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Sharing airspace with Uncrewed Aerial Vehicles (UAVs): Views of the General Aviation (GA) community

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ABSTRACT

Operations of Uncrewed Aerial Vehicles (UAVs or drones) are expanding, leading to competition for airspace with other users such as the General Aviation (GA) community, i.e., sports and leisure airspace users, particularly in uncontrolled airspace. As a result, there is an increasingly urgent need for a shared airspace resolution, whereby drones become integrated harmoniously in unsegregated operations with crewed aircraft, providing equitable airspace access for all. The purpose of the study was to engage with the GA community and elicit concerns and issues regarding the shared airspace concept as an initial step in the co-development of the future form of airspace. The method used was an online, interactive workshop with participants (n ~ 80) recruited from the GA community in the United Kingdom (UK). Data captured (verbal and written) were analysed qualitatively using thematic analysis, producing findings that summarised the issues identified on a range of different topics, grouped together under three over-arching themes: (1) operational environment; (2) technical and regulatory environment; and (3) equity and wider society. Almost a quarter of participants' comments (27%) were related to the opinion that shared airspace would only be possible if aircraft were fitted with Detect-And-Avoid (DAA) systems for de-confliction, based on onboard Electronic Conspicuity (EC) devices. Findings suggested that airspace management policies that establish equitable regulatory and technology environments regarding shared airspace are needed, and that those policies should be inclusive, having as a key aim the involvement of the GA community (and all other stakeholders) in the development process. The study represents a first step in the involvement of the wider aviation community in the co-design of shared airspace to include drones.

1. Introduction

Operations of Uncrewed Aerial Vehicles (UAVs), referred to as drones throughout this paper, have seen considerable expansion in recent times by commercial operators for purposes such as: video/photography, inspection (e.g. agriculture, infrastructure), environmental monitoring, last-mile logistics, mapping, emergency response and humanitarian aid (Rana et al., 2016; Scott and Scott 2017; Goodchild and Toy 2018; Lin et al., 2018; Aurambout et al., 2019; Sah et al., 2020; Darvishpoor et al., 2020). This expansion has taken place within an aviation ecosystem traditionally dominated by crewed aircraft operations, leading to competing demands for use of airspace. Consequently, there is an increasingly urgent need to consider ways in which drones can be accommodated harmoniously within an airspace system that has evolved around crewed aircraft.

Airspace can be broadly divided into controlled or uncontrolled airspace (Section 2.1). Commercial drone operations take place mainly in uncontrolled airspace, and typically involve operators applying for an airspace configuration change to the National Aviation Authority (NAA) to create a segregated volume of airspace for their intended drone flights that excludes all other air traffic, i.e., to effect a complete segregation of drones from other airspace users. In the UK for example, drone operators apply to the Civil Aviation Authority (CAA; the United Kingdom's NAA) for activation of a Segregated Airspace Volume (SAV) known as a

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Temporary Danger Area (TDA) (CAA, 2020b).

Uncontrolled airspace is extensively used by the sports and leisure (non-commercial) flying community, referred to as General Aviation (GA) hereafter in this paper,[1] including users such as private light aeroplanes/helicopters, gliders, microlights, hang gliders, paragliders/paramotors, hot air balloons, model aircraft flyers and other such operators. The current system of complete segregation via SAVs results in significant inconvenience to GA users, and improved systems are being sought to facilitate the non-segregated operation of drones and crewed aircraft. As one of the airspace user groups most likely to be affected by increasing drone operations, the views and opinions of the GA community are key to determine how best to integrate drones into shared airspace.

The aim of this research was two-fold: i) to engage and consult with a wide cross-section of GA users to understand and summarise their concerns and issues regarding the integration of drones into shared airspace as an initial step in the collective co-development of operating procedures that would be widely acceptable to all parties; and ii) to gauge the GA community's opinions on a potential new shared airspace concept (provisionally labelled 'Class Lima'), intended for non-segregated drone and crewed aircraft operations. Class Lima proposes adopting an inclusive approach that limits drone operations to within a certain, designated airspace zone, but in contrast to SAVs, crewed aircraft are also allowed to enter the designated zone when carrying appropriate deconfliction equipment.

The research was focussed on the situation in the United Kingdom (UK). However, it is also likely to be relevant more widely in other countries and regions around the world where similarly expanding drone operations are taking place within the context of complex airspace environments.

2. Airspace use by drones: a review

2.1. Drone interaction with the current airspace system

The International Civil Aviation Organization (ICAO) specifies a global scheme for the classification of airspace, in which airspace is classified as Classes A to G. Moving through the Classes from G to A, the requirements regarding Air Traffic Control (ATC) services and minimum aircraft equipment standards become increasingly stringent. Classes A to E are defined as controlled airspace where aircraft must comply with ATC instructions, whereas Classes F and G are outside controlled airspace (i.e. uncontrolled airspace) where a control service is not provided (ICAO 2018).

In addition, airspace around the world is typically divided into different types based on purpose or location. Aerodrome Traffic Zones (ATZs) are designated volumes of airspace (either controlled or uncontrolled) established around an aerodrome for the protection of traffic at that aerodrome. Control Zones (CTZs) are designated volumes of controlled airspace extending from the surface to some specified upper limit. Control Areas (CTAs) are designated volumes of controlled airspace extending from some specified lower limit up to some specified upper limit. Airways (including upper air routes) are corridors of controlled airspace (typically 10 nautical miles wide) that connect CTAs (Fig. 1). Also, some volumes of airspace can be designated as restricted, prohibited or danger areas to prevent aircraft flying too close to sensitive installations or dangerous locations (e.g. military firing ranges, military air-to-air refuelling, nuclear power stations) (ICAO 2018; EC 2012; NATS 2021).

Typically, the current way in which drone operations interact with airspace is through the activation of SAVs at the behest of operators

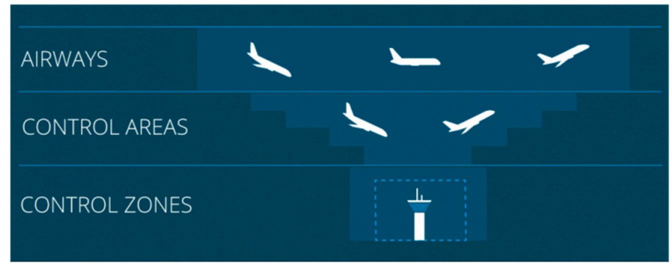

Fig. 1. Types of airspace.
The dashed line represents an ATZ. Source: adapted from NATS (2021).

applying to NAAs (Section 1). SAVs reduce the risk of inflight collisions involving drones by excluding all other air traffic from the volume of airspace intended for drone operations. The system of completely segregating other airspace users through a SAV results in inconvenience and a reduction of available airspace for GA users, who must find alternative areas and routings for their activities during activation periods. This can also create high traffic density 'choke points' where GA aircraft are funnelled to avoid a SAV.

Globally, aviation regulators are aware of the challenges posed by the increasing demand for airspace from drone operations and the need to accommodate this demand without disadvantaging other airspace users. The mechanism by which drones will be managed, controlled and integrated into shared airspace alongside crewed aircraft is being discussed and developed worldwide, and the generic over-arching term used by the ICAO to describe such service provision is the UAV Traffic Management (UTM) concept (ICAO 2020; CAA, 2019; Xu et al., 2020).

Through on-going developments within the UTM ecosystem (Section 2.3), the issue of how best to achieve drone integration is being addressed in many regions around the world (Decker and Chiambaretto 2022). For example, in Europe the concept is known as U-Space, with developments based on research conducted during the Concept of Operations for European UTM Systems (CORUS) project (CORUS Consortium, 2019). In the United States of America (USA), the development of a UTM system to integrate drones into national airspace is being progressed by the Federal Aviation Authority (FAA; the USA's NAA) and the National Aeronautics and Space Administration (NASA) (Hatfield et al., 2020). In the UK, the UTM research agenda is being led and coordinated by the Connected Places Catapult, the UK Government's innovation accelerator for cities, transport and places (CPC, 2020). UTM concepts are under development in China, where it is known as UAV Operation and Management System (UOMS), in Japan by the Japan Aerospace Exploration Agency (JAXA) and in Singapore by the Nanyang Technological University (Xu et al., 2020; Bauranov and Rakas 2021).

However, the ICAO (2020) recognises that UTM is a complex concept to deliver that is currently very much in the early stages of development, relying on a framework of emerging technology systems and regulatory environments, which suggests the concept is still some years away (possibly ~5+ years) from being fully implemented on a large scale worldwide. The shared airspace concept considered in the research reported in this paper (used as a framework for workshop discussions of the issues associated with shared airspace in general) was known as Class Lima.[2] Class Lima is currently under development in the UK and has now been renamed as Project Lima, but the term 'Class Lima' was used during the research and is therefore retained here.

Class Lima is proposed as a simpler alternative to a full UTM solution (Jelev 2021), designed to assist in the management of shared airspace given the increasing demand caused by the expansion of drone operations that is occurring now before the full roll-out of UTM can be realised

[1] The business aviation sector (both fixed and rotary wing) can sometimes be included under the general heading of GA as well, but in this paper the term GA is used to refer to only the sports and leisure flying community.

[2] It should be noted that Class Lima is not proposed as a new class of airspace to be added to the ICAO's global airspace classification scheme.

at some point in the future (i.e., bridging the gap between current demand for and future supply of UTM shared airspace). Moreover, even subsequent to the full roll-out of UTM, the more versatile, less prescriptive Class Lima could become a permanent solution for remote and/or low traffic density areas where a full UTM solution might be seen as disproportionately restrictive and costly. Further details of the Class Lima concept are provided in Section 2.4.

