

# Some Thoughts on Reducing the Risk of Aircraft Loss of Control

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**This paper focuses on the consideration of practical, cost effective technologies that could help reduce the aircraft risk of Loss of Control. Simple, practical, low cost technology solutions are advocated for both fixed wing and rotating wing aircraft as a means of quickly reducing the risk-- years before more elegant and sophisticated systems can be created and fitted into new aircraft designs.**

*The author's discussion and opinions are his and his alone and do not necessarily reflect that of Honeywell.*

## Abbreviations and Nomenclature used in this Paper

LOC is Loss of Control

ADI is the Attitude Display Indicator

ADR is the Air Data Reference

ADS-B is the Automatic Dependent System-Broadcast ----which is a system comprising a Transponder transmitting GPS position and other airplane data (ADS-B OUT) and a Receiver on own aircraft (ADS-B IN) to receive same.

AOA is Angle of Attack

BUSS is an Airbus Airspeed Back Up Speed Scale

CFIT is Controlled Flight Into Terrain

EADI is Electronic Attitude Display Indicator

EFIS is the Electronic Flight Instrument System

FBW is Fly-By-Wire Control

FD is Flight Director

FSADI is Frequency-Separated Attitude Display

HDD is Heads Down Display

HUD is Heads Up Display

P & C is Pulley and Cable conventional Control Systems

PACS is Positive Attitude Control System

SD is Spatial Disorientation

SVS is a Synthetic Vision System

URT is Upset Recovery Training

Vmos is the minimum operating speed

## Introduction

Loss of Control (LOC) accidents for commercial jet transports continue to mar the great record of safe operations around the world and are the highest risk for fatalities. The LOC risk is currently about 0.30 fatal accidents per million departures (Table 1 in the Appendix). Many of these LOC accidents occur in operations outside North America, Australia, Japan and Europe and it is suspected that the lack of pilot experience and training are significant factors. The LOC risk is highest for the conventional "Pulley and Cable" control system aircraft. While FBW designed aircraft have demonstrated significantly lower risk when compared to pure conventional "Pulley and Cable" aircraft, FBW aircraft are not immune to LOC.

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There have been many excellent papers written by well qualified people covering the LOC accident risk and possible solutions. See the References 1 thru 7 listed at the end of this paper for a partial list of these papers. Some good ideas are contained in these papers that include possible countermeasures such as pilot training and procedures, modified instruments, new instruments, pilot activated recovery systems and automatic recovery systems. This paper will try to focus on those ideas that could translate into practical low cost technologies utilizing existing equipment.

### **LOC Accident Cost and Risk**

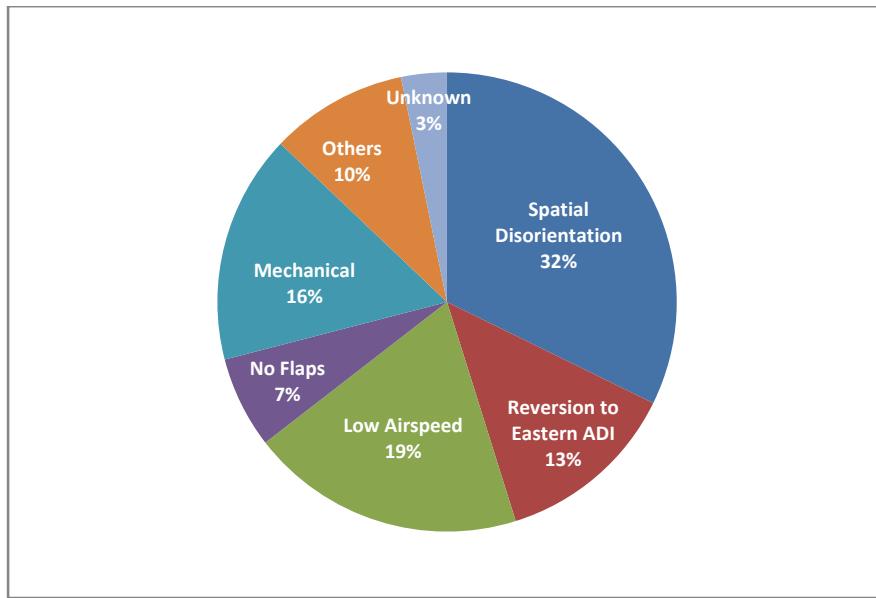
There were some 34 LOC accidents for the last ten years. See Table 1 in the Appendix. These accidents cost more than 3,100 lives and financial losses exceed or will exceed \$4 Billion US. There have been at least two large commercial jet fatal accidents already so far this year 2010 where LOC is suspected. With losses for conventional "pulley and cable" aircraft, LOC costs are about \$36 US per departure and \$4 US per departure for FBW aircraft. There seems a good business case for investment in some simple and practical technology to reduce the LOC risk.

### **LOC Accident Classification**

LOC accidents can be classified as follows:

Spatial Disorientation (SD) and suspected Reversion or confusion of Western to Eastern (Soviet era) Attitude formatted displays are about 45 % of the losses. Undetected loss of Airspeed leading to Stick Shaker and into Stall accidents are about 20% of the losses. Take-off accidents attempted with No Flaps continue to occur. Mechanical Failures leading to LOC are also significant and the pilot can do very little if the controls are not useable. LOC from Wake Vortex upsets ("others") is a risk growing as RNP procedures confine aircraft tracks during departures and initial approach.

Figure 1 expresses some of the classifications of the causes in a Pie Chart.



**Figure 1—Loss of Control Classification**

It is possible to minimize the LOC risk with some simple technology and with an excellent business case that can address a large number and majority of commercial jet and turboprop transport aircraft in revenue service (some 30,000 aircraft plus another 12,000 business aircraft).

## Technology Spatial Disorientation (SD)

SD accidents are also known by many terms such as Vertigo; Visual Illusions; Vestibular, Kinesthetic; Somatogravic Illusions and exceed a third of all LOC accidents. The aircraft Attitude Display Indicator (ADI) or Electronic Flight Instrument System (EFIS) also known as the Electronic ADI (EADI) is a key instrument and tool for the pilot to use in manual flight control and for monitoring automatic flight control.

SD leading to LOC is often a result of pilot distraction, perhaps by assuming the autopilot is engaged and flying the aircraft, or trying to engage the autopilot in an upset and some by wake vortex upsets. See References 6, 9, 10, 11, 12, 13, 14, 15 and 21.

