# The Magnitude of the Spatial Disorientation Problem in Transport Airplanes

Richard L. Newman; Angus H. Rupert

**INTRODUCTION:** Loss-of-control (LOC) is the major cause of transport airplane mishaps. There have been many published reports and papers examining these accidents. While these studies did mention spatial disorientation (SD) as a cause or a factor, none of them analyzed it further. The present study uses transport and commuter airplane mishap data for a recent 35-yr period and examines the results of those mishaps involving spatial disorientation.

**METHOD:** We identified LOC and SD accidents from five national aviation accident organizations and two independent groups. Only "normal" operations (air carrier, noncommercial transportation, ferry flights, and training) were considered. We reviewed transport and commuter airplane accidents using the published reports and identified 94 involving SD.

**RESULTS:** We found the distribution of SD mishaps differs from LOC mishaps. During initial climb, there were relatively fewer SD mishaps (16%) than LOC mishaps (31%). During enroute climb SD has relatively more mishaps (18%) than LOC (11%). During go-around or missed approach phases, there were relatively more SD mishaps (21%) than LOC mishaps (4%). Perhaps the most significant observation was an increasing number of SD mishaps during the period reviewed.

**DISCUSSION:** There are several possible reasons for the increasing numbers of SD mishaps over the study period from 1981 to 2016. Somatogravic illusion during go-around or missed approach accounts for only some of this increase. There is insufficient data to determine the reason for the remaining increase.

**KEYWORDS:** spatial disorientation, transport airplanes, somatogravic illusion, sensory illusions, aviation safety.

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Loss-of-control (LOC) is the major cause of transport airplane mishaps. During the decade 2001–2010, the Boeing Statistical Summary[3] reported 20 fatal mishaps (out of 87) that were caused by LOC. There have been many published reports and papers examining loss-of-control or upset accidents—Belcastro et al.,[1] Lambregts et al.,[13] Newman,[19,20] Wilborn and Foster,[24] and SAE-6237.[23] Each had slight variations in their time frames and scope, although all placed their emphasis on transport airplanes. While these studies did mention spatial disorientation (SD) as a cause or factor, none of them analyzed it further.

SD can be defined as the inability of the pilot to maintain awareness of his (and the aircraft's) orientation, position, and trajectory relative to the Earth.[2,16,21,24] We deliberately use the word "inability" in place of "failure" to avoid a negative connotation. Many authorities describe two types of SD: Type I, where the pilot is unaware that he/she has lost orientation, and Type II, where he/she is aware that orientation has been lost.

Newman[18] examined the 278 LOC mishaps from Belcastro et al.[1] and found 40 involved SD. The present study expands these data and examines the results of those mishaps involving SD in transport airplanes.

## METHODS

We identified mishaps to transport or commuter[6] airplanes operating in scheduled or nonscheduled passenger or cargo flights, positioning flights, and business or executive transportation. Aerial work, personal transportation, and training flights were also included.

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**Table I.** Percent of Mishaps and Fatalities by Phase of Flight.

| | PERCENT OF MISHAPS | | PERCENT OF FATALITIES | |
|---|---|---|---|---|
| **PHASE OF FLIGHT** | **SD MISHAPS** | **LOC MISHAPS** | **SD MISHAPS** | **LOC MISHAPS** |
| Initial Climb | 16% | 31% | 9% | 24% |
| Climb | 18% | 11% | 18% | 22% |
| Enroute | 21% | 17% | 27% | 31% |
| Descent/Level off | 4% | 5% | 3% | 4% |
| Approach | 14% | 23% | 18% | 13% |
| Landing | 2% | 8% | | 2% |
| Go-Around or Missed Approach | 21% | 4% | 21% | 4% |
| Other | 3% | 1% | 3% | 1% |

This review used the same set of databases as earlier studies:[1,19,23]

- Australian Transport Safety Bureau (www.atsb.gov.au);
- Canadian Transportation Safety Board (www.tsb.gc.ca);
- French Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile (BEA) (www.bea.aero/en/index.php);
- National Transportation Safety Board (www.ntsb.gov/ntsb/query.asp);
- United Kingdom Air Accidents Investigation Branch (www.gov.uk/government/organization/Air-accidents-investigation-branch);
- Aviation Safety Network (aviation-safety.net/database); and
- Database published by Dorsett.[5]

