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FOR THE SAFETY OF AIR NAVIGATION

EUROCONTROL

Airspace Infringement Risk Analysis

Part I

Safety Analysis of Airspace Infringements in Europe

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Abstract

EUROCONTROL commissioned National Aerospace Laboratory (NLR) with an analysis of a representative sample of airspace infringement occurrence reports. The aim of the study was to identify airspace infringement causal factors in sufficient detail and thus support the establishment of safety improvement strategies and identification of relevant risk mitigation measures.

A total of 473 airspace infringement occurrence reports submitted to state authorities and service providers in 2004 and 2005 were analysed, using a dedicated taxonomy developed by Eurocontrol. Scenarios and causes were identified and analysed. Mitigation measures are proposed on the basis of these results.

Keywords			
Airspace Infringement	Causal factors	Safety analysis	General aviation
Infringement scenarios	Risk mitigation	Safety	Safety occurrence

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CONTENTS

SUMMARY

In December 2005, the Eurocontrol Safety Team launched the Airspace Infringement Safety Improvement Initiative, recognising the severity of the threats to aircraft operations posed by airspace infringements. European-wide in scope, its aim is to achieve harmonised and effective implementation of risk mitigation measures against airspace infringements.

The main focus of the safety initiative is the infringement of controlled airspace. An important action taken by the Eurocontrol Initiative Team is to collect a representative sample of airspace infringement occurrence data. These data should aid the analysis of the causal factors in sufficient detail and support the establishment of safety improvement strategies and identification of relevant risk mitigation measures. These results will lay the foundation for the final product of the initiative - a European action plan for the prevention of airspace infringement to be agreed for implementation early 2008.

The report presents the analyses and comments on the airspace infringement data collected with the support of European air navigation service providers and state authorities. A dedicated taxonomy developed by Eurocontrol is applied to a subset of the complete occurrence data sample that includes infringements reported in 2004 and 2005. A total of 473 airspace infringements are analysed in this report.

The vast majority of the airspace infringements (nearly 76 %) investigated in the present study are caused by General aviation non-commercial pleasure flights that infringe controlled airspace. This is mainly due to navigation failure and non-adherence to the established airspace use procedures. However, the unavailability of data at European level about the total number of General aviation (GA) operations, including their sub-division in respect of ultra lights, gliders, balloon and mainstream GA does not allow establishing precisely the GA contribution to airspace infringement risk.

Commercial and military flights related airspace infringement scenarios amount to about 10 % of the analysed sample each. Inadequate coordination between the control sectors and/or units and failed air-ground communication are the factors causing most of the infringements involving commercial and military aviation.

The lower share of infringements caused by commercial and military flights can be explained by the fact that commercial and military pilots receive more training, have abundant flying experience compared to “recreational” pilots, are supported by extensive automation and are usually under the control of an air traffic unit throughout the flight, thus making it easier to detect any deviations from the flight plan. VFR pilots, on the other hand, fly mainly single crew operated aircraft, often without sophisticated navigation equipment and are provided Flight Information or ATC services that vary greatly in scope.

The information contained in the infringement reports could not provide for an in-depth assessment of the contribution of various ATM related factors like complex airspace design to airspace infringement risk. The occurrence data enabled only identification with sufficient confidence of the relative share of infringement scenarios and associated generic causation.

The insufficient depth of information about the contributory factors prompted a second dedicated study, specifically aimed at eliciting GA pilots’ knowledge about the in-depth

reasons for airspace infringements. The results of this study are published in “Airspace infringement risk analysis, Part II – Analysis of pilots reported causal factors and prevention measures”.

1. INTRODUCTION

1.1 Background

In December 2005, the Eurocontrol Safety Team launched the Airspace Infringement Safety Improvement Initiative, recognising the severity of the threat to aircraft operations posed by airspace infringements. European-wide in scope, it aims to achieve harmonised and effective implementation of risk mitigation measures against airspace infringements. The main focus of the safety initiative is the infringement of controlled airspace. However infringements of other airspace, such as Danger, Restricted and Prohibited Areas, as well as Temporary Segregated Areas are also addressed.

An important action taken by the Eurocontrol Initiative Team is to collect a representative sample of airspace infringement occurrence data. These data should aid the analysis of the causal factors in sufficient detail and support the establishment of safety improvement strategies and identification of relevant risk mitigation measures. These results will lay the foundation for the final product of the initiative - a European action plan for the prevention of airspace infringement to be agreed for implementation early 2008.

1.2 Study objective and scope

At present a relatively large sample is available, with airspace infringement occurrences obtained from a limited number of European countries. The objective of the present study is to use these data to identify all the actors involved (e.g. ATC, FIC, GA, etc) and the various event paths leading to an infringement, as well as their relative contribution to the airspace infringement risk. The scope is limited to airspace infringements that occurred in European countries.

The safety analysis was conducted by National Aerospace Laboratory (NLR) on behalf of EUROCONTROL.

The present study applies the definition of an airspace infringement that is used within the scope of the safety initiative. This definition is as follows:

“A flight into a notified airspace that has not been subject to approval by the designated controlling authority of that airspace in accordance with international and national regulations. Such airspace is considered to be:

a. Controlled airspace, including ICAO airspace classes A to E.

Note: VFR traffic cannot infringe Class E airspace because under ICAO rules neither an ATC clearance nor a radio communication is required to enter or operate within it, unless filed national differences call for one or the other (or both). IFR traffic can infringe Class E airspace when not in receipt of a clearance to enter it.

b. Aerodrome Traffic Zones, where these exist in Class G airspace."

1.3 Organisation of the report

This report is organised as follows. In section 2 the approach of the study is described. Section 3 presents the results. In section 4 these results are discussed. In section 5 a number of mitigating measures are proposed. Section 6 gives the conclusions and recommendations. Finally section 7 lists the references quoted in the report.

2. APPROACH

2.1 Data taxonomy

The Eurocontrol Initiative Team has developed a generic causal model of airspace infringements [Eurocontrol (2007)]. This model is used in the present study as the taxonomy to code the occurrence data. The model was developed in several successive steps, incorporating the recommendations made by Eurocontrol stakeholders. Its general structure is built on three, to some extent overlapping, parts:

- Descriptive part - the infringement scenario;
- Explanatory part that describes the symptoms and the network of contributors which, linked together in a variety of combinations, can lead to the identified airspace infringement scenarios;
- Consequence part – describes the potential barriers that can prevent airspace infringement from occurring or mitigate its effect.

The model is descriptive to allow for qualitative occurrence data analysis. The model includes infringement of controlled and restricted airspace. Six infringement scenarios and the related causal and contributory factors are established to cover it.

The following scenarios are considered in the model:

1. GA[1] flight infringes controlled airspace (CAS);
2. GA flight infringes restricted airspace;
3. Military (OAT) flight[2] infringes controlled airspace (CAS);
4. Military (OAT) flight infringes restricted airspace;
5. Commercial aviation[3] flight infringes controlled airspace (CAS);
6. Commercial aviation flight infringes restricted airspace.

For more details about these scenarios the reader is referred to [Eurocontrol (2007)].

The consequence model was developed as part of the present study into airspace infringements with the objective of supporting the analysis of the safety criticality of the reported occurrences. There are different methods of analysing the consequences of flight safety occurrences (other than accidents). A traditional approach is to use the minimum separation between the two aircraft involved, which takes into account the risk of collision. However, this approach does not consider the chance factor, i.e. that the presence of an aircraft in close proximity to another aircraft, which is in the wrong place, can be just a matter of chance. Recently the method of considering safety barriers or defence layers has prompted significant interest among the safety analysts and airlines in Europe. From a safety management point of view it is very important to know how many layers of defences

[1] ICAO definition of General Aviation applies
[2] According to the causal model, military flights conducted under GAT are covered by the other scenarios as they are considered fully compliant with ICAO rules
[3] ICAO definition of commercial air transport operation applies

were breached and how many remained available in a safety occurrence. This principle is applied in the same way as those occurrences in which only one aircraft was involved. That makes the method suitable for use in airspace infringement occurrence analysis.

The method of safety barriers proposed for this study takes into account the limitations of the available occurrence descriptions and is based on the arguments presented above. The barriers used in the model are based on the typical defence layers, including safety nets that can be available to controllers and pilots to avoid mid-air collisions or airspace infringements. The barriers are derived from the Safety Regulation Commission “Guidance Material for Harmonisation of Safety Occurrence Severity and Risk Assessment”, and reflect situations with both one and two aircraft involved. The barriers vary from soft barriers, like air to ground communications, to hard barriers, like STCA alerts. The resulting consequence part of the Airspace infringement model is no substitute for, and cannot be used in the place of safety occurrence severity assessments in the context of ESARR 2, although general coherency is ensured.

The consequence model developed for the present study is shown in Figure 1. For a detailed description of the different barriers, the reader is referred to [Eurocontrol (2007)].

Barriers may fail or may not be present at all, the latter leading to increase in occurrence safety criticality. For instance, an intruding aircraft may not be equipped with a transponder, which excludes the possibility of resolving the situation with the help of TCAS. Another example of a missing barrier is the non-availability of Airspace Infringement Warning (AIW) or STCA etc. The above information is needed for a complete and reliable evaluation of the safety criticality of analysed infringement occurrences.

The barriers method used in developing the model does not require the involvement of a second aircraft (other than the infringing one) in an occurrence that is being analysed. However, the criticality assessment process would always assume an imaginary aircraft which can be expected to be present in the airspace. Based on the location, airspace characteristics, and expected type of traffic, an assumption must also be made as to whether or not this imaginary aircraft is transponder and TCAS equipped.

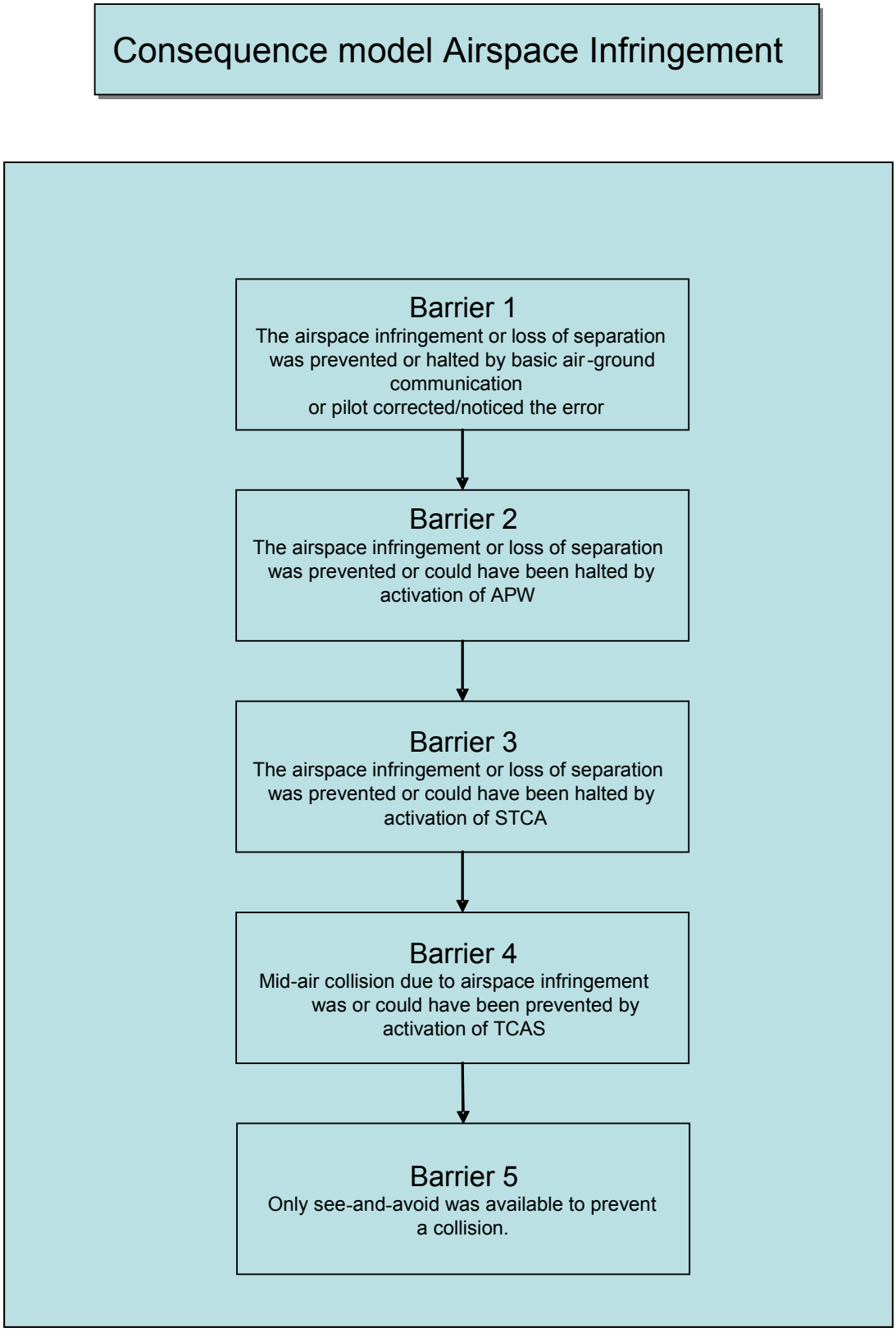

Figure 1: Barrier model

The sequence of the barriers shown in Figure 1 is based on what is likely to be expected in practice. It could be used as guidance when analysing the safety criticality of an airspace infringement. Depending on the particularities of the operational environment, a different sequence of barriers (to that in the current model) might be possible and actually observed. In such cases a barrier may not be effective anymore. For instance the STCA alert could be generated after the TCAS RA is issued in the cockpit. In that case the barrier formed by STCA is not effective and should not be counted.

