GASCo The General Aviation Safety Council

Jarvis Bagshaw Operational Safety & Human Performance

INVESTIGATION INTO THE HUMAN FACTORS EFFECTS OF ELECTRONIC CONSPICUITY DEVICES IN UK GENERAL AVIATION

RESEARCH AND GUIDANCE

For UK Civil Aviation Authority

Final Report

GASCo and Jarvis Bagshaw Ltd

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Abstract

Mid-air collisions are a serious threat in general aviation. Pilots are responsible for visual separation through see-and-avoid, but sighting issues remain the most common cause of Airprox events. Electronic Conspicuity (EC) devices have recently become common in GA and offer a means of supporting see-and-avoid. This research project reviewed the current literature and used a wide-ranging survey supported by a number of live-flights using eye-trackers to investigate the human factors issues related to the current EC situation.

Over 2000 survey responses were received (three quarters from pilots of fixed-wing GA aircraft <5700kg). About 85% reported using EC of some sort (over and above a standard transponder), many used two or more EC devices and there were seventy-nine different EC combinations in use by the sampled pilots. The overall mean chance of detecting and being detected was approximately 50% (based on the sample only) but highly variable across EC combinations. Due to limitations the real figure is almost certainly lower. Nevertheless, pilots over-estimate the probability by about 10 to 20%. They are generally more confident about being detected than about detecting others. Pilot estimates of probability were found to be unrelated to the calculated figures for their own combinations. This indicates a low understanding of detection and detectability likelihoods. This was reinforced by pilot opinions of fellow pilots; suggesting only 50% of pilots understand their devices.

Not only do pilots over-estimate the detection coverage of their EC, but many appear to use EC in a way that assumes complete coverage (despite knowing that it does not). On seeing an undetected aircraft, 43% admitted feeling negative emotion (including anger), suggesting an *unconscious* expectation of full coverage. Many pilots commented on the ‘false sense of security’ that EC can generate, and some comment on feelings of anxiety. Nevertheless, asked if they believed their device had saved them from a near-miss/collision, three-fifths of those who answered believed it had done so at least once.

Deeper analysis found that pilots are integrating EC more widely into the overall flying management task. Many pilots appear to use EC tactically and strategically to act, usually beyond visual range, to reduce future threats. Furthermore, some pilots report situations that imply that EC is factored into some risk-based decision making. Evidence of EC ‘reliance’ was also found, with some pilots saying they feel very uncomfortable flying without EC. The risk of this is clear where the probability of detecting other traffic on EC is only 50% on average.

The largest issue appears to be distraction by EC. Themes include distraction from the operational task priorities, unrealistic searches for EC targets, interacting with the device itself, information ‘overload’, and ‘nuisance’ or too many audio alerts (especially in busy and critical areas). Another distraction-related theme was general ‘head-down operation’ and a

deteriorating look-out habit. There is a concern around attention becoming systematically focussed on EC as a normal part of the overall task.

The survey results suggested a paradox in terms of EC safety and usability: EC appears to be least effective and most deleterious to the task in flight phases and situations where the mid-air collision risk is highest (confirmed by the literature review), such as when in busy areas (circuits, busy airspace, thermals, etc). Pilots report EC being overwhelming and distracting in these situations and many will ignore it (‘cry-wolf’ effect), switch it off, or even decide not to take it at all because of this. Hence in its current form EC is least effective (from a human factors perspective) in situations where it is most needed, and this will remain the case even if coverage and compatibility is substantially increased.

Live flying eye-tracking trials supported many elements of the analysis and uncovered several new themes. During trials, more non-EC visual targets were seen than aircraft showing on EC, confirming the compatibility problems. Visual lookout limitations were supported by the eye tracking (E.g. thorough active lookout in the direction of a threatening aircraft (unknown and non-EC) for several minutes failed to see the aircraft at all, despite ideal good conditions. Examples of active lookout were mapped and compared to EC cued-searching, demonstrating that EC-cued searching can restrict lookout considerably as emerged as a concern in the survey. Realistic visual range was confirmed to be about two miles, and up to three in perfect circumstances. The impact of a pilot conducting a visual search for an EC target well beyond visual range was clearly demonstrated to be a threat. Two trials showed examples of pilots resolving information from two aircraft (radio and EC) into one (a phenomenon termed ‘2-in-1’), and in one case concentrating on the EC aircraft at the expense of the other.

Recommendations are made in the form of draft guidance, practice and future research.

PART A - Background and Literature Review

Mid-air collisions are a serious threat in general aviation. Although rare, they still occur in UK airspace and are very often fatal. The primary means to avoid mid-air collision in uncontrolled airspace is ‘see-and-avoid’. This places the responsibility on pilots for their visual separation under the ‘rules of the air’. However sighting issues (described as failure to see traffic or a late sighting of traffic) remain the most common causes of Airprox events involving GA aircraft (CAA, 2021).

The limitations of see-and-avoid are well known. It has been well established that aircraft are extremely difficult to spot from other aircraft, and that converging aircraft are particularly challenging to see due to their constant position relative to each other. The limitations of the human visual and attentional systems are also well known. Physical limitations with the human eye include having only a very small arc of visual acuity, a focal length that ‘defaults’ to about one metre (empty field myopia), blind spots (areas without visual receptors on the retina), and others. Attentional issues include attentional thresholds that are not reached by gradually moving or growing objects, and ‘looking without seeing’ (pointing the eyes to an area but not perceiving the object of threat, due to attention being used by concurrent mental processes, other visual noise or clutter, ‘miss-expectation’, etc). As well as these and other human factors issues, there are environmental issues such as bright sun, background clutter, aircraft masking (e.g. by cockpit supports inside, clouds outside, etc), shadowing, poor transparencies and reflections, etc. In addition to all this, aircraft represent very small visual targets in a wide visual environment. They remain that way until extremely close, offering very little time to see and avoid a converging aircraft (see Figure 1 below).

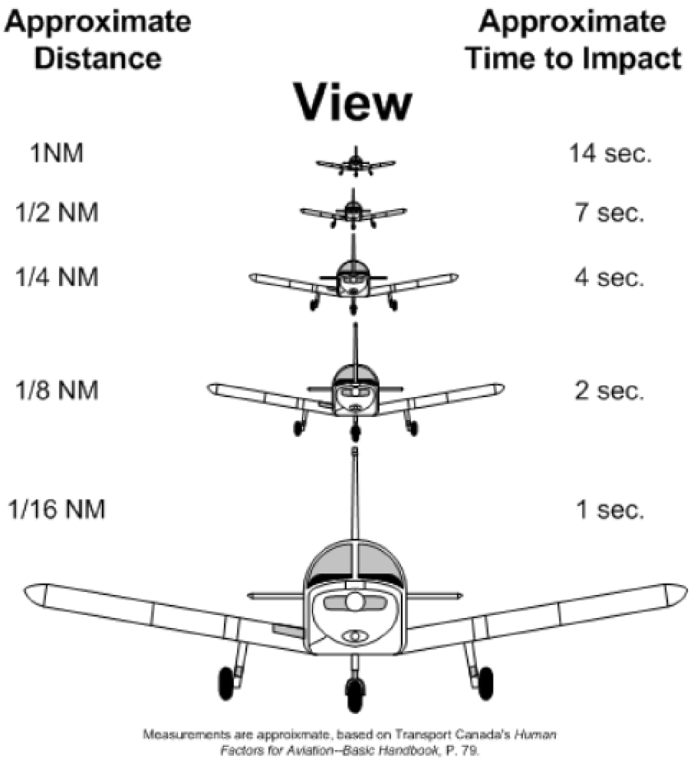


Figure 1. Closing aircraft appear very small until only seconds before impact (from Skybrary). For GA-sized aircraft approaching head on at ~120kts ground speed each.

Given all these limitations, inevitably there are many occasions where aircraft come into proximity without the pilots seeing each other's aircraft (or seeing them very late). In rare cases, this results in mid-air collisions, which continue to occur in UK general aviation.

Research from the US has found that mid-air collisions happen across all phases of flight, but most occur within three miles of the airport (most of those under 1000ft), and 39% (61 of the sample) happen in the approach phase (Taneja and Wiegmann 2001). Research from Morris (2005) supports this; 42% in the approach phase, 60% in the airport traffic pattern and 77% involving either take off, climb-out, descent for approach, traffic pattern or over/on the runway (Morris 2005).

The above figures should be unsurprising given that these are generally the busiest areas. For example, in the approach phase all aircraft landing at that airport must pass though the same narrow funnel (about 3 degrees from and in line with the runway centreline). This is more loosely true for other areas of the circuit but is still a factor; for example 19% of mid-air collisions happened in the downwind leg (Morris 2005). Hence only time (not proximity) creates the separation in such a phase. Nevertheless, a large number (42 of the sample; 27%) of accidents still happen in ‘cruise’ (Taneja and Wiegmann 2001) despite the random chance of a conflict in open airspace being lower for obvious reasons. It is also notable that only four collisions (just over 2%) occurred when visibility was five miles or less. Other research found that 67% of midair collisions occurred in clear sky (Morris 2005). Whereas these are US figures that might simply reflect activity patterns, they may also suggest that good weather and visibility are not factors in reducing the likelihood of midair collisions. Indeed it is possible that good VMC may be unhelpful in certain situations, for example where there is background clutter. Most midair collisions occurred between two fixed wing aircraft (85%) according to Morris (2005) but most combinations of fixed wing aeroplane, glider and rotary wing are represented in accident statistics.

Despite the limitations of ‘see and avoid’ (summarised earlier) pilot lookout is usually cited as the primary cause of mid-air collisions. This may or may not be fair. Nevertheless, many suggested ideas for improved scanning have been proposed over the last few decades in an effort to improve lookout and reduce mid-air collisions, including in GA and gliding. This is because pilot lookout is one of the few limitations in see-and-avoid that can be considered as being changeable. Some such advice is highly prescriptive in terms of cycling one’s visual resources (eyes and attention) through a range of internal and external areas. Two current examples are given by Skybrary (2023) below.

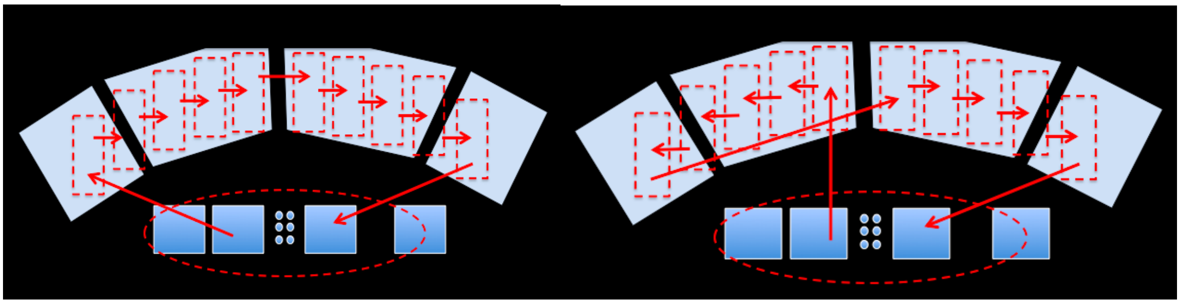


Figure 2. Side-to-side and front-to-side scanning techniques as proposed (Skybrary, 2023)

The advice may be worthwhile, if nothing else to remind pilots to scan the breadth of view whenever possible.

Even if this sort of scan were possible, Morris (2005) shows mathematically that given a theoretically optimal observer (i.e. a pilot with nothing else to do but scan for traffic, who always sees traffic when looking in that direction) scanning 10 degree sectors for 270 degrees horizontally for one second each (as recommended by FAA; 1983 advisory circular), is still not sufficient to assure avoidance, especially at higher closing speeds. Morris (2005) concludes that;

"…the see-and-avoid concept misleads pilots and controllers by encouraging overconfidence in visual scanning, while neglecting its inherent limitations and mitigation strategies"

If anything, Morris (2005) is understating the problem because in addition to his findings, the human factors of scanning means that it is unlikely that pilots would be able to continually repeat any such activity for any length of time (such as those in Figures 2 above). Jarvis (2017) found that in such monitoring tasks (vigilance tasks, akin to lookout) airline pilots do not continue to scan instruments in the prescribed way (sometimes not scanning at all). The reason can be explained in relation to the SEEV model (Wickens et al 2003, 2007) as the unconscious 'de-valuing' of expected information. This cannot be overridden by prescribing scan patterns to pilots.

In Taneja and Wiegmann's research (2001) 38% of pilots involved in midair collisions had less than one thousand hours whereas 25% had more than five thousand hours. Whereas this might hint at a pattern, comparative conclusions about pilot-experience differences can only be drawn by factoring in a measure of the amount of flying that each group undertakes (Jarvis and Harris 2007). This was not done. In any case, one thousand hours represents a high level of experience in GA pilots, so Taneja's and Wiegmann's data are not suggestive of a relationship between experience and midair collisions, and do not support inexperience as a factor. Jarvis and Harris (2008/2010) studied inexperienced glider pilot accidents and found no evidence that inexperienced pilots were more prone to mid-air collisions, despite very inexperienced pilots being far more vulnerable to accidents in general. The lack of a strongly evidenced link between pilot experience and midair collisions is unsurprising when it is considered that most factors limiting the success of 'see and avoid' are unrelated to practice and experience, and firmly related to the limitations of human vision, attention and the visual environment.

Pitts (1982) noted that visual acuity usually reaches 20/20 during the first year of life and remains relatively constant until 40 to 50 years of age. There was then a moderate but steady decline in acuity, particularly between 60 and 80. Factors influencing this loss of acuity are well known and include:

- **Presbyopia.** The ageing of the eye makes it more inflexible and so the ability to accommodate near detail becomes harder.
- **Cataracts.** It is estimated that one third of over-65-year-olds in the UK have some form of visually impairing cataract formation that reduces their visual acuity.
- **Reduced Pupil Sizes.** With age, the muscles controlling the pupils weaken. This causes the pupil to become smaller and less responsive to changes in ambient lighting. This can mean that older pilots find it harder to see things in low-light conditions or become dazzled in bright sunlight.
- **Reduced Peripheral Vision.** With age, peripheral vision reduces by ~1° to 3° per decade of life. By age 55, the average age of a UK GA Pilot, peripheral vision may have reduced by 10-15°, and by seventy-five closer to 30°. In younger adulthood, peripheral vision is about 180° horizontally and 110° vertically. By fifty-five this reduces to around 165° and ninety-five° and could be as low as 150°/80° by 70/80.
- **Age-related Macular Degeneration (AMD).** The health and condition of the retina also declines with age. This is normally first noticed in the late fifties and early sixties. The normal effect is a blurring of central vision.

Eye tests for pilot medicals help to detect these, but whilst there may be interventions (such as spectacles, surgical procedures and medications) that can help mitigate the effects, younger eyes will generally perform better than older ones.

It is now well established by valid live-flying research that the realistic visual detection of a standard light aircraft from another light aircraft is unlikely at ranges greater than two miles in daylight VMC. Strong valid research by Kephart RJ, Braasch MS (2010) found average visual detection of a Piper Saratoga from a Cessna 210 was 1.275 miles. Detection from an intercept was better than head-on (1.51 miles and 1.04 miles respectively). This would almost certainly be much less for smaller, less conspicuous aircraft such as gliders and microlights. Excellent research using live-flying trials in a Cessna 172 has convincingly shown that detection of drones (such as Iris or DJI Phantom quadcopters) in daylight VMC happens when range reduces to a tenth of a mile on average (Loffi et al 2016). This was found despite pilots being made aware of the drones’ presence. Even then, detection rates were only between 26% and 58% ranging across various drone presentations and courses, meaning that the drone was missed in over half the trials. Even a larger fixed-wing drone (Anaconda) showed a mean detection range of only 0.49 miles, with detection rates up to 84%. The situation is worse when the approach phase is investigated (a phase accounting for a substantial number of midair collisions). Trials undertaken in live experiments (Cessna 172 aircraft) found drone detection rates of only 30% using an intercept course on approach (Wallace et al 2019), with detections ranging from 213 feet to 2,324 feet. A static drone was seen on only three approaches out of twenty-two flown (13.6%) with mean detection range of only 747 feet.

The research projects mentioned above were conducted in good conditions, and these figures will change depending upon many factors including weather and visibility. In some cases, the detection range will be negligible (e.g. viewing an aircraft the direction of the sun). In other cases, depending upon many factors, there will be times when a pilot will be able to maintain visual contact with a known target considerably beyond such distances, or will see an aircraft at greater range (by lucky chance, a glint of light or strobe, a particular background contrast, etc). However, the live experiments were well conceived in order to give a valid estimate of the realistic ranges at which previously unknown aircraft could be noticed by pilots in the real world.

In summary, it is safe to assume that pilots flying purely VFR 'see-and-avoid' will usually remain unaware of unknown traffic until well within two miles proximity. Luck and good conditions will mean that pilots sometimes notice targets further away, but on many occasions the distance will be a lot less.

Factors such as closing speeds and angle of convergence will mean the time available for avoidance at the aforementioned distances will vary considerably. It has been found that 35% of mid-air collisions were 'head on' and the rest involve convergence (Taneja and Wiegmann, 2001). Many were found to involve over-taking aircraft. Given that visual acquisition is so limited (less than 1.5 miles in most cases), the opportunity to sight another aircraft is only available for a short period (perhaps 20 to 30 seconds at best when head on, given two relative slow aircraft and less than a minute if converging from 90 degrees). Given the well-known difficulties of seeing converging targets (static in the visual field), the narrow band of high visual acuity, and the chance that the pilot will not look in that precise direction, this is a very short period on which to rely. Arguably it is far too short, and so the chance of pilots noticing is not high.

Against this background, it is not surprising that the amount of 'pilot experience' has little correlation with midair collisions.

Given all the above, with the busy nature of UK airspace, it is sadly unsurprising that the UK continues to experience regular mid-air collisions between general aviation aircraft, as well as numerous airprox events. Furthermore, there is reason to believe that the situation could become worse still. The growth of uncrewed traffic such as autonomous passenger air vehicles and drones (CAA 2020, b) are set to make the UK skies much more congested and are already featuring increasingly in Airprox reports. Given the previously mentioned research by Loffi et al, 2016 (suggesting that smaller drones only become practically visible to GA pilots below 0.1m, assuming daylight VMC), this situation represents a serious future threat, particularly under see-and-avoid protocols.

The main proposed counter to this current and future risk is *Electronic Conspicuity* (EC).

Electronic Conspicuity (EC) is an umbrella term for a range of technologies that can help airspace users to be more aware of other aircraft in the same airspace (CAA, 2021). Also referred to with terms such as 'detect and avoid' (DDA), EC is growing quickly in the UK (see CAA, 2020,b). This has been driven by the CAA, manufacturers moving into the market space, and pilots keen to lower the risk of mid-air collisions and gain more perceived agency over the risk. The latter is an important factor that is easy to overlook. A US study found 78% of glider pilot respondents expressed the view that they were 'concerned' or 'very concerned' about mid-air collisions, with only 1.6% saying they were not at all concerned (Conliffe, 2013). Mid-air collisions are of concern (despite being far from the most common accident type) for many reasons, which might include:

1. Mid-air collisions are very often unescapably fatal.
2. Pilots know through experience that 'see-and-avoid' is limited and insufficient.
3. Low agency; such accidents include the activity of others, not under the pilot's control, as well as chance.

Pilots believe that the risk of mid-air collisions can be minimized by the use of anti-collision devices (Conliffe 2013). The UK CAA found that 89% of the GA pilots sampled believed that full electronic conspicuity would be beneficial to flight safety (CAA, 2020,a). Grote et al (2022) ran a pilot workshop and reported the firm belief among many UK GA pilots that detect-and-avoid is the only way to ensure de-confliction with drones. It is probable that EC also offers a perception of increased agency to pilots (i.e. offers them the potential to see all traffic and enable control over their own separation).

The UK CAA state that with the support of electronic conspicuity (EC) devices: "The aim is to change the axiom 'See and Avoid' to 'See, Be Seen and Avoid'" (CAA, 2020,b). It is undeniable that for most mid-air collisions involving unknown converging traffic, had either pilot become aware of the others' presence earlier (or at all), the event might have been avoided. This is the primary situation that EC aims to resolve, by supporting traffic visibility through electronic augmentation.

Currently (as of February 2023), EC in the UK is not universally mandated for GA aircraft using class-G airspace (CAA 2020,b, CAA 2021). Indeed, aircraft operating VFR in class-G (uncontrolled) airspace are not required to carry or use EC, radios or transponders, and not required to communicate with Air Traffic Control (CAA, 2021).

The CAA (in CAP 1391) outlines a recommended 'design brief' for EC including guidance on frequency, portability, weight and bulk, user-friendliness, alerting, antennae, power options, and much more. However, as the CAA point out, the biggest issue with the current situation is that the various EC devices cannot all talk to each other (CAA 2020,b). This is because many current systems are incompatible with others in terms of transmission and reception, meaning that no pilot can see *all* potential threats using any EC device (no matter how good or reliable that device is).

CAP 1391 calls for active coordination of development to achieve maximum interoperability (CAA, 2021) in the future, effectively meaning system compatibility in terms of detection. Nevertheless, at the time of writing there are a large number of different EC systems in use across UK airspace (CAA 2020,a). Some of these align closely with CAP 1391 specifications and some do not. No research has properly compared the merits of these in various situations (Grote et al, 2022) and different EC technologies have been adopted by various aviation communities. A UK CAA survey found that 44% of pilots use Mode S for electronic conspicuity, 32% used FLARM, 14% Mode AIRCRAFT 14%, 1% ADS-B, 1% ACAS, and 8% used no electronic conspicuity (CAA 2020,a). The highest proportional usage was in gliders (89%; FLARM) followed by rotorcraft (46% mode S) and fixed wing aircraft (36% mode S). Research on pilot attitudes has implied that the various take up of systems by different UK aviation communities has led to entrenched resistance to change to accommodate others (Grote 2022).

Against all this background, it seems sensible to stand by the axiom 'see and avoid' as the primary means of awareness and avoidance, and indeed this is emphasised in CAP 2000 (CAA, 2020,b). However, this is not as straightforward as it sounds now that many pilots use EC. The anticipated use of EC is to enhance pilot situational awareness through augmenting lookout (CAA, 2021), and it has been stressed that any EC device does not replace the need for effective visual scanning (CAA, 2021). However, the potential for inadvertent consequences is always present where automation is used to augment existing nonaugmented human tasks. The CAA acknowledges several such potential issues including focussing pilot attention in one area at the expense of others, pilots becoming ‘over-reliant’ on EC, and pilots assuming all aircraft are EC equipped (CAA 2021). No strong or valid research has been done on such issues to date. Neither has research looked at pilot understanding of the current situation, and of their device limitations and capabilities.

Trials of ADS-B for UK airfield tower personnel (A/G and AFIS) found generally positive results (CAA 2020,b) but there were also many factors reducing technical effectiveness. These included pilots forgetting to switch their device on, lack of charge, not switching off on the ground resulting in ‘clutter’ and use of a device programmed for the ‘wrong’ aircraft (though it should be noted that SkyDemon will warn users if their ADS-B code in their SkyEcho 2 does not match the aircraft registration they planned their sortie for). Many of these are basic human factors issues, and there are many potential complex human factors issues around usage that were not tested.

Basic human factors knowledge points to a number of potential problems in addition to the errors and activity that reduce technical effectiveness and coverage. EC aims to increase pilot awareness of traffic and will inevitably offer the pilot increased amounts of information. However, the issue of pilot awareness is not straightforward; more information does not necessarily equal more awareness and can even reduce awareness. Too much information quickly overwhelms our ability to process it all, and we can become unable to disassociate the signal from the noise (See CAA 2023). On the other hand, in the face of too little information, human beings struggle to remain vigilant for long periods, and there is no ‘silver bullet’ for improving vigilance (CAA 2023). Added to this are issues such as reliance on the display, verbal clutter (alerts), and distraction from key task priorities. For example, Jarvis (2018/2022) has shown the effect of alerts drawing attention away from primary monitoring priorities (in professional airline and helicopter crews). This could be a serious risk with EC alerts, particularly in certain situations (manoeuvring, critical flight phases, etc).

The current situation pertaining to incompatibility of EC devices has large implications from a human factors perspective. The basic issue is if (and how) the known information on EC impacts the unknown information not on EC. For example, information offered to pilots on EC may distract the pilot from more important visual information not shown on EC. These elements have yet to be validly researched. The following quote by US Secretary of State for Defence Donald Rumsfeld in 2002 led to the *Rumsfeld Matrix* and creates a simple model of the current situation to understand:

We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns—the ones we don't know we don't know. And if one looks … it is the latter category that tends to be the difficult ones.

Known-Knowns	**Known-Unknowns**
Aware of all aircraft through EC.	Aware of non-EC aircraft either visually or via Air Traffic Control / Radio calls.
Unknown-Knowns	**Unknown-Unknowns**
Aircraft not detected but are where expected (ie. In the circuit, climbing out from an ATZ, etc…).	Aircraft that we haven't seen, didn't expect to see, and don't understand why we haven't detected them.

Figure 3. The 'Rumsfeld Matrix' applied to the current UK EC situation.

Little guidance is currently available to GA pilots on how to use EC, or what the threats are, particularly in the current UK situation. The CAA has produced some general guidance on Human Factors Limitations (2022). This includes reminders to rely on core skills (e.g. lookout) because one's EC cannot see everything, getting to know one's device properly (and its capabilities), considering EC in flight planning (updates, charged batteries, etc), and ensuring secure placement that does not impede views or instruments.

In summary, there is a strong need for;

- Research into a number of important aspects around effectiveness of EC in the current and future UK situation, particularly the human factors vulnerabilities.
- Good evidence-based guidance for pilots, particularly around human factors.

- Wider management of the UK EC environment, particularly compatibility issues.

PART B – Methods

A large and in-depth survey of over two thousand general aviation pilots was followed by a limited number of live flying trials using eye-tracking glasses. The survey used several approaches including technical questions, probes of pilot understanding, and CIT questions (Critical Incident Technique) to elicit information based on events rather than pilot opinion. After the results were analysed, eye-tracking data were collected in live flights in order to triangulate some survey findings and provide supporting examples, particularly for illustrative purposes.

SURVEY

The survey is shown in Appendix A. The first section (Q1 to Q12) collected data about what EC respondents' usage including the device, mounting location, and use of audio alerts. The second section probes pilot perception and knowledge of their EC capability. The third section has a pair of modified CIT questions. These polar questions asked pilots to recall experiences where EC had been helpful (Q22) and unhelpful (Q23). A further open text question (Q24) supported these. These text questions were analysed using thematic 'template' (erring towards the 'grounded theory' end of the qualitative spectrum). For ethical reasons, no identifiable information was collected in the survey. Furthermore, no demographic or participant information was requested (i.e. age, gender, experience, etc). This was to encourage participation by reducing the time required for completion and reinforcing the message that the survey was about EC, not about the participants.

