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Loss of Control In-flight (LOC-I) Prevention: Beyond the Control of Pilots

1st | Edition

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Section 1—Foreword

Numerous fatalities resulted from Loss of Control In-Flight (LOC-I) accidents in recent years and the industry sees a need to take action. As an accident category LOC-I is very broad and there are many different sequences that can lead up to an accident. This makes it difficult to produce a single, effective guidance document to help prevent LOC-I. Numerous articles have been published, analyzing LOC-I from different angles, ranging from aircraft design to pilot training, regulatory oversight to change management.

This compendium concerns the airline transport pilot, and in particular those who fly swept-wing jet transport aircraft, but it is not a training manual. Jet transport pilots must understand that while some prior experience or training in military, General Aviation (GA), or other non-transport category aircraft can be useful, techniques that are applicable to other categories may not be appropriate or effective for transport aircraft. For example the use of large rudder deflections to recover a roll-upset may work well in small aircraft but typically should be avoided in transport category aircraft.

Note: To facilitate ease of reading, whenever the male form is used in the document, the female is also addressed. Additionally, the terms 'pilots' and 'flight crew' have been used interchangeably throughout.



Section 2—Content and Scope

The Guidance Material consists of two parts: organizational management, and; aircraft design/manufacture. The management section focuses on organisational and managerial issues which have the potential to create undesirable latent conditions contributory to LOC-I, while the design and manufacture section concentrates on aircraft characteristics and in particular some of the certification specification requirements for transport category aircraft, which may have an influence upon LOC-I.

The author would like to thank the Boeing Company and Capt. Knut Lande, for allowing him to reproduce some of the latter's and Boeing's material.

Section 3—Management Role in LOC-I Accidents

3.1 Introduction

Why bother to write about management in guidance material on LOC-I? Do management decisions contribute to this type of accident at all? Does management have to be familiar with LOC-I as an accident category? Aren't LOC-I accidents caused by the active failures of the pilots, who simply lost control of the airplane?

The fact is that an organization's management systems and the decisions that they generate frequently play a role in aviation accidents, LOC-I included. It is the ultimate responsibility of senior managers to ensure that management systems, and in particular safety management systems (SMS), are correctly designed, documented, implemented and maintained.

The following case studies are presented to inform the readers' contributions to a discussion based scenario:

CASE STUDY 1: "The aircraft is repeatedly dispatched with a faulty Inertial Reference System (IRS). Rather than seeking the root cause, the component is exchanged between aircraft to mask Minimum Equipment List (MEL) rectification due dates. There are documented operating procedures on the flight deck with "For Training Only" stamped across the page. Having flown regularly with the faulty equipment, pilots are used to failures and no longer routinely refer to written abnormal procedures. In cruise a failure leads to loss of attitude reference which the pilots do not manage correctly and the aircraft enters a spiral dive. It subsequently impacts the ocean."

CASE STUDY 2: "Spatial disorientation was the primary cause of the Sept. 13, 2008, crash of a Boeing 737-500 at Perm, Russia, according to the final report by the Russian Air Accident Investigation Commission (AAIC). Contributing factors were inadequate crew resource management (CRM), lack of proficiency in basic aircraft handling and a lack of skills associated with the use of a "Western-type" attitude indicator for recovery from an upset. During the approach the flight crew was challenged by night instrument meteorological conditions as well as by a navigation programming error and "throttle stager" that made manual engine management difficult and led to control problems caused by asymmetric thrust"¹.

¹ Marc Lacagnina: Misgauged Recovery, Flight Safety Foundation, AeroSafety World, May 2010

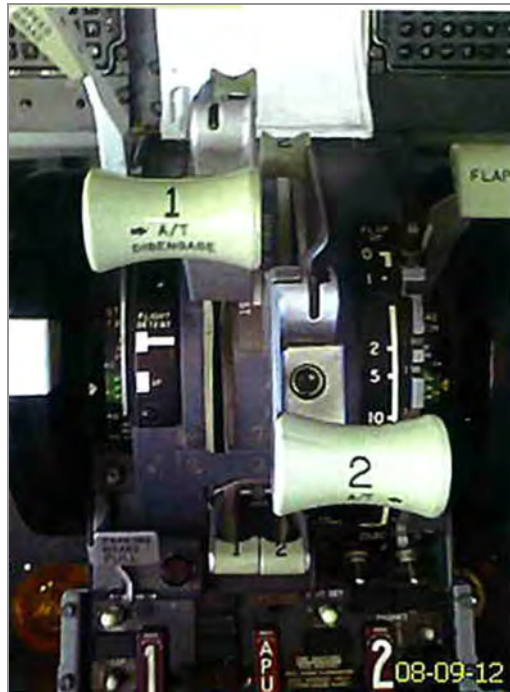


Figure 1: Case Study 2: photo taken on a previous flight shows the throttle stagger required to maintain 83 percent fan speed on both engines [Marc Lacagnina]

Management decisions may not have an immediate effect on the outcome of every flight but potentially they can play a role in an accident long before it occurs. The scenarios above clearly show that flawed maintenance practices and management oversight, perhaps in pursuit of cost reductions (no stock of replacement parts), have contributed to past LOC-I accidents. The first case study shows the consequences that “creative” application of the MEL can have. While the aircraft was dispatched perfectly legally (barring the operational procedures documentation) the work-around solution to a technical issue posed a latent operational threat that eventually led to the LOC-I accident. In the second case the pilot apparently overlooked that he had to fly with throttles split due to the unmanaged technical deficiency. When the throttle levers were set to equal positions the resulting thrust imbalance caused the aircraft to yaw, roll and ultimately to crash.

3.2 Management – Some Considerations

As a matter of routine, management decisions should be based on a thorough risk-assessment, which not only considers financial and commercial risks but also addresses the operational risks. Because commercial aviation is generally regarded as low risk due to ultra-low accident rates, significant operational hazards may often be underestimated or overlooked. In the minds of many managers, LOC-I may be an accident category that does not affect experienced and well trained airline pilots. However, statistical accident data shows that high-time airline pilots in a multi-crew environment can be at risk of LOC-I.

Considerations for management are:

- Training: Do your budgets allow for training programs that include dedicated Upset Prevention and Recovery Training (UPRT)?
- Information Sharing: Is your reporting system detecting cases of near-LOC-I situations, e.g. approach to stall scenarios or roll-upsets? If it is, do you share the lessons learned and have you taken appropriate action to eliminate root causes?

- Flight Data Analysis (FDA): Is your FDA program up-to date? Are your subject matter experts constantly seeking to refine trigger parameters that detect LOC-I precursors? Does your system detect excessive aircraft attitudes, unusual control deflections or approach to stall? Does your program include 'normal operations monitoring' as well as exceedance detection?
- Human Performance: Do you conduct training dedicated to human performance limitations? Are your pilots aware of the causes and consequences of spatial disorientation, optical illusion and somatogravic effects? Do you have an effective drug and alcohol management program? Do you have an effective fatigue risk management system (FRMS)?
- Simulator Operations Quality Assurance (SOQA) *The equivalent of the Flight Operations Quality Assurance (FOQA) using data from simulator training sessions*: Is your organisation aware of SOQA? Could you benefit from SOQA to learn more about flight crew performance in simulated emergency situations?
- Reporting: Does your reporting system address miss-rigging of aircraft or defective aircraft systems? Do pilots report excessive number of deferred defects or abuse of the MEL? Is there a confidential and/or non-punitive channel for reporting human performance deficiencies?
- Crew experience: are your flight crew really experienced pilots? Have your pilots had an opportunity to spend enough time outside their comfort zones, i.e. outside of the very narrow portion of the flight envelope that the typical airline pilot operates in?

If you answered 'NO' to any of the above questions, you might want to talk to your operational staff and your safety experts. There is always opportunity for improvement in each and every organization and changing these negative answers to positives could make the vital difference in accident prevention. If you answered 'YES' to all of the questions then you are probably an industry leader in LOC-I prevention and it is recommended that you expand the list to add more questions that will help identify precursors to LOC-I.

LOC-I accidents do not conform to a clear pattern and there have been multiple different reasons why pilots lost control of their aircraft. These include:

- Flawed maintenance practices leading to system malfunctions;
- Inadequate flight crew selection and training standards (e.g. behavioral deficiencies, lack of training with respect to illusions, high g-load environment, managing unexpected situations);
- Operating procedures (e.g. erosion of manual flying skills or deficiencies in handling automation);
- Environmental conditions (e.g. meteorological phenomena which cause aircraft upsets);
- Air traffic environment (e.g. wake vortices).

If there is a common factor in LOC-I accidents it appears to be the "startle-factor", when the situation facing the pilot is unexpected and/or unrecognised and he is unable to devise and implement a solution in the time available.

3.3 Flight Crew Selection Standards

A consistent and effective pilot selection process based on scientific principles is vital to the creation of a professional and reliable pilot group. The following case studies are presented to inform the readers' contributions to a discussion based scenario:

CASE STUDY 3: "On a ferry flight the pilots start to fly non-standard manoeuvres soon after departure. In the course of the flight, they decide to fly at the certified maximum altitude (service ceiling) and request a climb. Shortly after reaching the service ceiling both engines fail and the aircraft begins to glide downwards. Engine restarts are attempted without success due to a seized engine core condition. The aircraft eventually crash-lands in a field a few miles short of the destination airport and both pilots are fatally injured."

What has this got to do with management you may ask? Well, with the benefit of hindsight, these pilots were not risk managers, rather their behavior points to them being risk takers. The exploring part in their characters – "let's try it and see" – dominated on that flight. These pilots were willing to expose themselves and the aircraft to additional risk by flying manoeuvres which they would likely not have flown with passengers on board. In addition, they lacked the technical knowledge to understand the consequences of engine "core lock" and committed to a decision making error when they elected to continue to the destination airport, although there were a couple of suitable airports well within gliding range. A robust pilot selection and induction process should have identified these characteristics.

CASE STUDY 4: “A newly hired pilot attempted aerobatics in an aircraft not certified for aerobatic manoeuvres, and while he had received some instruction on aerobatics he had not completed formal training. Also on board was a young employee, who held a pilot’s license but was not a part of the flight crew. The aircraft crashed killing both of them and destroying the aircraft beyond recognition; the subsequent investigation revealed that the intention to fly manoeuvres beyond the certification limit of the aircraft was posted on social media by the pilot on the day before the accident.”

Appropriate screening for flying staff is a management responsibility and implementation requires a management decision. Who else, if not the management should decide on which type of personality to hire? While the court cases that inevitably follow these accidents focus on who was at the controls, the question that really needs to be asked is how management failed to identify that the pilots they hired were willing to take these risks?

In CASE 4 it turned out that the operator’s management actually had information about that particular pilot being a risk-taker, prior to the accident.

Here is some food for thought:

- Have you recently discussed your selection and screening processes with aviation psychologists?
- How do you make sure that your pilots are risk managers and not risk takers?
- Does your reporting system identify individuals who are considered risk-takers and if so how do you deal with that information?
- Have you identified pilots which might feel extremely uncomfortable when at unusual attitudes in a real aircraft (e.g. small aerobatic aircraft) to the point where they will lose their ability to take recovery action? It might sound awkward to raise that point. Could a pilot indeed feel uncomfortable when flying an airplane? The answer is yes – some pilots are simply less capable in maintaining capacity to control the aircraft when things go south. In training sessions, we have seen very experienced pilots freezing on the stick the first time they were in an unusual attitude.
- After an incident, has anyone in your management team said something like ‘We always had concerns about him?’

