Equipment failures in ATC: Finding an appropriate safety target

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ABSTRACT

The aviation community is currently faced with various approaches for the determination of Target Levels of Safety (TLS). The targets are usually derived for a specific airspace region, for a specific type of operation or a specific phase of flight. Therefore, current practices support the determination of TLS for specific aviation components in isolation. This paper argues that the setting of a new safety target for aviation has to be driven by an integrated system approach. Relevant past research on TLS is reviewed and augmented with the results from operational reports from two countries. A possible safety target for the year 2020 is suggested and scoped down to estimate the safety budget for air traffic control (ATC) equipment. The paper concludes with a discussion of the results and recommends useful practices to achieve the proposed integrated safety approach.

1.0 INTRODUCTION

The current safety assessments in aviation are based on the isolated analyses of various components of the air transport system (i.e. aviation system). Examples include isolated consideration of aircraft airworthiness, air traffic management (ATM), flight operations, airport operations, equipment reliability, and air navigation systems[1]. A major drawback of this approach is that there is an increased likelihood of an over-determined and expensive system. In future, safety assessments should attempt to encompass the air transport system as a whole, and move away from the current practice of assessing isolated systems. Such an approach should allow trade-offs to be made between the various components, and facilitate rationalisation of infrastructure while maintaining an acceptable level of safety in a cost-effective way.

Figure 1 shows the major components of the air transport system. This (expanded as required) should form the basis for a top-down safety analysis and calculations to determine the budgets for any desired component. As the main aim of this paper is to determine appropriate levels of risk or Target level of safety (TLS) for air traffic control (ATC) equipment, emphasis is put on the ATM component of Fig. 1.

An overall 'system risk' could be divided into 'design and certification risk', 'operational risk', and 'maintenance risk'[1]. The current understanding of safety puts an additional emphasis on the roles of human operators and procedures, as essential components of any system. Current and future advancements in the area of human reliability assessment and human error quantification will create a basis for the calculation of risk taking account of these non-technical elements of the system. Hence, for each component of an air transport system, consideration should be given to the risk imposed by human operators, equipment, and procedures.

This paper starts with a discussion on risk and reviews the various units and accident/incident ratios used in aviation safety analyses

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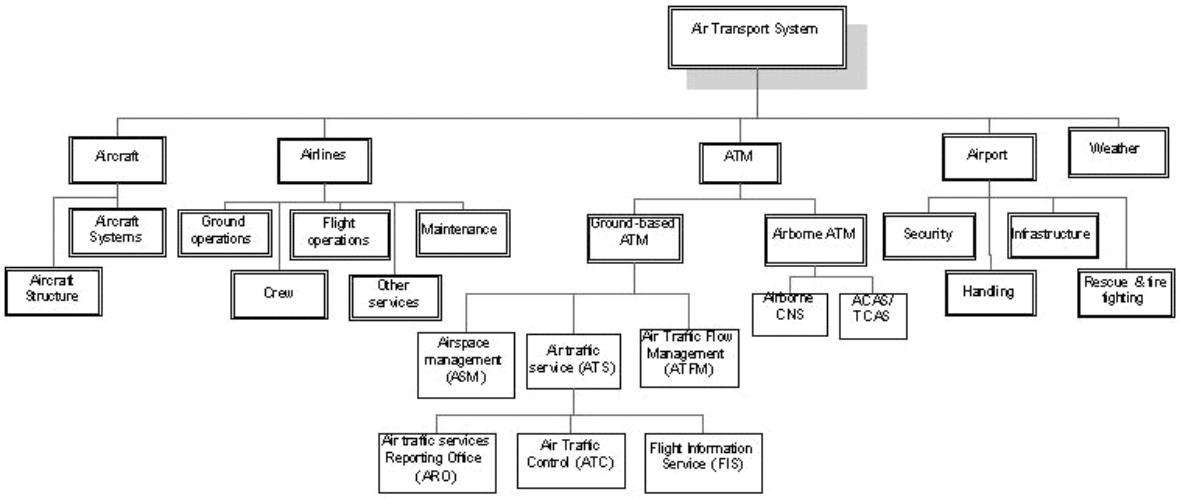


Figure 1. The air transport system.

today. It continues with a discussion of the concept of TLS, looking at the various approaches employed in the past and currently. In order to comprehend both the similarities and differences in these analyses, which have helped guide the proposal made in this paper for a TLS for the year 2020, a summary of the major findings is presented. Finally, the proposed TLS has been compared with the results gained from the analysis of available operational reports from two sources. This is followed by a detailed discussion of the results and conclusions.