EYE TRACKING

Pilots wore 60Hz eye tracking glasses (SMI Natural Gaze) during four live flights. Except in the case of the first flight, the pilots were not told the purpose of the flight until afterwards, to avoid artificially skewing their attention during the flight.

Figure 4. Pilot wearing SMI ‘Natural Gaze’ 60Hz eye-tracking glasses.

This was not a full scientific study. Although the application of the method was implemented to a high scientific standard, the small sample size and large differences between subjects/aircraft meant that full scientific conclusions were not possible. Subjective analysis of data was carried out by a researcher with over a decade of experience analysing pilot eye-tracking data and footage across a wide range of types. The main purpose of the flights was to support (or otherwise) survey findings, add ecological validity, add meaning and context, and provide illustrative examples.

PART C – Quantitative Survey Results and Analysis (Q1 to Q21)

The survey was administered via a number of channels over the Christmas and New Year holiday period of 2022/2023. All responses were voluntary, and no incentives were offered. 2084 responses were received. The raw response tables and charts are presented in Appendix A.

PART C1 – QUANTITATIVE SURVEY QUESTIONS (BASIC INFORMATION)

1815 respondents designated a single aircraft type (as requested). Numbers and percentages of types (Table 1 below) were calculated from these responses only.

	n	**%**
1. Fixed wing aircraft <5,700kgs	**1370**	**75.5**
2. Fixed wing aircraft >5,700kgs	**85**	**4.7**
3. Flex wing aircraft	**70**	**3.9**
4. Glider/Motor Glider	**171**	**9.4**
5. Helicopter	**51**	**2.8**
6. Autogyro	**44**	**2.4**
7. Paraglider or Hang glider	**9**	**0.5**
8.Paramotor	**9**	**0.5**
9. Balloon	**1**	**0.1**
10. Uncrewed Air System	**5**	**0.3**

Table 1. Number of responses (out of 1815) for each category of aircraft, and the resulting percentage (this is an accurate estimate of the proportions within the survey).

One-hundred and sixty-five respondents (out of all 2084) selected no EC options and so were assumed to use no EC (this assumption was supported by various free-text comments). Of the remainder, 184 reported using only a standard (non-ADS-B) transponder, leaving 1735 using EC devices with or without a non-ADS-B transponder. Table 2 shows the totals of these additional EC devices.

	n	%
Transponder with ADS-B transmitter	751	26.2
ADS-B Receiver (any; fixed or otherwise)	176	6.1
PilotAware (PAW) Classic/Rosetta	605	21.1
SafeSky	67	2.3
SkyEcho 2	849	29.6
SoftRF	2	0.1
TCAS I / II	48	1.7
FLARM or PFLARM	247	8.6
FLARM or PFLARM with ADS-B Receiver	99	3.5
OGN Tracker transmitter	10	0.3
FANET or Skytraxx	10	0.3
DJI AirSense	3	0.1
	2867	

Table 2. The numbers of devices reported. Note: 165 pilots selected no EC and a further 184 only selected a non-ADS-B transponder (not included in Table 2).

Table 2 shows that 2867 EC devices (not including standard transponders) were reported as being used by the sample.

Analysis note: Respondents were asked to select one aircraft type only, and designate the EC used in that type. However, 269 respondents selected multiple aircraft types. These respondents were designated one primary type based on their responses, and only the EC selected under that aircraft type was included. This was done in order to avoid skewing the analysis, despite inevitably meaning that a small amount of data was dropped. Table 2 onwards uses this data.

SkyEcho 2 was the most used EC device, followed by an ADS-B equipped transponder, PilotAware, and FLARM/PFLARM. FLARM was almost certainly under-represented because it is most used in gliders, which made up under 10% of the sample. In terms of displaying the information, the vast majority of respondents (88%) used SkyDemon (see Appendix A, Q3). As a signal format, ADS-B was by far the most ubiquitous; 55.8% could transmit ADS-B in one form or another, and 62.8% could receive it. PilotAware was next with 21.1%, but only an additional 2-3% receive it; thus it is a fairly closed community with a low likelihood of detection.

PART C2 – QUANTITATIVE SURVEY QUESTIONS (DEVICE PLACEMENT)

Many pilots use several devices together in their aircraft (not including standard non-ADS-B transponders). Appendix B shows tables of all EC combinations reported. In total seventy-nine different EC combinations were reported as being used, not including non-ADS-B transponders or non-EC. Tables 3 and 4 below analyse the EC combinations (including single EC devices) in terms of pilot numbers and the likelihood of detection with others in the survey sample (all 2084). The analysis splits the functioning into transmission (Tx) and reception (Rx). Table 3 (Rx) includes all EC devices capable of receiving signals (whether or not they also transmit). Table 4 (Tx) includes all EC devices capable of transmitting signals (whether or not they also receive).

The tables only show multiple combinations used by ten or more sample pilots. The number of pilots with each combination is in the white column. This includes single devices. For example, 402 respondents use the 'Skyecho2 only' (Tx) combination, whereas sixteen respondents use the 'Skyecho2 and SafeSky' (Tx) combination.

For each combination shown, the tables give the number of pilots in the survey whose aircraft would be detected by someone using that combination, or who would detect a combination (given that all Rx capable devices in their combination are being used to receive information). All surveyed pilots were included, including those without EC (hence they are factored in; i.e. *a zero chance of detecting you, and a zero chance of you detecting them*). The tables also show the equivalent probability (E.g. number or respondents detected divided by the number in the whole survey). The orange columns are for '*definite*' detection given proper functioning of the EC and usage of the full function. The green columns represent detection that is dependent upon other external factors (dependencies) such as ground stations, network availability, pilot selections, etc. Hence the far-left green columns show the maximum numbers and probabilities of detection if all such dependencies are satisfied.

How many other survey respondents' aircraft will these RX combinations detect, and what are the probabilities?	Number of respondents with this combination of receivers (n)	Number of respondents NEVER detected using this rx/combination)	Number ALWAYS detected (given proper functioning of this combination)	**CHANCE of detecting another respondent (if EC functioning properly)**	Additional Aircraft DETECTED - Dependent on other factors such as ground stations, wireless availability, EC selection, etc)	CHANCE (MAX) of DETECTING another survey respondent in the air (if functioning AND if all dependencies align)
PilotAware (PAW) ONLY. Classic/Rosetta	413	407	1326	0.64	350	0.80
SafeSky ONLY	21	393	66	0.03	1624	0.81
SkyEcho2 (assuming FLARM subscription) ONLY	532	619	1464	0.70	0	0.70
SoftRF ONLY	0	393	0	0.00	1690	0.81
FLARM/PFLARM ONLY	118	1833	249	0.12	1	0.12
FANET or Skytraxx ONLY	2	2073	9	0.00	1	0.00
Any stand-alone ADS-B Receiver ONLY	60	983	1100	0.53	0	0.53
FLARM/PFLARM with ADS-B Receiver ONLY	44	867	1215	0.58	1	0.58
DJI AirSense ONLY	2	983	1100	0.53	0	0.53

COMBINATIONS (10 or more respondents)						
SkyEcho2, P/FLARM with ADS-B rx	23	619	1464	**0.7**	0	0.7
SkyEcho2, ADS-B RX	36	619	1464	0.70	0	0.70
SkyEcho2, P/FLARM	76	619	1464	0.70	0	0.70
SkyEcho2, SafeSky	22	393	1464	0.70	226	0.81
PAW, P/FLARM ADS-B rx	10	407	1672	0.80	4	0.80
PAW, ADS-B rx	26	407	1561	0.75	115	0.80
PAW, P/FLARM	15	407	1463	0.70	213	0.80
SkyEcho2, PAW	113	407	1672	0.80	4	0.80

Table 3. List and analysis of combinations capable of receiving (Rx). Single devices are treated as a combination for analysis purposes (each table row is mutually exclusive).

How many other survey respondents will detect these Tx combinations, and what are the probabilities?	Number of respondents with this combination of transmitters	Number of other respondents who could NEVER detect this Tx combination	Number of other respondents who should ALWAYS detect this Tx/combination; given proper EC functioning	CHANCE of this Tx/combination being DETECTED by another respondent; given proper functioning)	Additional number DETECTING dependent on other factors; E.g. ground stations, wireless availability, EC selection, etc)
PilotAware (PAW). Classic/Rosetta ONLY	203	1427	597	0.29	59
SafeSky ONLY	14	2017	59	0.03	7
SkyEcho2 ONLY	402	525	1530	0.73	28
SoftRF ONLY	0	546	0	0.00	1537
FLARM or PFLARM ONLY	103	548	1057	0.51	478
FANET/Skytraxx ONLY	2	546	1060	0.51	477
OGN_Tracker ONLY	3	1427	0	0.00	656
Transponder with ADS-B out ONLY	177	581	1039	0.50	463

COMBINATIONS (10 or more respondents)						
SkyEcho2, Transponder ADS-B out, FLARM/P	22	457	1598	0.77	28	0.78
SkyEcho2, Transponder ADS-B out	190	463	1592	0.76	28	0.78
SkyEcho2, P/FLARM	61	474	1581	0.76	28	0.77
SkyEcho2, SafeSky	16	525	1530	0.73	28	0.75
PAW, P/FLARM, Transponder ADS-B out	12	457	1536	0.74	90	0.78
PAW, Transponder ADSB out	248	581	1474	0.71	28	0.72
SkyEcho2, PAW	93	525	1530	0.73	28	0.75
FLARM/PFLARM, Transponder ADSB out	26	457	1116	0.54	510	0.78
SkyEcho2, PAW, Transponder ADS-B out	22	463	1592	0.76	28	0.78

Table 4. List and analysis of combinations capable of transmitting (Tx). Single devices are treated as a combination for analysis purposes (each table row is mutually exclusive).

There are some important limitations to factor in when considering the output from Tables 3 and 4. These include:

1. Most importantly, the survey almost certainly under-represents non-EC equipped aircraft (as well as those using no EC other than a standard transponder). For obvious reasons, requests to complete a survey on electronic conspicuity usage are far more likely to attract responses from pilots who use electronic conspicuity. This is probably the largest limitation factor.
2. The analysis assumes that respondents always use their reported EC/combinations, and for the whole of every flight.
3. The analysis assumes that EC devices are fully serviceable and functioning correctly (whereas in reality, technical issues could include ariel placement and movement, low batteries, faults and breakages).
4. The analysis could not control for the amount of flying done by each respondent, meaning there is an assumption that each EC combination group fly equal amounts. The large sample size (2084 pilots) mitigates this uncontrolled variable to a degree (by reducing error effects of random chance) but still there may be systematic factors that skew this picture

(for example the choice of EC used by those who fly more could be different [on aggregate] to those who only fly occasionally). The magnitude of such an effect (if it exists) cannot be known.

5. Some aircraft types are clearly under-represented in the survey. Gliders are particularly under-represented, and so calculations that include FLARM/PFLARM in the combination will under-estimate the likelihood of detection, whereas non-FLARM/PFLARM-capable combinations will over-estimate detection.
6. Where a device is capable of both transmitting and receiving (Tx and Rx functions) then both are assumed to be used (since there is no additional information to determine otherwise). However, this is commonly not the case. For example, some pilots mount an EC device purely for its TX function (e.g. a glider pilot reported buying a Sky-Echo after a near-miss with a fixed wing aircraft, purely in order that other pilots could detect him). This factor will lead the analysis to over-estimate the chance of detection.
7. All respondents (849) using SkyEcho (either alone or as part of a combination of devices) were assumed to have P/FLARM detection capability.

Considering all the limitations (and particularly 1, 2, 5 and 6 above) it is likely that the figures arrived at by calculations based on the sample (e.g. Tables 3 and 4) significantly over-estimate the real chance of detection (detecting and being detected) when flying in UK airspace.

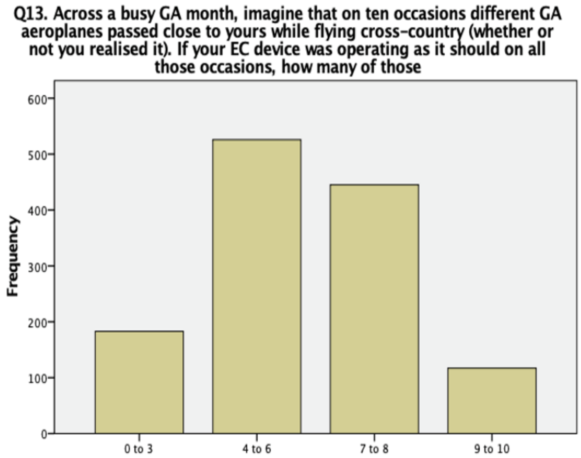
Likelihood of detection (general)

Based purely on the survey respondent pool, each aircraft has a 0.48 mean chance (SD 0.31) of detecting other aircraft electronically (max .52 if all dependencies align), and a 0.5 mean chance (SD 0.29) of being detected by another aircraft (max .55 if all dependencies align). The difference is probably due to some combinations not being included in the data, because they represented under ten pilots. Ninety-three pilots were not included in the Rx analysis and fifty-eight in the Tx analysis. For practical and conceptual purposes, an estimate of about 50% overall mean detection (SD = 30%) within the respondent pool is reasonable. The limitations previously discussed mean this is likely to be significantly lower in reality (and particularly if gliders and P/FLARM are discounted). However, it is important to note that (1) this is a mean figure that varies considerably between aircraft (approx. SD is 30%), and (2) many aircraft (devices/combinations) have widely different chances of detecting (Rx) and being detected (Tx). For example, a pilot using only a PilotAware system has about a 2 in 3 chance of detecting others (up to 4 in 5 if all dependencies are met) but only a 1 in 3 chance of being detected by others.

PART C3 – QUANTITATIVE SURVEY QUESTIONS (PERCEPTION AND UNDERSTANDING)

Pilot perception of EC likelihood of detecting and being detected (Q13-16, Q20-21).

Questions 13 to 16 probed pilot perception (and confidence in that perception) about EC capability. A scenario was suggested requiring pilots to state how many of ten random aircraft they think their EC would detect (Q13) and how many would detect them (Q15). Questions 14 and 16 asked pilots' level of confidence in their answers. Figures 6 to 9 show the answers (full breakdown in Appendix C).



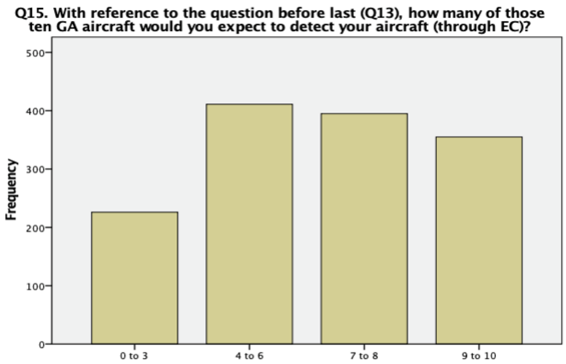
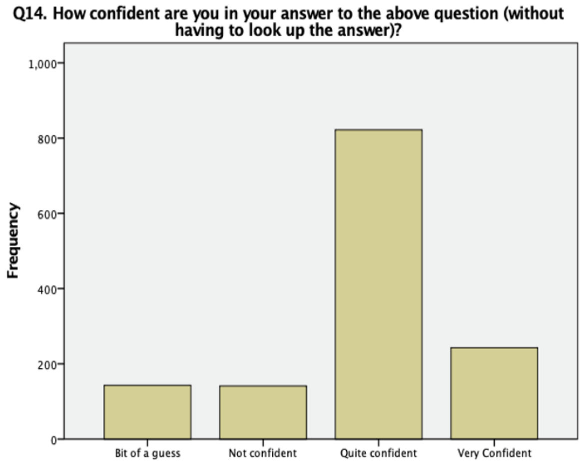


Figure 6 (left) and 8 (right). Response frequencies to Q13 and Q15. Q13 results only include respondents who had any Rx-capable EC. The average is about six. Question 15 results only include respondents who had any Tx-capable EC. The average is about seven.



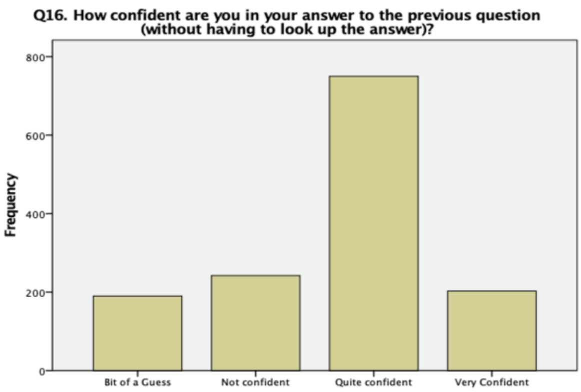


Figure 7 (left) and 9 (right). Confidence in answers to Q13 and Q15.

Of note, responses to Q13 are skewed towards lower perceived likelihood, compared to Q15 (average of about 6 and 7 respectively). When asked how many of the ten aircraft their EC would detect, only 9% opted for the highest likelihood (9-10 aircraft) in Q13, compared to a quarter in Q15. This suggests that pilots generally feel more confident about being noticed than about noticing others. This might be because they see evidence that they do not detect all aircraft electronically, but no evidence when they are not detected electronically by others.

In terms of confidence (Q14 and 16), about 79% of respondents said that they were 'quite confident' or 'very confident' about their answer to Q13, with the equivalent figure for Q15 at 69%. There was a large and highly significant positive correlation between Q14 and Q16 (0.66, $p<0.001$) meaning that there was a very strong similarity in the way respondents answered the questions. This suggests that participants generally felt more confident estimating how many other aircraft they would detect, compared to how many aircraft would detect them, but participants varied in the confidence of their answers.

Any answer over '8' is a clear over-estimate no matter what combination of EC the respondent uses. No combination of EC used by any respondent would detect more than eight out of ten aircraft (based on respondent pool). The highest combination is PAW, P/FLARM and ADS-B rx, which is 0.8 (max). A few lesser-used combinations have a lower chance of detection but reach 0.81 with all dependencies met. In terms of being detected (Tx), the highest combination was SkyEcho2 with an ADS-B out Transponder and P/FLARM, which reached 0.77, and 0.78 with all dependencies met.

Only a very small (and effectively non-significant) correlation was found between the chance of a respondent's EC detecting another aircraft and their answer to Q13 (0.07, $p<0.05$). This means that pilots' estimates for the likelihood of their EC detecting other aircraft were almost unrelated to the real chance of them detecting them (based on the sample). In other words, the respondents were not effective at estimating the proportion of aircraft that their particular EC combination would be expected to detect. In terms of being detected by others, the estimates were slightly better, but still only a small positive correlation of 0.103 (Pearson's), although statistically significant ($p<0.001$), meaning that this is very unlikely to be a random effect. This means that pilots' estimations for being detected were only slightly related to the real chance of being detected, and in any case, there was an underlying (and possibly) large over-estimation.

There was a very large and highly significant correlation between Q13 and Q15, suggesting that respondents tended to answer both questions similarly, despite several common combinations having quite contrasting capabilities (e.g. Pilot Aware has a two-thirds chance of detecting, but only a one-third chance of being detected; given the sample pool). Given the previous findings (little correlation between calculated estimates and pilots estimates), this suggests that, in general across the sample, pilots estimate the proportion of (a) their detections [Rx] and (b) others' detections of them [Tx] based on a common root, more than on the real chances of each.

These results suggest that as well as a general over-estimation of capability (see earlier analysis of Q13 and Q15) there is a low understanding among pilots of what their devices / combinations are capable of in terms of detecting and being detected. Two examples are below.

1. Pilots using only PilotAware estimate both the chance of detection and the chance of being detected as the same (approximately 0.6 to 0.7, based on a score of 2.65 for both Q13 and Q15). Whereas this is accurate in terms of detecting others (calculated as .64), it is a large over-estimate of being detected (calculated as only 0.29 without dependencies, and maximum of .31 even with all dependencies met).

2. Some pilots using only SafeSky substantially over-estimated the chance of being detected by others. The respondents estimated a mean chance of being detected was about 0.4 (calculation based on a score of 1.75 for Q15) and the calculated estimate is 0.029 (max 0.032), which is less than a 0.1 chance. Only one respondent chose 0 (the closest response). The respondents gave a mean estimated chance of detecting others as about 0.6 (calculation based on a score of 2.46 for Q13). The calculated estimate is .03, but with a maximum of 0.81 if all dependencies are met (in this case meaning if within range of a mobile network). It is unknown whether respondents factored this into their estimate.

On the other hand, pilots using only SkyEcho 2 (assuming an active P/FLARM capability) gave relatively accurate mean estimates on average. The respondents estimated the mean chance of being detected as .6 to .7 (calculation based on a score of 2.47 for Q15). The calculated estimate is .72 (max .75). The respondent mean estimated chance of detecting others was about .5 to .6 (based on a score of 2.16 for Q13) and the calculated estimate is .70 (max .70). Although these figures appear to be an under-estimate, the limitations on the calculation probably mean they are not (the pilot estimates are probably a slight over-estimate of the real situation).

It is quite possible that the SkyEcho users are more accurate by chance, given that their estimates are very similar to Pilot Aware and other users.

Question 20 asked pilots if they believed that their EC had ever prevented an AIRPROX or collision. A selection of ‘zero/never’ should have been included but was overlooked. This was mentioned in free text by a number of respondents. It is assumed that if respondents felt this had never happened, they omitted answering or selected ‘don’t know.’ The results are shown in Figure 10 below.

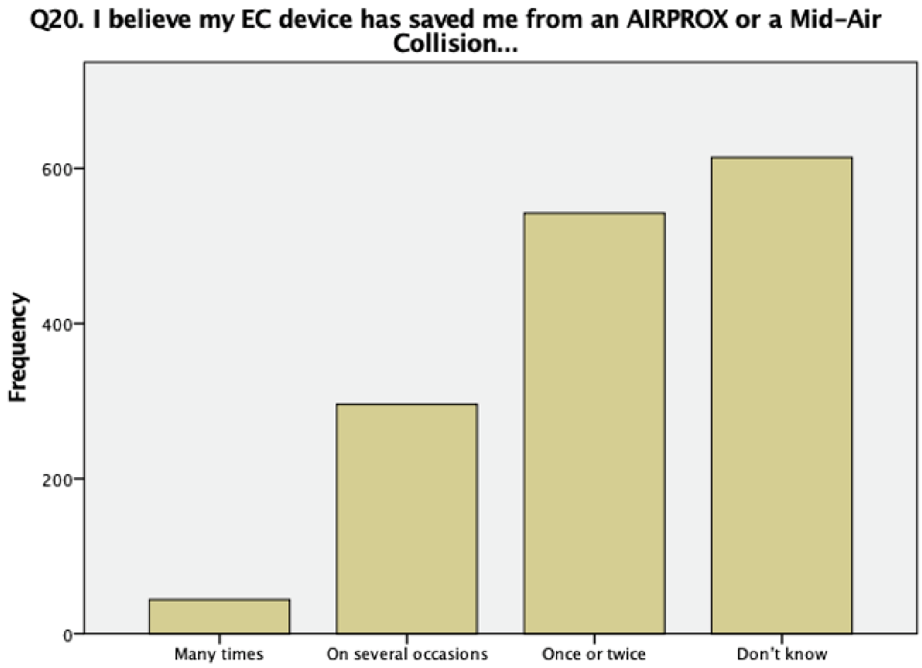


Figure 10. Chart of responses to Q20;” I believe my EC device has saved me from an AIRPROX or midair collision…”

In total, 882 participants offered the view that their device had saved them from an AIPROX or collision at least once (44 ‘many times’ + 296 “several occasions” + 542 “once or twice”). This is 42% of the whole sample, and 59 % of those who answered the question.

Those who answered higher for their estimate Q13 or Q15 (chance of detection) were significantly more likely to report that their EC has saved them from a mid-air collision ($r = .156$, $p<0.001$ for Q13, and $r = .1$, $p<0.001$ for Q15).

Question 21 asked pilots about how they felt when seeing another aircraft visually that was not being detected by their EC. The response frequencies are shown below (Figure 11).

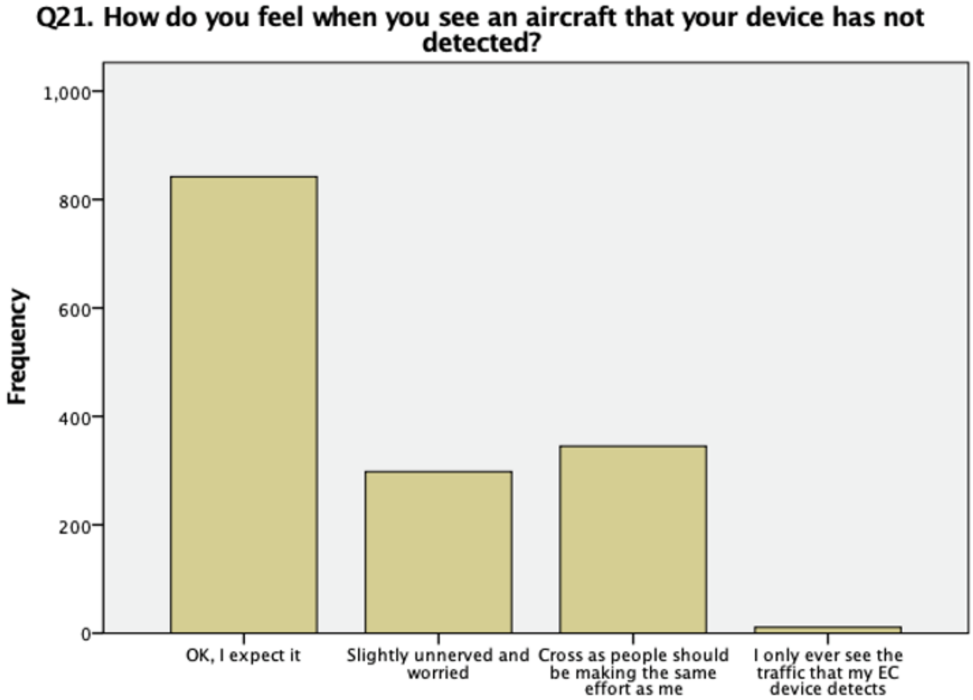


Figure 11. Response Frequencies for Q21 (How do you feel when you see another aircraft that your device has not detected?)

The majority (56%) reported feeling ‘ok’ (because they expected that to happen). Twenty percent reported feeling unnerved and worried and 23% reported feeling angry because they felt the other pilot was not making the same effort as they were. Only 1% claimed they always see the traffic. All these answers are understandable. However, it is of note that 43% (a large proportion) reported feeling an emotion that indicates they have an unconscious expectation of detecting most (if not all) other aircraft, despite probably knowing that this is highly unlikely. This is good evidence that the use of EC in an incomplete environment does provide a false sense of security (as many alluded to in the free text). This is a very real phenomenon, and not one that can be overcome simply by telling pilots it is false, because they are probably well aware of that already. It is caused by the way the underlying mental processes work in such environments.

