Abstract –

The paper seeks to highlight the challenges facing the aviation industry in the need to better understand and predict operational risk. It looks at the types of data available to improve the understanding of risk and discusses the need to bring it together using a common risk ‘currency’. The relationships between the different types of data are briefly addressed in regard to both understanding the current level of risk and predicting what it will be in the future. The conclusions are that a more comprehensive view of risk is required and that the fusion of incident based data together with risk exposure data provides a method for achieving this. The paper highlights the potential for future aviation regulation to be risk reduction based. The paper has been generated as a result of effort being undertaken at NATS to understand risk, but reflects it from a whole aviation viewpoint.

Keywords: aviation safety, operational risk, data association, risk assessment.

1 Introduction

Despite unparalleled growth in aviation, the industry has maintained a steady decline in the number of accidents each year [1]. The reasons for this success are widespread, but undoubtedly the collection and intelligent use of safety data has been a key factor.

The collection and intelligent use of safety data has been a cornerstone in the management of safety in aviation. Over the last decade aviation has developed extensive processes for the collection of safety data and varying levels of capability for its analysis. Analysis of this data has led to a number of organizations adopting measures for the monitoring of safe operations.

NATS, like others in the aviation community, are always looking to make the business safer and in doing so have recognised the need to have a more cohesive view of operational risk. With the ever increasing demands of capacity and environment, there is a need for operational risk to become an equitable partner in the debate.

Through the development of its ‘Strategic Plan for Safety’ NATS has endeavored to generate predictions on future risk within specific topic areas. This work has focused on trying to predict the effect of system improvements and has highlighted the need to better understand the interactions between an array of operational risk information.

This purpose of this paper is to describe the challenges that the aviation industry faces in the better understanding and prediction of risk. The paper attempts to outline the activities that NATS is working on in this field and to encourage the industry in joining together to meet the challenges it highlights.

2 The challenges

As safety within the industry has improved, the availability of simple lessons from accidents and incidents has reduced. To sustain the successful safety trend the industry has had to increasingly focus on the wider and lower level sources of safety information.

There are a plethora of safety related data sources that are available which could, and often do, guide the management of aviation risk. Where they are used to make risk decisions it is generally in an individual and isolated way and without a clear understanding of their relative importance. The problem to those with a high level responsibility for ensuring aviation safety is to identify the highest priorities to ensure that they are using resources effectively.

The challenge this sets the industry is to bring this complete range of safety related information together in a cohesive way to better understand and manage its risks. To achieve this requires the data to be fused together through a common understanding of the represented risks and their relative importance.

The value of such an understanding of risk within an organisation is clear in that it will enable better informed decisions in the management of risk. There is however a much wider benefit to the aviation community if a common understanding of risk can be developed.
The ever increasing integration of aviation systems demands a more effective understanding of risk across the aviation environment. Decisions taken in one organisation or one part of the domain have an increasingly significant impact on risk within other parts of the industry. It is only through a common understanding of this overall risk that those decisions can be made in an informed way.

Ultimately this leads to opportunities to manage the regulation of aviation in a different way. A common understanding and view of risk provides a measure to ensure that the aviation system is controlling its risk and is making changes that contribute to an overall risk reduction.

The greatest value from collecting historical safety performance data has to be in using it to look forward, to predict what the risk will be in the future. Risk prediction today is often at the level of looking at trends of safety information and assuming those trends will continue. This however does not recognise the many variables that affect safety performance and does not enable effective prediction of the affects of changes to the system. Efforts to make better predictions of risk have highlighted the need to understand the complex relationships between a wide range of data.

3 Types of Data
To better understand the challenge of generating a cohesive picture and prediction of risk requires consideration of the range of data available.

3.1 Incident data
Incident data has always been the core to the aviation industry's understanding of risk. Incident, or event based data, is data that is generated on the basis of something having occurred that is, or could be, an indication of the unsafe operation of the system. Incident data can be considered in three main categories.