2.0 RISK

The concept of risk has two elements: the probability (or frequency) with which a critical event† occurs and the specific consequences of its occurrence or its severity. After assessing the severity of a failure, together with the probability of its occurrence, a judgment can be made on whether the consequent risk is acceptable or not.

There is a tendency to present failures only in terms of severity and not the probability of occurrence (e.g.[2]; NASA shuttle flight software). The rationale behind this is that there is no doubt that failures will occur during the lifetime of the system component. The only question in such a situation is how severe those failures can be and what can be done to control or prevent them. In this context accidents are inevitable in any complex system[2]. Therefore, it is necessary to make decisions accordingly, rather than assume that accidents will not occur on the basis of low probability estimates. This model uses the catastrophic potential (i.e. severity) and cost of alternatives, but not the probability of occurrence itself.

This concept of presenting failures only in terms of severity is appropriate for fault management and development of contingency support. However, for the purpose of maintenance, infrastructure management, and overall system performance characteristics the emphasis is placed on probability of a piece of equipment failing in a defined time interval. Therefore, the area of system reliability recognises the need for defining both elements of risk, namely the probability of a critical event as well as its severity.

†A critical event could be defined as an error, failure, incident, accident, fatal accident, hull loss, etc.

3.0 THE ACCIDENT TO INCIDENT RATIO

A TLS expressed only in terms of accidents has two potential limitations. Firstly, the number of accidents is small for any adequate statistical analysis. Non-accident data, such as loss of procedural separation between aircraft in controlled airspace, is therefore necessary to establish the occurrence of any trends. Secondly, the number of accidents (or accident rate) is not necessarily the best measure of safety performance. For example, the currently used target of one accident in 10^7 flight hours demands the collection of operational data over many years to demonstrate whether the TLS has been met. A single accident may violate the TLS for a particular year, whilst many years without an accident will satisfy the TLS, but conceal any deterioration in safety prior to an accident[3]. In this context, past safety analyses (not only in aviation) have used the number of incidents together with the assumed accident/incident ratio. The United States Federal Aviation Administration(FAA)[4] cites several different analytical approaches. The two most common of these are discussed in the next paragraph.

In the 1940s, Heinrich introduced the idea of the existence of accidents where injuries did not occur, but considered only damage to property. This led to the creation of the so-called 'Heinrich pyramid' with established proportions of accidents, serious incidents, and incidents; 1:29:300[5]. After these initial studies, there was stagnation in the theoretical underpinnings of safety investigations until the practical work of Byrd in the 1970s. Byrd carried out his work in a steel factory and revised Heinrich's proportions to: 1:29:600[5].

However, whilst both of these studies are valuable in their statistical analyses, they do not seem to be appropriate in dealing with equipment failures in ATC, at least not in the ratios they offer. Both studies were designed to determine the risk and related ratio of on-the-job accidents and incidents. The reason for the weaknesses in both studies may originate from their design and in particular, the bias of analysing accident reports filed by supervisors only (which tend to blame injuries on workers); and much lower levels of equipment reliability and integrity compared to the systems used in ATC today.

For the purpose of this paper, additional attention has been given to the ratio between accident and incidents induced by ATC equipment failures. Throughout the literature, ATC equipment failures have never been recognised as a direct cause of any aviation accident; they have

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been classified only as contributory factors. However, classification of factors in aircraft accidents tends to be subjective[6], while the distinction between direct and contributory causes tends to be vague. As a result, organisations like the International Civil Aviation Organization (ICAO) and the National Aerospace Laboratory (NLR) of The Netherlands have moved away from the distinction between various categories of factors (i.e. direct, circumstantial, and contributing) and commenced to analyse all reported factors equally[6].

For the purpose of the research presented in this paper, it was necessary to define the ratio between aircraft accident and equipment failures. The aviation industry currently has strict requirements before releasing any new system into operation. The aim is to eliminate the majority of single-point failures. This safety through design concept is planned and exercised through several different principles that aim at hazard avoidance, elimination, and control. In line with the high reliability requirement for the overall ATC systems, as well as ATC equipment, EUROCONTROL assumes that one in 10,000 equipment failures will contribute to an aviation accident[7].

A number of arguments can be made to suggest that in future, this proposed ratio will decrease:

- The number of incidents might stay similar to current levels, but the probability of an incident leading to an accident should be even smaller due to increases both in equipment reliability and advanced solutions for redundancy and diversity (dissimilar redundancy).
- Changes should be seen in the type of incidents occurring. As a result of enhanced risk management approaches, serious incidents could be diminished.
- There should also be a decrease in the number of software-related incidents, which are prevalent even today. Hardware-related incidents should also slowly but surely diminish.