There is only a very small relationship between Q21 responses and the probability of the respondents' detecting another aircraft, as calculated from their combination ($r = .059$, $p<0.05$). Whereas such an effect would make sense (the better a pilots' EC detection capability, the more likely they are to report feeling 'cross' at the undetected pilot) the statistic shows this is not really the case.

EC understanding

Problems have already been highlighted with regards to pilots' understanding of detection likelihoods. It is not valid to ask direct technical questions in a survey in order to assess understanding, because those respondents who do not know are less likely to answer or may even look up the answers. Question 17 asked pilots to comment on their fellow pilots. Clearly the answers should be treated with caution, but they should also offer a reasonably honest indication of the situation. A Chart of Q17 frequencies is below (Figure 12).

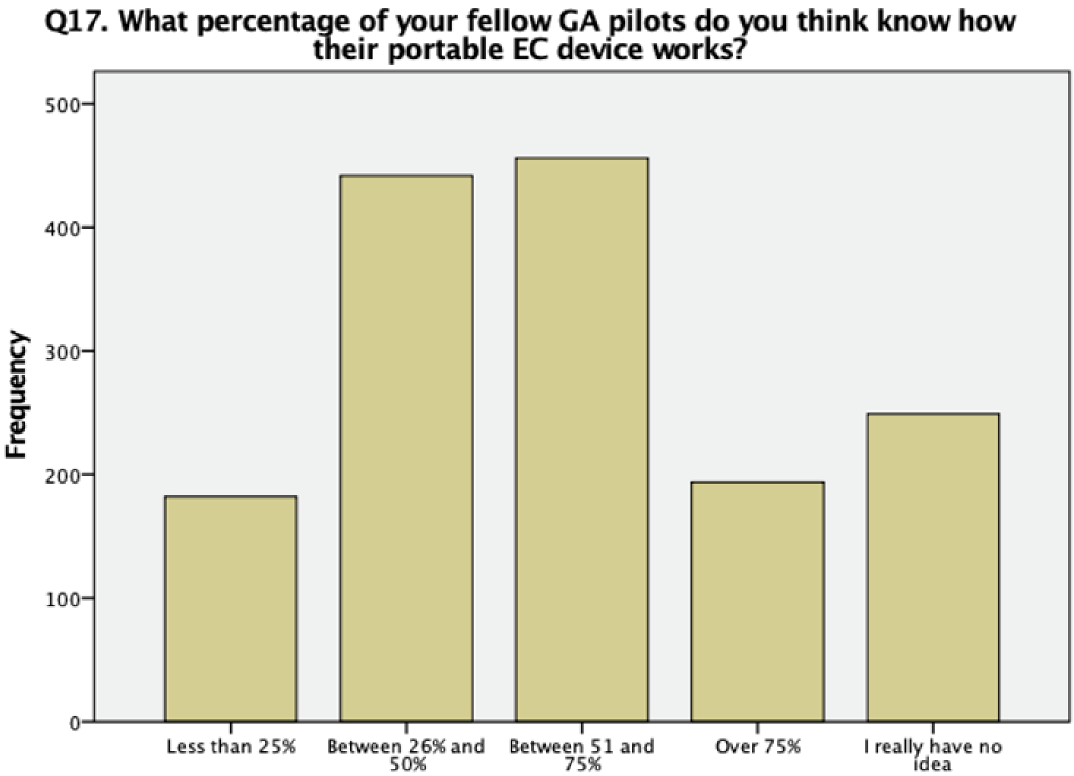


Figure 12; Chart of response frequencies to Q17 (“what percentage of your fellow GA pilots do you think know how their portable EC device works?”)

Despite clear limitations with Q17 (interpretation of phrasing and subjective opinion) the answers nevertheless do suggest a view that only about 50% of pilots on aggregate could be described as knowing ‘how their EC device works’. This in turn suggests a knowledge problem in GA with EC in general.

Whereas pilots themselves might be a factor in this lack of understanding (i.e. not learning about their equipment in sufficient depth), the current complexity within the situation, as well as the information from manufacturers, could also be factors. Appendix D discusses some marketing examples of the various systems (as of March 2023). In marketing, manufacturers tend to understate the limitations of the devices (particularly in relation to the incomplete nature of detectability). A full review of firms’ marketing material is not within the scope of this programme and would require further work.

PART C4 – CONCLUSION/SUMMARY FROM QUANTITATIVE SURVEY QUESTIONS (PART D1, D2 AND D3)

Of 2084 survey responses, just over three-quarters were GA fixed wing (<5700kg). SkyEcho 2, ADS-B equipped transponders, Pilot Aware, and FLARM/PFLARM were the most frequently reported EC devices. Two-hundred and sixty-nine (269) respondents reported using multiple EC devices in their single aircraft type, making seventy-nine combinations of EC devices in use by the sample in total (excluding non-ADS-B transponders). The most frequently reported combinations were SkyEcho2 with an ADS-B out Transponder, Pilot Aware with an ADS-B out Transponder, and SkyEcho2 with Pilot Aware.

There is incomplete compatibility between the various systems, and some aircraft flying without any EC at all. Calculations found that, on average, a survey respondent has approximately a 50% chance of electronic detection of (and by) all others in the survey (SD = 30%), notwithstanding a number of limitations that combine to mean that the figure is probably lower in the real environment. This means low reliability of detection and detectability, which results in pilots receiving an incomplete traffic picture. Moreover, pilots have no way of knowing how complete or incomplete their EC traffic picture is. Hence pilots cannot rely on EC for full traffic awareness, alerting or avoidance.

However, the data provide reason to believe that pilots not only over-estimate the completeness, but that at least some might be using EC in a way that assumes a complete picture.

Pilots (as a group) estimate the chance of detecting others and being detected by others as 60% and 70% respectively. Even assuming average detection reliability of 50%, the pilots' answers are a significant over-estimation. Over-estimation of this kind is to be expected because pilots will be aware of detected aircraft (because of EC) whereas undetected aircraft must be seen visually. The use of some combinations and devices resulted in more over-estimation than others. On average and overall, pilots feel a little more confident about being detected than they do about detecting others. Yet, when seeing an aircraft that was not detected by their EC, 43% of respondents admitted feeling a negative emotion (unnerved or angry). This suggests some pilots have an intuitive expectation of full coverage, despite knowing otherwise, supporting the idea that EC can provide a 'false sense of security' compared to not using EC.

Respondents opined that only about 50% of pilots understood their devices, on average. This is supported by the data on pilot estimates of detection based on their equipment combinations, because pilots' likelihood estimates of their EC detecting another aircraft were almost unrelated to the actual chance of detecting it. Reasons for such issues might include pilot application, natural biases, the complex current picture (device types and compatibility) and manufacturer messages.

The quantitative data collected suggest a risk that pilots overly rely on their EC to detect other traffic despite a reflective understanding of its limitations. In theory this could lead pilots to reduce activity on the primary task (look out), overly focus on EC targets, and miss electronically undetected targets.

PART D – CIT and Open-Text Survey Questions (Q22 to 24)

Over half of the respondents filled in the Critical Incident Technique (CIT) questions (Q22 and Q23) and/or the free text question (Q24). This yielded well over two thousand narrative data entries from over one thousand participants (an enormous amount of qualitative data by any project standard). Full thematic analysis was not possible within the scope, but basic thematic analysis was conducted based on large samples of events, with an additional read-through of the unsampled events.

The responses to the survey appeared to include honest and valuable reflection, as evidenced by self-criticism and comments that in other circumstance might be perceived as reflecting poorly on the individual making them.

This section describes the survey themes that were deduced with help from the literature review, pilot study, quantitative survey analysis, and various external sources. Clearly not all analysed comments could be shown, but a small proportion are used as examples for each theme/topic area.

PART D1 - EC TASK-INTEGRATION (HYPOTHETICAL CONSTRUCT: ‘EC CONFLICT AVOIDANCE SPACE’)

Q22 (relates to an event where EC was helpful) produced numerous specific (CIT) anecdotes relating to avoidance and resolution, which broke down relatively evenly into events relating to one of the following:

1. *Critical avoidance* (direct conflict avoided by EC)
2. *Separation* (traffic separation managed using EC)
3. *Awareness* (EC provided or supported traffic awareness EC, or avoidance/separation unspecified in the response).

The comments roughly represent a continuum of EC usage based on the range/time of the pilot’s actions or decisions (which are sometimes determined by range of the EC information/ warning). This continuum could be called the ‘reactive-strategic continuum,’ and is characterised below:

Reactive < ------------------ Tactical --------------- > Strategic

On the far left of this continuum were late avoiding action and near misses, and on the far right were pre-emptive decisions and strategic use of EC, such as re-planning a route in flight in order to avoid busy looking areas many miles along the existing route.

The frequency of comments generally reduced from the left to the right of the continuum (exact numbers not possible within scope, and in any case not necessarily a valid reflection). In other words, there were numerous recalled cases of critical avoidance, and only a few comments of EC supporting long range decisions. However, this uneven distribution is likely due to the framing of the CIT question, that specifically asked respondents to recall ‘*avoiding action’*. A selection of typical comments are as follows (from top to bottom these would be distributed left to right of the reactive-strategic continuum).

- C152 level flight. warned of traffic same level converging on position from right, hidden by wing. Moved head forward to spot a PC12… banked hard left and descended to separate.

- Towing a glider out with FLARM in the tug, it gave a red indication when an inbound glider on the wrong circuit came head-to-head. I made an immediate R turn… very late
- Head on traffic, opposite direction same height. Traffic warning was displayed … I turned right 45 degrees and 20 seconds later the traffic passed down my left side, same height.
- Was given an audio alert of a flex wing microlight that had climbed in front of me passing left to right within 1nm. Late notification by the EC allowed me to quickly focus lookout and see and avoid.
- Co-altitude, reciprocal heading, head-to-head. Resolved at 2nm thanks to EC
- EC device notified me of an aircraft traveling toward me in an area covered by the [low] sun... assists me in making a slight course correction to gain better visibility and thus seeing the aircraft and thus both aircraft being able to safely avoid
- Converging on a reporting point... despite knowing of another aircraft I couldn’t see it. My sky demon allowed me to see the position and identify the aircraft and ensure safe separation.
- I was flying to/from the same airfields as a friend... I knew they'd be overtaking me at some point. On the EC display I saw them approach and overtake below me. I delayed my descent until they had passed.
- Saw a mass of gliders on my planned course at a similar height to my planned level. Re-routed to give the gliders a wide berth. Saw none of them visually.
- I was able to ‘see’ congestion of air traffic further along the route I was taking and observe their direction of travel. This enabled me to plot a course that I knew would not be in conflict
- In training flights, checking for the concentration of traffic in local training areas so that I go to the least busy area.
- Instruction quite often includes general handling manoeuvres outside of controlled airspace with other traffic not on the frequency and not receiving a radar service but having an EC devise installed. These have appeared on my display enabling me to organise the lesson to avoid any potential conflict.

Note in the above list, the actions range along the continuum from those aimed at avoidance of imminent threats, to strategic decision-making based on EC that avoids perceived potential for loss of separation pre-emptively.

Many of the responses to Q22 were sufficiently detailed to determine the combination of visual and EC usage involved. These observations created a second continuum that can be called the ‘eye-to-screen’ continuum, describing the balance of information used by the pilot in the recalled event (amounts of visual support versus amounts of EC information). The continuum is characterised below:

Visual (eye) < ------------------ Visual/EC mix --------------- > EC (Screen)

At the far left of the continuum are situations where EC is not involved at all, only activity based purely upon look out and visual sighting. For obvious reasons, there are few such comments in the survey, because respondents were asked about EC. On the far right are situations involving no visual acquisition at all, only EC. Between these extremes are combined use of EC and visual (for example visual acquisition that was directed by EC).

The frequency of survey comments on this ‘eye-to-screen’ continuum was greatest towards the centre (combined visual and EC), but as before this distribution should be treated with caution based on the methodology, since it is likely to reflect the question asked. A selection of typical comments on the ‘eye-to-screen’ continuum are below (from top to bottom these would be distributed left to right on the continuum). Note: the top two comments are from Q23 since visual search was not part of Q22. Note in the list, the actions go from purely visual supported activity to purely EC supported activity (without sighting the other traffic).

- …located aircraft visually that has not been shown on my EC
- …aircraft crossing from right to left. It was seen visually but didn’t show up on SkyDemon
- …audio alert of a flex wing microlight that had climbed in front of me passing left to right within 1nm. Late notification by the EC allowed me to quickly focus lookout and see and avoid.
- Whilst soaring a ridge just below cloudbase, it warned me of opposite direction traffic doing the same. This allowed me to focus my lookout and visually identify them.
- In the circuit approaching the LAA Rally 2021. Unable to see aircraft behind me and he wasn't visual with me. His position was shown with callsign on my EC device and I was on his - successfully deconflicted to a position where we both saw each other visually.
- My PAW detected a motorglider coming towards me in my 12 o'clock at same height, enabling me to alter course before visually seeing it.
- Aircraft approaching at 90 degrees off my heading. Altered course by 90 degrees to the right in order to avoid. Conflicting traffic not sighted.

If the two described continuums are plotted on perpendicular axes, the EC usage (around conflict avoidance) can be represented in a 2D space (Figure 13, overleaf)

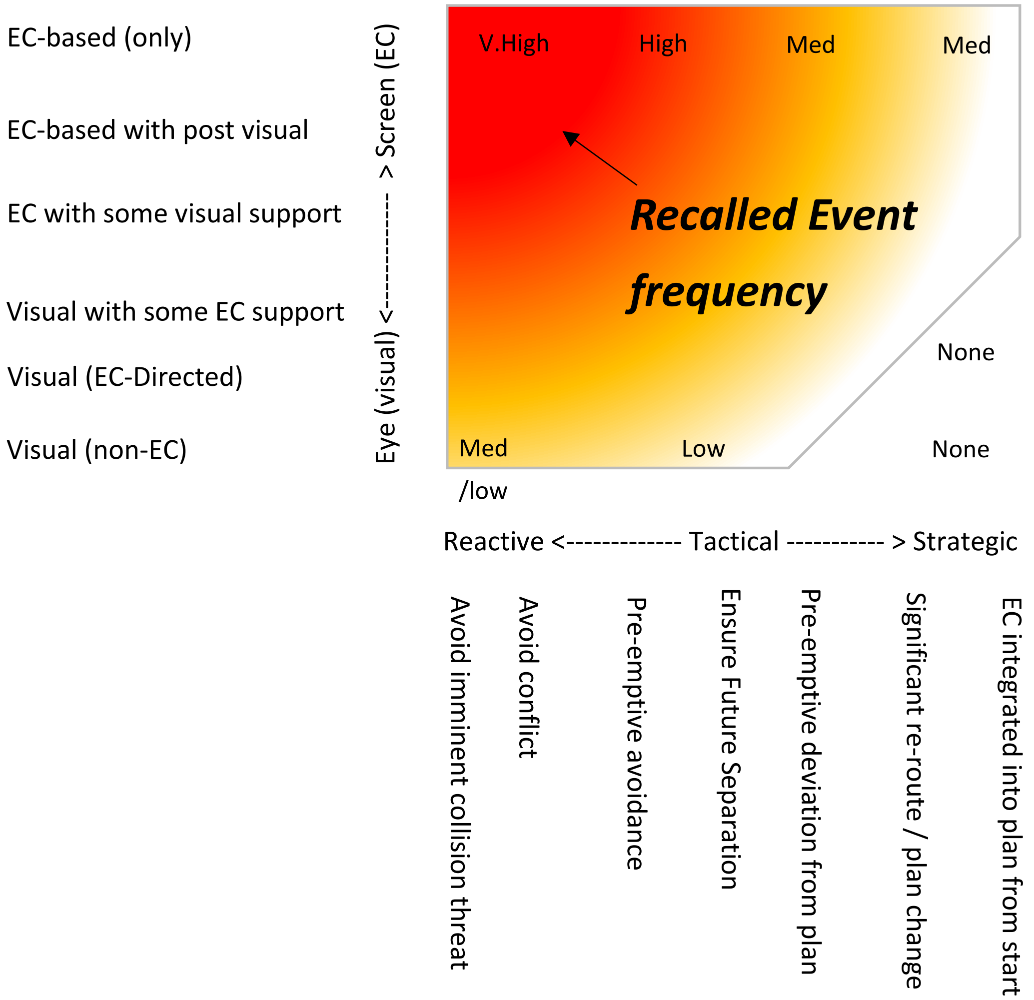


Figure 13: EC conflict avoidance space. The Eye-to-Screen continuum is on the vertical axis and the Reactive-Strategic Continuum is horizontal. Very approximately, the red area relates to relatively higher numbers of comments that fit the intercept. The labels inside the space (low, med, high) support this characterisation.

It is important to note that the colouring of Figure 13 (red and yellow) only represent an estimate of the frequency of comment types in the survey, not the relatively frequencies of such events in the real world. There are many reasons why this might be substantially different in the real world. Indeed there are good reasons why pilot activity would be the reverse (more strategic action than avoiding action) since critical avoidance would be expected to occur less than strategic avoidance. Nevertheless, assuming good faith and reasonable recall on the part of the respondents, and given the large numbers involved, the data suggest that in terms of deconfliction (of all kinds), pilots use EC to inform action across a wide range of distances, with or without visual support. About 25% of all specific +CIT comments could be characterised as belonging to the top-left space (wholly EC-based critical avoidance manoeuvre, sometimes with post visual and sometimes not). Over 15% involved the top right areas (wholly EC-based pre-emptive/strategy/planning). These figures do not include the many comments that appeared to fit these two areas but were insufficiently specific to be considered on Figure 13.

As figure 13 implies, the more pilots' avoidance activity is based on EC (as opposed to visual) the greater the range of distances over which avoidance activity can be actioned (the top of the space). Visual lookout and acquisition can only be used at lesser distances, which usually means avoiding a short-term conflict risk. The shape of the EC Conflict Avoidance Space (one corner cut off) reflects this. The results do not offer information to help assess the costs or benefits of such activity, just that it is occurring in de-confliction activity (assumptions being satisfied). Also, clearly the results only consider activity related to deconfliction related activity, not all pilot activity (since pilots were only asked about deconfliction).

Several conclusions can be drawn. Firstly, that many pilots report having taken critical collision avoidance action based on or supported by EC. Therefore, EC does appear to have been beneficial on many critical occasions and may have prevented some collisions. Secondly, that using EC, many pilots are taking active de-confliction decisions and actions across an extended range (of distance), equating to tactical and even strategical decision making (as well as reacting to potential conflicts). This means that EC has offered pilots an extended facility not previously enjoyed (and not necessarily what EC was primarily designed for), and pilots are using this additional capability.

The results strongly suggest that EC is not simply being used to prompt or support 'see-and-avoid' but has become integrated more widely into the overall flying management task. The implications of this are unknown; there may be both benefits and costs in terms of safety. However, a current concern must be that the incomplete nature of EC information creates risk in such task-integration.

The results also offer a matrix of pilot behaviour around EC that can be used in future research to interrogate real world data.

PART D2 – DETECTED/EMERGENT THEMES

This section highlights and discusses the main themes and areas detected in the survey comments (i.e. those mentioned most frequently or deemed to be particularly important).

Risk-based decisions

This section explores how pilots are acting in the top-right part of the EC conflict avoidance space (Figure 13, Part D1) and is aligned with the far right-hand end of the reaction-strategic continuum.

A number of comments suggest that pilots are making risk-based judgements and decisions partly based on EC. Decision making of this sort is mostly a strategic issue. For example, a pilot might decide to act in a way that they would not have done without EC, or to select an option using EC (or EC information) as part of the risk-mitigation. Example comments from the +CIT question (Q22) were shown earlier at the end of the reactive-strategic example list, and included instructors deciding which areas to use based on EC. Additional examples came from the negative CIT and open field (Q23/24), including:

- Some pilots'… belief that because they have ADS-B they do not have to acquire a service from an appropriate ATS. This is hazardous behaviour.
- A student descended right in front of me [wrong circuit direction]. I did not have Sky echo on as I was only running circuits. On speaking with the other pilot on the ground they assumed the circuit was clear as no one appeared on Skydemon

Notice that in the last example, the student used EC information (an absence of traffic on EC) as part of their circuit/joining decision. It is also worthy of note that the respondent chose not to use EC because they were "only running circuits" despite circuits being one of the most vulnerable phases of flight to mid-air collisions.

An anecdotal example that hints at such processes is pilots of different aircraft deciding to fly the same route in poor VFR using EC to support separation. The possibility in such cases is that EC could support a riskier choice.

There is no suggestion here of a ‘step-change’ in pilot decision making, but just that use of EC could create occasional subtle shifts in risk propensity around planning and overall flying decisions. The survey data were insufficient to elaborate further than has been discussed, and different techniques would be required to investigate the existence and magnitude of this. Caution would be required; standard techniques including forms of interviewing (cognitive, group, etc) are unlikely to elicit more than pilot perception and opinion which might not be a valid reflection of what is happening.

Where EC cannot be relied upon to detect all potential conflicts (as in UK airspace), factoring it into risk-based judgements may itself increase collision risk.

Reduced lookout

Among surveyed pilots, the most recurringly mentioned concern was related to EC leading to reduced lookout. This does appear to be a valid concern relating to a general idea that is complex and multi-faceted. It is therefore covered in more depth within subsequent themes. Some general examples are:

- My device is very good but it draws you to look in at the screen instead of looking out.
- .. can distract from a good look out while head is down looking at the panel.
- Temptation to watch screen and listen for verbal warning at detriment of keeping a proper visual lookout.
- I fly as mentor with several GA pilots who show an unhealthy dependency on EC at the expense of their lookout

EC ‘reliance’

The EC Conflict Avoidance Space (Figure 13) illustrates how EC appears to have integrated into the wider aircraft operating task to include strategic decisions, in-flight planning and routing. It also illustrates pilot perception that traffic avoidance is often based only on EC (top left of space). If new technology is being used in such ways, it would be normal for pilots to become somewhat reliant on it for certain task components.

EC could theoretically displace look-out (inadvertently) without the pilots’ full awareness. Comments and recollections suggesting this effect were found in the survey. A few examples are:

- I have watched other pilots mesmerised by their SKYDEMON traffic display and failing to keep a good lookout
- Noticed when flying with other pilots, who are P1, too much concentration on EC display on mobile device (usually iPad) not enough visual scanning of airspace. a good reminder to oneself not to do same!
- Possibly reduces reliance on visual scan and attention is focussed on EC.

It is probable that, much or all the time, an EC screen (that is often populated) offers higher 'expected value' than looking out of the window. Unsurprisingly therefore, many comments suggest some reliance on EC within the look-out task, avoidance task or overall operation. Examples are:

- Performing an overhead join at Sandown. Nothing showing in the circuit via PilotAware on my SkyDemon display and a visual scan did not pick up any aircraft. However a PA28 appeared from my right rear quadrant, with a parallel track at the same height. It flew through the dead-side and away. It is possible that the circuit appearing clear from the EC input led me to perform a less rigorous visual scan.
- [EC] essential in the busy Olympic area
- Flying in groups cross country with my buddies EC is essential to maintain our distance especially on long journeys.
- Gliders regularly fly in close proximity in thermals, and often on reciprocal headings beneath cloud streets. FLARM is pretty essential and also helps with situational awareness.
- As FLARM assists my SA and helps me prioritise lookout, I feel naked without it
- Was surprised to hear a pilot telling me that he would not fly without it now.

The suggestion from such comments is that, for some pilots EC has begun to feel 'essential' where it could not have done so previously (since it is relatively new). If so, this is not necessarily detrimental to safety (that remains to be seen or researched) but it suggests a type of reliance that could have unnoticed consequences. Comments that perfectly encapsulate this issue is as follows:

- As an instructor I see that people spend more time with their head in the cockpit. I call out traffic and the usual response is "I don't see it on SkyDemon"

- Some of my fellow pilots seem bewildered when a SkyEcho does not see another aircraft for them

In the above comments, the students' replies, and the 'bewildered' fellow pilots, strongly suggest a mindset in which all traffic is expected to be present on EC (at an unconscious level at least, even where pilots understand this is not true on a conscious level).

Many comments included terms such as "over-confidence", "false sense of security" and "complacency" to express similar ideas, frequently with the respondent referring to, or being concerned about, themselves. The word "assume" was also used a lot, e.g. "Tempting to rely on EC and *assume* that all traffic is known".

With perfect reliability, such a situation (and any such EC reliance) could be rationalised as increased capability. However, given the low reliability of detection (through EC non-usage and incompatibility) such *reliance* may be a serious risk, because of how the task changes to accommodate it. Hence, a major issue is how this could impact look-out and all elements of visual detection.

Note that the previous section (risk-based decisions) is further supported by the above comments. If EC is perceived as 'essential' then it could become a large deciding factor in a decision to engage in an activity, as opposed to deciding not to.

Distraction / fixation

Distraction was mentioned a lot and is a very large theme in the data. This section breaks distraction down into five areas:

1. Operational Task Distraction
2. Excessive or Overwhelming Amount of Information ('Noise')
3. EC directed Search Distraction
4. Alert-induced attention capture by EC device
5. Device-Interaction Distraction

Each of these will be explained further.

1. Operational task distraction

There is a perception among some respondents that EC can capture attention from other important tasks including in primary tasks. Such ideas are supported by literature (E.g. commercial air transport research by the principal author, showing degradations in priority monitoring caused by secondary-task fixation in air transport aircraft). Examples of operational task distraction reported in the survey were:

- I was fixated on a potential incident of two aircraft that were converging elsewhere not in my vicinity which I spotted on my screen. This impaired my scan and airmanship for a good two to three minutes.
- Where you get a bearingless contact. It can distract you from core aviation / navigation.
- Distracting me from actually flying the aircraft properly
- I'm an instructor/ examiner and think the current displays (phone/tablet) are often a distraction to students and pilots.

2. Excessive or overwhelming amount of information ('noise')

A very common theme (from CIT and free text) was the 'overwhelming' nature of EC in busy situations. The data suggest that in very busy traffic situations EC has been recognised as a serious distraction (through too much noise/signal) especially through EC audio traffic alerting. In such situations, density of targets is felt to make traffic avoidance more difficult. The situations mentioned frequently were circuit and pattern (including approach and take off), formation flying, glider gaggles (competition flying, thermalling, ridge soaring etc), fly-ins, etc. Unfortunately, as shown in the review these sorts of situations and phases account for most mid-air collisions. Hence even if EC were universal and compatible, it would be least effective (from a human factors perspective) in situations where aircraft are most likely to collide, precisely because those are the busiest traffic situations. Example comments related to excessive noise are as follows:

- In a busy circuit - can be distracting.
- Getting too much information especially if ridge soaring for instance. Pilots, especially the inexperienced can… start ignoring the threats that might actually be the ones to think about!
- If I set my FLARM to unlimited range it picks up too many detections as I'm near [airport]… so I have now limited it.
- When positioning to land in an ATZ - too many reports, and that's not the time to mess around trying to turn off the reporting.

- Close to landing lots of warnings at a fly in, just a distraction
- Information overload if trying to use EC at a very busy circuit.