3.1.1 System generated data
System generated data can be characterised by information that is captured automatically as the operation progresses. It does not require human intervention to ensure that an event is captured and can therefore be considered as highly reliable. Aviation has pioneered the automatic collection and analysis of a wide range of data, most significantly that of the aircraft flight data [2]. In the air traffic service field there is a wide range of data gathered automatically from the radar and radio systems. Examples include: aircraft separation monitoring, aircraft conflict alerting, unauthorised airspace incursion monitoring and radio frequency congestion monitoring. In addition the increasing use of automated and complex systems brings with it a significant amount of data on system availability or performance.

Assuming the integrity of the systems used to generate these data sets are robust, these data sources can be considered to be reliable and unbiased in their view of the performance that they are measuring.

3.1.2 Human reporting data
Aviation has been at the forefront of open reporting systems, encouraging employees to report incidents and occurrences [3]. Processes have been put in place to allow and encourage employees to report safety related events. The data this generates is obviously dependent upon the specific requirements for reporting, but is also significantly impacted by a number of other factors.

The factors affecting human incident reporting data have been well analysed but need to be carefully considered when generating an overall view of risk [4]. A view of risk based on purely incident reporting data is only the risk that is made visible by the employees reporting it. The factors effecting the reporting of incidents can be significant and therefore obscure the real picture. In essence you are only measuring the risk that the employees choose, or are able, to report. Ultimately you don’t know what you don’t know.

Clearly a group of employees with a mature safety culture should provide a good level of reporting, however that will still be influenced by personalities, organisational politics and the physical difficulties in producing the reports. Key factors to consider are the barriers to people reporting as requested, particularly the difficulty of reporting and the disinclination to report due to a culture of blame, or perceived blame, within the organisation [5].

The data provided by employees reporting errors or system deficiencies is extremely valuable and provides probably some of the best risk information available across aviation as a whole. It is therefore important to consider ways to overcome the barriers to reporting and to maximise the value from this data set. Possibilities for the simplification of reporting include simple event capture methods, where an employee makes a simple data entry to ‘flag’ a particular event. Although such a method does not provide the richness of data available in a written report, the improved coverage could significantly outweigh that loss.

3.1.3 Sample data
Aviation makes extensive use of auditing to ensure the safe adherence to procedures designed to control risks. These audits provide a valuable indication of conformance within the organisation and are used to control risks, however they are rarely used to provide a better
understanding of risk. Among other things an audit is likely to identify events and occurrences that could, but may not, form part of the reported understanding of risk. An audit however is only a sample of the performance of a particular part of the system and therefore to use it to understand overall risk requires extrapolation across the system. Obviously there are a number of factors that influence how the findings in one area/time period relate to another, but if understood then they can be used to enhance the view of risk.

On a lower level there are other forms of sample data that again provide opportunities to inform the view of risk within the industry. The implementation of LOSA (Line Operations Safety Audit) and other human performance observations provide a rich source of safety information that need to become part of an organisation’s understanding of its risk.

### 3.2 Risk exposure data

Although incident or event based data has historically been the mainstay of understanding aviation risk, there are other data sets that are significant in determining the overall risk to aviation. In its simplest form this may just be data that measures how often you perform an activity that is exposed to risk. It will however also include data that has a much more complex relationship to the resultant risk.

Traditionally some forms of exposure data have been applied in a simplistic way to analyse their effect. For example if a certain type of event tends to happen every X flight hours then an assumption may be made that it continues to happen on the same relative frequency as the number of hours changes. In many cases this simple relationship may be valid, or at least a useful approximation to use. In other cases however the relationship may be much more complex, where for example an increase in flight hours creates a disproportionate increase in human workload or decrease in human performance.

There is potentially a vast array of potential exposure information that could be of use in informing the understanding of risk. The following table provides an idea of some of the data that might be available to consider in an air traffic management environment.