When a pilot is attempting to recover from an unusual attitude, the type of aircraft ADI (EADI / EFIS) display can contribute confusion, time delay, 'bobble' (back and forth uncertainty) especially when the pilot has been exposed to thousands of hours of prior experience Eastern (Soviet era) ADIs or conversely Western ADIs (see Figure 2) . Also see References 9 and 13.

The Soviet era ADI was conceived in the early 1920s for instrument flight and was designed for a beginning pilot and was simpler to build mechanically. Many pilots had difficulty in adapting quickly in abnormal/unusual attitude situations, after Russia and Federated Republic Russian operators began to purchase used Western built aircraft that came equipped with Western ADI, EADI or EFIS cockpit displays and introduced them into operations in the 1990's. This has resulted in LOC incidents and accidents. Re-training has proved very difficult to transition with a pilot's life time flying experience with either type of display.



**Figure 2---- Western versus Eastern (Soviet Era) Attitude Display Indicators**

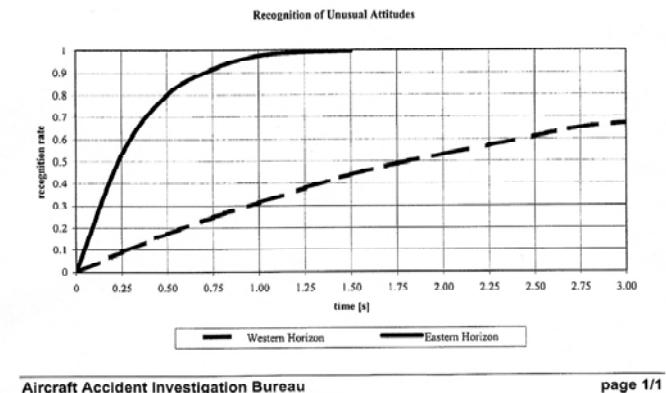
Note that the Western Attitude Display horizon symbol-line is aligned to the outside horizon and the airplane symbol stays fixed. The Eastern (Soviet) Display horizon symbol-line stays fixed and is aligned to the airplane while the airplane symbol moves with roll and pitch attitude. Many Turn and Bank instruments used in Western general aviation aircraft use a format similar to the Eastern format.

The Swiss investigative accident report CRX498 (page 70, and 71 of the report} for a SAAB 340 LOC accident at Zurich (Reference 9) provided some interesting data comparing pilot response time for pilots trained on Eastern (Soviet) ADIs while using a Western ADI format. A similar pilot response would probably occur for a pilot trained and experienced for Western ADIs when using an Eastern formatted display. See Figure 3.

**Annex 7**

The diagram below shows the results of a study which registered the time needed by pilots trained on eastern horizons to detect an attitude with certainty. The rigid curve represents the situation in which eastern horizons were used, the dotted curve represents the one, when artificial horizons of western make were used.

For instance after one second, 98% of pilots were able to interpret the attitude, if it was represented by eastern horizons. But only 32% of the same pilots could reliably determine attitude after one second on western instruments.



Aircraft Accident Investigation Bureau

page 1/1

**Figure 3---The Time Recognition Response for a pilot skilled in the Eastern (Soviet) Era ADI to interpret the Western Display\*** *this chart is apparently taken from Russian Research*

**Frequency-Separated Attitude Display Instruments (FSADI)**

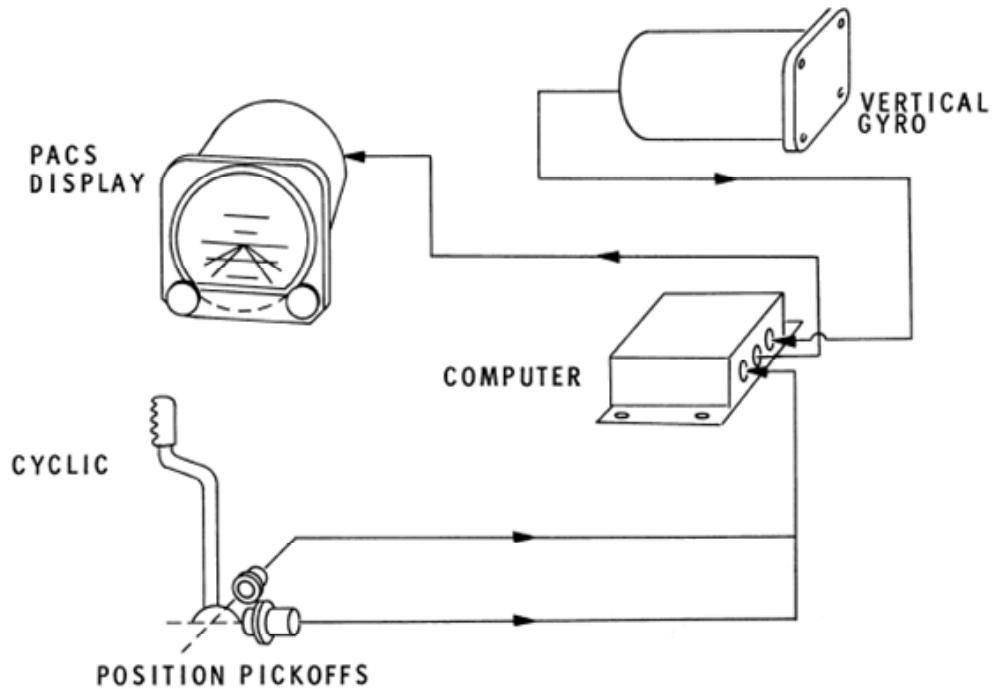
These display concepts were apparently first developed from US Defense Department Research in the 1960 era (post WW II). See References 19, 20 and 21. The FSADI could help bridge the Western ADI to the Soviet era ADI time delayed response (or vice versa) seamlessly. The movement of the control stick or control wheel with the ailerons or elevator would instantly move both the airplane symbol and then wash back over a short time to its normal display position as the roll and pitch of the aircraft developed. The Horizon Line remained independent. FSADI gave great feedback and phase margin in control for the pilot. There continues to be recent work accomplished by the US Navy Research Center---see Reference 22. Other work continues by the Air Force Research Labs in a spatial disorientation workshop.

With the concepts and knowledge available today, it seems certain that a better "Universal" ADI / EFIS could be developed so that pilots around the world could use, help reduce the learning time required and when the pilot is suddenly in an unusual attitude, improve the probability of recovery with a lower the risk of control reversal, confusion and time response. Some research to achieve such a "Universal ADI" would be very worthwhile.