3.4 Fatigue

Fatigue has been identified as a factor in numerous aviation accidents over the years and is a continuing problem facing flight crew in aircraft of all sizes. Please read the following account:

CASE STUDY 5: “On a long night flight, which was the second consecutive night with more than 11 hours of flight time, the wide-body aircraft is descended towards approach and landing at the flight crew’s home airport. It is clear weather in the very early hours of the morning. The aircraft is cleared for the Instrument Landing System (ILS) approach but it slowly starts a roll to the right after localizer capture. Both pilots are startled – they expected the aircraft to track the localizer. The Pilot Flying (PF) grabs the controls and attempts to disengage the autopilot only to realize that the autopilot had already been disengaged and he should have been flying the aircraft manually.”

What had happened? The PF had already hand-flown the aircraft earlier in the arrival but due to fatigue, he had forgotten to re-engage the autopilot.

Have stories like this ever surfaced in your organization? Have you implemented a Fatigue Risk Management System (FRMS) which encourages reporting of incidents related to fatigue? Have you conducted surveys to ask your safety-critical shift-workers (including flight dispatchers and mechanics) about fatigue related incidents and experiences? In your organization, do you allow organized napping so that the potential for micro-sleep can be mitigated? Do your reports point towards fatigue issues on certain routes or combinations of destinations in a roster? Have you considered the use of proven technology to detect micro-sleeps and draw lessons from the results?

Here is another case in which both pilots thought that the autopilot was engaged when in fact it was not. This time the flight ended in a fatal accident:

CASE STUDY 6: “Following a high-time departure, convective weather returns appeared on radar ahead. The First Officer did not feel comfortable. Soon after the aircraft got airborne the Captain asked for the autopilot (AP) to be engaged and the First Officer reached towards the AP engage button. For the next several seconds there was no input on the flight controls. Both pilots were busy with something other than flying the airplane. The aircraft started an ever-steepening roll to the right, followed by a spiral dive from low altitude, which was not recovered.”

Besides the element of fatigue in both cases the missing factor was “flight mode awareness”. Most operators stress the importance of mode awareness in their standard operating procedures, i.e. flight crew actively monitoring and calling out the mode in which the auto-flight system is engaged, if indeed it is engaged. Although this topic is covered in great detail in many training programs, unfortunately, original equipment manufacturers (OEMs) have not (yet) standardized the way flight modes are displayed to pilots. A simplification and global standardization of the flight mode annunciator (FMA)-script would help promote and improve flight mode awareness.

3.5 Modern Technology

Whether or not to invest in new technology is clearly a management decision. At the moment there is no single technological solution on the market which is capable of eliminating the LOC-I accidents altogether. Modern fly-by-wire (FBW) aircraft with some degree of automated envelope protection would appear to have an edge over traditional cable-and-pulley systems. Nevertheless, sensors can fail and provide incorrect information to the flight control computers. If there is a combination of failures not anticipated by the design team, it is likely that the aircraft performance and handling will be less than optimal and potentially unpredictable. For the moment it seems that a well-trained pilot is still the best gadget on board an aircraft, to cope with the full range of possible situations whether foreseen or not. So the question that needs to be asked is, regardless of the technology on your aircraft what do you do to make your pilots more competent in upset prevention and recovery?

3.6 Training for the Unexpected

There is an old adage that describes flying as endless hours of boredom, interspersed with a few moments of sheer terror. Management should be aware of the fact that LOC-I always takes the flight crew by surprise and it is therefore essential that training includes the surprise factor.

In modern commercial aviation with highly reliable systems and multiple redundancies a common perception amongst pilots is that system failure is rare. In contrast to developmental flight-testing, where the test pilot expects things to go wrong, the opposite holds true in commercial aviation; the pilot’s experience fosters an expectation that the aircraft systems will operate flawlessly. So when something does happen we can (initially at least) find the pilot taken by surprise or ‘startled’. In most cases a “let’s wait and see – run the checklist first”- attitude is an appropriate response. After all, we certainly do not want pilots to rush into procedures and in a multi-crew environment the simple fact that another pilot needs to be brought into the loop takes some extra time².

With incipient LOC-I situations the available time-span to make an initial response can be quite short. In 1997 a Boeing 767 crashed when the thrust reverser deployed during the last part of the climb to initial cruising level. From the moment one of the pilots stated “thrust reverser deployed” to the end of the Cockpit Voice Recorder (CVR) recording some meagre 27 seconds had passed. The aircraft yawed, rolled and dived to inflight breakup within that half minute.

² With some important exceptions like approach to stall on short final. The AIBN is investigating an incident where a Dash 8-100 flown by the captain, stalled at 300 feet and was recovered by the quick take over by the PM copilot, pulling 2,7 G and fire-walling the throttles.

Bear in mind that LOC-I is not limited to the take-off and landing phases of the flight, unlike many other accident categories. Statistics show that LOC-I can happen in all phases of flight, including the comparatively low workload cruise phase where pilots may have their seats moved back in an aft position and generally maintain a more relaxed flight deck environment. The following case study provides an example:

CASE STUDY 7: “During a North-Atlantic crossing the First Officer had to leave the flight deck for physiological needs. The Captain was PF and watched the aircraft slowly deviate away from its track. While still on autopilot he engaged a heading mode and attempted to turn back to the course line – without success. A few seconds later the autopilot disengaged and the aircraft rolled sharply to the right, exceeding 60° angle of bank.”

Needless to say the Captain was now required to fly the aircraft manually, and he applied a hard left control input to return to wings level. From the aft seat position it was difficult for him to apply the roll control input and at the same time use his right hand to open the flight deck door when the First Officer requested to return to his seat.

What had happened? After more than 20 years in continuous reliable operation a mechanical linkage in the rudder ratio system failed. This resulted in excessive rudder angle which induced a yaw-roll moment. The autopilot kept fighting against the moment by applying rudder trim. When the aircraft was utterly out of trim the autopilot disconnected and the pilot was left on his own to fly out of the upset.

This last case study raises some good questions:

- When did our pilots last fly the aircraft (or simulator) manually in a high altitude cruise so as to develop a good feel for the control inputs required?
- Could an ‘on-condition’ maintenance inspection and replacement program have picked up the impending failure of the rod in the rudder ratio system?
- Should we re-visit our flight deck procedures to always require a second person on the flight deck to open the door in case the remaining pilot gets busy?
- Should we re-visit our procedures regarding seat position when one pilot has left the flight deck?
- Last but not least – that particular Captain had accumulated more than 15,000 hours and it was the first time in his career to see a bank angle well beyond 30° AOB (Angle of Bank) – remember the earlier reference to the ‘startle factor’ in the development of LOC-I accidents.

A seasoned experimental test pilot who flies transport category aircraft in displays at major international air shows once explained to his fellow test pilots how he prepared for the flight and what sequence of manoeuvres he would typically fly. The most remarkable part of his presentation was the fact that he could go from one extreme end of the flight envelope to the other and back again in only 30 seconds. In other words, while your airplane might be on the verge of stall at one point in time it could exceed VMO/MMO (maximum operating speed/Mach No) only 15 seconds later. The dynamics are such that LOC-I accident precursors typically do not give the pilot a whole lot of time to react and recover the flight path.

3.7 Man-Machine Interface Issues

CASE STUDY 8: “In cruise flight, the Captain returns to the flight deck having left earlier for physiological reasons. He enters the access code, waiting for the First Officer to unlock the door. Meanwhile the First Officer is busy on the radio and at the same time makes entries in the Flight Management Computer (FMC) so as to fly a ‘direct-to’ leg to a waypoint as cleared by Air Traffic Control (ATC). The aircraft starts the turn but continues to roll to more than 130° AOB.”

What had happened? When the buzzer activated in response to the Captain’s request for entry the First Officer’s hand reached back to the rudder trim knob instead of the door unlock switch. He applied an input and waited for the sound of the door unlocking but since the door did not open he kept the input for several seconds and miss-trimmed the rudder to the extent that the yaw-roll couple drove the aircraft into a roll-upset. The aircraft was recovered successfully but lost more than 6,000 feet of altitude in the process.

The subsequent investigation revealed that some aircraft in the same fleet but a different variant had the door unlock switch adjacent to the rudder trim selector. Distracted by multiple tasks, the First Officer used the wrong control and was unable to comprehend the inappropriate response.

This case study shows how easy it is to go from perfectly normal to almost catastrophic flight conditions due to distraction and inadequate workload management. Flying requires pilots to manage distractions and workload in all phases of operation – reducing distractions on the flight deck will help to avoid accidents, including those due to LOC-I. What has this got to do with organizational management? Management makes decisions on aircraft acquisition, so can:

- Ensure that when aircraft are purchased, leased or modified, cockpit systems, controls and indicators remain consistent across the fleet;
- Use commercial pressure to lobby manufacturers for improvements in cockpit system ergonomics;
- Lobby manufacturers to standardize cockpit displays and control elements (e.g. FMA readouts and throttle controls);
- Demand that manufacturers develop new and more ‘human centric’ cockpit systems. Human centric is a system which is honest when it fails. The complex automation and cross-connection between systems makes it difficult for pilots to identify what effect the failure of one system has on the other.

3.8 LOC-I on Functional Check Flights

There is a special category of flights which does not attract a lot of attention but has its share of incidents and sometimes even accidents – these are “post maintenance acceptance flights”, also called “functional check flights”. These flights are conducted without passengers and are required to test and demonstrate the airworthiness and flight characteristics of an aircraft after heavy maintenance. Usually, specially trained and certified airline pilots occupy the cockpit seats together with an engineer on the jump seat. However, the amount of initial and recurrent training, the pilot’s previous minimum experience (not necessarily total flight time) and the level of exposure to functional check flights (from once a year to perhaps one such flight every week) can differ significantly between airlines; these pilots are still commercial airline pilots and not qualified flight test pilots. Especially when significant maintenance, modification or rectification work has been carried out on the flight control systems, these pilots must be alert to any anomalous aircraft or system behavior throughout the flight.

CASE STUDY 9: “The aircraft suddenly pitched nose down when hydraulic power was removed from the flight controls (‘manual reversion’) during a functional check flight. Fortunately the Captain was very familiar with this test and had 14,000 feet of altitude below when the event happened, which ultimately saved the aircraft. The aircraft next rolled to 79° roll angle when the Captain asked his First Officer to turn the hydraulics back on. The airspeed reached 440 knots, well above the maximum operating speed and the nose dropped to minus 26°. At 7,500 feet the aircraft entered clouds but seconds later at 6,500 feet the airplane’s descent was arrested and a shallow climb was established. The aircraft and flight crew were safe. The test initiation point was 15,000 feet at 250 knots – the same as in 143 previous cases.”

What went wrong? The First Officer was not familiar with the test and reached for the wrong switch when the Captain asked him to turn the hydraulics back on. Recognizing the problem the Captain finally managed to turn the hydraulics back on himself.

In another case, again a Boeing 737, the hinge fasteners of the elevator tab were ‘torqued’ to a wrong (lower) value. When testing the flight controls under ‘manual reversion’ (hydraulic power removed) the aircraft suddenly pitched up. Hydraulic power was immediately re-established and the aircraft attitude returned to normal. Because the torque of the elevator tab was below the value specified in the maintenance manual, the tab could weather-vane (float) into a position which resulted in a sudden pitch-up.

The above-mentioned flight crew were perhaps lucky but another crew ran out of luck when they tested the low speed protection system on an Airbus A320, during a return-from-lease functional test flight. The test was conducted at an inappropriately low altitude while on approach. The system, which is designed to prevent the aircraft from approaching a stalled condition, malfunctioned during the test and allowed the aircraft to stall. Previously, the aircraft had been washed and it was later concluded that the Angle of Attack (AOA) vanes froze in flight, giving an erroneous AOA signal to the system. This case is of particular interest, since this was an aircraft with fully automatic flight envelope protection which the pilots might expect to rely upon but if the sensors generate erroneous signals the protections are no longer valid. This highlights a difference between airline pilots whose experience is almost exclusively of fully functional aircraft systems, and qualified test pilots who routinely experience aircraft systems that are inoperative or functioning incorrectly.

