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AUTHORS	DATE	PP	REF
G.W.H. van Es	February 2002	17	

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ABSTRACT

The commercial aviation industry provides the safest form of transportation in the world. Nevertheless the pressure for continued improvement in safety will remain in response to the predicted growth in both passenger and freight traffic volumes. One of the most important tools to improve the safety of flight operations is to have a Flight Data Monitoring program implemented. Such a program obtains and analyses data recorded in flight. The prime objective of such a program is to detect deviations from flight manual limits and standard operating procedures. The use of flight data for these purposes employs only a very small fraction of the data generated by the on-board recorders. Every routine flight generates an enormous amount of data that are never used. The analysis of routine flights introduces a wide range of new possibilities and problems to airlines. This paper describes the activities of the National Aerospace Laboratory NLR regarding the development of techniques and ideas for analysing routine flight data. Based a number of real-life examples a comparison is made between traditional flight data analysis and advanced flight data analysis. Ideas for correlation of flight data with other available data sources are discussed. It is concluded that the extension of monitoring flight exceedances to the day-to-day data analysis of each flight is important to the goal of continued improvement in aviation safety. Even more can be expected from the correlation and analysis of human factor data and environmental data with flight data up to the level of day-to-day operations.

Nationaal Lucht- en Ruimtevaartlaboratorium
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G.W.H. van Es

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Summary

The commercial aviation industry provides the safest form of transportation in the world. Nevertheless the pressure for continued improvement in safety will remain in response to the predicted growth in both passenger and freight traffic volumes. One of the most important tools to improve the safety of flight operations is to have a Flight Data Monitoring program implemented. Such a program obtains and analyses data recorded in flight. The prime objective of such a program is to detect deviations from flight manual limits and standard operating procedures. The use of flight data for these purposes employs only a very small fraction of the data generated by the on-board recorders. Every routine flight generates an enormous amount of data that are never used. The analysis of routine flights introduces a wide range of new possibilities and problems to airlines. This paper describes the activities of the National Aerospace Laboratory NLR regarding the development of techniques and ideas for analysing routine flight data. Based a number of real-life examples a comparison is made between traditional flight data analysis and advanced flight data analysis. Ideas for correlation of flight data with other available data sources are discussed. It is concluded that the extension of monitoring flight exceedances to the day-to-day data analysis of each flight is important to the goal of continued improvement in aviation safety. Even more can be expected from the correlation and analysis of human factor data and environmental data with flight data up to the level of day-to-day operations.

Contents

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1 Introduction

The commercial aviation industry provides the safest form of transportation in the world. Nevertheless the pressure for continued improvement in safety will remain in response to the predicted growth in both passenger and freight traffic volumes. Therefore, the accident rate must be reduced in order to prevent the absolute number of accidents to increase. The number of aircraft in commercial service is expected to double by the year 2015. Thus there is an imperative to constantly improve safety just to remain with the same number of accidents. This has resulted in a number of initiatives for safety improvement throughout the aviation sector.

One of the most important tools to improve the safety of flight operations is to have a *Flight Data Monitoring* FDM program implemented. Such a program obtains and analyses data recorded in flight. The prime objective of such a program is to detect deviations from flight manual limits and standard operating procedures, which can be precursors to hazardous events. On basis of the analysis of flight data airlines can take corrective actions to eliminate or to reduce the frequency of occurrence of these accident precursors. In the traditional approach airlines only look at events in which an exceedance of an operational limit or procedure has occurred. The use of flight data for these purposes employs only a very small fraction of the data generated by the on-board recorders. Every “normal”, or routine flight generates an enormous amount of data that are never used. Presently, operators with an FDM program discard the data from these flights after a short period. However, no flight is completely devoid of slight deviations from Standard Operating Procedures (SOP's) or small working errors. These do not constitute incidents or violations but represent normal variability in day-to-day operations. Analysis of routine flights has attracted the attention of a number of airlines such as KLM and BA. These airlines were also pioneers in setting up the first FDM programs.

The analysis of routine flights introduces a wide range of new possibilities and problems to airlines. This paper describes the activities of the National Aerospace Laboratory NLR regarding the development of techniques and ideas for analysing routine flight data.

