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The Analysis of Airspace Infringements Over Complex Airspace in Europe and the United States of America

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The increase in the number of commercial flights highlights the need for air traffic to follow air procedures. Unfortunately, general aviation aircraft used for recreational purposes keep entering controlled and restricted airspace without obtaining permission from air traffic services. Given the safety and operational problems this could potentially cause, this paper examines the underlying reasons for these incidents occurring. In particular, it analyses airspace infringements between 2008 and 2017 involving general aviation flights that were recorded in airspace in which a large number of commercial flights also fly in Europe and America. The reports were analysed based on an initial assessment of their quality. Information was latent in the narrative and subsequently both qualitative (content analysis) and quantitative methods (descriptive statistics) of analysis were used. The analysis revealed that airspace infringements were related to the pilot's flight planning, that is, flight-route choice, navigation skills and communication, in addition to requirement to adhere to airspace procedure. The findings could be used by national authorities and flying clubs to promote safe flying in these regions.

KEYWORDS

1. Aviation. 2. General Aviation. 3. Airspace Infringement. 4. Airspace Design.

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1. INTRODUCTION. The rise in demand for air transport (EUROCONTROL, 2018) coupled with an increase in the number of commercial flights poses a major challenge to ensuring a safe, efficient and environmentally friendly air traffic management (ATM) system. In particular, it highlights the need for air traffic to follow the designated procedures and fly in airspace areas for which they have permission. Aircraft under the control of the air traffic services can deviate from their instructed flight-route, whilst other aircraft can stray from uncontrolled to controlled or restricted airspace without permission. The latter causes major problems for ATM since any aircraft that are affected must change route in order to avoid a mid-air collision. According to the United Kingdom Civil Aviation Authority (UK CAA), as presented in NATS (2018), such an incident by a single pilot can lead to delays for up to 30 airliners and 5,000 passengers and result in £50,000 (US $70,000) worth of wasted fuel. Such unauthorised entries into controlled airspace are

known as airspace infringements in Europe and airspace incursions or violations in the United States of America (USA).

There were approximately 800 such reported airspace infringement incidents in the UK in 2017 (General Aviation Safety Committee, 2016) and despite numerous efforts at both a European and national level, there has been no permanent reduction in the absolute numbers of such recorded incidents. Whilst a complete statistical picture of the reported airspace infringements in the USA is as yet unavailable, press reports highlight the importance of the issue with repeated discussions of unauthorised entries into restricted and special use areas and the role of the US Air Force in intercepting any infringing aircraft (Hajek, 2017).

Small recreational aircraft are the main actors in these incidents and the same geographical airspace areas are repeatedly infringed (General Aviation Safety Committee, 2016). Such small aircraft comprise 90% of the world's civil aircraft (General Aviation Manufacturers Association, 2018) and fall under the category of general aviation (GA), that is, a unique group of airspace users with a diverse fleet of aircraft, some ill-equipped to fly in controlled airspace. Such pilots are very cost conscious and their aircraft often have none of the latest technologies available to assist them. With this in mind, a recent study (Burns and Bonaceto, 2020) examined the use of a digital co-pilot for GA flights based on the use of accident data. Most GA pilots fly for recreational purposes at the weekends, though in the USA there are pilots who use their GA aircraft for business travel (Shetty and Hansman, 2012). Typically they fly in good visibility conditions and have relatively few flying hours compared with commercial aviation pilots. Nevertheless, recreational pilots typically do not fly at all for long periods of the year.

During the last decade, numerous studies have attempted to identify the factors that contribute to the occurrence of airspace infringements by using reported incidents (European Air Traffic Management, 2007a, 2007b, 2008). However, these analyses were inexhaustive in their nature and, in the intervening period, significant improvements have been made to incident reporting schemes that could enable current, richer data to be used. As evident in safety analyses across all transport modes (Kyriakidis et al., 2015), a thorough safety analysis of incidents and accidents needs high-quality data. Furthermore, in past studies of airspace infringements, airspace design features were not studied in detail, even though airspace is mostly predominantly controlled over busy airports and influences flight-route selection (Psyllou and Majumdar, 2019) and flight planning has seen substantial changes due to the use of flight planning apps and tablets (Psyllou et al., 2018a).

Therefore, this paper examines airspace infringements that were reported in controlled airspace areas that were both busy airspaces and frequently infringed. It does this by presenting a historical analysis of incident reports of airspace infringements between 2008 and 2017 in two regions that have the busiest air transport networks: three European nations and the USA. Both the airspace design and the GA sector differ between the European nations and the USA, and these differences were taken into account in this study. Whilst these air transport networks are known for their good air transport safety records and have incident reporting schemes in place, there are nonetheless differences, as is evident in past analyses (Wilke et al., 2015), meaning the collected information varies between the nations. Hence, the results need to be interpreted with respect to the information reported. Furthermore, voluntary reporting systems may also underrepresent the number of incidents, whereas systems that automatically identify such incidents are more likely to provide a better estimate of the actual number of incidents. Finally, the narrative description of an incident can vary