Keywords used in these searches were black hole, misperceived sight picture, sensory illusion, somatogravic illusion, spatial disorientation, loss of control, and uncontrolled descent. The first five of these keywords are SD descriptors and last two are LOC descriptors. From the resulting mishaps, each report or account was reviewed. Only "normal" operations were considered: scheduled and nonscheduled air carrier; business, corporate, medical, or personal transportation; non-revenue positioning flights; and training flights. Accidents resulting from criminal activities, engine-inoperative ferry flights, maintenance test flights, midair collisions, or pilot incapacitation were culled from the list.

## RESULTS

We examined each mishap report for evidence of SD. Of the 549 mishaps, we found 38 mishaps had SD as their primary cause, 56 had SD as a contributing factor, and 458 were LOC accidents with no SD involvement. Of the 94 SD mishaps, there were 6 incidents, 7 serious incidents, 6 noninjury accidents, 4 nonfatal accidents, and 71 fatal accidents with 3078 fatalities.[12,15] In the context of this paper, the number of fatalities includes ground fatalities. A chronological list is available from the authors.

Of the 94 SD mishaps, there were 64 Type I and 15 Type II SD mishaps. There were 15 mishaps which had insufficient information to make a determination. In aircraft with two pilots, the traditional SD type may require modification. In the present study, SD type was based solely on our assessment of the flying pilot's awareness.

Just under 3% of the SD mishaps happened during day-visual conditions while 55% happened during night-instrument conditions. There were 18% which happened during night-visual conditions and 24% which happened during day-instrument conditions. The fatalities are more extreme: less than 1% of the SD fatalities happened in day-visual conditions and 71% during night instrument conditions. There were 15% which happened during night-visual conditions and 14% which happened during day-instrument conditions.

**Table I** shows that the distribution of the 94 SD mishaps by phase of flight differs from the 458 LOC mishaps with no SD involvement. As can be seen, SD has more mishaps during climb (18% vs. 11%), but relatively fewer fatalities (18% vs. 22%) than LOC. This does not hold true for initial climb where SD has fewer numbers and fatalities than LOC (16% vs. 31%) (initial climb ends when the airplane is established in the climb configuration, usually 1500 ft[7]). During the go-around/missed approach phase of flight SD mishaps shows relatively more numbers (21% vs. 4%) and more fatalities than LOC mishaps.

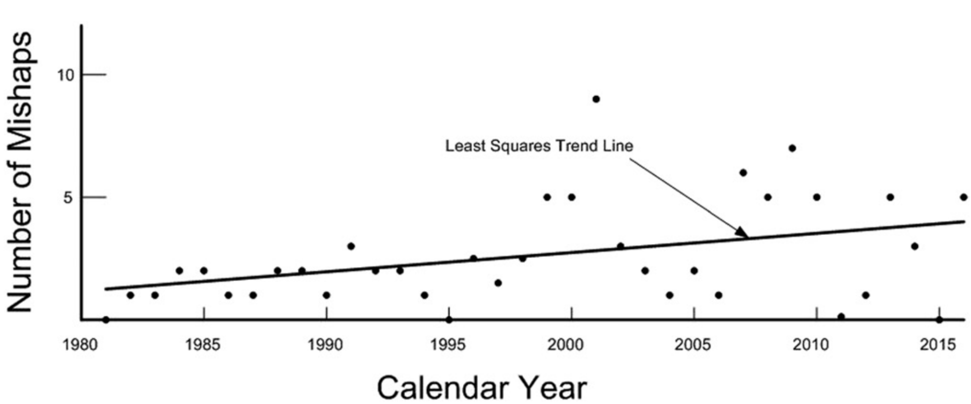


**Fig. 1.** Number of SD mishaps per year.

**Fig. 1** shows the chronological trend for spatial-disorientation mishaps. As is expected with relatively rare events, there is considerable year-to-year scatter. Nevertheless, the overall trend line is increasing slightly. Unfortunately, the exposure (number of flights or flight hours) is not available for much of the worldwide data, particularly for the nonairline flights. Therefore,