One current problem is the lack of target prioritisation that EC is able to provide. The pilot must still determine which targets are the threats in busy airspace and may not be able to properly compute the full situation when EC provides multiple close contacts. In any case, this eventually becomes impossible, as well as promoting error where the pilot inadvertently filters out the signal (e.g. cry-wolf).

A second ‘noise’ problem, frequently expressed, was ‘unnecessary’ noise or attention-grabbing alerts caused by EC emissions on the ground. Some example comments were:

- Gliders leaving their FLARMs on when they are on the ground causing spurious warnings on final and take off!
- Audio warnings on take-off / landing caused by aircraft on the ground transmitting ADSB out
- Strident attention-grabbing collision warnings while on final stage of approach to runway caused by an aircraft holding near the runway edge.

3. EC-directed search distraction

Another distraction-based theme was related to the attention captured by searching for non-threatening EC targets. When the EC target is close or represents a threat, such a search is justified (though still potentially distracting). However, it appears likely from the survey that sometimes pilots spend time and attention searching visually for EC targets that are too distant to be seen or are clearly of no consequence (such as a very different flight level, on the final approach to an overflown airfield, diverging, already passed, etc). On many occasions such searches would represent a distraction of pilot resources and could lead to low prioritisation of primary responsibilities and look out.

- I've seen this a number of times on training details with an excessive amount of focus on an aircraft five miles away and a subsequent lack of focus on the task at hand and surrounding terrain.
- I see pilots becoming distracted and not flying the aircraft whilst searching…
- …aircraft behind, crossing track… looking behind as much as possible and scanning in all directions and therefore quite distracting, taking away from Aviate Navigate Communicate and turning it into Navigate Aviate Communicate!

- As an instructor I have found that there can be a 'fixation' on a 'target' aircraft. If the aircraft shown even presents no 'threat' pilots will often purely search for a visual on that particular aircraft rather than maintaining a wider general lookout/scan and miss other aircraft without an EC device.
- I'm an instructor regularly flying with students in their own aircraft with EC I find they get fixated on trying to find aircraft displayed, in the sky I find it a huge distraction e.g. fixation looking right and high for what they've seen on SkyDemon instead of looking all around.

4. Alert-induced attention capture by EC device

Many comments suggest that when an alert occurs, pilots become focussed on the screen, at the possible expense of both traffic sighting and other flight priorities. Examples are:

- PAW gives audio warning first, prompting "look & see" followed by screen gazing. I prefer to look and see.
- With audible non-verbal alarms like FLARM the instinctive reaction is to look inside the cockpit at the display to see where the contact is. It would be better to look outside for the contact.
- The warning causes an eyes into cockpit situation to identify… instead of looking outside to detect the traffic.
- The first thing you do when it goes off is to put your head inside the cockpit

A related issue can be a problem caused by the reaction to an alert itself. Two examples of comments suggesting this are;

- …avoiding detected traffic and turning towards an undetected aircraft.
- Plane approached fast from below 2 o clock going through Farnborough corridor - passenger shouted and I deviated higher causing infringement

5. Device-interaction distraction

Another source of distraction is the EC device itself. A theme within many comments is the distraction (away from flying tasks) caused by interacting with the EC equipment (due to faults, adjustments, batteries, HMI difficulties, etc). This can also include extra preparation and planning (charging batteries for multiple devices, ensuring the kit is working, up to date, charged etc). Where such a distraction is significant or where a distraction occurs against an unfavourable situation, it would possibly cause more risk than it resolves (not only in terms of situation awareness, but all flying tasks). A few example comments in the survey were:

- Flying with other pilots I have noticed they are distracted when their portable devices loose connectivity resulting in frozen display due to no GPS and also no traffic information.
- It's just one more thing to set up and remember before you take off, a distraction from the proper conduct of a flight.
- Can look at the device too much instead of looking outside, particularly when trying to adjust display
- When the EC GPS signal fails, it’s a major distraction having to troubleshoot it and get it working again.

Visually acquiring the wrong aircraft

Several comments in the survey suggest that when pilots see an aircraft where they expect to see it based on the EC return, then they reasonably assume they have acquired the EC target and stop looking any further. However, If the acquired target is not the EC target (and even worse, a non-EC aircraft), this could lead to increased risk. Examples would be a pilot dismissing the EC threat (including alerts) because they are assessing the threat from the wrong aircraft and reduced look out in that area.

Example comments are as follows:

- Having seen an aircraft which was depicted on SkyDemon, assumed that was it, only to miss a second aircraft NOT shown the system
- Sighted another aircraft. FLARM warning which I assumed was the identified aircraft. However, there was a trailing aircraft that I hadn't spotted and the aircraft I was concentrating on didn't have FLARM. No danger in this instance but the confusion could have had more serious consequences.
- My EC was going off with frequent warnings unfortunately the aircraft that flew five feet above me wasn't using any kind of EC. He was visitor and hadn't read the briefing about OH joins and completed a non-standard join.
- Picked up one target that then became a distraction from (nearly) missing another and more threatening target

Systematic head-down operation

A large proportion of comments suggest that EC has promoted a shift in operating from 'head-up' to 'head-down', as if changing from VFR to IFR operation. It is impossible to validate or verify this from surveys or narrative data, but many comments are heavily suggestive of this.

This would represent an extension of the distraction phenomena explained previously. Rather than attention being captured or distracted by EC, the attention is systematically focussed on EC as a normal part of the overall task. The use of EC has enhanced a plethora of tactical/strategic electronic information that allow pilots to operate in a near-fully IFR manner when flying VFR. This phenomenon would be a habitual preference as opposed to a distraction. The net effect would be systematic degradation of pilot look-out, as opposed to intermittent degradation of look-out where distracting EC situations arise. Almost all comments alluding to this issue come from the fixed wing <5700kg aircraft category (which is also the main category of respondents). As before, the risk is obvious when the incomplete nature of EC is considered. Examples of comments alluding to this phenomenon are:

- Easy to fly by a screen and not as you should keeping a look out
- tends to invoke a "head in cockpit" approach to flying - have also noticed it when flying with other pilots
- looking up from tablet… to find tug and glider passing left wing half a mile.
- I have noticed that fellow pilots now spend too much time with head-in-cockpit visually absorbed in looking for traffic on EC linked displays.
- EC does encourage a "heads down" culture
- One of the other pilots in my (small) syndicate spends more time looking at the [EC] display than looking out of the cockpit window, which I find disconcerting, if not downright dangerous.

The data supporting this phenomenon are opinion-based (as opposed to being based on recalled events), though it is further supported by the number of pilots/instructors who believe they have directly observed this when flying with others. The phenomenon is theoretically possible and has a number of potential theoretical drivers. Objective research (almost certainly of an experimental nature) would be required to inform this issue further.

Improved Lookout

Directly contrary to the above theme (head-down), a number of pilots opined that EC had improved their visual lookout in general. The main mechanism cited could be described as greater 'look-out drive' motivated by a general raising of awareness after using EC (including the density of traffic and how difficult other aircraft are to see). Examples were:

- Now that I know how many aircraft are out there, I've significantly increased my visual scan period.
- Does it make one complacent? I don't think so. In fact it prompts me to look out more than I might otherwise have done.
- I find EC improves my visual scan, as one is prompted to look out further than before.
- EC… reminds the pilot to be aware of other aircraft and to maintain regular visual lookout.

Despite being contrary to the 'head-down' phenomenon of the previous section (which was opined by a larger number of respondents), this 'improved lookout' idea nevertheless appears quite possible and also has some potential theoretical 'drivers. A realisation that one is not seeing threats as easily as one had believed (or expected) could motivate intentions and might even generate a greater feeling of a 'need for awareness', and therefore improved look-out. As with many such themes emerging from the survey, experimental research would be required to explore this (whether it exists, to what extent, its longevity, etc).

Audio Alerts

The issue of audio alerting was frequently brought up by survey participants, indeed there were a very large number of comments specifically relating to audio. Almost all the comments fell into three themes.

1. Theme 1 – Direct benefit: The positive effect (mostly inferred from CIT comments) of audio alerts catching attention and alerting the pilot to a potential conflict. These were mostly as part of the recalled anecdotes in the CIT+ (Q22) questions.
2. Theme 2 – Indirect benefit: Facilitation and promotion of more 'head-up' time and therefore better look-out (less attention needed on the EC display).

3. Theme 3 - Negative impact of audio alerts; mostly relating to distraction and noise (usually in busy traffic environments). This is similar to the previous sub-section relating to 'noise', except in this case it is specifically related to audio alerts.

Theme 1 Examples (direct benefit)

- PAW alerted me by audio of an aircraft at my level crossing my path some 2-3 seconds before I saw it. I took avoiding action by descending as whilst they should have given way they did not.
- I received a traffic warning [audio], upon looking in the indicated direction I saw another aircraft closing fast that I hadn't previously seen in my visual scans
- Flying along, when I hear in my ears (relayed via SkyDemon): glider ahead, 12 o'clock, same level, range 6NM, reciprocal heading. I look for the glider, which is almost invisible, find it when the wing catches the light briefly and make a minor adjustment in heading to move out of the way.

From theme-1 comments it appears that audio alerts can achieve the intended and direct benefit of bringing pilots' attention to potential threats.

Theme 2 examples (indirect benefit):

- My device is very good but it draws you to look in at the screen instead of looking out. The audio warning helps a lot.
- Few [negative implications of EC] provided the device has an audible warning so that pilots are not glued to the screen.
- Tendency to spend more time looking at the yoke mounted iPad- that's why audio warnings through the headset are a big bonus

Theme-2 comments were mainly opinions that were regularly expressed in Q24. However, they are very consistent and frequent (especially considering Q24 was not asking for comments about EC benefits). A common view can be deduced that audio alerts assist in reducing systematic head-down effects and visual distraction (caused by looking at EC) and therefore free-up pilot resources to look outside more, with the ultimate aim of maintaining visual lookout while using EC. This sounds credible, despite the evidence all being subjective in nature. In theory there are theoretical reasons both for and against such a benefit, and future work of an objective experimental nature would be required to examine this.

Theme 3 Examples (Negative Impact of Audio Alerting):

- joining the busy circuit at Turweston the audio callouts for other traffic where overwhelming.
- Too many audio warnings when thermalling in gaggles
- Sometimes have to unplug the audio warnings as they can be distracting especially when the radio is busy or when landing.
- landing at Sherburn recently where the circuit was busy and several aircraft were awaiting at the threshold, the audio warnings were constant, especially on final, and could have become a distraction.
- I have had problems with audio drowning out other radio communications. On one occasion, I passed Wycombe during a gliding competition and for some minutes all I could hear were descriptions of nearby contacts. At my local airfield when on final approach, there is a gliding site within two miles and contacts are called at critical moments in the approach. It is why I no longer use the audio facility
- Sometimes have to unplug the audio warnings as they can be distracting especially when the radio is busy or when landing.

Theme-3 comments were in the form of opinions (e.g. from Q24) as well as reported experiences (mainly -CIT, Q23). Theme-3 audio alerting was a very large category, with many comments. However most were similar in nature, focussing on the noise and distraction in busy traffic situations. Many respondents claim to have switched off or reduced the volume the audio alerts in such circumstances, and some claim they no longer use audio for these reasons. The other main negative issue raised was in relation to audio alerts masking or being confused with ATC/radio.

From the above discussions it can be concluded that audio alerting creates a conundrum. Pilots find audio alerting very beneficial (both directly and indirectly) in relatively low volume traffic environments. However, and in general, the busier the traffic environment, the more detrimental audio alerts appear to become to safe operation. This creates something of a paradox, because busy traffic environments are more likely to generate potential collisions (see literature review) yet based on these data it is these situations in which EC alerts are felt to become not only of less use, but potentially hazardous.

Attribution of causality

Many pilots gave examples in the CIT+ question (Q22) of having to avoid another aircraft that did not appear to avoid them. A large number of respondents explicitly mentioned that the other pilot took no action, whereas very few mentioned the other pilot taking action (and in those cases the action was mutual). In most cases, respondents tended to recall the event in a manner that attributed the safe outcome to themselves or attributed the near-miss situation to the to the other pilot. A few examples are:

- The twin took no avoiding action and clearly had not seen me. Too many GA aircraft not using devices picked up on my SkyEcho2.
- On three separate occasions, a fixed wing aircraft on approach, whilst I am on final (and have announced I am on final) has undertaken me within 100ft - my PilotAware has warned me it is about to happen and I have been able to rapidly climb out of the way. One plane had no EC, two had SkyEcho and swore they had no visibility…!
- Flying back from Popham, two faster aircraft were catching me up and they were 150 feet above me and obviously couldn't see me below them… so I moved right, out of their way. Tried talking to them on safety comm but got no reply!
- Aircraft picked up on PilotAware… watched him approach and pass close. It was mine and passenger's opinion that he never saw me until within one hundred yards. He did not have any EC device.
- Aircraft detected on EC closing on me from behind. I veered off original track and saw the aircraft going fast right down the track where I had been as if he had never seen me!

In these situations, both aircraft must have had EC of some sort, despite some comments to the contrary. Whereas the respondents' EC detected the other aircraft's EC, the respondents' EC was not being detected by that in the other aircraft (EC incompatibility or technical issue). Hence the 'other pilots'' choice of EC was at least half the reason that the respondent was able to detect and avoid them. Similarly, the respondent's own choice of EC was half the reason the other aircraft was 'blind' to them. In other words, the cause of the situation was probably 50/50 despite many respondents relating such anecdotes in a manner that implied some fault on the part of the other pilot.

Given the answers to Q21 (where 23% of respondents reported feeling 'cross' with others for not making the same effort) it is possible that a socio-cultural phenomenon is occurring. This is understandable given the feeling that one's life might be put at risk by the decisions of others (and these decisions are outside one's control). Where others are not using any EC, this attitude is at least justifiable. However, in many cases, it appears that pilots extend this unfairly to others when they mistake incompatibility for no EC. If a pilot can detect an aircraft on their EC, then the detected aircraft must have some form of EC.

Pilot Anxiety

Many pilots commented on feelings of anxiety that EC produces. These were usually where EC warns of aircraft that cannot then be found visually. This may seem trivial but could be distracting and deleterious to the flying and look out task. Some examples are as follows:

- Aircraft targets displayed do cause some anxiety if they can't be found visually.
- Distraction is a problem, and can induce stress and anxiety
- PilotAware yellow and red circle cause anxiety when I can't see the target but I don't know where to look.
- It can be a bit disconcerting when more than one aircraft is on the screen.
- …signal kept disappearing and reappearing on screen which was unnerving
- Apparent aircraft flew towards me and seemed to fly very close and on same heading for several miles before turning away. Never saw the aircraft visually but it caused panic.

P2 EC-usage

Some respondents related good experiences when using EC as a P2 or involving the P2 (even a passenger). For example:

- Glider FLARM showed up on Sky demon, my passenger spotted it on the SkyDemon iPad display we both saw it late close but in time for an avoidance.
- EC works better with a P2 in the right-hand seat monitoring the EC for traffic and getting the visual on that traffic, so P1 can concentrate on a wider lookout scan.
- When flying two up, one has to keep lookout while the screen is being watched.
- Still a distraction when flying solo. Best when two flying with on I/c the aircraft and one monitoring the devices.
- It’s a good idea to go out in the p2 seat with someone else until you gain confidence and familiarity with it.

Such comments imply the use of a CRM (multicrew) approach to EC. This makes sense when considering the numerous distraction and workload challenges that have been discussed, as well as the need to actively resist the temptation to assume full coverage. Clearly however GA is often a single pilot activity, and so cannot be relied upon.

PART D3 – COMMON CONTEXTUAL THEMES

Many comments explicitly mentioned phases or situations in which EC had proved either helpful or unhelpful. These are laid out below.

1. Circuits (including approach etc)

Nearly 10% of CIT+ specific comments involved the circuit, or parts thereof. Examples were:

- I was joining… and announced downwind. Another aircraft joined on base at same level without announcing. I spotted this on PilotAware/Skydemon display and dived under the other aircraft to avoid.
- A busy fly-in event. Having EC allowed me to 'see' 6 aircraft in the circuit prior to joining it.
- Being able to see exact position of aircraft helped me to plan my arrival to avoid potential conflict.

The examples came from across the conflict avoidance space (Figure 13); from imminent avoiding actions to the usage of EC to plan joins before arriving. This reflects the enhanced mid-air collision risk referred to in the introduction.

2. Weather

Many comments involved specific mention of risks due to weather, and the benefit of EC in such situations. These included the following themes:

- Clouds masking visual targets
- Aircraft sharing levels due to skimming above or below cloud layers
- Sun and glare
- Reduced VFR and poor visibility
- IMC

Several such comments could suggest that EC is occasionally used as part of weather-related decision making or operational decisions (risk-based decision making).

3. Gliders

About 15% of comments (estimated) specifically mentioned gliders as the avoided targets (or made general comments about gliders) despite most such responses being from pilots in a non-gliding category. Many comments implied or stated that gliders were problematic in terms of see-and-avoid. Examples were:

- EC useful near glider sites
- Many occasions with gliders
- Gliders, difficult to spot and flying in unusual patterns, i.e. circling in thermals. EC invaluable when I found myself flying through a glider competition one time. Gliders everywhere and EC allowed my safe path to be planned

There may be a number of reasons for this, including the proliferation of FLARM within the glider community, the fact that gliders can be extremely difficult to see, and situations where many gliders fly in close proximity (thermals, near clubs, competitions, etc). It is understood that as of the present time, more glider pilots are adopting ADS-B capable CAP1391 devices, increasing the chances of detection. The thin wings and fuselage of a glider are the hardest to see when head or tail on, and that makes a non-manoeuvring glider on a straight-line track extremely difficult to spot visually.

PART D4 – INFERRED FREQUENCY OF EC-ASSISTED AVOIDANCE

The positive CIT question (Q22) asked pilots to recall situations in which EC helped them avoid another aircraft. It could be proposed that the number of pilots experiencing such an event might be inferred from the proportion who filled in Q22 (against those who did not). The answers to quantitative survey question Q21 can be used to assess this further (Q21 asked a similar question but in terms of frequency of occurrence).

Q21 answer	Number who recalled one (or more) EC avoidance events in Q22	Number who did not enter EC avoidance events in Q22
Once or twice	375	426
Several occasions	143	199
Many times	203	82
Total	**721**	**707**

Table 5. The number of pilots who made a comment in Q22 (positive CIT) about avoidance by EC (left column), against those who did not (right column), broken down by response to Q21.

Table 5 above shows the relationship between pilots' answers to Q21 broken down (left and right side) by whether or not they offered an avoidance anecdote for Q22 (pilots who used Q22 to state that they had not experienced such an event were not included). Note that pilots who answered, "don't know" (Q21) are not included.

Table 5 shows that pilots who reported 'many' such cases (in Q21) were much more likely to offer an anecdote (Q22) than not offer an anecdote, whereas those pilots who reported having one, two or several such events (Q21) were a little more likely to omit Q22 than to describe an event (although not significantly). This might simply be a factor of 'availability', meaning that pilots with more available and describable anecdotes are more likely to relate one, or are more likely to want to relate one.

Fundamentally, Table 5 shows that there were many pilots (707 in total) who reported that EC had saved them from an AIRPROX or collision at least once (Q1) but did not enter a text comment in Q22. This means that the number of text comments in Q22 probably underestimates the number of pilots who have experienced such an event. Additionally, some pilots offered a number of events in Q22. Thus, the survey data suggest that perceived near-misses are regularly avoided by EC.

PART D5 – CONCLUSIONS/SUMMARY PART D

Assuming good faith and reasonable perceptions in terms of comments, results suggest that as well as being used for its original intention, pilots are extending the use of EC into the overall operation. Specifically, as well as being used to prompt or support visual see-and-avoid, it has also become integrated more widely into the overall flying management task. Most EC usage can be represented on two continuums (Avoidance to Strategy, and Visual-only to EC-only). These form a 2D conflict avoidance 'space'. This means that whereas pilots do use EC to avoid immediate threats (either by directing their visual gaze to the conflict, or by basing the action solely on EC), they also use EC tactically and strategically to take action, usually beyond visual range, in order to reduce future threats. Furthermore, some pilots report situations that imply that EC factors into some risk-based decisions. The implications of this extended EC usage are unknown; there may be both benefits and costs in terms of safety. However, there should be concerns around such task-integration given the incomplete nature of UK EC.

Many comments suggest some 'reliance' on EC within the tasks of look-out, avoidance and overall operation. Comments imply that EC is felt to be 'essential' in certain situations, or that pilots feel uncomfortable flying without it. A number of comments strongly suggest a mindset in which there is an unconscious expectation that all traffic is presented on EC. This supports the quantitative findings related to EC (assumed full coverage, over-estimation of coverage, and false-sense-of-security). Moreover, many participants used the phrase "false sense of security", as well as "over-confidence" and "complacency". Hence both the quantitative and qualitative analysis point in the same direction. Augmented and accessible information (such as when laid out on a 2D screen) is very compelling and as EC is perceived as reliable it would offer greater expected 'value' than looking outside. It is easy to see how EC could displace look-out (inadvertently). The risk of this is clear where the probability of detecting other traffic on EC is only 50% on average.

The largest group of themes to emerge related to distractions. Direct distractions could be categorised as (1) distraction from the operational task priorities (2) distraction by an overwhelming amount of information, (3) distraction caused by searching for EC targets, and (4) distraction caused by interacting with the device itself (adjustment, diagnosing a fault, etc). Audio alerts were also mentioned a lot in this respect, especially as being overwhelming in busy and critical areas. Another distraction-related theme was 'head-down operation'. A large number of comments (particularly from GA fixed wing pilots) suggest that EC promotes a shift in operating from 'head-up' to 'head-down', as if going from VFR to IFR operation. By doing so, the attention becomes systematically focussed on EC as a normal part of the overall task.

Tactical and strategic EC would use almost certainly factor into this. The net effect would be systematically degraded pilot look-out, with the accompanying risk of 50% undetected traffic. Many described distractions were of no benefit, such as looking for EC aircraft far beyond visual capability or when no threat to oneself. Other described distractions were actively unsafe, such as overwhelming amounts of ‘spurious’ information when in a circuit or busy situation. Most such issues would be considered matters of workload management, but workload management is particularly challenging in single pilot operations. All distractions could add risk, with little compensatory benefit, especially given incomplete EC detectability.

There appears to be some safety-paradox in terms of EC usability. Pilots often mention being overwhelmed by EC targets and alerts in busy situations (such as circuits, formation flying, glider gaggles, fly-ins, etc). Yet, as shown in the literature review, these sorts of situations and phases account for most mid-air collisions. In such situations pilots report the EC being ineffective and distracting, and this often results in them ignoring the EC and alerting (cry-wolf) or even switching it off. Hence it appears that EC is least effective and most deleterious to the task when mid-air collision risk is highest. Even if EC were universal and compatible, in its current form it would still be least effective (from a human factors perspective) in situations where aircraft are most likely to collide.

Emotions and attitudes were raised in two main areas. The first was attribution of blame to other pilots. When offering avoidance anecdotes, many respondents attributed the safe outcome to themselves (detecting, manoeuvring, etc) and/or attributed the problem to the other pilot (sometimes stating that the other pilot had no EC, despite their aircraft being detected on the respondents EC). This supports Q21 findings whereby pilots express negative emotion towards others they do not detect. This is understandable given the feeling that one’s life might be put at risk by the decisions of others (out of one’s control). However, in many cases, it appears that pilots extend this unfairly to others when they mistake incompatibility for the other pilot not having EC, or not being engaged in avoidance. The second area was pilot anxiety caused by EC. This was especially strong where pilots related detecting converging aircraft but not being able to see them. Words used included ‘panic’, ‘stress’, ‘unnerving’ and ‘disconcerting’.

Positive comments included lookout improvement (prompted by seeing or learning how many other aircraft there were around them, due to EC), audio alerts catching attention without the need to look down, and ‘crew’ EC usage (e.g. the benefits of using EC as a P2/PAX).

PART E – Flight Trials

Full scientific research was outside the scope of the study.

A small number of flight trials were undertaken using eye trackers (in a limited manner). Such analysis cannot fully support or refute the survey results, only help to explain, describe and illustrate them. The trial flights were used to support (or otherwise) survey findings, add ecological validity, add meaning and context, and provide illustrative examples. The Trial Plan and assessment is shown as Appendix E.

All participants willingly volunteered and were briefed (except on the precise experimental purpose of lookout and EC). They fully understood the de-prioritisation of the experiment over both flight safety and participant needs. For example, all understood that they could remove the glasses at any time (or request help removing them) for any reason whatsoever and without needing to give a reason. All understood that they must remove the glasses if they felt at any time that the glasses/experiment compromised their performance, vision, attitude, or any safety issues at all. The experimenter was satisfied (Informal assessment) that the participants fully understood this and were genuinely willing to take part. The participants also wore and tested the glasses out of the aircraft as well as inside the aircraft prior to start and were asked whether they were still comfortable to (1) wear them and (2) fly with them on. Debriefing found that all participants felt there were no issues at all with wearing the glasses (flying or otherwise) and that the glasses did not affect the way the performed; they felt they acted completely normally (a common comment was that they forgot about the experiment).

Where possible after the flights, participants were shown some pieces of footage from the tracking, and asked questions where clarity was needed.

PART E1 - METHODS AND EQUIPMENT

Pilots were chosen from a pool of volunteers, and a subtle check was made that the pilot used EC. Each pilot flew at least one sector accompanied by the experimenter, in an aircraft with which they were familiar and current. A set of 60hz SMI eye tracking glasses were worn by the pilot and operated by the experimenter using a small laptop or portable data recording unit.

Pilots were told that the study was a test of the eye tracking equipment in general aviation aircraft, and not told that the lookout or EC was the focus of the study. This was to avoid skewing pilot behaviour (intentionally or unintentionally) to the lookout / EC tasking, which would be detrimental to the 'research' and potential impact upon pilot normal behaviour, thereby introducing safety implications. Pilots were briefed on the eye tracker, calibration, etc. They tried it out on the ground, both before and after being seated in the aircraft. Pilots were told that they could withdraw from the study at any time.

PART E2 - SUBJECTIVE ANALYSIS

The eye tracker footage was assessed subjectively (using knowledge of the flight and what happened). All EC related events were reviewed for reactions, scanning and behaviour and compared to the survey findings. Where possible periods of data were compared from equivalent non-EC periods or events (e.g. no traffic, no EC, visual acquisition of non-EC traffic, etc). Scan-path mapping was conducted on small EC segments and comparable non-EC segments in order to produce objective scan data demonstrating EC usage and equivalent comparable performance without EC.

PART E3 – RESULTS

The experimenter was satisfied that the scanning was realistic in all flights and unlikely to have been impression managed. This judgement is based on expertise (over a decade of analysing pilot eye-tracking) and from the observations and de-briefs.

Flight Trial-1

- Date – March 2023
- Aircraft – DHC Chipmunk
- Location – Turweston Airport
- EC equipment – SkyEcho 2 displayed on SkyDemon, positioned on knee pad. Aural alerts though second 'bone conduction' headset.
- Weather: Overcast, fair visibility.

