Reducing the Threat of the Somatogravic Illusion.

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Abstract.

Loss of control incidents, in particular those involving spatial disorientation make up a significant proportion of all aircraft accidents. Of these, the somatogravic illusion accounts for a considerable number having been cited as a causal factor in 7 large transport aircraft accident reports and 4 serious incidents since 1 Jan 2000, with the loss of 481 lives. All of these occurred in what is one of the most poorly performed phases of flight; the go-around. During in this period, there have also been 44 other documented cases of fatal accidents in all phases of flight, with the somatogravic illusion cited as a factor. Despite it having first been identified in the 1940s, there has been little change of the rate of somatogravic illusion accidents since. Being insidious in nature and nearly impossible to train for in the practical environment, it is still one of the most significant causes of lethal accidents in aviation. A reduction in the number of somatogravic illusion events could significantly improve fatal aircraft accident statistics. This paper analyses the current level of knowledge of this illusion amongst the pilot workforce based on a survey of 585 professional pilots from airlines, general aviation and the military. It identifies deficiencies in pilot-training, operating procedures and aircraft design, while making recommendations to resolve these shortcomings.

Keywords: Spatial Disorientation; Somatogravic Illusion; Vestibular System; Go-Around; Aircraft Accident.

Contents

Glossary of Acronyms and Abbreviations.

AI	Attitude Indicator
AP	Auto Pilot
ASAGA	Aeroplane State Awareness during Go-Around (Study, France)
ATPL	Air Transport Pilot’s Licence
ATSB	Australian Bureau of Transport Safety
BASI	Bureau of Air Safety Investigation (Australia)
BEA	Bureau d'Enquêtes et d'Analyses (France)
CAA	Civil Aviation Authority (UK)
CASA	Civil Aviation and Safety Authority (Australia)
CNS	Central Nervous System
CPL	Commercial Pilot’s Licence
EASA	European Aviation Safety Agency
FAA	Federal Aviation Agency (USA)
FD	Flight Director
FDR	Flight Data Recorder
FL	Flight Level
FMA	Flight Management-mode Annunciation
FMGS	Flight Guidance Management Computer
FMS	Flight Management System
fpm	Feet Per Minute
FSF	The Flight Safety Foundation
ft	Feet
FO	First Officer

g	Gravitational acceleration
GA	General Aviation
GPWS	Ground Proximity Warning System
HPL	Human Performance and Limitations
ICAO	International Council of Aircraft Operators
IF	Instrument Flight
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IRT	Instrument Rating Test
kn	Knots
MPL	Multi-pilot Pilot's Licence.
NASA	National Air and Space Agency (USA)
NATO	The North Atlantic Treaty Organisation
PF	Pilot Flying
PFD	Primary Flying Display
PM	Pilot Monitoring
RAF	Royal Air Force
SD	Spatial Disorientaion
SGI	The Somatogravic Illusion
STANAG	Standardisation Agreement (NATO)
USAF	United States Air Force
VMC	Visual Meterological Conditions
VSI	Vertical Speed Indicator

Introduction.

Spatial Disorientation (SD) is defined as *"a variety of incidents occurring in flight in which the pilot fails to sense correctly the position, motion or attitude of the aircraft or of him – or herself within the fixed coordinate system provided by the surface of the Earth and the gravitational vertical"* (Benson and Stott 2006 p433). The Somatogravic Illusion (SGI) is just one form of SD, the root cause of which is the incompatibility of the human vestibular system with accelerations experienced in aircraft operation. The somatogravic illusion is an incorrect perception of attitude due to the brain misinterpreting the gravito-inertial acceleration sensed by the vestibular system during prolonged linear acceleration; with reduced, absent or confused visual and proprioceptive information.

The human body evolved to cope with breaking into a run from standing still in a matter of a few seconds; not for the extended acceleration that can be achieved by mechanised transport. Periods of acceleration greater than this can lead to a pilot experiencing SGI. Whereas other forms of SD such as the leans and somatogyral illusion (Newman 2007 p7) may be physically demonstrated both on the ground and in the air, the conditions which may lead to SGI are very difficult to replicate, which makes training to counter it problematic. The numbers of accident reports which identify SGI as a causal factor indicate that current training is far from effective and it remains a significant threat to flight safety, particularly as it is often unrecognised.

Although SGI has previously been considered as human error with accidents where it has been attributed as a causal factor sometimes being categorised as pilot error, SGI should more accurately be described as a human limitation.

This paper evaluates the current level of knowledge of SGI amongst pilots, seeks to examine and identify current training deficiencies, identifies contributory and mitigating factors and makes recommendations to counter the threat of SGI through regulation, training, procedures and aircraft design. The paper also makes recommendations for further research.

The Somatogravic Illusion.

The vestibular system in each inner ear has five gravity and motion sensors. Three semi-circular canals detect angular acceleration while the saccule and utricle sense linear acceleration, including gravitational acceleration. Linear acceleration is detected by the otolith organs, grains of calcium carbonate suspended on a gelatinous mass. Any movement of this mass through tilt or inertia is sensed by hairs embedded in this mass, connected to nerve endings. If the head is accelerated, the resultant signal is processed by the Central Nervous System (CNS) by comparing it with the signals from the semi-circular canals (Anglaiki *et al* 2001) and proprioceptive sensors (Guyton 1956 p579), and low-pass filtered to differentiate acceleration from tilt (Correia Gracio 2013 p157). The time constant of this processing has been determined at around two seconds (Correia Gracio *et al* 2013 p224), after which, the CNS may incorrectly interpret the information as tilt in the absence of corroborating visual or proprioceptive inputs, leading to the an incorrect perception of gravito-inertial acceleration.

Proprioception is defined as *"the ability to sense stimuli arising within the body regarding position, motion, and equilibrium"* (Medicinenet 2016) and is what pilots may refer to as the *"seat of the pants"* sensations.

The somatogravic illusion is a particular threat to pilots when accelerating in the anterior/posterior (longitudinal) plane. During the take-off or go-around phases; a pilot lacking visual clues in Instrument Meteorological Conditions (IMC) or at night, may have an impression that they are pitching up and climbing too steeply should any period of longitudinal acceleration last more than about two seconds. This may induce them to counter the sensation by lowering the pitch attitude. This is illustrated by the following account from one of the respondents of the survey conducted as a part of this paper.

> *"The Captain, acting as PF lowered the nose to accelerate to S (Slat retract) speed, and on passing S, I retracted the Slats as instructed, but noticed the PM had selected a lower nose down attitude than required and was not following the FD [Flight Director] commands. The aircraft accelerated rapidly and the PF continued to lower the attitude. As we levelled off, I called "Attitude!" but he continued to push and we started to descend"* (Survey respondent 39).

Descent as a result of this illusion (SGI) has resulted in impact with the surface during these critical phases of flight (Bahrain 2002, CIS 2006, Libya 2013, CIS 2015-1, CIS 2015-2, Laos 2015 and CIS 2016). The reverse is also possible with pilots receiving a false impression that they are pitching down on deceleration, although accidents as a result of this are less common (Canada 2013).

The magnitude of the pitch illusion as a result of acceleration can be determined. An increase of 30kn over 10 seconds will generate a lateral acceleration of 0.16g, which will incline the perceived gravitational acceleration aft by 9 degrees. If the climb angle is less than 9 degrees, any counter control input may result in the aircraft descending (Davis *et al*, 2008 p177 and Zupan *et al* 2002).

It is estimated that about 80% of human orientation information is provided visually, with vestibular and proprioceptive senses providing roughly 10% each (Newman 2014 p52). In the absence of visual information, the CNS may default to the other senses. However, it appears that it is not necessarily correct to assume the inputs are processed separately, or that one will take precedence. Each may be providing information which is interpreted to reinforce a false impression from the other. This is illustrated by this respondent to the survey

> *"I lifted off, retracted the gear and flaps and held the climb attitude to accelerate to the climb speed of 220kn. But something felt wrong – it seemed that I was climbing steeper and steeper. I started to ease the nose down. The conflicting nose down indication of the Attitude Indicator seemed irrelevant– I was climbing – I was sure of that fact! My senses now told me that I was in a near vertical climb and I was convinced that all the forces of gravity were being taken on my back confirming the sensation"* (Survey respondent 1).

It appears that the combined outputs of the vestibular and proprioceptive sensors have the potential to be misinterpreted, with the potential for catastrophic results.

The History of Somatogravic Illusion Awareness.

The Somatogravic Illusion was first identified in 1946 as a result of the large number of aircraft accidents while taking off on dark nights during World War 2 black-out conditions (Collar 1949). This study explained the phenomenon, but the message was not fully taken on board, as many of the accidents involved piston powered aircraft and the report was published as jet fighters were introduced. It was incorrectly assumed that SGI induced accidents were more likely with high performance aircraft, for example, catapult launches of fighter jets at sea. However, SGI accidents continued to occur to all types. In 1965, the crash of a Vickers Vanguard at London Heathrow during a go-around resulted in the first hard evidence of SGI through information captured by a Flight Data Recorder (FDR). SGI wasn't identified as a factor in the accident report (ICAO 1969 p70), only subsequently (Benson and Stott 2006 p445).