2.2. Regulatory permission issues for drones

For over a century, NAAs have been responsible for developing appropriate regulations for the design, manufacture and operation of aircraft. These regulations are based on many decades of operational experience and in particular the detailed analysis of accidents. It is often said that aircraft certification documents are "written in blood" in that the knowledge gleaned from fatal accidents is meticulously curated. Examples such as the De-Havilland Comet disasters of the 1950's, the DC10 air crashes of the 1990's and more recently the Boeing 737 Max accidents are all grim reminders of the consequences of failure in aviation safety. Typically, NAAs use sets of rules which have a degree of proportionality. The strictest regulations apply to passenger-carrying commercial aircraft, with less restrictive legislation applying to non-commercial private aircraft.

There has been much debate in recent years as to the most appropriate way to regulate drones. The latest thinking has resulted in a set of rules which classify drones by risk. In Europe and the UK, drones that are big enough to perform a useful logistic function generally fall into the 'Specific' category and are governed by Specific Operations Risk Assessment (SORA) (EASA 2021). The SORA process involves assessment of both the ground risk (i.e., the threat to people on the ground) and the air risk (i.e., the threat to people in the air) and these are categorised for both the drone design and the operation. For example, a large (>25 kg) drone operating close to a busy airport and over a city would fall into the highest ground and air risk categories and would require compliance with rules/risk management processes similar to those governing crewed commercial aircraft. For lower ground and air risk operations, proportionate risk management rules are invoked.

The key challenge facing the drone industry is simply one of cost. The gold standard of aviation regulation is certification, sometimes cited as Technical Specification Order (TSO) compliance. Certification means that a system is proven to comply with very strict standards governing testing, supply chain quality, batch traceability, operating life and performance. Aircraft components such as flight instruments can frequently be bought as either TSO approved or not, and there are often significant price differences (orders of magnitude) between the two categories.

In summary, the issues regarding regulatory permission to design and operate commercial drone services are:

- A lack of clarity and uncertainty about both the rules and how to interpret them. Drones and their relevant systems are relatively new. NAAs have traditionally been responsible for regulating crewed aviation and this is primarily where their expertise lies. As previously mentioned, regulation is shaped by incidents. For example, as a result of a serious drone incident at Goodwood in 2019 (AAIB 2021), the UK's NAA (CAA) has made corresponding changes to their risk assessment process.
- Lengthy and uncertain approval timescales. Because of the currently small scale of the drone industry compared with the crewed aviation industry, the resources NAAs can allocate to the rising demand for approvals is lagging. This has resulted in lengthy approvals for drone operations and associated applications for changes to airspace configurations (e.g., Airspace Change Proposals (ACPs) in the UK or Airspace Authorizations in the USA).
- Inexperienced operators within the drone industry. Many developers/operators do not have an aviation background and the systems used can be based on 'hobby' grade parts. This had led to unrealistic expectations in terms of operational approval.

2.3. Attitudes of the GA community to shared airspace

A literature review was undertaken searching for previous work where the attitudes of the GA community regarding the integration of drones with crewed aircraft in shared airspace had been addressed. Many articles investigated the mechanisms and procedures by which shared airspace might be achieved, particularly regarding the development of UTM concepts. Barrado et al. (2020) identified and discussed the various services that will be required to enable U-Space (the European equivalent of UTM), including both pre/post-flight services (e.g., drone registration, weather information, operation plan processing, strategic de-confliction) and in-flight services (e.g., e-identification, position reporting, monitoring, traffic information, emergency management).

Capitán et al. (2021) presented software architecture for UTM that enabled monitoring of airspace in real-time, to permit tactical de-confliction and emergency management. Alarcón et al. (2020) evaluated flight procedures for drones to avoid geo-fenced no-fly zones (i.e., zones where drone flight is prohibited), procedures for drones to perform contingency actions to avoid collisions with crewed aircraft, and technology for drones autonomously to detect and avoid unexpected ground obstacles.

Guan et al. (2020) reviewed separation management and collision avoidance in UTM including standards necessary for safe separation, risk prediction and assessment, and detection and collision avoidance systems. Hatfield et al. (2020) described the efforts being made by the FAA and NASA to realise UTM within the National Airspace System (NAS) in the USA, and detailed the experience of the University of Alaska Fairbanks (UAF) participating as one of the testbeds in the NASA-led UTM program.

Merkert and Bushell (2020) reviewed current drone use and future strategic directions for effective drone control. The study identified that operational issues are becoming prominent, including the development of suitable means of airspace management. It was suggested that the integration of drones will require oversight and that Low Altitude Airspace Management (LAAM) systems were a promising strategy to achieve this, incorporating features such as: traffic awareness, position recording, geo-fencing, congestion management, real-time management of any issues arising, and the facility to issue drone instructions (e.g., for crash avoidance). Further research by Merkert et al. (2021) based on a survey of 825 drone operators in Australia suggested that, if a pricing structure similar to road user charging were adopted, drone operators would be willing to pay for using LAAM systems (e.g., A$7.09/hour to fly BVLOS).

With an emphasis on the situation in Europe and the USA, Decker and Chiambaretto (2022) identified the factors policymakers should consider when developing an economic framework for UTM such as: procedures for safe and equitable access to airspace, competition between UTM service providers, data sharing between parties, and necessary infrastructure for large scale drone operations. In a review of proposals for urban air mobility, Bauranov and Rakas (2021) investigated many different airspace concepts around the world that can be broadly grouped under the generic term UTM, finding that development of the concepts often focused on maximising safety and capacity, with little regard for technological complexity and social factors relating to public acceptance such as noise, visual pollution and privacy. Furthermore, it was suggested that, whilst some may be ready today, many of the necessary technologies (e.g., advanced communication, navigation, surveillance and detect-and-avoid systems) are not yet mature enough to enable safe operations.

Watkins et al. (2021) developed a set of three autonomous algorithms for UTM for: i) path planning; ii) strategic de-confliction; and iii) tactical de-confliction using detect-and-avoid systems. In simulated testing, the algorithms were found to be capable of scaling to high-congestion situations, whilst considerably reducing drone collisions. Addressing security concerns, Allouch et al. (2021) proposed UTM-Chain as a blockchain-based system to protect data exchanges between drones and their ground control stations.

Whilst there have been many studies focussing on the mechanisms and procedures underpinning shared airspace, no studies appeared to specifically investigate the attitudes of GA airspace users to those proposed mechanisms and procedures, and to the potential consequences of shared airspace for the GA community. Studies that did address attitudes in relation to drones tended to focus on wider public attitudes, rather than specifically those of the GA community, and were therefore not relevant to this study.

2.4. Class Lima concept – a more versatile shared airspace approach

The drone industry is developing rapidly and there are now a growing number of commercial operators. Currently, these operators offer predominantly low risk services such as camera drones and surveying platforms flown within Visual Line of Sight (VLOS) of a manual safety pilot. For many years, logistics (payload delivery) applications have been postulated, but to date very few commercial examples exist. This is primarily because of the higher risks such operations entail. In particular, in order to be commercially viable, a logistics drone needs to fly beyond the visual contact distance of the operator (Beyond Visual Line of Sight; BVLOS). This therefore raises concerns over communications reliability, air risk and remote platform health monitoring.

The drone industry needs incrementally to build operational experience in order to convince regulators (and the public) of the viability of logistics applications. The obvious way to do this is to start with low-risk operations first, operating in areas with low population density and little crewed air traffic (i.e., low ground and air risks). Coincidentally, this often includes regions where communities have poor logistics connections. In the UK for example, there are over 120 populated islands which rely on slow maritime links or expensive crewed aircraft. Such regions are normally in uncontrolled airspace and often found in areas of outstanding natural beauty where GA pilots value the right to fly with few restrictions.

The authors of this paper posit that the emerging UTM concept is not appropriate and/or possible for drone operations in these regions in the short term because the full roll-out of UTM services is realistically more than 5 years away (Section 2.1), and because it would be unnecessarily burdensome for airspace users. As a more versatile alternative to UTM, the Class Lima concept would be similar to a Transponder Mandatory Zone (TMZ; an area where aircraft must carry a transponder to enhance conspicuity within/around complex and/or busy airspace, typically established to enhance safety when a more restrictive airspace classification is unwarranted (CAA, 2020a)), but with some important differences:

- It would be a designated zone in qualifying locations (low population density, low airspace traffic density).
- There would be guaranteed transponder reception coverage within the zone.
- There would be free, low latency promulgation of drone flight plans and 'live' traffic status of drones. These would be accessible to all airspace users via various connected software applications, e.g., tools such as SkyDemon flight-planning and navigation software (SkyDemon 2021) and others. Live drone traffic information would also be accessible via Electronic Conspicuity (EC) devices, where EC is an umbrella term used to describe technologies fitted to aircraft that allow airspace users to be detected electronically, but only for those equipped with devices that are capable of receiving information as well as transmitting (i.e., can inform 'in' as well as 'out').
- An assurance that drone operators would track crewed traffic and ensure they maintained separation within the zone.
- There would be a requirement for drones operating in the zone to be capable of automatically avoiding any other EC sources. This provides an additional layer of safety should drone command links fail.
- There would be no additional costs and/or complex procedures for crewed traffic, except the need to fit EC equipment.
- There would be no reliance on an Air Navigation Service Provider (ANSP) as this is unnecessary, costly and technically challenging for remote regions.
- As a final layer of safety, all drones operating within a Class Lima zone would be capable of automatically providing regular position reports on a designated VHF frequency (VHF-Out). This would provide crewed aircraft with situational awareness that allows intervention should the primary separation systems fail.