Note that although operational experience to-date may not necessarily backup the arguments above, they are based on a future expectation that there will be a step change in software and hardware reliability. This step change should come as a result of considerable operational experience, knowledge and expertise. Note also that the decrease in the number of incidents should only consider the steady state as captured in the 'bath tub' reliability model.

It has been highlighted that perception of risk only in terms of accidents tends to mask the actual safety issues. For this reason it is important to include the number of incidents so as to estimate the appropriate accident/incident ratio. Estimates such as the one given by EUROCONTROL on the ratio of equipment failures to aircraft accident, should be verified by actual operational data. Furthermore, any prediction using the data as a starting point should take into account the arguments given above for the expected decrease in the ratio.

4.0 UNITS OF MEASUREMENT

The rate of accidents represents the number of accidents divided by the exposure to those events. Aviation accident statistics are presented in the variety of ratios and units, called units of measure. The most frequently used are the number of accidents per operation (take off or landing), per million flight hours flown, per flight, per million departures, per million aircraft-miles, per million aircraft-hours, per million passenger-hours, and per million passenger-miles.

No single measurement gives a complete picture of the problem. Each of these units gives only one perspective, whilst possibly hiding others. For example, rates per million passenger-miles are most useful for comparing air transport and other modes of transport, whilst aircraft departures are suitable for comparison of accidents between small commuter jets and large commercial jets (e.g. B747). In addition, for the determination of the required performance of the landing aids e.g. Instrument Landing System (ILS) or Microwave Landing System (MLS), the only appropriate measure would be the number of landings per time period of interest. Any other measure would mask the true performance values.

In addition to the units of measure, accident rates are determined by the definition of the critical event as well. These critical events range from accidents, fatal accidents, hull losses, to the number of fatalities or injuries. An accident, as defined by ICAO Annex 13[8], involves an occurrence associated with the operation of an aircraft, which takes place between the time that any persons board the aircraft with the intention of flight and that all such persons have disembarked, in which any person suffers death or serious injury, or in which the aircraft receives substantial damage. This definition therefore comprises fatal accidents as well as hull losses. Thus, in dealing with various accidents rates it is crucial to be aware of the precise definition of both the critical event and the unit of measure used.

The rate of aircraft accidents per million flying hours has remained fairly constant over recent years. If the same accident rate is assumed for the future together with predicted increases in traffic levels, there will be an increase in the absolute number of accidents. ICAO has predicted that by the year 2010 there will be an aircraft accident per week, i.e. 52 accidents per year[9]. This is the reason why the FAA and other aviation authorities have recognised the need to significantly decrease the risk of aircraft accidents. For example, by 2007, the FAA plans to reduce US aviation fatal accident rates by 80 percent compared to the 1996 level[10]. The planned strategies to accomplish this objective are as follows:

- detailed analysis of the recurrent causes of accidents in order to prevent accidents before occurring through appropriate, targeted, systematic interventions in the aviation system;
- to create an environment for safe and secure exchange of data and information within the aviation community ; and
- to develop new approaches for certification, auditing, and inspection, while targeting FAA resources where they will do the most good[11].

This paper proposes a framework for derivation of aviation TLS based on the rate of aircraft accidents (defined as a number of accidents per flight hour). Accident is defined according to the ICAO, while the flight hour has been chosen as the most appropriate measure of risk induced by equipment failures. It is usually more convenient to work in terms of flight hours rather than operational hours of ATC unit or sector. This approach avoids difficulties and differences associated with the geographical coverage of the system(s) being considered, phase of flight, the density and complexity of airspace, as well as available systems and equipment (e.g. number of radars, navaids, and communication systems).

5.0 THE ACCEPTABLE RISK OR TARGET LEVEL OF SAFETY

Technology and engineering have brought numerous inventions and benefits to the modern way of life. While these benefits are welcome, the risks associated with them are not. The high pressure on the engineering world to reduce risk and increase safety comes at a financial price. Therefore, it is important to manage the trade-off between risk and the cost of its reduction.