**Honeywell Positive Attitude Control System (PACS)**

In 1966, Honeywell without the knowledge of the military FSADI work, modified a mechanical ADI for Helicopter as an aid for an un-experienced pilot to quickly learn to control the helicopter and as a helpful aid experienced pilots in poor visibility in "brown outs" (blown up dust), at night time or in weather operations. Honeywell was not aware of the considerable work that the US Military research establishment had funded (including Universities) and conducted at that time in the 60's and 70's.

The Honeywell ADI used the Helicopter Cyclic stick position to drive a predictive bar or helicopter symbol mechanically. The pilot could directly position the aircraft symbol to a particular desired attitude with the Cyclic stick. The symbol would then gradually wash out as the resulting helicopter roll and pitch attitude developed and the aircraft symbol returned to its normal centered position on the ADI. The mechanization gave an excellent stability control margin even in turbulence. It was amazing how a completely unfamiliar pilot with little or no experience in fixed wing aircraft or with helicopters could quickly adapt to easily control a helicopter in flight. The invention in the '60s of the inexpensive solid state analog Operational Amplifier in a "TO-5" can (the size of a human's little nail finger) made the washout algorithm simple to implement. See Figure 4.



**Figure 4—1966 Honeywell Helicopter Cyclic Attitude Display system**

For a modern digital aircraft helicopter ADI, all the signals required for a Frequency-Separate Attitude Display such as aircraft control surface positions for ailerons and elevator exist and could be easily provided that could reduce the learning time to fly a helicopter and greatly help in maintaining a safe attitude during a "Brown-Outs", or limited visibility and night landings.

For both fixed wing and helicopter types, the type of attitude formats on various ADI /EFIS may vary and may be a factor in time response to recognizing a serious bank angle situation. There are many variations between air transport, general aviation and military ADIs used on various aircraft types. The application of Frequency-Separation Displays in a low cost practical manner could be a step forward in improving these ADI or EFIS displays.

#### **LOC risks for the Conventional "Pulley and Cable" control aircraft as compared to the "Fly by Wire" aircraft with Protective Envelopes.**

LOC risks are approximately 70 times worse for the Conventional "Pulley and Cable" control aircraft as compared to the "Fly by Wire" aircraft with hard or soft protective envelopes.

As mentioned earlier, the LOC accident losses (Table 1 in the Appendix) for conventional control system aircraft are approximately \$36 US per flight departure, while FBW aircraft are about \$4 per flight. See Figure 5.

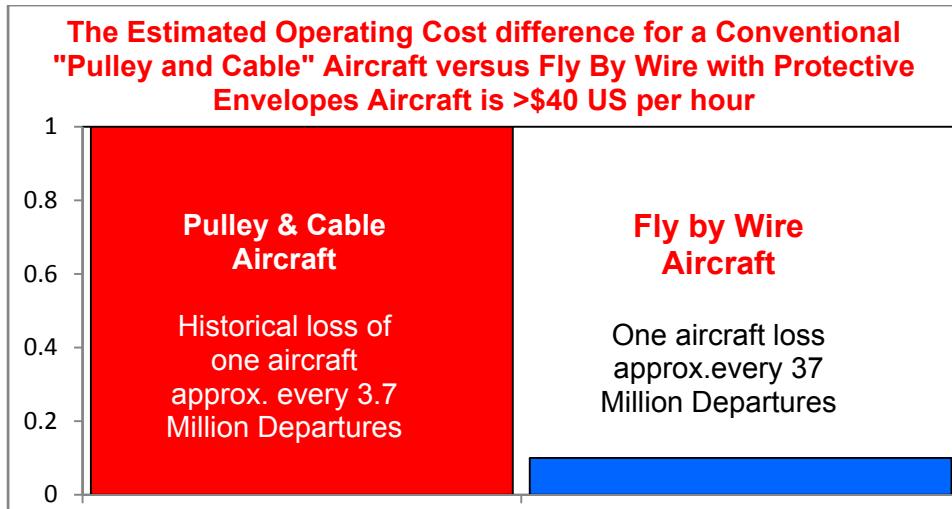


Figure 5--Inferred Operating Risk Cost Difference Between Conventional Versus Fly-By Wire Aircraft

#### Real World Bank Angle Exceedances of 35 degrees

Bank angles exceeding 35 degrees for conventional “pulley and cable” aircraft are commonly seen in real world operations. Data gathered from 9 million departures de-identified E-GPWS flight history gives a rate of occurrences for conventional control aircraft types that are about 1.8 per 1,000 flights. Figure 6 is a chart for typical aircraft types as expressed for occurrences at various pressure altitudes. Note that some of the maximum angles exceeded 50 degrees! It seems probable that many pilots experience unusual bank attitudes in their lifetime.

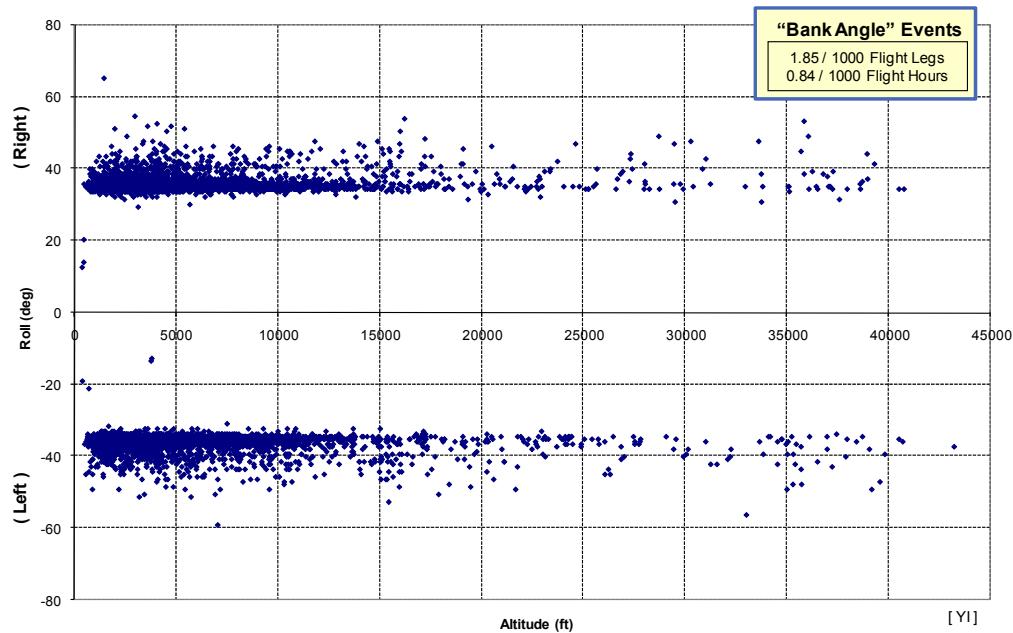


Figure 6---Bank Angle Occurrences exceeding 35 degrees for Typical Conventional Transport Aircraft.