Given that the Class Lima concept has implications for GA airspace users, it was important to involve this community in the development of the concept.

3. Methodology

A study eliciting and analysing the attitudes of the GA community towards the issues associated with the development of the shared airspace concept, ensuring equitable access for all users, was a novel undertaking, with no similar studies found in the literature.

3.1. Participant recruitment

The research utilised a workshop format. Workshop participants were recruited from stakeholders in the UK GA community based on the research team's wide network of relevant personal contacts, and also named organisations representing particular airspace user groups (e.g., regional branches of the Light Aircraft Association, the General Aviation Alliance). Potential participants were approached via email invitations, with around 80 attending and engaging in the workshop, which was conducted via Zoom due to COVID-19 restrictions. This facilitated attendance by participants from a wider geographic area and a diverse delegate list was achieved (Fig. 2).

3.2. Workshop format

An independent facilitator was employed to chair the workshop, which lasted 2 h (including a short break) and took place in March 2021. Members of the research team gave two short (10 min) presentations by way of introduction. The first outlined a potential use case for commercial drone operations in medical logistics for transporting medical cargos between hospitals, clinics, doctors' surgeries and laboratories (e.g., patient specimens, medicines). This use case is widely regarded as an area where commercial drone operations can offer benefits in terms of reduced service times, energy use and atmospheric emissions, particularly for hard-to-reach locations (Scott and Scott 2017; Lin et al., 2018; Wright et al., 2018; Eichleay et al., 2019). The second presentation described the current system for drone access to airspace (i.e., SAVs, known as TDAs in the UK) and introduced the potential for drone integration in shared airspace (i.e., the Class Lima concept). Alongside this, the chat sidebar in the virtual meeting software application was open continuously for participants to type comments. Following the presentations, the facilitator asked the research team to respond to questions and comments posted in the chat sidebar. Several participants also spoke about their experiences.

Participants were also asked to leave written comments using 'post-it' notes on six virtual whiteboards under the following headings: (1) What are the positive features of the Class Lima concept for your use of airspace?; (2) How might the Class Lima concept impact on your airspace activities?; (3) Do you see any issues with the Class Lima concept?; (4) What are your views on the widespread use of Electronic Conspicuity?; (5) Are there any wider challenges to shared airspace

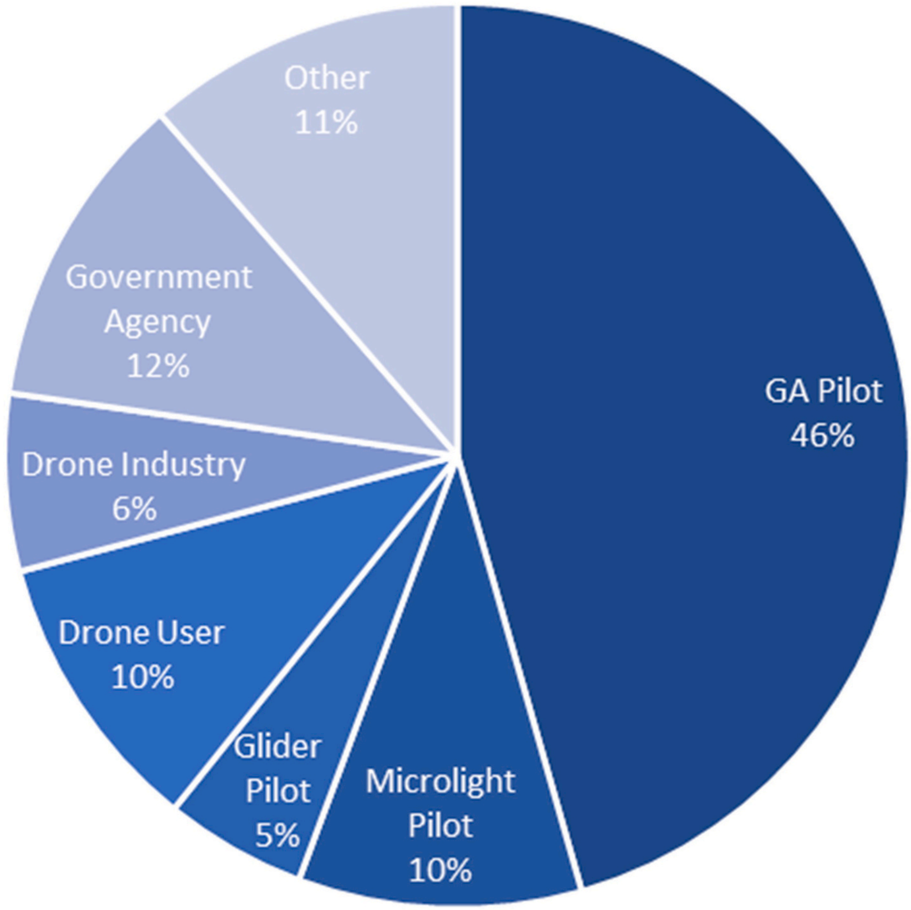

Fig. 2. Breakdown of workshop participants by interest group.
Other includes ATC interests, helicopter interests, model aircraft flyers and R&D interests.

worth mentioning?; and (6) What are the priorities for future research on drones in shared airspace? At the end of the workshop, three polls were conducted asking participants to indicate the extent of their agreement on a five-point Likert scale (strongly disagree to strongly agree) with the following statements: (S1) I am supportive of the Class Lima airspace management concept; (S2) I am confident that airspace regulations can enable drones to be used for parcel freight in general; and (S3) I am confident that airspace regulations can enable drones to be used for medical logistics.

Overall, the workshop was designed to be as interactive as possible, with multiple channels used to gather information (verbal, chat sidebar, virtual whiteboards, polls). This interactive approach was adopted as a way to foster a feeling of joint ownership of the issues involved, representing an opportunity for stakeholders to co-produce an appropriate way forward.

3.3. Analysis

Participants' comments, both verbal (transcribed) and written (chat sidebar and virtual whiteboards), were collated and analysed qualitatively using thematic analysis to produce a summary of GA airspace users' concerns and issues on the integration of drones into shared airspace. A thematic analysis approach was used due to its flexibility and suitability for identifying, analysing and reporting patterns and themes within qualitative data (Braun and Clarke 2006; Fereday and Muir-Cochrane 2006; Grote et al., 2021). All comments were reviewed carefully to identify and code the discussions according to topic, and then meaningful units of text on the same topic were collated to produce topic-specific summaries (Frith and Gleeson 2004; Grote et al., 2021).

For example, units of text that mentioned aspects such as visual identification of drones, in-flight avoiding actions, Detect-And-Avoid (DAA) systems, EC technologies, or VHF-Out systems (Section 4.3.1) were all related to the topic of in-flight de-confliction between aircraft, and coded and assigned accordingly; units of text that mentioned conditions (e.g. weather, obstacles) within drone operational envelopes (Section 4.3.2) were coded and assigned to the topic of drone operational envelopes and conditions; and units of text that mentioned circumstances that might occur at the extremities of drone operations (e.g. bird strikes, interactions with model aircraft or low-flying military aircraft), but are unlikely to occur very often (Section 4.3.3) were coded and assigned to the topic of edge-case handling. Units of text were coded by one member of the research team who had suitable subject matter expertise, meaning testing of any inter-rater variability was not possible.

Once the topics had been realised, these were then grouped conveniently under predominant themes (Fig. 3). For example, the three topics of i) in-flight de-confliction, ii) drone operational envelopes and conditions, and iii) edge-case handling were all related to the environment in which drone operations take place (i.e. the in-flight environment), and were therefore grouped together as the operational environment theme in Fig. 3. The predominant themes were closely linked to the data because an inductive (i.e. data-driven) approach was used for coding, rather than a theoretical approach where the data are coded according to a pre-existing theoretical framework or analytic preconception (Braun and Clarke 2006; Grote et al., 2021).