As a result, there are certain degrees of risk that must be accepted. Determining the acceptable level of risk† is generally the responsibility of management and is based on several principles. These are: the objective to be achieved, the alternatives available, and the consequences and values that can be identified. Based upon this, the Target level of safety (TLS) is a quantified level of risk (or potential loss)

† Note the difference between acceptable and tolerable risk. Tolerability refers to a "willingness to live with a risk so as to secure certain benefits and in the confidence that it is being properly controlled. Tolerable risk, is not ignored, but is controlled and reduced further if possible. Crossing the street outside of the designated pedestrian crossing would be an example of the tolerable risk. On the other hand, acceptable risk means that we are 'prepared to take risk as it is'[13]. It should be noted also that acceptable risk is a relative term. It is possible to recognise different risk perceptions: individual, public (group of individuals), industry (industry usually needs additional pressure to declare a product as unsafe), and risk perception by safety experts. They all differ in the level of risk they are willing to 'accept'.

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that a system should be designed to deliver[12]. In aviation, the TLS is usually expressed as a number of aircraft accidents per flight hour flown, which is used in this paper (see previous section).

The concepts of TLS and risk budgeting are directly linked. Indeed, risk budgeting represents a top-down distribution of TLS (or total aviation risk) between the independent sub-categories. The logic behind this process is to specify the maximum acceptable risk for each sub-category, so that each one has to produce equal or lower risk than prescribed (see Figs 1 and 2).

There are several methods to derive the TLS[12]. In most cases, the analysis starts from the current situation and uses an improvement factor to derive the desired TLS. In some cases, this improvement factor may be established as a continuing trend from the past translated into the future. It should incorporate traffic growth factors, as well as factors representing changes in the systems involved, the operational procedures, etc. In other cases, it may be based on a common agreement between technical experts, with the main idea underlying it being to set challenging, but still realistic safety improvement targets.

The following sections provide an overview of the most relevant aviation TLS analyses. The level of diversity between these approaches highlights the complexity of the problem and the need for a consistent top-down total air transport system approach.

5.1 JAA derivation of aviation TLS

The Joint Aviation Authorities (JAA) document JAR 25 is one of the main regulatory documents in aviation, and defines the fundamental principles that govern aircraft design and certification. JAR 25.1309 defines the risk of a serious accident due to 'operational and airframe-related causes' to be in the order of one per million hours of flight. About ten percent of the number of accidents related to operational and airframe causes is attributed to aircraft systems failures (e.g. hydraulics and electrical systems) and the rest (90%) to other operational aspects[14]. A EUROCONTROL review of existing TLS standards and practices[15] highlighted that this requirement is based on data from the 1960s and as such is outdated. Furthermore, the JAR requirement is related to aircraft design, encompassing only the aircraft equipment, without consideration for other components of the air transport system (including ATM). Accordingly this JAR requirement needs to be informed with all the major changes in the aviation industry since the 1960s. The following paragraphs indicate several key factors that symbolise the changes and growth in aviation since that period.

There has been a rapid expansion in the air transport industry over the last four decades due to a number of factors, including growth in the world economy, advancement in flight technology and the deregulation of the airline services. The result of these forces has been a steady decline in airline costs and passenger fares, which has further stimulated traffic growth. As an example of economic growth, ICAO cites that there has been an increase in total gross domestic product (GDP) by a factor of 3·8 over the same period[16]. The GDP is considered to be the most appropriate available measure of world output and indicates the health of the global economy.

Changes in flight technology have also had a major effect on the growth in travel demand. The modern era of air transportation began in the 1960s. The major drive was the replacement of piston engines with jet engines, which was accompanied by increased speed, reliability and comfort. This change led to a reduction in operational costs, which in turn led to increased travel demand.

In addition to this, changes in the regulatory environment in both the USA and Europe have had a big effect. The deregulation of airline services in the United States in 1978 allowed airlines to improve services, reduce average costs, increase routes, and increase efficiency of scheduling. In Europe, the introduction of a single market for aviation services by the European Union in 1992 has seen similar changes to that seen in the USA.

The ICAO Manual on Air Traffic Forecasting[17] suggests three methods for forecasting future civil aviation traffic. These methods are trend projection, econometric analysis, and market and industry survey. Econometric forecasting is the only method that takes into account various economic, social, and operational factors affecting air traffic. The objective here is to translate the relevant factors into projections of future traffic growth. Then the traffic growth factors are reviewed further to incorporate prospective changes by other factors that are not accommodated in the econometric analysis.