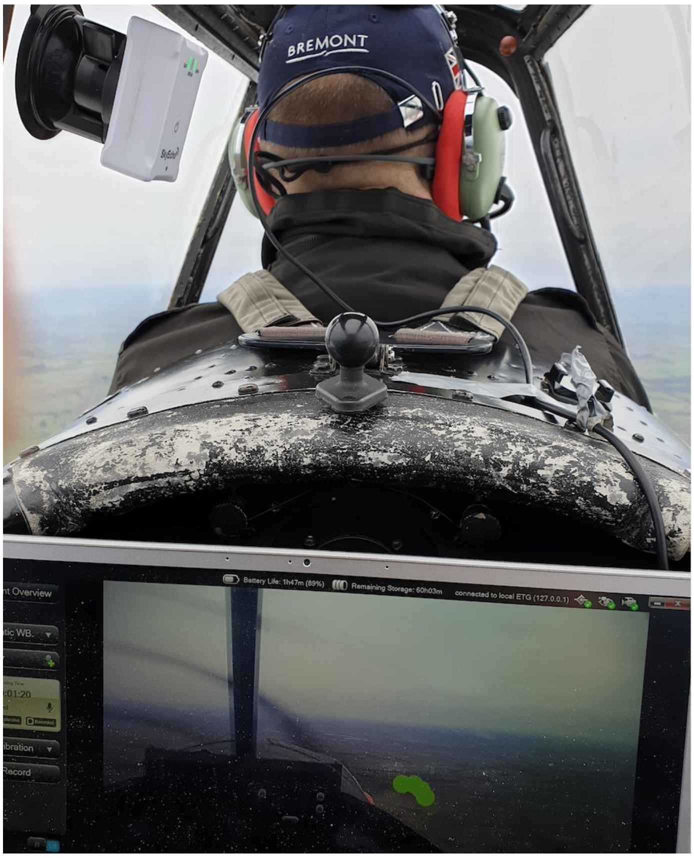


Figure 14 – Experimenter view during initial trial. Experimenter’s screen shows the eye-tracker scene camera (HD) with eye-point overlay.

The experimenter was accommodated in the rear cockpit (see Figure 14). Eye-tracking proved successful and practical. The pilot experienced no issues wearing the glasses throughout the flight (start up to shut down). The flight is shown below (Fig C15).

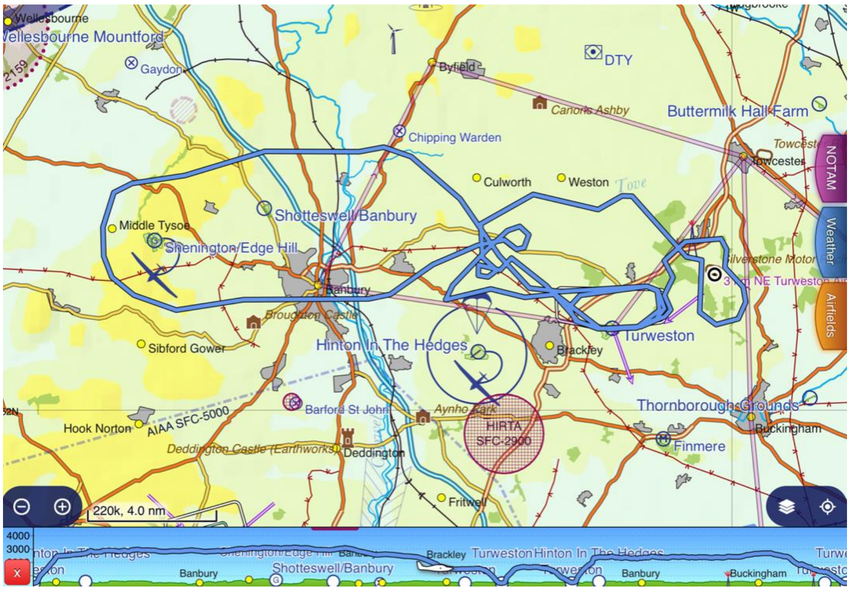


Figure 15 – Route taken in initial trial

Although not fully valid for the purpose of scientific investigation (the pilot was aware of the purpose) this first trial did show some important results.

Several aircraft were visible on EC despite it being a relatively light flying day. Visual acquisition on several targets was made at about two miles after much searching. Both these aircraft had relative movement, strobes, and were seen against contrasting ground. Even at two miles it was agreed that the aircraft were tiny targets and not easy to visually acquire (‘pick-out’). Indeed at two miles, these aircraft were too small to show up at all on the HD scene-camera of the eye tracker.

Returning for a circuit to land, several aircraft were shown on EC and visually acquired (within two miles). However, a different aircraft passed very close on a reciprocal heading (slightly below) that had not been detected by EC. Closest distance may have been 300m. See the action sequence of photos below (Figures 16 a to c).

Both the experimenter and pilot had assumed that aircraft calls on the radio were from the aircraft showing on the EC, so the close appearance of the non-EC aircraft was unexpected and surprising. The pilot reacted immediately by rolling to the right.

This event is related the theme *visually acquiring the wrong aircraft* (see PART D2, under distraction) that emerged from the survey data. It is a distraction effect of EC, but instead of visually acquiring the wrong aircraft, the pilot absorbs evidence from multiple sources into the EC target, potentially leaving the pilot with the feeling that there are no other aircraft, despite evidence from other sources such as radio calls. This is a result of quite normal confirmational thought processes. This is a potential risk, because the pilot can 'let down their guard' due to the belief that evidence of traffic is all coming from one aircraft. It is not possible to know whether without EC the pilot would remain more widely alert for the traffic, but the salience and 'expected value' of EC probably exacerbates the issue considerably, and offers a false sense of security, as raised in the survey.

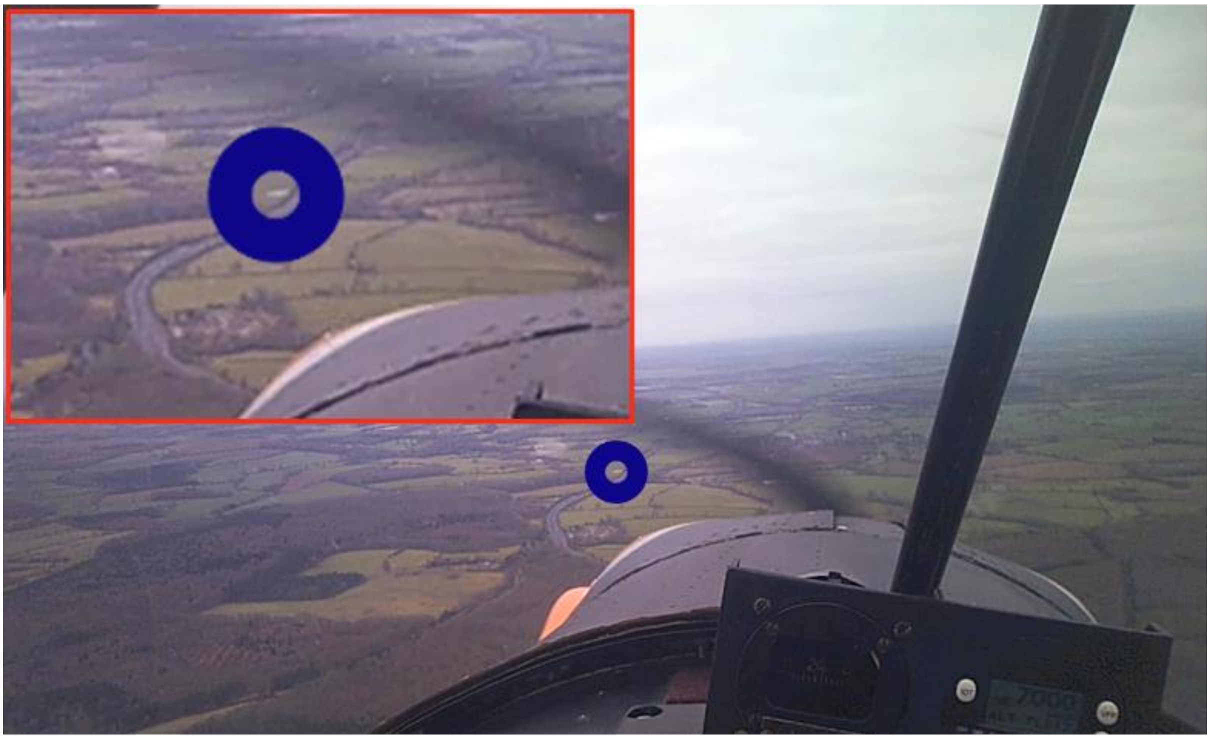


Figure 16 (a) - Undetected aircraft in circuit, sighted ahead (eye tracker symbol in blue). This caused the pilot to roll right immediately (roll already started in photo). The aircraft was much closer than the impression offered by the photo.

Figure 16 (b) – Right roll avoidance. Looking back at target aircraft, about to pass under the wing. Eye tracker symbol in blue. The aircraft was relatively close (closer than it appears on the photo).

Figure 16 (c) – Rolling back onto heading. Looking back at target aircraft (eye tracker symbol in thin red, changed in order to show aircraft more clearly). The aircraft is very close (the photo offers a misleading impression of distance).

To summarise, there are a number of key points supporting findings from the literature review and survey:

1. General aviation aircraft at two miles range are extremely difficult to acquire visually, even in very favourable conditions and without facing glare.
2. It is probably unrealistic to expect to visually acquire general aviation aircraft over two miles away.
3. Aircraft were in proximity without showing on EC
4. A real example of how EC can create a misimpression of traffic (false sense of security) was demonstrated. Both crew members assumed that radio calls were from the EC-detected aircraft, leading to the surprise when another aircraft appeared very close ahead and passing. Hence, despite evidence of two aircraft (radio calls and EC), the crew were only expecting one and had probably relaxed the look-out for the other. This was despite crew members having a realistic knowledge of EC coverage and knowing the survey results.

In terms of the eye-tracker usage, the participant said it felt little different to normal glasses, did not impact their flying or performance, and they forgot they were wearing an eye tracker.

Flight Trial-2

- Date – May 2023
- Aircraft – Robinson R-66
- Pilot – Low hours CPL, 20-30 years old, assessed as very competent by examiner, familiar with EC.
- Location – Bournemouth Airport
- EC equipment – SkyEcho 2 displayed on iPad, positioned below eye-level to pilot's right in a holder.
- Weather: 10k, some sunshine, some low cloud.

Figure 17 – Aircraft used for Trial-2

Two sectors were flown; Bournemouth to Lee-On-Solent and Lee-On-Solent to Bournemouth (see Figures 18 and 19 below). The experimenter was accommodated in a rear east. A collaborator (helicopter instructor/examiner) sat next to the pilot. The pilot wore the SMI 60hz eye tracking glasses throughout. Occasional direct sunlight caused brief losses of eye tracking.

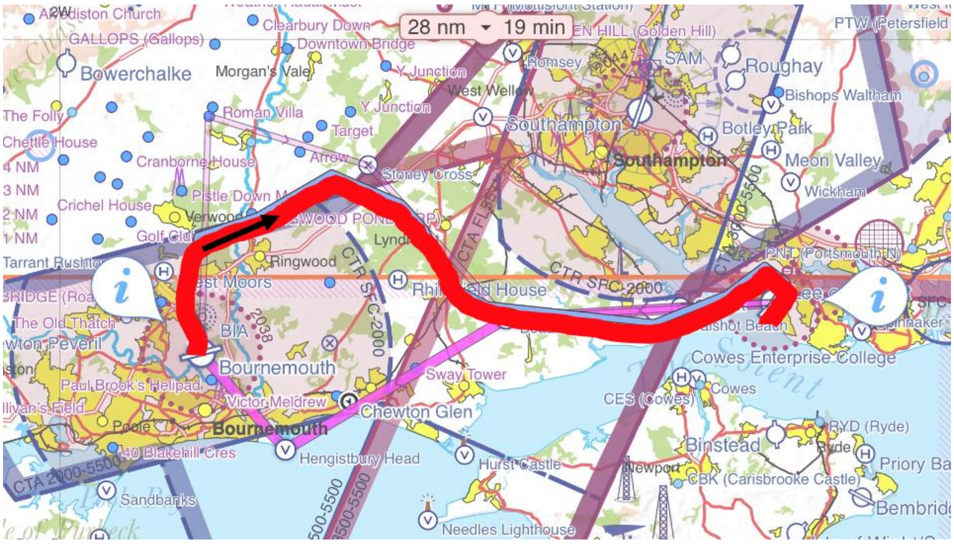


Figure 18 – Outbound sector

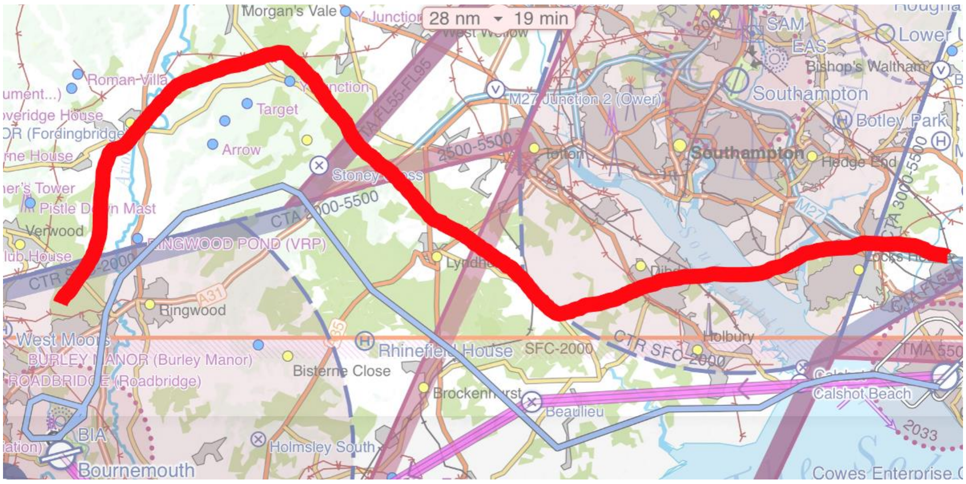


Figure 19 –Inbound sector (bottom)

No EC detections were seen in the outbound sector. However, three aircraft were spotted visually; two fixed-wing aircraft passing on a reciprocal heading to our left and right (between 1 and 2 miles away) and one (an R-44) on the same heading, keeping station in the R-66 pilot’s 4 o’clock, at about one mile distance. One fixed-wing and the R-44 were heard on the radio (it is assumed). Eye tracker footage was analysed subjectively and it was determined that the pilot retained a wide-ranging lookout (between other tasking, including tactical tasks and instrument monitoring). It focussed around the horizon with frequent scans of variable short dwells. This can be termed the ’undirected’ lookout task. The visual behaviour appears normal (in terms of fixation rates, patterns, etc). The scan-path is shown below (Figure 20).

Figure 20 – Scan path for forty second period on the outbound leg (demonstrating the lookout task; undirected). Template represents approximately 140 degrees visual field.

An equivalent lookout segment (45 seconds) is shown below for the return (inbound) sector. This was taken when there were no EC returns on the iPad. In line with the outbound sector, it shows a wide lookout task, however it should be noted that this segment was chosen because it represents a period that included active lookout.

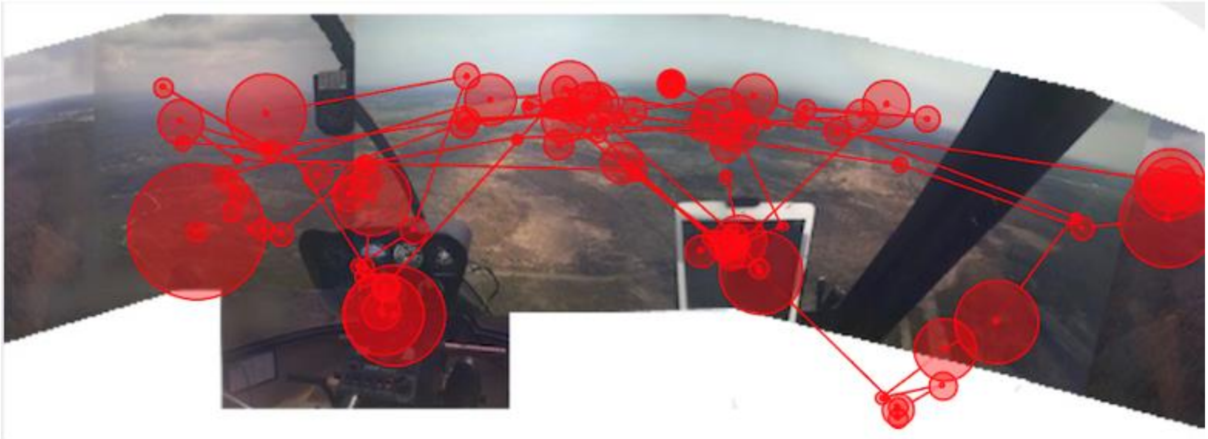


Figure 21 – Scan path for forty-five second period on the inbound leg (undirected lookout task)

One EC detection was made on the return sector (prior to the segment in Figure 21 above). A fixed-wing aircraft the 12 o'clock position was picked up on the iPad screen by the collaborator at approximately 10-12 miles. Several radio calls were assumed to be from that aircraft. The aircraft was destined for Bournemouth despite being on a reciprocal heading at that time. Eye tracker footage was analysed and showed the pilot spent two and a half minutes (from time of EC detection) searching for the single target (EC-cued scan) The scan path diagram for the first 60 seconds is shown below (Figure 22). It is worth noting that the whole 150 second period is very similar to that shown in Figure 22.

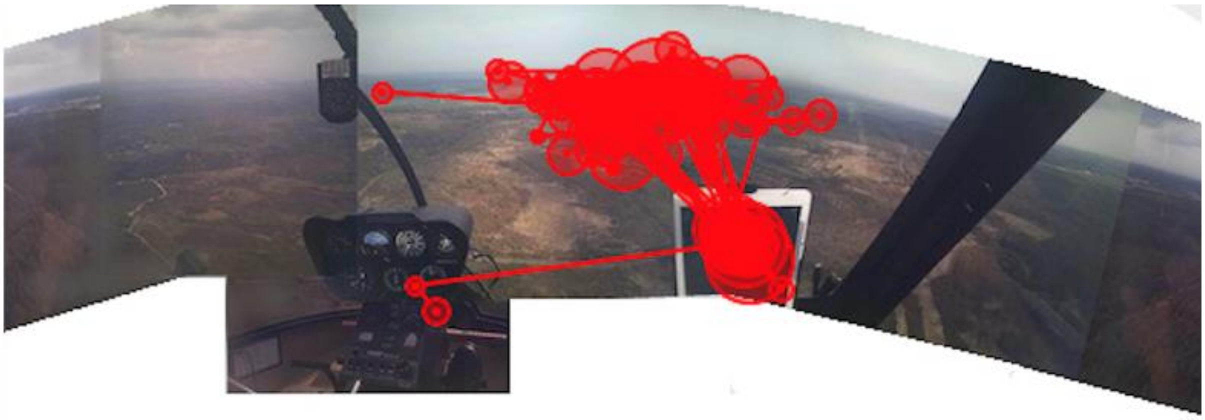


Figure 22. Scan path for 60 seconds immediately following the pilots noticing an EC target on the iPad, in the 12 o'clock position at between 10- and 12-miles range. This is the EC-cued lookout scan-path.

As seen in Figure 22 above, unlike the 'normal' lookout scan-path, the EC-cued scan was mostly limited to the iPad and the area where the target was presumed to be. This scan path is noticeably different to the lookout segments of the first sector (as can be seen without applying statistics or advanced analysis).

During the search, the experimenter (rear seat) observed both the collaborator and pilot searching continually for the target ahead for about two and a half minutes, with seemingly very little attention given to any other areas or other lookout. Additionally, during this period the experimenter observed that all communication between the pilot and collaborator was about the target and related to the search for it.

The EC-detected aircraft was spotted (at 1 – 2 miles) diverging to the right, slightly below. Looking right resulted in the pilot spotting another aircraft in a slight turn, slightly above, at about one mile. There was some disagreement about what this aircraft might have been (including a GA twin, and an airliner in the distance).

After landing, an opportunity arose to talk to the pilot of the aircraft from which the radio calls were heard (assumed to be the EC aircraft). Additional data was also reviewed.

The actual situation appears to have been as follows: the Bournemouth bound aircraft making radio calls was NOT the EC target in the R-66's 12 o'clock (that the R-66 crew assumed it to be). Indeed this aircraft (an aircraft from Leading Edge based at Oxford) had only a transponder, despite being a very modern aircraft with advanced GA avionics. The pilot of this aircraft had visual with the R-66 for some time and was slightly above. It is highly likely this aircraft was the one seen briefly afterwards, in a slight turn. The pilot of that aircraft had seen a motor glider in the position similar to that of the EC target seen by the R66 crew. Later flight data showed a trace for a motor-glider that matched the position and timing of the EC target. Hence, it is highly likely that the motor-glider (Grob 109) was the EC aircraft in the 12 0'clock, but it was making no communications, whereas the Leading Edge aircraft was making the communications but not showing on EC.

Hence, post-flight information points to the conclusion that the crew fixated their attention in an attempt to find an aircraft that they thought was shown on EC, when in fact that aircraft was to their right (unknown manoeuvring) sufficiently close for its pilot to have the R-66 comfortably visual. The aircraft was approximately in the area shown by the brown circle below, and due to the EC search this area was not visually covered (note, always outside the pilots' scan, due to the EC-cues).

Figure 23. Scan path of EC-cued search, with the approximate position of the Leading Edge aircraft shown by the brown circle, which was not looked in for the whole 150 seconds. The actual EC aircraft (motor-glider) was within the red scan path area, but only visually possible to acquire for the last 20 – 30 seconds of the 150 second period of EC-cued search fixation.

This incident adds more support to the finding of *visually acquiring the wrong aircraft* (see PART D2, under distraction). Additionally, as in Trial-1, the evidence from two different aircraft were mentally resolved into a single aircraft. In this case (Trial-2) the eye tracker shows that the intense searching for the EC target led to a situation where the non-EC aircraft could not have been noticed. The two events (Trial-1 and Trial-2) are mutually supporting, and extend the survey findings.

Conclusions and key points – Trial-2

Key Point 1 – The undirected look-out task (when being conducted) was wide ranging and generally focussed to the horizon, compared to the EC-cued search scan which was highly focussed.

Key Point 2 – The EC-cued search was over 150 seconds in duration (with no wider lookout task taking place during that time) despite the target being between about 2 and 12 miles. Hence the ‘target -fixation’ could be of no benefit for at least the first two minutes, yet it displaced all other look-out. This relates to a strong theme that emerged from the survey data, related to pilots ‘fixating’ on EC (and being distracted from other duties including lookout) despite the EC searches being far beyond visual range and having no chance of success.

Key Point 3 – Not only was the EC-cued search 150 seconds long, but it resulted in the crew not looking for, and remaining unaware of, the aircraft that was actually making the calls (that they thought they were looking for) which was to their right.

Key-point 4 – Radio communications were assumed to be coming from an EC detected aircraft, when in fact they were coming from a non-EC unseen aircraft, meaning that the crew were unintentionally resolving the evidence from two aircraft into one. This aligns with a key finding from Trial-1, regarding non-EC aircraft going unnoticed and ‘unlooked for’ despite radio calls.

In terms of the eye-tracker, the participant felt that it did not impact their flying or performance, and it was perfectly comfortable to wear.

Flight Trial-3

- Date – May 2023
- Aircraft – PA28
- Eye-tracked Pilot – Instructor, approx. 30 years old, familiar with EC. This was an instructional sortie. P1/S was a long-standing PPL (approx 70 years old) low hours per year, gaining proficiency with a view to flying the club aircraft from Bournemouth (previously flew at uncontrolled airfield).
- Location – Bournemouth Airport
- EC equipment – SkyEcho 2 displayed on iPad; handheld and instrument panel mounted
- Weather: V Good visibility, CAVOK

Figure 24 – PA28 Aircraft used for Flight Trial-3

The route was pre-planned and timed for the lesson purposes (not experimental ones). The experimenter was accommodated in the rear seats, and remained silent in the air apart from (1) a brief pre-briefed/practised calibration check (2) response to rear seat checks (e.g. “straps?”), and (3) once pointing out passing traffic.

Due to the time of the flight (about 17:00 – 18:00 on a weekday) there was very little other traffic. Only one EC target was seen, and was never within 15 miles, and was never converging or in a position that would cause the pilot to believe it might come closer. The pilot was aware of the target but made no changes to the flight and did not look at it often.

Two aircraft passed relatively close (potential threats), neither appearing on EC. One (visual target 'A') was opposite direction, very slightly below, and first seen (by the experimenter from the rear seat) passing almost abeam to the left (400-500m distance). This occurred while heading South-West over the Solent, towards the Needles. The other (Visual target 'B') was opposite direction, first notified as approaching Hengistbury Head by Bournemouth Radar and spotted by the instructor just over 2 miles away in ideal visual conditions against the sky. Both these events present interest for the research programme, despite not appearing on EC.

Visual target 'A' (Solent)

Target 'A' converged from an area between 10 o'clock and 11 o'clock, very slightly lower the trial aircraft. Neither pilot saw this aircraft (until after pointed out by the experimenter while passing). It was not showing on the EC. Analysis of the eye tracking footage showed that the instructor had been actively looking out in the preceding three minutes (covering the time Target 'A' would have been visible by eye), including performing wide sweeps and dwelling in the target area (between 10 and 11 o'clock). The conditions were excellent with good lighting ahead and to the left without glare in that area. The three minutes of instructor eye-tracker scanning prior to target 'A' passing, were analysed Figure 25 (below).

Figure 25: Gaze mapping of instructor (right seat) for duration of three minutes prior to target 'A' passing on the left-hand side. The template represents at least 220 degrees of arc around the instructor pilot. The wings are represented in grey, in each side window. Occasional 'over the shoulder' fixations are mapped onto the extreme edge of the field despite being further behind in reality.

Figure 25 shows very thorough lookout coverage by the instructor. Aircraft target ‘A’ would have been low in the left side of the front windscreen (centre panel in figure 25) while it was approaching unseen. Although having less coverage than the right side of the front windscreen, this area appears to receive plenty of lookout attention from the instructor. This is a strong demonstration that despite excellent active lookout behaviour in the area of a potential threat, and perfect visual conditions, pilots can simply fail to notice the other aircraft, even when within visual range.

The target aircraft transitioned to a less-viewed area as it passed down the left side. Figure 25 above suggests that the left side view (between the windscreen pillar and the wing leading edge) is notably sparse in terms of lookout attention. To investigate this further, a heatmap was generated (Figure 26 below). This clearly exposes the lookout ‘gap’, and stark comparison with the coverage from the right-hand window.