In 1985, the publication of a report into the crash of a Canberra taking off from Gibraltar identified SGI as a causal factor and recommended the dangers of disorientation, including SGI be given extra emphasis to RAF pilots (RAF 1985). The author remembers being lectured on it during his aviation medicine course prior to his RAF basic flying training in 1985 with specific reference to the Vanguard accident.

In 1986, ICAO recognised the need for Flight Safety and Human Factors training and a series of Human Factors Digests were published with Number 3 in 1991 detailing the knowledge requirements of SD and vestibular illusions (ICAO 1991). The ICAO Human Performance Limitations (HPL) syllabus was introduced in 1998 (ICAO 1998), although some aviation authorities such as CASA in Australia and the CAA in the UK had already included HPL training. However, this does not mean pilots were not being trained against the SGI threat prior to this initiative.

> *"I did my training in 1981 and Human Performance was not part of the exam syllabus. However, the threat of the somatogravic illusion was drummed into us during night training due to the big threat of it operating from remote airfields in Australia. I subsequently took a Human Performance exam when I came to work for a Hong Kong airline in 1997".* (Survey respondent 558).

Australia has a particular problem with SGI with many remotely located airfields and visual night operations conducted in areas where there is little, or no ground lighting - conditions similar to those prompting Collar's 1946 research. The Bureau of Air Safety Investigation (BASI) had been addressed the problem of SGI by highlighting the problem to pilots. This information initiative started in 1995 with the publication of the document *"Dark Night Take-offs in Australia*" (BASI 1995) and has continued with information leaflets and newsletters warning about SGI in other documents (ATSB 2012 and 2013).

In Canada, Transport Canada has conducted a similar on-going information campaign with newsletters (Canada 2013) and quizzes (Canada 2016), and a detailed analysis in a video into a SGI accident (Canada 1991). India has also published a circular aiming to educate pilots about the dangers of SD (India 2011).

The Flight Safety Foundation (FSF) has made operators aware of SGI for many years (FSF 1997 and 1999 p38). More recently, other aviation authorities have produced documents to promote SGI awareness (FAA 2015) and at least one is considering new regulation for training (EASA 2015). Some operators have made efforts to publicise SGI with articles in their safety magazines, such as Dragonair in Hong Kong (Ludlow 2013) and Air India (Kulkarni *et al* 2016), and operational notices (Virgin Australia 2015). Military operators frequently make reference to SGI in their periodicals (Stevenson and Cutler 2013 p16, and Yeo 2010 p21).

An Assessment of Somatogravic Illusion Knowledge amongst Pilots.

As a part of this paper, a survey of 585 working and retired professional pilots was conducted over 6 months to determine the current level of knowledge of SGI. Of these, 485 (83%) were airline pilots, 53 (9%) were from General Aviation (GA) and 47 (8%) were serving military pilots. Of the total, 239 (41%) received their training in GA, pilots trained in the military accounted for 203 (35%), and 143 (24%) received their training as part of an airline cadet scheme.

The experience level of the survey sample group varied from 250 to 30,000 hours, the mean experience was 10,165 hours. The group received their navigation technical subjects training between 1971 and 2014. However, 37 had not taken a minimum of Commercial Pilot's Licence (CPL) level exams, mostly serving military pilots.

Of the group, 71% stated they had experienced SD in their career and 41% considered they had experienced SGI. The number of military trained pilots who considered they had experienced SD was higher at 86% and 57% for SGI. This could be attributed to military pilots having been exposed to SGI as a function of the type of flying they had experienced, or it could be as a result of being more aware of SGI. These figures are not dissimilar to a survey conducted in 2001 of 752 UK military pilots and navigators where 34% said they had experienced a false sensation of pitching up, and 28%

of pitching down (Holmes *et al* 2002), and a survey of 2582 USAF aviators taken in 2002 where it was found that 44% and 37% respectively had said they had experienced the same sensations (Matthews *et al* 2002).

Of the group, 14% said they had not heard of SGI, and 24% considered they did not have a working knowledge of it. Comparing civilian trained pilots, both from GA and cadet schemes with their military counterparts, SGI knowledge was much higher amongst military trained pilots. The number of civilian trained pilots who said they didn't understand SGI was 31%, compared with 12% of military trained pilots.

The proportion of pilots who do not have a working knowledge of SGI remains constant at about 23% up until the 15,000 hour total experience point. From there up until 20,000 hours it increases to 26%, and after 20,000 hours, it rises to 52%. Although the number of pilots surveyed with this level of experience is small, it does highlight that higher time pilots who did their initial training before HPL became mandatory may lack SGI knowledge. It appears that there are some pilots who have never received training in SGI, as demonstrated by the following comments:

> *"I had learned about it [SGI] from my human performance course during my ATPL studies some fifteen years earlier, but this was the first time I had experienced it myself. I subsequently mentioned it to the Captain and he had never heard of it, having trained before human performance was part of the syllabus"* (Survey respondent 39).

And from a pilot who had trained in an airline cadet scheme in the 1970s and is currently a B777 captain:

> *"I have no idea what you're talking about, I have never heard of it"* (Survey respondent 519).

Of the total, 29% of the pilots either did not, or do not recall taking a HPL exam, although 26 of these are the current military pilots who have not done CPL exams. Of those trained before 1995 when HPL exams were becoming commonplace, 41% have no recollection of HPL training compared with 13% who trained after 1995.

It should be noted that pilots who have converted a licence from one aviation authority to another's will usually have to take a HPL exam on conversion if they cannot provide evidence that they have previously achieved a pass in the subject. This is the case in Hong Kong, where since 1995; pilots are required to have passed HPL.

> *"I took my ATPL [Air Transport Pilot's Licence] exams in the UK in 1986 and the syllabus didn't cover the topic. However, I later converted my UK ATPL to a Hong Kong one and I was required to take the human performance exam as I hadn't taken one previously"* (Survey respondent 496).

In comparison with the survey conducted for this study, France's Bureau d'Enquêtes et d'Analyses (BEA) in their Study on Aeroplane State Awareness during Go Around (ASAGA) surveyed 831 pilots, mainly from France but with some from the UK, concluding in the section regarding SGI that;

> *"Few pilots are aware of it and do not know the difference between the pitch perceived during a go-around and the actual pitch of the aeroplane can sometimes reach values of up to 15 degrees, but also that significantly positive pitch may be experienced while the true aeroplane pitch is negative"* (BEA 2013 p128).

The exact number is not stated, nor is it known if this means that the pilots surveyed did not know about SGI, or if they were unaware of it during the go-around. The ASAGA study does not make this distinction. It appears from the survey conducted for this paper that knowledge of SGI, although incomplete, is better than attributed to pilots by the ASAGA study.

Data from the survey and details of how it was conducted is included at Annex A.

Current Somatogravic Illusion Training.

Civilian Pilot Ground Training. All ICAO CPL/ATPL training syllabi have an element of SD training with at very least, a description of SGI. This may be taught in the classroom, read in the study notes or may also appear as questions in the student's practice examinations. But often, the resources allocated to the subject are relegated to the minimum to achieve a pass in the exam.

One study provider allocates just one paragraph of five lines to a description of SGI in their HPL study book of over 440 pages, with just one test question out of a total of 350 (Oxford 2009). Another dedicates one and a half pages to SGI with one diagram and a description of an accident (Bristol 2016). Another has a detailed description and with reference to an accident where SGI was a causal factor (Nordian 2016).

Testing is by written examinations using multi-choice questions. The European Aviation Safety Agency (EASA) HPL examination question database has a number of questions relating to SD with a number dedicated to SGI.

There are two problems with this training system. First, the HPL syllabus is large with information about SGI being reduced to little more than a simple description. The second is that candidates end up having to commit a large mass of information required to pass the exams to the medium term working memory, rather than the long term memory (Chase and Ericsson 1982). If skills are gained in this manner and there is no requirement to use them, they run the risk of becoming 'inert knowledge' and ineffective in a dynamic situation. (Dekker 2014 p99).

This is what three survey respondents had to say about the current HPL training.

> *"The technique I used to pass the exam was 'learn and dump' with much of the study being done the night before. I have no recollection of the syllabus content, let alone any coverage of spatial disorientation"* (Survey respondent 496).
>
> *"If I studied it [SGI] on my course, I will take your word for it. But I have no recollection of doing so"* (Survey respondent 252).
>
> "*I took my ATPL exams three years ago, but I don't recall anything about SGI in the syllabus or the exams"* (Survey respondent 501).

However, this is not always the case.

> *''During my training, I was "under the hood" for a night simulated IFR [Instrument Flight Rules] departure flying a Tobago. During the initial climb, I got a very strong sensation I was pitching up and kept on reducing the attitude. I knew from my ground-school and the*

> *night flying briefing what was happening and was able to counter the sensation by concentrating on flying the climb attit*ude'' (Survey respondent 154).

In addition, the questions themselves do not necessarily probe the level of the candidate's knowledge of SGI. For example, questions worded as such:

> *"Which part of the vestibular apparatus is responsible for the detection of linear acceleration?"*

And;

> *"Which force(s) affects the otoliths in the utriculus and sacculus?*

Test the candidate's knowledge of human physiology, but do not require an understanding of SGI to answer. The following question would be better:

> *"Linear acceleration in straight and level flight may give the illusion of what?"*

As it requires a working knowledge of the vestibular apparatus functions and their limitations.