2 Traditional approach of flight data analysis

In the traditional approach flight recorded data are used to analyse the following:

- *Events*: deviations from flight manual limits and standard operating procedures,
- *Aircraft condition*: mainly monitoring of engine characteristics,
- *Accidents/Incidents*: flight data are used for accident/incident investigation.

Flight data for aircraft condition monitoring and accident/incident investigation have been used for many years now by many airlines over the world. Detection of events using flight data is less common. Although some airlines like BA have been doing so for the past three decades. On a day-to-day scale, detection of events provides a view of the safety of flight operations. Consider an example of a classical event that is monitored: the hard landing. “When is a landing considered hard?” is a question that can have different answers depending on aircraft type and or airline involved. Some have defined a threshold based on the load factor experienced during touchdown. Others might use the sink rate prior to touchdown as a measure for a hard landing. Consider, for the example, that a landing is hard whenever the load factor at touchdown is 1.6 G’s or higher. Such a number typically comes from a maintenance manual, which defines hard landing inspections. Figure 1 gives an example of the load factor distribution at touchdown for a wide-body aircraft. The majority of the 8,000 landings in sample had a touchdown load factor that was in the range of 1.1 to 1.4 G’s. Only a very small part of the landings had load factors of 1.6 G’s or higher. Interesting is to see that there were also landings that had load factors lower than 1.0 G. This is partly caused by the way the trigger, which is set out to record the load factor, was programmed. Also the sample rate can cause variation in the recorded acceleration. In the traditional approach the analyst would only consider those landings in which the load factor was 1.6 G or higher. All other data would be disregarded. In the 8,000 landings there were only 25 that met the criteria for a hard landing used in this example. The other "normal" touchdowns can hold information about any trend on getting hard landings. To do such trend analysis data have to be collected in a different way than exceedance events. These “new” data are sometimes referred to as “routine events”, although they are not real events in terms of deviations from limits of procedures.

