.2 Loss of Control situations (LOC-I)

The chart at Figure 1 illustrates the relationship between loss of control in flight (LOC-I) accidents and those caused by Controlled Flight into Terrain (CFIT). It has been simplified in order to provide only a comparison between the two major causal factors under discussion. The data has been drawn from two studies, one by The Boeing Airplane Company and the other by ICAO. The left group (1987-2005) shows CFIT/LOC-I data prior to the development and deployment of sophisticated TAWS/EGPWS equipment (Terrain Alerting and Warning System/Enhanced Ground Proximity Warning System). The right group displays the same data for the period 1999 to 2008, and shows that Loss of Control In-flight replaced CFIT as the main causal factor for fatal accident to the Worldwide Commercial Jet Fleet.

On the basis of this information it can safely be asserted that LOSS OF CONTROL IS THE 'NUMBER ONE' RISK NOW — IF TAWS/EGPWS IS FUNCTIONAL.

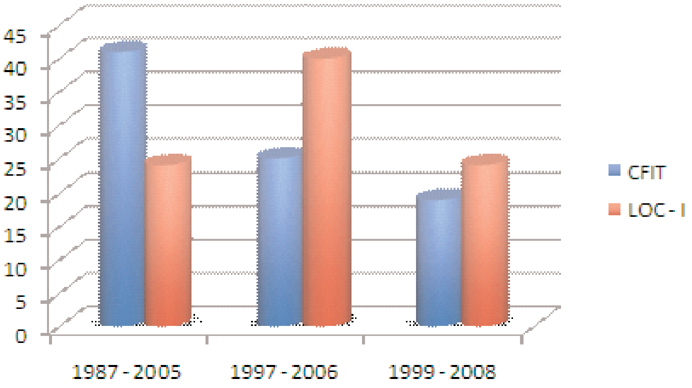


Figure 1. *Prepared by Capt Robert A.C. Scott, FRAeS.*

1.3 LOSS OF CONTROL (LOC-I) ACCIDENTS

Resources are finite in any business. Industry safety professionals are tasked with determining the primary issues of concern, then addressing them in a planned and forthright manner. Data clearly establishes loss of control in flight (LOC-I) as the primary danger today in flight operations.

An upset is not necessarily a departure from controlled flight (i.e. a stall/spin) but it also includes abnormal attitudes and gross over/under-speed conditions. An upset can be caused by a number of things, either separately or together. There are several reasons such events occur:

1. Auto-Pilot or Auto-Thrust problems and failures.
2. Miscalculated or wrong data entered into flight computers — giving rise to incorrect *V* speeds etc.
3. Loss of flight augmentation systems — e.g. flap/slat failure.
4. Loss of flight instruments e.g. after a birdstrike or in severe icing.
5. Environmental factors such as severe turbulence (CuNims/CAT/Wake turbulence), Volcanic Ash or icing, especially at night.
6. A lack of awareness, anticipation and/or attention by the pilots, possibly exacerbated by fatigue, illness or disorientation, poor monitoring, distraction or inaction.
7. Inappropriate flying techniques and crew-monitoring, especially when hand-flying (e.g. during a manually-flown Go-Around) or after a stall/near-stall at high altitude with the AP engaged.
8. Primary flight control problems.
9. Equipment malfunction(s).

Investigation of pilot actions during these events suggests pilots require specialised training to cope with aeroplane upsets. Research indicates most airline pilots rarely experience aeroplane upsets during their flying careers. It also indicates that many pilots have never trained in maximum-performance aeroplane manoeuvring, such as in aerobatic flight.

This does not necessarily suggest the need for training in aerobatics. However, aerobatics are proven to increase confidence, situational awareness, judgement and flying ability as well as teaching the quickest methods of recovering from unusual attitudes and loss of control. While lack of current experience in aerobatics may cause some loss of skills this is no different from the loss of skills found by the overuse of the aircraft's automatics. Aerobatics experience is merely one of the benefits of full and comprehensive training in upset recovery techniques.

1.3.1 Aeroplane upset

For our purposes, aeroplane 'upset' is defined as an aeroplane unintentionally exceeding the parameters normally experienced in line operations or training.

While specific values may vary among aeroplane types, the following unintentional conditions generally describe an aeroplane 'upset', as defined in the current FAA manual captioned 'Airplane Upset Recovery Training Aid'. Significantly, these flight conditions often occur in combination.

- Aircraft pitch attitude greater than 25° nose up.
- Aircraft pitch attitude greater than 10° nose down.
- Aircraft bank angle greater than 45°
- Flight within the above parameters but at airspeeds inappropriate for conditions.

Loss of control in flight (LOC-I) is established by the aviation industry, as a potential event demanding immediate and decisive attention to avoid further loss of life, vast financial losses, and decline of public confidence. In past years several developments in technology and improved training have resulted in significant safety improvements for the industry. Generally accepted developments increasing safety have been:

- The reliability of the modern jet engine.
- Improved and operator-friendly avionics.
- Improved training.
- Proactive not reactive safety programs.
- Technological improvements.
  1. Weather Radar.
  2. TCAS.
  3. TAWS.

CFIT reigned for years as the number one cause of hull losses and loss of life. The industry responded in a variety of ways including increased training — at least in emphasis, while regulatory agencies issued directives and regulations to companies and pilots regarding the seriousness of the matter. Such results produced some mitigation of the problem, but CFIT did not cease to be the major cause of accidents and loss of life until the advent of TAWS, with its mandatory installation and use.

Technology offers little assistance with the challenges inherent in flight upset, unless the aircraft are Fly-By-Wire/Flight Envelope Protection (FBW/FEP) equipped. Later Boeing and Airbus aircraft have auto-flight bank angle protection, etc. However, conventional aircraft technology, especially in automatic flight, has not reached the point where it can react and control flight actions at or beyond the parameters of upset in all circumstances. In fact, in an era when regulators encourage crews to utilise auto-flight and other sophisticated flight aids to the maximum degree possible, pilots are facing a situation where the parameters of flight 'upset' result in the disconnection of those same systems in some aeroplanes. Faced with such a challenge, the crew must then deal with an unfamiliar flight situation they are not ready for and have not been prepared to deal with. This 'shock' or 'stun' factor must be recognised when formulating the solution.

By necessity, flight 'upset' becomes a training question because of the technology resistant nature of the problem. The solution demands a practical approach, using already existing training aids, while remaining within the guidance of the current 'Upset Recovery Training Aid' guide. The need is established by a string of deadly accidents that illustrate the problem.

We should dispense with the common psychological barrier to action represented by the belief that "it won't happen here", because this is dangerous complacency. Anything less than a professional and active training program is no longer acceptable. To do otherwise would create the conditions that increases risk and could lead to a disaster. Training for flight upset should be as much part of a business model as anything else related to training and safe operations. **No airline or operator expected the following accidents to occur with their crews and aircraft, yet they did, with catastrophic results when not recovered.**

1.4 UPSET OCCURRENCES

1.4.1 Upset crash.
1.4.2 Upset recovery.
1.4.3 Go-around upset crash

Events discussed under this heading demonstrate the challenge ahead for the industry. Issues include the proper use of technology, preserving and enhancing non-automated pilot flying skills, corporate commitment, regulatory understanding and oversight and, significantly, 'buy in' by the pilot groups.

The post-American 587 syndrome (see Appendix 1) is finally waning under the pressure of events and acceptance of the problem. A growing number of operators are developing and implementing pilot training programs, including academic and simulator training. Regulatory agencies are again encouraging airlines to provide education and training in the subject. Aeroplane manufacturers have responded to the challenge by leading an industry team, formed to develop the Aeroplane Upset Recovery Training Aid, with the FAA and other industry experts. This 'aid' provides basic but useful guidance and templates for a training program, as well as sample training manual revisions and lessons to begin the process on the correct footing.

Upset recovery training should be according to manufacturers' drills and the *Airplane Upset Recovery Training Aid* guidance, covering all three phases of the upset scenario: Avoidance, Recognition and Recovery.

General Conclusions

As we have seen, aeroplane upsets happen for a variety of reasons. Some events are more easily prevented than others. Improvement in aeroplane design, aerodynamic simplicity and equipment reliability continues to be a goal. Avoidance of a situation that can cause an upset is a basic tenet and incorrect training must be avoided. Technical malfunctions outside of the norm have historically been rectified after accidents and when pertinent, have been included in new Certification requirements of aircraft.

However in too many recent accidents, the pilots' inability to recover from an unintended in-flight condition (upset or stall) has resulted in the loss of the aeroplane and occupants. The numbers of these types of accidents can, and should, be reduced. Accident data is clear; the greatest risk to Commercial Air Transport is loss of control in flight. Through proper training and education this risk can be reduced.

Avoidance and Recognition

Avoidance and Recognition are as important as recovery! Too often, in-flight upset is the result of pilot action or inaction.

Awareness and, when possible, avoidance of common external factors such as wind shear, clear-air turbulence, icing, and other external factors is good professional practice. In the end, the pilot's action and his or her awareness are essential factors in preventing 'Upset' events.

Regular professional study is recommended in order to maintain and increase professional competence, as well as avoid 'Upsets'. Pilots are encouraged to study environmental causes of upsets, as discussed in the 'Airplane Upset Recovery Training Aid'.

Let us now look at upset occurrences under three headings.

1.4.1 Upset crash

West Caribbean Airways 708 — MD-82 — 16 August 2005

Comité de Investigación de Accidentes Aéreos (CIAA, Aircraft Accidents Research Committee) of Venezuela.

On 16 August 2005, West Caribbean Airways flight 708, an MD-82 (HK-4374X) charter flight from Panama to Martinique, descended from cruise altitude in a nose up flight attitude, and crashed near Machiques, Venezuela, killing all 160 persons aboard.

Investigation by the Venezuela CIAA showed ground scarring indicating impact in a nose up, slight right roll attitude. Wreckage was distributed over a triangle shaped area, about 205 metres long by 110 metres at the widest point.

Both engines exhibited indications of high-speed compressor rotation at the time of ground impact, while the engine inlets, empennage and wing leading edges showed no sign of pre-impact damage.

The horizontal stabiliser was found at about the full aeroplane nose up position (12 units).

Additionally, the FDR showed that the aircraft had slowed while at cruise altitude, before beginning a descent that did not cease until ground impact. The stick-shaker activated and the aeroplane entered a deep stall.

Probable Prime Cause: A heavy aircraft flying in 'coffin corner' (See 2.3.13) close to its limiting altitude (FL330) on the day, a height they could not keep due to the weight. The rapid climb from FL310 using autothrottle, made it power-back the engines too much without the pilots realising this. Autopilot started to raise the nose to compensate, then disconnected and the plane entered a deep stall. The crew did not recognise the stall and did not recognise the low power from the engines. No stall recovery was attempted.

Avoidance Strategies: Ensure that crews have access to accurate and OEM-approved descriptions of the flight characteristics of the MD-82 in the slow flight regime and receive simulator training in recognition and avoidance of the *en route* stall by proper use of the autoflight system. Particular emphasis must be placed on the unrecoverable nature of the deep stall in the MD-82.

1.4.2 Upset recovery

Malaysian Flight 124 — B777 — 1 August 2005

Boeing 777–200 in Boeing livery. *Boeing photo.*

At approximately 17:03 Western Standard Time, on 1 August 2005, a Boeing 777-200 aircraft, registered 9M-MRG, was being operated on a scheduled international passenger service from Perth to Kuala Lumpur, Malaysia, 240km north-west of Perth, WA, the crew reported that, during climb out, they observed a LOW AIRSPEED advisory on the aircraft's Engine Indication and Crew Alerting System (EICAS), when climbing through flight level (FL) 380. At the same time, the aircraft's slip/skid indication deflected to the full right position on the Primary Flight Display (PFD). The PFD airspeed display then indicated that the aircraft was approaching the overspeed limit and the stall speed limit simultaneously. The aircraft pitched up and climbed to approximately FL410 and the indicated airspeed decreased from 270kt to 158kt. The stall warning and stick shaker devices also activated. The aircraft returned to Perth where an uneventful landing was completed.

Approximately 18 minutes after takeoff, as the aircraft climbed through 36,500ft, Flight Level (FL) 365, a pitch upset event commenced in response to erroneous vertical, lateral and longitudinal acceleration data provided by the Air Data Inertial Reference Unit (ADIRU) to the aircraft. The data was not flagged to the aircraft as invalid. Erroneous acceleration values were recorded for the remainder of the flight. The autopilot was manually disconnected and nose down control column was applied by the crew. The aircraft pitched to 18° nose up and climbed to approximately FL410 with a rate of climb up to 10,560ft per minute (fpm). The airspeed decreased from 270kt to 158kt. The autopilot (A/P) overspeed and stall protection activated simultaneously and the autopilot flight director system (AFDS) pitch mode failed prior to A/P disconnection. The stick shakers activated near the top of the climb.

The aircraft subsequently descended 4,000ft before momentary re-engagement of the autopilot by the flight crew resulted in another nose-up pitch (13°) and climb of 2,000ft. The maximum rate of climb during this excursion was 4,400fpm. The response of the aircraft reported by the flight crew was confirmed from the FDR data.

During the occurrence, the autothrottle system remained active or armed, even though the pilot in command attempted to disconnect it by pressing the thrust lever disconnect switch and pushing the autothrottle engage switch. The reason it remained active was because the flight crew did not de-select the autothrottle arm switches from the ARMED position to the OFF position. As a consequence, the autothrottle activated and automatically advanced the thrust levers when it sensed a low-speed condition, as a result of erroneous data being provided by the ADIRU.

The flight crew conducted a descent and return to Perth from FL380 without the autopilot engaged. During the approach, the aircraft's windshear alert warning system indicated a windshear condition, but the crew continued and landed the aircraft on Perth runway 03. The flight time was 46 minutes. The CVR was of limited value in this analysis because the upset event had been overwritten by subsequent ground operations.

Summary

This occurrence highlights the reliance of modern transport aircraft on computer software and hardware for successful operation. The ADIRU operational program software had been tested and certified to the standard required at the time of certification. However, that testing was limited to the original specification and requirements of the component. The increased use of automation to manage internal hardware failures was designed to reduce the workload of the flight crew, by reducing the number of checklists that require action in the event of a non-normal situation. When the hardware failure occurred, combined with the software anomaly, the crew were faced with an unexpected situation that had not been foreseen. Subsequently, the crew had not been trained to respond to a specific situation of this type and had no checklist to action for 'airspeed unreliable'.

Findings

Contributing safety factors

- An anomaly existed in the component software hierarchy that allowed inputs from a known faulty accelerometer to be processed by the air data inertial reference unit (ADIRU) and used by the primary flight computer, autopilot and other aircraft systems.

Other safety factors

- The software anomaly was not detected in the original testing and certification of the ADIRU.
- The aircraft documentation did not provide the flight crew with specific information and action items to assess and respond to the aircraft upset event.

Probable Prime Cause: Technical failure of sub-component ADIRU with software error connotations.

Avoidance Strategies: Crew acted correctly within the scope of their knowledge. Abnormal airspeed indication drill card needs to be prepared by the company and incorporated in the QRH.