A more effective question would be:

> *"A report into the crash of an A330 where the aircraft impacted the ground soon after going around at night in Instrument Meteorological Conditions (IMC) reported the pilots were influenced by the somatogravic illusion. What is the he cause and effect of this illusion?"*

The multiple choice answer would need to include an answer such as:

> *"The pilots suffered spatial disorientation leading them to believe that the acceleration they were experiencing was an increase in the pitch attitude, causing them to make incorrect control inputs"*

This would be more effective by testing the candidate's knowledge of the issue, and by being connected to an actual event. This essential information can be better committed to long term memory if, in the flying training phase it is included with an effective explanation for ensuring the climb attitude is maintained after take-off or during go-around. By this method, it then may become 'conditionalized knowledge' rather than latent knowledge with the pilot being able to apply techniques to mitigate the threat (Strube and Wender, 1993 p173). Although, this knowledge will certainly require periodic reinforcement through refresher training to be effective

The system of flight testing in the USA requires the examiner to verbally quiz the candidate on a number of topics. Questions relating to SGI features in both night and Instrument Flight (IF) test question banks; so the candidate can expect to have their knowledge of the subject probed prior to the flight test. This is a far more satisfactory method than a written examination, as instant feedback may be given by the examiner and the candidate debriefed, with any gaps in their knowledge immediately rectified. Whereas, a written examination will give no indication where the candidate's knowledge is deficient should they not achieve 100%. Feedback is rarely given in current multi-choice answer examination systems in order not to divulge the questions and answers in the bank.

Military Pilot Ground Training. Spatial Disorientation training in the military tends to be more thorough. Pilot aeromedical training for North Atlantic Treaty Organisation (NATO) members is directed by Standard NATO Agreement (STANAG) 3114 (NATO 2006) which details the knowledge the military pilot is expected to have. The majority of NATO air forces comply (NATO 2005).

In the UK, the trainee RAF pilot attends a week- long aeromedical course with an exam, and a training session in the Gyro 1 Integrated Physiological Trainer, a motion based SD training device which can demonstrate SGI (Daulby 1998). Aeromedical refresher courses are undertaken at no longer than 5 year intervals, as per STANAG 3114. This appears to be more effective than civilian training:

> "*I was trained in the RAF and the somatogravic illusion was a big topic during the aviation medical training. It was reinforced by a session in the Gyro 1 trainer. This was repeated every five years and I have always been very aware of the issue. I took the EASA human performance exam in 2013 and although the somatogravic illusion was included in the syllabus, it was poorly covered. I don't recall if it was tested in my exam"* (Survey respondent 555).

Other non-NATO air forces have similar programmes. For example, the Indian Air Force conducts a week long aviation medicine training course for ab-initio pilots with a two hour session in a disorientation training simulator (Baijal *et al* 2006), and the Republic of Singapore Air Force conduct a similar initial training scheme, with 3 yearly refreshers (Yeo 2010 p22).

Regular Simulator Training. Synthetic flight training devices utilising conventional hexapod Stewart platforms are not effective in replicating SGI because of the limitations imposed by the restricted travel of their actuators. They replicate longitudinal acceleration by pitching the pilot up while maintaining visual and instrument attitudes. They cannot realistically replicate SGI if the vestibular system is already being used to convince a pilot they are accelerating by utilising the mechanism which is responsible for the illusion in the first place (Ludlow 2013). Indeed, one study concludes that Stewart platforms are practically unusable for SD training (Kowalczuk *et al* 2002) and the ASAGA study concludes the main limitations of simulators is that they cannot correctly reproduce SGI (BEA 2013 p140).

A 2007 study into improving acceleration simulation using Stewart platforms found that pitching the pilot only accurately simulated acceleration if the subject observed a visual flow, with differences also being reported by the individual subjects (Berger *et al* 2007). As SGI is almost exclusively a non-visual phenomenon, this is particularly relevant when considering the employment of simulators for SGI training. However, ASAGA does make the recommendation that manufacturers of simulators in cooperation with aircraft manufacturers improve simulator fidelity with respect to SGI, especially during go-arounds (BEA 2013 p140). In response, the US Department of Transportation's Volpe National Transportation Systems Center in collaboration with NASA's Ames research facility has been investigating the simulation of SGI in Stewart platform simulators and report that the results look 'promising', and that two simulator manufacturers had expressed interest in their findings (Volpe 2016). However, another organisation tasked with research into simulating SD in hexapod devices reported whereas they had success with somatogyral events, it was still not possible to simulate SGI (Schulze *et al* 2016).

Specialised Simulator Training. Specialised SD simulators are almost exclusively the preserve of the military. At least two manufacturers produce dynamic training devices optimised for SD and such simulators are in service with at least 26 military forces around the world (AMST 2016 and ETC

2016). These vary from simple devices with 4 degrees of freedom to 6 axis simulators mounted on a centrifuge. Demonstrations of SGI are conducted on these (Daulby 1998, Yeo 2010 p22).

Flying Training. Many syllabi have some form of SD demonstration during the IF training phase. This invariably involves the instructor manoeuvring the aircraft with the pilot holding their eyes closed and being asked to describe the manoeuvre flown after the event. This is effective in emphasising that a pilot cannot rely on their vestibular and proprioceptive senses for orientation and only the instruments should be trusted. However, where SD effects such as the somatogyral illusion, otherwise known as the 'leans' or 'graveyard spiral' can be demonstrated adequately in airborne training, it is nearly impossible to replicate SGI. The FAA Handbook of Aeronautical Knowledge describes an IF training sequence which attempts to replicate SGI (FAA 2008 p1-8), but the author had no success with this in his experience of teaching IF and is not aware of any syllabus which currently includes it in basic training. Military training can successfully demonstrate SGI in flight and this usually involves a rapid acceleration at night and low level in a high performance fighter jet (Survey respondent 68 and report from a F4 Phantom pilot).

The only effective training for SGI available in the flying phase is a comprehensive briefing given to the student before the IF and night phases of their training, with sufficient emphasis on the importance of maintaining the climb attitude with reference to instruments after take-off or go-around and an explanation of the consequences of getting it wrong. References to the student's ground training, and/or real incidents can reinforce the lesson as highlighted by one pilot.

> *"I was told to make sure I maintained the climb on take-off at night or in IMC, but this information was not linked to any knowledge gained in the ground syllabus. If it had been, it would make much more sense"* (Survey respondent 501).

Recurrent training. Knowledge gained in training about an event which a pilot may encounter only occasionally - if at all - over their career, can only be effective if it is refreshed periodically. The NATO requirement for refresher training at least every 5 years appears to be effective; there is currently no equivalent requirement in civilian regulations. However, after an accident to an ATR72 in 2013 where SGI was cited as a causal factor, the Aircraft Accident Investigation Committee of the Lao People's Democratic Republic made the recommendation the operator included the effects of the SGI in its flight crew training (Laos 2015).

The FAA have issued a Safety Alert for Operators (SAFO) encouraging operators to warn pilots of the possibility of encountering the SGI during the go-around, and its potential consequences (FAA 2105), has also issued a safety brochure (FAA 2106). EASA has issued a rulemaking task for the loss of control or loss of flight path during go-around, or other phases. This is based on the BEA's ASAGA study (BEA 2013), but the issued terms of reference concentrates on aircraft design, with the limiting of thrust and elevator pitch trim inputs rather than pilot training (EASA 2015).

Factors Contributing to the Somatogravic Illusion.

Fatigue. This is frequently cited as a contributory factor in SD incidents (CIS 2002, CIS 2015, ICAO 1969, Libya 2013, Switzerland 2002 and CIS 2016). More than one survey respondent has mentioned fatigue as a factor in their SD experiences. As many SGI events occur at night, which often coincides with the end of a crew's duty, it appears that these events may be partially attributed to fatigue.

> *"Flying a light twin as a single pilot, it was 1am and the 5th sector of the day doing a 'Bank Run'. Departing from Launceston, Tasmania over a large unlit area, I was used to such departures and was well versed in the need to maintain the climb attitude. However, on this trip, fatigued and losing concentration, I lapsed and let the aircraft descent after departure in response to a strong sensation that I was climbing too rapidly. Luckily, I caught the descent and woke myself up sufficiently to continue the climb safely"* (Survey respondent 143).

Fatigue can lead to a reduction in performance which in itself may make the pilot more susceptible to SD events.

> *"On a night take-off in a Piper Saratoga in the initial climb, I started a turn to the right through about 150 degrees to get on track. I was surprised to see the only lights in the area, from the hangar area at the airport high in the windscreen; in other words – not where they should be! It was clear to me that I had entered a descent and I was about to impact the ground. This was the third sector in that work period; I was fatigued and had neglected my instrument scan."* (Survey respondent 377).

However, a 2007 study concluded the effect of sleep deprivation on SD was mostly non-significant in a sample group of 10 USAF pilots over 10 profiles flown in a simulator over a period of 28 hours (Previc *et al* 2007). It mentioned that the results were *"somewhat surprising*" and could offer no explanation.