The effectiveness of the barriers is an important issue in the occurrence criticality assessment. For instance TCAS is considered a very effective barrier in controlled airspace, whereas “see-and-avoid” is not. Although the effectiveness of barriers is very important, safety criticality increases mainly due to the fact that fewer barriers are available. The combined effect (fewer barriers and different effectiveness) is that the criticality will not increase entirely according to a linear pattern when fewer barriers are available. However, it is not easy to define a quantitative or qualitative scale that reflects this behaviour. The easiest scale to define is a qualitative one that takes into account solely the number of available barriers.

2.2 Airspace infringement occurrence data

Airspace infringement occurrence data collected by the Eurocontrol Initiative Team are used in the present study. The original data set provided for this study contained data on more than 3,000 occurrences reported to the state authorities and service providers in 2004 and 2005. The data covered operations in nine different European countries. The original dataset was considered too large to be analysed in depth in the time available for the present study. Therefore the size had to be reduced. The aim was to have a sample that contained around 500 occurrences that would be used for data coding and analysis. The original data were first checked for quality and completeness. Data from one country were not used and removed from the dataset as they contained insufficient information to be used for coding. A random sample comprising 500 occurrences was selected from the total data set. After coding, a final dataset of 473 airspace infringements remained for analysis[4].

2.3 Data coding process

The occurrences were coded by three experienced safety analysts of NLR-ATSI. To ensure consistent coding of the data, regular discussions were held regarding coding issues for particular occurrences. Each of the three analysts coded the same number of occurrences. Once the coding had been completed, some of the results were compared between the three different analysts to find any possible inconsistencies. Finally the data were combined into a single database.

[4] 27 occurrences from the sample of 500 were not included in the final data set for a range of reasons, e.g. the information for an occurrence contained inconsistencies or errors.

3. RESULTS

This section presents the results of the analysis of the data sample of airspace infringements. First the overall sample is considered, followed by the results for each of the six scenarios. Although the taxonomy contains numerous data fields it was not always possible to identify many of them due to a lack of relevant information. The results shown in the following sections are based on items from the taxonomy for which sufficient numbers could be identified that could be used for a meaningful statistical analysis.

3.1 Results for the overall data sample

Some of the results for the overall data sample are presented in this section. Figure 2 shows the distribution of the scenarios in the data sample analysed. Clearly the scenario "GA flight on infringement trajectory to CAS" is by far the largest category in the data sample (77%, 364 occurrences) followed by OAT flight on infringement trajectory to CAS (8%, 38 occurrences) and Commercial flight on infringement trajectory to CAS (6.8%, 32 occurrences). Infringements to restricted airspace are rare events, as shown in Figure 2.

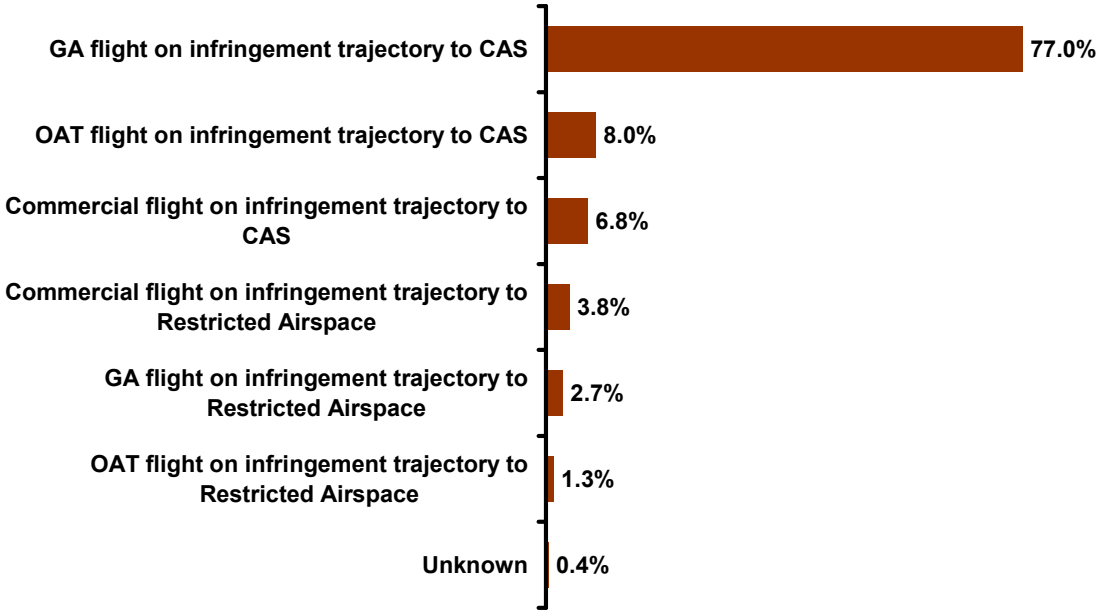

Figure 2: Distribution per airspace infringement scenario

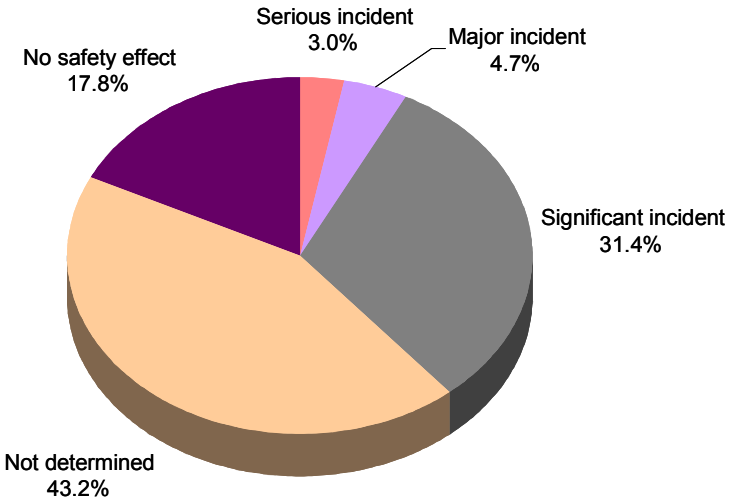

Figure 3: Occurrence severity distribution according to ESARR2 classification

(based on 236 occurrences)

Figure 3 shows the distribution of occurrence severity according to the ESARR 2 definitions. This distribution is based on 236 occurrences for which such a classification was specified by the original reporter of the event. In only 28% of all analysed occurrences was a severity classification provided.

The distribution of airspace infringements per flight phase for the overall data sample is shown in Figure 4.

Figure 5 shows the distribution per flight rules. A significant part of the flights involved in airspace infringement were conducted under VFR.

Figure 6 gives the distribution per infringed airspace type. The vast majority are infringements to TMA or CTR.

Figure 7 shows the distribution per transponder usage. Since in more than half of all cases the transponder usage is unclear, care should be taken when drawing conclusions from these results.