After any significant flight path divergence, returning a large transport category aircraft to normal attitudes takes time and frequently a lot of altitude. During a planned stall-test of an MD-90 by a qualified test pilot, the aircraft rapidly and unexpectedly inverted and developed a high descent rate. The test involved deliberate low speed flight with a pilot induced sideslip. One wing stalled first causing a rapid roll, which was exacerbated by the sideslip. Although the test pilot was well prepared for the test and immediately initiated the appropriate recovery, it took 10,000 feet to return the airplane to normal flight – the altitude at level-off was 5,000 feet.

3.9 Final Thoughts – Management

Management decisions have an impact on prevention of LOC-I accidents through:

- Selection and training of pilots;
- Standardisation of equipment;
- Provision of resources to analyze data and disseminate information.

Armed with good data, the responsibility of management is to provide funding for:

- Processes that effectively identify root causes, and;
- Implementation of corrective actions in a timely manner.

Identifying root causes should not be taken lightly. Several models have been developed to help analyze and explain the causes of an accident: James Reason's "Swiss Cheese Model", Helmreich's "Threat and Error Management Framework", the "Bow Tie Model", Rasmussen's "Drift into Danger" Model, the SHELL-Model, the Human Factors Analysis and Classification System (HFACS), Sidney Dekker's "New View" model and others. Are any of these models useful for the retrospective analysis of LOC-I accidents? Absolutely. Are these models alone going to prevent LOC-I accidents in the future? Probably not if used in class room training as something generic. Probably yes, if it is living practice in the airline to fill these models with the airline's own incident data and create correlations.

The job of an airline safety analyst includes use of models like these on a day-by-day basis but why should management need to know about them? Management needs to provide the resources that allow the models to be populated with meaningful data from which useful conclusions can be derived. The models help to expose the structure of an event and by applying those to several accidents or incidents who can identify common precursors or causes. For management it is important to understand why it takes resources, sometimes lots of resources, to identify the accident precursors, develop and test effective safety defences and properly assess residual risk:

Example: "Management of airline ABC bans all but essential manual flying from their operation because it is perceived to be less safe than automation. Manual flying practice to keep pilots current is confined to simulator training."

Before implementing this decision the airline should run a detailed risk analysis to determine whether or not it could have an impact on future LOC-I accidents (or safety in general). On one side of this analysis, it can be argued that automation undoubtedly does a great job most of the time. On the other hand, the results of a recent IATA LOC-I Survey for pilots gave multiple examples of when they had to revert to manual flying in normal line operations because the automation did not adequately manage the situation:

- Aircraft did not behave as expected;
- False Localizer (LOC) or Glideslope (GS) capture;
- Erratic tracking of LOC or GS signal;
- Late notice runway changes;
- Traffic avoidance;
- Energy management following ATC shortcuts (Note: pilots should always have the option to decline inappropriate instructions);
- Weather related (e.g. aircraft could not cope with decreasing tailwind);
- Potential VMO/MMO exceedances;
- Selection of incorrect automation mode requiring the pilot to take-over manually;
- System malfunction causing automation to disengage unexpectedly;
- Slow reaction of automation.

What are the lessons to be learned from the above list?

- The first is that manual flying skills are typically required when things have already gone wrong. It is often in the most complex situations that the pilot must take over. This adds to cockpit workload and may cause extra stress if a pilot's flying skills do not match the demands of the situation.
- The second is the potential for management decisions to be based on criteria that are too narrow or simply incorrect. These decisions may be over-reactions to single events and informed less by facts than assumptions. Root cause analysis models can help to guide decisions and ensure that they address all aspects of risk adequately and appropriately.

Ensuring that pilots are able to maintain a high standard in both the management of flight automation systems and in their manual flying skills is within the scope of responsibility of airline management. Airline Management has to be made aware that the UPRT document includes reference to EASA SIB 2013-05 for guidance on manual flying practice. Management has to provide an operational environment in which those skills can be constantly developed and maintained. Factors to consider in the decision whether to authorise and/or encourage manual flying include flight conditions (VMC/IMC), traffic density, individual alertness (consider effects of fatigue on the last sector of the day, after a very long flight or at circadian lows). To ensure that pilots are well prepared to make optimal decisions on the use of automation, relevant training programs and operational policies must be developed and promulgated.

The precise balance between use of automation and manual flying practice is still under debate among experts and airlines have tried a range of interventions: everything from giving pilots the opportunity to fly manually in smaller aircraft outside of commercial operations, to aerodrome traffic pattern training in the real aircraft; from dedicated manually flown simulator sessions to simply authorising manual flight in routine line operations. Some airlines actively manage the mix of long- and short-haul flying in recognition of the limited opportunity for manual flight in long-haul operations. Whatever the chosen strategy, it falls to management to provide the opportunities, resources and policies to ensure that erosion of manual handling skills and inadequate automation management do not present undue LOC-I risks.

Using Dr. Simon Bennett's words (2012)³ to conclude this chapter:

“Malfunctions are to be expected in aircraft, by virtue of their interactive complexity, tight coupling and risk-and-error-prone operating environment. In the risk-laden world of aviation the pilot is the last line of defense.”

LOC-I prevention, recognition and recovery are no exception.

³ Bennett, S. Dr. *The Air France 447 Accident – Organizationally and Socially Produced?* RAeS, The Aerospace Professional, p. 20-21. October 2012.

Section 4—Aircraft Design & Manufacture

Aircraft designers and manufacturers unquestionably possess the largest and most comprehensive body of knowledge with regard to their airplanes. After all, they are the ones who conceived of these marvellous machines, managed the complexities of their construction, nurtured them through flight test, certification and entry into service and in some cases supported them for thirty plus years of commercial operations. It might be argued that the view of any individual operator could be narrow and constrained by operational and regional factors, whereas an aircraft manufacturer would benefit from a global perspective of the worldwide fleet. Given this wealth of knowledge and experience, what capability does the commercial aviation industry have to challenge the design and manufacturing decisions of the aircraft builders? History tells us that compelling arguments have been made in the past for designs and technologies that later proved to be flawed. The tragic loss of several Comets before a simple design deficiency was identified is a prime example but how would the airlines have known?

This essential questioning oversight is the role of the aircraft certification authorities. Certification is a very costly and time-consuming process with numerous design specifications for airframe and engine components and countless technical standards to be observed. The certification authorities must ensure that each of those specifications and standards, which have evolved over time with the wisdom and experience of an entire industry, are adequately met or exceeded to ensure that the end product is safe. National (and nowadays supranational) aviation authorities have worked together to harmonize aircraft certification standards across the globe with the reassuring result that a passenger boarding an aircraft built in Brazil or in France, in the US or in Canada, can expect them all to meet much the same standards for certification. This harmonization is an ongoing process with the world's many Civil Aviation Authorities (CAAs) meeting on a regular basis.

However, it must be recognized in this process that aircraft manufacturers are commercial entities – their management teams are accountable to shareholders to run a successful business and above all to make a profit. Manufacturers may see specifications and standards not as the minimum permissible but as the commercial goal, viewing anything beyond this as an unnecessary cost liability. Although there are only a few manufacturers in the marketplace, selling aircraft is a very competitive business and customers are highly motivated by economics.

If a design is commercially successful a manufacturer may be tempted to stick with that basic concept for many years and will not see any business incentive to develop an entirely new aircraft. Hence the preferred manufacturing model is often to stretch and/or shrink fuselages, adding or removing frame sections to meet the varying demands of airline customers in terms of capacity, payload and range, rather than pursue the optimal design for each function. The aviation industry as a whole is very cyclic in its fortunes, with distinct phases of 'hire' and 'fire' in the workforce. This can lead to substantial migrations of talent and knowledge out of the sector, and difficulties in attracting young entrants to the job market. The underlying skill level of the workforce inevitably varies and some lessons have to be re-learned by younger designers and engineers.

So in summary, while some in the industry might see manufacturers as the unchallenged authority when it comes to their products, a closer look reveals:

- Cost management is as much a part of aircraft manufacturing as it is in airline operations, with widespread competitive contracting, outsourcing and pursuit of cheaper materials;
- Cycles of varying workforce competence through retirements and an inability to attract and retain new talent due to unpredictable employment prospects (both in design and production);
- Reluctance to develop and implement changes to structural design and system operating philosophies, especially when perceived as a unique selling point or when these systems have inherited legacy philosophies;
- Temptation to aim for the minimum certification requirements rather than to strive for design excellence.

Despite the efforts of the certification authorities (see above) a lack of complete commonality in the design and function of aircraft systems prevails – this might be a result of patent protections in a competitive market or a strongly held belief that a particular design or functionality is superior to another; it may even be that there is not enough evidence that any one system is better or worse than another. However, this lack of industry standardization sets a trap for pilots who have built their operational experience in one philosophical operating model and then must change to another. As humans they may revert to engrained habits when under stress or time pressure, and potentially employ techniques and procedures that worked for a previous aircraft type but not for the current one.

CASE 1: “In cruise flight, the pilot realized that the flaps were still extended in take-off position. Unaware of the implications of the flap/stabilizer interconnect at higher airspeeds, the pilot retracted the flaps. The aircraft violently pitched up and passengers were injured.”

There was nothing intrinsically wrong with the design philosophy of the interconnect system and we know that from time to time humans make mistakes. What matters is that the design of the primary cockpit flight display did not include a maximum speed limit indication for the flaps on the airspeed indicator (perhaps to save additional cost?) in design and manufacture. It is far more likely that a pilot would recognize and manage an impending flap overspeed if the limit was clearly displayed, and hence retract the flaps on schedule.

CASE 2: “During approach the autothrottle retarded the engines to idle thrust while the aircraft was still some several hundred feet in the air. The autopilot was locked on the glideslope signal and speed decayed well below reference speed (V_{ref}). The aircraft entered a stall from which the flight crew did not recover and it impacted the ground well short of the runway.”

This accident is well known and reiterating the causal factors at length is not required here. From a design perspective, although the aircraft type had been in operation for decades, this particular characteristic of the automation went unrecognized in design and appears to have manifested itself for the first time during the accident. The lesson to be learned here is that a design concept may harbor failure modes that lie dormant and undetected for long periods of time. What is the solution to this problem? It may be that pilots had observed this automation behavior several times before but intervened before any significant flight path deviation occurred. With a robust airline internal reporting system and good communication between operators and the manufacturers’ field service representatives there may have been opportunities to detect the early warning signs and prevent an accident.

Commercial aircraft have a design life of typically 30 years and it is not uncommon for pilots to operate aircraft from different generations throughout their careers. What is a good operational strategy in one aircraft might not be good at all in another.

CASE 3: “After departure the aircraft entered wake vortices of a preceding heavy type. The induced roll was counteracted by application of repetitive opposing rudder inputs. Ultimate loads on the vertical tail fin were exceeded and it broke off. The aircraft was uncontrollable and crashed into a suburban area.”

Again, this is a well-known accident and the details are not required. The lesson is that a pilot who has received dedicated upset prevention and recovery training in one type of aircraft (in this case he was taught to counteract roll upset with significant rudder input) needs to be re-educated if such action could be dangerous in the type of aircraft he currently flies. Manufacturers should highlight such important operational differences to airlines so that they can explore the training histories of their pilots for potentially detrimental learning.