Pilot experience and Age. It could be expected that with more experience, pilots are less susceptible to SD. However, this appears not to be the case. A review of SGI accidents since 1 Jan 2000 shows pilot experience ranging from 135 to 27,000 hours flying time logged (Annex C). Australia's BASI found the range of experience for 18 pilots involved in dark night take off accidents ranged from 189 to 19,006 hours, and the majority of them held instrument ratings, concluding that *''low time, inexperienced pilots are no more susceptible to factors in dark-night take-off accidents than more experienced crews"*. It did note that there was a higher proportion of pilots aged less than 30 years old in the sample group, but did not think this particularly relevant due to the small survey population (BASI 1995 p19). However, a study of UK military helicopter crews from 1992 concluded that younger pilots were more likely to rate their worst ever SD event as severe, which suggests that some desensitisation occurs with increasing experience. This is backed up by Previc *et al's* 2007 survey where it was noted that the age of the pilot was significant in that the older pilots were able to resolve SD conflicts, presumably because of their greater experience.

Instrument Scanning Failures. Failure to maintain a safe flight path is the cause of all SGI accidents, usually due to an ineffective instrument scan. This could be due to the primary Attitude Indicator (AI) not commanding sufficient attention because of poor design, as mentioned in the report into the Vanguard crash (ICAO 1969). In a Cessna Citation accident at Zurich in 2002, the report commented the FO, who was PF had a small mechanical AI compared to the Captain's larger electronic display (Switzerland 2002). It may be that the AI is poorly positioned. One survey respondent's account occurred when flying the Jet Provost which had a centrally mounted AI between the side by side seated pilots (Survey respondent 1). The need for IF to be conducted with the pilot's head turned towards the aircraft's centreline was a well-known limitation of the type.

It was stated at a recent conference about loss of control in flight that *"degraded instrument scanning is an opened door to SGI"* (de Courville 2012). de Courville highlighted that although attitude information has improved with the introduction of composite Primary Flying Displays (PFD) which include not only attitude information, but also performance information such as speed, altitude, vertical speed and heading, these parameters still need to be scanned in the classic 'T' scan to maintain the complete mental flight path picture. Distractions such as having to read the Flight Management Annunciations (FMAs), being distracted by the speed trend arrow increasing rapidly towards the red flaps limit band has a very powerful cognitive consequence which can disrupt the scan pattern, leading to less concentration on the all-important attitude. This was the case of a serious incident involving an A330 at Abidjan, Côte d'Ivoire in 2007 where after a level off over sea at night, the PF continued to pitch down after being distracted; the aircraft was subsequently recovered at an altitude of 600ft. Unfortunately, there is no incident report regarding this event as it was recorded only within the airline's own Safety Management System. However, an account of it is in de Courville's presentation (de Courville 2012).

After the stall of a B737 on go-around at Bournemouth Airport in 2007 due to the unnoticed disengagement of the AP and un-commanded pitch-up (AAIB 2009), the operator conducted a survey of its pilot workforce, tracking their eye movements in the simulator during go-arounds and discovered that often, their instrument scan was less than optimal, with pilots spending too much time concentrating on less important information. The ASAGA study conducted a similar survey in a simulator with 11 different crews conducting 3 go-around scenarios and noted that when the workload was high, there was significant attentional tunnelling with inappropriate lengths of attention being given to inconsequential information. Attention to the attitude by the PF was appropriate at the commencement of the go-around, but management of the procedure resulted in overly lengthy periods of attention on particularly the FMAs and the speed strip. The PM often concentrated more on the management items rather than the aircraft's flight path and rarely offered warning or advice on any flight path deviations by the PF. It was concluded that these performance lapses are frequently due to the unexpected nature of the go-around and the operational stress that it generates.

Factors Mitigating the Somatogravic Illusion.

Briefings: Where SGI is either a perceived or a known threat, briefing crews can be an effective mitigation in warning pilots. A RAF student pilot reported this:

> "*In the night flying briefing, my course had been warned extensively about SGI - especially using RAF Cranwell's Runway 27 as there were few lights off the end of that runway* " (Survey respondent 1).

This is a report form a GA pilot in Australia:

> *"I was used to such departures and was well versed in the need to maintain the climb attitude. However, on this trip, fatigued and loosing concentration, I lapsed and let the aircraft descent after departure in response to a strong sensation that I was climbing too rapidly. Luckily, I caught the descent and woke myself up sufficiently to continue the climb safely. As a mitigation strategy, this company's* documentation warned us where either the

> *somatogravic illusion or the 'black hole' effect was considered a threat."* (Survey respondent 143).

And a Royal Saudi Air Force F F15 pilot had this to report:

> *"It's something we are very aware of in our operation. Flying high performance fighters from desert airfields, the somatogravic illusion is a big threat and we brief the threat of spatial disorientation, including the somatogravic illusion regularly. It is also a threat during daylight in dusty conditions"* (Survey respondent 582).

Multi-pilot Operations: With more than one pilot on the flight deck, it can be assumed that there is an added level of protection from SGI. This appears to work in some cases:

> *"On a night take off from Runway 07R in Hong Kong with myself acting as PM, we entered cloud at about 1500ft, just as the Flight Mode Annunciator changed to 'Climb'. The Captain, acting as PF lowered the nose to accelerate to S (Slat retraction) speed, and on passing S, I retracted the Slats as instructed, but noticed the PF had selected a lower nose down attitude than required and was not following the FD commands. The aircraft accelerated rapidly and the PF continued to lower the attitude. When we levelled off, I said "Attitude!" But he continued to push and we started to descend. I then said, "We're descending", but with no response. At this point, I took control by selecting an AP [Autopilot] on; the aircraft followed the FD commands and started to climb"* (Survey respondent 39).

In one serious incident where SGI was stated as the cause, the PM took control, but only after two warnings from the PM that they were descending which were ignored by the PF who was convinced the aircraft was close to the stall, despite being nose down and at a speed of 245kn (Canada 2009). However, as the trigger for SGI is a physical process, it can affect both pilots equally, as described below:

> *"It was a departure to the North out of Shanghai Pudong airport which involved a track over the sea to depart to the South. It was a clear cloudless night, but very dark. Soon after getting airborne, we were cleared direct to waypoint NINAS some miles down track which involved a right turn through about 160 degrees. With the auto-pilot engaged, this was actioned through the FMC [Flight Management Computer] and at the same time we accelerated to 280kn. During the turn, the wind changed from a tailwind to a much stronger headwind as we climbed, and the auto-pilot pitched the aircraft up to maintain the speed. During this procedure and with the stars in the sky blending in with the lights used by Chinese fishing boats to attract their catch, I got disorientated with a strong sense that the aircraft had pitched up to a very high attitude. I forced myself to believe the attitude indication and with confirmation from the performance instruments, everything was as it should be with an attitude of about 13 degrees up. I checked with my colleague and he had the very same sensation. I know about the somatogravic illusion from my RAF training and immediately recognised it for what it was. Had the AP not been engaged then the automatic response to push forward could have been a very real threat."* (Survey respondent 470).

Both pilots being affected is reported in at least one accident where SGI was identified as a causal factor (Libya 2013). There is also a reduction in the defences from SGI if there is a strong cockpit gradient, or if low assertiveness from the PM is a factor. This appears to be the situation in the SGI attributed crash of an A320 in Bahrain in 2000 (Bahrain 2002).

Warning systems. The Ground Proximity Warning System (GPWS) has a mode which alerts the crew that they are descending after take-off or a go-around by issuing the audio warning *"Don't Sink!"* If this is ignored, other modes will warn of closure with terrain (Honeywell 2004). However, this system has two limitations. First, it has to have pre-set altitude parameters to prevent nuisance warnings and a descent as a result of the crew succumbing to SGI may commence above these values, thus delaying the warning. Second, as the *"Don't Sink!"* warning is audio only, the human brain when faced with multiple sensory inputs will tend to reject those it considers least important and ignore them. Described as "*inattentional deafness*", in high workload environments, it is often the hearing sense which is ignored first (Dehais *et al* 2012), or will be assessed as being unimportant (Novacek P2003).

A helicopter serious incident in the UK in 2012 had the aircraft nearly impacting the ground on approach in bad weather. Multiple GPWS warnings sounded, but neither pilot recalled hearing them (AAIB 2004). GPWS warnings were either not heard or ignored in SGI accidents, including the Bahrain A320 crash (Bahrain 2002) the crash of a CRJ200 at Almaty in 2013 (CIS 2015-1) and the crash of a B737 at Osh, Kyrgyzstan in 2015 (CIS 2016). GPWS is limited in that it is dependent on the pilot responding correctly (Stott 2013).

Auto-flight systems. These are a good defence as their attitude information is derived from gyroscopes as opposed to the human brain's perception of attitude. Use of the AP will result in the desired flight path, as long as the correct modes are in use.

An example of this is described by survey respondent 39 in the account under the multi-pilot operations paragraph on page 15, where the AP was selected in response to an undesired flight path. Had it been selected on prior to the aircraft entering IMC, then the threat would have been eliminated rather than corrected. Post-accident research carried out in a simulator after the crash of an A320 due to SGI at Sochi, Russia in 2006, concluded the accident would have not occurred had the FDs been followed, or the AP engaged (CIS 2006).

Somatogravic Illusion accident reports frequently feature manually flown departures and go-arounds (Bahrain 2002, CIS 2006, and CIS 2015-1). Protection afforded by auto-flight systems is lost if the AP is disengaged, either intentionally as in the crash of an A330 at Tripoli in 2010 Libya 2013); or unintentionally as in the case of a B737 crash at Kazan in 2013 where the AP automatically disengaged on initiation of the go-around; a fact not immediately recognised by the crew (CIS 2015-2). Circumstances which requires the aircraft to be flown manually after an automatic approach markedly increases the risk of a SGI event.