<table>
<thead>
<tr>
<th>Traffic levels</th>
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<tbody>
<tr>
<td>Staffing levels</td>
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<tr>
<td>Employee experience and training</td>
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<tr>
<td>Types of traffic &amp; complexity</td>
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<tr>
<td>Visibility conditions</td>
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<tr>
<td>System availability</td>
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<td>System accuracy</td>
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<tr>
<td>RF frequency usage levels</td>
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<td>Safety culture of the employees</td>
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</tbody>
</table>

It is only through understanding the relationships between the data and risk that it can reliably be used to inform the understanding of risk. Without that understanding there can be no clear understanding of how much impact one factor has compared to another. With such a wide range of data the relationships involved are going to be complex and difficult to accurately model. It is however likely that simplified relationships could be defined to ensure a wider and more effective understanding of risk.

Historical comparison will likely provide some explanation of the relationships but a fuller understanding may come from the perceptions of those directly involved in the operation. Their perceptions of how the data relates, although not necessarily complete, provide an excellent basis for defining a high value relationships.

Another option may be to consider a ‘perfect’ steady state condition, one where the level of none of the factors identified gave cause for concern. Any deviation from the ‘perfect’ state can then be considered as an event and treated as described in section 3.1. The difficulty here is that incident data generally consists of discrete events that can have a risk associated with them. A deviation from the norm can however be a prolonged situation and so does not easily lend itself to the same type of analysis. Despite the potential drawbacks of such an approach, there is merit in examining such approaches in more detail.

### 3.3 Risk mitigation effectiveness data

In a complex and high risk system such as aviation there are many risk mitigation measures (barriers) put in place to control risk. These measures are designed to ensure that events that do occur do not develop into the serious incidents and accidents that the system is aiming to avoid.

It is debatable whether the measures of effectiveness of these barriers are any different from the measures of exposure factors described above. In essence this probably depends upon how the barriers are considered in the system context. Not withstanding this, performance data for barriers will be a valuable source of data in the overall cohesive understanding of risk.

### 4 Common understanding of risk

To allow the wide sources of aviation safety data to be used in an inclusive way requires a common understanding of how they relate to each other.

The FAA (Federal Aviation Administration) has been working on ways to combine multiple sources of aviation safety data [6]. The approach here has been to use expert judgment to provide a relative weighting to the different data sources to enable them to be plotted on a common
This approach makes a significant step in bringing data together to provide a common view and enables those responsible for managing risk to see the trends of a range of data in a comparable way. The drawback to such an approach is that the simplification of the relationship between the data sets on the basis of their source may hide the relative risk that individual data points represent.

An alternative approach is to identify each piece of data with a common, and measurable, safety ‘currency’. Once the data has a common ‘currency’ the relative importance of each piece is predefined when they are combined.

Safety has been described as a construct and a concept [7] and is therefore not a finitely measurable indicator. Risk, defined as the measure of probability and impact of an incident, is however a generally accepted quantifiable measure. Although not necessarily comprehensively defined across the industry, it is used to assess and monitor safety performance [4]. The definition of risk as adopted in this work is based upon the latest ICAO thinking and is; the assessment, expressed in terms of predicted probability and severity, of the consequence(s) of a hazard taking as reference the worst foreseeable situation.

The agreement and assignment of that risk value to safety data is a major subject that would merit a paper in its own right. It is however worthwhile covering it briefly in this paper so that the difficulties in applying it to a wide range of safety data can be seen.

4.1 Risk assignment concept

There is a range of risk weighting concepts and risk matrices in use across the aviation industry [8]. The outcome of work to review these different approaches has been to formalise one approach that attempts to overcome the many drawbacks identified in the process [8]. In summary the proposal is to ask three discrete questions about the event you wish to risk rate:

a) What could have been the likely worst case outcome of this event?

b) What barriers were effective in ensuring that the event did not reach the likely worst case outcome?

c) How often would this event be likely occur?

The response to these three questions places the event at a particular place in a risk matrix.

In the context of the analysis of the resulting risk data, as described in this paper, the question regarding frequency is not required. Individual events can be rated for their own individual risk contribution; the contribution due to their relative frequency is addressed by the summation of their individual risks. The use of a frequency in the assignment of individual risk leads to a distortion of its overall contribution to risk when the individual events are combined.