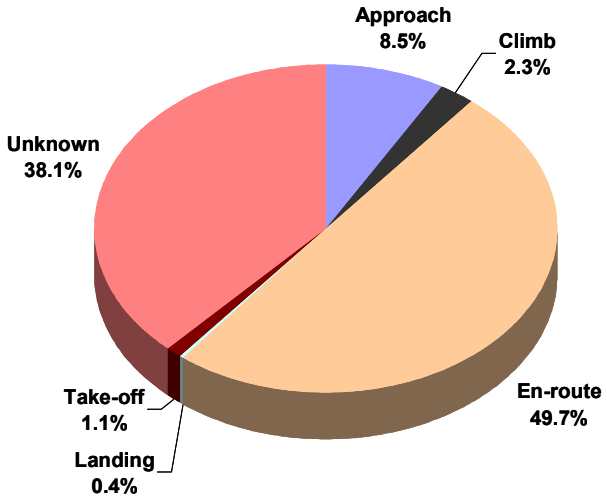

Figure 4: Distribution per phase of flight in the overall data sample

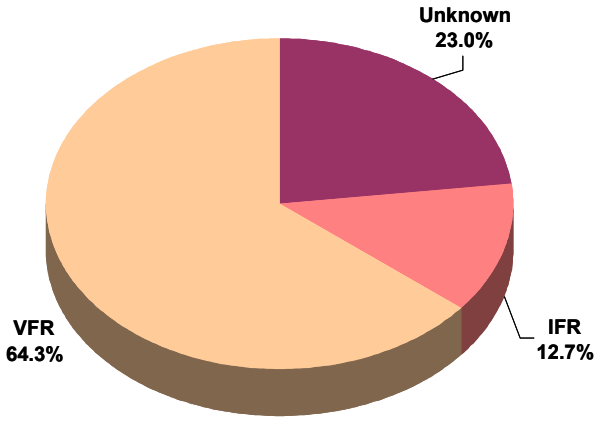

Figure 5: Distribution per flight rules in overall data sample

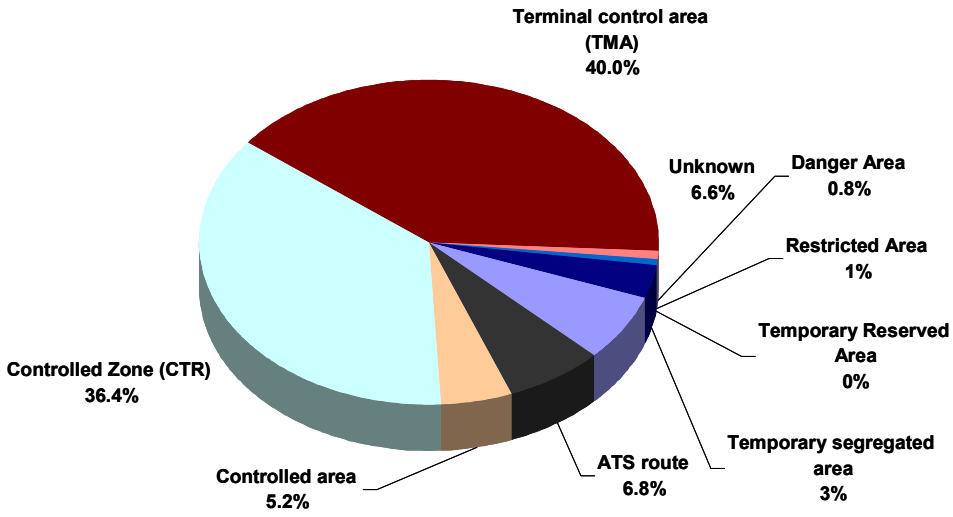

Figure 6: Distribution per infringed airspace type

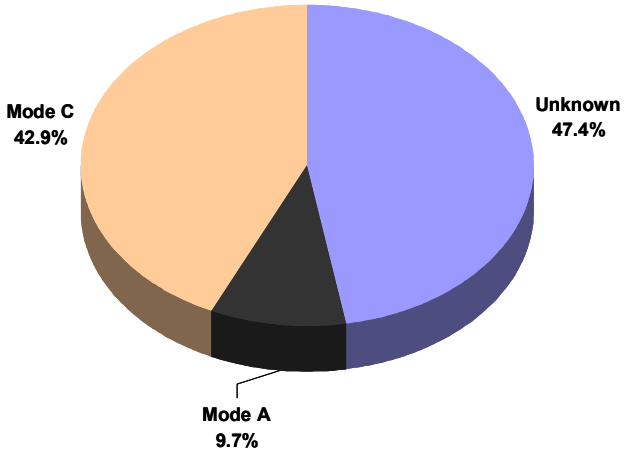

Figure 7: Distribution per transponder usage

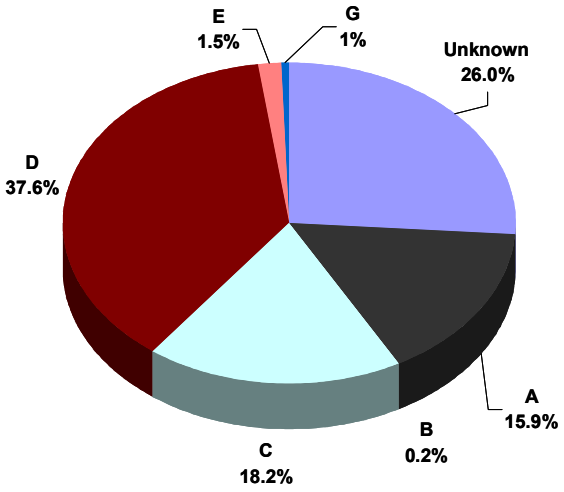

Figure 8: Distribution per airspace class

Figure 8 shows the distribution of infringements per airspace class. Great care should be taken with these results as there are significant differences in the use of different airspace classes in Europe and also in the countries contained in the data sample[5].

In Figure 9 the distribution per height, altitude and flight level is shown. The distribution is relative to the subset of occurrences with a known height, altitude or flight level. It was not possible to recalculate the information provided to a common reference, e.g. mean sea level.

The highest concentration of infringements is to be noted in the layer between 1500 and 4000 feet. This could be linked to the design of the controlled areas (e.g. TMAs). However, the analysis of possible interdependencies in a large part of European airspace would have been very resource demanding and has not been attempted by this study.

[5] The small share of infringed class G airspace represents the unauthorised entries into ATZ contained in the data sample provided by one organisation

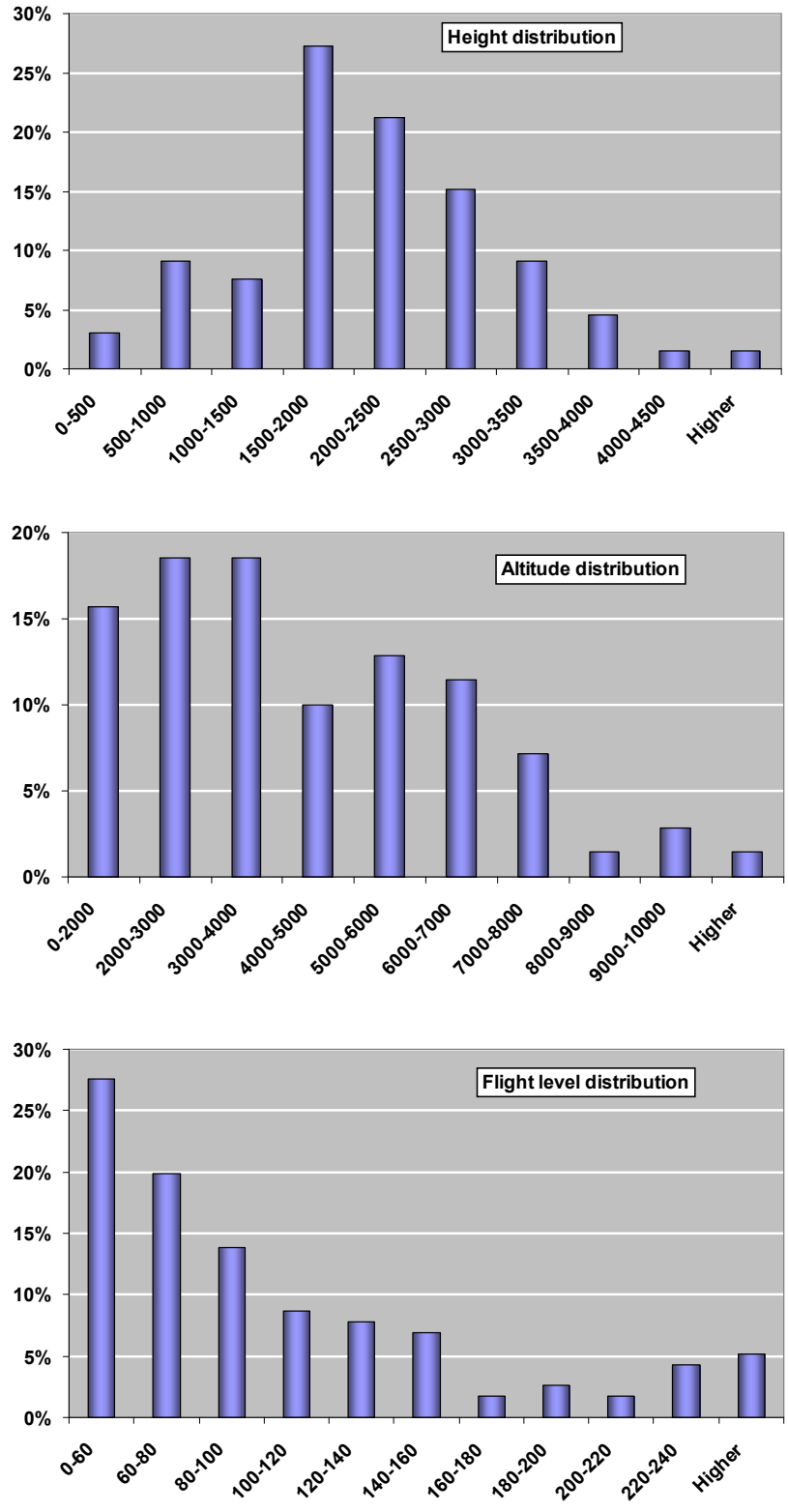

Figure 9: Height, altitude, flight level distribution

An explanatory factor was identified for each occurrence. More than one explanatory factor was identified in 35 occurrences. Figure 10 shows the top five explanatory factors. Clearly pilot-related factors dominate this list.

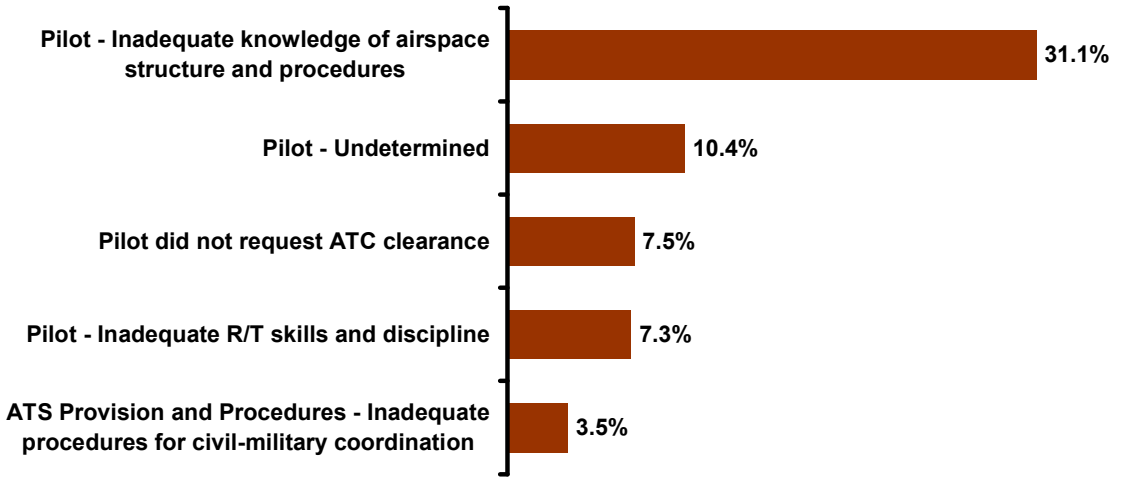

Figure 10: Top-five explanatory factors

Further details about the causal factors identified per scenario are provided in section 3.2.

The consequences of the airspace infringements in the sample were analysed using the concept of safety barriers. The taxonomy assumes that there are 5 different barriers that can prevent an airspace infringement from evolving into a mid-air collision. The results are listed in Table 1 below.

In almost half of all cases there are at least three or more barriers left. In a quarter of the cases only one barrier (see-and-avoid) is left.

Available safety barriers	Number of occurrences	Percentage
Unknown	**79**	**16.7%**
5	**0**	**0%**
4	**191**	**40.4%**
3	**42**	**8.9%**
2	**42**	**8.9%**
1	**119**	**25.2%**

Table 1: Safety barriers in analysed airspace infringement data sample

For the analysis TCAS is considered a barrier in the context of inadequate separation between controlled air traffic that is TCAS equipped and an infringing flight that is transponder equipped. TCAS is not considered, nor is it promoted by this study as a collision avoidance barrier in uncontrolled airspace.

3.2 Results by scenario

3.2.1 GA flight on infringement trajectory to CAS

The GA pilot that had called ATC was issued with a squawk and told to remain outside CAS. The aircraft was then observed deviating off track and entering the CTR (Class D). Repeated calls to the aircraft to change heading failed to have any effect until it had crossed a runway's climb-out flight path. This resulted in aircraft departures being delayed. Finally contact was re-established and the aircraft was then given navigational assistance and transferred away from the CTR.

The scenario "GA flight on infringement trajectory to CAS" is by far the largest in the data sample (77%, 364 occurrences) and therefore also the most important one in this study. The different characteristics of this infringement scenario are presented in this section.

The distribution per flight phase in which these occurrences take place is shown in Figure 11. This figure shows that 47.3% of the occurrences take place en-route. This is by far the most common phase, although care must be taken when drawing conclusions from this observation as in 41.8% of the cases the flight phase is unknown. Figure 12 shows the distribution per flight rules. It comes as no surprise that the vast majority are conducted under VFR.

Figure 13 shows he distribution per flight type. The vast majority of the GA airspace infringements to CAS are caused by non-commercial pleasure flights.