Engagement of an AP following a go-around from a manually flown approach is an effective defence strategy. However, this may not occur to a crew busy managing a missed approach. A survey of 67 airline pilots flying the same type revealed that 60% of them admitted to *"not using the auto-flight system when available and appropriate"* during go-arounds. (Li 2010).

If the crew are so strongly convinced the flight path flown by the auto-flight system is incorrect, they may be tempted to disconnect the AP and fly manually. In this situation, the defences against SGI are lost. Airbus have defined four 'Golden Rules', the fourth being *"Take action if things do not go as expected"* (Owens 2013). This is good advice, except when the pilot has an erroneous perception of the flight path. Despite best intentions, taking control of the aircraft from the auto-flight system could be a costly mistake. It needs to be emphasised that the main function of the auto-flight system is to alleviate high workloads.

Due to the imitations of auto-flight systems, the AP may need to be disengaged to enable an approach when the system may not cope. In January 2002, the commander of a B757 acting as PF while making an approach into Oslo Gardemoen Airport disconnected the AP to effect a more expeditious capture of the Instrument Landing System (ILS) glideslope from above, as the aircraft was high on the approach due to a late runway change and an un-noticed tailwind. The approach was never stabilised and a go-around initiated at 580ft. This was poorly handled due to an incorrectly set go-around altitude, the result was that the PF experienced SGI and initiated a manual pitch input which resulted in a 49 degree nose down attitude. The recovery resulted in a +3.59g load factor during which, the lowest radio altitude recorded was 321ft. Had the PF left the AP engaged and decided to cancel the approach earlier as they were outside the ILS capture parameters of the AP, this serious incident could have been avoided (AIBN 2003).

Conclusion.

Although the survey shows that SGI is understood by a majority of pilots, the situation where nearly a quarter of pilots have no practical working knowledge of it is far from satisfactory. Although SGI was identified 70 years ago, the full trend of accident and serious incidents attributed to it had not been fully appreciated, until the qualitative improvement of accident reporting in the last 15 years. The fact the trend shows there has been no improvement in the accident rates indicates that SGI knowledge is not complete. As the demand for air transport increases with a consequent requirement for new pilots, the number of accidents attributed to SGI will only rise unless there is a change in both initial and recurrent training. Current training can only warn pilots of the threat and hope they recognise it in time to prevent an undesired flight path into terrain. A practical and effective working knowledge of this human limitation through training, with the sensible use of effective automation in the right circumstances can have the potential to reduce the threat of SGI accidents.

Recommendations.

To Regulators.

● Initial spatial disorientation training should emphasise the situations where the somatogravic illusion is a threat, using real accident data as examples.

● Human Performance and Limitations examinations should include at least one question about the somatogravic illusion in every paper and the questions relate to specific circumstances in which the somatogravic illusion could be encountered.

● Universally distributed and constantly available publications warning of the threat of the somatogravic illusion should be made available to pilots, operators and training organisations.

● Mandate periodic Human Performance and Limitations refresher training to include spatial disorientation, particularly with regards to the somatogravic illusion.

To Operators.

● The auto-pilot should be engaged soon after take- off on departures at night, and/or poor visibility.

● If an approach is conducted at night and/or in poor visibility, the auto-pilot should remain engaged until the required visual references have been established and the landing clearance received.

● If going around at above minima, the manoeuvre should not be rushed and the use of less than full thrust should be considered. If the selection of full thrust is required to initiate the go-around, the selection of lower thrust should be considered as soon as it is safe to do so.

● Consideration should be given to flying go-arounds with the auto-pilot engaged. If the approach was flown manually, an auto-pilot should be engaged as soon as possible.

● If the approach is flown with the auto-pilot engaged, it should not be disengaged for a go-around.

● If the auto-pilot automatically disconnects on go-around with only one selected for the approach, the use of more than one auto-pilot on any approach in limited visibility and/or night, or any approach where a go-around is possible should be considered.

● The Pilot Monitoring should concentrate on monitoring the flight-path in the climb and go-around phases.

● The auto-pilot should be engaged if the pilot(s) sense the attitude is not the same as the one indicated..

To Air Traffic Control.

● Aircraft going around should be allowed to fly the published go-around profile without interruption, unless safety is compromised.

To Industry.

● Initiation of a go-around with automatic flight functions engaged should be one single pilot action engaging a dedicated go-around mode. It should not require the engagement of multiple modes.

● Flight directors must remain active after the initiation of a go-around. Flight Management should automatically switch to a lateral navigation mode which sequences the go-around track entered in the flight plan and simultaneously, a suitable vertical navigation mode.

● If the approach has been conducted without flight directors, they should turn on automatically on a go-around.

● Auto-pilots should not disconnect if a go-around is initiated. The facility to conduct a go-around with at least one auto-pilot engaged should be considered essential. If only one auto-pilot is engaged for the approach, it should not disengage on go-around initiation.

● Full thrust should not be required for a go-around. A reduced thrust or 'soft' go-around thrust setting should be available.

● Consider flight deck designs so that the primary flying display is directly in front of the pilot. It also needs suitably large and easy to interpret to command attention..

Future Research.

● Research is carried out into the improvement of warning systems to emphasise an undesired flight path, particularly in the go-around phase.

● Research is carried out to improve primary flying displays. This could take the form of an 'adaptive display' which reduces the information displayed to only that required to fly the aircraft on a safe flight path, and/or can reproduce a synthetic representation of the environment.

● Research is carried out into developing a cost-effective method of demonstrating the somatogravic illusion to airline pilots.

Curriculum Vitae.

The Author trained as a pilot in the RAF between 1985 and 1987. He subsequently flew the Victor in air-to-air refuelling operations before becoming a Qualified Flying Instructor in 1991. After 5 years of training RAF pilots on Chipmunk and Tucano aircraft, he returned to air-to-air refuelling flying the VC10 until 2001, during which time he was a Squadron executive and instructor. After leaving the RAF, a career in commercial flying has seen him operate the Boeing 747, both in passenger and freighter roles, and more recently, Airbus Fly By Wire types. He is currently a Captain with Hong Kong Dragon Airlines (Dragonair) as well as holding the post as Dragonair's Fleet Flight Safety Officer within the Cathay Pacific Group Safety Department. He is currently a part-time student at Cranfield University where he is studying for an MSc in Safety and Accident Investigation. He has logged over 14,000 hours of pilot flying time, has held gliding and civilian instructor ratings, and still regularly attempts to disorientate himself by flying aerobatics.

He became interested in the somatogravic illusion after experiencing it during his flying training and has been studying the phenomenon and its results in detail for the last four years. He has made it his task to inform pilots of what is essentially an 'untrainable' condition in response to a disturbing accident rate which shows no sign of reducing. In 2013, he wrote an article entitled "A fatal Illusion" which has been published in several flight safety magazines. This paper is the culmination of that work.

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Simon Ludlow, Hong Kong, November 2016.

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Annex A: The Spatial Disorientation Survey.

To assess the current level of knowledge of SGI, a survey was conducted between 17 Aug 2015 and 20 Mar 2016 with a sample base of 585 current and retired professional pilots. Dissemination of the survey was via electronic means, or by a paper form which differed from the electronic form by having a space for the respondent to voluntarily provide details of any SD event they had experienced. Some pilots were interviewed, with the interviewer completing either the paper or electronic form. Pilots asked to complete the electronic form were given the opportunity to provide SD event details by e-mail, and a number of interviewed pilots volunteered SD accounts which were written down by the interviewer with the interviewed pilots checking the accounts before publication. These are at Annex B.

Ethics. It was stressed that the survey was voluntary and that all information would be de-identified as much as was reasonably possible without degrading the data. Some pilots declined to participate. Verbal accounts taken by the interviewer were checked by the responding pilots for accuracy.

Survey Pilot Demographics. The sample group were a mix of pilots working in airlines, general aviation and the military. Care was taken to ensure that no one group predominated by distributing the survey via personal contacts, and by a request for participation on the British Airline Pilots Association (BALPA) website. The experience range was from just 250 hours to 30,000 and their training was undertaken between 1969 and 2015. Where it is known, the airline pilots were working in airlines in Australia, Canada, the EU, Hong, the PRC, Qatar, the UAE and the USA. The military pilots were from Hong Kong, Japan, Malaysia, Nigeria, Saudi Arabia, the UK and USA. Where it is known, the GA pilots from a mixture of employment in the corporate jet sector, flying instruction, glider towing and para-dropping. Some of these were working with Private Pilot Licences, as allowed by some regulators. Where it is known, the Civilian trained pilots came from cadet training programmes from Australia, New Zealand and the UK; and from GA in Australia, Canada, Europe, New Zealand, South Africa and the USA. And where it is known, the military trained pilots received their training in Australia, Belgium, Canada, France, Germany, Italy, Ireland, New Zealand, Saudi Arabia, Singapore, South Africa, the UK, and the USA.

Sample Group Choice. The sample group target was set at 500 responses. As well as paper forms being handed directly to the participants, the survey could also be completed electronically on a commercial survey website. Approximately 120 pilots were requested to complete the survey verbally with either paper or electronic forms being completed by the interviewer. Personal contacts of the author were invited to complete the survey privately via the internet or by interview. A link to the on-line survey was also posted on the BALPA website.