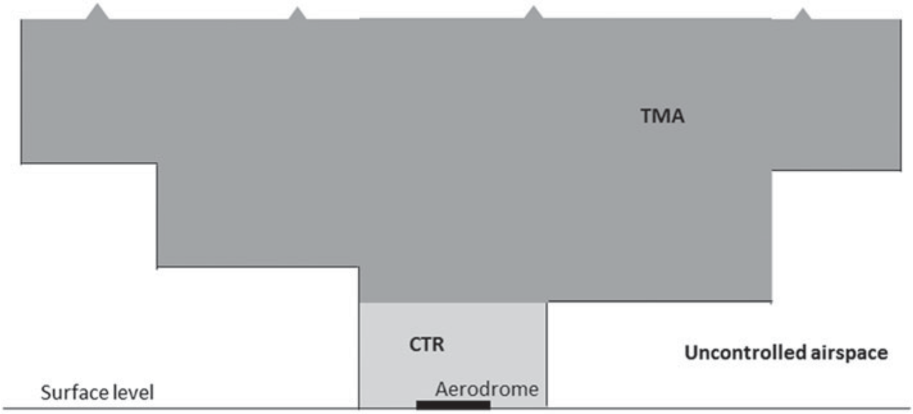

Figure 1. A cross-section of the airspace over a controlled airport. TMA = Terminal Manoeuvring Area; CTR = Control Zone.

in length and content and thus, inconsistent information is expected to be found within a dataset.

This paper is organised as follows. Section 2 briefly describes the GA operations and reviews the latest studies of GA safety in relation to human factors. The methodology is presented in Section 3, followed by the findings of the analysis of the reported airspace infringements that occurred in Europe and the USA in Section 4, before concluding. Information is latent in the narrative, thus, content analysis was applied to derive qualitative data, and descriptive statistics and frequency analysis were used to identify the most common contributory factors.

2. OVERVIEW OF THE GENERAL AVIATION OPERATIONS.

Airspace is often classified as controlled in order to facilitate commercial flights and often these areas are introduced in airspace where GA flies, for example, Southend controlled airport east of London, UK. Consequently, GA pilots must navigate in a small area of uncontrolled airspace. However, flying underneath controlled airspace can pose further challenges when the controlled airspace itself has levels that expand laterally, as is typical above airports as shown in Figure 1.

Globally, the GA fleet is ageing, with the majority of the fleet having an analogue-designed cockpit panel (General Aviation Manufacturers Association, 2018). The installation of a Global Positioning System (GPS) mounted on the panel emerged in the 2000s and this marked the beginning of space-based navigation for the sector (Psyllou et al., 2018b). The GPS was followed by the use of tablets and software applications by which pilots plan and navigate, for example, their position is calculated by either the Global Navigation Satellite Systems (GNSS) installed on the tablet or the GPS using an external connection. Despite the increased use of such space-based navigation, GPS is not mandatory for visual flight rules (VFR) flights; in fact, the GNSS should simply assist and not be the primary navigation system. However, with the installation of the Automatic Dependent Surveillance-Broadcast (ADS-B) Out in 2020, aircraft will continuously transmit highly accurate position and status information to air traffic services while flying in most controlled airspace.

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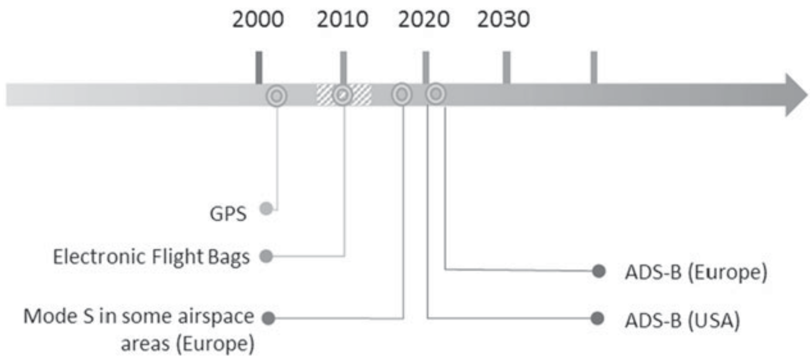

Figure 2. Timeline of the introduction of major navigation technologies in general aviation.

A timeline of the major events in the recent history of ATM is shown in Figure 2.

Though GA pilots often fly in uncontrolled airspace (European Air Traffic Management, 2007a), airspace design is of great importance to them in order to select their flight path. Flights passing through airspace that is either controlled or restricted, require pilots to fly around such areas, especially when it is unlikely that they would receive permission to enter (Psyllou and Majumdar, 2019). Such airspaces are those that serve the scheduled take-offs and landings of commercial traffic, for instance, London, UK and Los Angeles, USA, and typically GA pilots fly underneath the controlled airspace (Psyllou and Majumdar, 2019).

A further challenge for such pilots is that major cities generally have more than one airport and hence in such locations uncontrolled airspace becomes limited for GA traffic. For example, in London there is a narrow corridor between Stansted and Luton airports and this is a route frequently used by GA pilots. The consequence is that the pilots fly closer to the control zone of the airports in order to increase their distance from other GA traffic and thereby minimise the risk of collision.