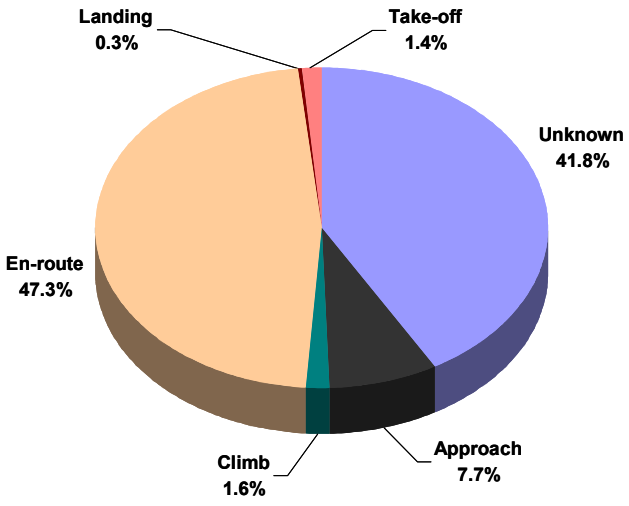

Figure 11: Distribution per flight phase in "GA flight on infringement trajectory to CAS" occurrences

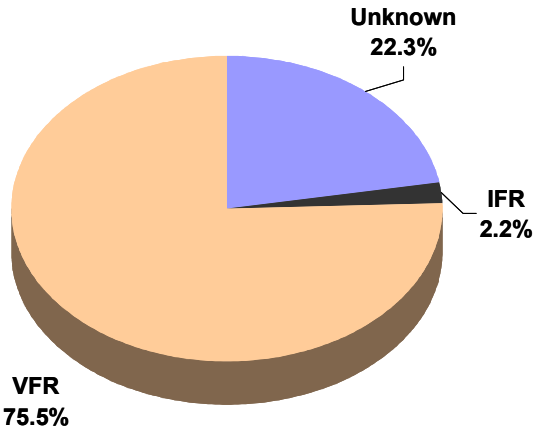

Figure 12: Distribution per flight rules in "GA flight on infringement trajectory to CAS" occurrences

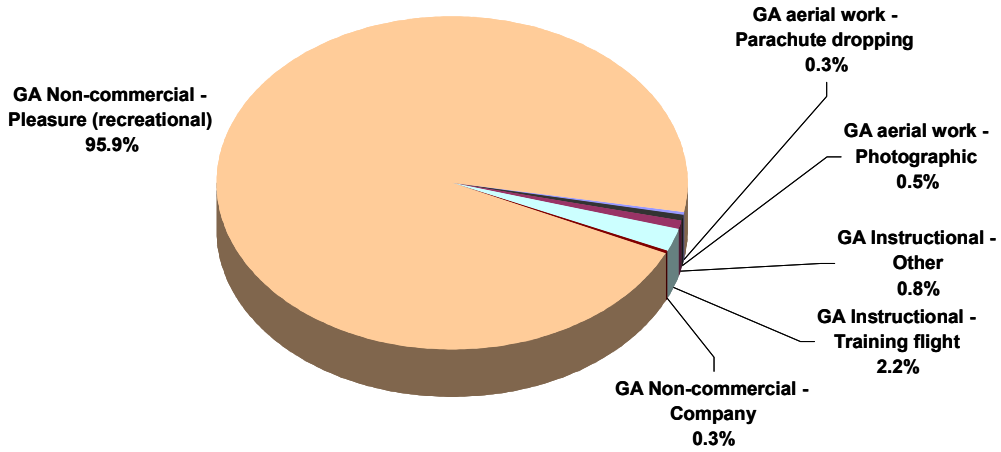

Figure 13: Distribution per flight type in "GA flight on infringement trajectory to CAS" occurrences

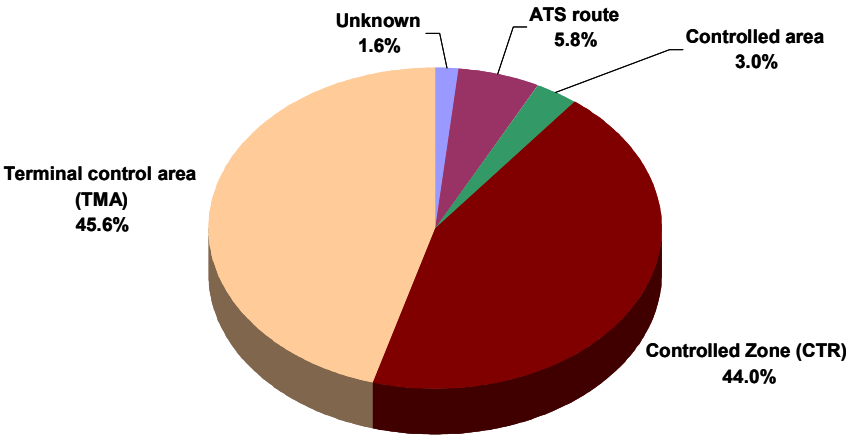

Figure 14:

Distribution per controlled airspace type in "GA flight on infringement trajectory to CAS" occurrences

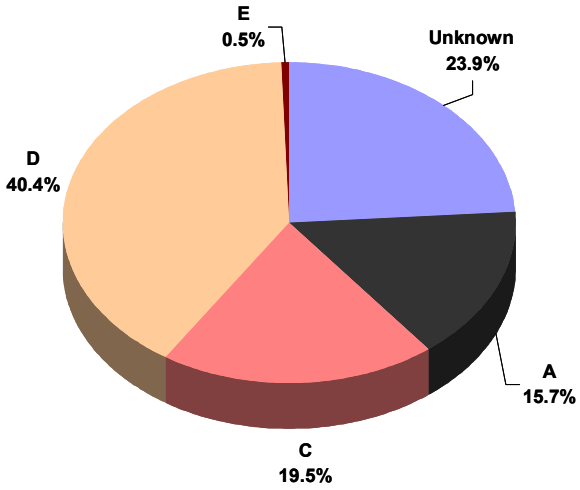

Figure 15:

Distribution per airspace class in "GA flight on infringement trajectory to CAS" occurrences

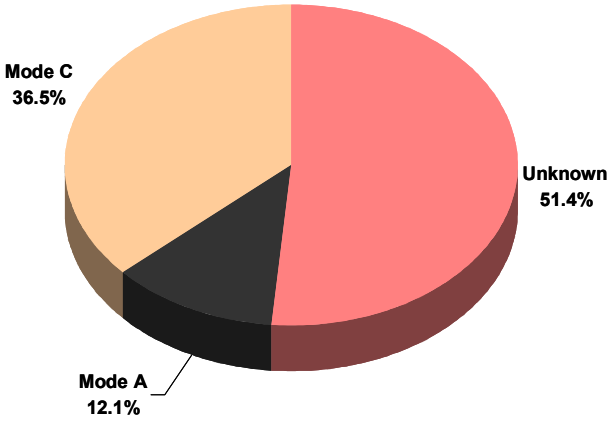

Figure 16:

Distribution of transponder usage in "GA flight on infringement trajectory to CAS" occurrences

Figure 14 gives the distribution of infringements per controlled airspace type. The vast majority are infringements to TMA or CTR, accounting for almost 90% of the cases.

Figure 15 shows the distribution of infringements per airspace class. Great care should be taken with these results as there are significant differences in the use of different airspace classes in Europe and also in the countries represented in the data sample.

Figure 16 shows the distribution of transponder usage. Since in more than half of all cases transponder usage is unclear, care should be taken when drawing conclusions from this result.

The descriptive diagram of the "GA flight on infringement trajectory to CAS" scenario is shown in

Figure *17*, together with the absolute number of times a factor is identified in the data sample. Note that more than one factor from the descriptive diagram can be selected for a single airspace infringement.

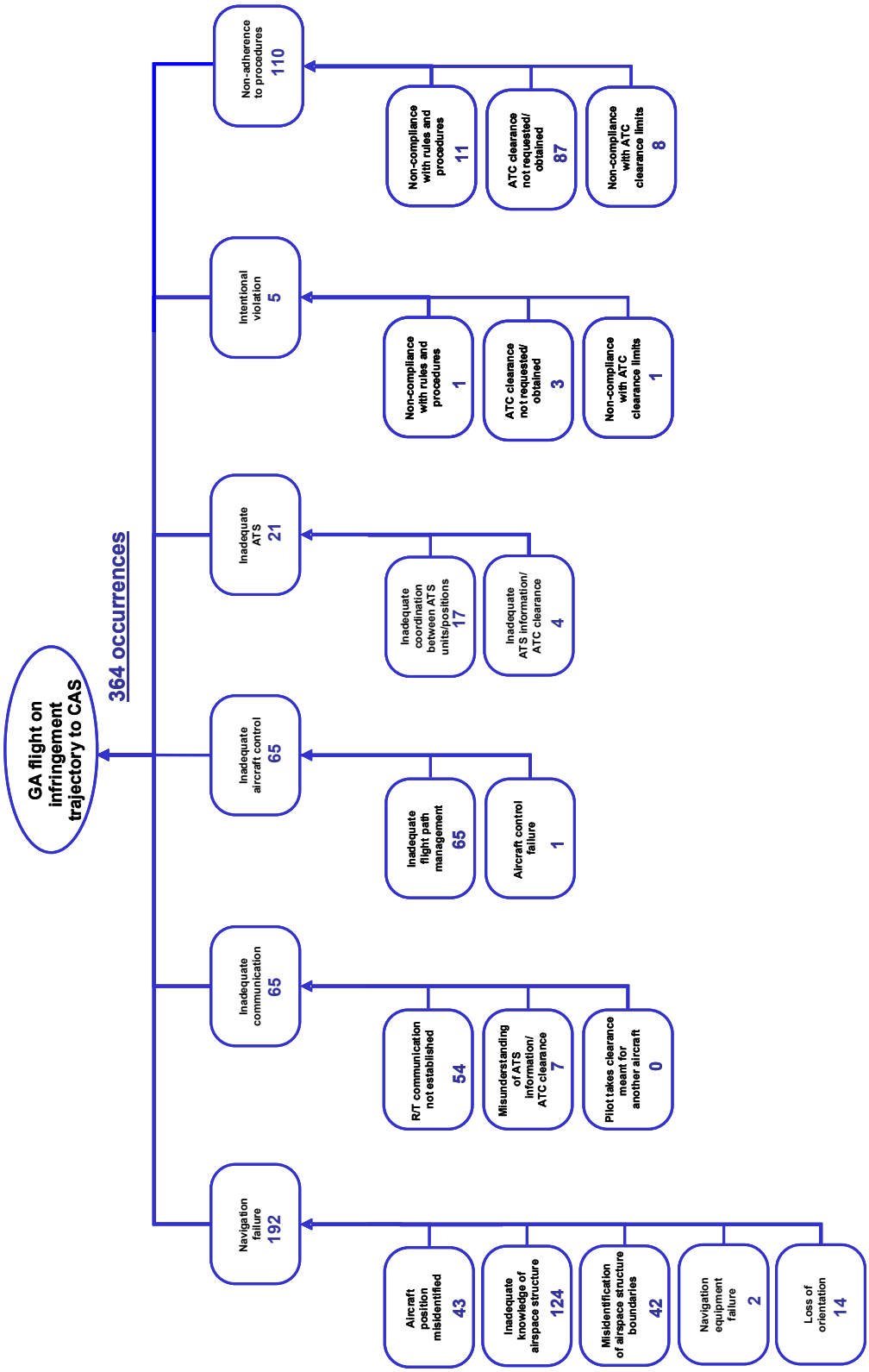

Figure 17: Quantified descriptive diagram for "GA flight on infringement trajectory to CAS"6

[6] The total of causal factors in each branch is not equal to the sum of causal factors belonging to the same branch due to the fact that more than one causal factor was identified in 35 occurrences. In these cases one of the causal factors is considered "the immediate cause".

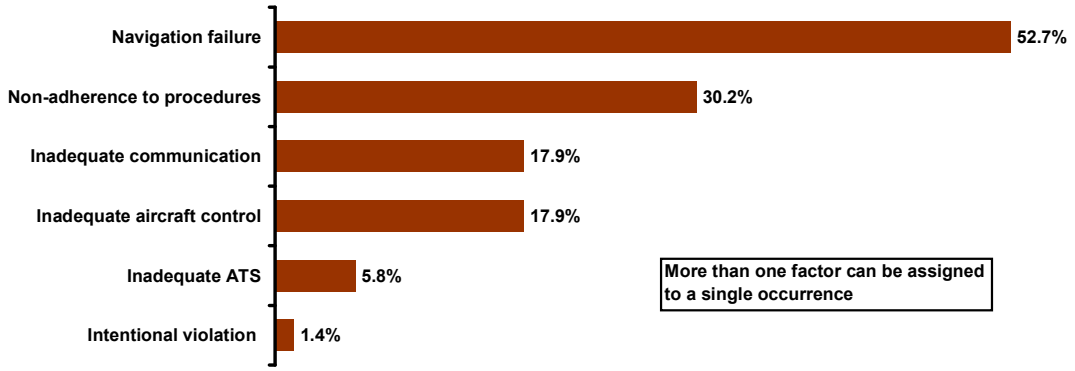

Figure 18: Frequency distribution of main factors from the descriptive diagram for "GA flight on infringement trajectory to CAS"

The frequency distribution of the main factors is shown in Figure 18. More than half of the factors assigned are related to a navigation failure. Furthermore, a large proportion of infringements are related to non-adherence to procedures. Inadequate communication and control are also cited frequently, however much less than navigation failure and non-adherence to procedures. The ATS contribution is reported to be relatively low – at about 6 %.