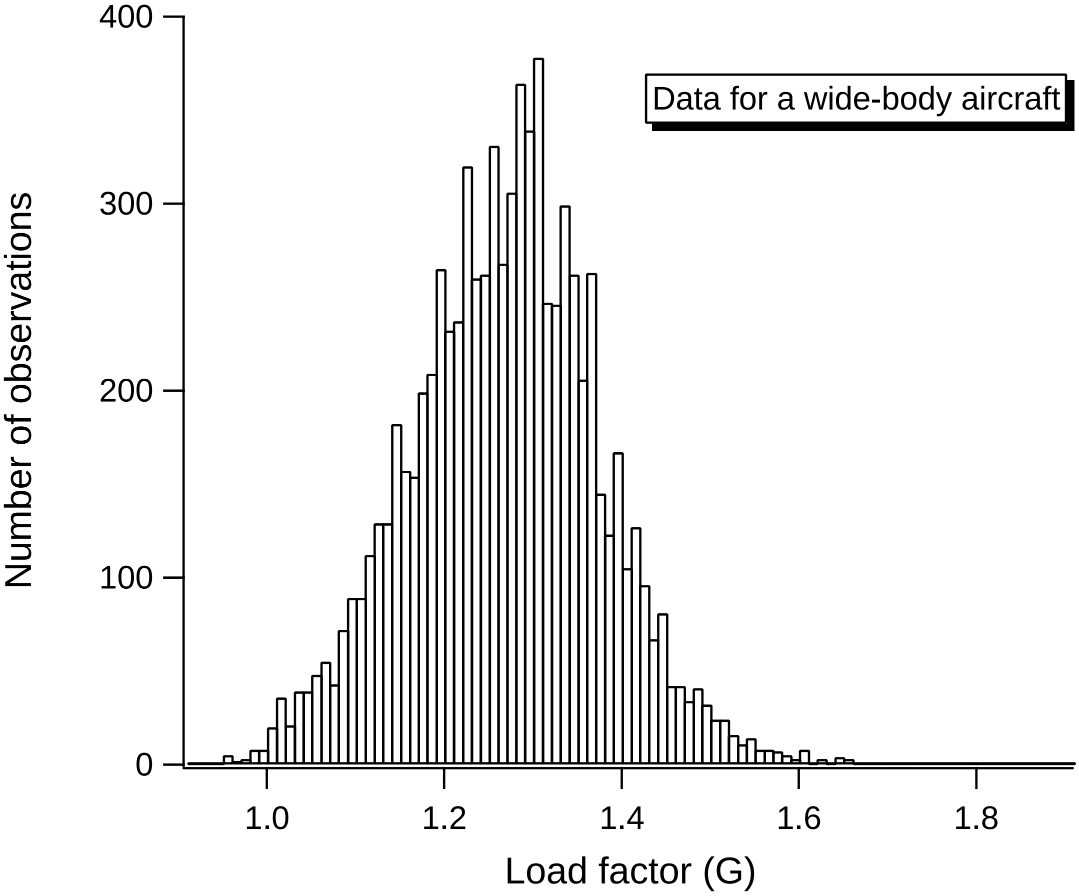

Figure 1: Load factor distribution at touchdown.

3 Routine event analysis

Routine events can be defined as “*snapshots of data obtained on all flights at predefined points for a moment in time*”. Routine event analysis includes calculation of the way (flight) parameters are distributed over numerous flights. These distributions can be compared or used for trend monitoring. Routine event analysis does not need an exceedance before identifying a trend. Since routine event data are collected for each flight, trends can be identified very rapidly. The number of routine events that can be monitored seems endless. The latest aircraft types record more flight parameters than the older aircraft types. For instance for the B777-200 more than 60,000 parameters are available. Typically only 2,000 parameters are recorded on a quick access recorder (QAR) for this aircraft. An example of routine event parameters that can be monitored during the approach & landing flight phase is shown in Table 1. Each of these parameters can be recorded at various altitudes, say 2000 ft., 1500 ft., 1000 ft., 500 ft., 100 ft., and touchdown. These parameters are typically selected to monitor if the approach was stabilised or not. This will require data on speed (including the target approach speed), glideslope & localizer deviation, rate of descent, flaps setting, landing gear position, and engine setting. The size of such a database (just 2 MB per 10,000 landings, per altitude) is modest considering today’s standard of hard disk volumes in which 60 GB of available memory is normal and affordable. It should be realised that in a routine event type of analysis, data are collected for a moment in time and therefore do not set considerably requirements on memory as would be the case for data collected in time tracks.

Table 1:Example of parameters monitored during the approach & landing.

Parameter	**Remarks**
Aircraft Type	-
Flight Date	-
Departure airport	-
Arrival airport	-
Speed (CAS)	-
Reference speed	1.3 times the minimum speed or 1.23 times the 1-g stall speed
Selected approach speed	Reference speed plus correction for headwind
Heading	-
Rate of descent	-
Flaps setting	-
Glideslope deviation	-
Localizer deviation	-
N1	The N1 values for each engine
Gear Down	Discrete value (up/down)
Autopilot setting	-
Pitch	-
Roll	-
Vertical acceleration	-

Nevertheless, a routine event data collection program generates a lot more data than for instance an exceedance-monitoring program. It is therefore evident that statistical techniques have to be used to get meaningful information from the data. Routine event analyses without a proper statistical analysis can result in useless and misleading information! As an example of routine event analysis, consider the data collection of hard landings for the wide-body aircraft discussed previously. The wide-body aircraft in the example conducted landings at more than forty different airports worldwide. The mean load factor and the standard deviation for two locations and all airports are listed in Table 2. The two locations were picked out of the forty because they form an interesting case how misleading numbers sometimes can be. Both airports X and Y have the same mean load factor, which is higher than the overall fleet average. The standard deviations, which are also the same, are only slightly higher than the fleet deviation. Note that the standard deviation is a measure of the spread of the data about the mean. At a first glance it could be concluded that both airports X and Y have a higher touchdown load factor than the fleet average and that there exist a potential problem at these locations. At least the numbers are telling so, or not? The saying ”*you have lies, damn lies, and you have statistics…”* certainly applies to this situation. In order to be not misleaded by the numbers, a more thorough analysis is required. More thorough means a formal statistical approach to the problem and not just a look at the mean values only. Data can show what is called "random sampling variability". In other words what looks like a difference between two groups of data could be caused by chance. Fortunately, the statisticians have developed techniques that can test whether or not a difference in a mean value is significant. It is beyond the scope of this paper to discuss these techniques. The reader is referred to standard textbooks on statistics for more details. The statistical tests have a general limitation; that is they only work up to a specified confidence level. This level cannot be a 100% meaning that there is always a possibility that the outcome of a statistical test is incorrect. Choosing a very high confidence level, say 99.99%, is not recommended. Such high levels will always results in the same result of a test: *"there is not a statistically significant difference"*. A level of 95% is more practical and normally used for statistical analysis. Application of a statistical test to the example data shown in Table 2, gives an interesting result. First the mean load factor of all airports is compared to the mean of airport Y. The result of the test is that the differences in the mean load factor values among the two groups "all airports" and "airport Y" are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference. Comparison of all airports with airport X showed that the differences in the mean values among the two groups "all airports" and "airport X" are greater than would be expected by chance; there is a statistically significant difference. So in conclusion the higher mean load factor at airport Y is merely due to chance whereas airport X does so a significant difference, which could trigger an analyst, to look at this airport to see what is causing this higher than average touchdown load factor.