The predicted traffic growth will influence target safety levels through the increase in the number of flight hours forecast. However, there are other factors, not necessarily included in this forecast of traffic growth, that have the potential to influence the level of safety. Some of these factors are: the growth in the total number of aircraft flying as well as in the passenger capacity of aircraft (e.g. Airbus A380, Airbus A350, Boeing 787 Dreamliner), increased airport and airspace congestion, technological development (e.g. advanced safety nets, satellite-based CNS/ATM), and pressure to find the tools to control and mitigate human error. Another important factor not considered is the increasing effect of environmental policies on aviation, in particular on air fares, costs, and restrictions to possible routes.

Therefore, it can be argued that the JAR requirement should be informed with an analysis based on an updated data sample of accident rates from the last four decades. At the same time, future predictions and regulations should be based on econometric forecasting, which will involve the effect of traffic growth as well as other economic, technical, and operational factors.

5.2 The UK CAA derivation of TLS

The UK Civil Aviation Authority (CAA) has calculated a worldwide fatal accident rate using the Worldwide Aircraft Accident Summary (WAAS) aviation database sample for the period 1990-1999 (Civil Aviation Authority, 2000). The CAA based its analysis on this sample and the following assumptions[18]:

- A fixed annual traffic growth rate till the year 2020 (i.e. 4% for western built jets),
- A constant number of fatal accidents per year (i.e. eight fatal accidents each year).

Based on these assumptions, the UK CAA predicted a rate of 1·8 E–7 fatal accidents per flight for the year 2020. For the purpose of this paper, this target has been translated into the rate per flight hour using the data available on the Boeing website[19]. The average flight in 1982 was about 1·4 hours, while in 2002 it was 1·94 hours. If this trend continues, the average flight in 2020 will be 2·43 hours. Using this assumption, the UK CAA's TLS for the year 2020 corresponds to 7·4 E–8 fatal accidents per flight hour.

5.3 ICAO derivation of TLS

There have been several attempts by ICAO to derive aviation target levels of safety. These originate from a number of the different studies and reports, which are presented below, from the earliest to the most recent.

a) ICAO North Atlantic Systems Planning Group (NATSPG)

The ICAO NATSPG initially developed a method using the rate of fatal accidents of jet aircraft back in the 1960s[15]. Their analysis was initiated by an estimated fatal accident rate of 2·34 E–06 and progressed to a TLS for collision due to loss of lateral separation (between 4E–08 and 1·5 E–08 fatal accidents per flight hour). The assumptions made in the NATSPG approach have not been explained in detail.

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Table 1
Summary of various analyses on TLS

Reference	Title	Database	Scope: Region/time period	Scope: Type of operation/ weight/type of accident	Target year	TLS
Joint Aviation Authorities	JAR 25.1309 Large Aeroplanes – Advisory Material – AMJ	Not specified	Worldwide 1960s	Serious accident	Not specified	1E–6 per flight hour
UK Civil	Aviation Safety Aviation	WAAS Review Authority	Worldwide 1990-1999 CAP 701	Jets & turbo props /MTOW>5,700t /fatal accidents	2020 MTOW>5,700t	1·8 E–7 per flight or 7.4 E–8 per /fatal accidents flight hour
ICAO	North Atlantic Systems Planning Group (NATSPG)	Not specified	Worldwide	Jets/1959-1966	Not specified	2·34 E–6 per flight
ICAO	Review of the General Concept of Separation Panel (RGCSP)	Not specified	Not specified	Jets/fatal accidents	2010	1E–7 per flight
ICAO	Annex 11	Not specified	Worldwide	*En route* fatal accidents	after the year 2000	5E–9 per flight hour per dimension
ICAO	All-Weather Operations Panel (AWOP) 15th meeting	Not specified	Worldwide 1959-1990	60,000lb/ Jets/MTOW> hull loss accidents	Not specified	1E–7 per flight hour

Key: MTOW = maximum take-off weight of the aircraft.

b) ICAO Review of the General Concept of Separation Panel (RGCSP)

In 1995, the ICAO RGCSP reviewed several approaches to deriving an ATM related TLS. This Panel assumed a total accident rate from all causes to be 1E–7 per flight hour, based on the previous NATSPG analysis and extrapolation to the reference year 2010[15]. Additionally, the panel proposed that the fatal accident risk, from all causes, should be 5E–09 per dimension (i.e. lateral, longitudinal, or vertical). This TLS is indicated in the latest version of ICAO Annex 11[20].

c) ICAO Annex 11

In the situation where 'fatal accidents per flight hour' is considered to be an appropriate metric, the ICAO Annex 11[20] proposes that a TLS of 5E–9 fatal accidents per flight hour per dimension should be applied for determining the acceptability of future en-route systems that will be implemented after the year 2000.