## Practical Affordable Technology

Modest investments by adding aural advisories and improving the visual ADI display format could help lever a lower the risk for conventional “pulley and cable” aircraft.

### 1. Add a Roll Arrow to the ADI / EFIS to help the Pilot Recovery from an Excessive Bank Angle

In their papers, Gary Gerhzhohn of Boeing, William J. Bramble Jr. of the NTSB and Dennis Beringer of the FAA and others (Reference papers 2, 8 and 21), have discussed and looked at the possible use of an roll and pitch recovery “Arrows” on the ADI / EFIS to help the pilot recover from unusual attitudes. In a simulation study, Gerhzhohn was able to show that such an Arrow helped reduce errors by 90%, recognition and hesitation time were reduced, helped remove ‘bobble’ (roll reversions) and confusion for the pilot. The pilots could quickly and correctly determine which way to correct the bank angle. For many ADI / EFIS existing displays this could be a modification with minimum investment.

See Figure 7 for one example of a corrective roll attitude Arrow.



Figure 7— Example ADI / EFIS with a Corrective Arrow for an Excessive Bank Angle Situation

### 2. Add an additional E-GPWS Aural Advisory to help the pilot to quickly recognize Unusual Attitude and the Corrective Roll Recovery Maneuver

Existing E-GPWS computers are currently fitted to more than 42,000 commercial, transport, military transport, helicopter and business aircraft. The E-GPWS has a built-in optional “BANK ANGLE!—BANK ANGLE!” aural normally set to about  $\pm 35$  degrees of bank angle and is easily enabled with a jumper program wire. Many operators have enabled this aural which has been very useful but the aural gives no suggested recovery action. Honeywell is considering the addition of adding an aural after the bank angle advisory ---“ROLL LEFT (or RIGHT) TO LEVEL! TO LEVEL!” as suggested by some pilots to help non-native English speaking pilots to more quickly recognize the aural correct roll direction advisory. The E-GPWS computer would simultaneously provide a signal to the ADI that would activate the correct recovery arrow. These are relatively simple software changes to most E-GPWS computers and EFIS /ADI Displays with **NO** change to aircraft wiring or hardware.

See Figure 8 for a simplified architectural diagram of this improvement.



**Figure 8—A Practical Simple Aural and Visual Improvement to help the pilot recover from Excessive Bank Angle**

### 3. Replace the Typical ADI with an Outside View to Inside the Cockpit

If the pilot can see the horizon clearly outside the aircraft, the probability of loss of control is probably very low. The Synthetic Vision System (SVS) Display does just that by bringing a “daytime clear visibility” synthetic outside view into the cockpit “Heads Down” into an overlay of primary flight instruments similar to those found on a Heads-Up Display (HUD). Both SVS and HUD are very valuable tools for the pilot. Honeywell has a long history in the successful development of both SVS and HUD displays and their application to business aircraft. There have been several SVI papers ---see References 23, 24 and 25. Adding virtual Terrain, Obstacles and the runways can be almost awesome. The databases for terrain, obstacles need to be of high integrity and complete. The pilot in good visual metrological conditions can spot and report any differences to help improve the databases. A typical SVS format is shown in Figure 9.



**Figure 9-- Synthetic Vision—bringing the outside world inside to the cockpit.**

During a recovery from an unusual attitude, the SVS display can automatically remove non-essential information from the display to help the pilot focus on the recovery.

#### 4. Adding Lateral Tactile Feedback for a situation leading to an Excessive Bank Angle

Another possible improvement for conventional control aircraft is to provide tactile feedback for over-banking such as a lateral “Stick-Nudger” based on the aileron positions (or control wheel), the roll angle and rate of entry to predict an over banked roll attitude. This would be similar to a pre-stall Stick Shaker in the pitch axis. Honeywell has experimented with a simple device designed to install in one of its Beech King Airs.

The concept is shown in Figure 10 and was designed to be Fail Safe to prevent the possibility of jamming of the control cables. An Eccentric Cam modulated the control cable before reaching a critical bank angle based on the aileron position, the excessive bank angle rate, roll attitude, all via a simple electronic controller. The actual device fit just below an inspection plate for the control cables over the wing. Its advantages are its simplicity and **NO** change to the existing rigging or cable controls.

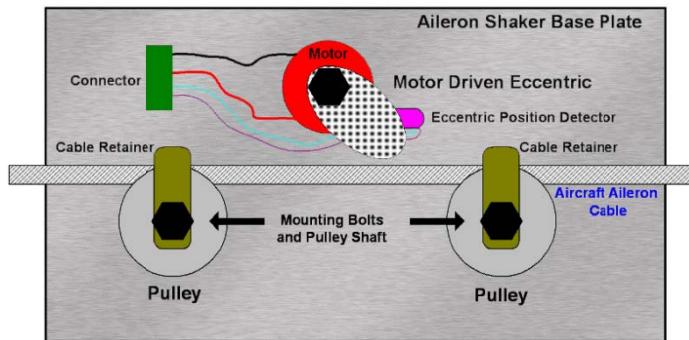


Figure 10--An example “Stick-Nudger” to help pilot recognition of an excessive Bank Angle situation.

#### 5. Add an Alert for Undetected Loss of Airspeed Leading to an aircraft Stall and Loss of Control

There have been a series of accidents where the pilots did not notice the progressive loss of airspeed until a stick shaker warning but with insufficient altitude to recover. These accidents are about 20 % of all LOC accidents. The NTSB in the USA has repeatedly recommended that an aural-visual alerting systems for Loss of Airspeed possibly leading to a stick shaker, stall and stall-spin be installed. See Reference 3.

An Angle of Attack (AOA) indication in the cockpit is a very useful tool for the pilot and is available on some types of aircraft. Unfortunately, it is not often available in all aircraft or in a format easily and quickly assessed by the pilot.