1.4.3 Go-around upset crash

The following example of a go-around upset accident identifies the necessity of being aware at all times of the aircraft 'Automatics' mode. It is also vital to remain aware of trim changes during a go-around and the vital need to correct the trim condition of the aircraft as it changes with the application of power. This includes the need for positive monitoring by the Pilot not Flying (PNF), now termed Pilot Monitoring (PM). This particular accident is a heavily CRM/HF orientated failure.

China Airlines A300-600 — Nagoya, Japan — 26 April 1994

Airbus A300-600R of China Airlines. *Airbus photo.*

Crew errors led to the aircraft stalling and crashing during approach. All 15 crew and 249 of the 264 passengers were killed.

Aircraft Accident Investigation Commission, Ministry of Transport, Japan, Accident report causes, abstract

While the aircraft was making an ILS approach to Runway 34 of Nagoya Airport, under manual control by the F/O, the F/O inadvertently activated the GO lever, which changed the FD (Flight Director) to GO AROUND mode and caused a thrust increase. This made the aircraft deviate above its normal glide path.

The Auto Pilots were subsequently engaged, with GO AROUND mode still engaged. Under these conditions the F/O continued pushing the control wheel in accordance with the Captain's instructions to continue the approach. As a result of this, the THS (Horizontal Stabiliser) moved to its full nose-up position and caused an abnormal out-of-trim situation.

The crew continued approach, unaware of the abnormal situation. The AOA increased and the 'Alpha Floor' function was activated because the aircraft was physically below its programmed height with the nose-up pitch angle increasing.

It is considered that, at this time, the Captain who had now taken-over the controls, judged that landing would be difficult and opted for go-around. The aircraft began to climb steeply with a high pitch angle attitude. **The Captain and the First Officer did not carry out an effective recovery operation, and the aircraft stalled and crashed.**

Probable Prime Cause: Incorrect use of approach & go-around automatic modes and TO/GA on go-around, with insufficient attention given to holding nose down while counteracting approach trim settings on climb-out.

Avoidance Strategies: A first remedial action is better training in awareness of aircraft performance with proper AP operation, followed by 'Upset' recognition and recovery training. Pilots should also undergo auto-approach and auto/manual go-around upset avoidance/recovery training with additional instruction on CRM positive monitoring and challenging techniques.

SEE APPENDIX 1 FOR MORE EXAMPLES OF UPSET EVENTS

PART TWO: AIRCRAFT AERODYNAMICS AND UPSETS

2.1 INTRODUCTION

Currently, consensus on upset causes and recovery techniques does not exist. Opinions tend to vary dramatically and recommended techniques are often contradictory from one authority to the next. Training providers and upset recovery curriculum developers often incorrectly expect a relatively high level of awareness and proficiency among aircrew. They also tend to assume high levels of situational awareness, intuitive understanding of how to overcome an aeroplane upset and an innate ability to overcome the incapacitating nature of an aeroplane upset. Evidence of accident investigation past and current does not justify these assumptions.

This document offers generalised guidance for the commercial pilot, utilising knowledge transferable to almost any type or class of swept wing jet aircraft. The temptation to assume every upset is unique and that an infinite variation of combinations of pilot control inputs may be necessary, should be resisted. Each aircraft can have characteristics that require specific attention by the pilot. It is the pilot's professional responsibility to know what these are and how they must be considered in an upset recovery scenario. For instance, the instability of swept wing aircraft in a stalled condition is known and must be taken into account.

Often the first challenge to be overcome in an upset event is spatial disorientation. Situational Awareness and resulting limits to pilot functionality are important issues in an aeroplane upset. Misunderstanding orientation of the aircraft, due either to inaccurate situational awareness or to a developing mental state of spatial disorientation, has caused accidents. This is even true when the pilot is hand-flying the aeroplane. Upset scenarios are incapacitating to the experienced and inexperienced alike. More troubling, CVR data shows crews ignoring many '*bank angle, bank angle*' cues from the avionics. There is evidence that aircrew have disregarded, even actively competed against, integrated flight envelope protection such as stick shakers and pushers; or have taken inappropriate action such as engaging the autopilot or rolled the wrong direction while disoriented. In some cases, investigators have concluded pilots thought they were smarter than the systems, or were not paying attention to the cues at all.

2.2 AERODYNAMIC CONSIDERATIONS

Before addressing the key issues around aircraft recovery from an in flight upset, a review of aerodynamic physics and rules may be helpful. This will emphasise the nature of the stall and especially the stall in swept wing turbojet aircraft.

2.2.1 Core concepts

To refresh memories, a review of the basic definition of Upset as defined in the 'Aeroplane Upset Recovery Training Aid', is useful. Should the aircraft find itself, regardless of cause, in a flight condition described hereunder, or worse, an upset situation exists:

- Pitch attitude more than 25° nose up.
- Pitch attitude more than 10° nose down.
- Bank angle more than 45°.
- Flight within the above parameters, at airspeeds inappropriate for the conditions.

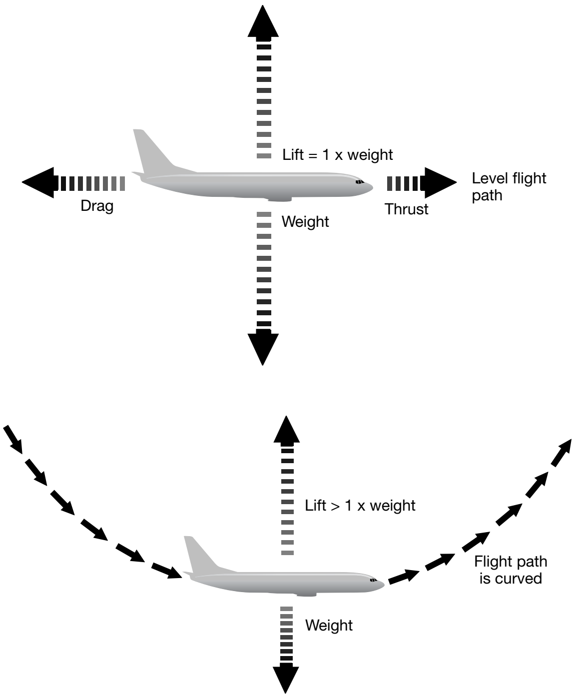


Figure 2.

2.2.2 Attitude control

How a pilot perceives the attitude of the aircraft, dictates his flying control inputs. Accurate perception helps to interpret roll, yaw and pitch movements correctly. Ailerons (and/or spoilers) control movement around the roll (longitudinal) axis. Regardless of what the pilot sees, manoeuvring the aircraft in roll can be thought of as head-to-hip or hip-to-head movement. Rudder controls movement around the yaw (normal) axis. Regardless of aircraft attitude, yaw will appear as an ear-to-ear movement to the pilot. The elevator controls movement about the pitch (lateral) axis and pitch will always appear as head-to-foot or foot-to head movement.

2.2.3 Load factors

The Load Factor measures acceleration as experienced by the aeroplane. Load factor is usually expressed as units of gravity (g). Acceleration (or load factor in g) is discussed relative to the principal axes of the aeroplane:

a. Longitudinal (fore and aft, thought of as speed change).
b. Lateral (force pushing or pulling the pilot out of his seat sideways).
c. Vertical (normal or force pressing the pilot into or pulling him out of his seat-bottom cushion).

Frequently, load factor is incorrectly seen as being only perpendicular to the longitudinal axis of the aeroplane. Load factor may be at any orientation to the aeroplane; the vertical, or normal, load factor represents only one of three possibilities.

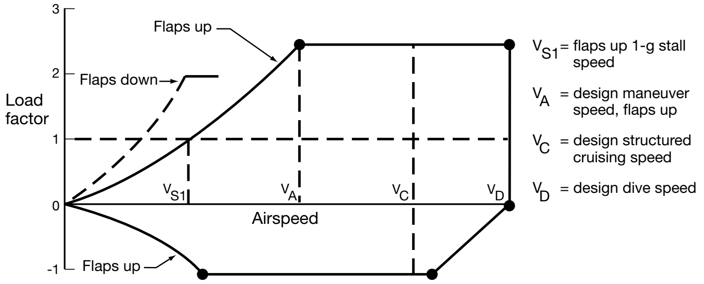


Figure 3.

In level flight, the vertical load is equal and opposite to the gravity vector acting on the aircraft, or 1g. The wing is producing lift equal to the weight of the aeroplane and is oriented in a direction opposed to the gravity vector. In a pull-up, or with any aft control movement, the load factor increases above 1g. If the pull force generated by the aeroplane (wings, fuselage, etc.) is twice that of gravity, the pilot would feel a force of 2g, with the flight path curving as shown in Figure 2.

Typically, current jet transport aeroplanes are certificated to withstand normal vertical load factors from –1.0g to 2.5g in clean configuration.

Figure 3 is a typical v-n diagram for a transport aeroplane (with ‘v’ for velocity and ‘n’ for the number of gs in acceleration).

Note on the v-n diagram, below Va (manoeuvring speed), the pilot has the ability to place the aircraft into a stall before reaching the 2.5 g limit load factor. **This would be an important consideration in recovery from a dive.**

If the speed is higher than Va, or if Va is unknown (not untypical in transport aircraft), at turbulence penetration speed, the pilot has the ability to create sufficient ‘g’ loads to overstress the aircraft before stall occurs.

A pilot must be concerned about lateral and vertical load factor limits. One or both of these load factor limits can easily be exceeded in transport aircraft, by generating excessive angle-of-attack or sideslip. The pilot controls angle-of-attack and vertical load factor with the elevator through the control column. Regardless of attitude, if back pressure on the control column is applied, so increasing the angle-of-attack, the vertical load factor increases. Conversely, applying forward pressure on the control column reduces the angle-of-attack and decreases the load factor.

Sideslip load factor is normally controlled using rudder. Asymmetric thrust can also generate sideslip, but excessive sideslip load factor is usually generated by over control of the rudder. Excessive use of rudder can cause significant structural damage or failure (See AA587 report in Appendix 1). Rudder induced structural damage can occur at airspeeds well below manoeuvring speed (Va).

2.2.4 Angle-of-attack (AOA)

AOA is also denoted by ‘alpha’ (α), and is the angle of the average chord line of the wing to the relative airflow, (See Figure 4(a))

The lift generated by a wing depends on the airspeed and the density of the air, together with the wing’s shape, area, and AOA; these last three factors comprise the ‘coefficient of lift’.

The coefficient of lift changes with the AOA but is independent of the airspeed. As the wing’s AOA increases, the coefficient of lift increases to a maximum point and then rapidly decreases (Figure 4(b)), so further increase in AOA beyond this point results in a decrease of lift and an increase of drag. The AOA at which the maximum lift is produced is known as the **stalling or critical AOA**.

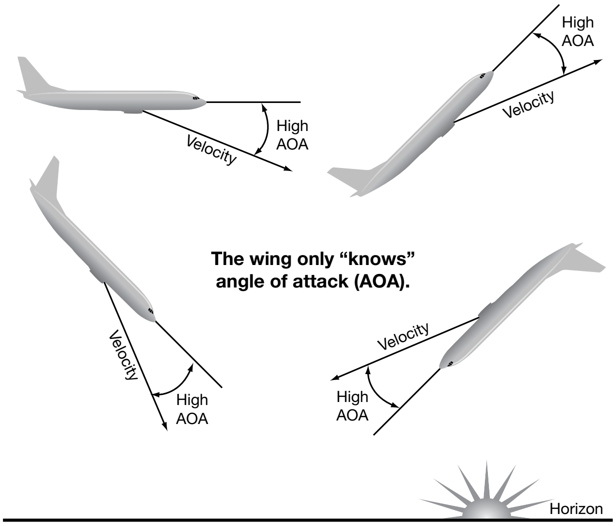


Figure 4(a).

If the AOA is increased beyond critical AOA (stall angle), the smooth flow of air over the wing will break down and the wing will stall resulting in a decrease of lift. This is true regardless of aeroplane speed or attitude. Therefore, to sustain a lifting force from the wings, the relative airflow over the wings must be maintained at an AOA below the stall angle.

To determine if the aircraft is in a stalled condition the following flight cues, either singly or in combination, provide useful information.

- buffeting, which may be severe reduction of pitch control authority
- reduction of roll control authority
- Inability to arrest descent rate

These situations are usually accompanied by a continuous stall warning (in icing conditions the wing may stall before the stall warning sounds/activates). A stall must not be confused with the approach-to-stall warning that occurs prior to the stall. An approach-to-stall is a controlled flight manoeuvre. A full stall is recoverable if resolved early in the stall. A prolonged stall condition can lead to an unrecoverable deep stall or a developed spin.

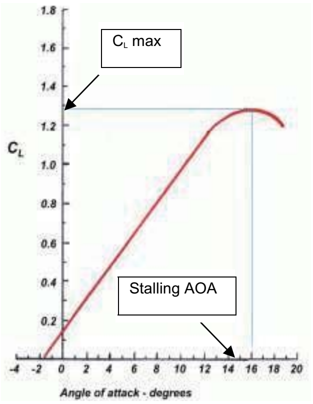


Figure 4(b).

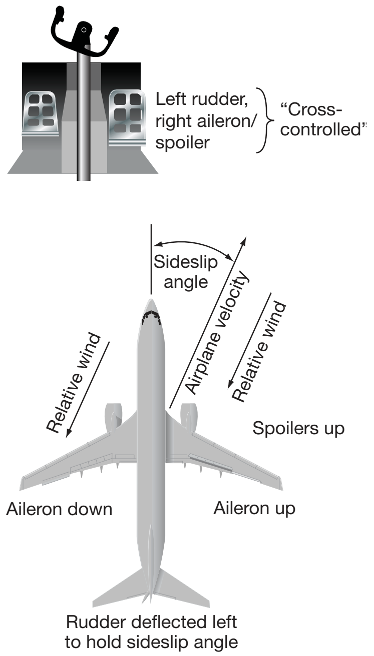


Figure 5.

On rectangular shaped wings typical of light general aviation aircraft used during initial flight training, a wing's stall pattern (i.e. boundary-layer separation on top of the wing) begins at the wing root and advances outward to the wingtip. This characteristic combines early stall warning with prolonged lateral control as airflow separates. However, swept-wing aircraft inherently display undesirable stall behaviour compared to an aircraft with straight wings. A swept-wing's stall progression starts at the wingtips first.

A simple swept and tapered wing will tend to stall first at the wingtips because the high loading outboard, due to taper and is aggravated by sweep-back. The boundary-layer outflow also resulting from sweep reduces the lift capability near the tips and further worsens the situation. This causes a loss of lift outboard (and therefore aft) which produces pitch up. A lot of design sophistication is needed, including the use of camber and twist, leading-edge breaker strips, fences etc., to suppress this inherent raw quality and cause an inboard section to stall first, so that the initial pitch tendency is a more desirable nose down. However, when a highly developed swept wing is taken beyond its initial stalling incidence, the tips may still become fully stalled before the inner wing in spite of the initial separation occurring inboard. The wing will then pitch up. (D.P. Davies — *Handling the Big Jets*)

On multi-engine swept-wing transport aircraft, flow separation from the area around the engine pylons contributes significantly to different lateral stability characteristics (less susceptibility to wing drop), with the onset of more widespread flow separation and loss of lift.