Flying in such close proximity to controlled and restricted airspace increases the likelihood of straying into this airspace. As explained in research by Psyllou et al. (2018b), this can be due to the inability of the GA pilot to maintain the heading of the aircraft at the flying altitude, which is typically less than 5,000 ft. Minor changes in the aircraft heading due to crosswinds are typical; however, the pilots are expected to notice such changes. Coupled with any distractions caused by, for instance, reading the charts, a pilot may be late noticing a small, but causal, change in the heading. Hence, the closer the aircraft is to the controlled airspace, the more likely it is to drift into this airspace given both the aircraft's direction and the direction of the wind.

Whilst pilots are concerned about airspace, the ease with which flight routes can be selected on a flight planning app can lead them to begin their flight planning a few hours prior to or indeed just before departure (Psyllou et al., 2018a). This raises concerns regarding the extent to which the pilots familiarise themselves with the flight route, and their preparedness in relation to what to expect during the flight, for example, which radio frequencies to tune into. Given the speed that flight routes can be changed when using the app, some GA pilots are also prepared to make their flight-route decisions in-flight, again raising concerns about their ability to accommodate the increased amount of information in-flight. Furthermore, confidence in the accuracy and precision of such technologies also encourages the pilots to use these technologies as their primary navigation system, for which they have not received official training (Psyllou et al., 2018b).

Since GA pilots fly close to controlled and restricted airspace, especially in areas with a high volume of commercial traffic, any incursion into such airspace can have major consequences for air traffic services involving the diversion of inbound/outbound traffic causing safety, operational and environmental impacts. Whilst the hope was that the integration of space-based navigation would assist pilots in avoiding such incidents, there is no evidence to support this. Rather, pilots seem to be more tolerant of flying even closer to controlled and restricted airspace given their trust in such navigation technologies. Hence, this paper analyses airspace infringement incidents that involved GA flights in Europe and the USA for which the consequences of such incidents could have been severe on the air transport network.

3. METHODOLOGY. The analysis of reported incidents of airspace infringements is modelled in three steps, as shown in Figure 3. First, reported incidents from the USA and Europe were collected and analysed in order to understand their context, type of flight and airspace in which the incident occurred. Given that the reported incidents provided only a partial understanding of these incidents, interviews with a carefully selected sample of GA pilots were also analysed and contributory factors of airspace infringements, that is, factors that led pilots to fly near controlled or restricted airspace resulting in an airspace infringement, were identified. These contributory factors were applied to incident data and the frequency of occurrence of these contributory factors is reported in this study. The findings of this study were peer-reviewed by three subject matter experts (SMEs) in September 2018, who were members of the committee for *AV060 Airfield and Airspace Capacity and Delay* of the *Transportation Research Board*, which is a programme unit of the National Academy of Science, Engineering and Medicine in the USA.

3.1. *Safety data collection and analysis.* Safety data that recorded airspace infringements with the potential to cause severe disruptions to their air transport network were selected from four nations: three European nations and the USA. The choice underlying nation selection was as follows. The airspaces of the UK and USA are among the busiest in the world, whereas Norway and Finland, though serving less commercial traffic, both suffer from a high number of recorded airspace infringement incidents. It is worth highlighting that GA significantly differs between the four nations with a greater number of pilots being registered in the USA.

Airspace infringements are mandatorily reported in Europe, in theory by both the pilot and the air traffic controller (ATCO) who was involved or observed the incident, the latter being the most frequent reporter of such incidents. In the USA, these incidents are voluntarily reported to the Aviation Safety Reporting System of NASA known as ASRS-NASA. Hence, the safety data from each nation were collected from the following organisations:

- National Aviation Authority Trafi in Finland;
- National Aviation Authority UK CAA in the UK;
- Air Navigation Service Provider Avinor in Norway and,
- ASRS-NASA in the USA.

In order to verify the effectiveness of the databases for the analysis of airspace infringements, the databases were assessed for their accessibility, accuracy, consistency,