**Table II.** Spatial Disorientation Outcomes.

| | MISHAPS | | FATALITIES | |
|---|---|---|---|---|
| **SPATIAL DISORIENTATION OUTCOMES** | **NUMBER** | **PERCENT** | **NUMBER** | **PERCENT** |
| Uncontrolled Descent to Surface | 47 | 50.0% | 2128 | 69.4% |
| Collision with Obstacles or Terrain | 22 | 23.4% | 862 | 28.1% |
| In-Flight Breakup | 5 | 3.2% | 76 | 2.5% |
| Unusual Attitude or Upset | 8 | 8.5% | | |
| Runway Overrun | 2 | 2.1% | | |
| Airplane Pitch or Roll Oscillations | 1 | 1.1% | | |
| Altitude Deviation | 1 | 1.1% | | |
| Descent Below Minimums | 1 | 1.1% | | |
| Off Airport Landing | 1 | 1.1% | | |
| Unsafe Loss of Altitude | 1 | 1.1% | | |
| Safe Landing | 5 | 1.1% | | |
| Total | 94 | 100% | 3066 | 100% |

all that can be said is that the number of SD mishaps is increasing.

**Table II** shows the outcomes of these loss-of-control mishaps. Included in the 47 "Uncontrolled Descent to Surface" mishaps are 14 classic spiral dives to the surface. Of the SD mishaps, 79% result in a catastrophic outcome. Approximately 6% result in an uneventful landing.

**Table III** shows the initiating cause. A mishap will have a single initiating cause and the columns will add up to overall totals. Approximately 40% of the SD mishaps were caused by the disorientation of the pilot. The rest had some other initiating trigger, the most common of which is instrument or sensor error.

**Table IV** shows the contributing factors. Note that a mishap may have multiple contributing factors and the columns will not add up to overall totals.

One of the techniques developed by Belcastro et al.[1] was the development of sequences of precursors that ultimately led to mishaps. In reviewing the data, we noticed some frequent scenarios. For transport airplanes, significant SD scenarios include the following: loss of aircraft state awareness on go-around (ASAGA)[4] or departure; pitot-static confusion;[17] or takeoff attempt with incorrect configuration.

Loss of aircraft state awareness on go-around or departure has become more common recently, particularly with the advent of large, long-range, twin-engine transports. Such airplanes have much more performance with all engines operating than previous aircraft with three or four engines. This is particularly true following a long-range flight with a lighter weight as a result of fuel burn-off.

Transport airplanes usually have separate pitot-static systems for each pilot with a selectable third system available as a backup. Some airplanes annunciate differences between the two systems. Absent such annunciation, pilots may be confused about the airplane's performance.[17]

If a crew attempts a takeoff with an incorrect flap setting or with mis-set trim, the pilot may become confused about abnormal control forces or unusual performance shortly after takeoff. Some airplanes provide warnings if this occurs as thrust is increased at the start of the takeoff.

Some SD scenarios are more likely in non-transport operations (e.g., light airplanes or helicopters): inadvertent instrument conditions during visual flight; lack of instrument flying skills; night circling approaches; visual scene misperception; or distraction. These scenarios are more likely in non-transport operations since transports are usually operated under instrument flight rules with stricter dispatch restrictions than non-transport.

Finally, some represent special aircraft or pilot-specific situations. Non-back-driven control sticks can create confusing

**Table III.** Primary Causes of Spatial Disorientation Mishaps.

| | MISHAPS | | FATALITIES | |
|---|---|---|---|---|
| **PRIMARY CAUSE OF SPATIAL DISORIENTATION MISHAPS** | **NUMBER** | **PERCENT** | **NUMBER** | **PERCENT** |
| Spatial Disorientation | 38 | 40.4% | 1328 | 43.3% |
| Instruments/Sensors | 27 | 28.7% | 785 | 25.5% |
| Flight Crew | 15 | 16.9% | 417 | 13.6% |
| In-Flight Fire or Smoke | 2 | 2.1% | 161 | 5.3% |
| Stall | 1 | 1.1% | 145 | 4.7% |
| Organizational Factors | 1 | 1.1% | 70 | 2.3% |
| Wind Shear, Turbulence, etc. | 2 | 2.1% | 58 | 1.9% |
| Navigation System | 1 | 1.1% | 50 | 1.5% |
| Weather (Visibility, etc.) | 1 | 1.1% | 21 | 0.7% |
| Electrical System | 2 | 2.1% | 17 | 0.6% |
| Flight Controls or Autopilot | 2 | 2.1% | 12 | 0.4% |
| Airframe Icing | 2 | 2.1% | 2 | 0.1% |
| Total | 94 | 100% | 3066 | 100% |