Airflow separation at the stall compromises aileron (or spoiler) control with little aerodynamic warning. In certification, transport category aeroplanes must demonstrate maintenance of control right up to the stall. Specifically, in a 30° banked slowdown to a stall, the aeroplane must be able to maintain 30° of bank into the stall, using whatever aileron and/or spoiler inputs are required. Those inputs can be dramatic.

Although all wings demonstrate negative stability beyond critical AOA, the swept-wing aircraft displays extremely dynamic lateral instability in a stall. This means that a swept-wing aircraft, when stalled can become very unstable, which may require the use of full control authority to immediately reduce the angle-of-attack and regain full aircraft control. At high altitude, sufficient control deflection must be used to ensure that the stall is prevented but control inputs should be smooth. Large control inputs may still be necessary but it is important to guard against control reversals. There is no situation that will require rapid full-scale control deflections from one extreme to the other.

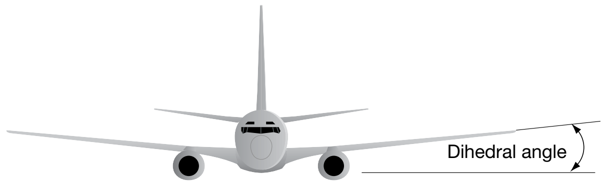


Figure 6.

Once the stall is prevented, smooth and gentle but positive control inputs should be used to recover to normal flight, making sure that a secondary stall is avoided.

It is obvious that, particularly when flying transport category jet swept-wing aircraft, an upset event is best prevented whatever the cause and **the STALL MUST BE AVOIDED**.

2.2.5 Sideslip angle

The sideslip angle is the angle between the longitudinal axis of the aeroplane and the relative airflow, as seen in the plan view (Figure 5).

2.2.6 Lateral and directional stability

Aerodynamically, asymmetric flight, or flight in sideslip, can be quite complex. Sideslip can generate strong aerodynamic rolling and yawing moments.

2.2.7 Wing dihedral

Wing Dihedral is the positive angle formed between the lateral axis of an aeroplane and line that passes through the centre of the wing (See Figure 6). Dihedral contributes to the lateral stability of an aeroplane. A wing with dihedral develops stable rolling moments with sideslip. If the relative wind comes from the side, the wing into the wind is subject to an increase in lift due to increased AOA. These changes in lift effect a rolling moment, tending to raise the windward wing; dihedral contributes to aircraft lateral stability.

2.2.8 Swept wing effect

High speed high altitude flight benefits from swept wing designs that delay the onset of compressibility effects. This wing sweep also contributes to a rolling moment in a sideslip and a similar stabilising force to dihedral effect. When the swept-wing aeroplane is placed in a sideslip, the wing into the wind experiences an increase in lift, since effective sweep is less, resulting in a rolling moment away from this wing. If a swept wing aircraft flying straight and level is disturbed, causing a wing to drop, the induced slide slip (by gravity) will tend to roll the aircraft back to level flight making the aircraft laterally stable. Since rudder input also produces sideslip and induced roll rates will increase with sideslip angle, large roll rates can, in some circumstances, be generated with small rudder inputs and precise control of roll angle using rudder can be very difficult. In addition, high structural loads on the tail assembly can be caused by relatively small rudder input, for which the aircraft structure is not designed. Therefore, **in upset recoveries, USE OF RUDDER IS generally NOT RECOMMENDED and in some cases expressly forbidden**. Pilots inappropriately using rudder for lateral (roll) control have contributed to numerous mishaps.

2.2.9 Roll damping

An aeroplane possesses positive roll damping while in normal flight. If a rolling moment is induced, either from ailerons (or spoilers), wind gust, or yaw from asymmetric thrust as examples, an aeroplane tends to cease rolling when the rolling moment is removed. If an aeroplane is stalled, the aeroplane has negative roll damping. The stall must be recovered properly, or induced rolling moment will cause the aircraft to roll and continue rolling, even after the rolling moment is removed. Not only will the aeroplane continue to roll while stalled, but it will generate ever-increasing yaw as well. Negative roll damping is a major contributor to an aeroplane entering a spin. This can be very critical, as large swept wing aircraft are frequently unrecoverable from a developed spin. Early action to positively reduce angle-of-attack is very important to stall/spin avoidance and recovery.

2.2.10 Weight and balance

Weight and Balance limitations must be respected. An aeroplane loaded outside the weight and balance envelope will not exhibit expected levels of stability and result in unpredictable aircraft handling characteristics, possibly no longer meeting certification requirements. This is a serious issue, particularly in an aft loading situation, where stall recovery may be severely affected. The problem will be exacerbated at high altitude.

At high altitude, an aft-loaded aeroplane will be more responsive to control pressures because it is less stable than with forward loading. When aft loaded, there exists increased possibility to put the aeroplane into a stall if the new control feel is not respected. The further aft an aeroplane is loaded, less effort is required by the tail to counteract the nose down pitching moment of the wing. Some airline load planning computers now attempt to load aeroplanes near the aft limit for cruise, to enhance efficiency. Some advanced aeroplanes have electronic controls programmed to improve aeroplane handling with aft loading.

2.3 AERODYNAMICS AND DYNAMIC MANOEUVRING

Most aircraft do not have an AOA instrument for the pilot to monitor in various phases of flight. Most stall-related mishaps occur during manoeuvring flight, not straight and level. The enormous AOA change the aeroplane creates, as a result of dynamic manoeuvring, is little appreciated. If an aeroplane is doing a 2g dive recovery at a constant airspeed, the AOA has increased and the associated stall speed is higher. Similarly, an aeroplane carrying out a 60° bank, level turn at 2g has a higher AOA; in each case the stall speed will have increased by 41%.

2.3.1 AOA management

If the load factor is reduced, AOA is reduced and the associated stall speed is decreased. Load factor (that is g-loading) can be used for relative AOA control. For a constant airspeed, if back pressure on the control column is applied, increasing load factor in any attitude, AOA increases and the stall speed is increased. If forward pressure on the control column is applied to unload the aeroplane, AOA is decreased and the associated stall speed is reduced. Decreasing AOA or applying forward pressure on the control column (unloading), can decrease stalling angle-of-attack and prevent stall warning, as well as assist stall recovery, if necessary.

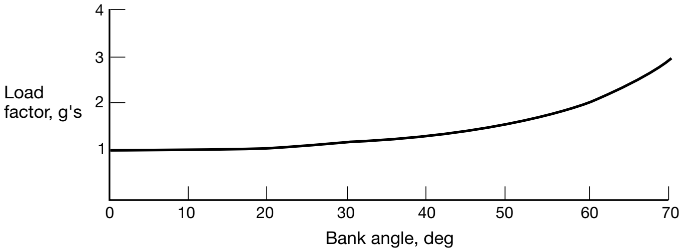


Figure 7.

2.3.2 Manoeuvring in roll and turning flight

Roll controls (ailerons or spoilers) must command a roll into a bank angle to tilt the lift vector in order for an aeroplane to turn. This action generates the horizontal component necessary to turn the aircraft. The rudder is not used to turn the aircraft. The aircraft is turned through the horizontal component of the lift force. Rudder is used during the turn, to co-ordinate the turn, and keeps the nose of the aircraft pointed along the flight path. Also, when the lift vector is tilted away from vertical in a bank angle, the vertical component becomes smaller. To maintain altitude while in the turn, aft movement of the control column is applied, increasing the AOA and associated lift vector and maintaining the vertical component of lift.

All of this is well known, but deserves review in the context of recovery from an upset. To arrest a descent in an over-banked nose low attitude, increasing g-load by applying back pressure on the control column will only cause a tighter turn. Depending on the bank angle, such action may not contribute significantly to generating a lift vector that points away from the ground. Indeed, maintaining level flight at bank angles beyond 66° requires a larger load factor than the 2.5g for which transport aeroplanes are generally certificated (See Figure 7).

Many pilots are warned about the ‘Graveyard Spiral’ in early training. The Graveyard Spiral occurs when the aeroplane is at a large bank angle and descending. In an attempt to arrest both the speed and sink rate, aft pressure on the control column is applied resulting in ‘up-elevator’. At a large bank angle, the only effect of the ‘up-elevator’ is to further tighten the turn. It is imperative to get the wings close to level before beginning any recovery pitching manoeuvre, or application of aft pressure on the control column. Doing so orientates the lift vector away from the gravity vector so that the forces acting on the aeroplane can be managed.

2.3.3 Manoeuvring in pitch

Controlling pitching motion involves controlling aerodynamic moment about the centre of gravity. The pilot controls the pitching moment (AOA) by means of the stabiliser and elevator. The horizontal stabiliser should be thought of as a trimming device, but could be used to control pitch in the event of an elevator failure. The elevator is the primary pitch control. Essentially, the pilot controls the amount of lift generated by the horizontal tail (by moving the elevator), which adjusts the AOA of the main wing and therefore modulates the amount of lift created by the main wing.

An important concept is that if the aeroplane is at a balanced, ‘in-trim’ angle-of-attack in flight, it will seek to return to that trimmed angle-of-attack, even if upset by external forces or momentary pilot input. This is a result of the longitudinal dynamic stability designed into that aeroplane.

Changes in aeroplane configuration also affect pitch control. For example, flap extension usually creates a nose-down pitching moment; flap retraction usually creates a nose-up pitch. Wing-mounted speed brakes usually produce a nose-up pitching moment when extended. Retraction of the flaps aggravated the situation in the Colgan (Buffalo, USA) approach accident. (See Appendix 1)

Pitch attitude may also change with thrust. With under-wing mounted engines, reducing thrust creates a nose-down pitching moment; increasing thrust creates a nose-up pitching moment. This is contrary to the general habit pattern in recovery of adding thrust during a nose high unusual attitude recovery. Thus, adding high power on a nose-high unusual attitude recovery aggravates the nose high attitude for aeroplanes with under wing mounted engines.

2.3.4 Lift vector management

The lift produced by wings is a lift vector always directed perpendicular to the flight path. Controlling the orientation and length of the lift vector is critical for avoiding potential upset scenarios and understanding proper upset recovery technique. The relative position of the lift vector is always the same, but the length of the vector is a function of airspeed and angle-of-attack (AOA).

Practically speaking, if a pilot feels a normal 1g force pressing him in the seat, he is generating a 1g lift vector, regardless of attitude or bank angle. If the pilot applies sufficient back pressure on the control column so that a 2g force is felt, a 2g lift vector is being created. As always, this occurs regardless of pitch attitude or bank angle. If the pilot applies forward pressure on the control column to generate a Negative lift vector, this will always result in negative 'g' and curved flight towards the ground irrespective of pitch attitude or bank angle, due to being less than the 1g required to maintain level flight.

For straight and level flight, the lift vector will be equal and opposite to the gravity vector. If the pilot applies back pressure on the control column to achieve a 2g wings level pitch up from level flight. The lift vector will be twice the gravity vector; hence, curved flight, causing altitude gain, will occur.

If the straight and level aeroplane is rolled into a 70° angle of bank, the same 2g lift vector would be insufficient to generate a lift vector with a vertical component large enough to prevent altitude loss. In fact, any bank angle greater than 66° results in altitude loss, or an inability to stop altitude loss, when the maximum certified design load of 2.5g for a transport aircraft is obeyed.

2.3.5 Energy management

The three sources of energy available to the pilot are:

a. Kinetic energy, increases with increasing airspeed.
b. Potential energy, proportional to altitude.
c. Chemical energy, from the fuel in the tanks

The aeroplane is continuously expending energy; in flight, due to drag. Thrust (from the stored chemical energy) is used to offset the drag associated with flight. During manoeuvring, these three types of energy can be traded, or exchanged, usually at the cost of additional drag. Airspeed can be traded for altitude, as in a 'zoom-climb'. Altitude can be traded for airspeed, as in a dive. Stored chemical energy can be traded for either altitude or airspeed by advancing or retarding the throttles.

This becomes important when the pilot wants to generate aerodynamic forces and moments to manoeuvre the aeroplane. Only kinetic energy (airspeed) can generate aerodynamic forces and manoeuvre capability. Potential energy (altitude) can only be converted to kinetic energy (airspeed).

High-performance jet aeroplanes are designed to exhibit very low drag in the cruise configuration. The penalty for trading airspeed for altitude is relatively small. Jet aeroplanes are also capable of gaining speed very rapidly in a descent, compared to propeller-driven aircraft. This requires considerable judgment. Drag management is an important skill with jet aircraft. Level flight acceleration capability is limited by the maximum thrust of the engines, which is problematic at higher altitudes. Deceleration capability is limited by the ability to generate large amounts of drag, which also can be problematic for a clean jet aeroplane in a descent. A clean aeroplane, operating near its limits, can go from the low-speed boundary to and through the high-speed boundary very quickly.

Producing a new energy state requires time. The amount of time is a function of the mass of the aeroplane and the magnitude of the applied forces. Aeroplanes of larger mass generally take longer to change orientation than do smaller ones. The longer time requires more planning ahead in a large-mass aeroplane and certainty that actions taken will achieve the final desired energy state.

2.3.6 High altitude considerations

Recent high-altitude (above FL250) accidents have occurred where crews have found themselves inadvertently in 'high altitude slowdown situations', resulting in stalled conditions from which they did not recover. There have been occasions where crews got into situations where they received an approach to stall warning. Some of the attempted recoveries from these warnings were not successful. While aerodynamic principles and certain hazards apply at all altitudes, they become particularly significant with respect to upsets at altitudes above FL250. Prompt and immediate stall recovery techniques are necessary, in the event of a high altitude stall. Available thrust is lower at high altitude so it will be necessary to trade altitude for airspeed to recover due to this loss of available thrust at the higher levels. According to a graph in 'Aerodynamics for Naval Aviators', there is only 30% of sea level thrust available at 40,000ft. Pilots should remain aware of this thrust loss of up to 70% above FL250.

2.3.7 Performance and buffet limits

The lowest point on the total drag curve is known as L/D max (or Vmd-minimum drag speed). The speed range slower than L/D max is known as slow flight, or the 'back side of the power-drag curve' or the 'region of reverse command'. Speed faster than L/D max is considered normal flight, or the 'front side of the power-drag curve'.

Normal flight (faster than L/D max) is inherently stable with respect to speed. When operating in level flight at a constant airspeed with constant thrust, speed-stability ensures that any airspeed disturbance (such as turbulence) is of short term duration and airspeed will eventually return to the original airspeed if the total thrust and attitude have not changed.

Slow flight (slower than L/D max) is inherently unstable with respect to speed and thrust settings. When operating at a constant airspeed, with constant thrust setting, any disturbance causing a decrease in airspeed will result in a further decrease in airspeed unless thrust is increased. The lower speed subjects the aeroplane to increased drag. This increase in drag causes a further decrease in airspeed, which may ultimately result in a stalled flight condition (see Figure 8).