Table 2 lists the frequency distribution of the different factors related to each main factor in the GA flight on infringement trajectory to CAS scenario. Navigation failure is mainly caused by the pilot's inadequate knowledge of airspace structure. Inadequate communication is often related to the simple fact that no R/T was established. Inadequate flight path management is the main cause for inadequate aircraft control. Most of the inadequate ATS is caused by inadequate coordination between ATS units/positions. However the sample size is limited so care should be taken with this last observation. Intentional violation is mainly caused by the fact that the pilot did not request or obtain ATS clearance. However there are only five cases, so some care should be taken when interpreting these situations. Finally non-adherence to procedures is mainly caused by the fact that the pilot did not request or obtain ATS clearance.

Table 2: Distribution of factors in the "GA flight on infringement trajectory to CAS" scenario

Navigation failure (192)	**percentage share ***
Aircraft position misidentified	22%
Inadequate knowledge of airspace structure	65%
Misidentification of airspace structure boundaries	22%
Navigation equipment failure	1%
Loss of orientation	7%

Inadequate communication (65)	
R/T communication not established	83%
Misunderstanding of ATS information/ATC clearance	11%
Pilot takes clearance meant for another aircraft	0%
Inadequate aircraft control (65)	
Inadequate flight path management	100%
Aircraft control failure	2%
Inadequate ATS (21)	
Inadequate coordination between ATS units/positions	81%
Inadequate ATS information/ATC clearance	19%
Intentional violation (5)	
Non-compliance with rules and procedures	20%
ATC clearance not requested/obtained	60%
Non-compliance with ATC clearance limits	20%
Non-adherence to procedures (110)	
Non-compliance with rules and procedures	10%
ATC clearance not requested/obtained	79%
Non-compliance with ATC clearance limits	7%

*Does not necessarily add up to 100%.

The results presented show the airspace infringements of GA flights into CAS and how they occurred. The reasons why these infringements occurred are covered by the explanatory factors contained within the taxonomy. The identification of these explanatory factors requires a detailed description of the occurrence or a taxonomy used by the reporting organisation which matches the one used in this study. Unfortunately, the level of detail of the occurrence data analysed is not always sufficient to identify all the explanatory factors involved. Furthermore the taxonomies applied by the reporting organisations encompass a low level of detail which does not match the detailed taxonomy used in this study. Nevertheless in 294 (80.1%) occurrences from the GA flight on infringement trajectory to CAS scenario at least one explanatory factor is identified. A total of 384 factors are assigned to these 294 cases, covering 65 different factors. Unfortunately, 50 of these 65 explanatory factors are cited less than 4 times, which limits the validity from a statistical point of view. Figure 19 shows the frequency of the explanatory factors which are cited at least 5 times or more. This list is clearly dominated by pilot-related factors. The "pilot - general" factor is used in those cases in which there is a strong indication that the infringement is related to the behaviour of the pilot. There were, however, insufficient details to exactly explain its behaviour.

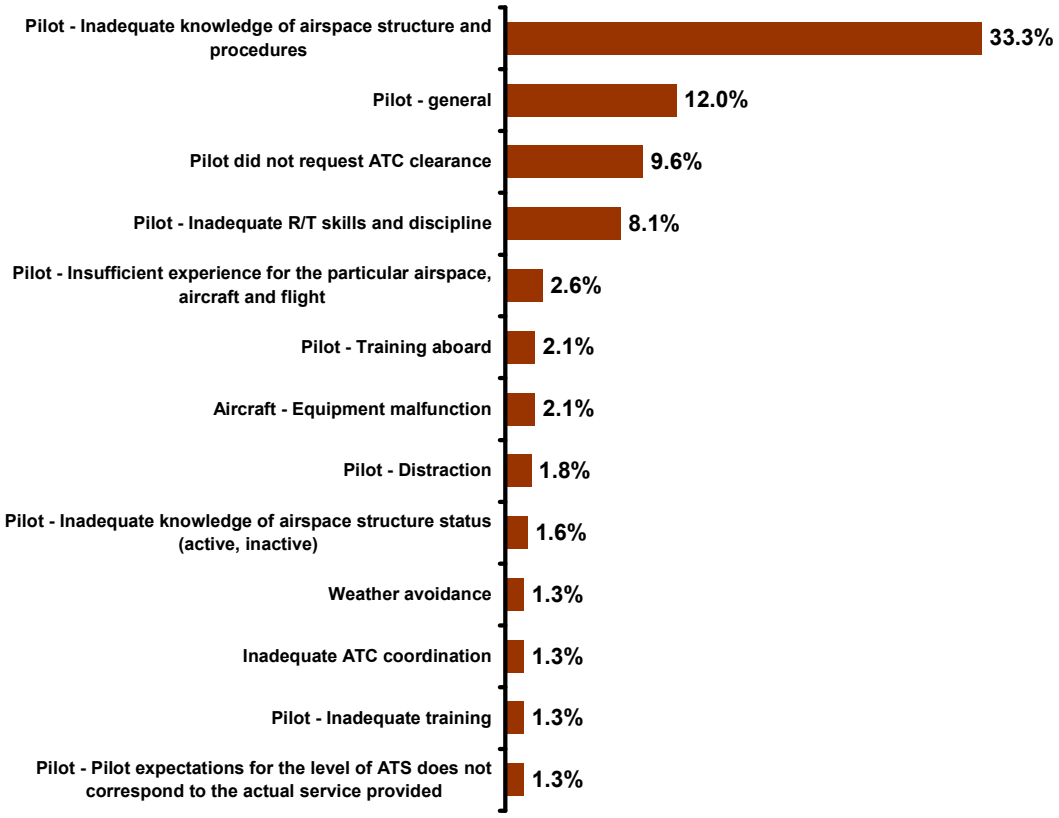

Figure 19:

Explanatory factors identified in the "GA flight on infringement trajectory to CAS" scenario

The effect of the airspace infringements is analysed using the concept of safety barriers. The taxonomy assumes that there are 5 different barriers that can prevent an airspace infringement from leading to a mid-air collision. The results for the GA flight on infringement trajectory to CAS scenario are listed in Table 3. A striking result is that in 28.8% of the infringements analysed in the GA flight on infringement trajectory to CAS scenario there is only one safety barrier left, which by definition is see-and-avoid. This barrier is not very effective. In almost half of all the cases there are at least three barriers left.

Table 4 shows the relation between the frequency of the explanatory factors and the average number of safety barriers. This table can be seen as a sort of risk matrix, where a combination of high average number of safety barriers and high frequency or a low average number of safety barriers and low frequency both indicate a level of risk.

Table 3: Safety barriers in the GA flight on infringement trajectory to CAS scenario

Available safety barriers	Number of occurrences	Percent
5	0	0%
4	140	38.5%
3	37	10.2%
2	32	8.8%
1	105	28.8%
Unknown	50	13.7%

Table 4: Relation between frequency explanatory factors and average number of safety barriers

Factor	Frequency	Average number of safety barriers left
Pilot - Inadequate knowledge of airspace structure and procedures	33.2%	3.9
Pilot - General	11.9%	1.4
Pilot did not request ATC clearance	9.6%	1.2
Pilot - Inadequate R/T skills and discipline	8.1%	3.7
Pilot - Insufficient experience for the particular airspace, aircraft and flight	2.6%	4.4
Aircraft - Equipment malfunction	2.1%	3.4
Pilot - Training aboard	2.1%	1.4
Pilot - Distraction	1.8%	1.4
Pilot - Inadequate knowledge of airspace structure status (active, inactive)	1.6%	2.3
Inadequate ATC coordination	1.3%	1.6
Pilot - Inadequate training	1.3%	3.8
Pilot - Pilot expectations for the level of ATS does not correspond to the actual service provided	1.3%	1.8

3.2.2 GA flight on infringement trajectory to Restricted Airspace

There are only 13 occurrences in the data sample related to the scenario GA flight on infringement trajectory to Restricted Airspace. This number is considered to be insufficient to conduct a meaningful statistical analysis[7]. For the sake of completeness, the quantified descriptive diagram is shown in Figure 20. Great care

[7] Although there are no hard lower limits to the sample size, sample sizes in the order of 50 to 60 occurrences or less are considered small samples.

should be taken when drawing conclusions from this diagram. In section 4 a qualitative analysis is presented for the GA flight on infringement trajectory to Restricted Airspace category.

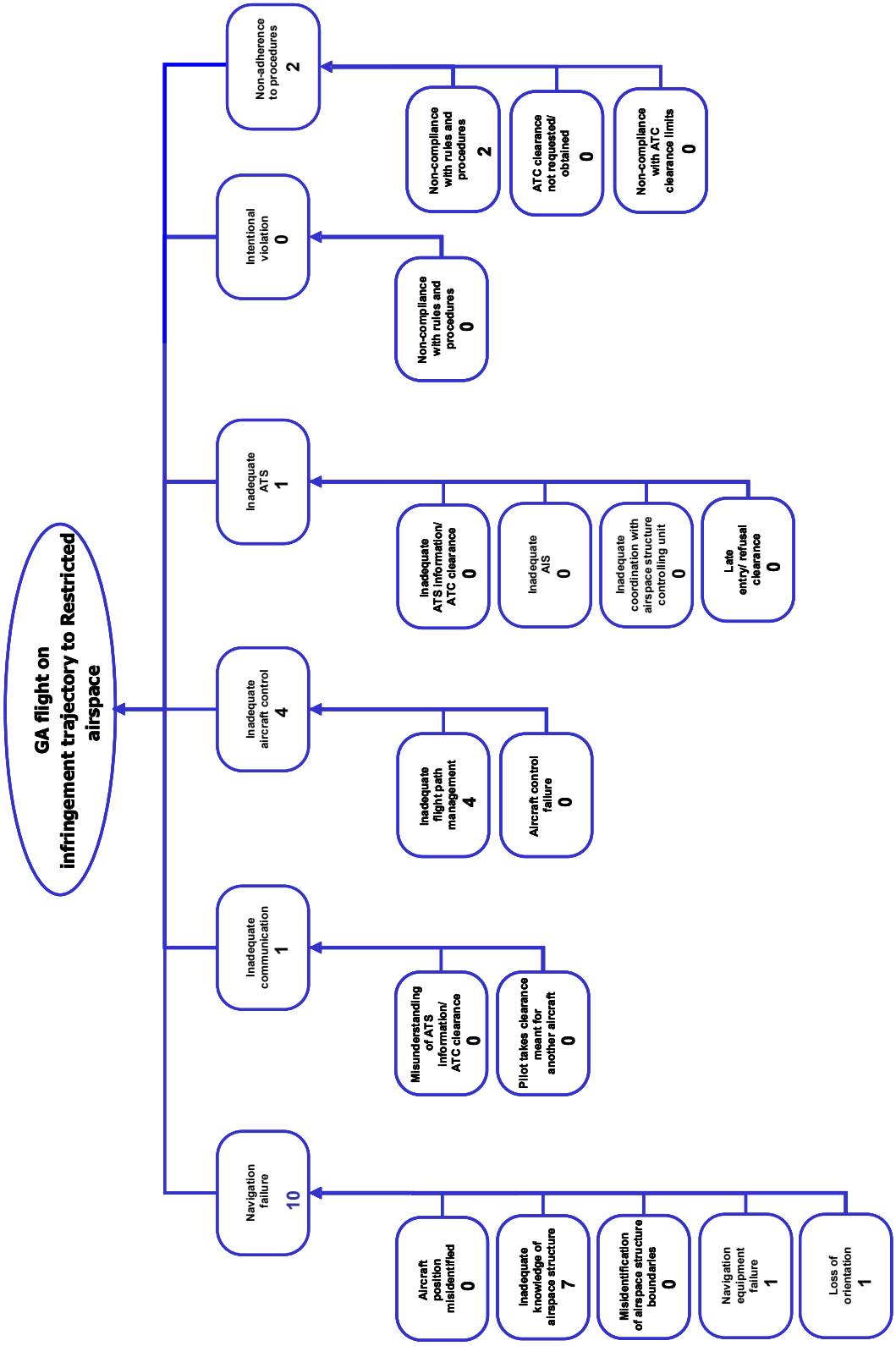

Figure 20:

Quantified descriptive diagram for GA flight on infringement trajectory to Restricted Airspace

3.2.3 Commercial flight on infringement trajectory to CAS

There are only 32 occurrences in the data sample related to the scenario Commercial flight on infringement trajectory to CAS. This number is considered to be insufficient to conduct a meaningful statistical analysis. For the sake of completeness, the quantified descriptive diagram is shown in Figure 21. Great care should be taken when drawing conclusions from this diagram. In section 4 a qualitative analysis is presented for the Commercial flight on infringement trajectory to CAS category.