Survey Responses. Some 97 paper forms were used; the remaining 488 were completed electronically. Eighty four of the surveys were conducted as an interview, the results of these being recorded either on paper or electronically. Just 2 pilots declined to complete the paper survey forms, 22 started the electronic survey without completing it and 1 submitted an incomplete electronic form, from which it was not possible to extract valid data.

The Questions Asked. The survey was titled ‘Pilot Spatial Disorientation Survey’ to prevent the respondent being informed of the true nature; although this would be transparent to most on completion. Each respondent was asked 9 questions. The first four were designed to find out how many pilots had experienced SD and SGI and to gauge their knowledge of SGI. They were first asked if they had experienced SD while in control of an aircraft, then if they had heard of the SGI/pitch-up illusion, and then if they currently understood what SGI was. The fourth asked if they had experienced SGI while flying.

The next 5 questions were about their experience. Five and 6 were to find out under what system they had trained and where they were working now, or had last worked if no longer flying. Seven and 8 were to establish if their navigation subjects training syllabus (if taken) included a HPL paper (or equivalent) and when they had taken it. For the purposes of the survey, the date is relevant as it indicated if it was likely that HPL was included in the syllabus they studied. A date of 1995 was used as the demarcation, after which HPL was common in most syllabi. Question 9 asked approximately how many hours they had logged.

There were no questions asked as to when or what sort of flying during which they had experienced SD, but a number of pilots volunteered information. Pilots were encouraged to share their experiences of SD on a large blank box on the paper form, by e-mail on the electronic version and verbally during the interview. Fifty seven respondents chose to respond, but only 26 were relevant to the scope of this survey. All but three of these are reproduced in Annex B.

It was intentional to make the survey as short as possible to encourage participation. The average time taken to complete the survey on line was just 58 seconds.

Results analysis. The analysis was done using Microsoft Excel. The first and main aim of the survey was to find out how many pilots were aware of SGI. The secondary aim was to discover the training backgrounds of the pilots, and for those who had knowledge of SGI, to ascertain the source of that knowledge to highlight the lack of SGI knowledge and training deficiencies. The third aim was to gain an idea of how many pilots had experienced SD and SGI during their career.

Response Demographics. Of the 585 pilots surveyed, 485 (83%) were currently employed by an airline, 53 (9%) in GA and 47 (8%) in Military forces. The range of experience was between 250 and 30,000 hours, the mean total flying experience of the group was 10,165 hours.

Of the 585 pilots surveyed, 239 (41%) received their initial training in GA, 203 (35%) as a Military pilot and 143 (24%) as part of an airline cadet training scheme.

Pilot experience of SD/SGI. Of the total, 415 (71%) considered they had experienced some form of SD during their flying career. This question was not crucial to the survey but was used as a vehicle to start thinking about SD. In fact, nearly all pilots should have experienced SD, as a demonstration of SD forms a part of the majority of IF training syllabi. It is possible that some of the pilots considered that it the question related to real rather than demonstrated experiences. Of these 415 pilots, 237 (41% of all pilots) consider they have experienced SGI.

SD Survey results.

1. Pilots who have experienced SD: 415 (71%)

2. Pilots who don't know about SGI: 83 (14%)

3. Pilots who don't understand SGI: 143 (24%)

4. Pilots who have experienced SGI: 237 (41%)

5. Training: GA: 239 (41%) Cadet: 143 (24%) Military: 203 (35%)

6: Employment: GA: 53 (9%) Airline: 485 (83%) Military: 47 (8%)

7: Number of pilots trained up to 1994/don't know about SGI: 210/63 (30%)

Number of pilots trained post 1995/don't know about SGI: 338/69 (20%)

Number of current military pilots without CPL level Nav exams: 26 (55%)

Number of current GA pilots without CPL level Nav exams: 11 (21%)

Number of airline cadets who don't understand SGI: 44 (31%)

Number of military trained pilots who don't understand SGI: 24 (12%)

Number of civilian trained pilots who don't understand SGI 119 (31%)

Number of military trained pilots who have experienced SD/SGI: 174/113 (86%/57%)

Number of pilots who did not/do not recall taking a HPL exam. 168(29%)

Those of above trained prior to 1994/post 1995. 86/44

8: Hours demographics

Experience.	Number.	SD – Yes.	SGI – Yes.	SGI – don't know.
0 - 5,000:	156	114	59	38 (24%)
5,001 - 10,000:	149	105	64	33 (22%)
10,001 - 15,000:	171	121	75	37 (22%)
15,001- 20,000:	87	62	34	23 (26%)
20,001+:	21	11	4	11 (52%)

Annex B: Somatogravic Illusion Accounts.

Survey Respondent 1: Student RAF Jet Provost Pilot, RAF, event in 1986. It was my first night solo. I had completed two dual flights the night before and in the night flying briefing, my course had been warned extensively about the somatogravic illusion - especially using RAF Cranwell's Runway 27 as there were few lights off the end of that runway, and that how it had claimed the lives of at least a couple of pilots before.

On a dark almost moonless night taking off at about 11pm from 27 with many of the lights of the local farming community extinguished, and with the words of the briefing lost in the excitement, I powered up to take off. The runway edge lights went faster and faster and at about 80 knots I lifted off, retracted the gear and flaps and held the climb attitude to accelerate to the climb speed of 220 knots. But something felt wrong – it seemed that I was climbing steeper and steeper. I started to ease the nose down. The conflicting nose down indication of the Attitude Indicator (AI) seemed irrelevant at first – I was climbing – I was sure of that fact! But then, the words of warning from the briefing came to me and a quick confirmatory scan showed that I had levelled off and was now starting to descend. It took all my willpower to believe the AI and concentrate on the attitude – ignoring all the other instruments. My senses now told me that I was in a near vertical climb and I was convinced that all the forces of gravity were being taken on my back confirming the sensation.

By the time I had reached 220kn and stopped accelerating; the situation was beginning to make more sense as the lights of Lincolnshire came into view and I got the true attitude into perspective with my confused senses at last coming to reason. I enjoyed the rest of the flight thoroughly with no other strange sensations. During the post flight beers, I mentioned my experience to my fellow course mates and was not entirely surprised to hear three of them admit they had the same sensation. I have never suffered from this since. [This account is very similar to an incident involving a Macchi 336 taking off in Australia in the 1980s from survey respondent 66].

Survey Respondent 39: A320 First Officer, Hong Kong, event in 2011. On a night take off from Runway 07R in Hong Kong with myself acting as PM, we entered cloud at about 1500ft, just as the FMA changed to 'Climb'. The Captain, acting as PF lowered the nose to accelerate to S (Slat retract) speed, and on passing S, I retracted the Slats as instructed, but noticed the PF had selected a lower nose down attitude than required and was not following the Flight Director commands. The aircraft accelerated rapidly and the PF continued to lower the attitude. When we levelled off, I called "Attitude"; but he continued to push and we started to descend. I then said, *"We're descending!"*, but with no response. At this point, I took control by selecting an auto-pilot on; the aircraft followed the Flight Director commands and started to climb. It was not until talking to the airline's Flight Safety Officer that I realised the Captain was probably experiencing the somatogravic illusion. I had learned about it from my human performance course during my ATPL studies some fifteen years earlier, but this was the first time I had experienced it myself. I subsequently mentioned it to the Captain and he had never heard of it, having trained before human performance was part of the syllabus. We were an experienced crew with over 25,000 hours flying between us.

Survey Respondent 68: Tornado GR1/4 Pilot, North Sea, event in 1989. It was during the Tornado conversion training and a profile designed to show you how insidious spatial disorientation could be; so it was done at night over the North Sea with very little outside references. If I remember correctly we flew S&L at 2000ft then working down to 500ft, engaged reheat to accelerate to attack speed then pitch up to x degrees (45?) simulating a loft attack and then over bank to y (I think it was 135 degrees) and recover back to entry height in the direction from where you came (i.e. a 180 degree manoeuvre). I remember as you accelerated you had the pitch up sense and as you pitched up to x you felt like you were almost going up vertical and had to resist this strong sense to push nose down and trust the head up display - as you did with the leans, though this was a lot more extreme. [Two other very similar accounts from Tornado GR1/4 pilots were also received].

Account from a F4 Phantom Pilot in the 1980s (Not a survey respondent). The IRT [Instrument Rating Test] for the Phantom used to include a level acceleration from 250 to 550kts at 1000ft in full reheat. The 250-400kt portion was interesting, but at 400kts you started to get ram effect that was so noticeable you could physically feel the extra thrust kick in. The next 100kts took 5 seconds or thereabouts. The somatogravic illusion was huge: coupled with the large trim changes too, I never managed to stay completely level. I never saw anyone else succeed either!