FBW aircraft have protective envelopes that silently can reduce the risk of a high angle of attack leading to aerodynamic stall. One aircraft manufacturer later added an aural “AIRSPEED!” alert to help the pilot beforehand identify the automatic lowering of the aircraft’s nose when the aircraft angle of attack had reached a protective envelope maximum. Other conventional control aircraft may have a silent visual flashing box around the aircraft’s digital airspeed readout when the airspeed has decreased to the Minimum Operating Speed (Vmos). See Figure 11. Unfortunately if the pilot is not scanning the airspeed indication because of a possible distraction, the pilot may not notice the silent flashing airspeed box when at or below that aircraft Minimum Operating Speed (Vmos). See the accident References 17. An optional aural alert “AIRSPEED LOW!” has now been developed that supplements the flashing airspeed box to provide both visual and aural awareness for the pilot. This is a software function that is hosted in the existing E-GPWS Computer as the interface exists and **NO** change is required to the aircraft hardware or aircraft wiring.

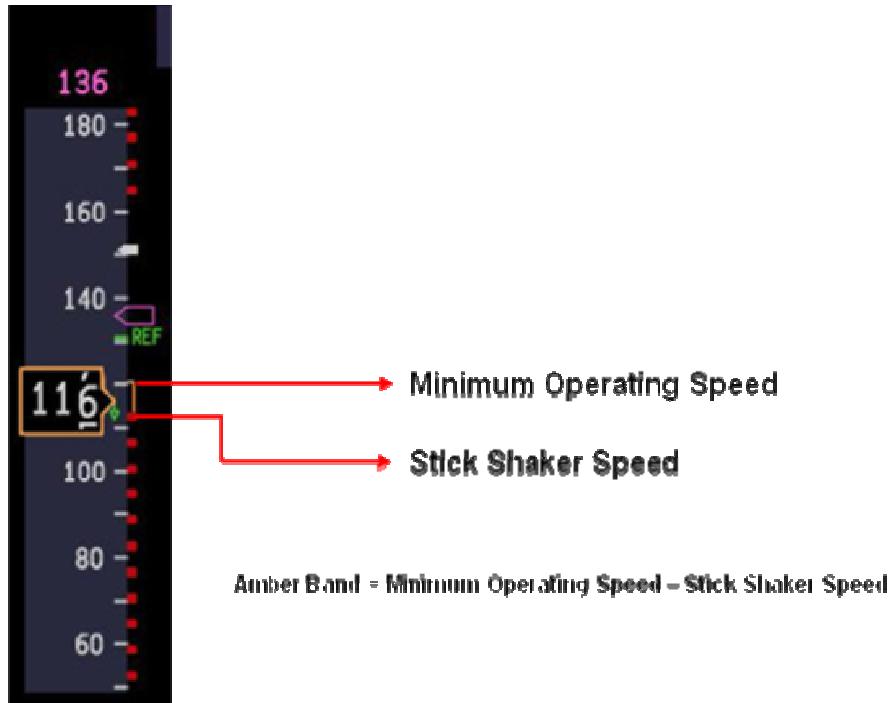


Figure 11---Typical Airspeed Tape and Flashing Speed at or below Minimum Operating Speed (Vmos)

## 6. Add Back Up Instrumentation in Case of Loss or False Airspeed Instrumentation

There are some accidents and incidents where the aircraft has lost airspeed instrumentation (and angle of attack) or had unreliable indication. See Reference 18. Many were caused by a blocked sensor orifices or restricted movement from tape during painting or other contaminate. In some incidents, resourceful pilots reverted to using the ADI Pitch Attitude, Thrust and to Angle of Attack (the latter when available) settings to control the aircraft. The GPS with its ground speed and altitude is also a useful tool.

An option offered by Airbus for both Long Range and Single Aisle aircraft is known as BUSS (back up speed scale). A brief description: BUSS provides a backup speed scale and a back up altitude scale that replaces simultaneously the normal speed and altitude scales when all the three Air Data References (ADR) are switched OFF. This enables the flight crew to fly at a safe speed and altitude in case of an unreliable speed/altitude indication. The backup speed scale information is based on the angle-of-attack, and depends on the slat/flap configuration. The backup altitude scale displays the GPS altitude. However, basic pitch and power procedure/technique is partially replaced by using the alternate speed scale. It is a useful tool e.g. in case of an unreliable airspeed indication.

Another concern is the propagation of common mode sensor failures to not only cockpit instrumentation but also into the automatics and FBW-protective envelopes making it extremely difficult for a pilot to quickly detect what sensor and instrumentation is faulty before LOC occurs.

## 7. Add an Independent Alert for No Take-Off Flaps Selected after a Take –Off

There have been accidents where the aircraft has inadvertently attempted to take-off without having selected any Take-Off Flaps. The aircraft lifted off but quickly entered Stick-Shaker and into a LOC Stall. Most of these accidents had no pilot recognizable Take-Off warning from the configuration warning system or the system was in-operative for various reasons. There have been many incidents where the aircraft, without take-off flaps, entered the runway and received a take-off warning horn as the thrust handles were advanced. The wise pilots were those who immediately stopped and pulled off the runway and returned to the take-off point and set the proper flaps. Some

pilots “not so wise” attempted to set the proper flaps during the take-off run and hoped that the runway was long enough to get the flaps set and airspeed adequate to climb out. Contributing factors are a warning horn which can mean other problems with configuration such as stabilizer trim out of range, mismatched flaps, asymmetric thrust and a line of aircraft waiting behind in a queue. Some of these accidents were:

20 August 2008,	Madrid, Spain	MD-80	166 Fatalities
5 September 2005,	Medan Indonesia	B-737-200	149 Fatalities
14 January 2003,	Pekanbaru, Indonesia	B-737-200	Total airplane loss but no Fatalities
31 August 1999,	Buenos Aires, Argentina	B-737-200	79 Fatalities
23 July 1993,	Yinchuan, China	BAe 146-300	56 Fatalities
9 January 1993,	Bouraq	HS-748	17 Fatalities
There have been hundreds of incidents----			

One simple risk reducing function is to provide an aural “CHECK FLAPS!” when entering a runway for Take-Off without Take-Off flaps set. This is currently a function in the E-GPWS requiring **NO** wiring or hardware change where flap position was interfaced to E-GPWS for enabling reactive Windshear functions. A table of acceptable take-off flaps is all that is required as the aircraft enters a “virtual box” around the runway. E-GPWS has the runway data used for the TAWS functions and to create a “virtual box” and with other flight safety functions hosted in E-GPWS. The hosted Take-Off function is **completely independent** of the Configuration Warning System and can also provide a Visual text message “FLAPS” on the existing Navigation-Terrain Display. See Figure 13.