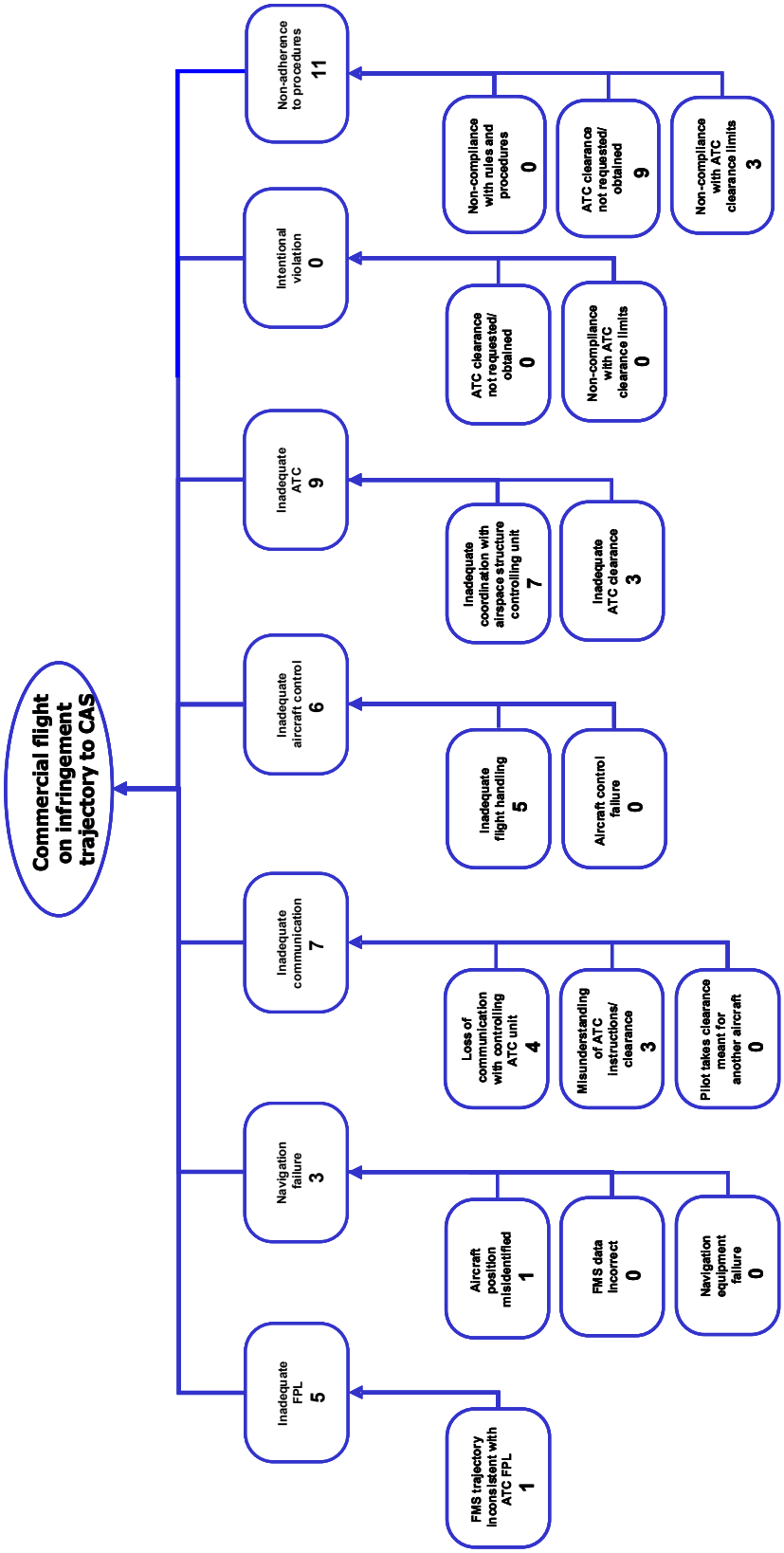

Figure 21: Quantified descriptive diagram for the scenario Commercial flight on infringement trajectory to CAS

3.2.4 Commercial flight on infringement trajectory to Restricted Airspace

There are only 18 occurrences in the data sample related to the scenario Commercial flight on infringement trajectory to restricted airspace. This number is considered to be insufficient to conduct a meaningful statistical analysis. For the sake of completeness, the quantified descriptive diagram is shown in Figure 22. Great care should be taken when drawing conclusions from this diagram. In section 4 a qualitative analysis is presented for the Commercial flight on infringement trajectory to restricted airspace category.

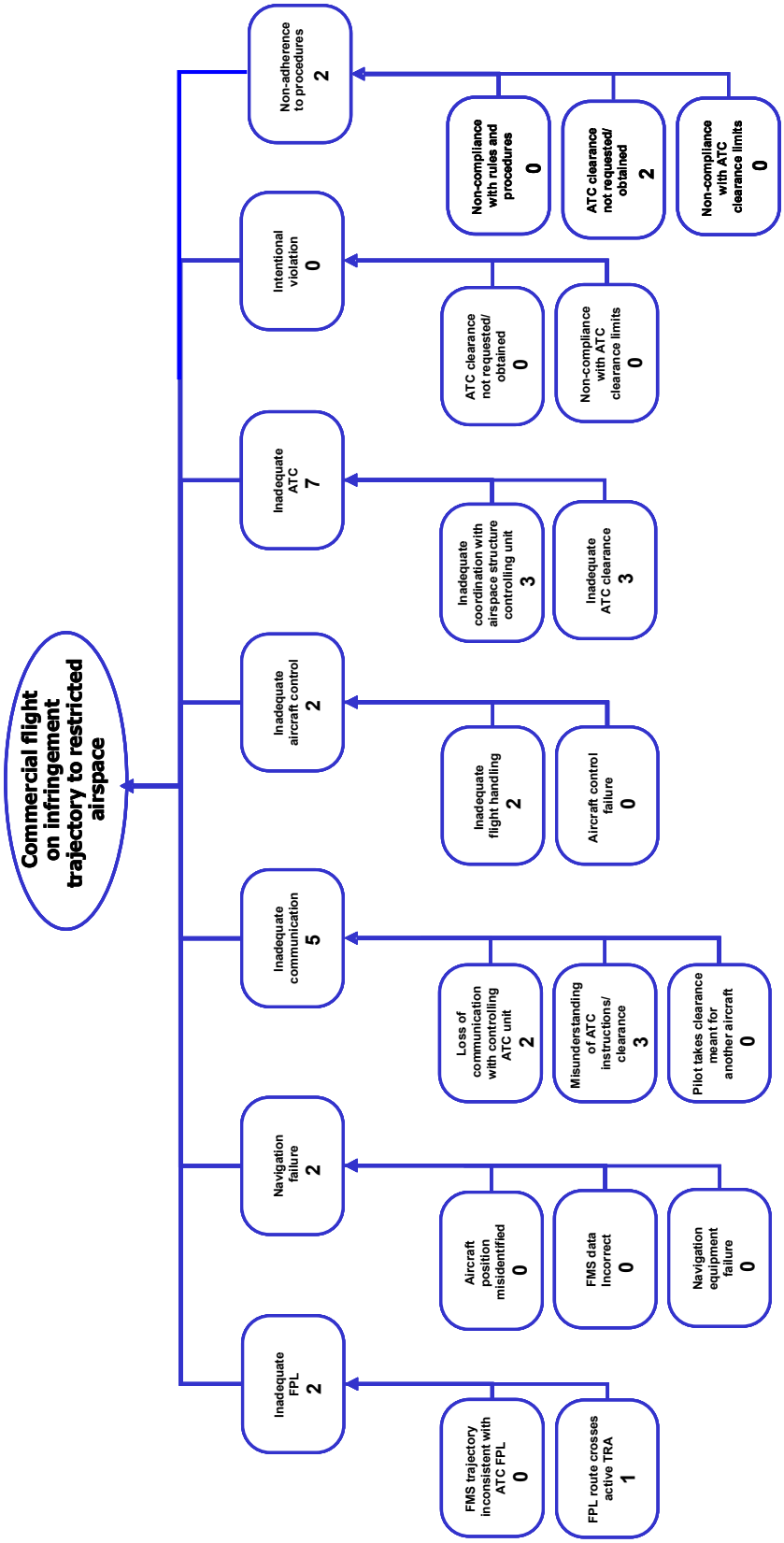

Figure 22: Quantified descriptive diagram for the scenario Commercial flight on infringement trajectory to Restricted Airspace.

3.2.5 OAT flight on infringement trajectory to CAS

There are only 38 occurrences in the data sample related to the scenario OAT flight on infringement trajectory to CAS. This number is considered to be insufficient to conduct a meaningful statistical analysis. For the sake of completeness, the quantified descriptive diagram is shown in Figure 23. Great care should be taken when drawing conclusions from this diagram. In section 4 a qualitative analysis is presented for the OAT flight on infringement trajectory to CAS category.

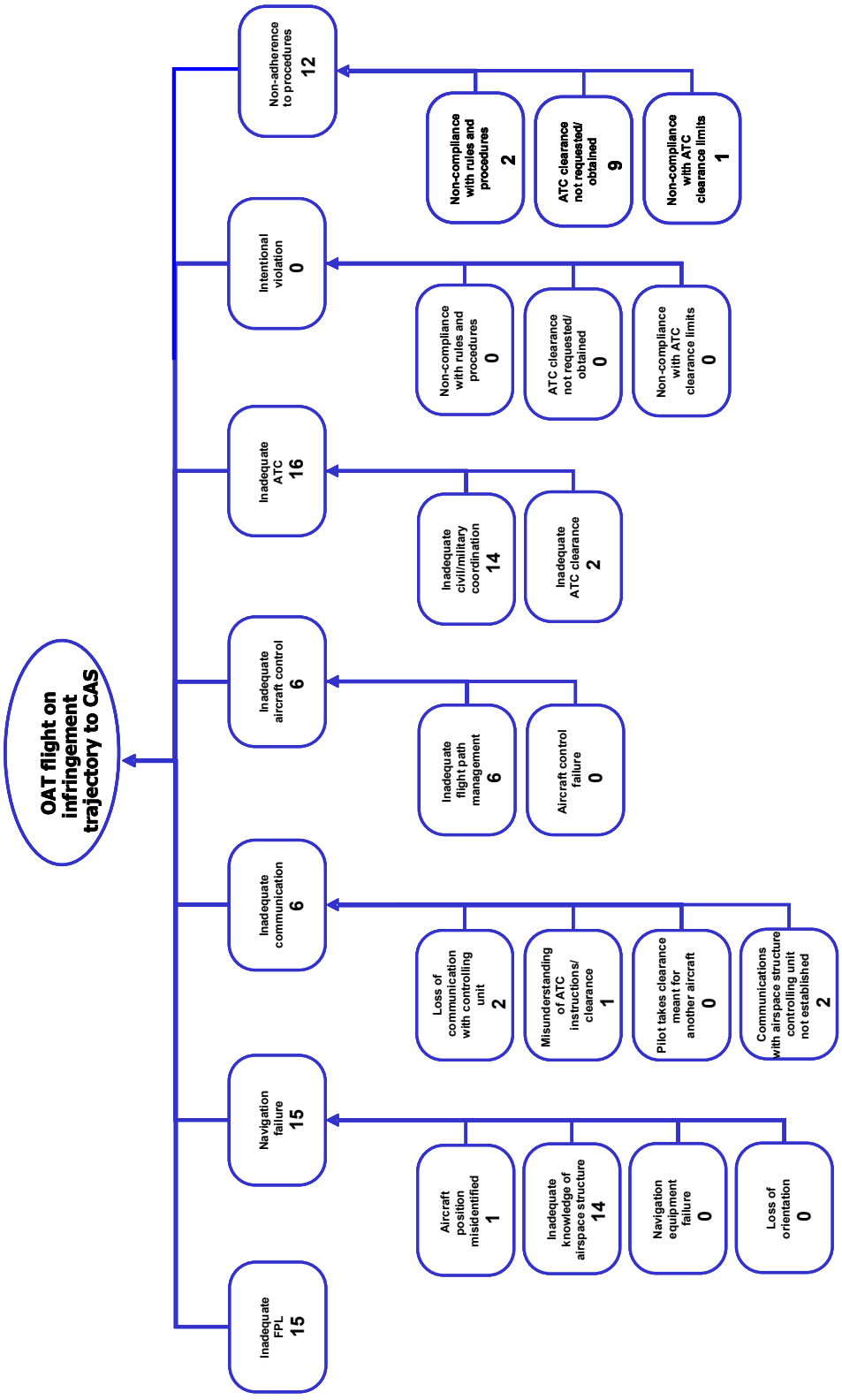

Figure 23:

Quantified descriptive diagram for the scenario OAT flight on infringement trajectory to CAS

3.2.6 OAT flight on infringement trajectory to Restricted Airspace

There are only 6 occurrences in the data sample related to the scenario OAT flight on infringement trajectory to Restricted Airspace. This number is considered to be insufficient to conduct a meaningful statistical analysis. For the sake of completeness, the quantified descriptive diagram is shown in Figure 24. Great care should be taken when drawing conclusions from this diagram. In section 4 a qualitative analysis is presented for the OAT flight on infringement trajectory to Restricted Airspace category.

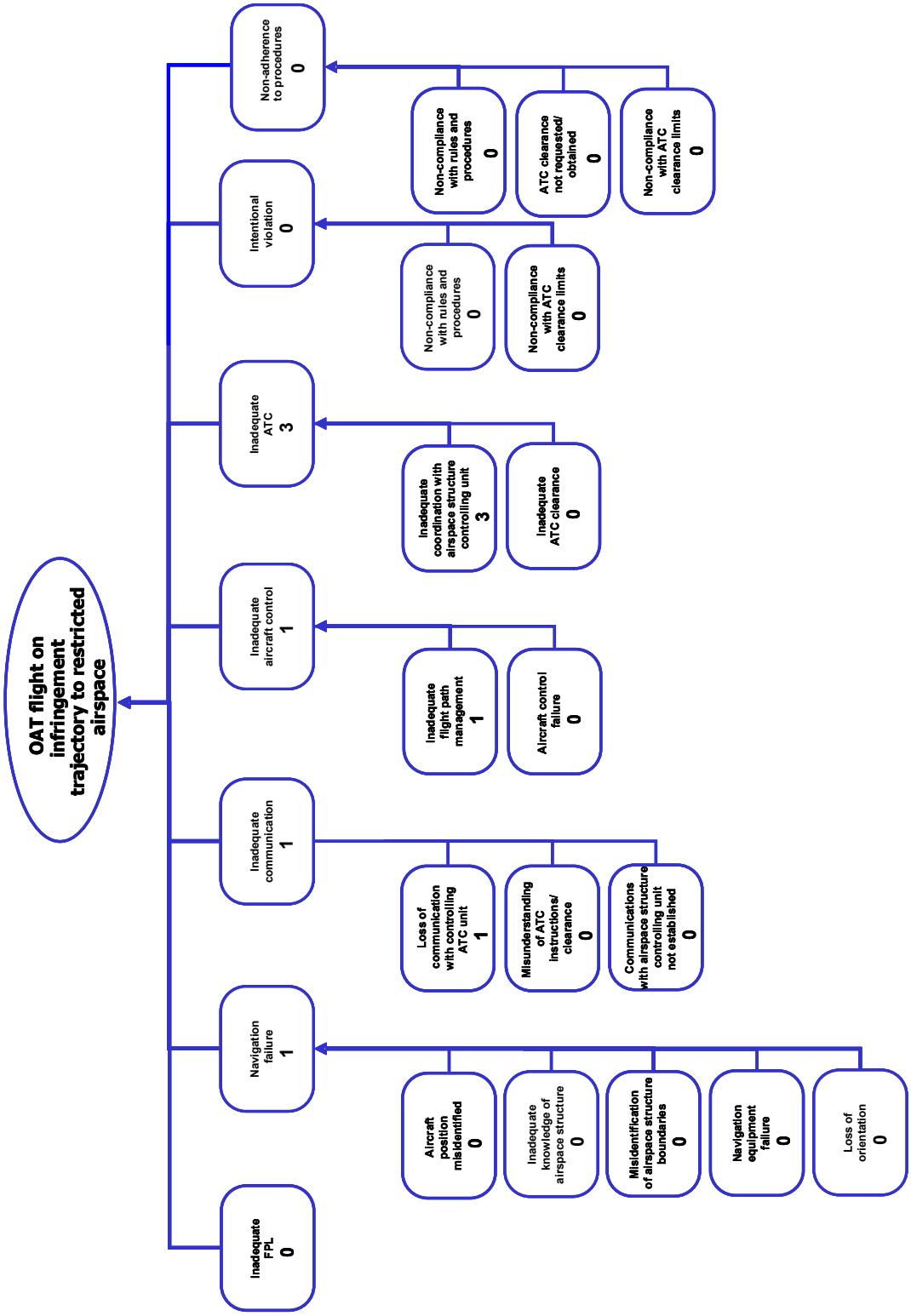

Figure 24: Quantified descriptive diagram for the scenario OAT flight on infringement trajectory to Restricted Airspace.

4. DISCUSSION OF THE RESULTS

This section addresses the results presented in section 3. The taxonomy applied in this study considers six different airspace infringement scenarios. The results show that one scenario dominates the airspace infringement occurrences analysed in this study, namely GA flight on infringement trajectory to CAS. This scenario accounts for 77% of all infringements analysed. This fact does not come as a real surprise. It was known that general aviation flights are more often involved in airspace infringements [see e.g. CAA UK, (2003), Roberts. T. (2006)]. Each of the remaining five scenarios has a relative small share in the overall data sample (see Figure 2). As a result, the individual sample size for each of those five scenarios is considered to be too small to conduct any statistical analysis from which meaningful results can be obtained. Only a high-level qualitative discussion can be offered for these scenarios, based on the limited data available from this study. This has been achieved on the basis of the narrative information and general knowledge about airspace infringements.

It should also be borne in mind that the data used in the present study are mainly obtained from civil ANSPs, which are typically not responsible for controlling restricted airspace. This could bias the relative share of the different airspace infringement scenarios found in this study. However it is believed that the main findings are not significantly affected by this as it is assumed that the share in reality is still relatively low compared to infringements into controlled areas. This is confirmed by independent data from the CAA UK [SRG, (2005)], which also shows a relative low number of infringements into restricted areas (share of 0.8% in the UK over a period of five years).

4.1 GA flight on infringement trajectory to CAS

Examination of the results related to the GA flight on infringement trajectory to CAS scenario demonstrates that a navigation failure is the most frequently cited factor (see Figure 18). This is mainly caused by the pilot's inadequate knowledge of the airspace structure (see Figure 19 and

Table 2). Adequate knowledge of airspace can be obtained from proper pre-flight preparation using up-to-date maps and charts, and navigation aids (GPS moving map). In a number of cases these factors are mentioned in the occurrence narrative. The importance of this factor (inadequate knowledge of the airspace structure) becomes evident when it is related to the overall data sample. In 26% of all airspace infringements, the pilot's inadequate knowledge of the airspace structure is cited as factor in the occurrence. When looking at the risk levels related to the pilot's inadequate knowledge of the airspace structure, the data show that in 4.8% of the cases only one safety barrier (see-and-avoid) is left and that in another 12% at least two barriers are left. See-and-avoid is the last-resort action to prevent a collision between IFR and VFR flights (in the airspace infringement context), if other barriers fail. In the present context, the fifth barrier is based on the so-called unalerted “see-and-avoid” concept. There is a difference between unalerted and alerted “see-and-avoid”. In alerted “see-and-avoid”, the pilot of an aircraft that is “legally” in controlled airspace is assisted in identifying the intruding traffic and has important back-up (e.g. provided by ATC) where visual identification cannot be achieved. On the other hand unalerted “see-and-avoid”, is associated with a potentially higher risk as it relies entirely and solely on the ability of the pilot to visually identify the other aircraft.

The frequency of the explanatory factors is related to the average number of safety barriers in Table 4. This table could be used to understand the risk levels associated with certain factors related to airspace infringements. Unfortunately there is as yet no accepted risk matrix for this concept using safety barriers in which acceptable levels of risk are indicated. Relative high frequencies with a high or low average number of barriers are an indication of a high risk level. Likewise a low frequency with a low average number of safety barriers is also an indication of a high risk level.

Other important factors related to navigation failure are aircraft position misidentified and misidentification of airspace structure boundaries. These factors are related to basic navigation skills. Previous studies have identified that the navigation training received by many GA pilots in the various European countries is barely adequate. The insufficient level of basic navigation skills suggests that navigation training and instruction should be reviewed and improved. Potential problems arising from the use of GPS for primary navigation by GA pilots could not be identified in the present study. However it is believed that the use of GPS also could contribute to the number of navigation problems that have resulted in infringements.

Another frequently cited factor in the GA flight on infringement trajectory to CAS scenario is the fact that the GA pilot has not requested or obtained ATC clearance. Limited knowledge of applicable ATC procedures could play a role in this, as well as airmanship. In 28% (25 out of 90) of these cases no R/T communication was established, which is almost half of all (25 of 54) R/T communication problems found in the GA flight on infringement trajectory to CAS scenario (see also

Figure *17*). Infringements may also be induced by ATC in the case of delayed controller's response to pilot's clearance request. The analysed data sample includes 4 cases of reported inadequate ATC clearance.

In general, R/T issues also play an important role as causal factors for airspace infringements. In nearly 15% of the GA airspace infringements into CAS cases (54 out of 364) no R/T could be established. To a considerable extent, this is attributable to inadequate R/T skills and discipline of the pilots who infringed the airspace. The insufficient R/T knowledge of pilots involved in airspace infringements is believed to be directly related to the limited R/T training GA VFR pilots normally receive. For many GA pilot students, a challenging aspect of the PPL syllabus is the basic R/T handling. This issue is of particular importance for pilots whose mother tongue is not English. Also, lack of experience could also contribute to an inadequate or missing R/T exchange. However, the present study was not able to identify the proficiency of the pilots involved in the airspace infringements. The observation regarding the role of R/T skills in airspace infringement occurrences is in line with the findings of the CAA UK study [CAA UK, (2003)].

The role of the use of transponders could not be identified with any precision. The data show that Mode C transponder setting is used in nearly 37% of the infringements into CAS, and in more than 12% a Mode A setting only. However, in 51.4% of the cases, the transponder setting details are unknown. It could be that in these cases no transponder was used or no transponder was fitted on the aircraft. However, it is also possible that a transponder was used. Examination of the narrative data on these cases to determine the transponder usage was in many cases inconclusive, or gave contradictory results.

The present study could only use whatever information was available as reported to the different organisations. The occurrence reports varied in quality and completeness which limited the in-depth application of the causal model developed by a previous Eurocontrol study to aid the analysis. The chances of infringements being detected either by controllers or, in cases of reduced separation, by TCAS/ACAS is reduced when aircraft are either not fitted with a transponder or are equipped but pilots elect or are instructed not to switch them on. Even where transponders are available and used, they may not be altitude-reporting (Mode A only), which impairs conflict resolution by TCAS/ACAS and/or the controller. In addition, such aircraft may not be displayed on a controller's screen where, for instance, conspicuity codes are suppressed in order to reduce radar display clutter.