In addition to the qualitative thematic analysis, responses to the polls provided supporting quantitative evidence. Not all participants opted to complete the polls (n = 45). While the polls give some insight into participant views following presentations and discussion of Class Lima,

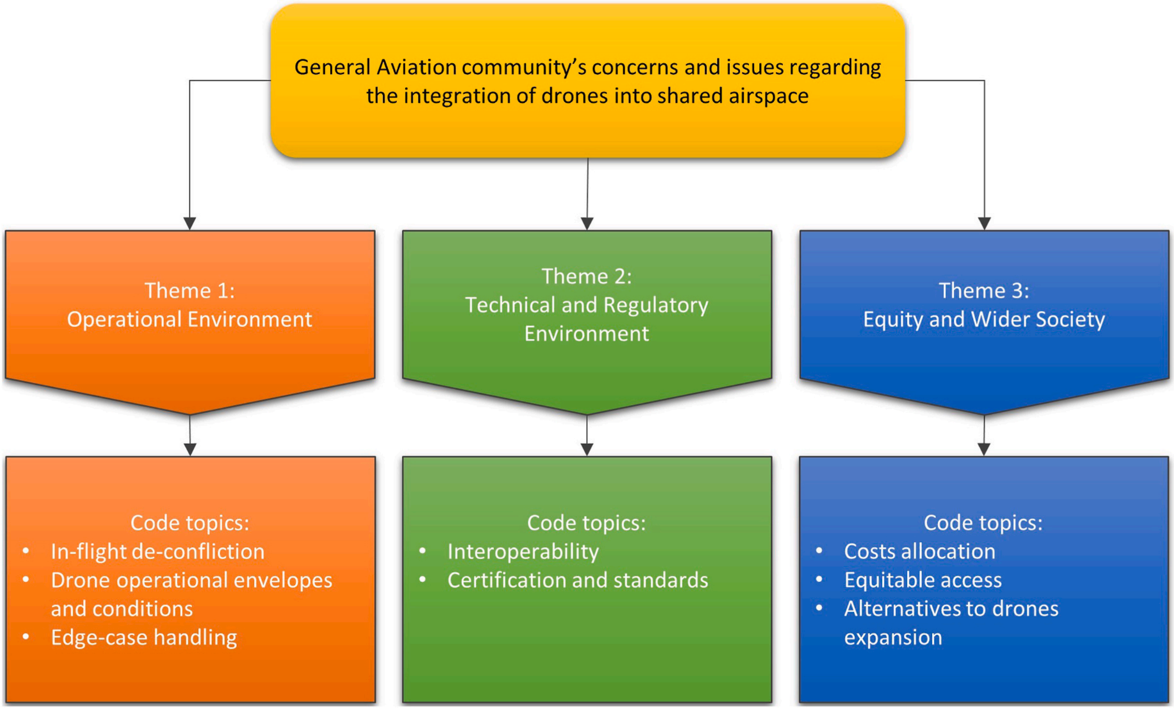

Fig. 3. Diagram of code topics and over-arching themes.

it is recognised that the questions are broad and therefore open to subjective interpretation.

4. Results and discussion

4.1. Code topics and predominant themes

There were over 400 participants' comments recorded during the 2-h workshop. The relationships between the code topics identified during the thematic analysis and the predominant themes into which they were grouped are shown in Fig. 3. Numbers of comments associated with each topic are provided in Section 4.2. Discussion summaries of participants' concerns and issues for each topic are provided in subsequent sections, grouped according to their associated over-arching themes. In addition, selected examples of participants' comments have been extracted from all three sources (i.e., verbal, chat sidebar, and virtual whiteboard 'post-its') and tabulated according to topic for all three themes (included as Appendix A: Table A.1, Table A.2 and Table A.3 for Theme 1, Theme 2 and Theme 3, respectively). The filter criterion for inclusion in these tables was an assessment by the research team member possessing suitable subject matter expertise of the comments that best represented and exemplified participants' concerns and issues. Also, it should be noted that it was possible for comments to be relevant to multiple topics.

4.2. Numbers of participants' comments

At least 51 (64%) of the 80 workshop participants were known to have made at least one contribution to the comments, either verbally or written in the chat sidebar. All virtual whiteboard comments were made anonymously, as were four of the verbal/sidebar comments, meaning individual participants' contributions were not distinguishable in these cases. The numbers of participants' comments associated with the issues related to each topic are shown in Table 1. Whilst comment prevalence is not necessarily directly correlated to topic importance (Grote et al., 2021), the results in Table 1 provided a quantitative indication of the relative importance to the participants of the different topics/issues. Results suggested that the most important issues were that: i) DAA systems based on onboard EC devices are necessary for aircraft de-confliction; ii) access to airspace should be equitable and safe for all users; iii) users will be excluded from more regions of airspace if they are unwilling/unable to carry EC devices; and iv) the costs associated with necessary new aircraft equipment are a concern.

4.3. Theme 1: operational environment

4.3.1. In-flight de-confliction

Concern was expressed over how GA airspace users would be able to ensure de-confliction from drones in shared airspace, which will inevitably rely on some system for identification as it is impossible to de-conflict objects if you do not know their position. The majority of GA traffic operating in low level uncontrolled airspace (i.e., where drone operations typically take place) operates under a cooperative principle of see-and-avoid, which can be viewed as a special case of DAA (discussed later in this section) and is sometimes called the 'see-and-be-seen' principle.

This is broadly influenced by the Big Sky Theory, which is the assumption that two randomly flying bodies in unconstrained airspace are very unlikely to collide as the volume of airspace is significantly larger than the volume of the bodies (Knecht 2001). Historically, much of the operational aviation safety and navigation standards were, and still are, based on this concept. However, the increasing proliferation of drones in uncontrolled airspace is viewed as a potential threat to this.

See-and-avoid relies on GA pilots being able to see drones with the naked eye, and the difficulty of visually identifying drones, which are often much smaller than the smallest crewed aircraft, was raised as a concern. This led to the suggestion that drones should incorporate high-visibility markings or lighting to aid visual identification. Another concern was that the additional time spent looking-out for drones would be a distraction from other flying tasks, although a continuous and thorough scan of surrounding airspace for potentially conflicting traffic is a routine requirement for aircraft operating under Visual Flight Rules (VFR).

A complicating factor is the position of drones in the general hierarchy of rights-of-way (i.e., who avoids whom, Fig. 4) stipulated in the

Table 1
Numbers of participants' comments associated with the issues related to each topic.

Topic	Issue	Number of Comments[a]
In-flight De-confliction	Detect-And-Avoid (DAA) systems, based on onboard Electronic Conspicuity (EC) devices, are necessary for de-confliction.	111
	Users will be excluded from yet more regions of airspace if they are unwilling/unable to carry EC devices, which could cause congestion/choke points.	53
	VHF-Out systems are unrealistic for de-confliction.	21
	See-and-avoid (SAA) de-confliction is difficult with drones, even if they incorporate high visibility features, and additional look-out could be distracting.	13
	Position of drones in the hierarchy of rights-of-way requires clarification.	8
Drone Operational Envelopes and Conditions	Weather limits for drones should be more clearly defined, and deactivation of drone operations promulgated rapidly.	14
	DAA systems should be extended to include avoidance of ground obstacles.	6
Edge-case Handling	Handling non-cooperative targets (i.e., no/failed EC device onboard) is a challenge.	22
	Accommodating model aircraft flyers and hobbyist drone users is a challenge.	11
	The handling of bird-strikes by drones is a concern.	7
	Degraded navigational performance due to possible interference with Global Navigation Satellite Systems (GNSS) is a concern.	5
	The safe interaction with military low flying systems is a challenge.	1
Interoperability	Standardised EC equipment is necessary to ensure interoperability.	18
	Standardised EC equipment should be mandated.	11
Certification and Standards	Operational authorisations for drones should provide an equivalent safety level relative to crewed aviation.	28
	Drone operators can be prone to corner-cutting on safety standards/regulations, and the NAA can be too lenient when dealing with offenders.	17
	Drones should be subject to a full airworthiness type certification scheme similar to that for crewed aircraft.	9
Costs Allocation	Costs associated with necessary new aircraft equipment are concerning, and the burden should not fall on GA airspace users.	48
	GA airspace users could meet the costs of necessary new aircraft equipment if they are reasonably affordable for everyone.	13
	The process of airspace changes will be expensive.	3
Equitable Access	Access to airspace should be equitable and safe for all users.	92
	All stakeholders should participate in airspace co-development, informed by wide-ranging impact studies of drone use scenarios.	39
Alternatives to Drones Expansion	Introduction of drones in beneficial niche use cases (e.g., medical logistics) could lead to over-proliferation in use cases where other modes are more suitable.	9
	There is doubt over the need for drone logistics and over their ability to provide a reliable level of service.	5

[a] It should be noted that it was possible for comments to be relevant to multiple topics/issues (Section 4.1), and therefore appear more than once in the numbers of comments.

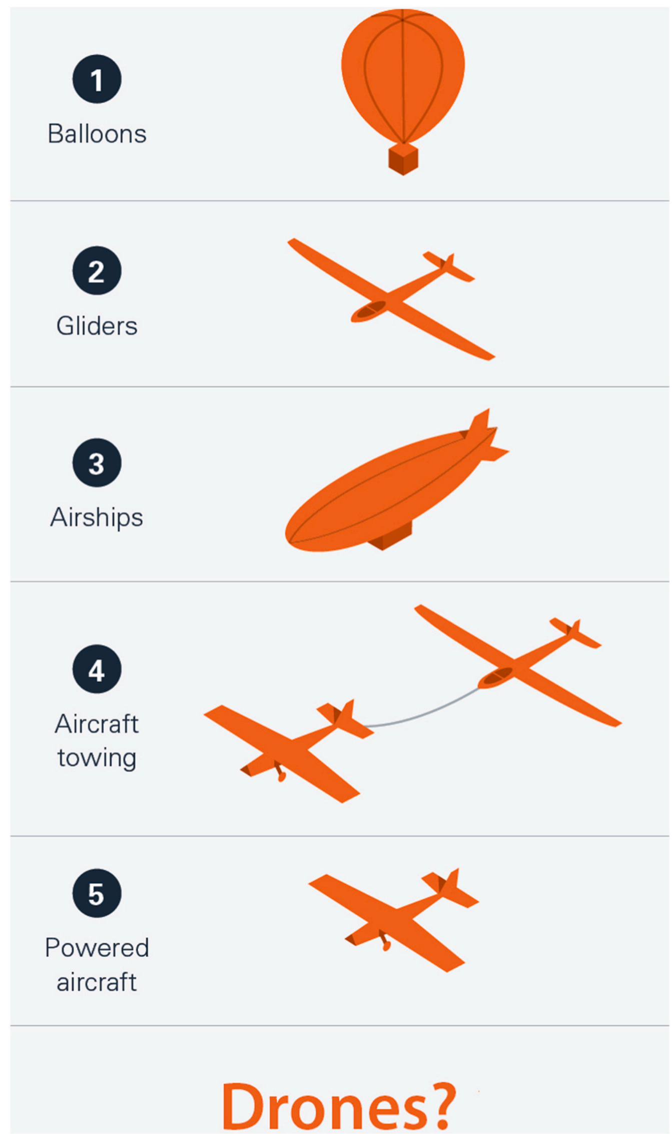

Fig. 4. Aircraft rights-of-way.
Aircraft at the top have right-of-way over those below. Source: adapted from CAA (2021).