**Table IV.** Contributing Factors in Spatial Disorientation Mishaps.

| | MISHAPS | | FATALITIES | |
|---|---|---|---|---|
| FACTORS IN SPATIAL DISORIENTATION MISHAPS | NUMBER | PERCENT | NUMBER | PERCENT |
| Improper Recovery | 19 | 20.2% | 847 | 27.6% |
| Pilot Involvement | 29 | 30.9% | 810 | 26.4% |
| Instruments/Sensors | 27 | 28.7% | 785 | 25.6% |
| Stalls | 10 | 10.6% | 668 | 21.8% |
| Flight Controls | 10 | 10.6% | 367 | 12.0% |
| Wind Shear, Turbulence, etc. | 3 | 3.2% | 58 | 1.9% |
| Airframe Icing | 3 | 2.1% | 4 | 0.1% |

situations where a pilot cannot tell if the other pilot is on the controls and, as a result, may not be able to correctly judge the aircraft response. Pilots trained on eastern European aircraft with moving-aircraft attitude indicators and now flying western aircraft with moving-horizon indicators may revert to their earlier training and become disoriented. **Table V** shows some scenarios observed in SD mishaps.

## DISCUSSION

Fig. 1 shows the increasing mishap trend for spatial-disorientation mishaps. A logical question is "Why?" One possible reason is the increase in ASAGA-like mishaps. As the BEA report stated in 2013, about 4% of public transport accidents that led to casualties over the last 25 yr were ASAGA-type. However, in 2009 and 2010 this rate rose by over 20%.[4]

While ASAGA-type mishaps contributed to the increase, they do not completely explain it. **Fig. 2** shows the SD chronological data with ASAGA-type SD accidents removed. The least squares trend line is slightly shallower, but the trend is still increasing.

What, then, can explain the increase? Aside from ASAGA-type upsets, the following are offered as possible explanations: pilots may be less experienced than before; pilots are spending less time hand-flying the airplane; training deficiencies; or electronic flight displays may be less effective in extreme attitudes.

Pilots, particularly copilots, may be less experienced than before. Recent changes to international pilot certification have allowed copilots with flight experience on the order of 200 h to fly as second-in-command.[11]

Pilots are spending more time flying with the autopilot engaged. On many routes, autopilot operation is mandatory to ensure flight within tolerances. Autopilot failure in such airspace requires immediate diversion.[8,9]

Pilot training may not be as effective in preventing SD. Simulator upset cues may differ subtly from airplane upset cues.[22] Upset recognition has historically emphasized lateral (roll) upsets with less emphasis on longitudinal upsets with somatogravic illusions. Training scenarios have traditionally emphasized engine-out, performance-limited events, and placed less emphasis on the highly dynamic all-engine cases. Additionally, electronic flight displays may be less effective than earlier displays in providing cues to the pilot for recognizing an upset.

Improper upset recovery technique is a frequent problem in both transport aircraft and in light aircraft. Often pilots had not had recent upset recovery practice since early training.[14,18,22] This may have been addressed by recent changes in airline training.[10] While improper recovery technique is not a factor in SD, it can result in the difference between an incident and a catastrophic outcome.

An inadvertent instrument condition during visual operations is a frequent problem in general aviation or helicopter operations. The pilot is trying to fly visually and may have difficulty in transitioning to instruments.