d) ICAO All-weather operations panel (AWOP)

The objective of the ICAO AWOP was to assess the required navigational performance (RNP) for approach, landing, and departure phases of flight[21]. Based upon historical data , ICAO's calculation determined the average hull loss per flight to be 1·87 E–6 or 1·27 E–6 per flight hour (using the same data set, the average flight is calculated to be 1·47 hours). Based on this historical data, ICAO proposed a TLS for the average flight hour to be 1E–7. The rationale for this risk improvement over the historical accident rate is the removal of pilot errors by the use of glass cockpit aircraft and the tunnel incident alarm. The glass cockpit is a system of electronic displays representing all the information regarding the aircraft's situation, position, and progress. The tunnel incident alarm is an alert that is triggered if the aircraft unintentionally leaves the assigned flight path, the 'tunnel', during the approach or landing phases of flight. Additionally, the objective in aviation safety is to reduce the number of accidents despite increasing flight hours. This is essential if public confidence in aviation is to be maintained as the global air transport system keeps expanding.

6.0 SUMMARY OF THE VARIOUS TLS ANALYSES

The previous section has given an overview of the research on aviation TLS which is summarised in Table 1 (based on the information available). This table enables comparison of the TLS taking into account the source of data, the time period covered by the data set, the type of accident, the type of aircraft operation, and the TLS unit used.

Once again the differences in the derivation of TLS should be pointed out. The summary presented shows the level of discrepancy in the method, data set, and taxonomies used. The major factors that drive the differences in the calculation of target levels of safety are:

- type of accident (accident, fatal accident, hull loss),
- weight of aircraft involved in the accident,
- differences in the definitions (i.e. taxonomies used),
- type of operations analysed: scheduled *vs* non-scheduled, commercial *vs* non-commercial (military, freight, general aviation), registered *vs* non-registered, domestic *vs* international,
- type of aircraft included: jets vs. turbo props,

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- time frame of the data set analysed,
- source of the data,
- region involved in the analysis (with or without former Soviet Union),
- targeted year for the TLS calculation: current vs. future levels.

After the review of the most relevant analysis and methods of TLS calculation, the TLS of 1E–8 accidents per flight hour will be used as the baseline for the year 2020 (target year of the research presented in this paper). The reasons for using this baseline are:

- the rate of 1E–07 is currently used as a target by ICAO for both fatal accidents and hull loss accidents (see Table 1);
- with the overall aim of reducing the accident rate by 80% over a ten-year period[11] and given the current safety targets, it is reasonable to aim at 1E–08 accidents per flight hour in the year 2020;
- The analysis conducted by the UK CAA to predict the role fatal accidents for 2020 (i.e. 7·4 E–8 fatal accidents per flight hour).

After the derivation of an overall aviation TLS, the next step is to proceed with the allocation of risk to each sub-component of the air transport system. The aim of this research is to analyse equipment failures in ATC, thus the remaining sections will focus on the relevant risk budgeting for ATC equipment. This process will be informed by the available literature and historical data, while taking into consideration current and future trade-offs between various components of the overall air transport system.

7.0 ATM AND ATC CONTRIBUTION TO AIRCRAFT ACCIDENT

The next step is to determine the risk budget allocation for the ATC system as a component of the overall air transport system, i.e. determine the contribution of ATC. According to the results of the UK CAA's analysis, the contribution of 'ATC and ground aids, to aircraft accidents is 1·7% (Table 14[18]).

EUROCONTROL currently uses 2% as a maximum direct contribution of ATM to aircraft accidents within the European Civil Aviation Conference (ECAC) region. Based on its analysis, EUROCONTROL has defined 'the maximum tolerable probability of ATM directly contributing to an accident of a commercial air transport aircraft' in ECAC region to be 1·55 E–8 per flight hour[22].

In the Netherlands, a study by the NLR on aviation accidents[6] determined that ATM-related accidents represent 8% of the total number of accidents. Additionally, 28% of these ATM-related accidents are directly caused by ATC, which makes the ATC contribution to aircraft accidents approximately 2·2%. The difference in the contribution of ATC in these two studies is due to the difference in classification of causal factors. While the UK CAA analysis divided all underlying factors into primary, causal, and circumstantial groups, the NLR analysis followed the recommendation by ICAO and did not use this distinction. The NLR study considered an occurrence as a causal factor only if that occurrence was part of the chain of events leading to the accident. The NLR approach seems to reflect better the aim of determining the overall ATC contribution to aircraft accidents.