Figure 26 – Heatmap of looking time over three minutes, using the same data as Figure 25

The reason for the omission of looking time appears to be the head position of the P1/S (student pilot). In the experiment flight, the relative seating positions (student seat much further forward than the instructor) meant that the normal flying head position of the P1/S precisely occupied the gap between the wing leading edge and the left forward cabin frame pillar (see figure 26, instructor eye-view, below). This was validated as the normal position by checking numerous pieces of footage. As can be seen, this meant that the instructor had no visibility (in their normal head position) within a considerable arc extending from the right (front) edge of the windscreen pillar and the trailing edge of the left wing.

Figure 26 – P1/s position as seen from the eyes of the instructor, precisely filling the visual field between the windscreen pillar and the leading edge. The p1/s silhouette has been slightly disguised.

Occasionally during the flight, the instructor moved their head forward in order to look in this blind spot, but this was usually to see a ground feature. Most of the time, the instructor omitted this area in terms of lookout. It is almost certain that the same thing happens to most pilots and instructors; there are many psychological reasons why the area would become increasingly omitted from the lookout despite them being aware of the risk.

The above provides a strong case for effective EC. The eye tracker shows that despite a thorough and active lookout in good visual conditions, a potentially threatening target aircraft was not seen at all (only noticed when passing abeam by the experimenter in the back). The instructor appears to loo many times in the direction of the target but failed to acquire it, and the target transitions to a less threatening but visually almost uncovered area. These findings support the view that there are deep systematic problems with pilot lookout that cannot be fully resolved through training or expectations around 'better' lookout.

Whereas these lookout problems are a systematic part of see-and-avoid, growing reliance on EC (as suggested in the survey) without full EC coverage or reliable detection, is also a serious risk. EC has the potential to displace lookout (as seen in Trial-2) and reduce propensity for lookout overall (hypothetically; as suggested by survey results).

Key summary points from aircraft target 'A' are:

1) Active and diligent lookout, even including looking towards a threatening aircraft within a few miles range, can fail to notice the other aircraft. This supports (with a documented example) the limitations of see-and-avoid as highlighted by the literature and supports a move to effective augmentation (EC).
2) Obscured areas of sky are vulnerable to being omitted from lookout scans. This also supports effective EC.
3) However, it is worth considering the possibility that ineffective EC may exaggerate and increase these vulnerabilities.

Visual target B (Hengistbury Head)

After requesting clearance back into the Bournemouth control zone from the South (Heading Southwest), Bournemouth Radar instructed the experiment aircraft to report at Hengistbury Head and advised *"opposite direction Cherokee traffic just about to leave at Hengistbury Head"*. At this time the experiment aircraft was approximately four miles from Hengistbury Head, and both aircraft were outside the control zone.

The management of target 'B' provides some interest in terms of the points emerging from the study. Firstly, it was spotted and reasonably long range (approximately 3 miles) and secondly, despite not appearing on EC, it led to a tactical separation decision (to descend) by the instructor before being visually acquired (similar to the use of EC as seen in many survey comments).

Although the instructor made repeated glances to the to try to find the target, it did not lead to search fixation (as in Trial-2). It is possible that this was related to the target being communicated rather than being EC, though this issue would need more research.

About 20 seconds after being notified, and immediately after target ‘B’ reported Hengistbury Head, the instructor visually acquired the traffic, at about 3 miles range. This is further than would be expected based on the reviewed research. The target was extremely small at this range. There are several reasons why a visual sighting was achieved at such a range in this case (and would not represent most situations). Firstly, conditions for seeing the target were noted by the experimenter as ideal (heavy contrast; a dark silhouette against a light sky, with the target well above the horizon). Figure 27 (below) shows the conditions. Secondly, the search was well cued, such that the instructor’s eye-point moved to the right area (Hengistbury Head) as a result of target B reporting their position over Hengistbury Head. Thirdly, the instructor was relatively young with very good eyesight, and the knowledge and experience to know where to look for the notified traffic. Nevertheless, the instructor was unable to find the target for 20 seconds (until the target reported) despite the instructor’s eye-point visiting precisely the same area (that the target was eventually seen in) a number of times. This supports a notion that three miles should be considered a ‘best case’ visual range for seeing GA aircraft (with precise cueing, perfect conditions and contrasts, and good eyesight). Two miles is probably more realistic as a maximum expectation in most situations.

Figure 27 – Image from the eye-tracker scene camera showing the visual conditions. Target aircraft B is arrowed, and about to pass to the left at about 300-400m range (eye-tracker symbol removed). The eye tracker scene camera offers a misleading impression that the target is distant.

Once the target was seen, the instructor focussed on it to a large extent, as would be expected given a closing target.

The key summary points of aircraft target ‘B’ are:

1. Example of pre-visual separation initiative to add perceived future separate (tactical manoeuvring) based on an unseen single target (as suggested happens with EC).

2. Strong evidence that the maximum realistic distance for GA visual acquisition is about three miles (in ideal circumstances and situations), and probably two miles in most cases. This event suggests that searching for a GA EC target beyond these distances is usually unrealistic and could be distraction, which should probably be avoided.

Debriefing

In debriefing, in terms of the experiment, the P1/S said that they forgot about the experiment once in the air. The instructor wearing the glasses felt that they acted completely normally, and the eye tracker presented no problems at all. However, they did point out that the colour of the UV shield took a few minutes to get used to on the ground (slightly different shade from their normal sunglasses) and also that they needed slight head movement to view information at the very bottom of the instrument panel, which they felt they would normally use only eye movement for. However, they pointed out that these were not problems, simply observations.

Flight Trial-4

- Date – 7 July 2023
- Aircraft –RV-9A
- Eye-tracked Pilot – Owner, highly experienced (approx. 40 years), experienced on type. Pilot remained naïve to the purpose of the study (EC specific) until after the flight.
- Location – Dunkeswell Airfield
- EC equipment – TCAS displayed on integral navigational and traffic display.
- Weather: V Good visibility, 3/8 Cumulus with base approx. 3000ft and strong convection

Figure 28–Aircraft used for Flight Trial-4

The experimenter was accommodated in the right seat. The flight took place between about 11:30 – 13:00. The main route was pre-planned, but approximately a third of the way round the experimenter requested changes when it became apparent that no EC targets were appearing in the area being flown. This was an attempt to fly in busier areas within closer proximity to Exeter, Dunkeswell, and North Hill gliding site. Several wide circuits were made of Dunkeswell prior to landing

Despite being a Saturday with good weather, the only aircraft seen on EC as well as visually were airliners (one passing overhead and one approaching into Exeter). One aircraft was detected on EC at very long range (about 12 – 15 miles, diverging, over 2,000ft below, with no likelihood of proximity) and was not seen visually. The pilot was aware of these EC targets but no changes to the flight were required, and the pilot pointed them out on the screen and noted them verbally (and visually in the case of the airliners). There was no significant fixation or effort required to look for these aircraft.

A number of aircraft were seen visually without painting on EC, as follows:

- A white high-wing Cessna close to Branscombe, flying on the opposite heading (East), passing very close to the right of the trial aircraft (about 300 to 500 metres and about 300ft to 500ft below, estimated). This aircraft could not be seen on the eye-tracker scene camera and therefore may never have been in line-of-sight of the trial pilot when within visual range. It was only seen by the experimenter (while passing). If this aircraft had detected the trial aircraft on EC or visually, it nevertheless passed close on the left.

- One white (fibreglass) glider, in a turn, South of North Hill gliding site, about 300ft below and 500m to the right (estimated). Only in a position to be seen by the experimenter.

- Three white soaring gliders circling in a single thermal South of North Hill gliding Site, about 500ft below and within half and one mile to the right. Only in a position to be seen by the experimenter.

- A white aircraft climbing away from Dunkeswell airfield as the trial aircraft was on long final. The aircraft was flying perpendicular and away from the trial aircraft and no threat (about one mile away). The experimenter pointed it out and the pilot confirmed visual.

In total therefore, six aircraft were seen visually, all within about one mile proximity (some much closer) without being detected by the EC. Only one possible GA aircraft was detected on EC, at about 12 – 14 miles.

Observations

The pilot tended not to look at the screen displaying the EC. He showed no tendency to search actively and continuously for EC targets (though there were none in proximity, which is a limitation to this). From conversations, it was apparent that the pilot was well aware of the limitations of his EC and treated it as a 'bonus'. There was no evidence that he used it intuitively as an augmentation to his visual look-out. It is highly likely that the scarcity of general aviation EC detections by TCAS has contributed to this behaviour, and contributed to the pilot maintaining lookout in the normal way. The pilot mentioned being aware that many aircraft do not get detected despite having EC, including friends' aircraft who regularly fly in the same locality or on the same trips.

Eye tracking quality was reduced by the July sun directly overhead the clear canopy (spilling into the glasses, despite the protective sun-visor), the pilot's own corrective lens glasses worn under the eye-tracker, and associated calibration difficulties in flight. Some tracking data were available, although the instrument panel was mostly unreadable from the scene camera due to the brightness on the LCD instrument displays.

Trial Conclusions

The flight trials supported and extended several phenomena raised in the survey, and added significant context and illustrations. Due to limitations and uncontrollable issues such as flight conditions, some survey phenomena had no opportunities to arise (such as avoidance based on EC or tactical and strategic EC usage). However other phenomenon was supported (or indeed uncovered) by the live flight trials. These are as follows:

EC incompatibility and incomplete detection

It was not the purpose of the trials to look at EC detectability levels. Nevertheless, the trials supported the survey analysis (likelihood of detection calculations of 50% average) and indeed supported the further limitations section that argued this as probably an over-estimate). On average across the trials, well over twice the number of aircraft were seen only visually than were detected by the EC. In all trails, at least one aircraft passed close (within 500m) opposite direction without appearing on EC. In trial-2 (R-66) four non-EC visual sightings were noted within a mile range or closer, compared to only one EC detection. In Flight Trial-4, only one potential GA aircraft was detected (distant), compared to six being seen only visually. No gliders appeared on the TCAS, but some grounded gliders were detected by SkyEcho-2 (FLARM subscription) in Trial-1. It cannot be known whether the experimenter's aircraft was being detected by other aircrafts' EC. However, an important limitation is that due to factors such as small sample size by convenience, weather and the need to retain naivety to the EC study intention, the experimenters were unable to control the types of EC equipment in the trials. This resulted in three trials using SkyEcho 2 and one trial with TCAS, but no trials using Pilot Aware.

2-in-1 illusion

The '2-in-1 illusion' emerged from the trial flights, not the survey. The term is coined by the author to encapsulate the phenomenon of resolving evidence of several nearby aircraft into an impression of a single EC target. Despite the term, this could include multiple aircraft. This phenomenon was shown to result in the pilot feeling that the EC target was the only threat (with no suspicion of a second threat) and then prioritising their attention and awareness towards it. Doing so leaves the pilot without suspicion of, and more vulnerable to missing, the non-EC aircraft which is commonly also a threat (the evidence from that aircraft could be resolved into the other). This happened on Trial-2 (R66) and possibly Trial-1 (Chipmunk) in circuit. This phenomenon did not appear in the survey but is related to the emerging theme called '*visually acquiring the wrong aircraft*' and various other EC distraction themes. A probable reason why the survey did not capture this phenomenon, is that pilots will not usually recognise it occurring, and are not likely to know when it occurred. This is because there is no obvious sign that highlights that evidence is being resolved into a single target, even if the undetected aircraft later appears visually (it is simply recalled as a non-EC aircraft that was eventually seen visually). Unless more information is available, then pilots could remain unaware that this occurred. It is probable that a number of survey comments relating to visual avoidance (or even acquisition) of EC undetected aircraft involved the 2-in-1 illusion. This reinforces the importance of deep observations in addition to self-reporting surveys, and also the importance of raising the issue to pilots, because it is unlikely to be learned by experience and pilots could remain unaware that it happens.

It is clear that such a phenomenon could happen without EC (e.g. where a visual sighting is assumed to be the same aircraft transmitting a position). However, EC increases this threat because it picks up the other traffic at far greater distances, and cues the visual search more accurately (than a radio call for example), potentially narrowing the lookout and lowering the probability of seeing the other aircraft. It can also act to lock the visual search away from other non-EC targets for a much longer period.

Narrow EC-visual search scan

Trial-1 and Trial-2 showed that when attempting to find an EC target visually, pilots make many transitions between the EC display and an area estimated to represent it in space. This activity is normal, but it is very narrow, detracts from other lookout, and can last for minutes. Eye tracker scanpath maps from Trial-2 displayed this graphically (Figure 22).

Visual search fixation beyond range

Trial-2 (R66) demonstrated a pilot (and crew, by observation) narrowing their visual attention to a tight EC-visual search scan (mentioned in the previous paragraph) for several minutes, despite the EC target aircraft being up to 12 miles away, and therefore far beyond visual range. This resulted in no wider lookout being carried out during the period. This is a general vulnerability created by EC showing distant targets, and means that non-EC targets stand less chance of being seen (as was demonstrated in the trial, in this case alongside a 2-in-1 illusion).

Tactical manoeuvring on anticipation of threat

Trial-3 confirmed that pilots will alter their tracks or altitude based on traffic knowledge without visual contact (tactical decision making). This is self-evident, and could be considered good threat management / anticipation. However, it is unknown how such decisions manifest in busy EC environments. In the case of Trial-3 the instructor decided to reduce altitude for separation despite no altitude information being offered about the other traffic.

False Sense of Security

Trial-1 and 2 demonstrated the false sense of security that EC provides, even when the crew are fully aware of the partial coverage. This was shown in the long visual search for the EC aircraft in Trial 2, and in Trial-1 the experimenter recalled feeling perturbed to see an aircraft pass so close without painting on EC, despite knowing this was likely to occur.

Useful Visual Range

Trials 1, 2 and 3 all confirmed that maximum useful visual range was up to three miles in ideal circumstances and 2 miles (or less) in normal circumstances.

Other lookout issues (non-EC)

Withdrawal of lookout from blind spots - Trial-2 demonstrated that pilots can unknowingly restrict their look out to unobstructed areas, leaving blind spots unmonitored. In this case the other pilot created an obscuration, and the instructor all-but stopped looking for traffic in that area.

Failure to see target despite correct-area search – Trial-3 showed that despite searching in for a within-range target, in the correct area, that target can remain unseen.

PART G – Recommendations, Training and Practice

The research uncovers numerous avenues that could be followed with a view to future safety improvement, including training, guidance and continued research. A major recommendation is a training programme around EC based on this study and other information. This section puts forward some formative ideas for guidance and training, but this is not intended as a training programme.

PART G1 – HUMAN FACTORS BULLETS FOR PILOTS

Publishing large volumes of text or results is unlikely to be picked up by the aviation community. Because of this, some key usable themes from the survey and trial results have been distilled down into short guidance and knowledge bullets, aimed at filling gaps in current knowledge and addressing some of the issues found.

Top 6 human-factor tips when using EC:

1. On average, EC detects less than 50% of other UK air-users (less than 80% even with the best combination of multiple functioning devices). Do not expect EC to see everything.
2. Aircraft that your EC detects DO *have* EC but may not detect your EC. Assume they CANNOT detect your EC, and never expect EC detected aircraft to avoid you.
3. Attention. Don't spend time *visually* seeking EC-detected aircraft that are:

a. Clearly no threat

b. More than 3 miles away (realistic visual range is under 2 miles)

Doing so can seriously detract from your other flight priorities

4. Assume new signs of traffic do NOT belong to an existing EC detected target, until you know for sure. I.e. avoid the two-in-one illusion.

5. When making decisions, ask yourself "would I do this this if I had no EC?

   …unless the answer is a firm Yes, then *DON'T DO IT…* Do not rely on EC

6. You WILL increase your EC reliance in the circuit, particular under high workload. Try to add thorough visual searches into your circuit, for example as part of your downwind checks.

Four Key Device Management Points with EC

1. Turn off your EC device when on the ground and off the runway. Ground alerts are an unwelcome distraction to others around the circuit and airfield.
2. Use an audio output to augment your visual scan and know how to mute it when you need to do so.
3. Know how to use the filters to remove unwanted screen clutter. Consider the utility of EC targets over 10 miles away and over 5,000ft above/below you.
4. Develop check lists:

a. (Pre-Flight) Ensure portable devices are updated and fully charged, and bring the correct cables/adaptors/device mounts.

b. (Pre-Take Off) Add a note in your FRCs to ensure that the EC device is switched on prior to entering the runway.

c. (Shut down checks) Add a note to turn off your EC device once you leave the runway.

Two key look out vulnerabilities to be aware of

1. The eye tracker showed that even searching precisely in the area of another aircraft within visual range does not guarantee seeing the aircraft.

2. Blind spots and obscured areas naturally fall out of the look-out scan without pilots knowing. If seated with another pilot side-by-side, the pilots could brief this threat pre-flight.

PART G2 - PRACTICE AND FAMILIARISATION ON THE GROUND - GUIDANCE

Technical

Many survey respondents report that seemingly simple processes such as device adjustment can be seriously distracting in the air, particularly if not well practised. So, before flying it is a good idea to practise common tasks such as adjustments of brightness, zoom, selections etc, as well as those that may be for unforeseen circumstances such as powering off/on. Also make a mental plan to abandon EC usage in flight if a lot of attention is required for device reasons (such as diagnosing faults).

Simulator Mode

Use your device's simulator mode (if it has one) to watch the development of threats (what a close aircraft looks like on the EC, when it triggers an alert, what the various alerts sound like, and how they relate to the displayed aircraft etc). This will mean that you will recognise the situation better in the air and are less likely to make perceptual errors.

Responding to alerts

In the cockpit on the ground, use simulator mode to generate alerts and practise moving your eyes in the right direction. If you find this challenging, or you make many errors, then slow down such that you take time to hear and process the information first, before moving the eyes. With practice this will become easier.

PART G3 – PRACTICE AND FAMILIARISATION AS P2 - GUIDANCE

Learning or practising using EC when flying is challenging as well as distracting. Yet learning and practicing EC in the flying environment is essential. It is therefore very useful for pilots to practise in the P2 role if possible. This is safer and more conducive to learning because attention can be focussed on the EC and associated look out. As a P2, one can learn (and learn more) about the device and its relationships to the visual environment without the distractions and responsibilities of flying. It is known that attentional-focus is vital for effective learning (for adults) and so devoting a lot of attention to EC and associated look-out will be more conducive to learning than when splitting attention with all the other tasks required to fly and operate.

Doing this is highly advisable when first learning an EC device, but equally applicable for all pilots as good practice. Much can be missed under the workload of being P1, and it is impossible to devote all one's attention to the EC/look out task. Practicing using EC as P2 will have large benefits once using it as P1. These will include lower risk of distraction caused by unfamiliarity or unrealistic usage.

The aim of P2 EC practice is to learn about your EC device in the environment, NOT to learn about your EC device itself. Be as familiar as possible with the device prior to the P2 flights (including adjustments, switching, selections, zooms, etc) so that on the flight you can pay at least as much (preferably more) attention to the environment as the device.

IMPORTANT – As P2, while it is a good idea to keep the commander updated about threatening targets and visual sightings (and to ask that s/he does the same) DO NOT continually or regularly talk about your activities or the EC. Doing this can draw the commander's attention away from their priorities.

It is a good idea to pre-plan the sorts of things you will practise when P2, rather than simply being a passenger watching the EC and the outside view. Some suggestions for active learning and practise in the P2 role are as follows.

- Actively try to find some EC aircraft at long distance (at least 2 miles) and see how challenging it is. What is the furthest you see can visually acquire an EC target? If so, reflect upon whether you would have seen that aircraft visually with a normal look-out scan.
- When you cannot see an EC-detected aircraft visually (within a few miles), or when you do see one, try to identify the factors that are helping or hindering that visual contact (there will be many). These could include:
- ▪ External factors: Sun direction, background colour, background clutter, high or low visibility, light level, rain, clouds or obstructions, etc.
- ▪ Target Characteristics: Aircraft colour, size, strobes, speed, height, relative movement, etc.
- ▪ Subject factors: Visibility from your aircraft/seat, canopy clarity, glare, your eyesight, etc.
- Spend some time intentionally trying to find some non-EC-detected aircraft. Look in areas where EC is not showing aircraft within 3 miles, and check that EC-detected aircraft you have seen are really the ones showing on EC.

- Count/tally the number of aircraft you see visually that EC did not detect, and the number of EC-detected aircraft you see visually. Compare at the end of the flight and consider the reasons.
- When an EC detected aircraft becomes visible, practise transferring your gaze back and forth between the EC and the target aircraft in order to get used to how EC-targets translate at various distances and directions. If there are two visually acquired EC targets, practise alternating between the EC and either aircraft (EC1- Visual1- EC1 then EC2- Visual2- EC2). See how accurately you can transfer your eyes straight to the target (visual from EC or EC from visual).
- Follow a target visually for several minutes if possible while also tracking it on EC, in order to get used to the transitional acquisition between EC and visual.
- Zoom out regularly and view the EC situation at range. Note the busy areas and clusters of aircraft and see if they remain in the same place over time. Determine why, or why not; i.e. if they do stay around a fixed location then it may be due to an airfield, airspace feature, short gliding ridge, etc. If not, it may be due to a thermal, aircraft formation, or just a random cluster, etc.

PART G4 – PILOT EYESIGHT

Methods which may be used to maintain or improve visual performance with age could be studied and suggested; particularly as 'see and avoid' is the primary means of safe separation for most GA pilots. Evidence of high-street eye exams for the recently introduced Pilot Medical Declaration (PMD) for the over 50s could be considered.

PART G5 – DEVICE DESIGN AND COMPATIBILITY

Augmented automation and designed-in error trapping for EC devices should be encouraged. For example, SkyDemon will automatically warn users if their ADS-B code in their SkyEcho 2 does not match the aircraft registration they planned their sortie for. This is a good example of cooperation between independent manufacturers. Use of automation and error-trapping in this way can help mitigate risks of basic human error when operating EC devices.

Clarity in function and confident target acquisition are important aims for EC design. Not only does ambiguity distract from other tasks, but can cause loss of confidence in use of EC. Illustrated by a respondent comment in section PART D is the anxiety and ambiguity caused by bearingless/range-less warnings ("PilotAware yellow and red circle cause anxiety when I can't see the target but I don't know where to look"). These warnings use the signal strength of Mode 3 and Mode S transmissions. This relies on the ‘free space path loss’ (FSPL) equation and an estimate of Equivalent Isotropic Radiated Power (EIRP) of the transponding aircraft. Estimation of the receiver/antenna and installation performance would be needed to give an idea of range through a signal strength algorithm. However, transponders can be different classes ranging from 125W to 500W output – thus the range warning is meaningless in many cases. Such issues require consideration, because they can lead to anxiety, loss of confidence in the equipment, and ultimately may cause pilots to stop using EC.

PART G6 – FUTURE RESEARCH

As with all research, the more that is learned, the more there is to learn. The four eye-tracking trials picked up an enormous amount of good quality information, but were nevertheless very limited (small sample, uncontrolled, etc). Continued work would be needed to support and learn about some areas that were not covered. These include use of other EC types, tactical and strategic usage and decision making, avoidance, effect of clutter, busy EC screen usage, effect of audio alerting, positive impacts of EC on lookout and more. Longer term trends such as ‘head-down operation’ would also require future research.

The survey was highly successful, and any future survey would be able to focus better on finding out more about the EC human factor usage that has been uncovered.

As EC increases and changes, there is a need to continue to monitor the effects, as some vulnerabilities will lessen but others might emerge.

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1. What EC capability does the aircraft type that you fly most often normally have fitted (choose one aircraft classification only and select all that EC options that apply)? Note: If you would like to provide data on more than one aircraft classification, please feel free to complete a separate survey															
Answer Choices	**Transponder**	**Transponder with ADS-B transmitter**	**ADS-B Receiver (Stratux,**	**professionally installed ADS-B Receiver**	**PilotAware**	**SafeSky**	**SkyEcho 2**	**SoftRF**	**TCAS I / II**	**FLARM or PFLARM**	**PFLARM with ADS-B Receiver**	**OGN Tracker transmitter**	**FANET or Skytraxx**	**DJI AirSense**	**Response Total**
Fixed wing aircraft <5,700kgs	27.73% 688	19.83% 492	2.38% 59	2.46% 61	16.61% 412	1.49% 37	23.82% 591	0.04% 1	0.89% 22	2.62% 65	1.98% 49	0.12% 3	0.04% 1	0.00% 0	2481
Fixed wing aircraft >5,700kgs	22.54% 48	22.07% 47	1.41% 3	5.16% 11	21.60% 46	3.29% 7	15.02% 32	0.47% 1	2.35% 5	2.82% 6	1.88% 4	0.47% 1	0.47% 1	0.47% 1	213
Flex wing aircraft	18.55% 23	15.32% 19	0.81% 1	0.00% 0	37.10% 46	3.23% 4	20.97% 26	0.00% 0	0.00% 0	3.23% 4	0.81% 1	0.00% 0	0.00% 0	0.00% 0	124
Glider/Motor glider	16.26% 47	8.65% 25	0.69% 2	0.69% 2	2.08% 6	0.00% 0	17.65% 51	0.00% 0	0.35% 1	42.56% 123	10.03% 29	1.04% 3	0.00% 0	0.00% 0	289
Helicopter	31.15% 38	17.21% 21	5.74% 7	4.92% 6	8.20% 10	0.82% 1	22.13% 27	0.00% 0	7.38% 9	0.00% 0	2.46% 3	0.00% 0	0.00% 0	0.00% 0	122
Autogyro	26.37% 24	19.78% 18	4.40% 4	1.10% 1	20.88% 19	1.10% 1	20.88% 19	0.00% 0	1.10% 1	3.30% 3	1.10% 1	0.00% 0	0.00% 0	0.00% 0	91
Paraglider or Hang glider	4.76% 1	0.00% 0	0.00% 0	0.00% 0	4.76% 1	9.52% 2	19.05% 4	0.00% 0	0.00% 0	38.10% 8	0.00% 0	9.52% 2	14.29% 3	0.00% 0	21
Paramotor	4.55% 1	0.00% 0	0.00% 0	0.00% 0	9.09% 2	13.64% 3	50.00% 11	0.00% 0	0.00% 0	9.09% 2	0.00% 0	0.00% 0	13.64% 3	0.00% 0	22
Balloon	50.00% 1	0.00% 0	0.00% 0	0.00% 0	50.00% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	2
Uncrewed Air System	0.00% 0	25.00% 2	37.50% 3	0.00% 0	12.50% 1	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	0.00% 0	12.50% 1	12.50% 1	8
														answered	1521
														skipped	35

Appendix A – Quantitative Survey Questions (Q1 to Q21) and Results Raw Tables/Charts

2. What portable EC device(s) do you use in the UK? Select all that apply

	Answer Choices	Response Percent	Response Total
1	FLARM/PowerFLARM transceivers	7.55%	97
2	PowerFLARM with ADS-B receive	2.34%	30
3	ADS-B Receive-only device (such as Stratux or Garmin GDL90)	2.88%	37
4	Pilot Aware Classic or Rosetta	37.62%	483
5	SkyEcho 2	61.14%	785
6	FANET or Skytraxx	0.23%	3
7	OGN Tracker	0.55%	7
8	SafeSky	5.14%	66
9	SoftRF	0.16%	2
10	Other (please specify):	4.60%	59
		answered	1284
		skipped	272

3. How do you display the information from these portable EC devices? Select all that apply				
Answer Choices			**Response Percent**	**Response Total**
1	Aircrew		2.22%	29
2	AirMate		0.15%	2
3	Air Nav Pro		0.15%	2
4	AIR Traffic Display		0.15%	2
5	AvPlan		0.08%	1
6	Butterfly Display for FLARM and/or ADS-B		0.54%	7
7	EasyVFR		3.45%	45
8	FLARM LED display		5.13%	67
9	ForeFlight		1.99%	26
10	LX Nav FLARMVIEW		1.38%	18
11	Oudie		1.99%	26
12	PilotAware RADAR		6.74%	88
13	RunwayHD		2.76%	36
14	SkyDemon		83.61%	1092
15	Sky-Map		0.31%	4
16	TrafficView		0.38%	5
17	VisionAir		0.00%	0

4. Considering the most common type of EC display that you use, where is it mounted?				
Answer Choices			**Response Percent**	**Response Total**
1	Kneepad		22.11%	318
2	Panel		41.38%	595
3	Yoke		13.42%	193
4	Windscreen		17.32%	249
5	Other – describe where you mount your display		11.40%	164
			answered	1438
			skipped	118

5. Where do you sit in your aircraft?

Answer Choices			Response Percent	Response Total
1	Left Hand Seat		71.10%	1075
2	Right Hand Seat		7.74%	117
3	Centre (e.g. single or tandem seating arrangement)		21.16%	320
			answered	1512
			skipped	44

6. Where do you mount or carry your portable EC display in the cockpit? Select the nearest number on the image below				
Answer Choices			**Response Percent**	**Response Total**
1	1		1.47%	20
2	2		2.06%	28
3	3		5.73%	78
4	4		3.01%	41
5	5		5.80%	79
6	6		14.83%	202
7	7		10.06%	137
8	8		9.40%	128
9	9		6.90%	94
10	10		10.87%	148
11	11		19.31%	263
12			0.66%	9
13	Other position (please specify, e.g. on the seat next to me):		9.91%	135
			answered	1362
			skipped	194

Figure 29. Survey Q6 asked respondents to indicate where on this cockpit diagram they would mount or carry their portable EC display in the cockpit. The responses to Q6 are shown against each cockpit position expressed as a total of the 1,362 responses received.