rules of the air for aircraft on converging paths (EASA 2020; CAA, 2021). The hierarchy is organised in order of control over the aircraft flight trajectory, with balloons and gliders being the most beholden to wind and weather conditions having priority over powered aircraft, who are able to avoid such phenomena with their on-board propulsion systems, which also means they are able to maintain desired altitudes and headings. More specifically, the rules state that for two aircraft on converging paths, the aircraft that has the other on its right shall give way, except that: powered heavier-than-air aircraft shall give way to airships, gliders and balloons; airships shall give way to gliders and balloons; gliders shall give way to balloons; and powered aircraft shall give way to aircraft which are towing other aircraft or objects (ICAO 2005; EASA, 2020).

Most current drone operations have a safety pilot on the ground who can and will override and take avoiding action in any conflict situation, which effectively puts drones at the bottom of the hierarchy shown in Fig. 4, giving way to all other aircraft. Drones will not necessarily each have a pilot in the future, thus a decision will be needed regarding where drones will be placed in the hierarchy. The main contention here is the right-of-way between powered, crewed aircraft and drones, as it is a reasonably settled matter that aircraft with more control over their flight trajectory give way to those with less.

Many participants' comments (111 in Table 1) suggested that, for deconfliction to be truly possible in shared airspace, a DAA solution was necessary, whereby aircraft can detect each other via some form of EC technology (Section 2.4) and take avoiding action if required. In particular, if drones were placed at the bottom of the rights-of-way hierarchy and required to avoid all other traffic, a DAA system would be essential because drones cannot rely on visual contact (i.e., see-and-avoid) to avoid crewed aircraft.

Many EC technologies exist, but there have been no comparisons reported in the literature as to which technology is best suited to different situations. Currently, different EC technologies (including avoiding the use of EC technology all together) have been adopted in various aviation communities, leading to an entrenched resistance to change to accommodate others (Section 4.4.1). Particular concerns regarding EC raised by participants included:

i) being forced to carry such equipment in order to be permitted entry to shared airspace;
ii) the cost of installing EC equipment on their aircraft (Section 4.5.1);
iii) interoperability between the different EC technologies (Section 4.4.1);
iv) the need for avoiding actions taken to resolve conflicts to be coordinated between the aircraft involved (e.g., Traffic Collision Avoidance System, TCAS, routinely fitted to commercial airliners);
v) the use of EC equipment requires more heads-down time inside the cockpit, which distracts from maintaining a good look-out.

Anecdotal evidence from participants suggested that drone operators were flying drones with EC not working (i.e., onboard EC devices unserviceable) in contravention of the requirements of their operational approval. This was used to raise the issue of poor airmanship and a general lack of respect for other airspace users on the part of drone operators (Section 4.4.2).

Another system to increase situational awareness of potential conflicts with drones is VHF-Out, whereby drones continuously broadcast automated position reports over a VHF audio frequency. However, concerns were raised by participants that this was an unrealistic proposition for reasons such as:

i) pilots would have to monitor yet another frequency, increasing their general workload;
ii) it would be impossible to maintain situational awareness from a barrage of drone position reports;
iii) such a system may not be possible due to frequency congestion on the VHF spectrum.

A further concern raised in many participants' comments (53 in Table 1) was that blocks of Class Lima airspace represented more regions of uncontrolled airspace for GA users to avoid if they do not want to/cannot carry EC equipment on-board. This leads to 'pinball' navigation being required rather than more direct routings between origin and destination and the possibility of 'choke points' similar to those that can be caused by SAVs (Section 2.1), although any aircraft that are equipped with EC would be able to fly through Class Lima airspace to obtain direct routings. However, 'pinball' navigation is already an issue in uncontrolled airspace due to the increasing amount of airspace configuration changes (i.e., ACPs in the UK) being approved by the NAA, and the concern raised was more that the Class Lima concept could exacerbate the problem rather than initiate it.

4.3.2. Drone operational envelopes and conditions

Participants suggested that weather limits for drone operations should be more clearly defined, providing more certainty to pilots that outside defined weather conditions (e.g., maximum wind speed, minimum visibility and/or cloud base), drone operations would not be active. However, GA users often require good weather conditions (e.g., Visual Meteorological Conditions, VMC) to conduct their activities, and therefore the more likely situation was that drones would remain operational in weather conditions that would ground many GA operations (e.g., low visibility in mist or fog). A related issue was how to deal with rapidly changing weather conditions and the associated promulgation of whether or not drones were operational. For traditional danger areas, there is usually a Danger Area Crossing Service (DACS) or a Danger Area Activity Information Service (DAAIS) available on a published VHF audio frequency that is able to provide crossing clearances or advise whether the danger area is active or not, and these could be an option for promulgation.

Drones typically operate at low levels and participants suggested that DAA systems on drones should be extended to include detection and avoidance of ground obstacles (e.g., masts, electricity pylons/wires). Such obstacles would represent non-cooperative targets (i.e., no EC technology), unless they were fitted with conspicuity beacons detectable by on-board EC equipment, although installation of beacons on obstacles would obviously incur costs. Significant temporary obstacles (e.g., tall tower cranes used in construction) are typically publicised via the Notice to Airmen system (NOTAM system; used to promulgate timely awareness of temporary hazards or the abnormal status of aeronautical facilities/services/procedures affecting flight operations; known as Notice to Air Missions in the USA) from which information could be extracted and utilised for obstacle avoidance. An alternative solution could be to fit drones with a Ground Proximity Warning System (GPWS) to assist with avoiding controlled flight into terrain or obstacles. This would require drones to be equipped with a database of terrain and obstacles (or receive such data via real-time up-link), or could be achieved with sensors alone, for example, a radio altimeter looking downwards and LiDAR (or similar) laterally.

4.3.3. Edge-case handling

The handling of edge-cases (i.e., circumstances that could conceivably occur at the extremities of operations but would be unlikely to occur very often) was the subject of several questions raised by participants (itemised in the following paragraph), alongside a general concern over the difficulties involved in overcoming the technical challenges associated with finding solutions to the edge-cases identified.

The main questions posed by participants were related to:

i) How drones might handle bird-strikes, and whether this would lead to a catastrophic failure of the drone involved, in contrast to crewed aircraft which are usually still flyable following a bird-strike. This is likely to depend on the size of the drone, with decreasing drone size likely to lead to an increasing likelihood of catastrophic failure.
ii) How model aircraft flyers and hobbyist drone users (as opposed to commercial drone operators who might be expected to be more aware of relevant regulations and subject to more rigorous

operational approval procedures) might be accommodated within shared airspace, in particular without prohibitive equipment costs being involved.

iii) The consequences for drone operations of interference with Global Navigation Satellite Systems (GNSS) (e.g., jamming or spoofing attacks) leading to degraded navigational performance of drones.

iv) How shared airspace concepts would interact safely with military low flying systems.

v) How non-cooperative targets in shared airspace can be handled, involving aircraft that either have no EC technology or a systems failure on-board.

4.4. Theme 2: technical and regulatory environment

4.4.1. Interoperability

There are a slew of different EC technologies available, and their compatibility with one another was identified as a concern by participants. Some form of standardisation to ensure interoperability of EC equipment was seen as necessary. However, mandating an existing standard would force a switch of equipment for those that do not already use that standard, whilst introducing a new standard would force a switch of equipment for all. In both cases, resistance is likely to be encountered from a substantial body of existing EC users.

Automatic Dependent Surveillance-Broadcast (ADS-B), an EC technology whereby aircraft broadcast data such as position, identification, altitude and velocity, is the preferred standard in the USA, with the FAA (the USA's NAA) recently (2020) adopting regulations mandating the carriage of ADS-B devices for all aircraft in most controlled airspace within the USA (FAA 2021a; FAA 2021b). ADS-B is the preferred standard in the UK as well, but nothing has been enforced. Furthermore, UK ANSPs are not allowed to use ADS-B as the sole source of surveillance radar, which means aircraft may need to have equipment for two systems on-board. For example, both ADS-B and a traditional Secondary Surveillance Radar (SSR) transponder depending on the requirements of the airspace in which they intend to operate. In addition, there are concerns regarding the long-term viability of ADS-B due to frequency spectrum congestion (i.e., lack of bandwidth) if the number of aircraft using the system continues to increase as expected, and other technologies may therefore represent better solutions for standardised interoperability (Bauranov and Rakas 2021).

4.4.2. Certification and standards

It was suggested by participants that drone operators were prone to corner-cutting on matters relating to safety and regulations, and that a strong profit incentive was sometimes pursued at the expense of safety. Furthermore, the NAA was seen as not being harsh enough in dealing with drone operators found to be non-compliant with required standards.