The results presented need to be augmented for possible statistical error and uncertainties linked to the reporting processes as well as to provide additional protection for the future. As an example, EUROCONTROL used this as a basis for the 0·9% allowance in the calculation of the ATM safety targets for ECAC region[23]··. Having this in mind, together with the results from UK CAA and NLR studies, this paper uses a maximum contribution of ATC of 3%. Thus the rate of aircraft accidents assumed for the year 2020 as a result of ATC is considered to be 3E–10 per flight hour. Now, after deriving the TLS for ATC specifically, this functional block should be divided between human operators, equipment and procedures. This approach now gives the opportunity to define the appropriate risk induced by ATC equipment which is presented in the next Section.

8.0 ATC EQUIPMENT CONTRIBUTION TO AIRCRAFT ACCIDENTS

It is important to determine the contribution of equipment (or their failure or malfunction) to the ATC risk budget. The historical data on the proportion of incidents in which equipment failure is implicated varies to a certain degree. Interviews with system control staff in two European ATC centres , as well as the approximation used by the CORA 2 documentation[7] reveal that equipment failures are the causal factor in 0·01 or one percent of all incidents. However, these assumptions are based on an overall aviation context and not ATC only.

On the other hand, the study by NLR[6] determined that the particular causal factor 'ATC ground aid malfunction or unavailable' has been attributed to 5% of all ATM related accidents or 18% of all ATC related accidents. It should be noted that this causal factor includes 'unavailable' ATC equipment meaning equipment that was taken out of service by ATC staff, presumably for maintenance reasons. In addition, the research was based on data samples that incorporated older systems with lower levels of automation. Future systems are shifting more towards a higher level of automation, as well as higher reliability.

Therefore, it can be approximated that equipment failures represent the causal factor in 10% of all ATC related accidents (or 3% in all ATM related accidents). This is based on the assumption that unscheduled failures constitute about 50% of the failures in the NLR analysis above. This approach derives a risk of 3E–11 per flight hour flown. The reasoning presented seems to correlate with the widespread argument that human error represents the causal factor in 70-80% of all accidents[24]. A graphical representation of the determined risk budgets is given in Fig. 2.

9.0 ANALYSIS OF OPERATIONAL FAILURE REPORTS

An analysis of operational reports from incident databases has been conducted to corroborate those derived from the literature. The incident reports used were from two Civil Aviation Authorities (the aviation safety regulators), presented as Source A and Source B, and for the periods 1999 to 2003 and 2002 to 2003, respectively. In addition, available accident statistics for the same period have been used to calculate appropriate accident rates.

It is important to highlight that the time period studied, 1999-2003/2002-2003 for both countries could be considered steady (uniform) with respect to the ATC service provided and other aviation related factors (e.g. traffic levels, jet fuel prices, airline fares, regulations). Therefore, the average number of incidents and accidents reported in this period could be considered representative and appropriate for further analysis.

This data analysis consisted of several processing phases: collection of reports, extraction of incidents involving only equipment failures which required the intervention of the controller, and further classification according to the ATC function affected. A critical part of the whole process was to prepare the data for a meaningful analysis. This step in the processing chain dealt with several problems: the lack of consistent reporting schemes, ambiguous reports, different taxonomies, and differences in the characteristics of the equipment and the relevant automation level. As a result, the analysis presented in this paper involved a total of 1,089 reports from which 991 were due to equipment failures. The rest were mainly composed of non-ATC equipment, as well as other non-technical types of incidents.

The final results of this process are presented in Table 2. The average number of failures is calculated for both data sets. This is followed by the calculation of the incident rate based on the average flight hours flown for the given time periods. The final step involved adjustment of the calculated incident rate to give the probability of an

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Table 2
Analysis of operational failure reports and results

Source	Year	Total number of equipment failure reports	Scope: Average per year	Rate of failure) incident (per flight hour flown)	Assumed rate of failure – accident (per flight hour flown
	1999	71	121	8·80 E–05	8·80 E–09
	2000	101			
A	2001	114			
	2002	198			
	2003	121			
B	2002	223	193	2·07 E–04	2·07 E–08
	2003	163			

accident caused by equipment failure (using the accident to incident rate of 1 in 10,000). In other words this calculation produced the operational level of safety for two countries and two respective time periods.

Finally, the total number of commercial aircraft accidents for the same time periods have been extracted from the available aviation statistics. These figures have been divided with the actual flight hours flown in each country to determine the 'total' accident rates. These rates ranged between 4E–06 and 8E–06 aircraft accidents per flight hour for the period 1999-2003.