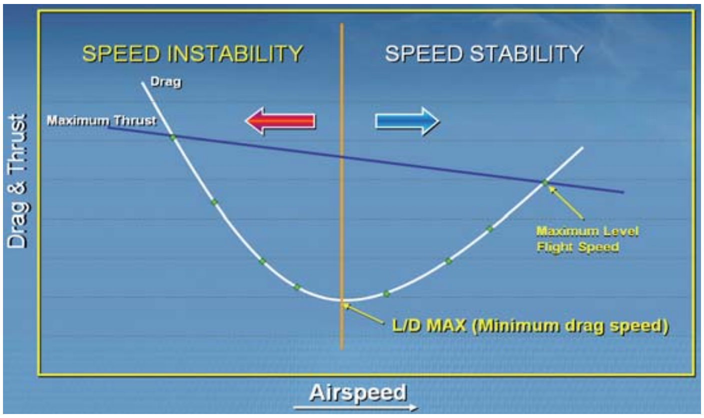


Figure 8.

Flight slower than L/D max at high altitudes must be avoided, due to the inefficiency and inherent instability of the slow flight speed range. When operating slower than L/D max, where total drag exceeds total thrust available, the aeroplane will be unable to maintain altitude. At this point the only remaining option to exit the slow flight regime is to descend.

External factors, such as changing winds, increased drag in turns, turbulence, icing or internal factors, such as anti-ice use, autothrottle rollback, engine malfunction or failure can cause airspeed decay. Heavily damped autothrottles, designed for passenger comfort, may not apply thrust aggressively enough to prevent a slowdown below L/D max. Auto -throttles are generally programmed to apply only maximum cruise thrust (MCR) and not the maximum continuous thrust (MCT) available. Manual intervention by the pilot to achieve maximum thrust will probably be necessary'.

Slower cruising speeds are an issue. As aeroplanes are pushed to more efficient flight profiles, to save fuel, high altitude cruising at lower Mach numbers becomes common. The crew may have less time to recognise and respond to speed deterioration at altitude as a consequence.

Flight slower than L/D max must be avoided in the high altitude environment. Proper flight planning and adherence to published climb profiles and cruise speeds ensures that speeds slower than L/D max are avoided.

2.3.8 Optimum altitude

Optimum Altitude is the best cruise altitude for minimum cost or minimum fuel burn for a given weight, air temperature and selected speed. An increase in air temperature will lower the optimum altitude because of decreased engine performance. When flying at optimum altitude, outside air temperature (OAT) should be monitored to ensure adequate performance capability. When the optimum altitude is not available then aircraft are generally flown above the optimum altitude because the optimum altitude will increase and so approach the aircraft altitude as the aircraft weight decreases. It is however imperative that when flying above the Optimum Altitude that the Maximum Altitude is not exceeded.

2.3.9 Maximum altitude

Maximum Altitude is the greatest altitude that can be flown determined by the following factors:

- Maximum Certified altitude (often determined by Pressurisation Load limits on the fuselage).
- Thrust limited altitude — the altitude at which sufficient thrust is available to provide a specific minimum rate of climb (nominally a residual 300fpm ROC). Some aircraft are what is known as Wing limited and others Thrust limited. In the latter case, the thrust limited altitude will be below the wings manoeuvre capability.
- Buffet or Manoeuvre Limited Altitude — the altitude at which a specific manoeuvre margin exists prior to buffet onset, nominally a 0.3g margin (40° bank angle in level flight) for JAA certified aircraft and 0.2g margin (33° bank in level flight) for FAA certified aircraft. This gives a practical 1.2/1.3g limit.

2.3.10 Optimum cimb speed deviations

Aeroplane manuals and flight management systems produce optimum climb speed charts and speeds. Optimum climb speeds for minimum fuel or minimum cost are faster than speeds for maximum rate of climb or maximum gradient. If an increase in climb rate is required by ATC, this is best achieved by reducing the normal climb speed down to, but not below, the L/D max or minimum drag speed. If vertical speed mode is used, it is imperative to monitor speed to ensure it does not decrease below L/D max — acceleration from speeds close to L/D max can be extremely slow and it is preferable to keep a speed margin above L/D max.

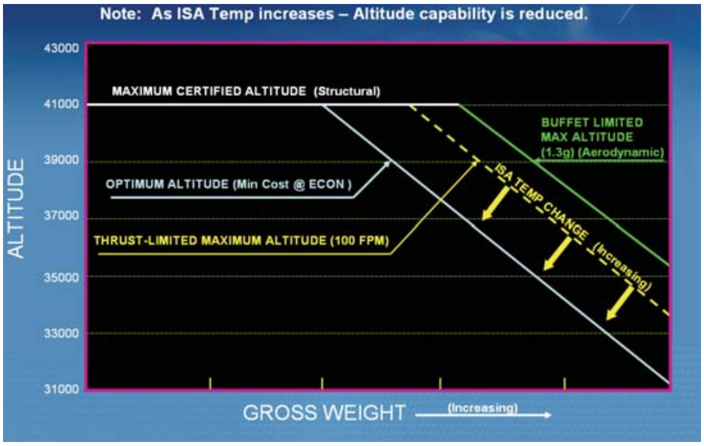
It must be emphasised that many low speed events have been caused by inappropriate use of vertical speed mode. When using Vertical Speed mode, the aircraft performance, particularly airspeed, must be continually monitored, especially in climb at high altitude. During climb the selected VS must be reduced as aircraft climb performance decreases at higher altitudes, to maintain the required airspeed/Mach Number. Many serious incidents/accidents have occurred during climb when the selected VS has not been reduced, causing the aircraft speed to decrease in some cases leading to a stall/aircraft loss. For this reason use of VS in climb at high altitudes is not recommended and an autopilot mode that maintains climb speed should be engaged (Boeing use: LVL CHG or FLCH depending on the aircraft, while Airbus use CLB). Using VNAV is another option, to ensure speed protection that is not available in VS. The only time VS may need to be considered is if it is necessary to modulate ROC for TCAS reasons, that is, to avoid an RA. The bottom line is: 'know your aeroplane'.

2.3.11 Thrust limited condition and recovery

When operating jet transport aeroplanes at the Thrust Limited Altitude it is important that crews be aware of outside air temperature and thrust capability. Pilot situational awareness requires knowledge of the Tropopause Altitude which may result in a temperature inversion which in turn may reduce the Thrust Limited Altitude. To avoid losing airspeed when at the Thrust Limited Altitude, good airmanship dictates that the Bank Angle programmed by the Flight Management system is monitored. If this is greater than 15°, consider limiting it to 15° of bank by using 'Heading Select', Ensure reselection of FMC/Navigation mode when the turn is complete. Normal bank angle selection [FMC bank angle limit is normally 30°] is satisfactory when flying at Optimum Altitude as the protection above the stall is not less than 1.5g. The two Figure 9 graphs illustrate the variable maximum altitude capability conditions for an aircraft, affecting their choice.

If a condition of airspeed decay occurs at altitude, take immediate action to recover:

- Reduce bank angle.
- Increase thrust — select maximum continuous thrust if the aeroplane's autothrottle system is maintaining thrust at a lower limit.



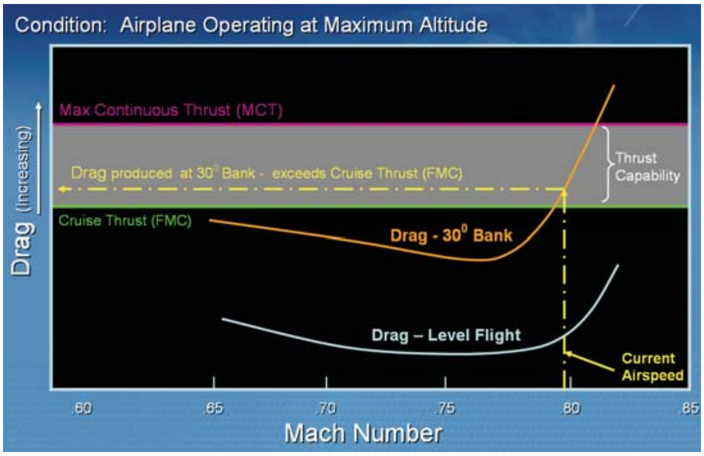


Figure 9.

If a high drag situation occurs, where maximum available thrust will not arrest the airspeed decay, the only available option is to descend.

- Descend if necessary.

2.3.12 Manoeuvring stability

For the same control surface movement at constant airspeed, an aeroplane at 35,000ft experiences a higher pitch rate than an aeroplane at 5,000ft because of less aerodynamic damping. Therefore, the change in angle-of-attack is greater, creating more lift and a higher load factor.

An additional effect is that, for a given pitch attitude change, the change in rate of climb is proportional to the true airspeed. For a pitch attitude change to achieve 500ft per minute (fpm) at 290kt (KIAS) at sea level, the same change in attitude at 290KIAS (490kt true air speed) at 35,000ft would be almost 900fpm. This emphasises the need for gentle, smooth and small, measured control inputs, when required at high altitude, particularly after disconnecting the autopilot or when recovering from an upset situation and in a stall recovery.

Flying near maximum altitude will result in reduced bank angle capability; therefore autopilot or crew inputs must be kept below buffet thresholds. The Lateral Navigation capability of some aircraft will not always ensure bank angle is limited, to respect buffet and thrust margins. Some FMCs may command up to 30° of bank and for FAA certified aircraft this would be within 3° of the 1.2g buffet margin. EASA/JAA certified aircraft are required to use 1.3g as the minimum buffet protection. FAA, however, permits this to be reduced to 1.2g and it is the operator's choice to utilise a more restrictive buffet limit than required by their certifying authority, by way of a pin selection on the FMC. As a consequence, when manoeuvring at or near maximum altitude, there may be insufficient thrust to maintain altitude and airspeed.

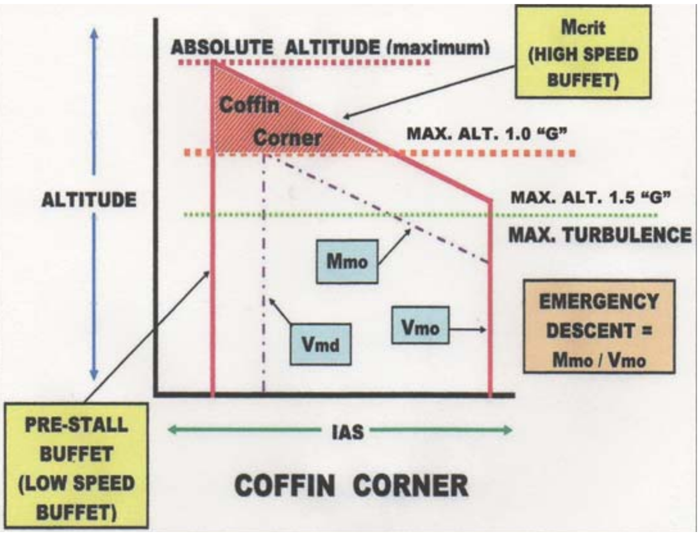


Figure 10. *Capt Christopher 'Chris' N. White, FRAeS.*

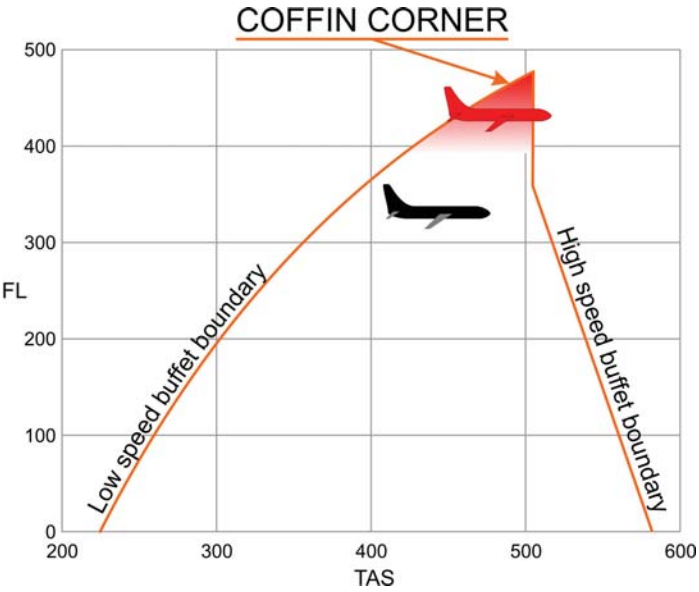


Figure 10(a). *Capt Philip 'Phil' H.S. Smith, MRAeS.*

2.3.13 Buffet-limited maximum altitude

There are two types of buffet to consider in flight; low speed buffet and high-speed buffet. As altitude increases, the airspeed at which low speed buffet occurs increases. As altitude increases, high-speed buffet speed decreases. Therefore, at a given weight, as altitude increases, the margin between high speed and low speed buffet decreases. The top end of the graph is known as 'Coffin Corner', where aircraft may have to fly limited by their weight, when a highest possible altitude is chosen for optimum range.

Figure 10 is a training slide used in class when addressing the subject of flight in 'Coffin Corner'. It is generalised and only used to introduce and explain the various limitations of the buffet envelope, for easier assimilation and retention. It does not

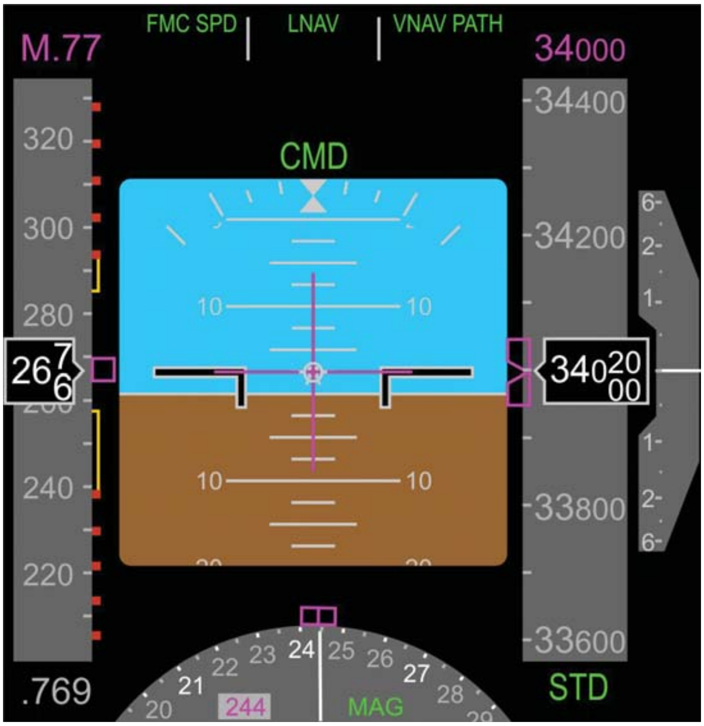


Figure 11.

represent any particular aircraft but is a useful training aid. Figure 10(a) shows 'Coffin Corner' in a more conventional graphical presentation, for a 'generic' aircraft.

The adjacent Figure 11 shows a modern glass-cockpit aircraft Attitude Display Indicator (ADI). The instrument shows the aircraft to be at FL340, at an indicated airspeed of 270kt and cruising at 2.5° nose up. The left-hand Air Speed Indicator (ASI) strip-gauge also shows the computer generated input of two 'barber-pole' joysticks that indicate a 258kt pre-stall speed (lower yellow) and the high 285kt Mach-speed buffet (upper red) limits of the aircraft, at this height and aircraft weight. The ADI shows the 'Hockey Sticks' on the speed tape as the both High speed and Low speed buffet boundaries' converge, as in Figures 10 and 10(a).