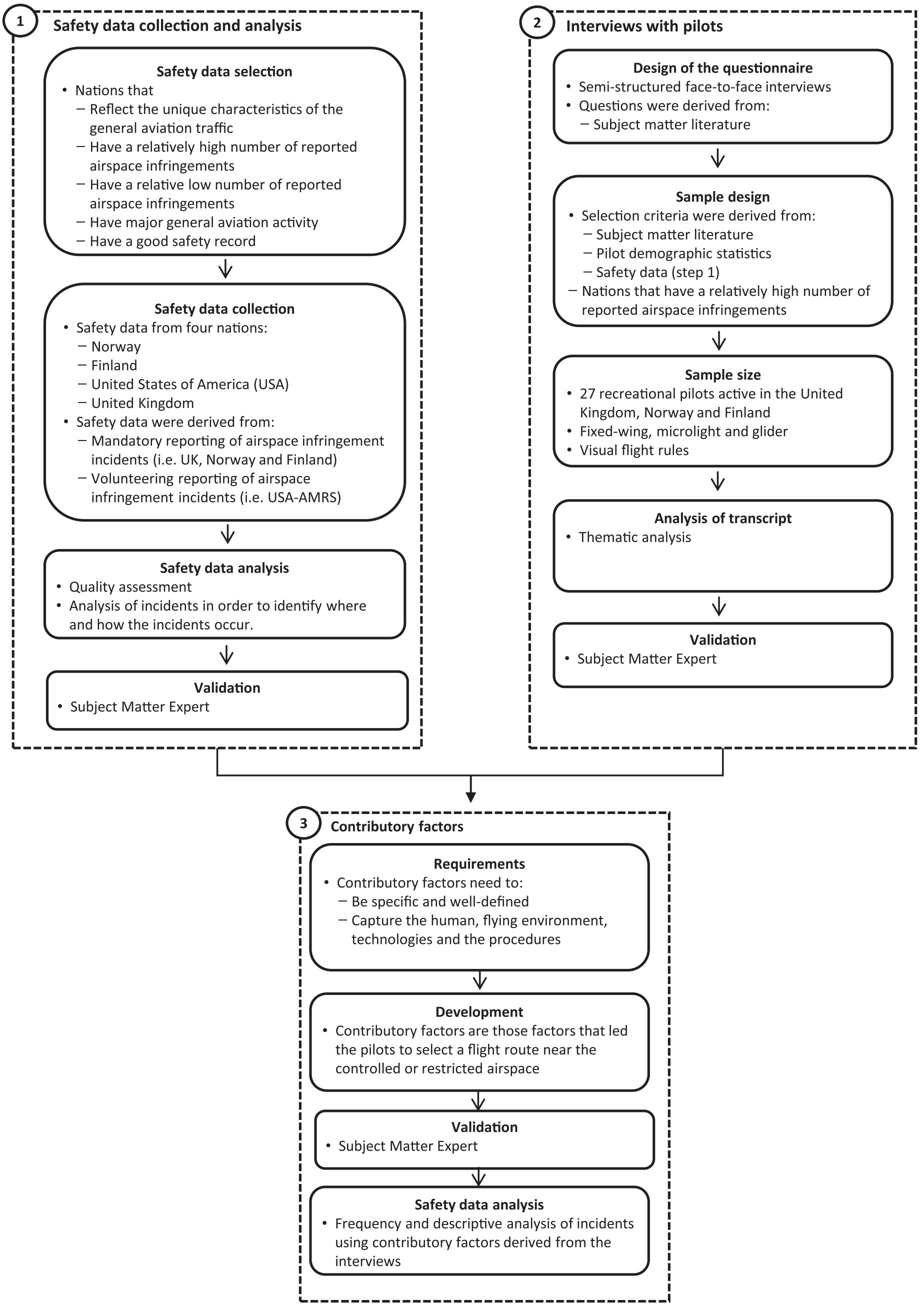

Figure 3. Outline of the methodology.

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completeness, credentials, interpretability, timeliness, relevance, and the richness of the narrative description of the incident. These quality dimensions, except the latter, were introduced in research by Pipino et al. (2002) and were further developed for aviation safety occurrences in a study by Dupuy (2012). The richness of the narrative description was introduced to overcome the absence of a measure to assess the efficacy of the incident narrative. The dimensions are outlined below.

The dimension of accessibility determines that the data are available and quickly retrievable. This is determined by how many data fields the dataset can provide without any further modifications. An arithmetic weighting system was introduced in Dupuy (2012), which penalises the inferred and implicit data fields (Equation (1)). Hence, explicit data fields make the dataset more accessible. The lower the score of this criterion, the greater the number of data fields to be created by analysts, thereby increasing the time needed for the analysis.

$$\text{accessibility} = \frac{1 \times N_{\text{explicit}} + 0.80 \times N_{\text{implicit}} + 0.20 \times N_{\text{inferred}} + 0 \times N_{\text{not available}}}{\text{Total number of required datafields}} \tag{1}$$

where N is the number of data fields.

The dimension of accuracy determines that the data are correct, close to reality and free from error. This is determined by assessing the agreement between the data fields, especially with that of the narrative description of the incident.

The dimension of completeness estimates the rate of missing data and is equal to the difference in the percentage of the complete data. The percentage of data missing for each datafield is estimated and the arithmetic average of all the missing data is calculated (Equation (2)).

$$\text{completeness} = 100 - \text{arithmetic average of missing values percentage} \tag{2}$$

The dimension of consistency establishes that the data are presented in a systematic format. It is measured by the percentage of data that are presented in the same manner within each data field (consistent). If a data field had to be either recoded or newly coded for the purpose of this analysis, it was also considered but reduced the quality of the data, as indicated by arithmetic weights introduced in Dupuy's work (2012). A lower score of this criterion indicates that not all the data can be used for all stages of the analysis (Equation (3)).

$$\text{consistency} = \frac{1 \times N_{\text{consistent}} + 0.80 \times N_{\text{recoded}} + 0.20 \times N_{\text{newly coded}} + 0 \times N_{\text{not available}}}{\text{Total number of required datafields}} \tag{3}$$

where N is the number of data fields.

The dimension of credibility ensures that data are obtained from reliable sources. For example, incidents can be assumed to come from reliable sources if they are reported by an ATCO trained to report such incidents; the incidents will have already been investigated following the procedures of the stakeholder. On the other hand, for incidents reported by individuals who have not been trained to do so, their credentials are lower as reporters provide information to their own best knowledge, unless the incidents have been investigated.