As mentioned earlier, aircraft certification standards have changed over time as the industry has developed and learned. It is hard to believe that as recently as the 1940s every type of aircraft, from single-engine trainers to multi-engine bombers, had to undergo spin-testing. Fortunately, aircraft manufacturers also had to demonstrate that a pilot could recover the aircraft from a spin. Regulations have of course changed, and multi-engine aircraft are not spun any more – that privilege is reserved for single-engine aircraft and gliders. This generational change is due in part to the fact that bigger airplanes are operated by two (2) (nowadays), well trained and experienced professional pilots. It is considered unlikely that these skilled multi-crew will not recognize the signs of an approach to the stall (a pre-requisite for spin) or fail to take appropriate recovery action in time. This consideration has proved wrong again and again in stall/LOC-I accidents. The concept of only training for “approach to stall” and not for “stall recovery” has proved not to prevent stalls. “Approach to stall” training in simulators is a canned training setup and the pilots know what to expect. Most pilots flying

aircraft with stick pushers have never felt the pusher in operation, neither in aircraft nor in simulator. If the flight crew of a large aircraft for some reason enter a spin they are in a flight regime that they have never seen before, at least not in that aircraft type. Compounding this absence of pilot experience beyond controlled flight is that today's high fidelity simulators, as good as they are at representing aircraft systems and behavior within the flight envelope, cannot replicate aircraft behavior outside that regime. The flight test data is simply not available to programme the simulators.

4.1 Certification Standards

Most large aeroplanes in operation today have been certified under FAR Part 25, EASA CS 25 or a similar set of regulatory standards. It is not the intention here to explain those standards in any detail or point out any differences between them. It is generally accepted that these aviation authorities are engaged in an on-going dialogue and significant differences will be resolved.

Although they are detailed and systematic documents with decades of traceable evolution, it is not possible to pin-point any one specific chapter or paragraph of the certification standards when it comes to LOC-I prevention. There is no single standard that requires a design to demonstrate that it is not susceptible to LOC-I; it is hard to imagine how it could be done.

This may be because there are numerous pathways to a LOC-I condition which, once embarked upon, may or may not be recoverable:

- Aerodynamic stall and departure from controlled flight;
- Severe airframe icing compromising aircraft systems and performance (aerodynamics and mass);
- Inadequate control in high altitude flight;
- Automation mismanagement;
- Automation misinterpretation / misunderstanding / mode confusion
- Blocked or compromised air data sensors;
- Incorrect aircraft configuration;
- High speed above VMO/MMO;
- High load factors beyond design loads;
- Inflight fires compromising control systems and aircraft structures.

Inflight fires of Li-Ion / Li-metal batteries have emerged as a LOC-I risk and there are two (2) recent accidents in which these fires have led to flight crew losing control. However, since current fire suppression systems on board of aircraft are not designed to control the intense heat that is generated by such fires, the topic is excluded. Such risks have to be addressed primarily at the airline level by imposing constraints on shippers for the transportation of such goods, rather than changes to aircraft certification standards.

Flight in volcanic ash clouds can lead to thrust loss, degradation of aerodynamic surfaces and windscreens and damage to air data sensors, to the extent that normal flight cannot be maintained. The same holds true for bird-strike encounters. Although these may also be considered as LOC-I events, pilots generally retain some degree of control and for that reason they will not be addressed here. There is little more that could be done through certification standards to mitigate these risks.

One way to approach LOC-I prevention in certification standards is to look for "handling characteristics" as a key-word, on the assumption that the handling characteristics should at least not be violent, unexpected, unpredictable or present difficulties for upset recovery.

The following section focuses on "handling characteristics" and the conditions under which these characteristics have to be demonstrated by flight test pilots during certification. The reasoning is that an airline pilot should be provided with at least a basic knowledge of the requirements that have been met during the certification process. Perhaps more crucially, he needs to be aware that handling characteristics might be unknown and unpredictable beyond the certified parameters. For example, if the certification specification mandates a "prompt recovery" after the first indications of stall, a pilot cannot expect the aircraft behavior to remain benign and recoverable if the recovery action is delayed. This has not necessarily been tested.

Searching EASA CS25 for “handling” one will find numerous examples. The term is used in conjunction with “handling characteristics” and these are a direct indication of how the aircraft will behave, or “handle”, in a potential LOC-I situation. The term is mainly used in reference to:

- System failures;
- Icing conditions;
- Controllability and Manoeuvrability;
- Thrust loss;
- In-flight thrust reverser deployment.

Example specifications are:

- “In showing compliance with the requirements of CS 25.143(a) and (b) account should be taken of aeroelastic effects and structural dynamics (including aeroplane response to rough runways and water waves) which may influence the aeroplane handling qualities in flight and on the surface. The oscillation characteristics of the flight deck, in likely atmospheric conditions, should be such that there is no reduction in ability to control and manoeuvre the aeroplane safely.”
- An acceptable means of showing compliance with CS 25.143(b)(1) is to demonstrate that it is possible to regain full control of the aeroplane without attaining a dangerous flight condition in the event of a sudden and complete failure of the critical engine (AMC 25.143(b)(1) Control Following Engine Failure).
- The controllability, stability, trim, and stalling characteristics of the aeroplane must be shown for each altitude up to the maximum expected in operation.

4.2 Manoeuvring Envelope or V_n -Diagram

A fundamental illustration of aircraft characteristics is the manoeuvring envelope, also called the V_n -diagram, as specified in CS 25.333. The specified structural strength requirements must be met at each combination of airspeed and load factor on and within the boundaries of the representative manoeuvring envelope of sub-paragraph (b) of this specification. This envelope must also be used in determining the aeroplane structural operating limitations as specified in CS 25.1501.

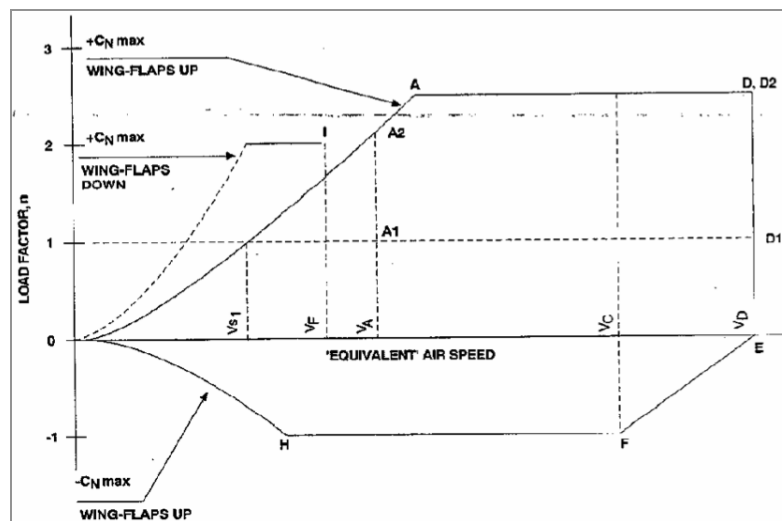


Figure 2: Example manoeuvring envelope or V_n diagram

Airline pilots routinely spend the majority of their flight time close to the intersection of V_C (design cruise speed) and load factor $n_z = +1.0$, or normal +1.0 G flight. For landing a pilot slows from V_C towards the left and spends the last seconds just to the right of the curved dashed line depicting minimum speed with landing flaps extended. During take-off, the parameters move in the opposite direction, close to the line $n_z = +1.0$, or just above at lift off. In normal turns of up to 30° AOB the load factor will also be only slightly above $n_z = +1.0$. The larger remaining portions of the manoeuvre envelope are therefore unexplored and perhaps entirely unknown to the average airline pilot.

However, this narrow and benign slice of the envelope is alien to the developing LOC-I condition. These are very dynamic situations and as was mentioned earlier there might only be seconds between an airspeed rapidly approaching V_D (Design diving speed) an approach to stall. The dynamics are summarized in chart in 5.3 below.

4.3 Dynamics of an Upset

Figure 3 shows different pathways into an unusual attitude, starting from an initial upset⁴. Such an upset could be the result of a wake vortex encounter, an un-commanded rudder deflection or a gross misapplication of a flight control for example:

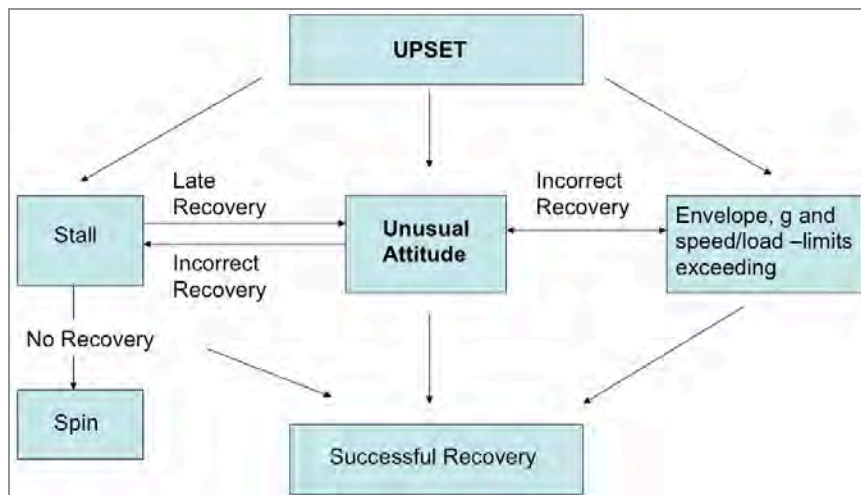


Figure 3: Dynamic of an upset

Below are some possible LOC-I evolution scenarios:

- A low energy situation develops into a stall, which is neither recognized nor properly resolved by the pilot. The nose drops and the aircraft rolls due to sideslip or uneven wing stall. The aircraft develops an unusual attitude and enters a fully developed spin. Startled by the dynamics of the situation the pilot fails to initiate timely recovery action. The aircraft gains speed and finally breaks up;
- An upset from an un-commanded rudder deflection causes a rapid roll to beyond 90° AOB and the pitch attitude becomes steeply nose down. Airspeed builds quickly above V_{MO} and the aircraft is damaged by G-loads during the recovery;
- A wake turbulence upset causes disturbances in pitch and roll. The speed increases rapidly and during the recovery an unusual attitude occurs. In the attempt to recover the pilot inadvertently enters a stall with sideslip and the aircraft starts a spin.

It is important to understand that two pre-requisites for an aircraft to enter a spin are an aerodynamically stalled wing and physical side-slip. As wings seldom stall evenly, inevitably leading to unbalanced roll and side-slip, spins can happen any time a stall is not properly recovered.

A characteristic of a spin for most aircraft types is a significant nose down attitude, which can lead to a rapid increase in airspeed especially if thrust is not immediately reduced. With weight and thrust acting together (see Figure 4 below) the aircraft will quickly accelerate from stall speed at the left of the V_n speed range towards V_{MO}/M_{MO} and beyond. Because time plays such a crucial role it becomes clear why, in recent years, the emphasis has shifted to the avoidance of upset situations ("prevention training") rather than relying on upset recovery training.