It is important to clarify that different aircraft have different margins, warnings, therefore consequences (e.g., Auto Pilot disconnect) and pilot actions, depending how far into the barbers' poles one is and before one gets to real high-speed/mach (or low speed pre-stall) buffet.

At high altitudes the excess thrust available is limited. Crews must be aware that additional thrust is available by manually selecting maximum available/continuous thrust at any time. On non-FADEC engines, crews must ensure the engines are not 'overboosted'. Auto throttles cannot usually provide Maximum Continuous Thrust (MCT) automatically. Manual thrust selection by the pilot may be necessary. However, in extreme airspeed decay situations MCT may also be insufficient in which case a descent will be necessary, in order to prevent further airspeed decay into an approach to stall and stall situation (also see '2.3.7 Performance and buffet limits').

Suitable training in recognition of the approach to an upset-induced stall and prompt recovery would go a long way to avoid such events happening. In particular, high altitude buffeting should be thoroughly covered, to highlight the similarity between Mach buffet and pre-stall buffet, particularly if there is no airspeed reference. In view of the narrow operating range of airspeeds and the sensitivity in general of controls in this flight regime, training should highlight the need for smoothness of control required to extract oneself from either side of 'coffin corner'; without immediately finding yourself out of it but, inadvertently, on the other side of the envelope.

Pilots should be taught the art of gentle recovery techniques by the use of carefully judged inputs, so that bank angle changes or power applications do not result in an undue nose-up attitude in the recovery, thus making the situation worse. At high altitude, acceleration would be best made by descent.

2.3.14 In-flight icing stall margins

In-flight icing is a serious hazard. Ice degrades or destroys an aerofoil's ability to produce lift. The aeroplane will stall at much higher speeds and lower angles-of-attack than normal. If stalled, the aeroplane can roll or pitch uncontrollably, leading to a serious in-flight upset situation. With ice, an aeroplane may exhibit stall onset characteristics before stick shaker activation.

Autopilots and auto throttles mask the effects of airframe icing and this can contribute to ultimate loss of control. There have been several accidents in which the autopilot trimmed the aeroplane into a stall upset, by masking the heavy control forces.

2.4 LOW LEVEL GO-AROUND 'UPSET' WHEN USING TAKE-OFF OR GO-AROUND POWER

Increasing thrust on under-wing, podded jet engines can cause a significant pitch-up. When TO/GA power is used, as in a Go-Around with the Autopilot engaged, the extra trimming required is controlled automatically.

However, when making a manual go-around using maximum go-around thrust, it is particularly important to anticipate trim changes as TO/GA power is applied and to counteract these with appropriate elevator inputs, while trimming-out any tendency for excessive attitude change. In the all-engine case it is generally not necessary to apply Maximum go-around thrust. A reduced thrust setting sufficient to achieve a 2,000fpm climb would be satisfactory. Alternatively leave the A/P engaged and let it control the go-around.

In both propeller and jet aircraft, there is a possibility of disorientation during a go-around because of the 'false pitch-up' (somatogravic) effect produced by large longitudinal acceleration felt by the inner-ear as the aircraft speed increases. Therefore, it is vital that the correct pitch attitude is selected and maintained, while the aircraft is kept in trim as it accelerates. A Go-around is an 'out of the ordinary' event and, by definition, they happen at the end of a sector when the aircraft is at a lower AUM and when fatigue and disorientation are more likely. Therefore, it is important that the Go-Around case is considered and briefed with an emphasis on the initial actions and SOPs.

A 'somatogravic' illusion may be created when under the influence of rapid acceleration, such as experienced during take-off which may create an illusion that the aircraft nose is pitching up. A disoriented pilot experiencing such an illusion while flying may push the nose low into a dive attitude. Rapid deceleration may have opposite effect, with a disoriented pilot pulling the nose up into a climb or even into a stall attitude. A manual go-around with maximum go-around thrust can result in extreme nose-high attitudes if appropriate trim is not applied.

FOR EXAMPLES OF UPSET EVENTS — SEE 1.4 & APPENDIX 1

PART THREE: FLIGHT UPSET RECOVERY AND MITIGATION

Pilots should remember that each operator of any particular aircraft type will have preferred Standard Operating Procedures (SOP) which may contain operator specific procedures for handling In Flight Upset, to ensure crew standardisation. Such SOPs are controlling, as this document is indicative rather than prescriptive.

3.1 AEROPLANE UPSET RECOVERY TECHNIQUES — DESCRIPTIONS

Both primary and secondary flight controls are used to recover from an in-flight upset, with strong emphasis on the primary flight controls, as recommended by the Flight Upset Recovery Training Aid. Primary flight controls include aileron (spoilers), elevator, and rudder that should only be used sparingly and only if absolutely necessary. Secondary control devices, such as stabiliser trim, thrust, and speed-brakes, should be considered incrementally, to supplement primary flight control inputs. Aircraft energy must be managed to stop the divergence from normal and assigned flight path. After trends outside the approved flight envelope are arrested, recovery to a flight profile within the approved flight envelope can be accomplished.

Aeroplane in-flight upset events fall into several categories both individually and in combination:

3.1.1 Nose high, wings level

1a Nose attitude high & increasing, airspeed decreasing rapidly with ability to manoeuvre decreasing.

3.1.2 Nose low, wings level

2a Low airspeed (speed decreasing) — Pitch attitude less than 10° nose down, airspeed low.
2b High airspeed (speed increasing) — Pitch attitude greater than 10° nose down, airspeed high.

3.1.3 High bank angles

3a Nose high — Bank angle beyond 45° pitch attitude greater than 25° nose up & airspeed decreasing.
3b Nose low — Bank angle beyond 45° pitch attitude less than 10° nose down & airspeed increasing.

3.1.4 High altitude — level flight — slow speed

4a Level flight, altitude greater than FL250, speed decreasing.

3.2 RECOMMENDED RECOVERY TECHNIQUES

Recommended recovery techniques are summarised into two basic aeroplane upset situations: nose high and nose low. High altitude recovery from a low speed event is discussed separately.

Consolidation of recovery techniques into these situations is for simplification and ease of retention.

Aeroplanes designed with electronic flight control systems, commonly referred to as 'fly-by-wire' aeroplanes, have features that, while not eliminating the event, begin taking control of the aircraft once the event has reached a certain point of deviation and assist the pilot in recovery. But, when fly-by-wire aeroplanes are in the degraded flight control mode, basic recovery techniques and aerodynamic principles may be appropriate. In upset events pilot intervention at some point is required, regardless of aeroplane type. Aeroplane Auto-flight systems are intended for use when the flight is operated within its normal operating envelope. Continuing to use them in certain situations, or when a severe upset commences, can hinder the recovery from this condition. Except that, where a loss of airspeed is recognised at high altitude and the autopilot has not disengaged, it may be preferable to leave the autopilot engaged, disconnect the autothrottle to permit selection of Maximum Continuous Power and use VS or pitch command gently, to descend and regain speed to avoid an 'upset'.

When an aeroplane is in a recognised and confirmed 'upset', the autopilot and auto throttle must be disconnected prior to initiating recovery inputs.

An early assessment of the energy state of the aircraft is essential to determine the ongoing (energy) trend of the event. This includes, but is not limited to, altitude, airspeed, attitude, load factor, power setting, position of flight controls, position of drag and high-lift devices and the rate of change in the situation as corrective inputs are made. In consequence, the crew may need to make configuration changes, such as use of speed brakes or lowering the landing gear for drag as necessary, to aid in the recovery. Managing the energy within the event is critical in an 'upset' situation.

IS THE AIRCRAFT STALLED?
... RECOVER FROM THE STALL FIRST!

3.3. STALL

An aeroplane is stalled when the angle-of-attack is beyond the stalling angle. A stall is characterised by any individual, or a combination occurrence of the following:

- Buffeting: Possibly heavy at times.
- A reduction or lack of pitch authority.
- A reduction or lack of roll control.
- Inability to arrest descent rate.

These characteristics are usually accompanied by a continuous stall warning.

A stall must not be confused with a stall warning that alerts of an approaching stall within preset parameters, and occurs prior to the actual stall. Recovery from an approach to stall warning is not the same as recovering from a stall. An approach to stall is a controlled flight manoeuvre. A stall is a potentially hazardous manoeuvre involving loss of height and loss of control, but remains recoverable in the early stages.

Because air no longer flows smoothly over the wings during a stall, aileron control of roll becomes less effective. Simultaneously, the tendency for the ailerons to generate adverse yaw increases, as does the lift from the advancing wing, which accentuates the probability that the aircraft will enter into a spin.

To recover from a stall, the angle-of-attack must be reduced below the stalling angle, by applying a nose down pitch control input and maintaining it until stall recovery. Under certain conditions, on aeroplanes with under wing-mounted engines, it may be necessary to reduce thrust to prevent the angle-of-attack from continuing to increase. Once unstalled, recovery action may then be initiated.

3.3.1 Nose-high, wings-level, recovery profile

3.3.1a **Situation:** *Nose attitude high & increasing, airspeed decreasing rapidly with ability to manoeuvre decreasing.* Note that pitch may not be increasing; it might even be decreasing while the angle-of-attack increases as the airspeed decreases.

Begin the recovery by disengaging the autopilot and auto throttle while identifying and confirming the situation. Apply nose down elevator to achieve a nose down pitch rate. This may require the careful application of a full nose-down input, being careful not to apply negative 'g' beyond manufacturer's design limits. If a sustained column force is required to obtain the desired response, consider trimming off some of the control forces. Caution should be used as the system that trims the stabiliser may have more authority than the elevator. This may compound or initiate an out of trim condition. However, it may be difficult to know how much trim to command and care must be taken to avoid using excessive trim initially. Do not 'fly' the aeroplane with pitch trimming; slow or stop elevator trimming until the control forces reduce to a comfortable level. Boeing flight studies demonstrate pitch actions of elevator and trim recovers approximately 90% of nose high events.

If at this point the pitch rate is not controlled, additional techniques may be attempted. Use of these techniques depends on the circumstances of the situation, and control characteristics of the specific aeroplane.

Consider controlling Pitch by rolling the aeroplane to a bank angle that causes the nose to descend towards the horizon. Angle of bank during this manoeuvre should not normally exceed approximately 45°, with a maximum of 60°. Also, maintaining continuous nose down elevator pressure keeps the wing angle-of-attack as low as possible, making the normal roll controls effective. When low airspeed triggers the stick shaker, or at speeds even lower, control positions up to full deflection of the ailerons and spoilers may be used. This rolling manoeuvre changes the increasing pitch rate into a turning manoeuvre, allowing the pitch to decrease. In the majority of situations, this technique is enough to recover the aeroplane from the nose-high, wings-level, upset.

Other techniques may be used to achieve a nose down pitch rate. Flight tests have shown that if altitude permits, an effective method for getting a nose down pitch rate involves reduction of power on aeroplanes with under wing-mounted engines. This reduces upward pitch moment in such designs. In fact, in some situations for some aeroplane models, it may be necessary to reduce thrust to prevent the angle-of-attack from continuing to increase. Note: This is counter-intuitive to many pilots. When appropriate, this crew action results in the nose lowering at higher speeds, and a milder pitch down.

If control provided by the ailerons and spoilers is ineffective, rudder input may be required to induce a rolling manoeuvre for recovery. A small amount of rudder input is sufficient. **Excessive rudder applied too quickly, or held too long, can result in loss of lateral and directional control.**

Caution must be used when applying rudder because of the low-energy situation. This is the least desirable technique **and use of rudder is not recommended in upset recovery**.

Successful recovery completion involves rolling to wings level, if necessary, as the nose approaches the horizon.

Recover to slightly nose-low attitude to reduce potential for entering another upset. Check airspeed, and adjust thrust and pitch as necessary.

3.3.2 Nose-Low, Wings-Level Recovery Techniques

3.3.2a **Situation:** *Pitch attitude unintentionally greater than 10° nose low, airspeed low.*

Recognise and confirm the situation. Once confirmed, begin the recovery by disengaging the autopilot and autothrottle. In a nose-low, low-speed situation, the aeroplane may be stalled at a relatively low pitch. **This in no way changes the requirement to recover from the stall first**. This may require nose down elevator, and possibly reduction of power in aeroplanes with under wing mounted engines. With the aircraft recovered from the stall, apply thrust; the aircraft must be returned to the desired pitch attitude through nose up elevator.

It is essential to **avoid the secondary stall**. This is normally indicated by stall warning, or aeroplane buffeting. Aeroplane 'g' forces and airspeed limitations must be respected. If a secondary stall is encountered during any portion of the recovery, AOA must be reduced immediately to regain non stalled flight.

3.3.2b **Situation:** *Pitch attitude unintentionally greater than 10° nose low, airspeed high.*

Aircrew must recognise and confirm the situation. Disengage the autopilot and auto throttle. Apply nose up elevator, and it may become necessary to cautiously apply stabiliser trim to assist in obtaining the desired nose up pitch rate. Addition of stabiliser trim may become necessary during extreme out-of-trim conditions. Note: Remember that the stabiliser system may have more authority than elevator. Thrust reduction, and deploying of speed brakes should be considered. Recovery is considered complete when pitch, thrust, and aeroplane configuration corresponding to the desired airspeed is established.

An aerodynamically clean aeroplane can quickly exceed its certified limits. When applying nose up elevator, several factors should be considered. Keeping MSA awareness and prevention of terrain contact is paramount. An accelerated stall may be induced by exceeding the stall angle-of-attack. Aeroplane 'g' forces and airspeed limitations must be respected. Serious damage is likely to result from exceeding structural design limits.

3.3.3 High-Bank-Angle Recovery Techniques

In high-bank situations, bank can exceed 90°, therefore the primary objective is to return the aeroplane to near wings level by the shortest direction. However, if the aeroplane is stalled the first necessity is to recover from the stall.

3.3.3a **Situation:** *Bank angle greater than 45°, pitch attitude greater than 25° nose high and airspeed decreasing.*

A nose-high, high-angle-of-bank event requires deliberate flight control inputs for safe, efficient recovery. A large angle of bank is useful in reducing excessively high pitch attitudes.

The flight crew must successfully recognise and confirm the situation. The autopilot and auto throttle must be disconnected, Move the control column forward to reduce the angle-of-attack adjusting the bank angle, not exceeding 60°, to pitch the nose down. It is critical that the flight crew maintain constant awareness of energy management and aeroplane roll rate. Completing the recovery, roll to wings level attitude as the nose approaches the horizon, recovering to a slightly nose-low attitude. Airspeed must be maintained by adjusting thrust and pitch as required.

3.3.3b **Situation:** *Bank angle greater than 45°, pitch attitude less than 10° nose low and airspeed increasing.*

The nose-low, high-angle-of-bank flight attitude requires prompt action, because in this situation altitude is rapidly being exchanged for airspeed. Airspeed can rapidly increase beyond aeroplane certified design limits. Flight crew must immediately recognise and confirm the situation and immediately disengage the autopilot and auto throttle. Along with autopilot and auto throttle disconnection, simultaneous application of roll and adjustment of thrust may also be required.

