SWISS CHEESE

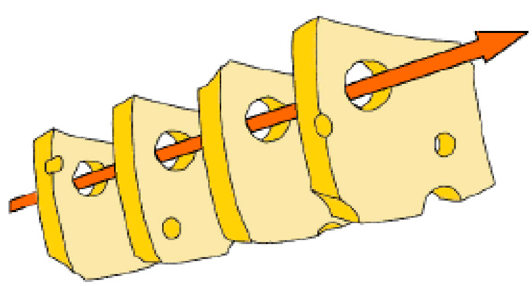
The BGA Safety Team looks at an astonishing accident that illustrates the importance of the management environment

THIRTEEN minutes after taking off from Birmingham on 10 June 1990, Malaga-bound flight BA 5390 suffered sudden decompression as the port cockpit window detached, ending up in the Thames Valley. Captain Tim Lancaster nearly followed it: he was partially sucked out of the windscreen aperture and, until the cabin crew reached him, was held only because his right leg was trapped by the control column [1]. As the BAC One-Eleven descended from 17,000ft to an emergency landing in Southampton, he spent the ensuing 20 minutes pinned by the slipstream to the cockpit exterior while a cabin steward gripped his ankles.

As he flailed in the airflow at speeds up to 340 knots, Lancaster was presumed by the crew to have died. Happily, despite arm, wrist and thumb fractures, bruising, frostbite and shock, he fully recovered and continued as an airline pilot for another 25 years.

Background

Shortly before the accident, the aircraft had entered British Airways' Birmingham engineering facility with reported bubbling and darkening of the port windscreen – signs that the laminated heating elements were overheating. The night maintenance team, which regularly had more work than it could complete, was especially short-handed, but the shift maintenance manager knew that the morning team was also depleted so he changed the windscreen himself. During a protracted search for bolts to replace the damaged and corroded originals, he mistook the bolt diameter, and fitted replacements that were 0.7mm narrower and 2.5mm too short. Since they were of the correct pitch, they partially engaged in the captive nuts and held until at 17,000ft they were overcome by the difference in pressure between the cabin and outside air.



An accident can only happen if the holes in successive slices line up

Contributory factors

The AAIB investigation found a number of factors without which the accident would not have occurred. Firstly, the aircraft was designed so that the windscreen was fitted from the outside, and thus relied upon the bolts to hold it in place against the pressure difference. Bolts of the same thread pitch came in two slightly different diameters, with no distinguishing markings. Bolts of different lengths were used for different windscreens on the same aircraft, and unclearly illustrated in the maintenance documents. Poor storekeeping meant that there were not enough bolts in the primary store so that the manager had to travel to a second store where weak lighting and faint labelling meant that he identified the bolts by feel and imperfect eyesight. The undersize bolts engaged in the captive nuts whose self-locking function required the threads to be formed out-of-round. The slipping of the threads when they were tightened felt the same as the action of the torque-limiting screwdriver. An inappropriate work platform and the need to hold the screwdriver with both hands prevented the shift maintenance manager from seeing the bolt while it was being tightened. Finally, the manufacturer judged the installation non-critical so an independent check was not required.

After the accident, the bolts removed from the damaged windscreen, although of the correct diameter, were also found to be too short – the shift maintenance manager had correctly matched the new bolts to the same length – and windscreens in two other aircraft of the BA fleet of 34 similarly turned out to be fitted with short bolts. In the second store, the labels on many drawers proved not to match their contents.

Swiss cheese model

The idea that accidents often require the coincidence of several contributory factors is illustrated by psychologist James Reason's 'Swiss cheese model' [2]. This compares each safety-enhancing 'defence' to a slice of Emmental cheese whose holes represent untrapped errors, so that an accident can only happen if the holes in successive slices line up. Holes will always occur, but well-designed safety systems ensure that other defences will block them. Bolt failure would thus be mitigated in flight if air pressure held the window in position; and independent checks can catch errors during maintenance.

Problems occur, to use Reason's analogy, when slices cut through the same bubble in

■ Clubs can obtain printed copies of Safety Briefings from the BGA Office.