Figure 13---No Take-Off Flap Aural and Visual Advisory

## 8. Add display of Virtual Wake Vortex Turbulence

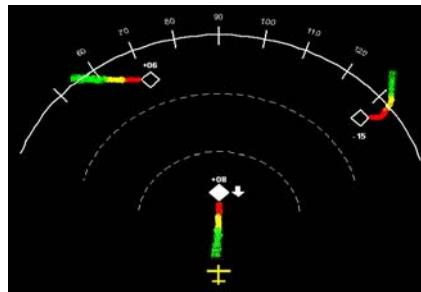
There have been many LOC incidents and a few accidents caused by inadvertent flight into Wake Vortex-Turbulence. See reference 23 as an example incident. As pressure to decrease traffic spacing, reduce community noise, reduce fuel burn, the traffic track is concentrated especially using RNP procedures, the probability of LOC will increase wake vortex encounters as discussed in Reference 4.

Figure 14 shows how pilot awareness to the vortex danger could be displayed on a Navigation Display by simply adding a tail or other icon to the displayed ADS-B target Icon to represent possible wake vortex location and strength. Many aircraft traffic use or will be using ADS-B OUT transponders that transmit the aircraft’s GPS location and other data such as the aircraft’s configuration, FMS winds etc. Receiving the ADS-B out by using an ADS-B IN receiver on own aircraft can be used to obtain the other aircraft’s GPS traffic location and their winds, etc. This data is then combined with own aircraft wind data and own accelerations from turbulence to calculate and create a probable location shown as a “Tad Pole’s Tail” or a “Circular Twirl” Icon and colored to indicate possible vortex strength behind the displayed ADS-B Traffic Icon on the Navigation Display.

There is a tendency to over complicate the computation of Virtual Wake Vortex locations and intensity.

But a simple algorithm based on Isaac Newton's momentum flow that gives an airplane its lift, gives a good first order approximation of where the Wake Vortex will lie. Wind information, the other aircraft's position with some other existing aircraft data, improves the probability of where the wake vortex probably lies---an area for the pilot to avoid or stay above.

This is a powerful tool for pilot awareness of the wake vortex turbulence and potential LOC.



**Figure 14- Wake Vortex Icons on a Navigation Display portraying ADS-B Traffic.**

## **9. Improve Training**

Training can be an excellent tool and cost effective in lowering LOC risks. In 2008, four invited speakers at the annual IASS Flight Safety Foundation, presented excellent papers on various aspects of training. These papers (References 2, 7, 9 and 10) were very thoughtful guides towards establishing invaluable training for all pilots. Another great paper is Reference 4. Exposing each pilot to actual somatogravic illusions adds vital experience and understanding. Crider's papers (Reference 5 and 6) provide excellent detail about the various past LOC accident examples that can be used as an Academic curriculum for the pilot.

In spite of the best technology, technology can mean very little without good professional training and "hands on" familiarity with these technology tools. Exposing the pilot in the simulator to unusual attitudes is invaluable and to practise recovery especially with the particular EFIS-ADI that the pilot uses in every day operations.

Airmanship needs to be practised and enforced with proven Standard Operating Procedures and SOPs that evolve with industry experience and knowledge gained from the real world and research and development. Demonstrating Somatogravic illusions in the simulator is invaluable. Ingenuity and innovation can help drive down the simulator costs so that every transport pilot can learn and handle somatogravic illusions.

Advanced Manoeuvre (AM) and Upset Recovery Training (URT) is being practised by several airlines and should greatly reduce LOC risk. See reference 4 and 10.

## **"For a Few Dollars More"-more elegant, sophisticated Expensive Technology to reduce the LOC Risk**

### **1. Utilize the Existing Auto-pilot Servo's and Servo Amplifiers to Provide "Soft Protection" against Excessive Attitudes for Conventional "Pulley and Cable" aircraft.**

Another possible solution before reaching an unusual roll or pitch attitude is to utilize the existing installed autopilot servo and servo amplifiers to help automatically restrict unusual roll and pitch attitude. Autopilot servos are installed on every airplane, attached to the aircraft's control surfaces. The autopilot servos are torque limited which allows the pilot to overpower the servo if needed. This would also help give tactile feedback in the form of a "soft protection" for the aircraft. However, the complexities of certification and application of using existing auto-pilot components could be very complex, difficult and probably too expensive to implement.

## **2. FBW Aircraft with Protective Envelopes**

As earlier discussed, FBW aircraft with full or resistive tactile protective envelopes have proven in service to be significantly resistant to excessive bank angles leading to LOC. However these aircraft are not immune to flight into terrain or a somatogravic illusion and compounded by a distraction leading to perhaps an inadvertent pitch down such as during a go around and flight into the ground or water short of the runway. There are at least two accidents, possibly three, where the pilot, under possible somatogravic illusion, did not respond to GPWS warnings and flew into water or ground on a go around.

Honeywell successfully demonstrated automatic recoveries in 2005 using an "Assisted Recovery" algorithm to the autopilot for both conventional and FBW aircraft. Recoveries were made from flight paths into mountainous terrain, obstacles and restricted areas. An interesting demonstration was also made using a standard production FBW aircraft (removed temporarily from revenue service) and deliberately flown towards a mountain. The algorithm was 'armed' by an E-GPWS warning but the recovery delayed until the calculated time to impact has become very short. The normal recovery acceleration was kept in the order of  $50 \times 10^{-3}$  Gs. There was no modification made to the aircraft or systems to make successful automatic recoveries. With good integrity WGS-84 databases for runway ends, obstacles, prohibited areas and terrain, a FBW aircraft could **NOT** be flown without great difficulty into a place where there is no runway.

A simple dive recovery algorithm to wings level and until the warning ceased would suffice for most of the FBW accident scenarios short of the runway. The level of integrity must be high to prevent inadvertent activations. To ensure the integrity of the runway terrain and obstacle database, E-GPWS flight history is currently accumulated automatically in non-volatile memory for all alerts and warnings, Flight History is also retained for every approach to the runway ends and also for runway lift-off on take-off in GPS WGS-84 latitude-longitude, altitude and track coordinates. The data is then audited to validate accurate nuisance free operation and to ensure that there would be a warning when needed. Honeywell has been able to build and validate runway ends for the airports worldwide independently of "Official" State Sources and FMS Navigation Databases. Runway data integrity grows with additional as the number of flights into a specific runway grows with time and additional validation from surveyed ground points and satellite pictures of the runway. Honeywell has retrieved and audited millions of departures to date. As the integrity of the databases grows, the system could be activated and hardened for each runway at a specific airport by specific airport and runway.