⁴ Courtesy Cpt. Vladimir Birykov, Russian Interstate Aviation Committee, SUPRA-Task Force Meeting, European Flight Test Safety Workshop, Vienna, 2009

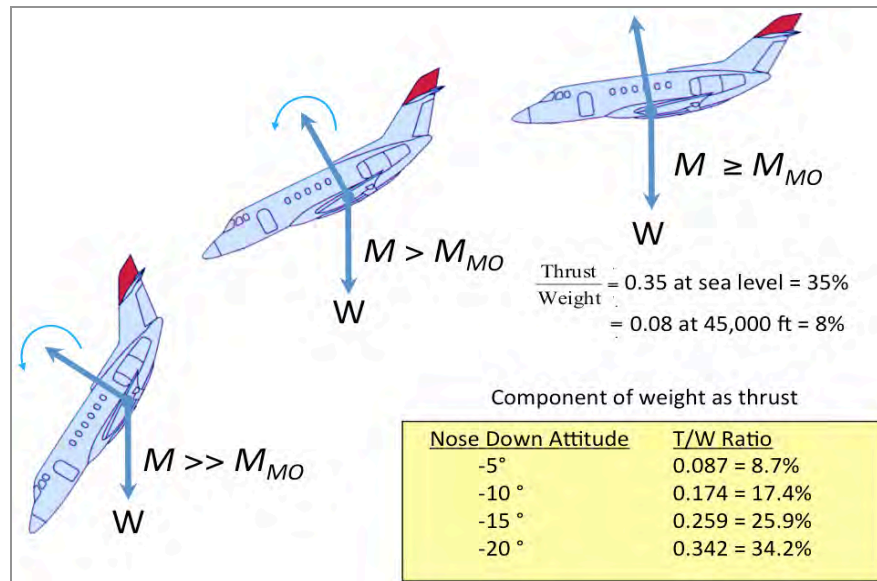


Figure 4: Thrust component adding to weight – accelerating aircraft rapidly (Courtesy: NTPS)

This figure shows how a component of the weight vector adds to the thrust and causes the aircraft to rapidly accelerate. In the example, the thrust-to-weight ratio is only 0.08 at 45,000 feet in level flight. This is typical for jet transports at high altitude – there is barely any excess thrust available that could be used for acceleration or climb. This has two implications:

- If as a consequence of an upset the attitude drops to only 20° nose down then effective thrust-to-weight (T/W) has a relationship of 34%. This is a value comparable to the T/W relationship available during take-off in sea level conditions on many jet transports. The aircraft will inevitably accelerate rapidly as it does at take-off; perhaps well beyond V_{MO}/M_{MO} unless quick recovery action is initiated.
- Airline pilots physically interact most with their aircraft at low altitudes where performance (both aerodynamic and thrust) is at its highest and naturally they get used to it. Therefore, the absence of any significant excess thrust and the substantially degraded aerodynamic performance of the wings at high altitude may not be adequately anticipated and the time taken to recognise and recover could lead to a catastrophic overspeed.

4.4 Rudder Considerations

On some rare occasions in the past aircraft control has been lost because parts of the airframe have separated. One such example is an accident where the aircraft crashed shortly after take-off, when the fin separated from the aircraft due to rudder deflection reversals by the pilot, in an attempt to correct for roll caused by the wake vortices of a preceding B747.

As a result of that accident a “Boeing Flight Operations Technical Bulletin – Flight Operations Group” was published on May 13, 2002. The information is still relevant and describes the issues associated with reversals of rudder inputs as follows:

“Jet transport airplanes, especially those with wing mounted engines, have large and powerful rudders. These powerful rudders are necessary to provide sufficient directional control of asymmetric thrust after an engine failure on take-off and to provide suitable crosswind capability for both take-off and landing. As the airplane flies faster, less rudder is needed for directional control and the available rudder deflections is therefore reduced. This reduction in rudder deflection is achieved through rudder limiting.

Manoeuvring an airplane using the rudder will result in a yaw and roll response, the roll being the result of sideslip. For example, if the pilot applies left rudder the nose will yaw left (Figure 5). The yawing response to the left will generate a sideslip (right wing forward) which will cause the aeroplane to roll to the left (i.e. roll due to sideslip). The rotational rudder force on the vertical fin tends to roll the airplane to the right, but as the sideslip moves the right wing forward, the net airplane roll rate is to the left.

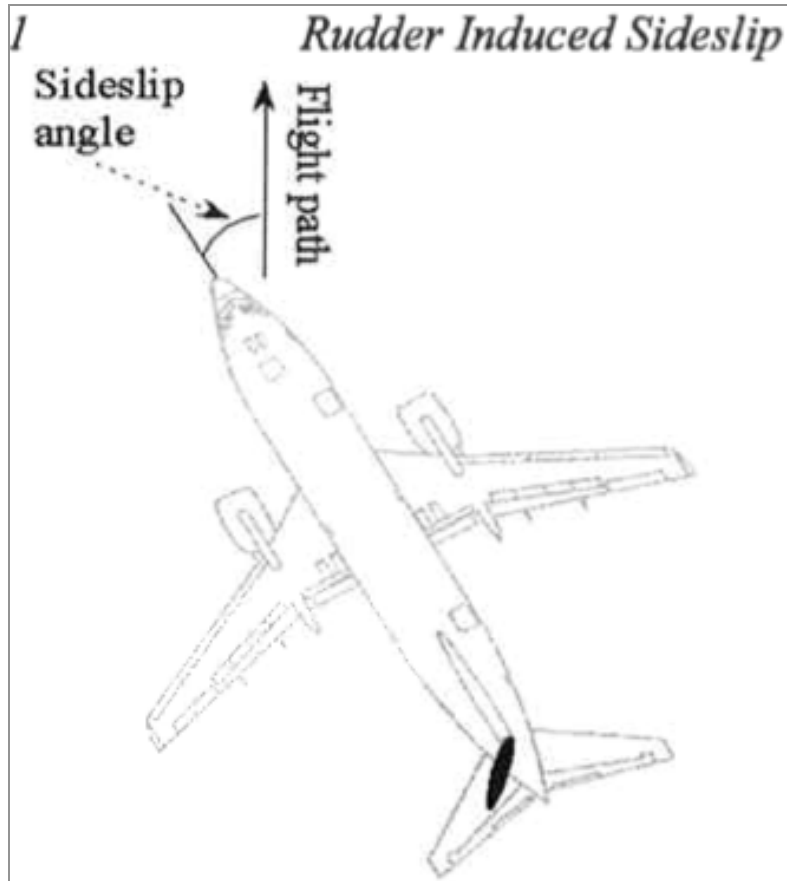


Figure 5: Rudder induced sideslip (Courtesy Boeing)

It is difficult to perceive sideslip in flight and few modern transport airplanes have true sideslip indicators. In older instrument panels displacement of the “ball” of the turn-and-slip indicator was reflection of side force or acceleration, not sideslip angle. Some newer aircraft have electronic flight displays with slip/skid indication, which is again actually an indication of side force or acceleration, not sideslip. As the pilot applies more rudder, more sideslip is generated and a greater roll response will result. Large, abrupt rudder inputs can generate brief but very large sideslip angles, much larger than encountered in a steady state sideslip – that which is reached with a slow pedal input and held for a period of time. This is due to the dynamic response characteristics of the airplane (Figure 6) and the “over yaw” that can amplify the roll rate. It is important to use rudder carefully so that unintended large sideslip angles and resulting roll rates do not develop. The magnitude of roll rate that is generated by rudder input is typically proportional to the sideslip angle produced, *not* the angle of rudder deflection.

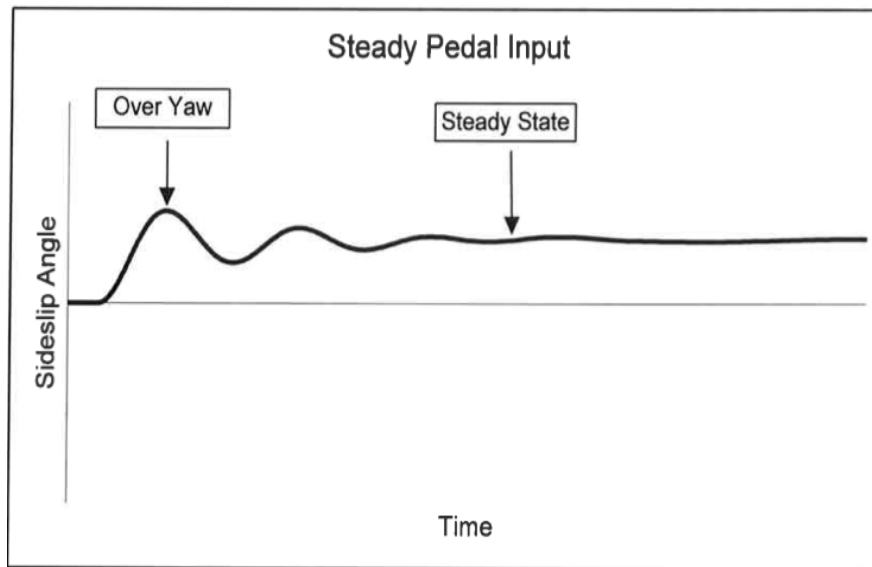


Figure 6: Sideslip response to abrupt steady rudder input (Courtesy Boeing)

Precise roll control using rudder is difficult and therefore not generally recommended for jet transport aircraft. Because sideslip must build up to generate the roll, there is a time lag between the pilot making a rudder input and perceiving a significant roll rate. This lag has caused some pilots to be surprised by the subsequent and potentially abrupt roll onset and in some cases to interpret the roll as being due to an external influence not related to their rudder input. If the pilot reacts to this abrupt roll onset with another large rudder input in the opposite direction, large amplitude oscillations in roll and yaw can result. Cyclic rudder pedal inputs can result in very large amplitude sideslip oscillations (Figure 7).

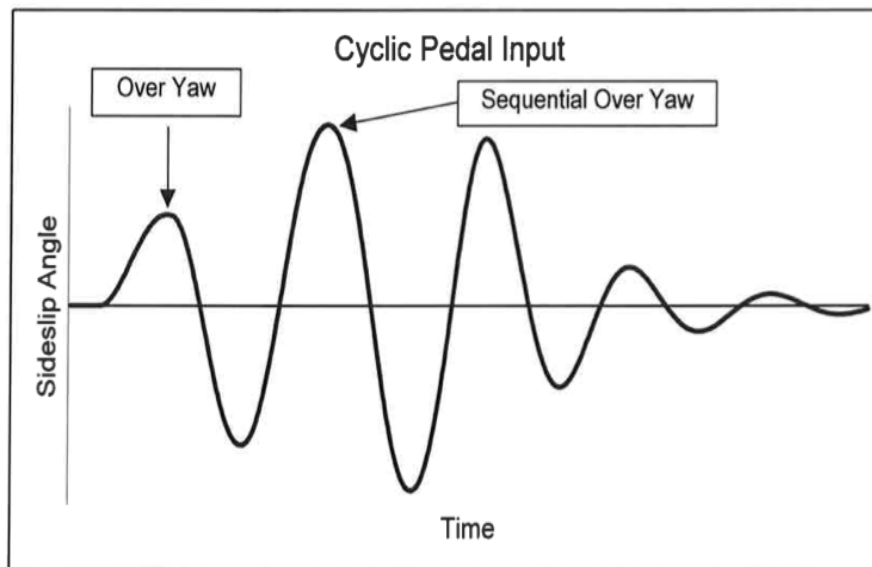


Figure 7: Sideslip response to abrupt cyclic rudder input (Courtesy Boeing)

The sideslip angle that is momentarily reached with such “sequential over yaw” can be much larger than the ‘over yaw’ associated with a single, abrupt rudder input (see Figure 6 and Figure 7). When the rudder is reversed at this sequential over yaw/sideslip angle, the rudder induced fin force is added to the sideslip induced fin force (see Figure 8). The resulting structural loads can exceed the limit loads and possibly the ultimate loads, which may well result in structural damage.