Survey Respondent 121: A320 Captain, Hong Kong, event in 2009. It was a night VMC approach into Hong Kong runway 07R with me acting as PM to an experienced First Officer as PF. He had left configuration late and on passing 2000ft, was going to have to work hard to make the company's new stabilisation criteria at 1500ft. He requested gear down, then Flap 3, shortly followed by Flap Full and then for a new V App to be input into the FMGC [Flight Management Guidance Computer], soon after which I had to contact tower on a frequency change and complete the final items of the landing checklist. For this extended period, I was "heads down" while the aircraft decelerated rapidly. During the reading of the checklist, I had the overwhelming sensation that we had pitched to about 45 degrees nose down. I had to stop and look up, realising soon after that everything was OK and we were at the correct attitude for the approach. It was a very uncomfortable feeling, and had I not seen the runway lights just where they should be, I consider that it would have been very difficult to believe the attitude displayed by the Primary Flying Display.

Survey Respondent 143: GA pilot, Australia, event in 2011. Flying a light twin as a single pilot, it was 1am and the 5th sector of the day doing a 'Bank Run'. Departing from Launceston, Tasmania over a large unlit area, I was used to such departures and was well versed in the need to maintain the climb attitude. However, on this trip, fatigued and loosing concentration, I lapsed and let the aircraft descent after departure in response to a strong sensation that I was climbing too rapidly. Luckily, I caught the descent and woke myself up sufficiently to continue the climb safely. As a mitigation strategy, this company's documentation warned us where either the somatogravic illusion or "black hole" effect was considered a threat.

Survey Respondent 154: Airline Cadet Pilot, Adelaide, Australia, event in 2013. During my training, I was "under the hood" for a night simulated IFR departure flying a Tobago. During the initial climb, I got a very strong sensation I was pitching up and kept on reducing the pitch angle. I knew from my ground-school and the night flying briefing what was happening and was able to counter the sensation by concentrating on flying the climb attitude.

Survey Respondent 203: GAF Nomad pilot, Marshall Islands, event in 1983. I had just dropped some cargo off at the atoll island of Kili and was returning to Ebon with the non-pilot loadmaster who occupied the right seat. We departed over the sea towards a rain shower which was heading for the island. Soon after take-off, we entered heavy rain. I had not been concentrating on instrument flying as it was a VFR departure and I had not anticipated having to fly IF, so there was little planned transition to instruments. Soon after entering the rain, I saw white beneath the aircraft which at first I thought was cloud. However, I rapidly realised that it was surf breaking on the reef and it was just beneath the aircraft. I pulled up rapidly and climbed away safely. This was before HPL training and I had no idea what had happened to me until I read about the somatogravic illusion some years later. I had about 2500 hours at the time, mostly VFR flying in singles, so I had initially attributed it to my lack of experience.

Survey Respondent 236: Westwind Corporate Jet Pilot, Australia, event in 1996. The take-off was to the south at Alice Springs, over uninhabited desert. Just north of the airport is a ridge, which blocks light from the town, so when it is dark, it is very dark.

Added distraction was a rushed departure due to opposite direction inbound traffic (Alice Springs is a no-tower airport at night). At rotation the inbound was at about 1000' - so I was looking out of the window at its' (very bright) landing lights while turning right at quite low level, flying from the RHS.

The Captain noticed the descent, and called "Xxxx [expletive deleted] - pull up." When I glanced down I saw 1000fpm descent on the VSI and 50 feet (at bottom) on the rad alt on the pull up. It doesn't get any closer than that, I think.

Survey respondent 252: A320 First Officer, Trained in a cadet scheme in 2006. If I studied it [SGI] on my course, I will take your word for it. But I have no recollection of doing so and have never heard of it.

Survey Respondent 377: GA pilot, Australia, event in 1992. On a night take-off in a Piper Saratoga in the initial climb, I started a turn to the right through about 150 degrees to get on track. I was surprised to see the only lights in the area, from the hangar area at the airport high in the windscreen; in other words – not where they should be! It was clear to me that I had entered a descent and I was about to impact the ground. This was the third sector in that work period, I was fatigued and had neglected my instrument scan. If I hadn't initiated an early turn and seen the hangar lights, I would have become yet another one of Australia's dark night take-off statistics.

Survey Respondent 414: GA pilot, Australia, event in 1987. I had about 2000 hours and a brand new Grade 4 IR, which allowed night VFR flight, when I was taking off from a remote strip in Australia at night in a single piston aircraft. It had been working a long day, and due to inattention, my scan broke down on the departure. I found myself spiralling towards the ground. It scared the hell out of me and I had no idea what had caused me to lose control. So I went and read up disorientation to learn more about it as I had very little knowledge of it from my CPL studies, as Human Performance was not a part of the syllabus then. Since, I have converted my licence to another county's and had to take a HPL exam as there was not one in the exams I took in Australia. [Note: This is not a SGI case, but included to indicate the lack of training in older syllabi].

Survey Respondent 443: Airline Cadet Pilot, Hamilton, New Zealand, event in 2013. It was during night flying training. I had about 60 hours total time and was flying a C172 from Hamilton. While on a night solo, I had a very strong sensation of pitching up soon after take-off over a dark unlit area. I could remember the words of advice from my ground school and briefing and realised that I was suffering from a form of spatial disorientation. I concentrated on the AI, holding the attitude until the sensation passed, which was a short while after the acceleration had stopped.

Survey Respondent 470: A320 Captain, Shanghai – event in 2014. We were on a HSN [Radio Navigation Beacon] departure to the North out of Shanghai Pudong airport which involved a track over the sea to depart to the South. It was a clear cloudless night, but very dark. Soon after getting airborne, we were cleared direct to waypoint NINAS some miles down track which involved a right turn through about 160 degrees. With the AP engaged, this was actioned through the FMC and at the same time we accelerated to 280kn. During the turn, the wind changed from a tailwind to a much stronger headwind as we climbed, and the AP pitched the aircraft up to maintain the speed. During this procedure and with the stars in the sky blending in with the lights used by Chinese fishing boats to attract catch, I got disorientated with a strong sense that the aircraft had pitched up to a very high attitude. I forced myself to believe the attitude indication and with confirmation from the performance instruments, everything was as it should be with an attitude of about 13 degrees up. I checked with my colleague and he had the very same sensation. I know about the somatogravic illusion from my RAF training and immediately recognised it for what it was. Had the auto-pilot not been engaged then the natural response to push forward could have been a very real threat.

Survey Respondent 496: A330 Captain, Hong Kong. I remember spatial disorientation training from RAF pilot training. I took my ATPL exams in the UK in 1986 and the syllabus didn't cover the topic. However, I later converted my UK ATPL to a Hong Kong one and I was required to take the HPL exam as I hadn't taken one previously. The technique I used to pass the exam was 'learn and dump' with much of the study being done the night before. I have no recollection of the syllabus content, let alone any coverage of spatial disorientation.

Survey Respondent 501: A320 First Officer, Hong Kong, I took my ATPL exams three years ago, but I don't remember anything about the somatogravic illusion in the syllabus or exams. But I do recall that I was told to make sure I maintained the climb on take-off at night or in IMC, but this information was not linked to any knowledge gained in the ground syllabus. If it had been, it would make much more sense.

Survey Respondent 519: B777 Captain, Hong Kong. (Cadet trained at Hamble, UK in the 1970s): I have no idea what you're talking about, I have never heard of it [SGI].

Survey Respondent 535: A330 First Officer, Hong Kong. (Cadet – trained at Adelaide). I took my ATPL exams in 2004, but if there was anything about the somatogravic illusion, I don't remember it. I will have to take your word that it was in the syllabus. However, I do know about it having read an article in the company flight safety magazine two years ago.

Survey Respondent 555: A320 First Officer, Hong Kong. I was trained in the RAF and the somatogravic illusion was a big topic during the aviation medical training. It was reinforced by a session in the Gyro 1 trainer. This was repeated every five years and I have always been very aware of the issue. I too the EASA Human Factors exam in 2013 and although the somatogravic illusion was included in the syllabus, it was poorly covered. I don't recall if it was tested in my exam.

Survey Respondent 556: F18 Pilot – Over the sea off Australia, event in the 1980's. We were conducting a multi aircraft anti-ship attack over the sea at night. I was running in at 1000ft when we got the call to break off the attack and climb to FL350. Being young and exuberant, I decided to engage full re-heat and accelerate before pulling up. I had the sensation that I had done a half loop and was now flying inverted.

Survey Respondent 558: **GA pilot, Australia, event in 1988**. It was a departure from Lake Grace, WA in a Piper Arrow. The departure was over water with no surface lights. I turned onto track after take-off and very soon after got the sensation that things were not right. I caught it just in time, narrowly avoiding flying the aircraft into the lake. Not long after, a C172 did crash off this runway and the somatogravic illusion was considered the main cause. I did my training in 1981 and human performance was not part of the exam syllabus. However, the threat of the somatogravic illusion was drummed into us during night training due to the big threat of it operating from remote airfields in Australia. I subsequently took a human performance exam when I came to work for a Hong Kong airline in 1997.

Survey Respondent 577: A320 First Officer. Hong Kong. (MPL cadet –Trained in Melbourne, 2013). I remember being briefed on it carefully during ground school in Hong Kong on my MPL course. It was quite a while before we started the flying phase, but I did recall the lesson and remembered it

Survey Respondent 582: F15 Pilot, Royal Saudi Air Force. It's something we are very aware of in our operation. Flying high performance fighters from desert airfields, the somatogravic illusion is a big threat and we brief the threat of spatial disorientation, including the somatogravic illusion regularly. It is also a threat during daylight in dusty conditions.