## **3. Improve the Side Stick or Control Wheel with Tactile Force Feedback**

Most current aircraft with FBW and protective envelopes lack both feel and visual feedback from the Side Stick Control. This author would like to see these current side sticks replaced with tactile force feedback side sticks to help the pilot more easily recognize and differentiate what the aircraft is actually doing from that of the other pilot. This technology exists today but would probably require considerable re-do of the aircraft's control architecture, software and re-certification for existing aircraft types.

## **4. EFIS Vertical Airspeed Tape Scale**

The author's opinion is that the EFIS airspeed tape used on most commercial transport aircraft which read zero airspeed at the lower part of the tape similar to a vertical temperature thermometer should be reversed.

The speed tape typically uses a red stripped area for flap or aircraft overspeed. The natural reaction for a pilot is to push away (nose down) for an aural flap over speed warning and with an airspeed indication akin to a thermometer this will increase the airspeed. For many aircraft types, this red stripped area is also physically close to the normal operating speed when on approach. See Figure 12.

There have been accidents and incidents where a flap overspeed alert coupled with SD may have contributed to a critical distraction at a critical time leading to LOC (Reference 12).

In the 1980's, there was considerable debate as to how the airspeed scale should be shown as a typical thermometer or reversed. Honeywell has built and helped certify formatted airspeed tapes for some aircraft (Gulfstream) that could be easily reversed by a program pin and wire. Unfortunately, in the 80's as more glass attitude displays were selected for new aircraft types, the industry gravitated to a vertical scale akin to the temperature thermometer. Now, because of the thousands of aircraft flying this format, it would be difficult to make a change. This could be a concern to some of whether this could introduce a training problem for the pilots, converting from an increasing Airspeed Vertical Speed Tape to that of a reversed scale. Some operators have experienced no such problem for pilots flying either vertical tape presentations for the same business aircraft type.



Figure 12----Airspeed Tape with a Flap Overspeed Stripped Tape

##### 5. Create and Install a “Universal” ADI / EFIS Attitude Display

As discussed earlier, the knowledge available today of Frequency-Separated Attitude Display, it is certain that a better “Universal” ADI / EFIS could be developed that all pilots around the world could use that would reduce the learning time required and improve the probability of recovery when the pilot is suddenly faces an unusual attitude, and would lower the risk of control reversal, confusion and time response. Some research to achieve such a “Universal ADI” would be very worthwhile. With a flexible graphics module, the display improvement might be accomplished in software with no change to the hardware.

##### 6. New technology for Flight Simulators to Lower Training Time and Expense.

Expanding fidelity of the aircraft at the edges of flight control needs to be developed.

There is a great need for demonstrating somatogravic and other illusions. But technology needs to be created that is practical and low cost. Innovation is needed to produce better training in less time which will save expense.

## Recommendations and Conclusions

1. The current LOC accident risk and losses of 300 lives per year and a capital loss of about \$400 Million US, equates to an additional operating cost of about \$40 US per departure US per hour with about \$36 of that for conventional “P&C” aircraft. A business economic case for an investment exists to develop practical low cost technology to reduce LOC risks and costs.
2. From many excellent research papers describing the LOC problem and some suggested solutions, we now need our industry to focus on practical technology solutions to the existing aircraft fleets for both conventional “Pulley and Cable” flight control and FBW controlled aircraft.
3. Improvements to existing aircraft should emphasize the use of existing aircraft hardware and wiring. Most aircraft operators and owners are strapped economically for funds to invest in adding new hardware or systems.
4. One of easiest simple practical technology we can use is to improve the existing excessive E-GPWS “BANK ANGLE!” aural alert by adding an additional aural “---ROLL RIGHT TO LEVEL!” (Or LEFT). This would help the pilot quickly recognize the required correct roll manoeuvre when the aircraft has got an unusual bank angle exceeding 35 degrees and advance the aural alert for high roll rate. With some 35,000 plus aircraft currently fitted with E-GPWS (over 90% of the civil and military transport fleets), this is one of the most practical low cost technologies to pursue as NO new hardware or aircraft wiring change is required.
5. Add a Roll Direction Arrow visually on the ADI to help remove the uncertainty for the pilot to visually quickly recognize and correct the excessive roll attitude. For some 15,000 conventional control aircraft (EFIS), no new wiring or hardware changes are required to interface with the EFIS-ADI—just adding software to the ADI.
6. To ensure the best development and application of these practical aural and visual improvements, solid Human Factor support for these improvement technologies should be concurrently conducted.
7. We need to see if existing EFIS and ADI Displays could be easily improved by the use of Frequency-Separation Attitude Display concepts developed by our civil and military Research and Development. This could help make the resulting display a “Universal” tool for all pilots.
8. During any accident investigation involving possible LOC, tests in the simulator should be conducted using the specific ADI to check if at high bank angles that the ADI possibly masks some of the key roll attitude information at the top of the display that could contribute adding to a pilot’s confusion of which direction to roll or pitch the aircraft.
9. We need improved pilot training on the various specific aircraft using each pilot’s everyday specific EFIS -ADI -EADI tool through demonstrating unusual attitude situations and practicing recovery. We need to pursue cost effective Somatogravic Simulation and Upset Recovery Training.
10. Bring the outside view into the cockpit with Synthetic Vision and Attitude Display.
11. We need to add a Virtual Wake Vortex Icons behind ADS-B traffic icon and express the strength and position of the Wake Vortex
12. We need to add back-up airspeed and altitude instrumentation to all aircraft such as the Airbus “BUSS”.
13. We need to publicize the LOC risk and utilize the best publicity channels of the International Civil Aviation Organization (ICAO); the Flight Safety Foundation and the International Aviation Transport Association (IATA) to promote simple low cost and practical technology and training.

14. For new aircraft designs, we need to consider inverting the Vertical Speed Tape (increasing Speed down Airspeed Tape Indication).
15. We need to add Automatic Recovery (ATAM) or Dive Recovery algorithms for FBW / Protective envelope aircraft (the missing protective envelope) and to add tactile feedback to the side sticks.
16. We should consider the addition of Tactile Feedback to over-banking in conventional control aircraft such as a Lateral “Stick-Nudger”.
17. We should re-consider the automatic engagement of the Autopilot when an unusual attitude is developing, to help restrict the attitudes and utilizing existing installed servos and servo amplifiers or separately activate an automatic protective envelope or “Soft-Protection” device.