The dimension of interpretability verifies that data are presented in appropriate language, symbols and units and are easily comprehended by the analysts.

The dimension of timeliness assesses that the data are current in terms of any delay in providing and processing the incident report. It can be defined as the elapsed time from when the incident occurred, to the point in time when the incident was first recorded. This can be measured by comparing the dates on which the incident occurred, the report was filed and the investigation was completed.

The dimension of relevance determines that the data are suitable for the analysis of airspace infringements. Hence, the required data fields for this analysis were determined and grouped into the following eight categories: incident information, description, aircraft, ATCO, severity, environment, airspace and contributory factors. The score was estimated using gap analysis between the data fields that were originally available (relevant) and those that were required. The lower the score, the less the information provided in the dataset (Equation (4)).

$$\text{relevance} = \frac{1}{N_{\text{categories}}} \sum_{i=1}^{N_{\text{categories}}} \frac{N_{\text{relevant},i}}{N_{\text{required},i}} \times 100 \tag{4}$$

where N is the number of data fields.

The richness of the narrative description (Equation (5)) estimates the ability of the description to provide key information about the incident, that is, the transponder code, filed flight plan, infringing altitude, by analysing a sample of narratives (2–5%). The richness of the descriptions was calculated using Equation (5). Narratives are expected to be

- Detailed: likely to provide the majority of the required information if the score is greater than 75%;
- Moderate: some of the narratives may provide limited information if the score is between 50% and 74%;
- Poor/Moderate: the narratives are less likely to provide the required information if the score is between 25% and 49% or,
- Poor: the narratives are unlikely to provide the required information if the score is less than 25%.

$$\text{narrative} = \frac{1}{N_{\text{parameter}}} \sum_{j=1}^{N_{\text{parameter}}} \frac{N_{\text{incident that } j \text{ exists}}}{N_{\text{incidents}}} \times 100 \tag{5}$$

where N is the number of data fields.

Subsequently, suitable data were individually analysed. Content analysis was applied using keywords, which were either words or phrases, and any segment of the narrative that appeared relevant to the context in which the airspace infringement developed. An example of narrative analysis is shown in Appendix 1. Descriptive statistics (e.g. frequency analysis) were conducted to understand the characteristics of the incidents and to identify trends. The dataset contained the following four types of data:

- Continuous data (e.g. infringing altitude);
- Ordinary categorical data (e.g. severity of occurrences, number of aircraft involved);

- Nominal categorical data (e.g. airspace type and class, time the two-way radio contact was established); and
- Textual data (e.g. aircraft model).

3.2. *Interviews.* In order to overcome the limitations of the incident data, interviews with GA pilots were analysed and contributory factors were retrieved as follows.

3.2.1. *Design.* A formal, semi-structured interview was designed to capture the manner in which the pilots selected the flight route and its relevance to the airspace infringements, as shown in Appendix 2. The pilots were asked to describe their flight route selection for a typical flight they had recently flown, and were asked about the challenges they had expected to face during that flight. These questions enabled information regarding flight planning to be collected; such information is rarely captured in incident reports.

A total of 27 face-to-face interviews were conducted and pilots were randomly selected from flying clubs across the UK and through the airspace navigation service provider and the national aviation authorities in both Finland and Norway. Most pilots were based at an airfield that was located near controlled airspace. Twenty pilots flew a fixed-wing aircraft, four flew an ultralight aircraft and three flew a glider.

3.2.2. *Analysis.* Interview transcripts were analysed using ATLAS.ti software, which is a qualitative data analysis and research software. The analysis of the interviews followed the guidelines for the *Publication of Qualitative Research Studies in Psychology and Related Fields* (Coyle and Lyons, 2007). The phenomenological method (Elliott et al., 1999) was used to extract information from the interview transcripts, that is, coding the interviews to understand the underlying reasons for incursions into complex airspace.

The analysis was conducted in three stages as follows. Firstly, participants who planned a route near controlled or restricted airspace were selected for further analysis. For those cases, the parameters that led to this decision were coded in the interviews. We can illustrate the process using the following example. A participant selected a flight route within 100 ft of controlled airspace, which started at 1,500 ft in good weather conditions for VFR flight. The rationale behind the selection of the flight route close to controlled airspace was examined by eliciting the factors that influenced the decision, for example, airspace was controlled at the preferred flying altitude and space-based navigation technology was to be used.

Secondly, the factors that could potentially cause the aircraft to stray into controlled or restricted airspace while flying such a route were coded, for instance, the pilot's ability to maintain the heading of the aircraft. Using the same example as above, the potential factors that would offset the flight route to controlled airspace were reviewed using the pilot's explanation for flight route selection. For example, the participant stated that during this segment of the flight, considerable attention is required by the pilot to maintain the aircraft heading and stay under the controlled airspace. Hence, the contributory factors of airspace infringements while flying such a route include (i) the failure to maintain the aircraft heading and (ii) flying at an altitude lower than desired.

Thirdly, the factors were reviewed: duplicates were removed and similar factors were combined (e.g. two factors that described flying at an altitude lower than desired were merged). The factors were then aggregated into meaningful categories.

These findings were validated by an SME, a GA pilot with more than 130 h of flying experience who had worked in air operations and safety, including training and selection. The SME was briefed regarding the validation task and was provided with a supporting

Table 1. Outline of data and their quality.