To overcome this problem, the proposal is to use only a two dimensional matrix with questions about the potential outcome and the barriers to prevent that outcome. An example of such a matrix is shown in figure 1.

Figure 1.

This matrix provides the framework on which to assess the risk of any incident or event on a similar scale. The selection of a row and column based upon the answers to the questions raised provides for a risk category (A to E) to enable the incident to be prioritised. To enable it to be used in a number of different domains within aviation, for example for aircraft operators, air traffic service providers and airport operators, guidance can be given for each category that matches the types of events and risks that manifest themselves in that domain.

The risk category enables prioritisation and qualitative analysis to be performed. To enable quantitative analysis each of the risk categories can be numerically weighted to allow it to be combined to give an overall risk value [4]. An example set of risk weightings is shown in figure 2. In this example matrix an A risk event is worth 100 and an E risk worth between 1 and 10 depending upon its location in the matrix. These values are examples and would need to be adjusted through statistical and expert analysis.

Figure 2.
5 Data relationships

5.1 Current risk

The application of a common risk ‘currency’ to all your available sources of risk data provides a means to generate one view of the current, and historical, level of risk. The incident data that forms this view can either be taken as it stands and accepted as a partial view, but one based on all the available risk data, or could be extrapolated to provide a fuller view of the risk across the organisation.

As highlighted in section 3.1.2 human reporting data is subject to a number of pressures and issues, not least of which is the reporting culture of the employees who are expected to raise the reports. Employee safety culture assessments provide one indication of that culture [9] and could therefore be used as a factor to overcome low or unreliable incident reporting rates within particular parts of an organisation.

Data on events that is obtained as part of a sampling activity also requires extrapolation to give a better view of overall risk within the organisation. To do such extrapolation requires an understanding of the relationship that the event has to the types of exposure data available. In its simplest form that relationship could just be a direct relationship between the number of reported events and the overall quantity of the activity being undertaken. For example the number of misheard radio transmissions could be considered to be directly proportional to the number of flights, number of flight hours, or perhaps most appropriately the number of radio transmissions made. It is however likely that the true relationship is far more complex, involving such things as the experience of the controller and pilot, levels of interference on the system, workload and the native language of the parties involved. There is however a compromise needed to allow optimum use of the information that is actually available. It may be that using the rate per flight hour is the best extrapolation available and to do this is better than not extrapolating the data at all. If further data could be made available to improve the correlation then that may be worthwhile but there is clearly a limit to the value of the complexity of the process used to provide a view of risk that can never be entirely accurate.

5.2 Predicted risk

There is clearly much to be gained from the fusion of historical safety data in the understanding of risk. The main benefit however comes from using that fused data to predict risk and, more importantly, to predict risk as a result of changes to the system. An historical review of risk data often reveals trends that do not purely match those to be expected relative to the simple exposure factors that are traditionally considered. Clearly there will be a degree of random exposure to events that no tool will be able to predict, but with a wide base of risk information the random effects should be minor compared to the underlying risk trends.

The challenge this creates is in identifying how the risk indicators are influenced by the more complex sources of exposure data. It will be through the understanding of the complex relationships that exist between historical safety data and risk exposure data that predictions will be possible.

In the every day operation the people involved are constantly making risk judgments based on their understanding of the factors that affect it. They are in a small way making safety predictions based on their expert judgment of the situation. If that understanding could be captured, along with the data on which they base those decisions, then the process could be repeated to allow a longer term quantitative prediction of risk to be made.

The complexity of the relationship and the availability of comprehensive exposure data is again likely to be a limiting factor in any such approach. The data that may be available real-time to those managing risks on a day to day basis may not be available in an historical and reliable format. There will however be a significant pool of exposure data that will be available, as per the example in section 3.2, and the fusion of it to allow its optimum use needs to occur. If the decision making process in the operational environment relies heavily on other sources of information, there may well be merit in attempting to capture it to improve the understanding of future risk.