A desire for an Equivalent Level of Safety (ELOS) for drones relative to crewed aviation was expressed, whereby an ELOS would be granted for drone operations if compensating factors (e.g., imposed design changes, limitations, equipment) can be shown to provide safety levels equivalent to that of literal compliance with regulations. This is essentially what is achieved on a case-specific basis when a drone operator submits an application to the NAA for an operational authorisation who then assesses the safety case and risk assessment produced by the operator. A drone operator could specify a Minimum Equipment List (MEL) in the safety case, without which they would not fly (commercial crewed aviation uses MELs already).

The prospect that drones should be subject to a full airworthiness type certification scheme similar to that used for crewed aircraft was raised by participants. Typically, drones are not currently subject to such a scheme (e.g., there is no standard scheme for full airworthiness type certification specifically for drones in the USA, Europe or the UK at present), with airworthiness being assessed by the NAA as part of the operator's case-specific application for operational authorisation.

Other concerns relating to certification and standards raised by participants included the ability of drones to meet Required Navigation Performance (RNP) standards (specified standards of navigation that allow aircraft to be navigated along a precise path with a high level of accuracy and integrity) and the associated reliance on GNSS accuracy (Section 4.3.3), and that high software reliability standards should be followed and verified for drones.

4.5. Theme 3: equity and wider society

4.5.1. Costs allocation

A recurrent concern for participants throughout the workshop was the issue of who should bear the cost of any new aircraft equipment necessary to be able to access shared airspace. Broadly, participants' opinions were divided into one of two positions:

i) the status quo operates very well currently, therefore any new entrants who want to use airspace in new ways (i.e., commercial drone operators in shared airspace) should be the ones ensuring everyone else (i.e., existing users) has the required equipment; or

ii) continuous improvement in technology is to be expected over time and therefore GA pilots would be willing to install the new equipment required, but efforts should still be made to standardise equipment and minimise cost burdens.

Overall, the majority of participants' comments (48 cf. 13 in Table 1) erred on the side of the need for commercial drone operators to meet the burden of costs for any new equipment required (i.e., position one). In a study by Merkert et al. (2021), drone operators were found to be willing to pay for access to shared airspace systems via a pricing structure similar to road user charging (Section 2.3). This could offer a way to overcome the issue of who should meet any cost burdens associated with shared airspace, i.e., drone operators could bear the costs through their willingness to pay for access, which would align with the majority opinion expressed by participants.

As a way to offset some of the costs associated with the purchase of EC equipment in the UK, the Department for Transport (DfT) launched a funding scheme in October 2020 aimed at encouraging the uptake of EC within the GA and drone communities. The fund is being administered by the NAA and offers a 50% rebate (up to a maximum of £250) on the cost of an EC device. The fund will remain open until March 31, 2022 (or until the funding is used). The approximate costs associated with purchasing examples of EC devices commonly used by the GA community are shown in Table 2.

One other issue raised by participants related to the cost associated with processing applications for airspace configuration changes

Table 2
Purchase costs associated with examples of EC devices commonly used in GA aircraft.

Type of EC Device	Approximate Cost[a]
SSR Transponder[b]	£1550
FLARM	£640
ADS-B	£440
PilotAware	£270

[a] Approximate costs were based on prices (in UK pounds, excluding tax) for basic model equipment (excluding costs of any installation and/or externally connected peripheral equipment) listed for online purchase from a large avionics supplier to GA in the UK and Europe (LX Avionics, 2022).

[b] Typically, new SSR transponders are Mode S (i.e., allowing data exchange as well as providing the identification/altitude information available from older and more basic Mode A/C SSR transponders), and also have a built-in ADS-B capability (i.e., Extended Squitter; ES).

submitted to NAAs for approval, as would be the case for the implementation of a shared airspace concept such as Class Lima. In the UK for example, airspace configuration changes (i.e., ACPs) are proposed by airspace change sponsors (typically ANSPs or airport operators, but can also be other organisations), and the NAA receives varying numbers of ACPs each year of differing degrees of size and complexity (for all airspace changes, not just those related to drone operations), all of which incur costs to process. A related concern raised by participants was the cost associated with lodging opposition by those that disagree with proposed changes.

4.5.2. Equitable access

The issue of how to ensure that the ongoing rights to access uncontrolled airspace are managed in a way that is equitable and safe for all users was raised in many participants' comments (92 in Table 1). One likened the designation of airspace for drone use (albeit shared with crewed aircraft) to the Inclosure Act of 1773 that created a law enabling enclosure of land, removing the right of commoners' access (HMG, 1773). Fundamental to ensuring equitable access is how to initially define 'equitable access' in terms of rights to airspace, and which airspace utilisation metrics should be developed/utilised as the basis for implementing and monitoring an equitable system of rights. A related concern was that society in general will not care about whether or not the GA community has equitable access to airspace if the expansion of drone operations improves their lives, leading to the GA community losing access due to the weight of public opinion in favour of drones.

Participants suggested there was a general paucity of societal impact studies investigating the effects on people and communities that could occur as a result of increasing drone logistics activities. To provide the GA community (and other stakeholder groups) with the opportunity and necessary knowledge to participate in the co-development of future shared airspace, it is important that clear, realistic scenarios of future drone use (including wider societal impacts) are established and disseminated.

4.5.3. Alternatives to drones expansion

Participants expressed scepticism as to the ability of drones to provide a reliable all-weather service that could compare favourably with other modes (e.g., van-based logistics) in terms of service level and overall cost benefits. In addition, questions were raised over whether there was any demand for drone logistics operations at all, with a desire expressed to see more justification of the needs and economic cases for expansion.

Participants were concerned about function creep, as identified by Boucher (2016), whereby drone logistics operations are initiated for a use case where drones are the most suitable transport mode (especially a use case likely to be seen by the public as being particularly beneficial to society such as medical logistics), which then proves to be a gateway to their take-up across other use cases where other modes might represent better alternatives. In other words, the 'slippery slope' argument starting with (for example) drones for medical logistics and ending with full roll-out to wider parcel deliveries.

4.6. Participant polls

The results of the participant polls (Fig. 5) suggested that respondents (n = 45) tended to show a slight preference for agreement with all three statements (S1, S2 and S3, as detailed in Section 3.2), indicating a small majority in favour of Class Lima (40% strongly agree or agree vs. 27% disagree or strongly disagree), drones for parcel logistics (40% strongly agree or agree vs. 31% disagree or strongly disagree), and drones for medical logistics (56% strongly agree or agree vs. 9% disagree or strongly disagree). Scores were assigned to participant responses (strongly disagree = 1 to strongly agree = 5), which resulted in average response scores for each statement of: S1 = 3.2, S2 = 3.2 and S3 = 3.6, confirming the small margin of support for all three statements among the participants (i.e., average response scores greater than the neutral score of 3).

The 45 poll respondents were disaggregated according to those who were drone users (and/or had drone industry interests) (n = 6) and those who were not drone users (n = 29), with 10 respondents electing not to disclose this information. Comparison of results for drone users (Fig. 6 and average response scores of S1 = 4.5, S2 = 4.3 and S3 = 4.5) with those for non-drone users (Fig. 7 and average response scores of S1 = 2.6, S2 = 2.9 and S3 = 3.3) revealed that drone users were more favourably disposed towards the Class Lima concept and the two drone use cases (i.e. parcel freight and medical logistics), and therefore more likely to agree or strongly agree with the three statements, which skewed overall results in that direction. It is likely that drone users (and those with drone industry interests) would have a vested interest in resolving the use of shared airspace and this may explain the more positive views. However, the 10 unknown respondents (average response scores of S1 = 4.0, S2 = 3.4 and S3 = 4.0) meant that the effect of drone user responses on overall results was not possible to determine

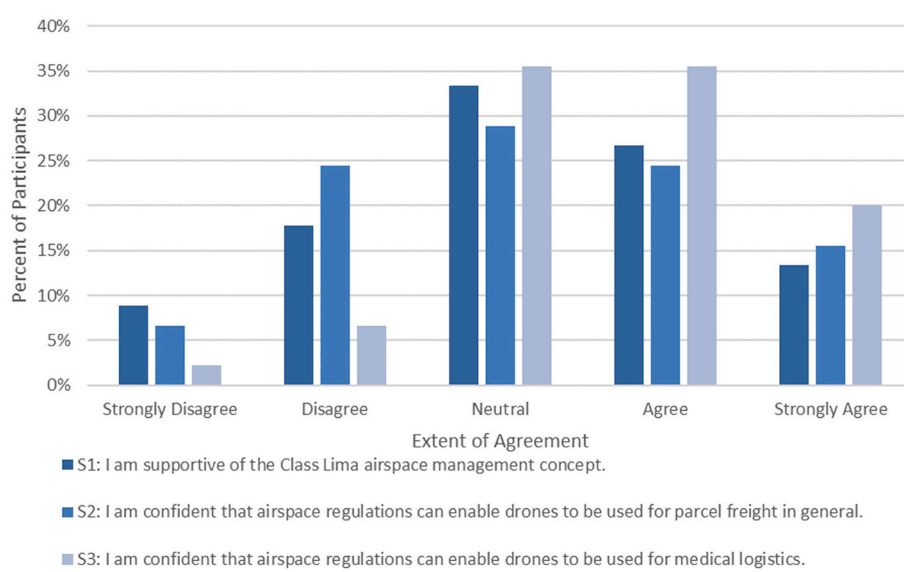

Fig. 5. Workshop participants' responses to polls.
There were 45 workshop participants who responded to the polls, n = 45.