Data provider	Avinor	Trafi	UK CAA	NASA
Nation	Norway	Finland	UK	USA
Study period	2008–2016	2008–2015	2008–2014	2008–2017
Sample size	977	963	2734	1979
Quality dimension				
Accessibility	82%	53%	47%	65%
Accuracy	Data values were correct	Data values were correct	A portion of data values were in no agreement with the information in the narrative	Data values were correct
Completeness	50%	34%	14%	50%
Consistency	68%	48%	36%	62%
Credibility	It is assumed that the data were obtained from reliable sources, i.e. ATCOs, who were trained accordingly to report the incidents	It is assumed that the data were obtained from reliable sources, i.e. ATCOs and investigators	It is assumed that the data were obtained from reliable sources, i.e. investigators	It is assumed that the data were obtained from reliable sources, i.e. investigators
Interpretability	It is assumed that the data fields were interpreted in the correct and similar manner by the reporters, investigators and analysts			
Relevance	88%	58%	51%	54%
Timeliness	Average = 0·45 Days SD = 2·16 days	N/A	N/A	N/A
Richness of the narrative	Detailed	Poor/Moderate	Poor	Poor

document that included the listed contributory factors and their definitions, the evaluation criteria and the instructions for the validation process. Each contributory factor was evaluated in that it could contribute to airspace infringements, was not generic and was well defined (regarding its name and definition). For each contributory factor, the SME was asked to provide a comment, including suggestions to rename or delete the factor. Furthermore, the SME was asked to write the overall comments about the contributory factors related to a particular flight-route decision making. The safety data were statistically analysed on the basis of the contributory factors.

4. RESULTS. A total of 6,653 reports of airspace infringement incidents were analysed. The data originated from organisations that possess a safety management system and thus, it can be assumed that the data were obtained from reliable sources and that the information was correctly interpreted by the reporters, investigators and analysts. The four databases differed in their structure, size and quality, as seen in Table 1, implying therefore that there would be differences in the findings between the nations, given the differences in the information collected.

Avinor's database possessed rich narrative descriptions of an incident, even though in each case the reporter was the ATCO who rarely contributed to an incident. Coupled with the high number of immediately available and consistent information, it was expected that its analysis would provide insights into the underlying reasons the incidents occurred. For example, whether the pilot responded to a radio call from the ATCO following the airspace infringement could be determined. Despite Trafi's dataset consisting of a smaller amount of immediately available and consistent information, its narratives provided further insights. The lack of rich narrative in the UK CAA and the NASA-AMRS limited the analysis to the information that was captured by the remaining data fields in the incident report forms. However, in the NASA-AMRS database, some incidents contained both the ATCO's and the pilot's reports, and thus, it was expected that these incident reports would provide further insights. Therefore, the differences in the type and quality of the collected information among the databases required them to be analysed separately. Furthermore, the incident reports derived from Avinor and Trafi were expected to provide essential information due to the detailed narrative descriptions.

4.1. *Macroscopic analysis.* In Europe (Norway, Finland and the UK), incidents mostly involved GA VFR flights undertaken by fixed-wing motorised aircraft. GA aircraft were more likely to infringe in the en route phase of the flight and in the following types of controlled airspace: terminal manoeuvring areas (TMAs) and control zones (CTRs), through which commercial flights pass. The most frequently infringed class of airspace was Charlie, where the ATCO separates both the instrument flight rules (IFR) and VFR flights from VFR flights (International Civil Aviation Organization, 2001). However, danger and restricted airspace areas were also infringed over the Gulf of Finland where pilots must navigate through a narrow area formed by restricted airspace areas.

The airspace in the region over the European capitals recorded the highest number of airspace infringements, as seen in Figure 4. Pilots infringed, on average, at 4,121 ft (standard deviation, $SD = 1,466$ ft) over Oslo and at 2,224 ft ($SD = 983$ ft) over Helsinki. At these altitudes, GA aircraft can be in conflict with commercial jet aircraft that are either in take-off or landing phases of flight. The airspace over these areas can be complex for VFR flights, as it comprises different types of airspace (TMAs, CTRs, special use areas and restricted areas) that pilots must not infringe. Their horizontal lower boundaries varied laterally and began at 1,500 ft, in areas where the distance between the terrain and the lower boundary could be as low as 700 ft (e.g. in southern Oslo). Approximately 40% of the infringing aircraft flew within a distance of 500 ft and 250 ft from the lower boundary in Oslo and Helsinki respectively, implying that whilst pilots planned a route in uncontrolled airspace it was near controlled airspace.

In the USA, GA aircraft used for personal flights, known as Part 91 in USA, were involved in approximately 30% of the total number of reported incidents. In simple terms, Part 91 is comparable with the private pilot licence in Europe. Flights commanded by two pilots operating under Part 135 (i.e. non-scheduled charter and air taxi operations) or Part 121 (i.e. scheduled air carriers) also infringed airspace (approximately 30%); however, they were flying at higher altitudes, for example, on average at 12,408 ft ($SD = 10,732$ ft) in California, compared with altitudes flown during single-pilot flights (on average at 5,052·21 ft ($SD = 6,540$ ft) in California). Hence, only personal flights were included in the analysis.