Another useful way of analysing routine event data is to look at the distribution of the data. Most people know distribution of data in the form of the well-known histograms (See e.g. Figure 1). Unfortunately, histograms can be misleading. In a histogram the data are distributed by user defined bins. Binning of the data involves a loss of information. Furthermore, there is considerable arbitrariness as to how the bins are chosen. This subjective treatment of the data makes a histogram not very useful for analysis purposes. A more objective way for comparison of distributions is by putting the data in *cumulative frequency distributions*. These can be seen as "*unbinned histograms*". In a cumulative frequency distribution the data are sorted and ranked cumulatively from 0 to 100%. Figure 2 and Figure 3 show the cumulative frequency distributions for the hard landings considered in the example. From these plots it could be concluded that the load factors at airport X and Y are differently distributed than for the complete fleet. Again the statisticians have developed techniques (such as the Kolmogorov-Smirnov test) that can determine if two distributions are statistically different or not. It is beyond the scope of this paper to discuss these techniques in detail. However, the results of these techniques applied to the example will be presented. The statistical tests showed that the distribution of load factor at touchdown are statistically significantly different from the fleet distribution for both airport X and Y. Remember that a comparison of the *mean* load factors showed that only airport X was different from the fleet average. Looking more closely to Figure 3 it becomes clear that the differences for airport Y are concentrated between 1.2 and 1.3 G's whereas for airport X the difference starts at 1.2 G and continues up to the higher load factors. This can be considered more a trend towards hard landings than in the case of airport Y.

Table 2:Load factor data at different locations.

Airport	**Mean load factor at touchdown (G)**	**Standard deviation**
All	1.26	0.11
X	1.30	0.12
Y	1.30	0.12