It may be necessary to decrease back pressure to improve roll effectiveness by aerodynamically unloading the aeroplane. If the aeroplane has already exceeded 90° of bank, it may require control 'pushing' to unload, as necessary to improve roll control and prevent lift vector redirection towards the ground! Full aileron and spoiler inputs may be required to smoothly establish a recovery roll rate toward the nearest horizon line. It is important that positive 'g' force is not increased, or that nose-up elevator or stabiliser trim be used until the aeroplane approaches wings level attitude. If the input of full lateral control (ailerons and spoilers) is not satisfactory, it may become necessary to apply rudder in the direction of the desired roll sufficient to arrest the situation, and no further.

Only a small amount of rudder input is needed. Excessive rudder applied too quickly or held too long may result in loss of lateral and directional control and cause structural damage. As the wings approach level flight, extend speed brakes, if required. Complete the recovery by establishing a pitch, thrust, or aeroplane drag device configuration that corresponds to the desired airspeed. In large transport-category aeroplanes, in the event that a very high roll rate develops during an upset, do not attempt to 'roll through' by adding further pro-roll controls so as to compete a full 360° roll manoeuvre in an attempt to achieve wings level more quickly.

3.3.4 Level flight — high altitude — slow speed events

Note: As companies institute lower cruise speeds at high altitude for efficiency, slow speed events at high altitude are statistically increasing. The crew must be continually vigilant, to ensure appropriate airspeed ranges are maintained in the high flight levels.

3.3.4a **Situation:** *Level flight, altitude greater than FL250, speed decreasing*.

The crew must successfully recognise and confirm the situation. If the situation is discovered prior to stick shaker, or activation of other approach to stall warning, first attempt to apply increased thrust as necessary, up to the maximum available for the (high) altitude. Keep the autopilot (AP) engaged if it has not disconnected, switch-off the autothrottle as it may only allow maximum cruise power instead of maximum continuous thrust (MCT) and apply MCT manually. Reduce bank if turning and level the wings if speed is still reducing. If speed loss continues, descend on AP using Vertical Speed (VS), or the 'pitch command' to regain speed. If the aeroplane responds to additional power input sufficiently to regain correct speed for level flight, the crew should maintain a speed deemed adequate for the altitude before re-engaging autopilot if it had disconnected and re-engage the autothrottles. Inform ATC, set a lower cruise altitude and check TCAS/ACAS to ensure separation from other aircraft at lower altitudes.

However, as is usually the case, if the situation announces itself with stick shaker, or activation of other approach to stall warning, the crew must correctly identify the airspeed loss situation immediately, initiating action to prevent a full stall. **The stall must be prevented**. On some aircraft, addition of remaining power up to the maximum available at high altitude may be sufficient to prevent the stall and eventually stop the stall warning devices, allowing deliberate return to controlled level cruise flight.

It is more likely that additional thrust will be insufficient to restore the condition prior to the initiation of a stall warning. **The stall must be prevented**. The only other remaining option, to restore the situation with approach to stall warnings, is to initiate a change of pitch, in this case a nose low attitude that results in altitude loss, but increases speed and energy. This control input should change the pitch angle sufficiently as to prevent the stall and eventually restore normal flight. **Altitude loss must be accepted**, sufficient to produce a proper and safe outcome. During the recovery, it is critical that the flight crew maintain constant awareness of energy management, aeroplane pitch rate, airspeed increase, and inform ATC in a timely manner being especially mindful that any altitude loss may compromise ATC separation minima.

Should a high altitude low speed stall result, the crew must remember **to break the stall condition first** before attempting further recovery. At high altitude, this invariably requires an immediate, smooth yet positive pitch-down control input, which must be held until the aircraft is under control and recovery to level flight can be commenced. It must be pointed out that every aeroplane SOP and QRH are liable to be slightly different and controlling in such matters. Once the stall condition is 'broken', the crew may initiate the appropriate recovery control commands. This can result in the loss of several thousand feet of altitude.

Completing the recovery, command wings level attitude as the nose approaches the horizon, recovering to a slightly nose-low attitude. Airspeed must be maintained by adjusting thrust and pitch as required. The crew must determine a safe attitude where speed above L/Dmax can be maintained at an acceptable cruise power setting.

3.4 CONSOLIDATED SUMMARY OF AEROPLANE RECOVERY TECHNIQUES

These summaries incorporate high-bank-angle scenario techniques. Please refer to the high altitude recovery section below for a more detailed breakdown of recommended recovery actions.

3.4.1 Nose-high recovery (greater than 25° nose high):

- Recognise and confirm the situation.
- Disengage autopilot and auto throttle.
- Apply sufficient nose down elevator, as necessary.
- Use appropriate techniques:
  - Roll (adjust bank angle) to obtain a nose down pitch rate.
  - Reduce thrust (aircraft with under wing-mounted engines).

- Complete the recovery:
  - Upon approaching the horizon, roll to wings level.
  - Check airspeed, and adjust thrust as necessary.
  - Establish desired pitch attitude.

3.4.2 **Nose-low recovery** (below 10° nose low):

- Recognise and confirm the situation.
- Disengage autopilot and auto throttle.
- Recover from stall first, if necessary.
- Input roll commands to the shortest direction to wings level. If bank angle is more than 90°, first aerodynamically unload, and then roll.
- Recovery to level flight:
  - Apply nose up elevator.
  - Apply stabiliser trim, as necessary.
  - Adjust thrust and drag as required.

3.4.3 **High altitude recovery** (from speed loss for any reason)

Above FL250, if the autopilot is controlling the aircraft satisfactorily leave the auto-pilot engaged and set maximum continuous thrust (MCT) manually, if necessary.

- Recognise and confirm the situation.
  - Apply Maximum Continuous Thrust (MCT) — Disconnect autothrottle if necessary
  - Reduce bank if turning — level the wings if speed still reducing.
  - If speed loss continues, descend on AP using VS or pitch command to regain speed, Advise ATC, set lower Altitude, check TCAS/ACAS.
  - If speed loss rapid and approaching the stall warning. Check aircraft trim positions. If abnormal, expect large pitch/roll change if the Autopilot/Auto Throttle control is inadequate.
- Disengage autopilot and auto throttle.
  - Prevent approach to stall by positive but smooth control inputs
  - Pitch down, wings level,
- Set thrust to the maximum available. The Stall must be prevented.
- Input pitch commands sufficient to prevent, or recover from, an approach to stall condition.
  - Pitch down is the prime recovery action at altitude (Slats/flaps may be selected below the maximum altitude for deployment — beware any trim change).
  - If the aircraft stalls: Apply forward stick to decrease the angle-of-attack and unstall the wing. Hold forward stick until the wing is fully unstalled and avoid a secondary stall. If necessary, roll wings level and when speed increases to normal speed values.
- Recover to level flight:
  - Carefully pitch up to normal pitch attitude, set required thrust and re-trim to maintain appropriate airspeed and altitude.
  - If airspeed/barometric information is unreliable — obtain from QRH and set correct attitude and thrust for aircraft weight and altitude.
  - If required, it is possible to cross-check indicated altitudes and speeds against GPS altitude and IRS/GPS groundspeed which may give useable values and indicate changes.

3.4.4 In ALL cases — Once recovered to level flight:

3.4.4a Maintain the correct level attitude

- Adjust Elevator/stab trim, as necessary. (If incorrect trim had caused the upset then re-trimming may already have been essential — as in the MD-82 accident mentioned earlier in the document)
- Confirm the aircraft is above MSA. If not, initiate climb and check position — if available, the terrain feature on the Navigation Display will give a gross-error check.

3.4.4b Adjust thrust and drag as required

To resume cruise attitude and power settings — the auto pilot could be re-engaged, but it may be best to use the auto-throttle with caution only, particularly if the upset was caused by unreliable airspeeds/air data.

3.4.4c Check and adjust aircraft configuration

- As a crew, assess why the upset happened and the likelihood of recurrence. Consider autopilot pilot/avionics problems, instrument or control failures, as well as pilot disorientation, fatigue or illness. If appropriate, re-engage AP/AT
- Assess any damage to the aircraft or injury to passengers and crew. Crews may need to consider various methods to further improve controllability (shifting CG, adjusting flaps or gear or speed brake, trim, descending, control wheel breakouts, differential thrust, non-normal procedures, etc.) as the situation dictates.
- Crews should follow the best principles of CRM and use all the guidance and resources available to them to analyse the issues and, if deemed necessary, validate performance using controllability checks before considering whether to carry on to their destination or to initiate diversion to a suitable alternate.

REMEMBER
IS THE AIRCRAFT IN A STALLED CONDITION?
... RECOVER FROM THE STALL FIRST!

This document was created by the Royal Aeronautical Society Flight Operations Group to inform airmen of a critical situation evolving in the aerospace system. Believing the pilot is the first line of defence in any such situation, the Society feels confident that knowledge given to the Line Pilot is the best practice currently available. In the future, the industry will develop flight simulation and training systems to help the pilot meet the challenge. This has always been the way forward in air safety and progress.

The RAeS Flight Operations Group wishes everyone — Fair Skies and Tailwinds!

Capt P.H.S. Smith, MRAeS, photo.

APPENDIX 1 — UPSET EVENTS

Under the general heading of Avoidance Strategies, operators must ensure crews have access to accurate and OEM-approved descriptions of the flight characteristics of their aircraft in the slow flight regime. Crews should also receive simulator training in recognition and avoidance, also recovery if necessary, of the en-route stall by proper use of the autoflight system. Particular emphasis must also be placed on the unrecoverable nature of the deep stall in certain aircraft such as the rear-mounted engines, T-tailplane aircraft like the MD-82.

Upset recovery training should be according to manufacturers' drills and Airplane Upset Recovery Training Aid guidance, covering all three phases of the upset scenario: Avoidance, Recognition and Recovery.

The following unrecovered aeroplane 'Upset' tragedies were selected for brief examination, because they illustrate the problem in clear and unambiguous terms. Sadly, there are many others. In fact recent tragedies, while investigations continue, show indications of possible crew control mismanagement, including lack of awareness of actual flight conditions without auto flight.

1. IN FLIGHT RESULTING IN A FATAL ACCIDENT
   - 1.1 US Air 427 — Boeing 737 — September 1994
   - 1.2 American Airlines 587 — A300 — November 2001
   - 1.3 Pinnacle Airlines 3701 — CRJ200 — October 2004
   - 1.4 Korean Air Flight 8509 — B747 — December 1999
   - 1.5 AdamAir Flight DHI 574 — B737-4Q8 — 1 January 2007
   - 1.6 Colgan Air Flight 3407 — Bombardier DHC-8-400 — 12 February 2009

2. IN FLIGHT WITH SUCCESSFUL RECOVERY
   - 2.1 Recovery when subject to In-flight icing contamination (three events)

3. ON GO-AROUND
   - 3.1 11 December 1998; Thai Airways International A310-200
   - 3.2 16 February 1998; China Airlines A300-600; near Taipei, Taiwan

1. IN FLIGHT RESULTING IN A FATAL ACCIDENT

1.1 USAir 427

Had the Rudder PCU not been defective thus causing a hard-over deflection of the control surface, this upset might have been recoverable. In the circumstances, it was not.

At approximately 19:03 Eastern Daylight time on 8 September 1994, USAir flight 427 ORD — PIT descended out of control and crashed, killing all on board outside of Pittsburgh, PA.

In the Executive Summary of the Final Report of this accident the NTSB states the following:

"*The National Transportation Safety Board determines that the probable cause of the USAir flight 427 accident was a loss of control of the aeroplane resulting from the movement of the rudder surface to its blowdown limit.*

The rudder surface most likely deflected in a direction opposite to that commanded by the pilots as a result of a jam of the main rudder power control unit servo valve secondary slide to the servo valve housing offset from its neutral position and overtravel of the primary slide.

The safety issues in this report focused on Boeing 737 rudder malfunctions, including rudder reversals, the adequacy of the 737 rudder system design; unusual attitude training for air carrier pilots; and flight data recorder (FDR) parameters (NTSB Report reference page ix)."

After building thousands of B737 series aircraft, a danger to safe operation was discovered under tragic circumstances which had existed since the original design and that had not been anticipated. However, pilot training to mitigate the consequences of such nasty surprises can be planned for.

The report includes commentary on the inadequacy of Commercial Air Transport pilot training to address this type of unexpected flight upset. It resulted in remodelled training for crews flying the B737 and increased knowledge of more sophisticated aeronautical issues like cross-over speeds.

With the engineering correction to the Rudder System and the higher cross-over speeds provided by Boeing for those aircraft that had not been modified, [all of those post accident] then such a situation would be recoverable now — should the 'now' impossible happen again. At the time of this accident, before the Boeing main rudder PCU modification action, it would have been well nigh impossible for the crew to recover from this 'upset', particularly at low altitude.

Of interest to operators is the fact that this investigation required more than four years to complete with the cost to industry of direct and indirect losses exceeding $1.5bn dollars.

Probable Prime Cause: Directional control was lost when the aircraft experienced a rudder hardover due to a technical failure. It is likely that the event took the crew totally by surprise and in a way that prevented timely diagnosis and recovery.

Avoidance Strategies: It is unlikely that a crew could have recovered from this particular situation due to the nature of the failure. However, it is considered that training in recovery from rudder hardover events may provide valuable recognition and recovery skills for countering a less drastic situation.

1.2 American Airlines 587

Barely one month following the attacks of 11 September 2001, New York City again faced tragedy from the sky. This time it was not the madness of terrorism but human error.

At 09:16 eastern standard time American Airlines flight 587, an Airbus A300-605 N14053, crashed into a residential area of Belle Harbor, New York. AA587 was a regularly scheduled flight from JFK to Americas International Airport, Santo Domingo, Dominican Republic. Two hundred and sixty passengers and crew were killed as were five people on the ground.

Once fears of terrorism were eliminated, it was evident the aircraft impacted the ground in an ominous fashion. The location of the vertical stabiliser and rudder in Jamaica Bay was proof positive of a structural breakup while in flight.

During the investigation it became apparent that AA 587 encountered wake turbulence a few minutes after takeoff, from a B747 that departed the same runway immediately prior. The pilot flying AA 587 was the First Officer. It was this encounter where the trouble started. Wake turbulence around busy traffic areas, mixing aircraft of various sizes and capability is hardly unknown: it is, in fact, quite frequent.

The Executive Summary of the NTSB Final Report on the loss of AA 587 says the following:

"The National Transportation Safety Board determines that the probable cause of this accident was the in-flight separation of the vertical stabiliser as a result of the loads beyond ultimate design created by the first officer's unnecessary and excessive rudder pedal inputs. Contributing to these rudder pedal inputs were the characteristics of the Airbus A300-600 rudder system design **and elements of the American Airlines Advanced Aircraft Manoeuvring Program.**" (NTSB report reference page xi)

In effect the report states that the flying pilot excessively loaded the rudder beyond design limits and that the system was so designed as to allow him to do it.