## Appendix

### Loss of Control Accidents-- a partial list of the last 10 years

Ten years--- 2000 to January 2010      34 accidents    3,144 fatalities    \$ 4 Billions Loss  
 Three accidents average per year at 0.3 accidents per Million Departures

There are many air transport Loss of control accidents believed to be caused by pilot spatial disorientation or undetected loss of airspeed:						
Date	Location	Operator	Aircraft Type	Fatalities	Est'd Loss	Probable Cause
January 2, 2010, 7:00 AM	Beirut, Lebanon	Ethiopian Airways	B-737-800	90 fatalities	\$ 210M	Spatial disorientation-EG PWS 10x "Bank Angle!"
July 15, 2009, 10:00 AM	Iran	Caspian Airlines, Yemen	TU-154	168 f	\$ 2.7 M	Unknown but believed to be mechanical
June 30, 2009, 10:00 AM	Comoros	Yemen	A-310	153 f 1 s	\$ 132 M	SD, undetected loss of airspeed into full stall
June 1, 2009, 10:00 AM	Mid Atlantic	Air France	A-330-3	228 f	\$ 640 M	Ice Crystals? Loss of Instrumentation
February 25, 2009, 10:00 AM	Schiphol	Turkish	B-737-8	9 f 86 s	\$ 90 M	Undetected Loss of airspeed--sticks shaker--stall
February 12, 2009, 10:00 AM	Buffalo	CoglanAir	DH C-8 Q400	49 f	\$ 165 M	Undetected Loss of airspeed/Stall Neg. Tng
November 27, 2008, 10:00 AM	Perpignan, France	XL Airways	A-320	7 f	\$ 45 M	Operator testflight—Stall---No airspeed alert.
September 20, 2008, 10:00 AM	Perm, Russia	Aeroflot-Nord, Itekair	B-737-5	88 f	\$ 95 M	SD and other Soviet past ADI experience
August 24, 2009, 10:00 AM	Bishkek, Kyrgyzstan	Itekair	B-737-2	68 f/90	\$ 55 M	Mechanical--LOC attempting to return to apt.
August 20, 2008, 10:00 AM	Madrid	Spanair	MD-82, DC-9	166 f 1 f	\$ 320 M	No Flap T.O. leading into full stall.
July 6, 2008, 10:00 AM	Saltillo, Mexico	USA Jet Airlines	DC-9	1 f	\$ 10M	SD into full stall
September 16, 2007, 10:00 AM	Phuket, TH	One-Two-Go Airlines	MD-82	90 f 40 s	\$ 45 M	Loss of Control after high speed landing
May 4, 2007, 10:00 AM	Douala, Cameroon	Kenya Airways	B737-8	114 f 2 s	\$ 105M	Undetected roll, EGPWS Bank Angle!" and SD
February 13, 2007, 10:00 AM	Vnukovo, Russia	Fort Aero	CRJ-100	0 f	\$ 5 M	Reversi onto Soviet past ADI experience
January 1, 2007, 10:00 AM	Sulawesi, Indonesia	Adam Air	B-737-	102 f	\$ 56 M	IRS problem, procedures, SD into spiral
August 22, 2006, 10:00 AM	Donetsk, Ukraine	Pulkovo Airlines	TU-154	170 f	\$ 87 M	Hi Alt Undetected Loss of Airspeed—full stall
May 3, 2006, 10:00 AM	Sochi, Russia	Armavia Airlines	A-320	113 f	\$ 65 M	SD Pitch down—reversi onto Soviet experience.
September 5, 2005, 10:00 AM	Medan, Indonesia	Mandala Airlines	B-737	148 f	\$ 148 M	No Flap T.O. leading to full stall.
August 16, 2005, 10:00 AM	Machiques, Venezuela	West Caribbean	MD-82	160 f	\$ 165 M	Undetected loss of airspeed into Hi Alt Stall.
March 23, 2005, 10:00 AM	Mwanza, Tanzania	Airline Transport	IL-76	8 f	\$ 3M	Possible overloaded into stall.
November 21, 2004, 10:00 AM	Baotou, China	China Yunann	CRJ-200	53 f	\$ 14 M	Failure to De-Ice--stall
Jan. 3, 2004, 10:00 AM	Sharm el Sheikh, Egypt	Flash Airlines	B737-3	145 f	\$ 150 M	SD—reversi onto Soviet ADI past experience.
December 25, 2003, 10:00 AM	Cotonou, Benin	UTA	B-727	140 f 20 s	\$ 9 M	Overloaded, CG—attempted to return to airport.
July 8, 2003, 10:00 AM	Port Sudan, Sudan	Sudan Airways	B-737-2	117 f	\$ 14 M	Loss of control after eng failure.
March 6, 2003, 10:00 AM	Tamara Nassar, Sudan	Air Algerie	B-737-2	103 f 1 s	\$ 56 M	Loss of control after eng failure.
May 4, 2002, 10:00 AM	Kano, Nigeria	EAS Airlines	BAC111	75 f 4 s	\$ 15 M	Loss of control after eng failure.
January 16, 2002, 10:00 AM	Yogyakarta, Indonesia	Garuda	B-737-3	1 f	\$ 5 M	Undetected Loss of airspeed after dual eng flameout.
November 12, 2001, 10:00 AM	Belle Harbor, NY	American Airlines	A-300	265 f	\$ 540 M	Over control of rudder-- Neg. Tng
Aug. 23, 2000, 10:00 AM	Manama, Bahrain	Gulf Air	A-320	143 f	\$ 160 M	SD---flap overspeed tape
July 25, 2000, 10:00 AM	Paris, France	Air France	Concorde	113 f	\$ 240 M	Tire burst--fuel tank fire
July 17, 2000, 10:00 AM	Patna, India	Alliance Air	B-737	60 f	\$ 8 M	Undetected loss of airspeed into stall
February 16, 2000, 10:00 AM	Sacramento CA	Emery Worldwide	DC-8	3 f	\$ 10 M	Elevator Tab disconnected--maintenance
January 31, 2000, 10:00 AM	Port Hueneme, CA	Alaska Airlines	MD-80	88 f	\$ 180 M	Jammed Stabilizer--maintenance
Jan. 10, 2000, 10:00 AM	Zurich, Switzerland	CrossAir	Saab 340	10 f	\$ 20 M	SD—reversion to Soviet ADI past experience

Table 1---Some Example Loss of Control Accidents

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