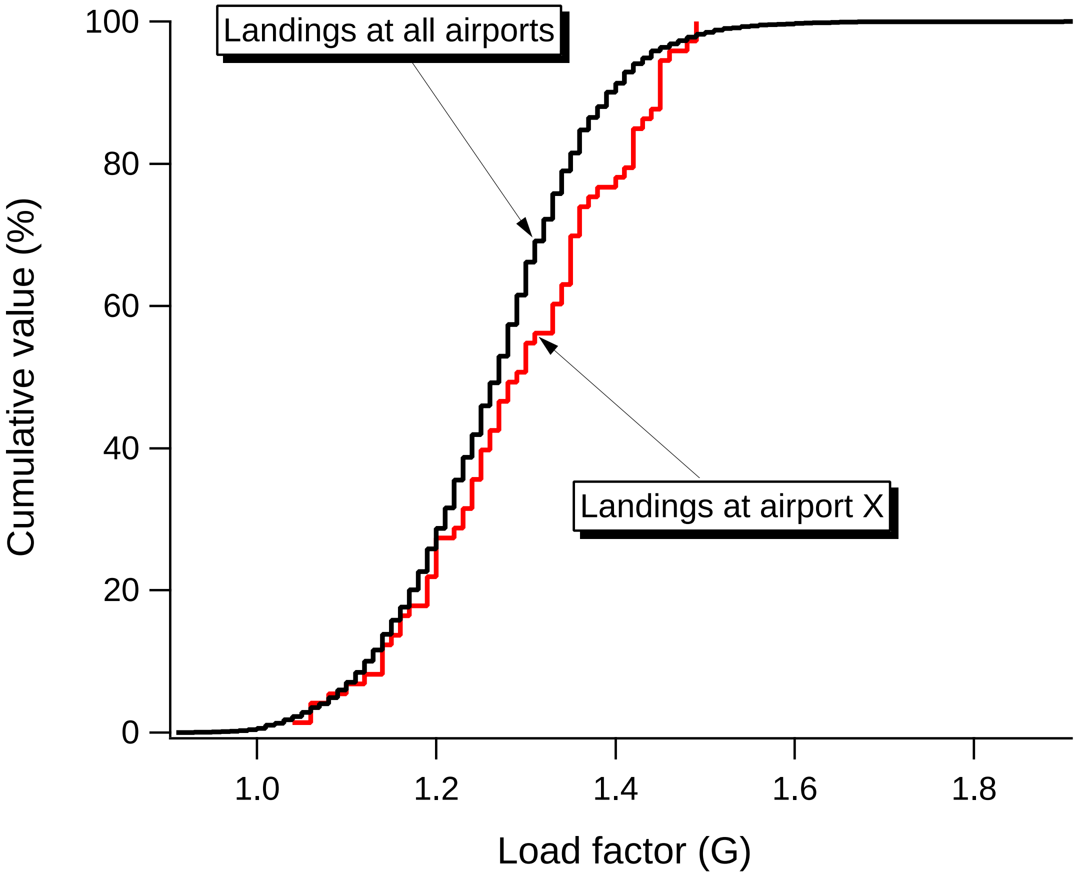

Figure 2:Cumulative frequency chart of the load factor for all airports and airport X.

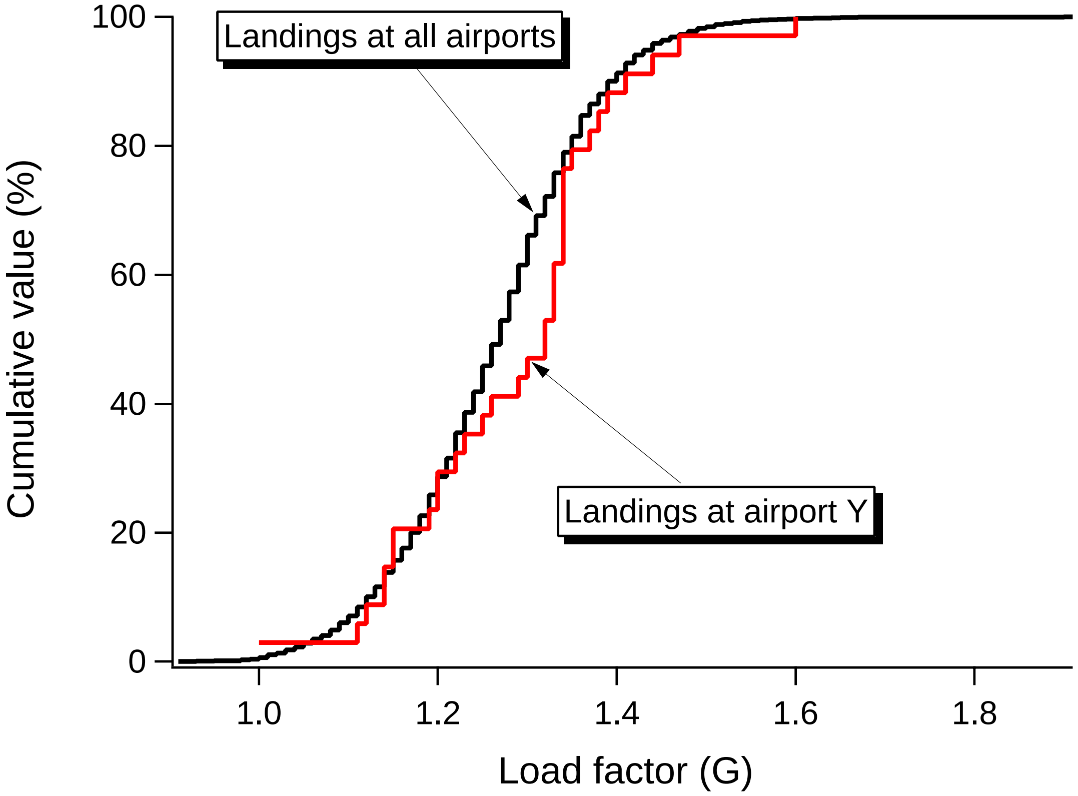

Figure 3: Cumulative frequency chart of the load factor for all airports and airport Y.