For our purposes, the Board's concentration on American Airline's Advanced Aircraft Manoeuvring Program is significant and troubling. It is clear that American Airlines had made a strong commitment to address the dangers present in loss of control flight upset events. The airline created an aggressive program designed to improve their pilot's awareness and skills. The design of the program was an 'in-house' training department effort that, at least initially, sought input from manufacturers and regulators. Yet, the final program was in opposition to other industry training, despite manufacturer participation. As time passed, disagreements on basic aerodynamic theory and technique began to surface within the airline. While the program was well meaning, with the very best of intentions, it came under question within the company operations management. The NTSB Final Report discussed one significant issue.

"*On 6 February 2003, American Airlines provided the Safety Board with a copy of a 27 May 1997, memorandum from the company's managing director of flight operations technical to the company's chief pilot and vice-president of flight. The memorandum stated that the managing director of flight operations technical had 'grave concerns about some flawed aerodynamic theory and flying techniques that have been presented in the AAMP (Advanced Aircraft Manoeuvring Program). The memorandum also stated that it was wrong and 'exceptionally dangerous' to teach pilots to use the rudder as the primary means of roll control in recoveries from high Angles of Attack (AOAs).*" (Memo reference: p 89).

The memorandum continued to request a review of a number of concerns regarding the program, some raised by manufacturer test pilots. In addition to a propensity for the first officer to use excessive rudder, such instruction created a toxic combination that, under demands of the event, stressed the Airbus vertical stabiliser and rudder beyond design limits.

This chain of events illustrates key issues regarding training for in-flight upsets. The event brought the entire concept into question, in some minds. Carriers developing such programmes ceased their development. The fact that, through such a programme, American Airlines exposure and liability increased was not lost on the industry. It also provided additional rationalisation for those opposed to such training for various reasons, such as cost, the effort involved, or simple change resistance. By any estimation AA 587 stands as a classic in-flight upset event with tragic consequences.

Probable Prime Cause: Inappropriate training programme against the recommendations of the aircraft manufacturer. AA pilots were subjected to flawed training in upset recovery, which required rudder inputs to level the wings of a modified A300-600 series simulator. This accident was caused by the negative effect of the Company's inappropriate in-house-developed Advanced Aircraft Manoeuvring Program which artificially suppressed simulator yaw and roll control and encouraged use of the rudder to level wings, contrary to manufacturer's guidance.

Possible Remedial Action: Only use training programmes that are approved by the aircraft manufacturer.

1.3 Pinnacle Airlines Flight 3701

Bombardier photo.

On 14 October 2004, at approximately 22:15:06 central daylight time, CRJ-200 Pinnacle Airlines flight 3701, a repositioning flight from Little Rock, Arkansas to Minneapolis-St Paul International Airport in Minnesota crashed near the Jefferson City, Missouri Airport, killing the crew who were the only souls aboard the aircraft.

The NTSB Final Report was scathing:
Quote: "The National Transportation Safety Board determines that the probable causes of this accident were (1) the pilot's unprofessional behaviour, deviation from standard operating procedures, and poor airmanship, which resulted in an in-flight emergency from which they were unable to recover, in part because of the pilots inadequate training; (2) the pilots failure to prepare for an emergency landing in a timely manner, including communicating with air traffic controllers immediately after the emergency about the loss of both engines and the availability of landing sites; and (3) the pilots improper management of the double engine failure checklist which allowed the engine cores to stop rotating and resulted in the core lock engine condition. Contributing to this accident were (1) the core lock engine condition, which prevented at least one engine from being restarted, and (2) the aeroplane flight manuals which did not communicate to pilots the importance of maintaining above a minimum airspeed to keep the engine cores rotating." (Report reference: page x).

Aircraft knowledge and basic aerodynamics can be taught, but the professional application of these can only be trained for and must be constantly honed. Additionally, a well designed and appropriately taught and monitored training program, containing an in-flight upset section, is a useful tool for detecting, and if need be removing, pilots from the system who cannot or will not improve their performance.

The key issue established by Pinnacle 3701 is that, regardless of the behaviour and the predicament that resulted, the crew could have probably recovered sufficiently to save their lives and the aircraft with knowledge contained in in-flight upset training programs.

The problem arose because the pilots allowed the speed to decrease in the latter part of the climb so that at FL410 the speed was well below minimum drag and the altitude could not be maintained at that speed. If the crew had then disconnected the altitude lock and descended to achieve the required speed they could have resumed flight at FL410 — as described in the 'Upset Recovery Aid'.

Certainly lack of crew professionalism was the primary cause of the accident — lack of knowledge of aircraft performance, discipline, etc, but the aircraft was capable of maintaining FL410 at its weight, if operated properly. Reasons for the crew indiscipline could go back to selection, training, company culture, lack of proper company supervision.

Prime Cause: The total lack of professionalism by the crew by allowing the aircraft to reduce to a speed that was unsustainable at the cruise altitude of FL410. Thereafter, through lack of discipline and lack of knowledge of aircraft performance and then failure to apply the required abnormal procedures, the crew allowed the aircraft to stall and both engines to fail. Lack of LOC-I training and Crew Resource Management compounded the problem, as the pilots were unable to recover from the upset and continue to an alternate airfield. But the prime cause was the incompetence of the crew, putting a fully serviceable aircraft into this position of their own volition, in the first place. Reasons for such crew indiscipline could go back to selection, training, company culture, lack of a proper company, Safety Management System, etc.

Avoidance Strategies: Crews should be totally familiar with the characteristics of their aircraft throughout the flight regime, particularly in the cruise, where the largest part of all flights is conducted. Instil strict operational discipline. Training should emphasise the methodical and systematic diagnosis of in-flight emergency situations, use of the appropriate checklists and crew co-operation. Crews must be taught to remain alert and monitor the aircraft behaviour at all times, especially when flying close to the maximum altitude limit, and be prepared to take corrective action should the speed start to move towards the limits of the normal envelope. Operators note that 'Avoidance' starts at crew selection and initial training.

1.4 Korean Air Flight 8509

Boeing photo.

On 22 December 1999, Korean Air Cargo Flight No: 8509 Aircraft: B747-2B5F (HL 7451) on a cargo flight to Milan-Malpensa, Italy, crashed shortly after takeoff from London Stansted Airport, Essex, England killing all four on board.

UK accident investigators have attributed the fatal crash of the freighter to a faulty cockpit instrument and the crew's failure to respond to a developing emergency.

The captain's attitude director indicator (ADI) showed a correct pitch reading for the 747 during departure from London Stansted, but falsely showed the aircraft as being wings-level when it was actually in a dangerously steep left bank, says the UK Air Accidents Investigation Branch's (AAIB) report.

The data showed the aircraft take-off and climb, initially on runway heading. It reached an altitude of 2,150ft amsl, 37 seconds after take-off, when it commenced a left turn. The pitch attitude then started to decrease and continued to decrease in a continuous turn to the left until the end of the data. The maximum altitude reached was 2,532ft amsl, 11 seconds before the end of the data. The data ended 55 seconds after take-off. The final recorded data indicated an altitude of 967 feet amsl, with a pitch attitude of 38° nose down on a heading of 126°M. Throughout the short flight all four engines were developing power at, or close to, the take-off setting of 1.4 EPR.

The investigation identified the following causal factors:

a. The pilots did not respond appropriately to the comparator warnings during the climb after takeoff from Stansted, despite prompts from the flight engineer.
b. The commander, as the handling pilot, maintained a left roll

control input, rolling the aircraft to approximately 90° of left bank and there was no control input to correct the pitch attitude throughout the turn.

c. The first officer either did not monitor the aircraft attitude during the climbing turn or, having done so, did not alert the commander to the extreme unsafe attitude that developed.

d. The maintenance activity at Stansted was misdirected, despite the fault having been correctly reported using the Fault Reporting Manual. Consequently the aircraft was presented for service with the same fault experienced on the previous sector; the No 1 INU roll signal driving the captain's ADI was erroneous.

e. The agreement for local engineering support of the Operator's engineering personnel was unclear on the division of responsibility, resulting in erroneous defect identification, and mis-directed maintenance action.

Comment

Attitudes of deference to senior members of the community may have played a part in this accident. Questioning the behaviour or performance of 'elder statesmen' by less senior members is still regarded as unacceptable in some organisations and by individuals who may have not come to terms with modern education and training methods. The willingness of an experienced captain to listen to information provided by a subordinate is a vital requirement, as is the need for that captain to facilitate an environment where such advice is readily volunteered. Aircrew are humans and humans make mistakes. Airlines must develop a culture where no aircrew member perceives he/she has suffered a 'loss of face' by having an error drawn to their attention. The positive aspect of said culture should be the use of such an opportunity to commend the informant for his/her alertness; so that he/she is made to feel useful as a full contributor and monitoring member of the crew.

Six safety recommendations were made during the course of the investigation. The most prominent was the first one which reads:

Safety Recommendation No 2003-62: That Korean Air continue to update their training and Flight Quality Assurance programs, to accommodate Crew Resource Management evolution and industry developments, to address issues specific to their operational environment and ensure adaptation of imported training material to accommodate the Korean culture.

Probable Prime Cause: Following reported problems with the Left hand Attitude indicator, the captain did not cross-check the after take-off rotation attitude and bank angle against stand-by instruments and monitoring pilot did not intervene with any warning of over-banking, after lift-off rotation.

Avoidance Strategies: Better Instrument Flight (I/F) instruments cross-checking instruction with improved maintenance action handover methods and consolidation in CRM and monitoring procedures.

1.5 Adamair Flight DHI 574

On 1 January 2007, a Boeing Company 737-4Q8 aircraft, registered PK-KKW, operated by Adam SkyConnection Airlines (AdamAir) as flight number DHI 574, was on a scheduled passenger flight from Surabaya (SUB), East Java to Manado (MDC), Sulawesi, at FL 350 (35,000ft) when it disappeared from radar.

The aircraft departed from Djuanda Airport, Surabaya, at 05:59 Co-ordinated Universal Time (UTC) under the instrument flight rules (IFR), with an estimated time of arrival (ETA) at Sam Ratulangi Airport, Manado, of 08:14. The fuel endurance on departure from Surabaya was 4 hours 30 minutes, and the crew had flight planned for an alternate of Gorontalo (GTO). The pilot in command (PIC) was the pilot flying the sector to Manado and the co-pilot was the monitoring/support pilot. All 102 people on board were killed.

Investigation by the Indonesian National Transportation Safety Committee (NTSC) showed that:

The pilots were faced with an Inertial Reference System (IRS) malfunction and did not have sufficient knowledge of the aircraft system to quickly and appropriately troubleshoot the problem. Their actions to rectify the problem resulted in decision errors, and the pilots were so engrossed with trouble shooting IRS anomalies for at least the last 13 minutes of the flight, with minimal regard to other flight requirements.

The DFDR analysis showed that the aircraft was in cruise at FL 350 with the autopilot engaged. The autopilot was holding 5° left aileron wheel in order to maintain wings level. Following the crew's selection of the number-2 (right) IRS Mode Selector Unit to ATT (Attitude) mode, the autopilot disengaged. The control wheel (aileron) then centred and the aircraft began a slow roll to the right. The aural alert, BANK ANGLE, sounded as the aircraft passed 35° right bank.

The DFDR data showed that roll rate was momentarily arrested several times, but there was only one significant attempt to arrest the roll. Positive and sustained roll attitude recovery was not achieved. Even after the aircraft had reached a bank angle of 100°, with the pitch attitude approaching 60° aircraft nose down, the pilot did not roll the aircraft's wings level before attempting pitch recovery in accordance with standard operating procedures. The aircraft reached 3.5g, as the speed reached Mach 0.926 during sustained nose-up elevator control input, while still in a right bank. The recorded airspeed exceeded Vdive (400 kcas), and reached a maximum of approximately 490 kcas just prior to the end of recording.

Findings

The PIC did not manage 'task sharing' and crew resource management practices were not followed. There was no evidence that the pilots were appropriately controlling the aircraft, even after the BANK ANGLE alert sounded as the aircraft's roll exceeded 35° right bank.

This accident resulted from a combination of factors, including the failure of the pilots to adequately monitor the flight instruments, particularly during the final 2 minutes of the flight. Preoccupation with a malfunction of the Inertial Reference System (IRS) diverted both pilots' attention from the flight instruments and allowed the increasing descent and bank angle to go unnoticed. The pilots did not detect and appropriately arrest the descent soon enough to prevent loss of control.

At the time of the accident, AdamAir did not provide their pilots with IRS malfunction corrective action training in the simulator, nor did they provide aircraft upset recovery training in accordance with the Airplane Upset Recovery Training Aid developed by Boeing and Airbus.

Causes

1. Flight crew co-ordination was less than effective. The PIC did not manage the task sharing; crew resource management practices were not followed.
2. The crew focused their attention on trouble shooting the Inertial Reference System (IRS) failure and neither pilot was flying the aircraft.
3. After the autopilot disengaged and the aircraft exceeded 30° right bank, the pilots appeared to have become spatially disoriented.
4. The AdamAir syllabus of pilot training did not cover complete or partial IRS failure.
5. The pilots had not received training in aircraft upset recovery, including spatial disorientation.

Probable Prime Cause: Insufficient crew technical knowledge possibly due to insufficient 'need-to-know' training and poor monitoring of the flight, with no one 'minding the shop' while trouble-shooting a problem.

Avoidance Strategies: Improved technical courses with aircraft upset avoidance and recovery training and better CRM crew monitoring duties instruction.

1.6 Colgan Air Flight 3407

This accident is selected as an example of a LOC-I fatal event because of the multiplicity of factors that arise from it in so many areas such as in Training and Human Factors, inter alia.

Colgan Air Flight 3407, operated as a 'Continental Connection' under a codeshare agreement with Continental Airlines, was a daily US regional airline commuter flight from Newark Liberty International Airport in New Jersey to Buffalo Niagara International Airport in New York State.

According to the NTSB report, on 12 February 2009, at about 22:17 Eastern Standard Time, a Colgan Air, Inc, Bombardier DHC-8-400, N200WQ, operating as Continental Connection flight 3407, was on an instrument approach to Buffalo-Niagara International Airport, Buffalo, New York, when it crashed into a residence in Clarence Center, New York (State), about five nautical miles northeast of the airport. The two pilots, two flight attendants, and 45 passengers aboard the aeroplane were killed, one person on the ground was killed, and the aeroplane was destroyed by impact forces and a post-crash fire. The flight was operating under the provisions of 14 Code of Federal Regulations Part 121. Night visual meteorological conditions prevailed at the time of the accident.

Probable Cause

The National Transportation Safety Board determines that the probable cause of this accident was the captain's inappropriate response to the activation of the stick shaker, which led to an aerodynamic stall from which the aeroplane did not recover. Contributing to the accident were (1) the flight crew's failure to monitor airspeed in relation to the rising position of the low speed cue, (2) the flight crew's failure to adhere to sterile cockpit procedures, (3) the captain's failure to effectively manage the flight, and (4) Colgan Air's inadequate procedures for airspeed selection and management during approaches in icing conditions. The safety issues discussed in the report focused on strategies to prevent flight crew monitoring failures, pilot professionalism, fatigue, remedial training, pilot training records, airspeed selection procedures, stall training, Federal Aviation Administration (FAA) oversight, flight operational quality assurance programs, use of personal portable electronic devices on the flight deck, the FAA's use of safety alerts for operators to transmit safety-critical information, and weather information provided to pilots. Safety recommendations concerning these issues are addressed to the FAA.
Findings (selection from 46)

1. Explicit cues associated with the impending stick shaker onset, including the decreasing margin between indicated airspeed and the low-speed cue, the airspeed trend vector pointing downward into the low-speed cue, the changing colour of the numbers on the aeroplane's indicated airspeed display, and the aeroplane's excessive nose-up pitch attitude, were presented on the flight instruments with adequate time for the pilots to initiate corrective action, but neither pilot responded to the presence of these cues.