5.3 Describing future system changes

Once the relationships between the data sources and resultant risk are understood, to be able to predict the change in risk from a future change, requires that change to be described in ways that reflect those relationships. For example a system change to an air traffic management system would need to be described in ways that are part of the risk understanding, for example through the decrease in workload, or the increase in a particular type of interaction that carries risk. Clearly to be able to describe changes in this way will involve detailed expert understanding of the change and how it effects the operation. However if the risk is measured in a way that reflects the user’s understanding of their risks, then the step of describing changes in that way is a logical one.

A further advantage of this approach is that by describing the benefits of the change in the same terms which are used to measure risk, the resulting effect can be measured. This then facilitates and effective feedback mechanism for the monitoring of risk improvements.
6 Regulating risk

The aviation environment is one of tight safety regulation. Changes to the aviation system require careful review and demonstration that they meet agreed regulatory requirements. These requirements are however generally domain orientated and described as to meet certain risk probability goals. Such an approach does not necessarily enable the most effective management of risk within the aviation environment.

The regulation of safety within European aviation is controlled by various different organisations responsible for different parts of the domain. For example aircraft design and operation is regulated by the European Aviation Safety Agency (EASA) but air traffic service provision is regulated by individual state regulators. Such an approach makes the coordinated management of overall aviation risk difficult; however there are proposals to bring all the regulation together under EASA.

As the aviation regulation process becomes more coordinated the ability to regulate the overall industry on the basis of risk reduction becomes an exciting possibility. CANSO (Civil Air Navigation Services Organisation) has identified ‘Prescriptive, excessively complex safety Regulation’ as one of the issues that the aviation industry faces and has set a goal for ‘Simplified, performance based safety regulation covering the whole aviation chain.’ [10].

The present certification processes require changes to be assessed on how they, once implemented, achieve certain probability goals. For example in very simplistic terms they might require that the probability of a catastrophic accident is less than one in 10 million flight hours. The problem with this approach is that assessing probabilities as low as this is very difficult, but more importantly that it doesn’t necessarily take into account the state of the system as it is now.

If the risk of aviation is widely understood and measured then an alternative approach to regulation can be considered. Changes to the system could be described in ways that reflect the data set used to measure the risk at the present time and therefore their effect on future risk can be predicted. This would enable the certification of changes on the basis of the positive reduction in risk to aviation that they provide.

The major benefit of such an approach is that it would allow the aviation system to develop and continually reduce its risk rather than trying to achieve goals that may not reflect the actual present performance of the system. The other significant benefit that it brings is that it enables the effect of changes to be monitored in a way that can determine their effectiveness and the accuracy of their predicted performance.

7 Conclusion

It is well recognised that aviation has been successful in using safety data to manage its risks. Notwithstanding this, the challenges that face the industry through growth and increased integration mean that improved ways to understand and predict risk are required.

A more comprehensive and unified view of risk throughout the industry would benefit the effective and efficient management of risk. To provide this requires both a common understanding of risk and also an understanding of the complex relationships that exist between the many types of safety and risk exposure data that are available.

The common understanding of risk is an area that is under much consideration in the industry and there is widespread recognition in the value of a simple common process to allow comparable risk data to be developed. That common risk understanding not only needs to work across varied types of incident data but also varying sources of data across the industry.

The data relationships that will allow the wide range of safety data to be fused together will be complex and diverse. They will need to be determined from both data analysis and expert opinion to allow models to be developed for the data to be combined. Inevitably compromises will be required between complexity and achievability, but the overall goal will need to be one of making the best use of data available.

With a cohesive view of risk based on the incident and exposure data available, the greatest value will be to use that data to predict future risk. To do this will require changes to be described in ways that can be applied to that fused risk data set so that their effect can be predicted.

Ultimately such an approach opens up new possibilities for the future regulation of aviation safety. The present methods of goal based regulation could be replaced with regulation based on ensuring aviation risk reduction.

NATS is pursuing efforts in all the areas outlined in this paper and welcomes input and coordination with other interested industry partners.

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References