ASAGA was first addressed by the French BEA[2] and is a problem encountered with many transport operations, particularly with large twin-engine aircraft. Historically, most go-around or missed approach training concentrated on the engine-out go-around. In recent years, the BEA noticed a significant number of mishaps following all-engine go-arounds,



**Table V.** Frequent Scenarios in Spatial Disorientation Mishaps.

| | MISHAPS | | FATALITIES | |
|---|---|---|---|---|
| FREQUENT SPATIAL DISORIENTATION SCENARIOS | NUMBER | PERCENT | NUMBER | PERCENT |
| Primary Flight Data Failure | 18 | 19.1% | 142 | 4.6% |
| Loss of Aircraft State Awareness on Go-Around (ASAGA) | 15 | 16.0% | 721 | 23.5% |
| Pitot-Static Confusion | 12 | 12.8% | 568 | 18.5% |
| Improper Upset Recovery | 9 | 9.6% | 631 | 20.6% |
| Loss of Aircraft State Awareness on Departure | 6 | 6.4% | 25 | 0.8% |
| "Black Hole" Operations | 5 | 5.3% | 17 | 0.6% |
| Cockpit Smoke Blocks View of Instruments | 3 | 3.2% | 390 | 12.7% |
| Outside-in Pilot Background and Inside-out Instruments | 3 | 3.2% | 246 | 8.0% |
| Unnoticed Increase in Drag or Decrease in Thrust | 3 | 3.2% | 145 | 4.7% |
| Night Circling Approach | 3 | 3.2% | 65 | 2.1% |

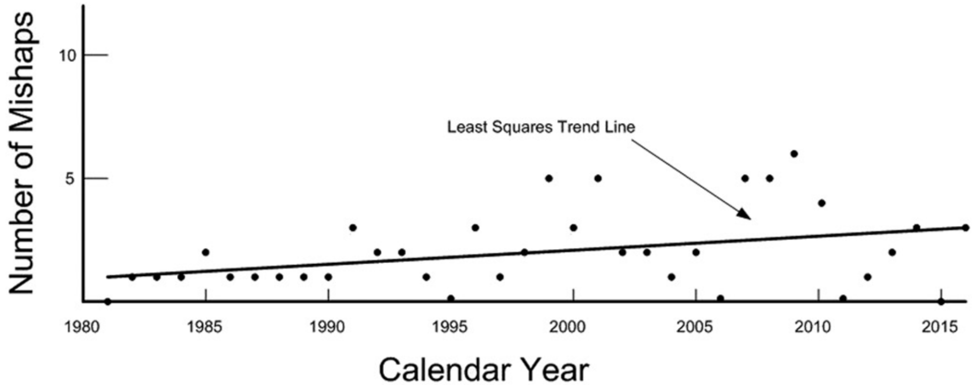


**Fig. 2.** Number of non-ASAGA SD mishaps per year.

particularly with a lightweight airplane following a long-range flight. With all engines operating, the airplane may well have more performance than expected. The first problem is the acceleration and steep climb may trigger the somatogravic illusion with a perception of much steeper climb than is present. A second factor is the rapid sequence of events. Loss of aircraft state awareness on departure is similar, but the somatogravic illusion will likely be less severe because the aircraft weight will usually be greater and the resulting performance will be less.

Night circling approaches are problematic since the pilot is maneuvering, often aggressively, at low altitude with limited external visual cues. These are not common in airline operations, since most instrument approaches are straight-in approaches.

Non-back-driven sidesticks is a potential problem in certain fly-by-wire airplanes which do not have built-in feedback for one pilot to recognize if the other pilot is making control inputs. In some situations, the pilot flying may not realize that the pilot not flying is making control inputs and, as a result, loses aircraft state information.

Outside-in pilot background and inside-out instruments is the situation where the pilot who was trained on eastern European aircraft with moving aircraft-attitude indicators is flying a western built aircraft with a moving-horizon attitude indicator. This is a relatively rare situation outside of Eastern Europe.

Pilot attempts to "help" the autopilot were a problem in the 1980s and 1990s. These no longer seem to be a significant issue.

Pitot-static confusion[17] happens when one or more pitot tubes are blocked or when one or more static ports are blocked. In either case, the indicated airspeed or altimeter may behave in apparently strange ways. A relatively common effect is a blocked pitot tube, which will indicate a low reading, but will increase as the aircraft climbs. In many airplanes, the problem is compounded with arcane warnings. The result is often confusion on the part of the pilot about what the airplane is doing.

The annual number of SD mishaps appears to be increasing. This is a surprising finding in view of the overall reduction of aviation mishaps in general and should be investigated further.

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