2. The reason the captain did not recognise the impending onset of the stick shaker could not be determined from the available evidence, but the first officer's tasks at the time the low-speed cue was visible would have likely reduced opportunities for her timely recognition of the impending event; the failure of both pilots to detect this situation was the result of a significant breakdown in their monitoring responsibilities and workload management.

3. The captain's response to stick shaker activation should have been automatic, but his improper flight control inputs were inconsistent with his training and were instead consistent with startle and confusion.

4. The captain did not recognise the stick pusher's action to decrease angle-of-attack as a proper step in a stall recovery and his improper flight control inputs to override the stick-pusher exacerbated the situation.

5. The captain's failure to effectively manage the flight (1) enabled conversation that delayed checklist completion and conflicted with sterile cockpit procedures and (2) created an environment that impeded timely error detection.

6. The monitoring errors made by the accident flight crew demonstrate the continuing need for specific pilot training on active monitoring skills.

7. The flight crewmembers' performance during the flight, including the captain's deviations from standard operating procedures and the first officer's failure to challenge these deviations, was not consistent with the crew resource management (CRM) training that they had received or the concepts in the Federal Aviation Administration's CRM guidance.

8. The pilots' performance was likely impaired because of fatigue, but the extent of their impairment and the degree to which it contributed to the performance deficiencies that occurred during the flight cannot be conclusively determined.

9. The captain had not established a good foundation of attitude instrument flying skills early in his career, and his continued weaknesses in basic aircraft control and instrument flying were not identified and adequately addressed.

10. The circumstances of this and other accidents in which pilots have responded incorrectly to the stick pusher demonstrate the continuing need to train pilots on the actions of the stick-pusher and the aeroplane's initial response to the pusher.

11. Distractions caused by personal portable electronic devices affect flight safety because they can detract from a flight crew's ability to monitor and cross-check instruments, detect hazards, and avoid errors.

Crew failures — observations

- Inadequate monitoring of Airspeed and flight Instruments [both Pilots]
- Inappropriate Checking [Training] for recovery from a stall [reduce AoA] as identified by the comments of some of the Colgan check airmen who stated that outside of ±100ft change of altitude would be considered a fail — thus instituting a power out recovery as the only means of acceptable performance — creating in turn a possible mind set.
- Inadequate Training regarding the stick push and the process by which it is activated [would not activate with a tail-plane stall] but only with an aerodynamic stall.

Probable Prime Cause: Captain's inappropriate response to the activation of the stick push causing an inflight upset subsequently and departure from controlled flight.

Avoidance Strategies: Correct and Standardised Training for avoidance of and recovery from in flight upsets.

Saab photo.

2. IN FLIGHT WITH SUCCESSFUL RECOVERY

2.1 Recovery when subject to In-flight Icing contamination (three events)

With thanks to Dennis A. Crider, Chief Technical Advisor, Vehicle Simulation NTSB, Washington DC.

A Saab 340A on 11 November 1998, regularly scheduled passenger flight from Albury, New South Wales, Australia, to Melbourne, Victoria, encountered icing while operating in instrument meteorological conditions. The crew noted ice accumulating on the wings and windshield wipers but felt that the level of icing was below that required to activate the wing de-icing system. The crew entered the holding pattern at Eildon Weir where the aircraft slowed and stalled without a stall warning, losing 2,300ft of altitude with 30-degree roll excursions and a 30-degree nose-down pitch upset before recovery.

The second example, a Saab 340B+ operated as American Eagle 3008, encountered icing on 2 January 2006, a regularly scheduled passenger flight from San Luis Obispo to Los Angeles, California. The autopilot maintained climb rate as the aircraft slowed and then stalled while climbing through 11,500ft. The aircraft rolled 87° left, 144° right, 75° left, and 97° right with a peak nose-low pitch of 47° before recovering at about 6,500 feet.

The last Saab 340 flaps-up example occurred on 18 June 2004, on a flight from Albury, New South Wales, Australia, to Melbourne, Victoria. The Saab 340 had just levelled off at 12,000ft over Bathurst when the aircraft began to slow. The stick shaker activated briefly and the aircraft rolled only 7° before the pilot pitched down.

How did the crew for the 2004 Albury event recover from their upset immediately while the crew for the Bathurst event lost 1,200ft, the crew of the Eildon Weir event lost 2,300ft, and the crew at San Luis Obispo lost 5,000ft? The answer is apparent from a comparison of their recoveries. When plotted against one another, the elevator plotted with altitude and with the times of upset start (as set by initial upset roll-off) and recovery (considering roll recovery and arrested rate of descent) noted on the plots, shows that the Albury flying pilot applied nose-down pitch control and held it in, establishing a more nose-down elevator (and a lower angle-of-attack) after the event.

The Saab 340 icing upsets all recovered as soon as nose-up pitch control was reduced to near zero elevator and maintained. The Albury crew was successful because they smartly moved the elevator in the nose-down direction and maintained a near-neutral elevator as the aircraft recovered.

Instead of recovery from actual stall, airline crews are taught recovery from approach to stall with the goal of minimising altitude loss. Ironically, the Albury (Bathurst event) crew that immediately input and held nose-down pitch control, experienced the least altitude loss. The first action in stall upset recovery must be to lower the angle-of-attack and get the wings lifting effectively (unstalled) again.

Probable Prime Causes of upset: Crew inattention to reducing speeds and poor monitoring of ice accretion rates. Late stall recovery action from two of the crews.

Avoidance Strategies: Review flight in icing guidance on aircraft type operated and stay prepared to immediately apply stall recovery action at the onset of stall approach symptoms.

3. GO-AROUND CRASHES

(These accidents are heavily CRM/HF orientated failures).

3.1 Thai Airways International A310-200; 11 December 1998; near Surat Thani, Thailand

During its third landing attempt, the aircraft crashed just outside the Surat Thani airport. The aircraft was on a domestic flight from Bangkok to Surat Thani. There were 90 fatalities among the 132 passengers and 11 fatalities among the 14 crew members. It is believed that on the first 2 approaches the captain applied his own thrust for the GA so could control the pitch up but on the third GA, after which they were going to divert, the TO/GA switches were activated, probably by the F/O, which increased thrust rapidly without the captain realising, so he suddenly found himself at about 48° nose-up pitch, while tired and on a dark night.

Aircraft Accident Investigation Committee of the Kingdom of Thailand accident report causes, abstract.

Probable causes:
After careful consideration, the Aircraft accident Investigation Committee of the Kingdom of Thailand ultimately came to the conclusion that the accident occurred because the aircraft entered into a stall condition which might have been caused by the following:

a. The pilot attempted to approach the airport in lower than minimum visibility with rain
b. The pilot could not maintain the VOR course as set forth in the approach chart. The aircraft flew left of VOR course on every approach.
c. The pilots suffered from the accumulation of stress and were not aware of the situation until the aircraft entered into the upset position.
d. The pilots had not been informed of the document concerning the wide body aeroplane upset recovery provided by Airbus for use in pilot training.
e. The lighting system and approach chart did not facilitate the low visibility approach
f. Stall warning and pitch systems might not fully function as described in the FCMM & AMM
g. Safety recommendation (Last one of seven recommendations): **Pilots should undergo aeroplane upset recovery training**

Probable Prime Cause: Use of TO/GA on go-around with insufficient attention given to holding nose down while counteracting approach trim settings as power rises.

Avoidance Strategies: Pilots should undergo aircraft upset avoidance and recovery instruction and more positive CRM monitoring training. Crews should be encouraged to consider using less than TO/GA power for go-around (such as MCP) at light weights.

3.2 China Airlines A300-600 — 16 February 1998 — near Taipei, Taiwan

The scheduled flight had been inbound from the island of Bali in Indonesia. The aircraft crashed into a residential area short of the runway during a go-around following its second landing attempt. The Airbus carried out an ILS/DME approach runway to 05L at Taipei Chiang Kai Shek Airport in light rain and fog, when it came in 1,000ft too high on the glide slope (at 1,515ft, 1.2nm short of the threshold). The Autopilots were disengaged 9 seconds before Go-Around thrust was set and a manual Go-around was initiated, at which point the aircraft was 1,475ft over the threshold. The gear was raised and the flaps set to 20° as the Airbus climbed through 1,723ft in a 35° nose-up attitude. On reaching 2,751ft, 42.7° nose-up and at a speed of 45kt, the aircraft stalled.

Control was not regained and the aircraft struck the ground 200ft to the left of the runway. It hit a utility pole and a highway median. It then skidded into several houses, surrounded by fish farms, rice paddies, factories and warehouses, then exploded. Weather was 2,400ft visibility, RVR runway 05L of 3,900ft, 300ft broken ceiling, 3,000ft overcast. The event occurred under conditions of darkness with rain and reduced visibility due to fog. All 15 crew and 182 passengers were killed. At least seven persons on the ground were also killed.

The investigation team determined that the following factors combination caused the accident:

a. During all the descent and the approach, the aircraft was higher than the normal path;
b. The crew co-ordination between the captain and the first officer was inadequate; i.e., above the glidescope.
c. During 12 seconds, the crew did not counteract the pitch up tendency due to the thrust increase after go-around, and then the reaction of the crew was not sufficient. As a consequence the pitch up increased until the aircraft stalled.

Probable Prime Cause: Poorly executed Instrument approaches leading to a second manual go-around, with insufficient attention given to holding nose down while counteracting approach trim settings with the application of more power than necessary for the missed approach procedure.

Avoidance Strategies: Better Instrument Approach training should be offered to pilots, with go-around upset avoidance and recovery instruction and additional CRM monitoring training in assertiveness.

END OF APPENDIX 1

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END OF APPENDIX 2

APPENDIX 3 — GLOSSARY OF TERMS, ACRONYMS AND ABBREVIATIONS

ACRONYMS

ACAS	Airborne Collision Avoidance System
ADI	Attitude Display Indicator
ADIRU	Air Data Inertial Reference Unit
AFM	Approved Flight Manual
AGL	Above Ground Level
AMM	Aircraft Maintenance Manual
AOA	Angle-of-Attack
A/P or AP	Auto Pilot
ASI	Air Speed Indicator; read directly from the cockpit panel instrument
ASRS	Aviation Safety Reporting System
AT	Auto Throttle
ATC	Air Traffic Control
AUM	All Up Mass; weight
CAP or Capt	Captain
CAS	Calibrated Air Speed; IAS corrected for instrument and installation errors
CAT	Clear Air Turbulence
CIAA	CIAA, Aircraft Accidents Research Committee of Venezuela
CFIT	Controlled Flight Into Terrain
CG	Centre of gravity
CHG or CH	Change; as in LVL CHG (Level Change)
Cl	Coefficient of Lift
CRM	Crew Resources Management
Cu Nim	Cumulo Nimbus (cloud)
EASA	European Aviation Safety Agency
ECAMS	Electronic Centralised Aircraft Monitoring System
EGPWS	Enhanced Ground Proximity Warning System
EICAS	Engine Indicating and Crew Alerting System
FAA	Federal Aviation Administration
FBW	Fly by Wire
FCOM	Flight Crew Operating Manual
FD	Flight Director
FDR	Flight Data Recorder
FEP	Flight Envelope Protection
FL	Flight Level (based on a 1013.2Mb Altimeter setting)
FMC	Flight Management Computer
F/O	First Officer; co-pilot
fpm	feet per minute
FSF	Flight Safety Foundation
Ft or ft	Feet
g	Gravity effect; unit of
GA	General Aviation
HF	Human Factors
IAS	Indicated air Speed; read directly from the ASI driven by the pitot-static system
ICAO	International Civil Aviation Organization
I/F	Instrument Flight
ILS	Instrument Landing System

IMC	Instrument Meteorological Conditions
JAA	Joint Aviation Authority; European Community, (now EASA)
KCAS	Knots Calibrated Air Speed; in knots
KIAS	Knots Indicated Air Speed; as given by the Air Speed Indicator; in knots
KTAS	Knots Indicated Air Speed; the true airspeed (in knots) of an aircraft relative to undisturbed air
L/D max	Lift/Drag Maximum; or Vmd-minimum drag speed
LOC – I	Loss of Control in Flight
LVL	Level; as in LVL CHG (Level Change)
MAC	Mean Aerodynamic Chord
Mb	Millibars; Atmospheric pressure measurement
MAG	Magnetic
MCR	Maximum Cruise Thrust (Boeing); Max Cruise Power for some other constructors
MCT	Maximum Continuous Thrust
MD	McDonnell Douglas; aircraft manufacturer
Mmo	Maximum Mach operating number
MSA	Minimum Safe Altitude
MSL	Mean Sea Level
NASA	National Aeronautics Space Administration
NTSB	National Transportation Safety Board
PF	Pilot Flying
PFD	Primary Flight Display
PIO	Pilot-Induced Oscillation
PM	Pilot Monitoring
PNF	Pilot Not Flying
QRH	Quick Reference Handbook; Abnormal & Emergency drills checklists/ handbook
RAeS	Royal Aeronautical Society, London
ROC	Rate of Climb
RTO	Rejected Take-Off
SOP	Standard Operating Procedures
SPD	Speed
STD	Standard
TAWS	Terrain Alerting and Warning System
TCAS	Traffic Alert and Collision Avoidance System
THS	Tail Horizontal Stabiliser
TO/GA	Take-off / Go-Around (auto throttle switches)
VMC	Visual Meteorological Conditions
V/S or VS	Vertical Speed
VSI	Vertical Speed Indicator

V SPEEDS

Va	Design manoeuvre speed, flaps up
Vc	Design structured cruising speed
Vd	Design dive speed
Vh	Speed in level flight with maximum continuous power
Vs1	Flaps up 1g stall speed
VMd	Velocity Minimum Drag
VMo	Maximum Operating limit speed
VNe	Never-Exceed speed
V1	Speed up to which take-off can be discontinued on a particular runway
VR	Rotation Speed; speed at which the aircraft is lifted off the ground and into the air during the take-off run
V2	Minimum Safety speed after becoming airborne, for a given aircraft weight

END OF APPENDIX 3

APPENDIX 4 — UNITS OF MEASUREMENT

°	degree (angle or temperature)
deg	degree (angle or trемperature)
deg/s	degrees per second
ft	feet
ft/min	feet per minute
ft/s	feet per second
hPa	hectoPascal
hr	hour
in	inch
inHg	inches of mercury
kg	kilogram
kt	knot
m	metre
mbar	millibar
mi	mile
min	minute
nm	nautical mile
sec	second

END OF APPENDIX 4

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