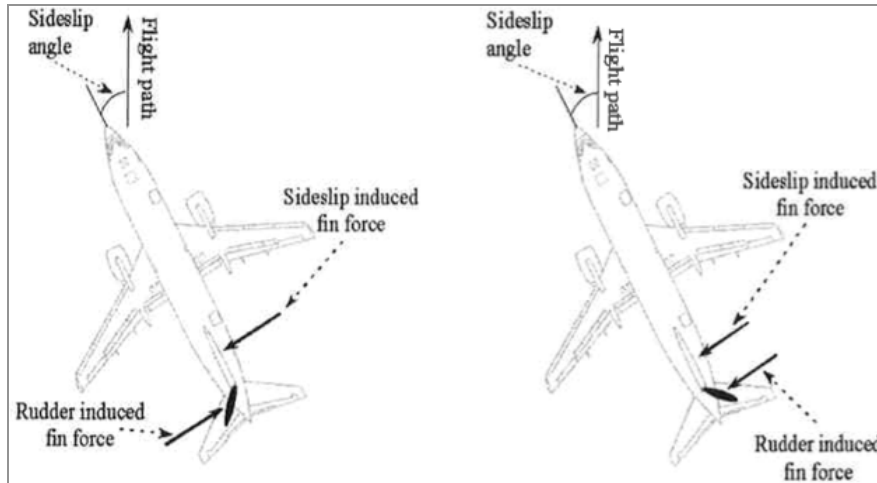


Figure 8: Rudder induced sideslip force (left) and rapid rudder reversal forces (right). (Courtesy Boeing)

Lessons to be learned:

- Jet transport airplanes have large and powerful rudders;
- On some aircraft, as speed increases, the maximum available rudder deflection can be applied with comparatively light pedal forces and small pedal deflections;
- Use of rudder up to full deflection during engine failures and crosswind take-offs and landings, is well within the structural capability of the aircraft;
- At or below structural design manoeuvring speed (V_A) airplanes are capable of withstanding a single input to any set of control surfaces (elevators, ailerons, rudder(s)) to their maximum available authority (as limited by control surface limiters, blow-down, or control stops), with the condition that the inputs are in one axis only (not in combination) and do not include control input reversal or oscillatory inputs;
- Manufacturers may flight test full rudder deflections at speeds above V_A and up to maximum operating airspeed/Mach No (V_{MO}/MMO), and for some aircraft even up to the design dive speed/Mach No (V_D / M_D). In such cases pilots do not have to be concerned about how fast or how hard to deflect the rudder pedal (in one direction only) throughout the flight envelope, at least from a structural integrity standpoint;
- As an airplane flies faster, less rudder deflection is required to achieve a given effect but the rudder limiting function varies between airplane models;
- Airplanes are designed and tested based on certain assumptions about how pilots will use the rudder – these assumptions drive the FAA/EASA certification requirements and hence the manufacturer’s design choices;
- Pilots should be aware that airplanes are designed and certified with the structural capability to accommodate a rapid and immediate rudder pedal input from zero to full deflection in one direction only;
- Pilots must use the rudder in a manner that avoids large sideslip angles and resulting excessive roll rates – the roll rate is proportional to the sideslip angle, not the magnitude of rudder deflection;
- If pilots react to an abrupt roll onset with a large opposite rudder input, large amplitude oscillations in roll can ensue, potentially generating loads that exceed the limit- and possibly the ultimate loads, leading to structural damage.

4.5 Rudder Certification Criteria

In transport aircraft there are three rudder manoeuvre structural load design requirements that the rudder and vertical fin must meet in order to be certified. These requirements are applicable for all airspeeds up to the design manoeuvring speed (V_A). Newer airplane designs meet these requirements up to the design dive speed (V_D).

1. At a zero sideslip condition the airplane must be able to withstand a rapid rudder input to full rudder deflection. A Safety Factor of 1.5 is then applied. This means the structure must have at least 50% safety margin over the maximum load generated by this manoeuvre⁵.
2. Starting from a zero sideslip condition, the airplane must be able to withstand a rapid rudder input to full deflection that is held at full deflection until the maximum sideslip angle (over yaw) is achieved. The airplane will exceed the maximum steady state sideslip due to the dynamic response characteristics of the airplane. A Safety Factor of 1.5 is then applied.
3. Starting from a maximum steady heading sideslip condition with full rudder deflection, the rudder is rapidly returned to neutral while maintaining the sideslip angle. A Safety Factor of 1.5 is then applied.

4.6 Aerodynamic Stalls

In the study of LOC-I accidents, significant attention is given to the subject of aerodynamic stalls. In fact to some, stalls are such an important factor that they use the term almost interchangeably with LOC-I. There is a school of thought that if stall conditions could be avoided, we would have solved the LOC-I problem and in commercial aviation we have indeed seen a significant number of LOC-I events that were related to an undetected or uncorrected reduction of airspeed.

A recent research project⁶ focused on the aerodynamic stall, stall behavior and stall recovery in some detail, so the topic is only briefly touched upon here with a review of the relevant certification standards for transport category aircraft.

In general, manufacturers have to address two broad areas:

- Stalling speeds;
- Handling characteristics at stalling speed.

While the determination of the stalling speed is purely a performance consideration, the handling characteristics clearly affect the way the aircraft behaves and thus have an impact on LOC-I prevention and recovery. With the upcoming regulation EASA CS-SIMD⁷ ("simulator data") aircraft OEMs may be required to conduct flight tests for the purpose of generating data packages for simulators out to the edges of the flight envelope and perhaps beyond. The intention is to enhance the aerodynamic model within full flight simulators (FFS) and so improve the quality of pilot training at the edge of the envelope.

⁵ The following conditions are engineering design conditions that may be physically impossible to fly

⁶ Eric Groen et al, SUPRA Project, TNO, The Netherlands

⁷ Certification Specifications and Guidance Material for the development of the definition of scope of the aircraft validation source data to support the objective qualification of simulator(s) associated to the pilot type rating training (simulator data)

4.6.1 Stall Demonstration – CS 25.203

The certification standard states:

- (a) Stalls must be shown in straight flight and in 30° banked turns with –
 - 1) Power off; and
 - 2) The power necessary to maintain level flight at $1.5 V_{SR1}$ (where V_{SR1} corresponds to the reference stall speed at maximum landing weight with flaps in the approach position and the landing gear retracted. (See AMC 25.201(a)(2).)
- (b) In each condition required by sub paragraph (a) of this paragraph, it must be possible to meet the applicable requirements of CS25.203 with –
 - 1) Flaps, landing gear and deceleration devices in any likely combination of positions approved for operation; (See AMC 25.201(b)(1).)
 - 2) Representative weights within the range for which certification is requested;
 - 3) The most adverse centre of gravity for recovery and
 - 4) The airplane trimmed for straight flight at the speed prescribed in CS 25.103 (b)(6).
- (c) The following procedures must be used to show compliance with CS 25.203 :
 - 1) Starting at a speed sufficiently above the stalling speed to ensure that a steady rate of speed reduction can be established, apply the longitudinal control so that the speed reduction does not exceed 0.5 m/s^2 (one knot per second) until the airplane is stalled. (See AMC 25.103(c).)
 - 2) In addition, for turning flight stalls, apply the longitudinal control to achieve airspeed deceleration rates up to 5.6 km/h (3 kt) per second. (See AMC 25.201(c)(2).)
 - 3) As soon as the airplane is stalled, recover by normal recovery techniques.
- (d) The aeroplane is considered stalled when the behavior of the aeroplane gives the pilot a clear and distinctive indication of an acceptable nature that the aeroplane is stalled. (See AMC 25.201 (d).) Acceptable indications of a stall, occurring either individually or in combination, are –
 - 1) A nose down pitch that cannot be readily arrested;
 - 2) Buffeting, of a magnitude and severity that is a strong and effective deterrent to further speed reduction; or
 - 3) The pitch control reaches the aft stop and no further increase in pitch attitude occurs when the control is held full aft for a short time before recovery is initiated. (See AMC 25.201(d)(3).)

Some observations on these standard requirements:

- It is not required to demonstrate stalls at bank angles exceeding 30° AOB.
- The stall is entered with a specific airspeed decay rate of one (1) knot/second. In a dynamic situation of developing LOC-I, airspeed decay rate is likely to be much higher. The airline pilot may be faced with an “accelerated” stall, the handling characteristics of which will almost certainly be less benign than the demonstrated flight test stall.
- There is no requirement for a stall to be demonstrated in combination with side-slip, whereas accident data shows that stalls have occurred with significant side-slip. Pilots failing to recognize and correct for the side-slip may experience a stall behavior that is much more violent than that demonstrated in test.
- In test the aircraft is trimmed for straight flight whereas accident data shows that in some accident cases the stabilizer control logic had started to automatically trim the aircraft in an attempt to hold altitude. Pilots encountering a stall in this out-of-trim condition will experience stall characteristics that have not been demonstrated during certification.
- The test standard relies on application of normal recovery techniques as soon as the airplane is stalled: the test pilot will not (and does not have to) delay the response and record the consequent aircraft behavior. Airline pilots who do not take prompt recovery action when experiencing the first sign of a stall will become their own test pilots and might unleash unknown aircraft behavior.
- One indication of a stall is buffeting of a “magnitude and severity that is a strong deterrent to further speed reduction”: studies have shown that the buffeting generated in simulators can be of a lesser magnitude to that generated by the airplane. With lack of fidelity there is a likelihood that pilots will be startled by the more violent buffet in the aircraft and may draw incorrect conclusions (e.g. in-flight breakup). Pilot training programs should emphasise any known differences.

Paragraph (d) of the standard states that, “The aeroplane is considered stalled when the behavior of the aeroplane gives the pilot a clear and distinctive indication of an acceptable nature that the aeroplane is stalled.” On large transport aircraft the indication might not be as clear and distinctive as one would assume. A distinctive indication could be a definite ‘pitch-break’ that we see in many small GA aircraft but transport category aircraft might not have such a distinctive ‘pitch-break’, in particular when the stabilizer trims nose-up in an attempt to maintain straight and level flight.

There are big differences between a test pilot and an airline pilot in terms of LOC-I and stall encounters:

- The test pilot knows when he will conduct stalls and can be well prepared;
- The airline pilot has no knowledge of an impending stall and is not prepared, with a consequent risk of the “startle factor”;
- The test pilot enters a stall in a defined way as prescribed by the certification standard, so as to make stall speed and handling characteristics comparable (+1G stall, one (1) knot/second decay rate).
- The airline pilot may enter the stall from any attitude, (e.g. from an upset condition), and at any airspeed decay rate.
- The test pilot has additional cockpit instrumentation (e.g. angle of attack and side-slip angle) not typically available to the airline pilot.

4.6.2 Stall Characteristics are described in CS 25.203

The certification standard states:

It must be possible to produce and to correct roll and yaw by unreversed use of aileron and rudder controls, up to the time the aeroplane is stalled. No abnormal nose-up pitching may occur. The longitudinal control force must be positive up to and throughout the stall. In addition, it must be possible to promptly prevent stalling and to recover from a stall by normal use of the controls.

For level wing stalls, the roll occurring between the stall and the completion of the recovery may not exceed approximately 20°.

For turning flight stalls, the action of the aeroplane after the stall may not be so violent or extreme as to make it difficult, with normal piloting skill, to effect a prompt recovery and to regain control of the aeroplane. The maximum bank angle that occurs during the recovery may not exceed –

- 1) Approximately 60° in the original direction of the turn, or 30° in the opposite direction, for deceleration rates up to 0.5 m/s² (one (1) knot per second); and
- 2) Approximately 90° in the original direction of the turn, or 60° in the opposite direction, for deceleration rates in excess of 0.5 m/s² (one (1) knot per second).