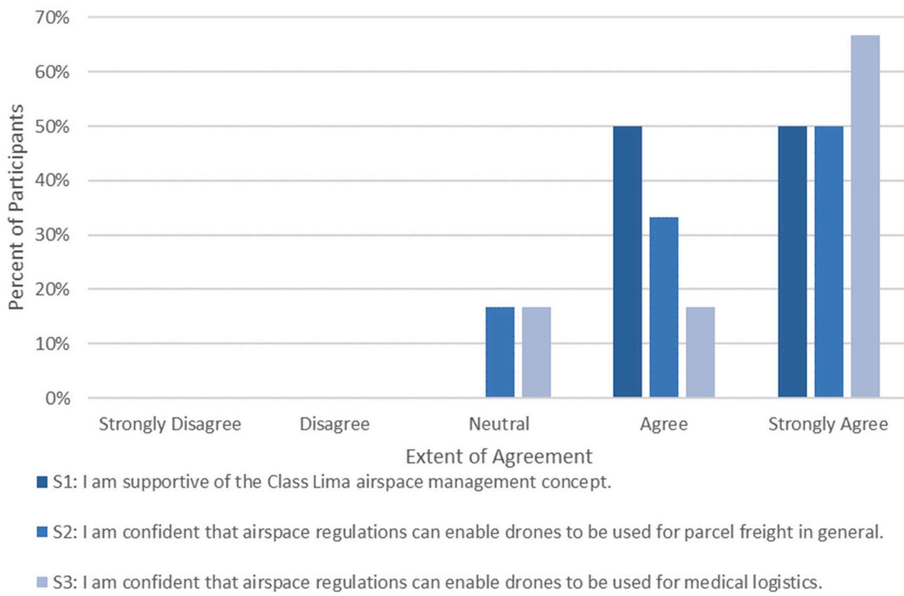

Fig. 6. Workshop participants' responses to polls – Drone users.
Includes all respondents identifying as drone users (and/or drone industry interests), n = 6.

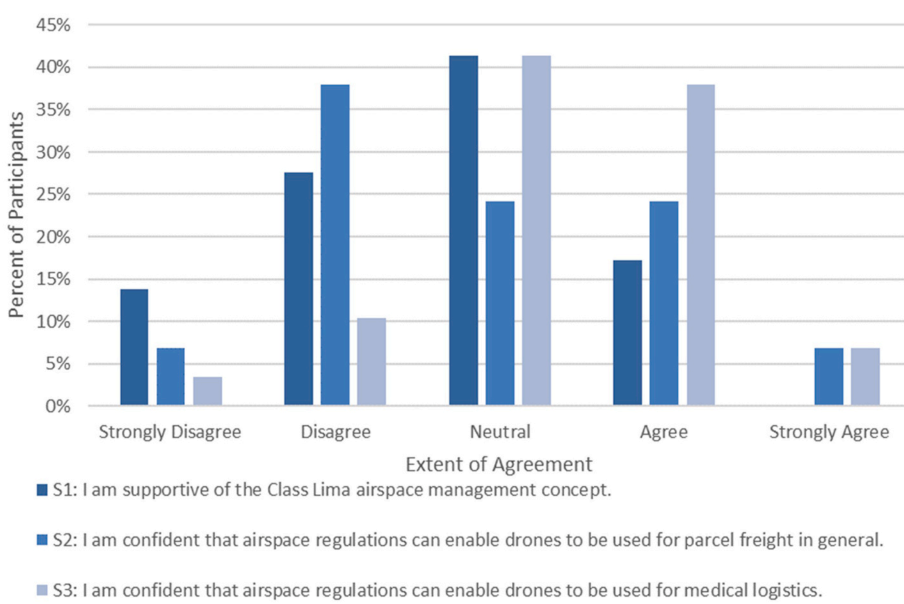

Fig. 7. Workshop participants' responses to polls – Non-drone users.
Includes all respondents identifying as something other than drone user (and/or drone industry interests), n = 29.

conclusively. In addition, the drone user sample size (n = 6) was too small to render reliable results from statistical tests of whether or not the differences in responses between the two groups were significant.

In addition, results suggested that drones specifically for medical logistics (56% strongly agree or agree, and overall average response score for S3 = 3.6) were viewed more favourably than for parcel logistics in general (40% strongly agree or agree, and overall average response score for S2 = 3.2). This supports the qualitative finding of the workshop that drone logistics on a smaller scale for a purpose likely to be seen as beneficial to society (i.e., operations limited to medical logistics) were viewed more favourably than drone logistics on a larger scale for parcel deliveries in general, i.e., evidence of the concern expressed by participants regarding function creep starting with drones for medical logistics and ending with full roll-out to wider parcel deliveries explained in Section 4.5.3.

4.7. Implications of the research

In general, the workshop results suggested that the GA community have many and varied concerns regarding the increasing need to share airspace with drones. Some of these concerns require technical solutions (e.g., DAA systems, EC equipment), while others require regulatory and governance solutions (e.g., rights-of-way, certification standards, sanctions for non-compliance with authorisations), and consideration of wider concepts that are less easily defined such as fairness and societal benefits (e.g., equitable airspace access, costs allocation, alternative logistics modes). Regarding drone use cases, whilst the specific purpose of medical logistics may be acceptable, the GA community appear to have reservations over the widespread use of drones for parcel deliveries.

The increasing use of airspace by expanding drone operations has parallels with the niche-innovation trajectories (i.e. how technologies grow and become established within an existing regime) analysed by Verbong et al. (2008) for emerging renewable energy technologies in the Netherlands. In this case, findings suggested that innovations suffered from recurring setbacks involving hype-disappointment cycles, costly failures, changing/unstable political priorities, and a limited learning capability that focused on technology (i.e., R&D) at the expense of other aspects (e.g., societal acceptability, commercial prospects, legislation and regulation). The development of a shared airspace concept for drones represents a slightly different situation in that the existing regime (i.e., the GA community) is actually quite a disparate (though well-established) community, and that the commercial interests of the niche (i.e., drone operators) may be stronger than the regime, providing the impetus to drive forward the development trajectory of shared airspace, minimising and overcoming any setbacks encountered on the way.

In recent research, Söderbaum (2020) suggested that the best way to approach decision-making is through multidimensional analysis, accounting for the fact that, typically, there are multiple objectives involved that different groups or individuals are hoping to achieve (i.e., many-sided analysis), which highlights the importance of engaging with the GA community (and any other stakeholders) in the co-development of the shared airspace concept. Hopkins and Schwanen (2018) investigated the governance processes regarding the emergence of automated vehicle technology and found that, in general, the views and opinions of wider stakeholders were not well included. The engagement with the GA community reported in this paper is an initial effort to prevent a similar situation developing regarding the emergence of commercial drone operations. Providing cause for optimism in this respect, a key implication of the research was that there appears to be a strong appetite within the GA community to be involved with, and have influence on, the co-development of shared airspace as technical, regulatory and wider solutions are sought, and as drone use cases are developed and expanded.

For policymakers, the implication is that any policies aimed at establishing suitable frameworks for progressing the implementation and management of shared airspace systems should not only focus on the development of the necessary technological and regulatory environments, but also should be inclusive policies aiming to involve all stakeholders (including the GA community as one of the foremost stakeholders) in such development. Given the strong opinions of stakeholders like the GA community, it seems that such an inclusive policy approach will be necessary to minimise any resistance to the implementation of shared airspace and to ensure that access to it is perceived as equitable by all users.

The importance of stakeholder involvement suggests that, rather than allowing an atomised system of shared airspace management to develop, overseen by different private sector service providers, some form of centralised oversight of policy development and management by national and/or international authorities/agencies (e.g., governments, NAAs, ICAO) will be necessary. This would provide central points of authority that could assume the responsibility for overseeing a coordinated and unified approach to ensuring the continued involvement of all stakeholders as the development of shared airspace progresses.

It would also seem sensible for policymakers to adopt an international, rather than national, perspective on shared airspace, pursuing policies with international commonality whenever possible. Implementing shared airspace solutions on a purely national basis is likely to increase the risk of a future situation characterised by a patchwork of country-specific technologies, regulations and procedures that could be an impediment to the efficient operation of the GA community worldwide, and also to the operation of a multi-national drone industry. The Class Lima shared airspace solution proposed in this paper (now known as Project Lima) is being developed in the UK as part of the UK CAA's Innovation Sandbox programme (a programme for trialling innovative solutions in the real-world that may not fit within the scope of existing regulations), and therefore would require increased awareness internationally to become a viable international solution.

5. Conclusions

Many issues and concerns of the GA community regarding the shared airspace concept were captured during the workshop, which provided an example of good practice for stakeholder engagement. The outcomes have been classified through qualitative thematic analysis according to three over-arching themes: (1) operational environment; (2) technical and regulatory environment; and (3) equity and wider society. Having identified these issues and concerns, the challenge is now to ensure the GA community remains actively engaged in the co-development of the future form of shared airspace, and is able to have influence over how associated issues and concerns are resolved. As one initiative to ensure continued GA community involvement, an open invitation has been extended to participants in this research to participate in future research and development.

The implication of this research from an airspace management policy perspective is that there is a need to establish equitable regulatory and technology environments relating to shared airspace for both drone and crewed aircraft operations. The Class Lima concept, which limits drone operations to certain designated airspace zones but allows crewed aircraft to enter if they are carrying appropriate de-confliction equipment, aims to do this. The research has shown the importance of engaging with a diverse set of airspace users in the co-development of the shared airspace concept. This would appear a major step forward compared with many innovations which focus on the specific use case rather than its interaction with other users and uses of the same space. Finally, from the perspective of further research, there is a need to commence test flights to investigate how the interaction between drones and GA aircraft might be achieved in the real-world.