The states of California, Florida and Texas reported the greatest number of infringements, with California recording double the number of such incidents when compared with Florida. The airspace near key international airports such as Los Angeles, San Francisco and Miami recorded the highest number of incidents; all of these airspace areas can be

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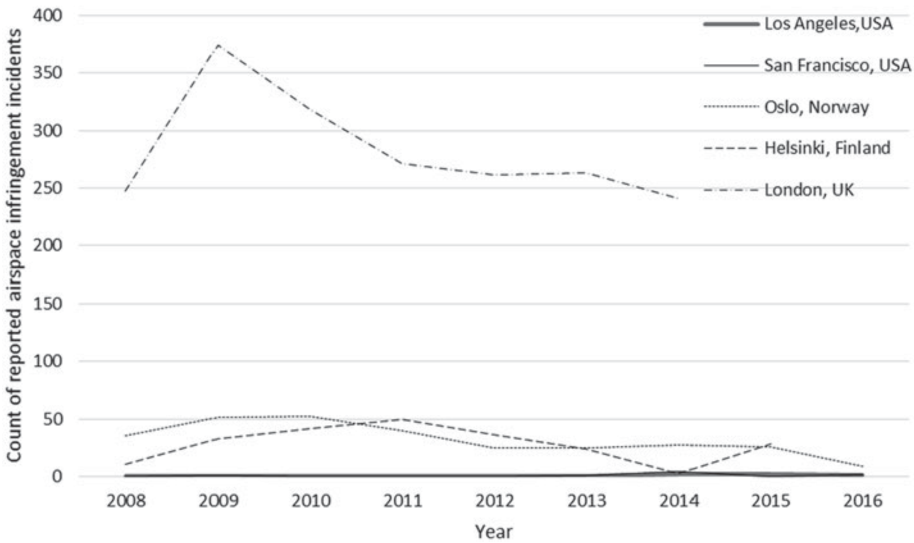

Figure 4. Reported incidents per airspace over the studied period.

Table 2. Frequency of contributory factors per nation.

	Geographical area		
Contributory factors related to	California, USA	Norway	Finland
Airspace procedures	12	59	40
Communication	8	66	49
Distraction in-flight	9	0	2
Flight-route selection	19	59	28
Navigation	34	3	53
Planning	17	17	6

complex for VFR flights. Controlled airspace areas incorporating various flight rules were adjacent, whilst GA airports were also located underneath or nearby this complex airspace. However, there was a disparity between the absolute number of reported airspace infringements between Europe and the USA, for example, there were 3.8 more reported incidents in the UK than California.

4.2. *Contributory factors.* The most common contributory factors per nation are shown in Table 2, based on a frequency analysis.

In Norway, in approximately 20% of incidents, the pilot was unaware of airspace procedures, for example, the time required for a pilot to request entry clearance, and the necessary procedures to activate and use a flight plan. There were approximately 20% of incidents for which the pilot had inadequate knowledge of the airspace boundaries for reasons such as using out-of-date maps or the pilot being unaware of airspace design changes.

Approximately 13% of pilots were listening to a radio frequency other than the one for the airspace they were infringing, thereby preventing the ATCO from contacting them directly. Given that the incidents were reported by the ATCO, information about the type of the navigation aids the pilot used could not be derived.

In Finland, contributory factors were only available for 360 incidents, as a detailed narrative description was infrequently provided. Approximately, 11% of pilots had inadequate knowledge of airspace procedures, 7% of the pilots misidentified their aircraft position, 5% of the pilots were lost and 7% of the pilots infringed following a flight diversion due to deteriorating weather conditions.

Factors that led to loss of situational awareness were wind drift and those related to navigation, for instance, the pilots incorrectly identified the landmarks or failed to cross-reference the charts with the terrain.

In the USA, 26% of pilots lost their situational awareness primarily due to their reliance on space-based navigation (mounted GPS and apps installed on tablets). By 2010, flight planning apps had become popular; this could relate to the increase in the number of reported incidents in 2014 in which the pilot used electronic aeronautical charts that did not show certain airspace information. It seems that this was a technical issue relating to software that was subsequently addressed. Furthermore, 20% of pilots flew a route in uncontrolled airspace but near to controlled airspace, and 10% of these aircraft flew such a route across controlled classes of airspace over Los Angeles and San Francisco airports, both airspaces containing a large amount of commercial traffic.

Finally, it was observed that 17% of the pilots did not adequately prepare for the flight, in that they did not carefully study the various types of airspace across the route, in particular, in relation to special use airspace (SUA) areas. As evident in the narratives, the pilots were unaware of the presence of SUA when they used a flight planning app, probably due to a technical issue with the software setting specification. Furthermore, the pilots also claimed that Notices to Airmen were not easily accessible or that SUA could become active when the pilot was already airborne.