Some observations on these standards:

- In turning stalls aircraft behavior may not be so violent or extreme as to make it difficult to regain control but bank angle can exceed the values that an airline pilot will typically have experienced in his career;
- Especially at higher deceleration rates in excess of one (1) knot/second, the standard allows that the aircraft may bank to approximately 90° AOB in the direction of turn during recovery and may even roll to 60° AOB in the opposite direction to the turn;
- One (1) knot/second is not a very high rate of speed decay and anything in excess of one (1) knot/second is considered a “high deceleration rate”⁸ by the standards;

⁸ For comparison, a typical jet transport accelerates 40 knots in 10 seconds during takeoff roll. A 1 knot per second bleed rate means putting the end of the speed trend vector down by 10 knots.

4.7 Spins and Spin Prevention

While Upset Prevention and Recovery Training (UPRT) in General Aviation deals extensively with spins and spin recovery, the subjects are only addressed briefly here. Here is some food for thought:

- Transport Category aircraft (along with all multi-engine aircraft, even light twin pistons) do not undergo spin testing during certification as the standards have no requirement (unlike gliders and single engine aircraft);
- The absence of a certification requirement to conduct spin testing does not imply that these aircraft cannot spin. A large aircraft is still capable of spinning – there is just no requirement to test it for spin and spin recovery. Why is there no such requirement? Good question – perhaps this is because of the regulator's perception that bigger aircraft are usually flown either by more experienced pilots or even by multi-pilot crew. There might be the perception that these pilots will timely recognize the undesired aircraft state and recovery prior to a spin;
- There have been accidents to multi-engine aircraft due to inadvertent entry into a spin;
- As there is no flight test data from the manufacturers it cannot be recommended to train for spin recovery in Flight Simulation Training Devices (FSTDs) as it would likely produce a negative training outcome. The simulator instructor panel during a cross controls (rudder and aileron) application at high angle of attack will reveal that angle of attack and sideslip angle will freeze at some high values. Return to normal flight will be seemingly easy, which is highly unlikely in the real aircraft;
- Spins can only develop when aerodynamic stall and sideslip co-exist. Unlike helicopter pilots and those who fly 'tail-draggers', the jet transport pilot does not need to pay much attention to the rudder in normal flight. While good training should emphasize the avoidance of sideslip, it is difficult for pilots to detect sideslip (especially at the critical low speeds) unless the aircraft is equipped with a sideslip-indicator;
- Although general rules for spin recovery exist (NASA Standard method for example), seemingly subtle changes to an airframe can have a big impact on the aerodynamics and aircraft behavior in stalls and spins and thus on the necessary recovery technique.

Requirements for spin training have gradually disappeared from the global pilot training syllabus. They were first removed from the US FAA requirements in the 1950's and that gradually spread to European countries thereafter. Before the pan-European JAR FCL requirements were introduced spin training was optional in some countries if the flight school had airplanes approved for aerobatics. In the Part FCL syllabus today it remains optional but in reality is seldom practiced, even for instructor ratings.

In military pilot training stalling, spinning and aerobatics have always been important piloting skills. A significant benefit is better envelope awareness and consequently better spin/LOC-I prevention and recovery but military pilots are often required to operate close to or at the edges of the flight envelope anyway, while commercial pilots are only required to fly to 45° AOB during skill tests, and normally see a maximum of 30° AOB during line flying.

In spin and aerobatic training the pilot learns to control the airplane even outside the normal flight envelope but if a pilot has never seen these extreme flight attitudes and conditions, we cannot expect him to cope well with them.

An aerobatic pilot will have a vastly different reaction to unusual attitudes when compared to pilots who have not been trained. A pilot well trained in stall and spin recovery is far more likely to recognize the situation and take proper actions before an unrecoverable LOC-I condition arises.

Sometimes, new spin modes are discovered after many years in operation⁹:

“The T-37 was subjected to a flight test program in 2001 because they had found another departure [from controlled flight] mode. This must have been after thousands of hours in service as it was introduced in 1958. This ‘new’ departure mode was found after the airplane departed controlled flight, and autorotation started, during a formation break where the aircraft rolled and pitched out of the formation.”

⁹ Rein Inge Hoff, private communication

It is enlightening that this rolling departure mode was found after so many years in training service. The lesson here is that the certification standards are right to put the emphasis on prevention through recognition rather than on recovery, because the aircraft behavior might be entirely unpredictable once the edge of the envelope is passed, even to the experienced test pilot. The aerodynamic models of simulators are certainly not good enough to predict or re-produce such departure modes.

4.8 Maximum Operating Speed and Mach Number (V_{MO}/M_{MO}) – Cs 25.253

4.8.1 Introduction

Airline pilots are well aware of the maximum operating Mach No, M_{MO} or airspeed V_{MO} . The “barber pole” on airspeed indicators delineates these speeds and an overspeed warning is activated when the speed is exceeded. Some airplane flight control systems include some element of automatic overspeed protection. But how far could a pilot stray into an overspeed condition before the aircraft sustains damage or exhibits unusual flight characteristics? What are the margins? Is there immediate danger if V_{MO}/M_{MO} is exceeded?

During certification flight tests the operating conditions and characteristics likely to cause inadvertent speed increases (including upsets in pitch and roll) must be simulated with the airplane trimmed at any likely cruise speed up to V_{MO}/M_{MO} . These conditions and characteristics include gust upsets, inadvertent control movements, low stick force gradient in relation to control friction, passenger movement, levelling off from climb, and descent from Mach to airspeed limit altitudes (see CS25.253 for details).

4.8.2 Use of Longitudinal Trim to Assist Dive Recovery

With respect to the use of longitudinal trim system to assist recovery CS25.255 and Book 2 (Acceptable Means of Compliance to CS25) say:

CS 25.255(f) requires the ability to produce at least 1.5 g for recovery from an overspeed condition of V_{DF}/M_{DF} , using either the primary longitudinal control alone or the primary longitudinal control and the longitudinal trim system. Although the longitudinal trim system may be used to assist in producing the required normal acceleration, it is not acceptable for recovery to be completely dependent upon the use of this system. It should be possible to produce 1.2 g by applying not more than 556 N (125 lbf) of longitudinal control force using the primary longitudinal control alone.

Recovery capability is generally critical at altitudes where airspeed (V_{DF}) is limiting. If at higher altitudes (on the M_{DF} boundary) the manoeuvre capability is limited by buffeting of such an intensity that it is a strong deterrent to further increase in normal acceleration, some reduction of manoeuvre capability will be acceptable, provided that it does not reduce to below 1.3 g. The entry speed for flight test demonstrations of compliance with this requirement should be limited to the extent necessary to accomplish a recovery without exceeding V_{DF}/M_{DF} , and the normal acceleration should be measured as near to V_{DF}/M_{DF} as is practical.

4.8.3 Overspeed Protection Systems – General

According to CS 25 – Book 2 the following factors should be considered in the design of high-speed protection:

- The duration of airspeed excursions, rate of airspeed change, turbulence, and gust characteristics;
- Operations at or near V_{MO}/M_{MO} in routine atmospheric conditions (e.g., light turbulence) are considered safe. Small, brief excursions above V_{MO}/M_{MO} , by themselves, are not unsafe.

The flight guidance system (FGS) design should strive to strike a balance between providing adequate speed protection margin and avoiding nuisance activation of high-speed protection.

Note:

The following factors apply only to designs that provide high-speed protection through FGS control of airspeed.

FGS in altitude hold mode:

- a) Climbing to control airspeed is not desirable, because departing an assigned altitude can be disruptive to ATC and potentially hazardous (for example, in reduced vertical separation minima (RVSM) airspace). It is better that the FGS remain in altitude hold mode.
- b) The autothrust function, if operating normally, should effect high-speed protection by limiting its speed reference to the normal speed envelope (i.e., at or below V_{MO}/M_{MO}).
- c) The basic aeroplane high-speed alert should be sufficient for the pilot to recognize the overspeed condition and take corrective action to reduce thrust as necessary. However, if the airspeed exceeds a margin beyond V_{MO}/M_{MO} (e.g., 11 km/h (6 knot)), the FGS may transition from altitude hold to the overspeed protection mode and depart (climb above) the selected altitude.

During climbs and descents:

- a) When the elevator channel of the FGS is not controlling airspeed, the autothrust function (if engaged) should reduce thrust, as needed to prevent sustained airspeed excursions beyond V_{MO}/M_{MO} (e.g., 11 km/h (6 knot)), down to the minimum appropriate value.
- b) When thrust is already the minimum appropriate value, or the autothrust function is not operating, the FGS should begin using the elevator channel, as needed, for high-speed protection.
- c) If conditions are encountered that result in airspeed excursions above V_{MO}/M_{MO} , it is preferable for the FGS to smoothly and positively guide or control the airplane back to within the speed range of the normal flight envelope.

What does the foregoing tell us in relation to the questions raised in the introduction above?

- Small excursions of less than six (6) knots above M_{MO}/V_{MO} are nothing for the pilot to worry about; he simply needs to take the appropriate corrective action;
- Designers are allowed to rely upon the use of control forces for recovery which are well above those an airline pilot would apply in normal operations. This is not to say that pilots have to rely on such high control forces, rather than as they are allowed if required. If a pilot has never experienced control forces much higher than those in normal operation, he will perhaps not make use of the full control force that is available to him and may be required by design for an overspeed recovery;
- In automated overspeed protections the elevator channel is permitted to send a corrective pitch up input, thereby causing the aircraft to leave its assigned altitude. While from the point of flight physics this makes perfect sense, it introduces additional workload for the pilot in an already stressful situation: busting an altitude and potentially reducing separation are well known risks for the pilot.

4.8.4 Benefit of Overspeed Protection Systems

Automated overspeed protection systems may be seen as something designed to help avoid a dangerous high speed condition. At least that is the perception of many pilots – why else would a designer make the effort to develop and certify the system if not for the benefit of protecting the aircraft? Well, there is one big commercial aspect which is not so well known, and that is significant aircraft weight savings. By installing an overspeed protection system the designer is permitted by the standards to bring V_{MO}/M_{MO} much closer to the design dive speed and hence the speed at which the airframe will eventually start to flutter and disintegrate. In other words, the structural integrity margins between the maximum normal operating speeds used by the pilot and the speed at which damage will occur may be narrower, meaning that the aircraft structure need not be as robust. Structural strength usually equates to weight in aircraft construction so ultimately the overspeed protection system allows a lighter overall aircraft structure. Here is the standard (CS25.335 (3) – Design Dive Speed):

- b) Design dive speed, V_D . V_D must be selected so that V_C/M_C is not greater than $0.8 V_D/M_D$, or so that the minimum speed margin between V_C/M_C and V_D/M_D is the greater of the following values:
 - 1) From an initial condition of stabilized flight at V_C/M_C , the airplane is upset, flown for 20 seconds along a flight path 7.5° below the initial path, and then pulled up at a load factor of 1.5 g (0.5 g acceleration increment). The speed increase occurring in this maneuver may be calculated if reliable or conservative aerodynamic data is issued. Power as specified in CS 25.175 (b)(1)(iv) is assumed until the pullup is initiated, at which time power reduction and the use of pilot controlled drag devices may be assumed;

- 2) The minimum speed margin must be enough to provide for atmospheric variations (such as horizontal gusts, and penetration of jet streams and cold fronts) and for instrument errors and airframe production variations. These factors may be considered on a probability basis. The margin at altitude where M_C is limited by compressibility effects must not be less than $0.07M$ unless a lower margin is determined using a rational analysis that includes the effects of any automatic systems. In any case, the margin may not be reduced to less than $0.05M$. (See AMC 25.335(b)(2)).

CS25.335(3)(b)(1) above explains how dive speed V_D is achieved in flight test. This is a speed that the airline pilot will (hopefully) never see – it is well above V_{MO}/M_{MO} . The intent of the demonstration is to show the highest speed at which the airframe remains free from flutter, with the actual flutter speed being slightly faster. Demonstration of V_D is one of the most hazardous of flight tests and consequently takes an incremental approach.