Consider as a second example the speed at 500 ft AGL during the landing. Typically airlines require that the flight must be *stabilised* at this altitude. Some airlines differentiate between IMC and VMC conditions for the altitude at which the flight should be stabilised. For this example only the 500 ft. gate is considered regardless of meteorological conditions. At the 500 ft. gate the aircraft should be at or very close to the selected final approach speed (FAS). The FAS is the reference speed (V_{REF}) plus a correction for wind. Normally this correction is not more than 20 Kt. An indication for a potential unstabilised approach considering speed is a deviation from the FAS of more than, say ±5 Kt. In some publications such as the FSF ALAR Tool kit it is recommended that the speed should be between V_{REF} and V_{REF} + 20 Kt. for a stabilised approach. However when flying in strong (gusty) wind conditions the FAS will normally be V_{REF} + 20 Kt. Even small variations in speed can then lead to an unstabilised approach according to the FSF ALAR Tool kit definition. Therefore for the present example only deviations from the FAS are considered. Figure 4 shows an example of the distribution of the FAS deviation. Two lines are shown: one for the fleet average and one for airport Z known for it's high-speed approaches. Statistical tests clearly showed that a significant difference exist between the distributions of the fleet average and airport Z. It is also clear from Figure 4 that more than 50% of all approaches on airport Z show a deviation from the FAS of 5 Kt. or higher. For the entire fleet this is less than 20%.

Although requirements for a stabilised approach are not limited to speed only (see Table 1), it is considered a very important element. However for a thorough analysis of approach stability it is always recommended to consider other elements such as, glideslope & localizer deviation, rate of descent, flaps setting, landing gear position, and engine setting.

The examples show that with the use of proper statistical tools, routine event data can identify potential trends, which might jeopardise the safety of flight operations. Routine event data can help determining trends much quicker than by analysing exceedance event data. Furthermore exceedance events offer only a small window into the view of the total system safety performance. Routine event data give a much wider view on the safety performance and provide valuable trending insight into normal operations of an airline.