5. CONCLUSIONS.

The aim of this study was to examine the occurrence of unauthorised entries into airspace areas where the impact on operations, safety and the environment would be severe. The busy airspace of Europe and the USA was selected, and incidents reported between 2008 and 2017 were analysed. The four datasets were assessed for their adequacy for the thorough analysis of the incident reports. The data were assessed, among others, for their consistency, completeness, accuracy and relevance to the study. As expected, the four datasets differed in size, structure and content primarily resulting from the differences in reporting culture among nations, as evident in studies of ATM-related incidents (Wilke et al., 2015). As a result, the datasets were analysed separately. Furthermore, the detailed data quality assessment further enabled identification of the datasets that were more likely to provide insights into the underlying reasons for the incidents (i.e. the datasets that possessed rich narratives). Coupled with explicit and consistent information collected separately in other data fields, these detailed incident reports succeeded in capturing information related to pilot performance and airspace design and procedures, thus adding to the studies conducted over the last decade.

It is evident that airspace infringements can be attributed to three main factors associated with the pilot: (i) flight planning and selection of the flight route, (ii) the navigation skills of the pilots and (iii) communication. In addition, the airspace procedures that pilots must adhere to are important.

Pilots were aware of the presence of controlled airspace and planned a route offset to the controlled airspace as permission to fly in such airspace is rarely issued. The main challenge that pilots face on such occasions is that they fly at altitudes that are lower than desired. Furthermore, they often fly closer to controlled airspace to increase their distance from

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other GA traffic in the area to prevent an accident from occurring in uncontrolled airspace. Hence, flying such a route very close to the controlled airspace increases the likelihood of aircraft straying into controlled airspace. Given that the pilots were flying in uncontrolled airspace, they were not necessarily in radio contact with the ATCO who was managing the traffic in the controlled airspace.

The increasing use of space-based navigation (e.g. mounted GNSS receivers and apps installed on tablets), has encouraged pilots to be confident about the position of their aircraft; however, the ability of such devices to continuously provide an accurate and precise estimation of the aircraft's position has yet to be determined. As a result of flying at such short distance from controlled airspace, an error in position measurements could result in an airspace infringement. Hence, the proximity of flights to the controlled airspace and the reliance of the pilots on space-based navigation could explain why such incidents involving GA aircraft continue to occur in the airspace over key national commercial airports such as London and San Francisco. These results are generalisable and provide a comprehensive overview of the relationship between airspace design, human factors and airspace infringements. Specifically, a pilot plans a route that is an offset to the controlled and restricted airspace; however, the distance they maintain from that airspace differs according to their personal preference and their confidence in the space-based navigation technologies.

The findings of this study could be used by the authorities, for example, policymakers and flying clubs, to prevent airspace infringements from occurring by disseminating the findings of the flight-route selection and the likelihood of violating airspace while navigating through complex airspace. Of particular importance is the pilot's reliance on technologies; the consequences of such reliance should be communicated to the GA community during the safety training and workshops that are already organised by the authorities and presented in papers read by the GA community. Both the airspace navigation service provider and the national aviation regulator, as part of the hazard identification process, could also use these findings for safety investigations and analyses of such incidents. Subsequently, such insights will enhance the safety monitoring of incidents and improve risk management. Finally, the findings of this study could inform decisions on future airspace design changes over the areas in which GA currently flies by considering the potential impact of airspace design on airspace infringements.

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APPENDIX 1. ANALYSIS OF THE NARRATIVE DESCRIPTION OF AN INCIDENT

The incident occurred as follows. A visual flight rule flight with a transponder code 7000 flew north-west of [control zone] (CTR) and climbed into the [terminal manoeuvring area] (TMA) reaching 3,000 ft. The pilot did not request permission from the ATCO to fly in either the CTR or the TMA. The pilot did not respond to ATCO's calls on the radio but he/she responded to a radio call on a different frequency whilst the aircraft was flying inside controlled airspace.

The contributory factor *Pilot was on the wrong radio frequency* is found as the pilot responded to a radio frequency that was different from the mandatory radio frequency of the TMA. Furthermore, *the pilot was flying in uncontrolled airspace and near controlled airspace* as the aircraft was constantly flying within 500 ft inside the TMA until it exited controlled airspace whilst the traffic did not intend to fly in controlled airspace (transponder code and radio frequency was different from the required). Furthermore, this flight-route decision could be influenced by *the small volume uncontrolled airspace*, i.e. airspace design.

APPENDIX 2. QUESTIONNAIRE OF THE INTERVIEW

1. Suppose that you want to fly from an origin (e.g. flying club of the participant) to a destination and return to the origin. Could you please describe how are you going to decide the route and the departure times of your flight? Please give some essential details.

2. Considering your description, what difficulties might you experience while flying this route and what do they mean for you?
3. For the same flight, describe the available on-board equipment and how you will use it for this route.
4. If we go back to your first flight at the beginning of the summer flying season, do you think you would have made the same decisions? When was this first flight?
5. Now, let's think of flyers in your flying club/peers. Do you think they will choose the same route as you and why?
6. Can you recall any cases in which you were near to infringing controlled airspace or indeed infringed it or listened to other people's similar experience? What happened?
7. Can you recall any other specific episodes during the past year in flying and daily life?
8. Have you been to any lecture/event about safety or changes of airspace design?
9. Do you think that airspace infringements have to be mitigated? If yes, what do you think can be done to avoid these incidents involving general aviation flights?
10. Do you have anything you would like to add, comment or suggest?