7. Where would you like to mount or carry your portable EC display in the cockpit? Select the nearest number on the image below				
Answer Choices			**Response Percent**	**Response Total**
1	1		2.41%	32
2	2		2.56%	34
3	3		8.12%	108
4	4		1.80%	24
5	5		9.77%	130
6	6		24.44%	325
7	7		10.68%	142
8	8		9.25%	123
9	9		4.51%	60
10	10		10.60%	141
11	11		6.69%	89
12	Other position (please specify, e.g. on the seat next to me):		9.17%	122
			answered	1330
			skipped	226

8. Are the most common traffic and navigation displays that you use on the same display screen (e.g. a tablet)?				
Answer Choices			**Response Percent**	**Response Total**
1	Yes		81.73%	1208
2	No		12.58%	186
3	Not applicable		5.68%	84
			answered	1478
			skipped	78

9. Do you use audio warnings?				
Answer Choices			**Response Percent**	**Response Total**
1	a. Yes		63.23%	932
2	b. No (Skip to Section 3 - EC OPERATION)		36.77%	542
			answered	1474
			skipped	82

10. If you use audio warnings, how do you hear them?			
Answer Choices		**Response Percent**	**Response Total**
1	Through the aircraft intercom	43.22%	414
2	Through a separate headset	15.55%	149
3	Through a loudspeaker	22.76%	218
4	Other – please describe	18.48%	177
		answered	958
		skipped	598

11. If you use audio warnings, what device provides the audio warning?			
Answer Choices		**Response Percent**	**Response Total**
1	The certified electronic instrument that is mounted on my avionics panel.	15.82%	149
2	The separate EC App/Electronic Flight Bag (SkyDemon, etc…) that I use.	70.70%	666
3	Other – describe if not one of the above:	13.48%	127
		answered	942
		skipped	614

12. Is your traffic audio warning separate from your traffic/navigation display?

	Answer Choices		Response Percent	Response Total
1	Yes		23.27%	229
2	No		70.73%	696
3	Not applicable		6.00%	59
			answered	984
			skipped	572

13. Across a busy GA month, imagine that on ten occasions different GA aeroplanes passed close to yours while flying cross-country (whether or not you realised it). If your EC device was operating as, it should on all those occasions, how many of those aircraft would it have detected? Note: Regardless of warning generated, your knowledge of them, etc

Answer Choices			Response Percent	Response Total
1	All of them (10)		2.31%	34
2	Almost all (9)		6.25%	92
3	A reasonable majority (7-8)		31.93%	470
4	About half (4-6)		37.43%	551
5	A minority (1-3)		13.52%	199
6	None (0)		2.11%	31
7	Other (please specify):		6.52%	96
			answered	1472
			skipped	84

14. How confident are you in your answer to the above question (without having to look up the answer)?				
Answer Choices			Response Percent	Response Total
1	Very confident		19.80%	290
2	Quite confident		58.98%	864
3	Not confident		10.58%	155
4	It was a bit of a guess		10.72%	157
			answered	1465
			skipped	91

15. With reference to the question before last (Q13), how many of those ten GA aircraft would you expect to detect your aircraft (through EC)?

Answer Choices			Response Percent	Response Total
1	All 10		11.24%	162
2	8-9		13.81%	199
3	6-7		27.76%	400
4	4-5		29.42%	424
5	2-3		13.81%	199
6	0-1		4.02%	58
			answered	1441
			skipped	115

16. How confident are you in your answer to the previous question (without having to look up the answer)?			
Answer Choices		**Response Percent**	**Response Total**
1	Very confident	15.29%	220
2	Quite confident	53.30%	767
3	Not confident	17.44%	251
4	It was a bit of a guess	14.04%	202
		answered	1439
		skipped	117

17. What percentage of your fellow GA pilots do you think know how their portable EC device works?			
Answer Choices		**Response Percent**	**Response Total**
1	Less than 25%	11.86%	175
2	Between 26% and 50%	28.93%	427
3	Between 51 and 75%	30.15%	445
4	Over 75%	12.74%	188
5	I really have no idea	16.40%	242
		answered	1476
		skipped	80

18. What do you think your fellow GA pilots would say the reliable range for detection of their portable EC device is? Note: Assume a standard performance for the various types of portable device			
Answer Choices		**Response Percent**	**Response Total**
1	Within 5 NM	30.89%	456
2	Within 10 NM	36.86%	544
3	Within 20 NM	11.65%	172
4	Within 30 NM	1.96%	29
5	In excess of 30 NM	1.15%	17
6	I really have no idea	17.55%	259
		answered	1476
		skipped	80

19. What range would your ideal EC device reliably warn you or others at?				
Answer Choices			**Percent**	**Total**
1	1 NM		1.35%	20
2	2 NM		9.18%	136
3	5 NM		38.22%	566
4	10 NM		35.99%	533
5	20 NM		12.36%	183
6	≥ 30 NM		2.97%	44
			answered	1481
			skipped	75

20. I believe my EC device has saved me from an AIRPROX or a Mid-Air Collision...				
Answer Choices			**Response Percent**	**Response Total**
1	Many times		2.96%	43
2	On several occasions		20.25%	294
3	Once or twice		35.95%	522
4	Don’t know		40.91%	594
			answered	1452
			skipped	104

21. How do you feel when you see an aircraft that your device has not detected?				
Answer Choices			**Response Percent**	**Response Total**
1	OK, I expect it		56.23%	817
2	Slightly unnerved and worried		19.96%	290
3	Cross as people should be making the same effort as me		23.19%	337
4	I only ever see the traffic that my EC device detects		0.69%	10
			answered	1453
			skipped	103

Appendix B - Tables of all EC combinations reported

One combination per row. Devices in that combination are designated by a ‘1’ in the first twelve columns.

Transponder with ADS-B transmitter	ADS-B Receiver (ANY)	PilotAware	SafeSky	SkyEcho 2	SoftRF	TCAS I / II	FLARM or PFLARM	FLARM or PFLARM with	OGN Tracker	FANET or Skytraxx	DJI AirSense	Number of devices in combination	Number of Pilots using combination
												0	349
											1	1	2
										1		1	2
									1			1	2
								1				1	17
								1	1			2	1
							1					1	98
							1			1		2	6
							1	1				2	1
						1						1	3
				1								1	373
				1				1				2	13
				1				1	1			3	1
				1			1					2	58
				1			1	1	1			4	1
				1		1						2	8
				1		1	1					3	1
			1									1	13
			1						1			2	1
			1	1								2	16
			1	1			1					3	4
		1										1	196

		1					1					2	3
		1				1						2	1
		1		1								2	92
		1		1			1					3	3
		1	1									2	4
		1	1	1								3	3
	1											1	20
	1						1					2	4
	1					1						2	2
	1			1								2	16
	1			1			1					3	2
	1			1			1	1				4	1
	1			1		1						3	3
	1		1									2	1
	1		1	1	1							4	1
	1	1										2	7
	1	1								1		3	1
	1	1					1					3	1
	1	1		1								3	1
	1	1	1	1								4	1

Table B1 – continued below

Transponder with ADS-B	ADS-B Receiver (ANY)	PilotAware	SafeSky	SkyEcho 2	SoftRF	TCAS I / II	FLARM or PFLARM	FLARM or PFLARM with	OGN Tracker transmitter	FANET or Skytraxx	DJI AirSense	Number of devices in this	Number of Pilots using this
1												1	104
1								1				2	26
1							1					2	20
1							1	1				3	3

1						1						2	14
1						1		1				3	1
1				1								2	159
1				1				1				3	9
1				1			1					3	18
1				1			1	1				4	1
1			1									2	7
1			1	1								3	6
1			1	1			1					4	1
1		1										2	216
1		1							1			3	1
1		1						1				3	10
1		1					1					3	11
1		1					1		1			4	1
1		1				1						3	1
1		1		1								3	21
1		1	1									3	2
1		1	1						1			4	1
1		1	1	1								4	3
1	1											2	40
1	1							1				3	7
1	1						1					3	2
1	1						1	1				4	1
1	1					1						3	10
1	1			1								3	20
1	1			1				1				4	2
1	1			1			1					4	3
1	1			1		1						4	3

1	1		1	1								4	2
1	1	1										3	19
1	1	1						1				4	2
1	1	1					1					4	1
1	1	1		1								4	1
1	1	1		1			1	1				6	1
1	1	1	1	1	1	1	1	1	1	1	1	12	1
													2084

Table B1 – (continued from previous page). All 81 combinations of EC used by the 2084 survey respondents in one main/designated aircraft group each (not including standard / mode-S transponders). The final row is assumed to be erroneous (one participant ticked all the EC options for a single aircraft)

PilotAware	SafeSky	SkyEcho 2	SoftRF	TCAS I / II	FLARM or PFLARM	FANET or Skytraxx	Transponder with ADS-B transmitter	OGN Tracker transmitter	n Pilots	Number of devices in this combination
									388	0
								1	3	1
							1		177	1
						1			2	1
					1				103	1
					1		1		26	2
					1	1			6	2
				1					5	1
				1			1		25	2
		1							402	1
		1						1	1	2
		1					1		190	2
		1			1				61	2

		1			1			1	1	3
		1			1		1		22	3
		1		1					11	2
		1		1			1		3	3
		1		1	1				1	3
	1								14	1
	1							1	1	2
	1						1		7	2
	1	1							16	2
	1	1					1		8	3
	1	1			1				4	3
	1	1			1		1		1	4
	1	1	1						1	3
1									203	1
1							1		247	2
1							1	1	1	3
1						1			1	2
1					1				4	2
1					1		1		12	3
1					1		1	1	1	4
1				1					1	2
1				1			1		1	3
1		1							93	2
1		1					1		22	3
1		1			1				3	3
1		1			1		1		1	4
1	1								4	2
1	1						1		2	3

1	1						1	1	1	4
1	1	1							4	3
1	1	1					1		3	4
1	1	1	1	1	1	1	1	1	1	9

Table B2. Transmitting (only) combinations. E.g. PAW is the only TX-device in 203 cases, whereas in a further 247 cases pilots use both PAW and Transponder with ADS-B-out to transmit EC position

PilotAware	SafeSky	SkyEcho 2	SoftRF	TCAS I / II	FLARM or PFLARM	FANET or Skytraxx	ADS-B Receiver (ANY	FLARM/PFLARM with ADS-	DJI AirSense	n Pilots	Number of devices in this
										455	0
									1	2	1
								1		44	1
							1			60	1
							1	1		7	2
						1				2	1
					1					118	1
					1			1		4	2
					1		1			6	2
					1		1	1		1	3
					1	1				6	2
				1						17	1
				1				1		1	2
				1			1			12	2
		1								532	1
		1						1		23	2
		1					1			36	2
		1					1	1		2	3
		1			1					76	2

		1			1			1		2	3
		1			1		1			5	3
		1			1		1	1		1	4
		1		1						8	2
		1		1			1			6	3
		1		1	1					1	3
	1									21	1
	1						1			1	2
	1	1								22	2
	1	1					1			2	3
	1	1			1					5	3
	1	1	1				1			1	4
1										413	1
1								1		10	2
1							1			26	2
1							1	1		2	3
1						1	1			1	3
1					1					15	2
1					1		1			2	3
1				1						2	2
1		1								113	2
1		1					1			2	3
1		1			1					3	3
1		1			1		1	1		1	5
1	1									7	2
1	1	1								6	3
1	1	1					1			1	4
1	1	1	1	1	1	1	1	1	1	1	10

Table B3. Receiving (only) combinations. E.g. PAW is the only RX-device in 413 cases, whereas in a further 113 cases pilots use both PAW and SkyEcho 2 as receivers.

Appendix C - Full frequency analysis of Questions 13 to 16 (IBM SPSS output)

Frequencies

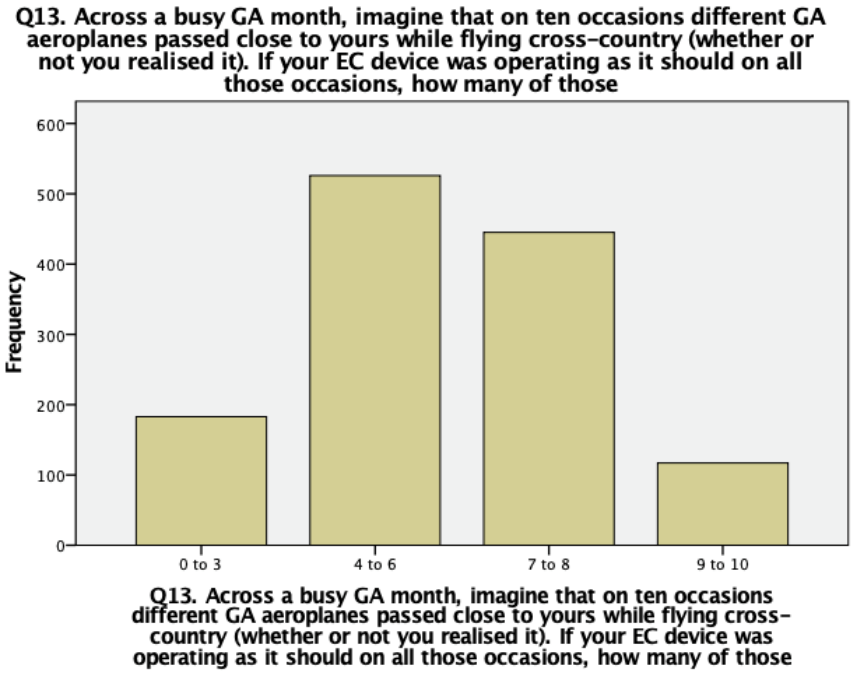
Statistics

Q13. Across a busy GA month, imagine that on ten occasions different GA aeroplanes passed close to your

N	Valid	1271
	Missing	326
Mean		2.39

Q13. Across a busy GA month, imagine that on ten occasions different GA aeroplanes passed close to yours while flying cross-country (whether or not you realised it). If your EC device was operating as it should on all those occasions, how many of those

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0 to 3	183	11.5	14.4	14.4
	4 to 6	526	32.9	41.4	55.8
	7 to 8	445	27.9	35.0	90.8
	9 to 10	117	7.3	9.2	100.0
	Total	1271	79.6	100.0	
Missing	System	326	20.4		
Total		1597	100.0		



Full results of response frequencies to Q13 (IBM SPSS output). Only includes respondents who had any Rx-capable EC. The average is about 6.

Frequencies

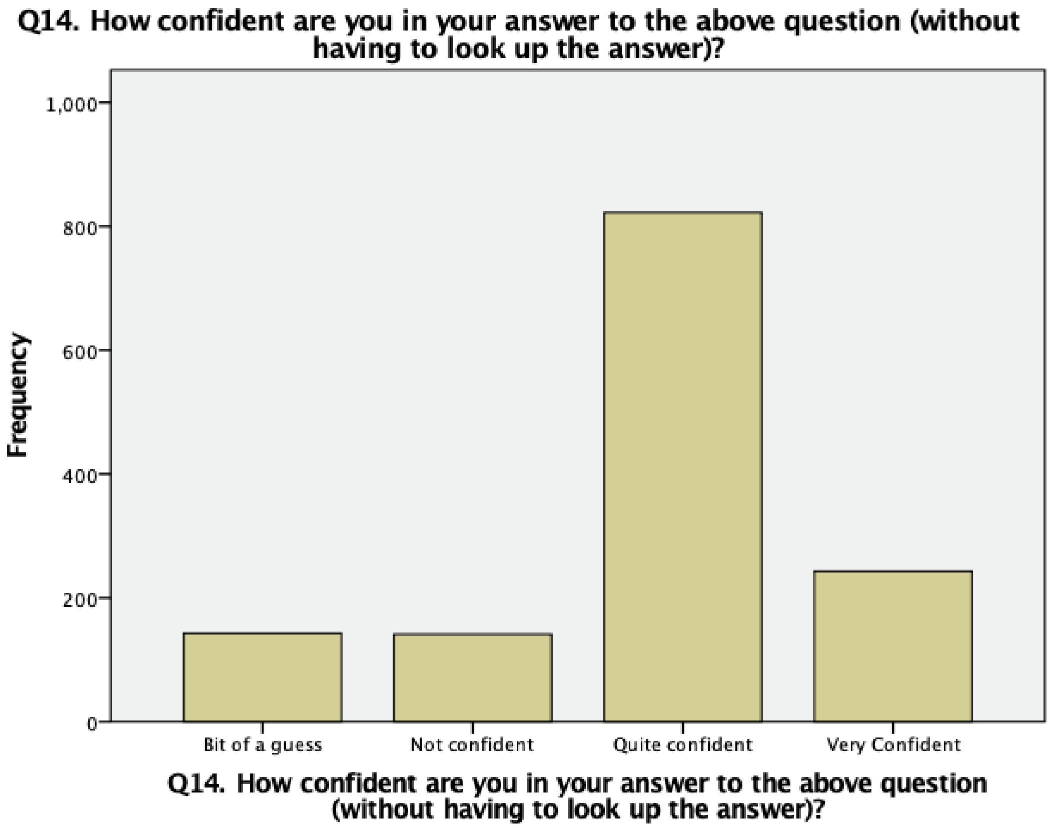
Statistics

Q14. How confident are you in your answer to the above question (without having to look up the answer)?

N	Valid	1349
	Missing	248
Mean		2.86

Q14. How confident are you in your answer to the above question (without having to look up the answer)?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Bit of a guess	143	9.0	10.6	10.6
	Not confident	141	8.8	10.5	21.1
	Quite confident	822	51.5	60.9	82.0
	Very Confident	243	15.2	18.0	100.0
	Total	1349	84.5	100.0	
Missing	System	248	15.5		
Total		1597	100.0		



Full results of response frequencies to Q14 (IBM SPSS output). Only includes respondents who had any Rx-capable EC.

Frequencies

Statistics

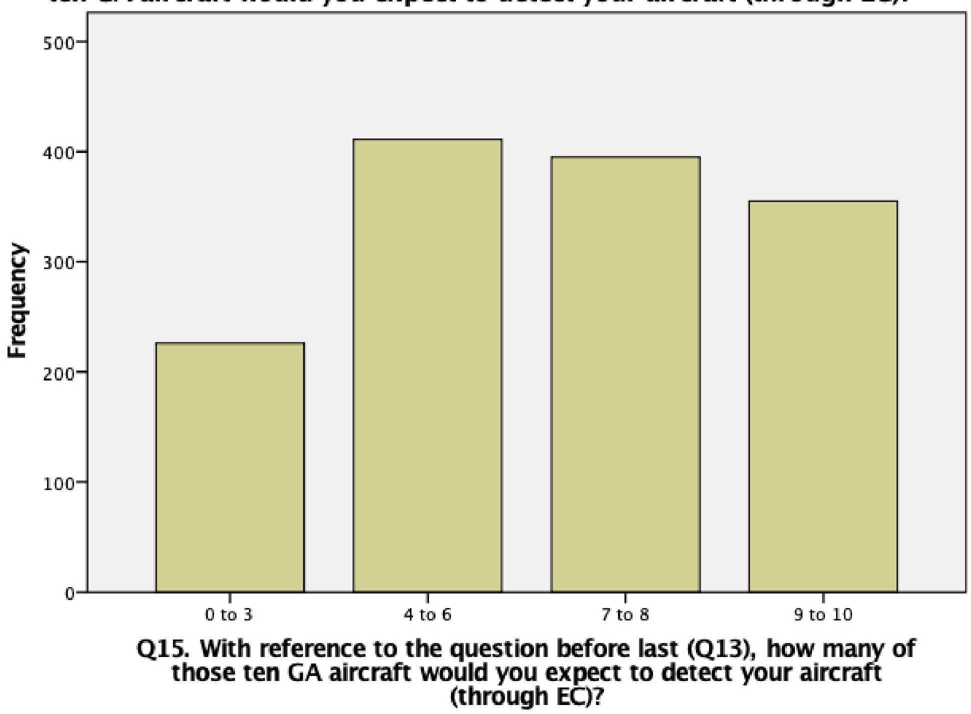
Q15. With reference to the question before last (Q13), how many of those ten GA aircraft would you expec

N	Valid	1387
	Missing	309
Mean		2.63

Q15. With reference to the question before last (Q13), how many of those ten GA aircraft would you expect to detect your aircraft (through EC)?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0 to 3	226	13.3	16.3	16.3
	4 to 6	411	24.2	29.6	45.9
	7 to 8	395	23.3	28.5	74.4
	9 to 10	355	20.9	25.6	100.0
	Total	1387	81.8	100.0	
Missing	System	309	18.2		
Total		1696	100.0		

Q15. With reference to the question before last (Q13), how many of those ten GA aircraft would you expect to detect your aircraft (through EC)?



Full results of response frequencies to Q15 (IBM SPSS output). Only includes respondents who had any TX-capable EC (beyond a standard transponder). The average is about 7.

Frequencies

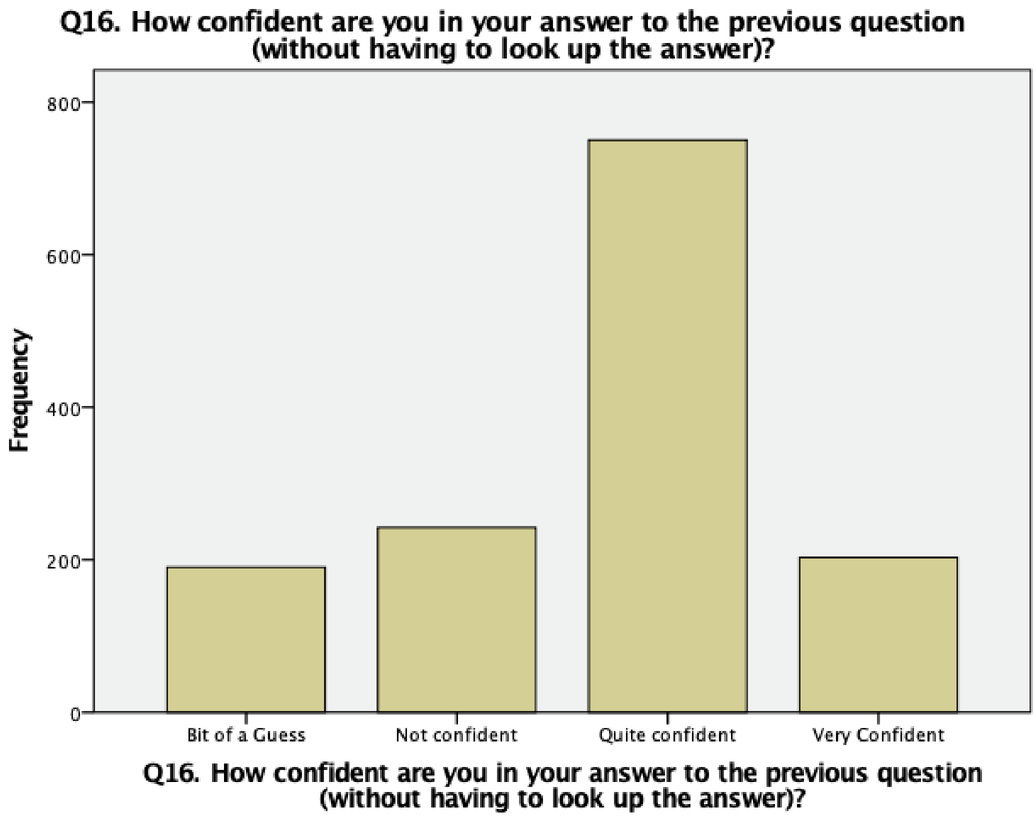
Statistics

Q16. How confident are you in your answer to the previous question (without having to look up the answer)?

N	Valid	1385
	Missing	311
Mean		2.70

Q16. How confident are you in your answer to the previous question (without having to look up the answer)?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Bit of a Guess	190	11.2	13.7	13.7
	Not confident	242	14.3	17.5	31.2
	Quite confident	750	44.2	54.2	85.3
	Very Confident	203	12.0	14.7	100.0
	Total	1385	81.7	100.0	
Missing	System	311	18.3		
Total		1696	100.0		



Full results of response frequencies to Q16 (IBM SPSS output). Only includes respondents who had any TX-capable EC (beyond a standard transponder).

Q17. What percentage of your fellow GA pilots do you think know how their portable EC device works?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Less than 25%	182	8.7	12.0	12.0
	Between 26% and 50%	442	21.2	29.0	41.0
	Between 51 and 75%	456	21.9	29.9	70.9
	Over 75%	194	9.3	12.7	83.7
	I really have no idea	249	11.9	16.3	100.0
	Total	1523	73.1	100.0	
Missing	System	561	26.9		
Total		2084	100.0		

Q20. I believe my EC device has saved me from an AIRPROX or a Mid-Air Collision...