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CRediT authorship contribution statement

Matt Grote: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft, preparation, Writing – review & editing, Project administration. **Aliaksei Pilko:** Conceptualization, Methodology, Investigation, Formal analysis, Writing – review & editing. **James Scanlan:** Conceptualization, Methodology, Investigation, Writing – original draft, preparation, Writing – review & editing. **Tom Cherrett:** Conceptualization, Methodology, Investigation, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Janet Dickinson:** Conceptualization, Methodology, Investigation, Formal analysis, Writing – review & editing. **Angela Smith:** Conceptualization, Methodology, Investigation, Formal analysis, Writing – review & editing. **Andrew Oakey:** Conceptualization, Methodology, Investigation, Writing – review & editing. **Greg Marsden:** Writing – review & editing.

Declaration of competing interest

None.

APPENDIX A

Table A.1
Examples of participants' comments relating to topics in Theme 1.

Participants' Comments
In-Flight De-Confliction (Section 4.3.1**):**
• "Visibility of drones, I have trialled this, it is very hard to spot [drones] from the air, especially over the sea with white waves."
• "If you make large drones highly visible – for example, high intensity lighting – then GA pilots have an opportunity to avoid visually."
• "There is a vital rule here: in all circumstances UAVs must make the avoiding action when in proximity to crewed aircraft."
• "Commercial drone operators should be spending their time certifying a reliable autonomous detect and avoid system."
• "EC … makes me feel 'a bit' safer, but it can lead to more heads-down in the cockpit, and is reliant on good faith on all sides."
• "ADS-B … would have to be mandatory to make it safe."
• "If drones have an avoid capability, how do we ensure that drone and GA aircraft that come into conflict take coordinated avoiding actions that move them apart, not the opposite?"
• "VHF-Out is unrealistic. There is enough workload without a number of drones reporting in your ear."
• "Situational awareness in Class G via VHF[-Out] transmissions is not possible."
• "Have you considered frequency congestion if VHF[-Out] auto broadcast?"
• "Experience so far with [commercial drone operator deleted] in [location deleted] has been very poor. There is now a total lack of trust. They did not engage with GA, despite claiming otherwise, they avoid difficult questions, and provide misleading info. Their ADS-B does not work."
• "Flying a non-radio aircraft with no electrical system [to power EC equipment] as I do, 'Class L' simply represents another area I would have to avoid."
• "It is just another airspace to avoid … creates choke points".
Drone Operational Envelopes and Conditions (Section 4.3.2**):**
• "That didn't answer the question reference [drone] weather limits, i.e., low visibility ops, cloud minima and visibility minima please?"
• "[Drone] trials at [location deleted] have been cancelled about 40% of the time due to wind, cloud, rain."
• "But to close off these large areas of airspace [TDAs] for maybe six [drone] flights a day, eight [drone] flights a day, that's not really realistic, and they're often sitting empty because the weather is not good enough [for drones to fly]."
• "Weather limitation for [location deleted] trial is supposed to not activate TDA if cloud base is below 1,500 ft or wind over 25 kts. Reality is, TDA is activated waiting for weather improvement."
• "Detect And Avoid on non-cooperative targets (wires, birds, parascenders, model planes, masts, hobby drones) is the key."
• "EC doesn't cover non-cooperative targets like birds, masts, etc."
Edge-Case Handling (Section 4.3.3**):**
• "Bird-strike is an on-going risk to aircraft, as are masts, …this work should now be done by drones."
• "Manned aircraft hit birds, but generally are only damaged and can keep flying. Probably not the case with a drone hitting a Red Kite [a type of large bird with mass ~1 kg]."
• "Class Lima also doesn't cover model fliers, hobby drones, paragliders etc., you just ban them completely?"
• "Get all model flyers, parascenders, hobby drone-ists to buy a £500 [EC] device? Sorry can't agree."
• "GNSS failure probability might be very low, but jamming of GNSS is prevalent with many instances every day."
• "Police are very aware of GPS spoofing."
• "My key concern would be interactions between drones and fast jets in the UK [Military] Low-Flying system."
• "True DAA on non-cooperative targets is the key for BVLOS ops as it encompasses all air users."
• "True DAA for non-cooperative targets I guess is complex and expensive, and I feel just addressing EC is fudging the issue and moving costs to the GA community."

Table A.2
Examples of participants' comments relating to topics in Theme 2.

Participants' Comments
Interoperability (Section 4.4.1**):**
• "Standards and interoperability are very good points."
• "EC policy is unclear, and the systems are not interoperable."
• "I'd be in favour of EC if there was one single box that saw everyone."
• "This concept only works if EC technology can be standardised – too many competing systems at the moment."
• "ADS-B … is the way to go."
• "UK ATC not having and not being allowed to use ADS-B is a major block."
• "FAA mandated it [ADS-B for EC], but CAA says it will be industry led".
Certification and Standards (Section 4.4.2**):**
• "The UAS industry and CAA needs to be more diligent in policing other members of its community who don't meet such standards. They are damaging confidence in and the credibility of the industry."
• "Potential issues? Less than scrupulous [commercial drone] operators not having serviceable ADS-B, not reporting incidents."

(*continued on next page*)

Table A.2 (*continued*)

Participants' Comments
• "[Commercial drone operator deleted] claimed to have ADS-B on their trial at [location deleted], but when I went up to find them, it turns out the software is faulty." • "[The recent drone crash at] Goodwood was an example of why the CAA needed to 'step-up' to UAS certification." • "I fear the [commercial drone operator deleted] experience doesn't reflect well on the CAA's oversight." • "CAA scrutiny of [commercial drone operator deleted] was dreadful." • "The CAA cannot cope with the current set of rules. Do not expect anything to be done any time soon." • "If drones operated under the same reliability/safety rules as crewed aircraft there would be no need to route differently for ground risks." • "Why is it not possible to set airworthiness standards for drones?" • "Drones will have to invest in airworthiness, ground support infrastructure and be able to comply with existing crewed operating procedures and laws." • "How would a drone cope with jamming/spoofing of GPS?" • "How accurate is the GPS on-board UAVs?" • "GPS altitude isn't very accurate due to the geometry of GNSS system." • "Who certifies that the detect and avoid algorithms are good enough?" • "High software assurance levels are also needed."

Table A.3
Examples of participants' comments relating to topics in Theme 3.

Participants' Comments
Costs Allocation (Section 4.5.1**):**
• "Responsible pilots have made personal investments [in EC], but it is up to UAV to invest and not place that responsibility or cost on other airspace users" • "If commercial drone operators want [an EC system], they should be developing a free of charge conspicuous device that everyone can use." • "So you [commercial drone operators] are expecting other airspace users to purchase [EC] equipment for your benefit to subsidise your operation. Totally unacceptable." • "So arrogant that the commercial drone operators expect all these people to spend money [on EC] so that the drone operators can make profits." • "The bottom line is that Class Lima will exclude many airspace users … who can't afford to pay £500 for an EC device, and that goes against the CAA vision of airspace for all." • "Crewed [aircraft] ops will probably have to buy-in to EC in the future, but if that requirement is driven by UAS then it should be funded by the prospective new airspace users [i.e., commercial drone operators]." • "Generally in favour when EC devices become affordable and standardised to some degree." • "It would be great to see EC become cheap enough to allow everyone to use it." • "[EC systems] should be affordable to all users of the airspace." • "I am a big believer in EC and have been equipped with ADS-B for 5 years." • "Simply blocking innovation will just kill the aviation industry in the UK. The UK used to lead in aviation innovation. We need to think intelligently." • "Airspace should be available for all users in a safe and economically realistic manner, acknowledging the advance of technology balanced against historical use cases." • "[Drone logistics] trials for each individual NHS [UK's National Health Service] Trust … entails multiple cost, multiple TDAs and multiple responses to ACPs." • "The idea is to avoid expensive ACPs."
Equitable Access (Section 4.5.2**):**
• "Still concerned that some in the UAS segment do not understand the requirement to provide equitable access to airspace to all users." • "The point is that the drone (both recreational and commercial), GA and gliding communities need to come together to find a solution to safely integrate. I don't think it's fair or very imaginative to keep segregating via TDAs." • "No one user should believe they have exclusive access to airspace." • "Airspace for all, or the equitable use of airspace to give it its official term, is the fundamental principle that has to be abided by – the question is just how." • "This whole thing is reminiscent of the Inclosure Act 1773, which created a law that enabled enclosure of land, at the same time removing the right of commoners' access." • "We all require a common airspace measurement/utilisation metric/display system in order to scale the level of interaction necessary." • "Are you aware of any societal impact studies?" • "Society won't give a damn about inter-operability with GA if told that drones will improve their lives."
Alternatives to Drones (Section 4.5.3**):**
• "Statement of needs often downplay alternates. … Vans and ferry will operate in all weathers." • "Where is the demand [for drone logistics] from? There does not appear to have been a business case published … examining the drone versus alternates." • "Concern of Amazon [parcel deliveries] lurking in the background when the NHS [UK's National Health service logistics] side is in place." • "For certain types of operations clearly the drone can be a good option i.e., heart delivery, blood, etc." • "We all, I'm sure, understand and sympathise with the need for improved NHS [UK's National Health Service] logistics."

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