Note:

- The power requirement specified in CS 25.175(b)(1)(iv) points to “the maximum cruising power selected by the applicant as an operating limitation (see CS 25.1521), except that the power need not exceed that required at V_{MO}/M_{MO} .”
- A margin lower than $0.07M$ (but not less than 0.05) between Design Dive Mach number M_D and Design Cruise Mach Number M_C may be used with an automatic system.

This does not sound to be very much. After all, a reduction of the margin from $0.07M$ between V_D and V_C to $0.05M$ is a difference of only $0.02M$. What is this in practical numbers? Mach number is true airspeed (TAS) divided by speed of sound, which is dependent upon temperature – a typical value at the cruising altitudes of commercial jet aircraft in International Standard Atmosphere (ISA) conditions is roughly 300 m/s . Therefore, $0.02M$ equals 6 m/s or 12 knots TAS . What is this in terms of Indicated Airspeed (IAS)? At let's say FL330 (33,000 feet on the standard altimeter setting), where the air density is roughly 33% of the sea level value, we divide TAS with the square root of density ratio and we obtain $20\text{ Knots Indicated Airspeed (KIAS)}$ – quite a difference in speed when we talk about going above our barber pole!

It therefore pays substantial dividends for an aircraft manufacturer to install automatic overspeed protection, making his product rather more attractive to operators in terms of economics. For thirty years or so of operation, flight after flight, there will be a structural weight saving that comes with reducing the margin between flutter speed and maximum operational speed – a weight saving that delivers higher payloads, better revenues and lower fuel costs.

4.9 Stability – Cs 25.171

An aeroplane must be longitudinally, directionally and laterally stable in accordance with the provisions of CS 25.173 to 25.177. In addition, suitable stability and control feel (static stability) is required in any condition normally encountered in service, if flight tests show it is necessary for safe operation.

4.9.1 CS 25.173 Static longitudinal stability

Static longitudinal stability is a term that is often used but rarely well understood. Except for a gross loading error, when payload is too far forward or aft, there is little that the pilot can do about static longitudinal stability. This is inherent to the design and has to do with the location of the aerodynamic center of the airplane (the “neutral point”) in relation to the center of gravity. The location of the aerodynamic center is influenced by wing planform, wing shape, transonic effects and in particular (to bring it aft) by the horizontal tail size and moment arm (“horizontal tail volume”). Large tails and long tail arms, which improve stability margin, imply large surface areas and hence create more drag. In simple words, to fly with less fuel it would be nice to have the smallest allowable stability margin.

Stability margin can be directly felt on the controls of a reversible flight control system. Except for the friction which a pilot would have to overcome he would feel no push or pull force when he changes speed in an aircraft that exhibits neutral static longitudinal stability. In a very stable aircraft the forces required to change speed would be large – so too much stability can make handling difficult and is not desirable, either.

In other words, static longitudinal stability has got to do something with elevator control forces. Under the conditions specified in CS 25.175, the characteristics of the elevator control forces (including friction) must be as follows:

- a) A pull must be required to obtain and maintain speeds below the specified trim speed, and a push must be required to obtain and maintain speeds above the specified trim speed. This must be shown at any speed that can be obtained except speeds higher than the landing gear or wing flap operating limit speeds or VFC/MFC, whichever is appropriate, or lower than the minimum speed for steady unstalled flight.
- b) The airspeed must return to within 10% of the original trim speed for the climb, approach and landing conditions specified in CS 25.175 (a), (c) and (d), and must return to within 7.5% of the original trim speed for the cruising condition specified in CS 25.175 (b), when the control force is slowly released from any speed within the range specified in sub-paragraph (a) of this paragraph.
- c) The average gradient of the stable slope of the stick force versus speed curve may not be less than 4 N (1 pound) for each 11,2 km/h (6 kt). (See AMC 25.173(c).)
- d) Within the free return speed range specified in subparagraph (b) of this paragraph, it is permissible for the aeroplane, without control forces, to stabilise on speeds above or below the desired trim speeds if exceptional attention on the part of the pilot is not required to return to and maintain the desired trim speed and altitude.

What do we learn from this paragraph?

- It is obvious that a pull is required in order to fly at slower speed than trim speed and vice versa.
- The requirement that the airspeed must return to within 10% of the trim speed comes from the days and ages when cables and pulleys were used extensively. The requirement makes sure that because of friction in the system the aircraft will not be in trim at some speed other than the original trim speed.
- Probably the most significant piece of information is in item c) where a minimum stick force gradient is mandated. In other words, the requirement specifies that a minimum force has to be pulled (or pushed) if the pilot deviates by a certain amount from trim speed. The intention of the paragraph is to give the aircraft an opportunity to tell the pilot that he deviated from trim speed, even if he does not look at the instruments (airspeed indicator). In a typical loss-of-control accident a pilot turns base to final, bleeds speed by pulling so to tighten the turn and stalls. The stick force that is required to deviate from trim speed is an indication of flying at a speed other than the one intended. In contrast to certification standards of smaller (general aviation) aircraft, such as Part 23 aircraft, the paragraph specifies the amount of force that is required per speed deviation: for every six (6) knots a force of one pound (1 lb) push or pull is required. Needless to say that a reversal of force gradients is not permitted.

Trimming an aircraft for speed seems irrational, complicated and not very desirable to the outsider. If you asked a non-pilot what the purpose of the trim is he would likely not have an answer. "To trim" is not in our daily vocabulary and other than pilots and boat captains we do not have a need to "trim" in daily life¹⁰ – not even when driving a car. So it seems logical that manufacturers, through the use of flight guidance algorithms and computers, eliminate the need to trim. This step seems rational even more so, since student pilots often have difficulties to properly trim the aircraft. Also, trim changes required differ from aircraft to aircraft and largely change when flaps or landing gear are extended. So eliminating the need to trim the aircraft seems a good idea. But what is the impact – when it comes to loss of control accidents?

Assume that for some reason the flight guidance system tries to keep the aircraft in trim when in fact the pilot should be made aware of the fact that he is well below his trim speed, perhaps already approaching a stall. Except for a visual cue – the airspeed indication – there is not much information he has. Assume now that the airspeed indication gives erratic information and the pilot has reasons to not trust the indications. Once he disengages the autopilot he will find a perfectly trimmed aircraft. The aircraft is neither nose- nor tail heavy. How can that be? Doesn't CS 25.173(c) specify a minimum force gradient when one deviates from trim speed?

¹⁰ Apart from trimming a hedge – which is an entirely different story.

Manufacturers can argue with equivalent level of safety (ELS) to overcome certain requirements. If a stick force gradient is required and the manufacturer wishes to use an auto-trim system so that the pilot does not feel speed deviations on his stick, he can argue his case with ELS. Eliminating a requirement to trim the aircraft can be sold to the customers as a means to “relief pilot workload” and get rid of something which is perceived as impractical, old-fashioned and obsolete. In normal operation it likely is – in a LOC-I stick forces, however, can give the haptic feedback desperately needed if things go wrong. So some manufacturers chose not to use auto-trim when in manual flight.

What is the benefit for manufacturers? Clearly, they do not have to implement force-feedback on their controllers. The pilot now operates against a spring and the strength of the spring does not have to be a function of deviation from speed. In other words, the manufacturer can introduce a rather simple, inexpensive controller and gets the benefit of selling that system as an advantage to previous from the point of ease of handling.

4.10 Aeroelastic Stability Requirements

CS 25.629 informs about aeroelastic stability requirements. Aeroelastic phenomena include flutter, divergence, control reversal and any undue loss of stability and control as a result of structural deformation. The aeroelastic evaluation must include whirl modes associated with any propeller or rotating device that contributes significant dynamic forces. Compliance with this paragraph must be shown by analyses, tests, or some combination thereof as found necessary by the respective certifying Agency:

- (b) Aeroelastic stability envelopes. The aeroplane must be designed to be free from aeroelastic instability for all configurations and design conditions within the aeroelastic stability envelopes as follows:
- 1) For normal conditions without failures, malfunctions, or adverse conditions, all combinations of altitudes and speeds encompassed by the V_D/M_D versus altitude envelope enlarged at all points by an increase of 15 percent in equivalent airspeed (EAS) at constant Mach number and constant altitude. In addition, a proper margin of stability must exist at all speeds up to V_D/M_D and, there must be no large and rapid reduction in stability as V_D/M_D is approached. The enlarged envelope may be limited to Mach 1.0 when M_D is less than 1.0 at all design altitudes; and
 - 2) For the conditions described in CS 25.629(d) below

What do we learn from this paragraph?

- The aircraft will not break up immediately when V_{MO}/M_{MO} is exceeded. There is a 15% margin between V_D/M_D . These are “dive speeds” which the pilot in normal operation will never get to see.

All speeds in context with structural loads and aeroelastic boundaries are expressed at “Equivalent Airspeeds (EAS)” – this is a speed which is not indicated in the aircraft so most pilots (except for those who just completed their initial training) will not be too familiar with the concept of EAS. Here is a simple explanation.

Whenever you fly at constant EAS, you fly at constant dynamic pressure q . This is in contrast to flight with constant calibrated airspeed (CAS), were you fly at constant differential pressure. For low speeds (generally referred to as “incompressible flow”, i.e. below $M < 0,3$) there is no difference between dynamic pressure q and differential pressure Δp . As your Mach number increases the difference becomes more obvious. By definition, dynamic pressure q is density of the atmosphere at flight altitude, divided by two, and multiplied by the square of TAS.

Density varies with altitude – so in order to obtain dynamic pressure one needs to look up the value for the respective altitude, divide it by two and multiply it with the square of TAS. This is cumbersome – and there is an easy way around the problem.

The way EAS is defined one can multiply EAS-squared with half the sea level density to obtain dynamic pressure. The altitude dependence is eliminated when EAS is given, since sea level density is a constant. It is 1.225 kg/m^3 in ISA-conditions.

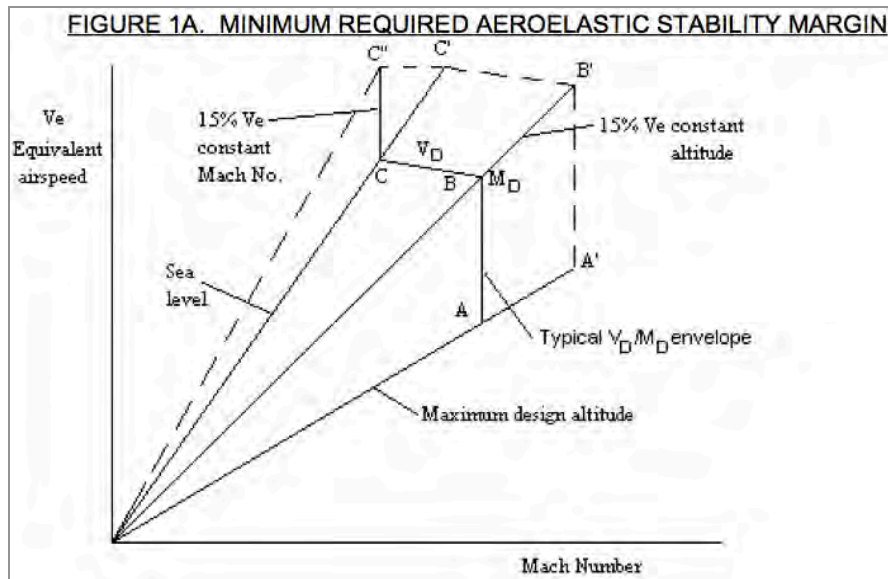


Figure 9: Minimum required aeroelastic stability margin



Section 5—References and Recommended Reading

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