4.2 GA flight on infringement trajectory to Restricted Airspace

The little data that are available suggest that similar causes as found for the GA flight on infringement trajectory to CAS scenario apply to the GA flight on infringement trajectory to restricted airspace scenario. In particular the pilot's inadequate knowledge of the airspace structure seems to be important. The fact that there is a strong similarity to the scenario GA flight infringing CAS comes as no surprise. The events and factors leading to the infringements in both scenarios are such that is does not matter whether the airspace is controlled or restricted. In both cases the pilot was unaware of the airspace or did not follow the proper procedures which could have avoided the infringement.

4.3 Commercial flight on infringement trajectory to CAS

Airspace infringements caused by commercial flights are a relatively rare event, as demonstrated by the 32 occurrences identified in the data sample[8]. Commercial flights are usually under the control of an air traffic unit throughout the duration of the flight. As a result, any deviation from the flight plan is usually detected quickly and corrected. The factors, such as insufficient R/T knowledge and inadequate navigation skills that are referred to in the infringement scenarios analysed above are less likely to occur with commercial pilots. Commercial pilots receive more training and are the subject of regular monitoring and assessments of their skills. For obvious reasons, commercial pilots gain a lot more operational experience than GA “recreational” pilots. Such operational experience can improve for instance the R/T skills. However, this does not mean that commercial pilots cannot make any mistakes in air to ground communication. Indeed there are a number of cases in the “Commercial flight on infringement trajectory to CAS” scenario in which communication problems are a factor. The contribution of ATC in “Commercial flight on infringement trajectory to CAS” is believed to be higher than in scenarios involving GA flights. Coordination between different sectors seems to play a role in this respect.

[8] This low number is also confirmed from a query that was run on the NLR Air Safety Database. From a total of 314,000 airline safety reports, only 24 airspace infringement occurrences could be identified. It is believed that commercial airline pilots tend to under report airspace infringements. However even when this is taken into account the number of airspace infringements will most likely remain low, which confirms the findings of the present study.

4.4 Commercial flight on infringement trajectory to Restricted Airspace

There is no clear indication what is causing commercial flights to infringe restricted airspace. However, the limited data tends to suggest that coordination between different sectors (including civil - military) could be an important factor. The sector coordination factor in ATM-related safety occurrences is not uncommon. Its presence in airspace infringements is therefore no surprise.

4.5 OAT flight on infringement trajectory to CAS

OAT flights on infringement trajectory to CAS are rare events and account for a similar share as commercial flights. In general, military pilots receive more training and are monitored more strictly. They must also meet more demanding licensing requirements than PPL holders. On average, military pilots should gain more operational experience than GA VFR pilots who do 'recreational' flying and are usually assisted by military ATC. As a result, it is no surprise to find a low share of infringements caused by military flights, similar to that of the commercial flights. However, it should be noted that the majority of the data analysed in this study are obtained from civil ANSPs, which could to some extent bias the low share found.

The limited data suggest that the causes of OAT flights infringing controlled airspace are variable. Inadequate coordination between civil and military controlled sectors, inadequate FPL and navigation failures seem to be the most important factors. Poor coordination between civil and military sectors in general is not an uncommon problem. Its presence in airspace infringements is therefore not a surprise. Inadequate FPLs could also be related to the coordination factor.

4.6 OAT flight on infringement trajectory to Restricted Airspace

There is insufficient information to make a meaningful qualitative assessment of this scenario. However the limited data tends to suggest that coordination between different sectors could be a factor of some importance.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the analysis of the 473 airspace infringements in eight different European countries presented in this report, the following conclusions are made:

- The vast majority of the airspace infringements investigated in the present study are caused by general aviation pleasure flights that infringe controlled airspace. This is mainly due to the insufficient R/T and navigation skills which are most likely caused by low flying experience and insufficient training. VFR flights are mainly performed by single-crew operated aircraft, which are often without sophisticated navigation equipment and are provided Flight Information or ATC services that vary greatly in scope.

- Commercial and military flights related airspace infringement scenarios amount each about 10 % of the analysed sample. Important explanatory factors are that commercial and military pilots receive more training, in general have more flying experience, are supported by extensive automation and are usually under the control of an air traffic unit throughout the flight, making it easier to detect and correct any deviations from the flight plan.

- Infringements of restricted airspace are rare events as they could hardly be identified in the present study. This could be partly caused by potential underreporting of these events to EUROCONTROL as the airspace infringement data originated mainly from civil ANSPs, which usually do not control compliance with restricted airspace. However, it is not believed that this will significantly affect the relative amount of infringements of restricted airspace identified in this study.

- The unavailability of data at European level about the total number of General aviation (GA) operations, as well as the sub-division in respect of ultra lights, gliders, balloon and mainstream GA does not allow establishing precisely the contribution of the different types of airspace user operations to airspace infringement risk.

- The occurrence reports used in the present study varied in quality and level of detail, which limited the full application of the causal model developed by a dedicated EUROCONTROL study. The collected data could not provide for an in-depth assessment of the contribution of various ATM related factors like complex airspace design to airspace infringement risk. The occurrence data enabled only identification with sufficient confidence of the relative share of infringement scenarios and associated generic causation. The lack of detailed information about the contributory factors necessitates further study of the in-depth reasons for airspace infringement.

5.2 Potential mitigation measures

In section 4 a number of mitigation measures are proposed which could either prevent infringements from occurring or could reduce the risk of infringements. The measures are based on the most frequent causal factors identified in this study in combination with a high change of effectiveness and success. These last two factors are merely based on expert judgement rather than on any kind of quantitative analysis (e.g. benefit analysis). The mitigation measures presented are mainly aimed at the general aviation pilot (in particular the recreational pilot) due to the high share of GA VFR infringements in the overall analysed data sample.

There are three main factors that cause airspace infringements by general aviation 'recreational' pilots (see e.g. Figure 19). Inadequate knowledge of airspace structure and procedures, insufficient basic navigation skills and inadequate air ground communication account for more than 60% of all factors. The question is now of course how this risk of airspace infringement can be reduced. Two approaches to this problem are possible. One is to improve the behaviour of the 'infringer'; the other is to improve the amount and quality of the barriers. Both can reduce the risk of airspace infringements.

In general, the behaviour of pilots that has resulted in airspace infringements is related to three factors: training (ab initio and recurrent), experience (regular exposure) and attitude, or any combination thereof. Both ab initio training and recurrent training of the general aviation pilot generally concentrate more on aircraft handling, the skill you need to survive flight, than on navigation skills and use of the radio (including the associated procedures to communicate with ATC). Initial training includes theory and a number of supervised and solo navigation flights. However, after receiving a license, enhancing navigational skills and generally gaining proficiency is, other than fulfilling the minimum recurrence requirements, up to the pilot. From the results of this study it is evident that the required level of expertise is not achieved or maintained, at least in the case of infringement-related subjects. The large share of the number of cases in which the pilot had an inadequate knowledge of the airspace he/she was flying in is related to this low level of expertise.

Options for improvement are initial training, recurrent training and recurrent requirements, and in general a professional attitude towards flying. Initial training can be enhanced by devoting extra attention to the skills necessary of flying in any airspace in a proper manner, i.e. navigation, radio-use and knowledge and application of procedures. However this is not considered to be an adequate basis for mitigation. Other than the very basic skills required, proficiency in this field is directly related to operational practice. Therefore recurrency training and recurrency requirements offer more with regard to possible mitigation. In general, current recurrency requirements and therefore training is aimed at basic flying skills. A mandatory navigation flight with an instructor could become part of the curriculum in order to improve the navigation and radio skills of the pilot. This could improve awareness and skills, which in the end would help to reduce unintentional infringement of controlled airspace.

The high share of infringements involving general aviation flights calls for efforts to raise the awareness of the general aviation pilot on the need to continually improve his/her skills as a factor which would enhance mitigation. This is, however, difficult to achieve, since it involves many aspects of a general aviation pilot's personal life and priorities. An awareness campaign amongst general aviation pilots might help, although its success could be limited. Regular briefings given by flying clubs to their members could also assist in improving risk awareness. Furthermore, such briefing

and awareness initiatives should be held at regular intervals (for example once a year) otherwise their effect will diminish. Unfortunately, general aviation (recreational) pilots flying irregularly would not necessarily be reached by such initiatives. As identified by this study the vast majority of airspace infringements involve recreational flights (see e.g. Figure 13).

Enhancing the level of services provided to general aviation VFR flights should also be examined for the identification of airspace infringement prevention measures. A good practice in this respect is the provision of radar information or radar advisories to VFR flights performed in close proximity to controlled airspace with high traffic density.

Also, improved coordination between control units (including civil-military) could have a positive impact on all types of infringement scenarios analysed in section 4.

With regard to increasing the number of the relevant barriers, one potential solution is already being announced. In Europe it will become mandatory for all IFR flights and for VFR flights in designated airspaces to use a Mode S transponder[9]. Traditional SSR stations interrogate all aircraft within their range, whereas with Mode S the station can establish selective and addressed interrogations with aircraft within its coverage. Such selective interrogation improves the quality and integrity of the detection, identification and altitude reporting. The requirements for Mode S can increase the number of safety barriers and thus reduce the risk of a flight infringing controlled or restricted airspaces. Furthermore, the controller will be better placed to identify and position aircraft that are on an infringement trajectory.

Further means to improve and increase the number of available barriers are the so-called safety net functions. Dedicated applications on board the aircraft and in the ATC systems can alert pilots and controllers to a potential or actual infringement of controlled or restricted airspaces. Practical examples of the said functions are the infringement alert provided by many GPS systems and the Controlled Airspace Infringement Tool (CAIT) developed by NATS.

5.3 Recommendations

The following recommendations are made:

- The findings of the present study should be made known to all airspace infringement risk stakeholders;
- Improved training for general aviation pilots in basic R/T and navigation skills should be considered at European level;
- A dedicated airspace infringement occurrence reporting campaign should be considered for a limited period (6 months) which could provide more factual

[9] For aircraft flying IFR as General Air Traffic (GAT), the latest dates for the carriage and operation of Mode S ELS airborne equipment in designated airspace are as follows: New production aircraft to be compliant by 31 March 2007 and completion of aircraft retrofits by 31 March 2007. All aircraft flying VFR in designated airspace are required to carry and operate Mode S ELS airborne equipment by 31 March 2005 with the following transitional period: new production aircraft to be compliant by 31 March 2005, although there is now a general relaxation until 31 March 2008 and completion of retrofits, irrespective of date of first CoA issue, by 31 March 2008.

information on the airspace infringements considered in the taxonomy developed within the scope of the Airspace infringement initiative. This campaign will require the participation of ANSPs (civil and military) as well as pilots (general aviation, commercial and military) and aircraft operators in Europe.

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ABBREVIATIONS

ACAS	Airborne Collision Avoidance System
ACC	Area Control Centre
AI	Airspace Infringement
AIC	Aeronautical Information Circular
AIS	Aeronautical Information Services
AIW	Airspace Infringement Warning
ANSP	Air Navigation Service Provider
ANSP	Air Navigation Service Provider
APW	Area Proximity Warning
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATM	Air Traffic Management
ATS	Air Traffic Services
ATZ	Aerodrome Traffic Zone
CAA	Civil Aviation Administration
CAS	Controlled Airspace
CRM	Crew Resource Management
CTR	Controlled Area
DA	Danger Area
ESARR	Eurocontrol Safety Regulatory Requirement
FIC	Flight Information Centre
FIS	Flight Information Service
FMS	Flight Management System
FPL	Flight Plan
FUA	Flexible Use of Airspace
GA	General Aviation
GAT	General Air Traffic
GPS	Global Positioning System
HEIDI	Harmonisation of European Incident Definition Initiative for ATM
HMI	Human Machine Interface
IFR	Instrument Flight Rules
ICAO	International Civil Aviation Organisation
NOTAM	Notice to Airmen
OAT	Operational Air Traffic

PA	Prohibited Area
RA	Restricted Area
R/T	Radiotelephony
SISG	Safety Improvement Sub Group
SSR	Secondary Surveillance Radar
STCA	Short Term Conflict Alert
TMA	Terminal Control Area
TRA	Temporary Reserved Area
VMC	Visual Meteorological Conditions
VFR	Visual Flight Rules