Survey Respondent 585: A320 First Officer. Hong Kong. I have noticed that I don't have the same 'seat of the pants' skills that more experienced pilots have, particularly those who come from a GA background. They sometimes say "did you feel that?" when I felt nothing. I think pilots coming through the cadet system rely on instruments more as we have less visual flying experience than those with lots of GA flying time.

Annex C: Somatogravic Illusion Accidents and Serious Incidents from 1 January 2000 to 31 October 2016

Somatogravic Illusion accidents and serious incidents have been identified and recorded since 1942. However, the lack of information in the absence of satisfactory flight data makes the classification of SGI a very difficult task. Where pilots are available to provide evidence, this makes the task easier. But as the majority of accidents attributable to SGI are fatal to the pilots, this denies the most useful source of information to the accident investigator.

Accident reporting has improved markedly since the start of the 21st century with detailed Flight Data Recorder and Cockpit Voice Recorder analysis, detailed ICAO Annex 13 reporting and a greater knowledge and understanding of SGI amongst accident investigators. These factors define the point at which this list is compiled – although it must be noted that SGI events have been recorded for at least the last 70 years.

The following list of 56 SGI cases is derived from serious incident and accident reports where the SGI was identified as a causal factor in the subsequent investigation where reports have been published up to the release of this paper. It can by no means be considered as complete as there is limited data from countries where accident reports are not routinely published, or even conducted for that matter. Military accident data is scarce as reports are often classified, and rarely made public. And it is probable that some accidents for which there are no causes identified could be attributed to SGI. The author's experience as an airline's Flight Safety Officer leads him to believe that there are certainly a number of SGI incidents which are unknown because they simply have not been reported. Also, there is at least one accidents currently under investigation where it is highly likely that SGI will be identified as a causal factor.

Date	Type	Operation	Location	Conditions.	Phase	Pilot Hrs	A/SI	Fatal/POB
13 Jun 00	Falcon 20	Charter Freight	Peterborough, Ontario, Canada	Night IMC	GA	11800/2300	A	0/2
23 Aug 00	A320	Scheduled Pax	Bahrain	Night VMC	GA	4416/608	A	143/143
23 Dec 00	King Air	Charter Pax	Blackbushe, UK	Day IMC	Take Off	2664	A	5/5
04 Apr 01	F18	Military	At Sea	Night VMC	Deck T/O	n/k	A	1/1
24 Aug 01	Learjet 25	Charter Freight	Ithaca, NY, USA	Night IMC	Take Off	4826/3534	A	2/2
17 Sep 01	MiG 21	Military	India	Night VMC	Take Off	495	A	1/1
11 Oct 01	Metro	Medevac	Manitoba, Canada	Night IMC	GA	3100/1200	A	2/3
20 Dec 01	Citation 5	Charter	Zurich, Switzerland	Night IMC	Take Off	4738/1110	A	2/2
22 Jan 02	B757	Scheduled Pax	Oslo, Norway.	Day IMC	GA	8034/2485	SI	0/82
10 Feb 02	Cesena 182	Private	Cedar Key, FLA, USA	Night VMC	Take Off	1000	A	4/4
12 Dec 02	S76	Charter Pax	Trent Platform, North Sea.	Night VMC	Take Off	7305/ 1600	SI	0/10
08 Aug 03	Cesena 340	Charter Pax	Bishop, CA, USA	Night VMC	Take Off	1302	A	1/1
27 Sep 03	Cesena 182	Private	Concorde, MA, USA	Day IMC	GA	2600	A	2/2
29 Sep 03	Beech 35	Private	Belen, NM, USA	Night VMC	Take Off	n/k	A	1/1
22 Dec 03	Beech 58	Charter Pax	Missoula, MT, USA	Night IMC	Take Off	4850/2136	A	0/2
11 Jul 04	Cessna 172	Private	Paris, AK, USA	Night IMC	Take Off	600	A	2/2
30 Sep 05	PA 31	Charter Pax	Kasechewan, ONT, Canada	Night VMC	Take Off	1600/nk	A	0/8
03 May 06	A320	Scheduled Pax	Sochi, Russia	Night IMC	GA	5458/2185	A	113/113
14 Dec 06	Bell 406	Charter Pax	Dagesborough,DE, USA	Night VMC	Take Off	2800	A	2/2
24 Jan 07	Mirage 2000	Military	Gwailor, India	Night VMC	Take Off	n/k	A	1/1
30 Mar 07	A330	Scheduled Pax	Abidjan, Ivory Coast	Night VMC	GA	n/k	SI	0/ n/k
07 Jan 07	King Air	Medevac	Sandy Bay, Saskatoon, Canada	Night IMC	GA	8814/672	A	1/4
20 Nov 07	Mooney M20	Private	Binghampton, NY, USA	Day IMC	Take Off	1500	A	1/1
16 Jan 08	Beech 58	Charter	Cleveland, OH, USA	Night VMC	Take Off	18600	A	1/1
05 Mar 08	A310	Scheduled Pax	Quebec City, Canada	Night IMC	Take Off	n/k	SI	0/98
07 Jun 08	Cessna 206	Private	Cedar Key, FLA, USA	Night VMC	Take Off	n/k	A	3/3
21 Jun 08	Piper PA28	Private	Rockland, ME, USA	Day IMC	Take Off	500	A	1/1

Date	Type	Operation	Location	Conditions.	Phase	Pilot Hrs	A/SI	Fatal/POB
09 Aug 08	Bell 206	Charter	Yukon, Canada	Day VMC	Take Off	26000	A	1/1
26 Sep 08	Cesena 406	Charter Pax	Martha's Vineyard, USA	Night IMC	Take Off	16746	A	1/1
07 Nov 08	Piper PA 31	Private	Bathurst, NSW, Australia	Night VMC	Take Off	2099	A	4/4
18 Feb 09	Super Puma	Scheduled Pax	ETAP C Platform, North Sea	Night VMC	App	17200/1300	SI	0/18
23 Sep 09	Cessna 210	Private	Hilltop Lakes, TX, USA	Night VMC	GA	1276	A	1/1
12 Oct 09	PC9	Military	Connemara, Ireland.	Day IMC	Cruise	2523/120	A	2/2
21 Oct 09	PA23 Aztec	Private	Summerville, SC, USA	Night VMC	Take Off	4000	A	4/4
04 Nov 09	C172	Training.	Tallahassee, FL, USA	Night VMC	Take Off	1202/600	A	2/2
23 Sep 09	Cessna 182	Private	Kewanee, IL, USA	Night VMC	Take Off	2269	A	1/3
12 May 10	A330-200*	Scheduled Pax	Tripoli, Libiya	Night IMC	GA	17016/4216	A	103/104
17 Aug 10	AS350	Charter Pax	Sept Isles, Quebec, Canada	Day IMC	Cruise	235	A	4/4
18 Nov 10	F18	Military	Cold Lake, Alberta, Canada	Night IMC	Approach	473	A	0/1
02 Dec 10	DHC8A	Scheduled Pax	Svolvaer, Norway	Night VMC	Approach	n/k	SI	0/38
05 Feb 11	Cesena 310	Charter Pax	Bathurst, Australia	Night VMC	Take Off	1465	A	1/1
30 Mar 11	Beech 58	Charter Pax	Greensboro' NC, USA	Night IMC	Take Off	2884	A	2/2
27 Aug 11	R44	Private	St Ferdinand, Quebec, Canada	Night VMC	Take Off	879	A	4/4
30 Aug 11	PA28	Private	Provincetown, MA, USA	Night VMC	Take Off	340	A	1/2
21 May 12	Hughes 369	Crop-spraying	Lake Sumner, New Zealand	Day VMC	Take Off	3789	A	1/1
24 Aug 12	Bell 407	Charter Pax	South Holsten, VA, USA	Night VMC	Take Off	26000	A	1/1
15 Jan 13	Cesena 208	Charter Freight	Pelleston, MI, USA	Night VMC	Take off	1921	A	1/1
29 Jan 13	CRJ200	Scheduled Pax	Almaty, Kazakhstan.	Day IMC	GA	18194/3507	A	21/21
25 Mar 13	Cesena 210	Private	Roma, QLD, Australia	Night VMC	Take Off	6000	A	2/2
03 Aug 13	Cirrus SR22	Private	St Louis, MS, USA	Night IMC	Take Off	475	A	2/2
23 Aug 13	Super Puma	Scheduled Pax	Sumburgh, UK	Day IMC	Landing	10504/3060	A	4/18
23 Sep 13	C182	Training	Hamilton, Victoria, Aus.	Night VMC	GA	135	A	1/1
16 Oct 13	ATR 72	Scheduled Pax	Pakse, Laos	Day IMC	GA	5600/400	A	49/49
17 Nov 13	B737-500	Scheduled Pax	Kazan, Russia	Night IMC	GA	2500/2000	A	52/52
13 Mar 14	AW139	Private	Gillingham, Norfolk, UK	Night VMC	Take Off	2320/ 1187	A	4/4
13 Jun 14	PA46 Malibu	Private	White Plains, NY, USA	Day IMC	Take Off	5371	A	1/1
22 Nov 15	B737- 300	Scheduled Pax	Osh, Kazakhstan.	Day IMC	GA	10600/16400	A	0/153

*The report for this serious incident comes from the operator's own assessment from an internal safety report and was not formally investigated by an accident investigation system.