10.0 DISCUSSION OF THE RESULTS

The previous sections described the process of deriving an overall aviation TLS for the referent year 2020 and further risk budgeting for ATC equipment. In order to support these predicted levels, available operational reports for the period 1999-2003 have been analysed and extrapolated to the levels for the year 2020. In general, the results showed a degree of agreement, as shown below.

Firstly, it is important to discuss the overall results for the current period. The UK CAA study calculated a worldwide rate of fatal accidents per flight for the year 2000. For the purpose of this paper, this rate was translated into a rate per flight hour and approximated to 1E–06 per flight hour[18]. Similarly, accident rates for the two countries analysed were slightly higher than the worldwide average (ranging from 4E–06 to 8E–06 aircraft accidents per flight hour).

Having the accident rate for the year 2000 and predicted accident rates for the year 2010 (1E–07[12]) and 2020 (1E–08, used in this paper), it is apparent that future safety levels are predicted to improve tenfold every decade. This is in line with the attempts of various aviation institutions to significantly improve future aviation safety levels (e.g. FAA, ICAO).

The next step is to use the established rate of improvement and apply it to the ATC equipment failures. Using the same analogy and the ratios within an air transport system, as presented in Fig. 2, it is possible to translate the 2020 rate of ATC equipment contribution to aircraft accident to the present levels (i.e. 2000). The calculation presented in Section 8 showed that for the year 2020 this effect is of the order of 3E–11 per flight hour. Using the reverse logic, this effect equals to the level of 3E–09 for the year 2000. Therefore, we can conclude that the predicted level of ATC contribution to aircraft accidents conforms to the levels acquired from the operational reports, as shown in the last column of Table 2.

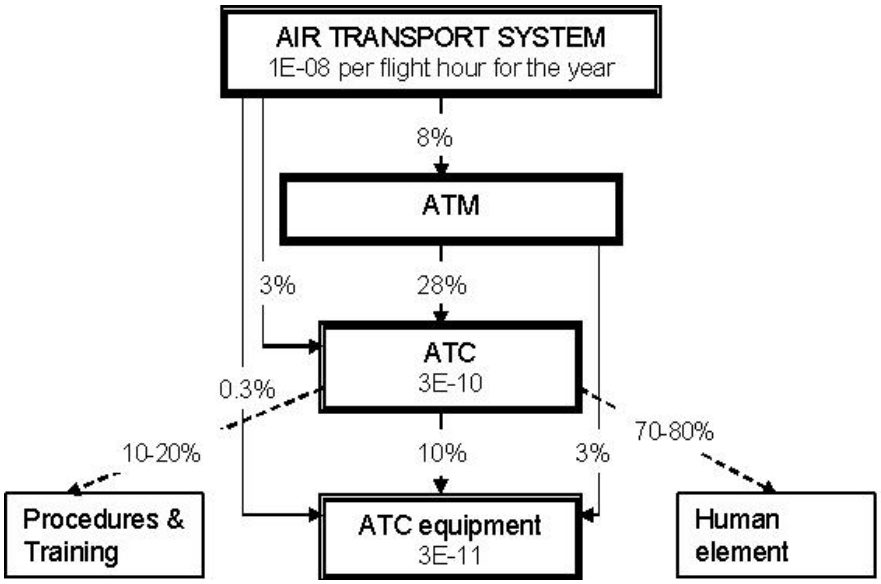


Figure 2. Aviation TLS and risk budgeting.

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11.0 CONCLUSION

The aim of this paper was to provide an overview of the current understanding of TLS for the air transport system. The available literature showed that aviation currently does not have an agreed integrated approach for the determination of the overall TLS. This paper has suggested one possible approach and exercised it on the example of one sub-component, namely ATC equipment. In other words, this paper focused on the determination of the maximum allowed accident risk imposed by ATC equipment for the target year 2020. The process was based on the available literature supported by operational reports dealing with ATC equipment failures.

The data analysis and related discussions showed that the 'total system' approach is feasible. Even higher levels of conformity would be achieved with better tuning of the current and future trade-offs within the air transport system (Fig. 2). The future advancements in technology, changes in the levels of traffic, and overall changes in the ATC/ATM philosophy (e.g. shifting of separation responsibility from the ground to the air) have a potential to improve safety. At the same time it is reasonable to assume that the distribution of the levels of risk within the air transport system will change. The results specific to ATC given here should be used as an input to a complete safety analysis that should consider trade-offs between the various components of the aviation system to realise risk budgets for a safe and cost effective system.

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