HIS BEHAVIOUR WAS THAT OF ONE USED TO FINDING A DIFFERENCE BETWEEN THEORY AND REALITY

the cheese – that is, the vulnerabilities have a common origin. The manufacturer did not regard windscreen replacement as a critical task because if a single bolt failed others would take the load. Unfortunately, this was not the case if all the bolts were drawn from the same source. Another single cause was the use of the torque-limiting screwdriver, which disguised the sound of the threads slipping and obscured them visually.

Hot cheese analogy

Researchers studying how medical devices can be designed to avoid 'operator errors' have proposed a modification to the Swiss cheese model for when steps that should improve safety instead introduce new vulnerabilities [3]. The slices of cheese are stacked vertically and heated so that they drip new risks onto the slices below. The Birmingham windscreen would not have been lost if the old bolts had been refitted, but it was thought good practice (but not obligatory) to replace them with new parts.

Unintended consequences occur in gliding too. Alarms fitted to prevent wheels-up landings have distracted pilots from flying the glider; and an exercise intended to help pilots in the rare event of a parachute landing led to a fractured pelvis and broken arm when the inflated canopy dragged the trainee over the clubhouse.

Human factors

The AAIB report concluded that the shift maintenance manager showed inadequate care, poor trade practices, failure to adhere to company standards and the use of unsuitable equipment, symptomatic of a long-term disregard for procedures. Yet he was hardly an idle or sloppy worker. Other engineers regarded him as 'solid and careful', and his employer thought him exemplary – and had previously commended him on his work. He had arrived 45 minutes early to catch up with paperwork and organise the shift, and worked on administration over his sandwiches during the meal break. Although he had replaced six previous windscreens, he refreshed his memory by checking the maintenance manual before starting the task. A behavioural psychologist judged him to be 'conscientious but pragmatic rather than conscientious and meticulous'.

While the AAIB report notes several ways in which the shift maintenance manager deviated from expected procedures, it also indicates possible explanations. He set a higher torque than was specified because experience told him that many bolts would otherwise be left up to three turns loose. He disregarded the storeman's advice that longer bolts were needed because he was matching those removed from the aircraft. His reliance upon physical resemblance proved justified by the number of labelling errors in the second parts store. Similarly, when he spotted that the countersinks were bigger than the bolt heads, he interpreted it as imprecise machining. And when he used wider bolts to fit another aircraft windscreen the following night, he put the difference down to differences in modification state between the ageing aircraft. While these actions include several examples of confirmation bias, perhaps exacerbated by sleep deprivation and circadian effects on the first day of a night shift, his behaviour in each case was that of one used to finding a difference between theory and reality.

Latent conditions

Reason identified *latent conditions* that make mistakes more likely: poor design, gaps in supervision, undetected manufacturing defects or maintenance failures, unworkable procedures, clumsy automation, shortfalls in training, and less than adequate tools and equipment. Except for automation, all these conditions were apparent in this accident and were features of the organisation and environment beyond the control of the shift maintenance manager.

In addition, the psychologist noted that without regular external checks of working practices, equipment, knowledge and techniques, and with no training in quality assurance, the maintenance engineers were left a muddled impression of the company's priorities. While the area manager is said to have "continually stressed that there were other objectives besides maximising the work throughput", he recognised the pressures to produce aircraft, and it is likely that it was performance in this respect that made the maintenance team proud of its work record and earned its commendations.

In gliding clubs, too, there can be a perceived pressure to deliver, and accidents have ensued when aircraft have knowingly been flown with defective brakes, engines, radios or FLARM, and when the pilot was unfit or the conditions unsuitable.

It's essential for gliding safety that rules and procedures are practicable, their reasons are understood, facilities are adequate, priorities clear, and supervision effective.

Tim Freegarde and the BGA safety team

■ The BGA's *Managing Flying Risk* collects advice on good practice and can be found, along with *Laws and Rules* including *Operational Regulations*, on the BGA website [4].

[1] AAIB Accident report 1/92 G-BJRT (1992) *https://tinyurl.com/flyright2229*
[2] J Reason, *Managing the Risks of Organizational Accidents*, Ashgate. (1998)
[3] Y Li, H Thimbleby, J R Coll Physicians Edinb 44, 116 (2014) *https://tinyurl.com/flyright2230*
[4] BGA, *Laws and Rules* *https://tinyurl.com/flyright2231*

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