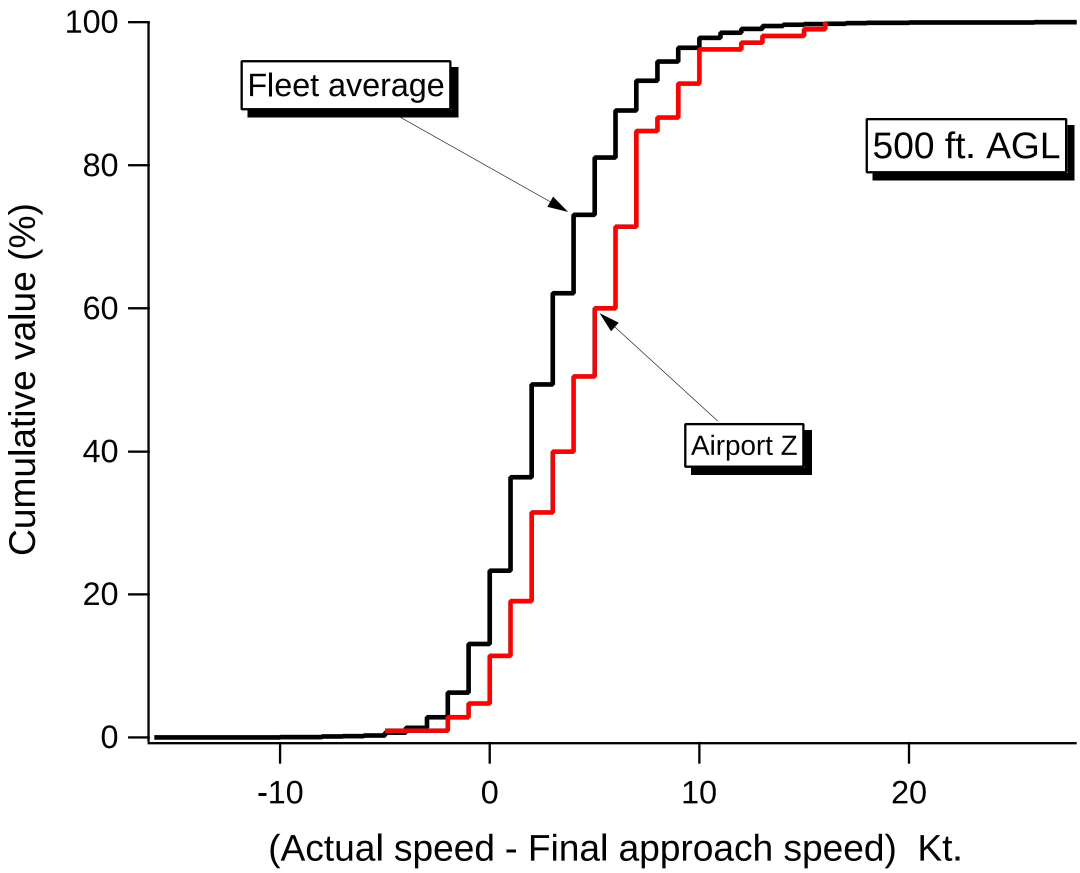

Figure 4: Speed distribution at 500 ft. AGL.

4 Correlation with other data

Routine event data are not very “intelligent” data. For instance background data like weather conditions are normally not collected during a routine event monitoring program. Therefore they do not allow for the same in-depth analyses provided by for instance the exceedance event data or incident reports.
As an example consider the analysis of hard landings for the wide-body aircraft discussed previously. Hard landings can have many different causes, for instance sudden, strong wind changes during the flare, an unstabilised approach, tailwind conditions, or an improper flaring technique. Such causes cannot be determined from routine event data only. To make routine event data more effective it is necessary to correlate the data with other data sources. Combining of other shorts of data like human factors data (e.g. simulator data, line observations etc.) and environmental data (e.g. weather data, air traffic control data) with flight operational data presently only occurs when some single accident or incident is analysed in depth. Significant additional value is to be gained when all these data sources are analysed in a correlated manner, among others because this provides the capability to detect trends and correlations that cannot be identified when analysing data from individual routine events. A schematic set-up of such a process is given in Figure 5.

In the area of human factor data many civil aviation authorities recognise the value of subjective reports made by the flight crews involved in incidents and accidents, and have set up mandatory occurrence reporting regulations. However, when pilots have experienced a routine flight (i.e. the thresholds for filing a mandatory occurrence report have not been exceeded), they will have very little to report. Therefore, conventional ways of gathering human factor data – collecting pilot reports – will not yield the proper results. The last few years, several airlines have held Line Operational Safety Audits (LOSAs) campaigns, mounted to sift through the line operation for safety-related situations that needed improvement. Part of these campaigns was the deployment of observers on the flight deck that made quiet, non-jeopardy notes of normal operations by the pilots. This method of human factor data collection holds potential as a supplement to routine flight data analysis.

The correlation of different data sources is problematic due to the differences in data taxonomy: e.g. differences in definitions of data fields, differences in level of detail, and/or differences in applied terminology. Ongoing initiatives such as the Joint Taxonomy working group run by ICAO/NASA are trying to solve this problem. Unfortunately, the focus of most initiatives is on accidents and incidents only. It is without doubt that no initiative will actually solve the taxonomy problem completely. Mapping techniques to exchange data between different systems are therefore required with the potential loss of information.

Expert knowledge must be applied to make meaningful correlations between human factors, flight operational and environmental data (See Figure 5). Formal techniques to integrate expert knowledge extraction and implementation into the correlation process should therefore be developed. The development of such techniques is not easy and requires a wide variety of expertises.
Systematic methods for the correlation and analysis of different data sources should be developed. These methods should be easy to use but should also include statistical techniques. To reduce the resources required the correlation and analysis process should be automated as much as possible. Also expert knowledge must be brought into the analysis process to convert the statistical data into information that is understandable and meaningful to the operator's management and the pilots.