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Many times	44	2.1	2.9	2.9
	On several occasions	296	14.2	19.8	22.7
	Once or twice	542	26.0	36.2	59.0
	Don't know	614	29.5	41.0	100.0
	Total	1496	71.8	100.0	
Missing	System	588	28.2		
Total		2084	100.0		

Q21. How do you feel when you see an aircraft that your device has not detected?

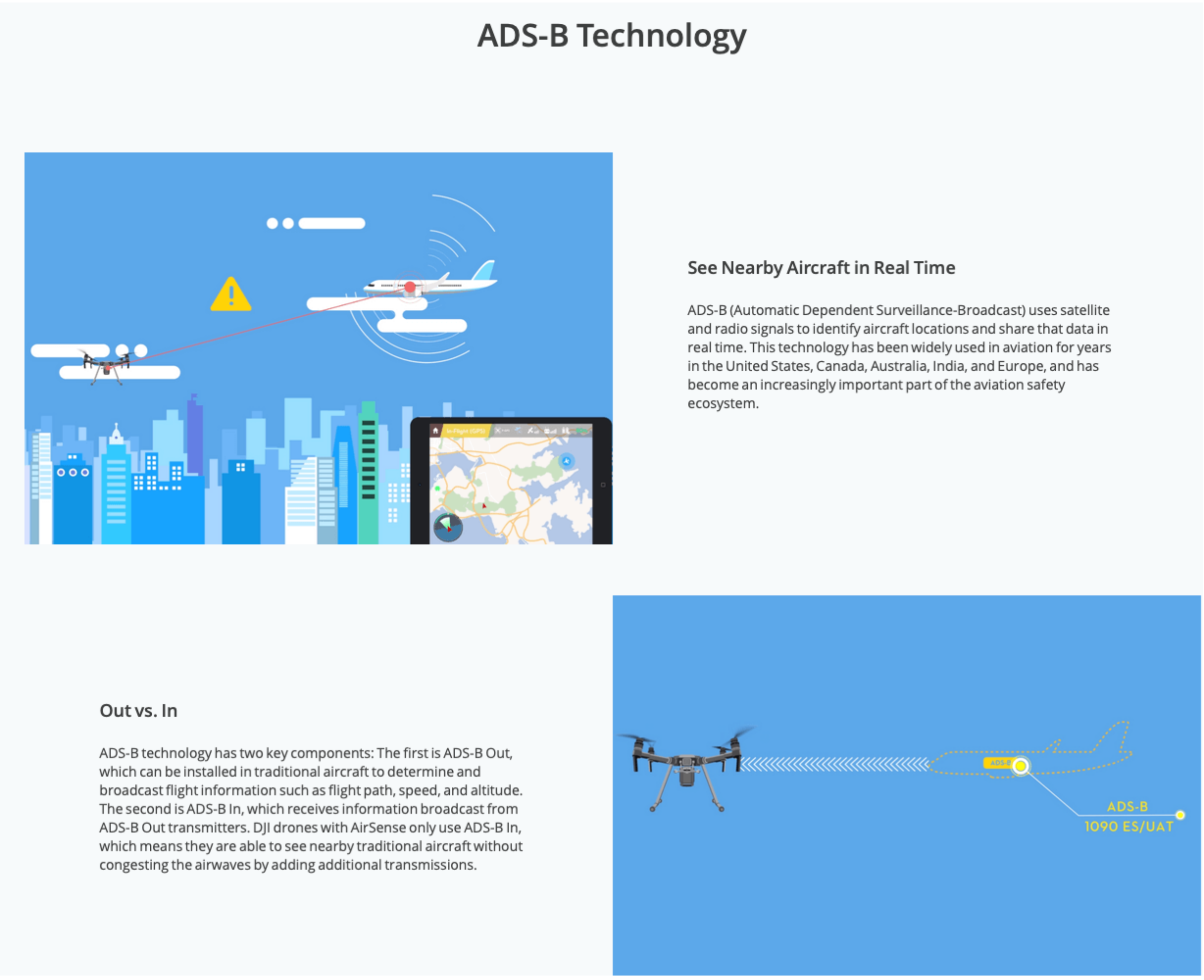
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	OK, I expect it	842	40.4	56.3	56.3
	Slightly unnerved and worried	298	14.3	19.9	76.2
	Cross as people should be making the same effort as me	345	16.6	23.1	99.3
	I only ever see the traffic that my EC device detects	11	.5	.7	100.0
	Total	1496	71.8	100.0	
Missing	System	588	28.2		
Total		2084	100.0		

Above three tables: Results of response frequencies to Q17, Q20 and Q21 (IBM SPSS output).

Appendix D - Examples of marketing material (as of February 2023)

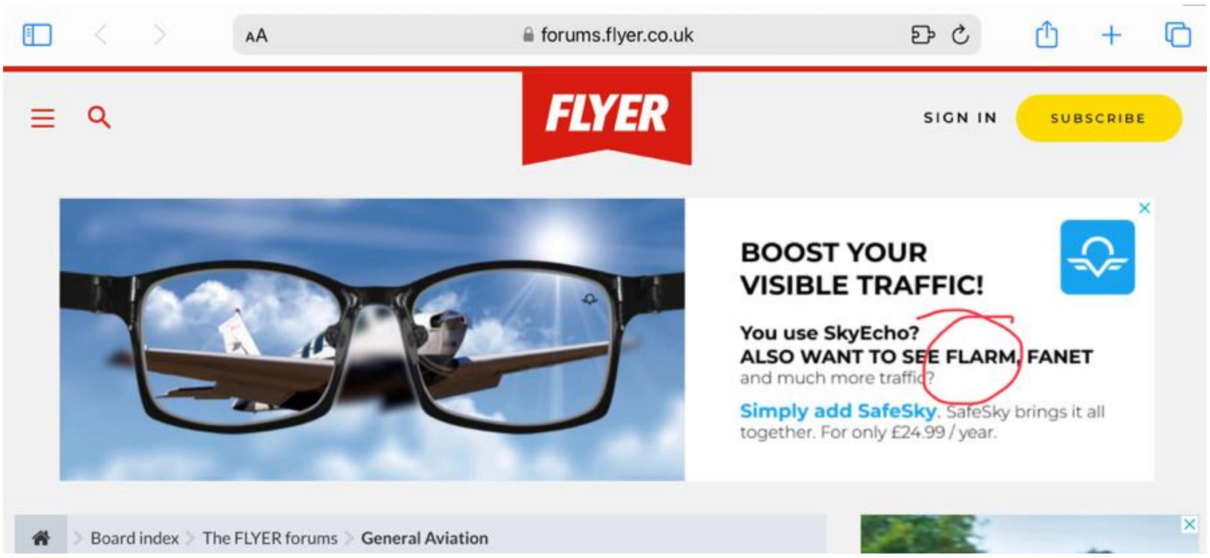
Examples of marketing for several systems are shown. Understandably, marketing material for EC devices (including many not shown here) showcases the positive factors of the particular device but is quiet on the limitations of the capability. The marketing is highly visible (in magazines etc) and could help create the over-optimistic opinions found in the research.

Example 1 – DJI Airsense

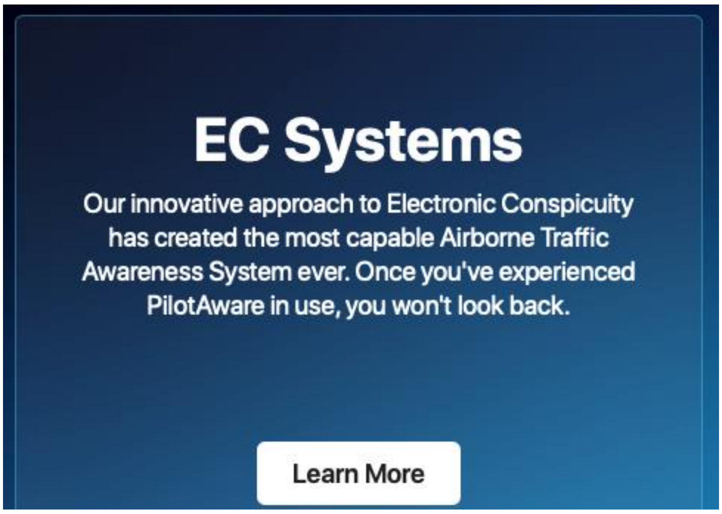


Above: Most of the home page (selected for UK) for DJI Air Sense.

Example 2 - SafeSky



Example 3 – Pilot Aware



Appendix E – Trial Plan

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Trial PEEPER

Human Factors (HF) in Electronic Conspicuity (EC)

Trial Plan & Trial Instruction

Administration

Customer: Mr Andrew Belshaw, Future Technology, ATM, CAA.

Trial Manager: Mr Gary Coleman, GASCo.

Trial Scientist: Dr Steve Jarvis, Jarvis-Bagshaw Ltd.

Release Authority: Mr Mike O’Donoghue, GASCo.

Record of Changes:

Issue	Date	Detail	Owner
Issue 1	24 Feb 23	Initial Issue	Gary Coleman
Issue 2	13 May 23	Trial version	Mike O’Donoghue

Background Introduction

Mid-air collisions are a serious threat in general aviation. Although rare, they still occur in UK airspace and are very often fatal. The primary means for mid-air collision avoidance in uncontrolled Class G airspace is ‘see-and-avoid’, meaning that pilots are responsible for their visual separation. However sighting issues (described as failure to see traffic or a late sighting of traffic) remain the most common causes of Airprox events involving GA aircraft.

To aid the fallibility of the eye to detect all conflict, various Electronic Conspicuity (EC) devices are now used across the diaspora of General Aviation (GA) aircraft types. However, little study has been conducted into the effectiveness of these EC systems and how they should be used. Finally, little study has been done to identify the Human Factors (HF) that may also affect the use of these devices and how pilots train themselves in their use.

As part of a CAA-sponsored HF in EC study, GASCo and Jarvis Bagshaw have conducted a survey of 2,084 GA pilots across the aircraft type diaspora. This survey has been coupled to an in-depth literature review, and an initial field trial of eye-tracking technology in a light GA aircraft. This Trial Plan and Trial Instruction details the Aim and Objectives of flight trials to acquire data for education purposes. It is expected the material gathered will help mitigate the negative effects of HF to EC technology and help inform areas for future study.

Trial Plan Aim

The aim of the Trial PEEPER is to identify and acquire suitable education material to help combat HF that affect good outcomes for ‘detect and avoid’ scenarios.

Trial Plan Objectives

The following objectives have been set in support of the aim.

1. Ensure that Trial PEEPER is safe and legal, and that the aircraft/occupants are exposed to no more risk than they would under normal GA flight operations.
2. Gain footage suitable for ECHF publicity.
3. Ensure that the test subject has no knowledge of the scrutiny of EC HF to which the Trial PEEPER seeks to gain.
4. Ensure that the performance and reputation of the test subject is protected.
5. Save all material iaw with any data protection requirements.

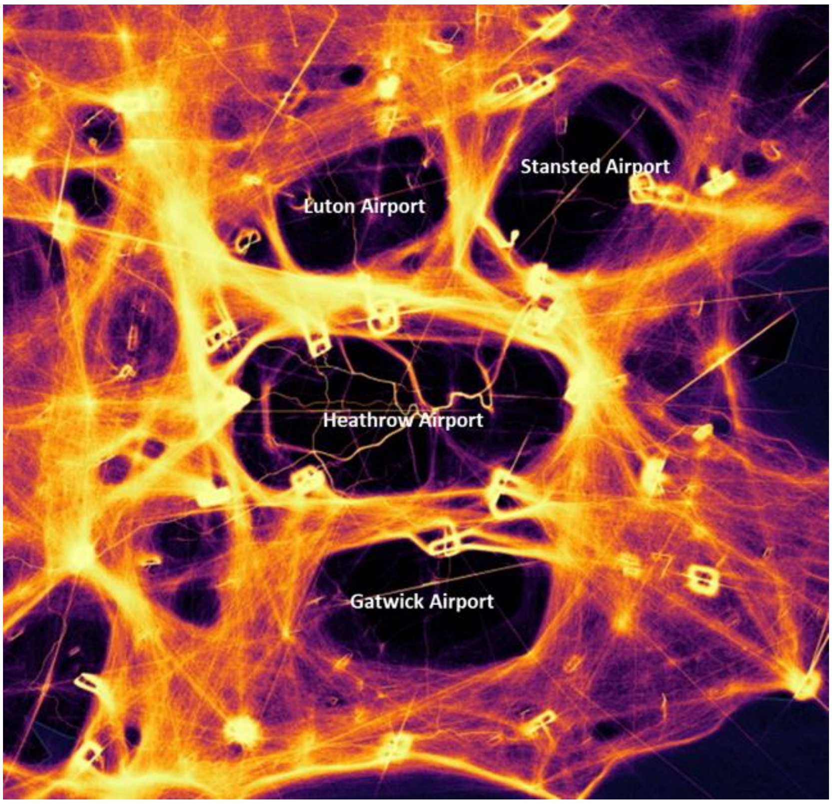
General Outline of the Trial

The plan is to get several GA aircraft types to fly the Trial Scientist with various EC types whilst the pilot wears eye tracking glasses. These glasses were tested for flight by the Trial Manager, and they were judged to be no more intrusive than flying with sunglasses or corrective spectacles. The results were recorded by the Trial Scientist on a laptop computer whilst the pilot flew the sortie. The glasses are good at showing where the pilot is looking, what scan patterns they employ and how their attention to various visual stimuli is attracted. However, the glasses were poor at showing the actual target aircraft on the recording inside a range of roughly ¼nm (as verified by the EC device) for an average GA sized aircraft. The pilot could see the target at around 2-3nm in a typical encounter. At normal GA closure speeds (90kts to 90kts closure) a 1/4nm head-on encounter would be 5 secs from impact. At 2nm that time to impact, at the same closure speeds and head-on aspect, would be 40 secs, and at a range where the pilot could likely identify it as a GA type (1nm) then it would be 20secs. Thus, the immediacy to decide and fly away from the conflict under the Rules of the Air inside these ranges is an urgent affair. At ranges exceeding that, the pilot is really making a strategic decision, where the decision is less urgent and the outcome far less certain. For these longer-range potential encounters then only visual means via an Electronic Flight Bag (EFB) display is used, whereas, for the quicker and more urgent short-range encounters an aural/visual alert is more likely.

We therefore plan to fly for around an hour a flight collecting evidence and footage to support our education material production. The subject pilot will not be made aware of what we are looking for and we will ask them to fly a typical “Airfield A to Airfield A” sortie for an hour. This will only be flown on good weather days, during weekends and bank holidays to ensure maximum traffic density and in areas where GA is popular. The student pilot will be told that we are collecting data on how far they acquire their next turning point visually, when really, we are interested in looking at their division of look out, flying the aircraft and manipulating their EC equipment.

Trial Peeper – Sortie Requirements

Area of interest. To minimise travel for the Trial Scientist and to maximise the chance of ECHF events, then airfields in the Southeast of the UK will be targeted for suitable candidates. Further routings in, or adjacent to busy areas as indicated by the SkyDemon ‘heat map’ below will be used.



Aircraft Type. We will invite pilots from the microlight, light aircraft, motor-glider and gliding communities to volunteer to fly the Trial Scientist.

EC Type. As the 3 most popular protocols, we will invite those using ADS-B, FLARM or PilotAware transmit/receive devices. These have GPS-tagged positions and so give the most reliable bearing/range warnings to the pilot.

EC Display/Warning Type. We will insist that the aircraft uses an EFB, such as SkyDemon or ForeFlight, or a manufacturer's display such as FLARM. We will take pilots that use aural and/or visual warning. The use of EC equipment will also provide a mitigation for real mid-air collision risk during the flight.

Number of Live-Fly Data Points. As this Trial aims to capture data for educational purposes, rather than to prove any theorem, then there is no need to replicate events as experiments. However, to provide enough data points for the education material then Trial PEEPER will aim to attract a minimum of 2 flights of each type from the microlight, light aircraft, motor-glider and gliding communities, with a total of at least 8 flight recordings in total.

Safety Responsibilities. The owner/operator of the aircraft will remain responsible for the airworthiness of the aircraft. The pilot will be always responsible for the safety of the aircraft and flight. The pilot is responsible for ensuring the aircraft is airworthy and insured before the flight. The pilot has the right to cancel or amend the flight at any time without any recourse from the Trial. This will operate as a cost-sharing flight between 2 private individuals.

The scientist will be deemed a private individual for this activity and is to ensure that they are content with their insurance provision prior to the flight. This will be a private arrangement between the individuals concerned and the GASCo Charity and Jarvis Bagshaw Ltd will not be accountable for the safety of this activity.

The attached undertaking at Annex A will make these responsibilities clear and will be signed by both parties, as private individuals, before each flight.

As GASCo is the UK's leading GA safety organisation, it strongly encourages the use of Threat and Error Management (TEM) and the use of safety checklists. One such is the GASCo “I’M SAFE” checklist[1]. This has been added at Annex B to consider and mitigate the risks of this private flight. The activity should be considered no riskier than a normal GA flight on a busy weekend. This sits within the DfT’s appetite for risk to allow such flying activity to occur in the UK.

Funding and Cost Sharing. For participating in Trial PEEPER, the aircraft pilot will receive 50% of the direct costs[2] as a contribution. The amount will be agreed before the flight takes place. This is a non-commercial flight and so there can be no element of profit generated by the pilot or aircraft owner/operator.

The guidance on cost sharing has been taken from CAP1589[3] and ORS4 No 1554[4].

Trial PEEPER Subject Selection. Trial PEEPER will initially invite pilots with suitable EC devices from the following airfields, or in the adjacent area (within 10 nm of any of these):

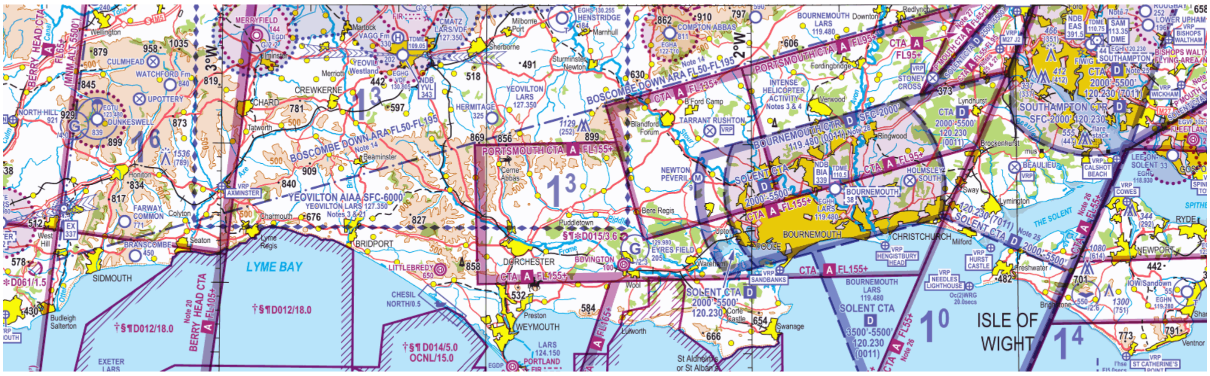
Bicester	Dunkeswell
Bournemouth	North Hill
Exeter	Lee-on-Solent

[1] https://www.gasco.org.uk/upload/docs/PDF%20docs/GASCo%20Checklist.pdf

[2] Direct costs are those that are incurred in relation to the specific flight (ie. Fuel, airfield landing fees, rental, etc…).

[3] https://publicapps.caa.co.uk/modalapplication.aspx?appid=11&mode=detail&id=8052

[4] https://publicapps.caa.co.uk/docs/33/ORS4%20No%201554.pdf



Proposed area of flights to collect the best footage due to expected levels of traffic at a weekend on a good VMC weather day.

Trial Instruction

To ensure that Trial PEEPER has an element of control and base-line replication across the pilot subjects and their aircraft, the Trial Instruction at Annex C should be followed.

A calling notice, requesting participants for a cost-sharing flight to gather media footage for GASCo is at Annex D. This will be adapted closer to the time.

G P COLEMAN

Trial Manager

Trial PEEPER

Annexes:

A. Cost-Sharing Flight Agreement.

B. GASCo I'M SAFE Leaflet.

C. Trial Instruction – Trial PEEPER – Limited Distribution.

D. Cost-Sharing Flight Calling Notice.

Annex A To Trial PEEPER dated 24 Feb 23

Cost-Sharing Flight Agreement

The flight in aircraft registration ……………………………. is a cost-sharing flight between the following 2 private individuals iaw CAP1589 and ORS4 No 1554:

Pilot Full Name: …………………………………………………………….

Passenger Full Name: ………………………………………….……………

These are 2 private individuals that consent to fly together, record images and then gift them to the GASCo flight safety charity to produce safety material for the greater benefit of the global GA community. As such, the direct costs of the flight will be shared at 50% between the individuals at an agreed rate of:

………………………………… per flying hour

This amount will be *pro-rata* to the nearest 5 mins as agreed after the flight.

The pilot remains responsible as the aircraft commander for the safe and legal conduct of the flight. They have the right to cancel or amend the flight at any time. The passenger will collect the video material whilst the pilot conducts these normal flight activities via eye-tracking video equipment.

These images will be used by GASCo with the full consent of the pilot/passenger concerned. They will be anonymised and edited to ensure that the individual cannot be identified in the final material unless they give consent to do so.

GASCo have no legal liability for the conduct of the flight.

Signature of Pilot: ………………………………………………… Date: ………………………….

Signature of Passenger: ……………………………………... Date: ………………………….

GASCo

Are you Fit to Fly?

Ask yourself the question:

Can I really say... I'm Safe?

I	**ILLNESS**	Are you well enough to fly?
M	**MEDICATION**	Side effects, covering problems? *(Read the back of your medical certificate for instructions)*
S	**STRESS**	Any pressure, passengers, annoyed?
A	**ALCOHOL**	No alcohol in the bloodstream is the only safe option *(the legal limit is 25% of UK driving limit)*
F	**FATIGUE**	Enough sleep, well rested?
E	**EATING**	Had something suitable and nutritious to eat before the flight?

Some Hazardous Pilot attitudes discussed at GASCo Safety Evenings:

ANTI-AUTHORITY	Don't tell me what to do!
IMPULSIVENESS	Do something now, at once!
INVULNERABILTY	It won't happen to me, I always get away with this.
MACHO-COMPLEX	I can handle it; especially if you think I can't.
RESIGNATION	There is nothing I can do about it
COMPLACENCY	I always have done it this way and it works fine!

How can an ordinary pilot expect to survive?; Is it just the luck of the draw?

Here is some food for thought.

- There is a difference between skill and judgement, judgement is more important to survival than skill.
- The less skilled self-disciplined pilot is often at less risk than an experienced pilot pushing to the limit.
- If you are not aware of your personal limits, your first mistake is likely to be your last.

Documents:

- Are your licence, medical and logbook up to date and valid?
- Is your insurance up to date and valid?
- Are the aircraft documents valid, licences, certificates, engineering sign offs etc

Planning:

- Are your maps, charts and flight guides up to date and valid?
- Did you check and interrogate for both planned flight and for possible diversions:
  - NOTAMs?
  - Airspace, both horizontal and vertical limits?
  - Weather for the route and for diversions?
  - Do I have accurate airfield data for my planned and alternates airfields?
- Assessed the likelihood of carburettor icing?
- What runway length do I need for this configuration?

Your machine:

- Are the necessary documents on board?
- Have you completed necessary weight and balance calculations and planned aircraft loading appropriately?
- Have you created a distraction free climate for pre-flight inspection?
- Are you following the POH guidance on pre-flight inspection?
- Is my safety gear checked for validity, stowed correctly and accessible once the aircraft is loaded?

Finally

- Have I briefed the passenger thoroughly on emergency drills and equipment, sterile cockpit procedures and how they can contribute looking out for other aircraft.

As I close up:

- Have I done as much thinking and planning on the ground so that if I meet trouble in the air I will have sufficient capacity to AVIATE, NAVIGATE and COMMUNICATE

Do I have the **right recent experience** and **skill level** to execute this flight safely?

GASCo/2015/1002

GASCo

The General Aviation Safety Council (GASCo)
Rochester Airport, Chatham, Kent ME5 9SD - 01634 200203

ANNEX C to TRIAL PEEPER 24 FEB 23

Trial Instruction – Trial PEEPER – Limited Distribution

Trial PEEPER is designed to collect information on the use of EC equipment in-flight using eye-tracking technology. To ensure that the subject pilot does not alter or influence their look-out behaviour, a ‘cover story’ of collecting footage of individuals spotting visual navigation turning points shall be used. The following scripts should be used by the Trial Scientist who will be sitting as a passenger for the duration of the flight recording the eye-tracking footage. The following scripts suggest some guidelines for the conduct of this media gathering. The exact wording may be adjusted at the time as the conversation develops.

Introductory Script

“I will fly as your passenger in this cost-shared private flight. We are trying to gather educational footage for the GASCo Charity in order to provide media showing where our eyes are looking. In particular, we are interested in knowing when you think you start to see your visual navigation turning point, when you positively identify it and what makes you think it is what it should look like. As your passenger, as an experienced GA pilot myself, I will call out anything I see that I think may help keep the flight safe – i.e... Weather, conflicting aircraft, aircraft problems, etc… But other than that, expect me to be a normal passenger enjoying the experience of this leisure flight.”

In flight Script on setting off for the next Waypoint

“Just a reminder, please let me know when you start to see your visual navigation turning point, when you positively identify it and what makes you think it is what it should look like. I will make notes for the video footage.”

Post-flight Script

“Thanks for taking me flying. I think we got some great footage. I will share with you what we wish to share with GASCo. In order to not influence other pilots participating in this, I ask you not to reveal the detail and how you found the experience. I will be in touch about what we want to use, and how we want to use it, in due course. I promise I will not use anything without your consent first."

ON COMPLETION OF ALL FLIGHTS FOR TRIAL PEEPER

Thanks for agreeing to the use of the footage so far. We were actually looking for HF events that would help us produce a video to educate on the use of EC equipment in GA aircraft. To gather that information, without influencing your behaviour, we had to use a cover aim regarding the visual turning points. Please can you consent for us to use the footage that we require to produce a draft version of a video. We will give you access to the proposed final draft, and only with your consent, will we use this. We can leave you anonymous throughout, or we can credit you at the end of the video as someone who has participated in this safety-related education video for the benefit of all GA.

Annex C To TRIAL PEEPER dated 24 Feb23

SUGGESTED CALLING NOTE FOR SOCIAL MEDIA & EMAILS

This is a draft of a potential advert requesting support for the media footage. It is felt important to reveal the eye-tracking glasses technology, the cover of the visual navigation exercise and the need to have EC equipment with an EFB/Display. GASCo will collate the responses and put suitable pilots in touch with the eye-tracking equipment operator.