Commercial-off-the-shelf tools for FDM such as BASIS, SESMA, FLIDRAS, GRAF and Airbus's LOMS could be used as basis for the data correlation techniques proposed. Especially the Airbus tool LOMS has a great potential in this area.

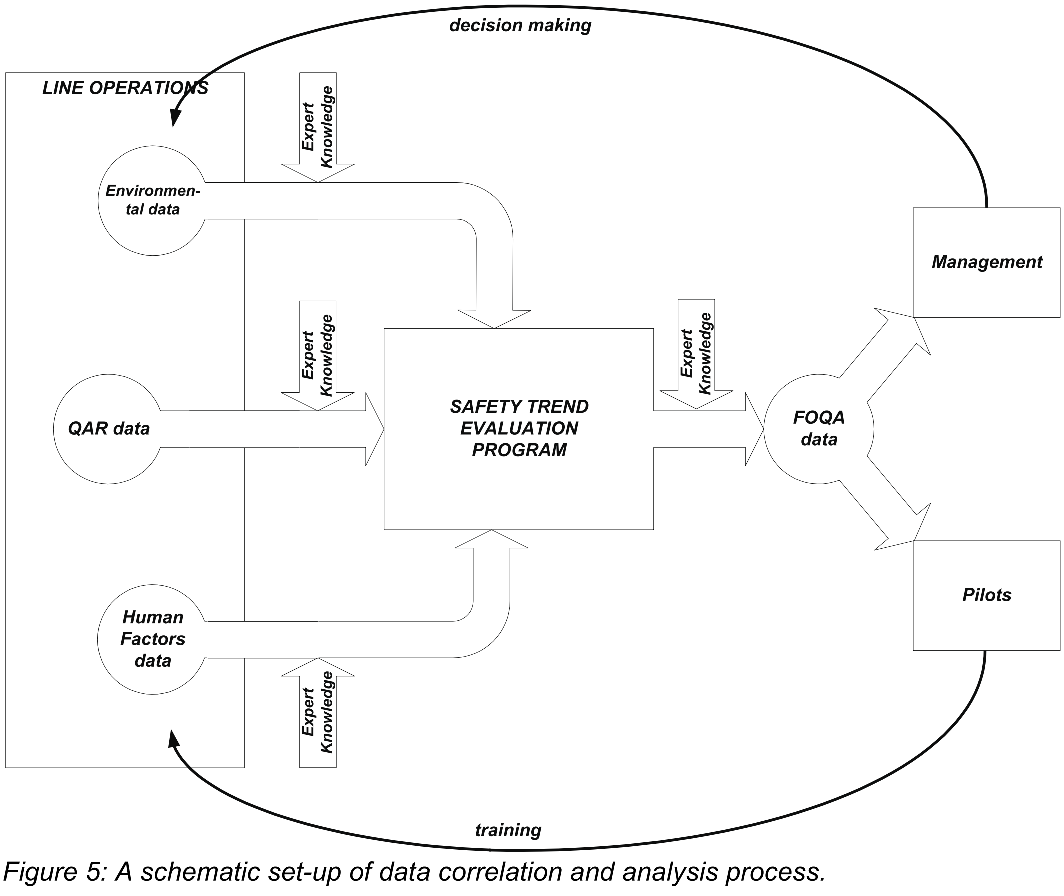

Figure 5: A schematic set-up of data correlation and analysis process.

5 Final remarks

Redirection of the present attention from accidents to data from day-to-day operations is seen as essential in reducing the likelihood of hazardous events. A methodology for systematic analysis of flight operations has direct potential application for airlines. Airlines can use such a model to assess their current safety level, and use it as a decision making aid when considering changes in equipment, organisation, procedures, etc. The extension of monitoring exceedances to the day-to-day data analysis of each flight is important to the goal of continued improvement in safety. Even more can be expected from the correlation and analysis of human factor data and environmental data with flight data up to the level of day-to-day operations. However, development of correlation and analysis tools and demonstration of the usefulness of such a system, will require funding and commitment from all parties in the aviation sector.