Civil Aviation Authority

Report 2012/01

Flight Data Monitoring Based Precursors Project

Part 1 – Runway Excursions

An investigation into the feasibility of obtaining meaningful, reliable and practicable precursor indicators of Landing Runway Overruns from a commercial Flight Data Monitoring analysis system.

Contents

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Executive Summary

Flight Data Monitoring (FDM) is the systematic, pro-active and non-punitive use of digital flight data from routine operations to improve aviation safety. CAA's long experience with FDM derived information has shown it to have great potential as a reliable information source when considering exposure to aviation risk scenarios. By developing a set of targeted, reliable and consistent measures the CAA seek to contribute to direct Operator action to mitigate against real risks.

The significant seven safety issues, identified by CAA and widely acknowledged by industry, cover the main categories of occurrence identified in aviation accidents that result in potentially catastrophic outcomes: Airborne Conflict, Airborne and Post-Crash Fire, Controlled Flight Into Terrain (CFIT), Loss of Control, Ground Handling, Runway Excursion and Runway Incursion/Ground Collision. Specifically, FDM lends itself well to monitoring issues related to Airborne Conflict, Controlled Flight Into Terrain (CFIT), Loss of Control and Runway Excursion. This work focuses on one element of Runway Excursions, identified by industry as one of the priority issues at the Safety Conference in 2010. It is intended that other significant seven safety issues will be looked at through further work in the future.

The objectives of this Project are to:

1. Demonstrate the effectiveness of a standardised FDM module to help Operators, individually and as a group, better monitor and act upon identified high risk issues, in this case that of Landing Runway Excursions, through their SMS;

2. Encourage the use of such FDM analysis techniques by the wider UK Industry to monitor and address these issues; and

3. Gain an FDM overview of high risk issues through co-operation with Operators using such techniques on Runway Excursions.

Conclusions

Current, highly capable FDM analysis tools can be improved to produce reliable measures that will help Operators track their risks including in this case those relating to landing runway excursions, one of the CAA's significant seven issues.

The FDM system is a complex matrix of system and user set conditions and constants that can have significant consequences on the output. The trial showed that there were a number of issues with this particular implementation that initially affected the data from the approach analysis but which were addressed by program changes and adjusted constants.

Starting from the Aerobytes FDM system it is recommended that Operators use the following measures (state values) and implement the event limits (see Table 5) and stable approach criteria suggested below:

- Height First Stabilised
- Height Last Unstabilised and parameter last outside stability limits
- Distance from 20ft AGL to Touchdown
- Distance from runway threshold to touchdown
- Speed at Touchdown vs Target Approach Speed (Airbus: Vapp or Other: Vref)
- Ground Speed at Touchdown
- Runway distance remaining (Runway length minus T/D distance)

Stable Approach (Appr) Algorithm Criteria	Limit
Stable Appr - Airspeed vs Estimated (max)	15 kt
Stable Appr - Airspeed vs Estimated (min)	-5 kt
Stable Appr - Airspeed vs Selected (max)	15 kt
Stable Appr - Airspeed vs Selected (min)	-5 kt
Stable Appr - Airspeed vs Vapp (max)	15 kt
Stable Appr - Airspeed vs Vapp (min)	-5 kt
Stable Appr - Airspeed vs Vref (max)	20 kt.
Stable Appr - Airspeed vs Vref (min)	-5 kt
Stable Appr - Heading Range	45 deg
Stable Appr - ILS G/S Dev (max)	1 dot
Stable Appr - ILS G/S Dev (min)	-1 dot
Stable Appr - ILS LOC Range	1 dot
Stable Appr - RALT cut-off for Airspeed	100 ft
Stable Appr - RALT cut-off for ILS	100 ft
Stable Appr - RALT cut-off for Vertical Speed	100 ft
Stable Appr - Selected Speed vs Airspeed hi	10 kt
Stable Appr - Selected Speed vs Airspeed lo	-30 kt
Stable Appr - Sink-rate (max)	1000 fpm
Stable Appr - Sink-rate (min)	200 fpm
Stable Appr - Window Duration	15 secs

To support the measures, both airport and runway movement statistics should be retained to differentiate between various types of approaches e.g. Precision and Non Precision.

A combination of the statistical elements of the precursor measures and the contextual/causal information from these events will best enable the assessment of risk and then target remedial actions.

In the future, higher resolution GPS data on touchdown points should be used to develop measures of safety margins e.g. length of runway remaining. However, such data is not available on most current aircraft and is therefore a longer term objective.

Finally, while expanding the application to other types for both measures and events it would be helpful if aircraft manufacturers could add insight into braking performance estimation so as to bring a risk assessment measure within reach.

Software Developments Subsequent to Initial Analysis

Following the initial analysis a number of useful improvements and refinements were incorporated into the system:

- The detection of false glideslope signals and of the glideslope aerial position has been enhanced.
- A nominal three degree 'virtual' glideslope has been added as a derived parameter to help monitor the flight path of non-precision approaches.
- The system's glideslope detection together with the use of a runway database enables the system to indicate which type of approach was flown Precision, RNP, ILS, NPA or Visual.
- To improve the accuracy of the analysis of basic numeric parameters user configurable linear interpolation has been added.

A series of landing distance measures have been incorporated into the system to enhance understanding of the potential for a landing overrun:

- A more robust distance measure has been developed. If the runway supports ILS and the glideslope signal is sufficient to detect the glideslope aerial then the system will use this point on the ground as a physical reference and calculate distance from the aerial until touchdown plus the distance of the aerial from the threshold. Otherwise the system will attempt to lookup the threshold crossing height for the runway and calculate the distance from the point the aircraft passes through that altitude (corrected PALT is used if RALT is not recorded) to touchdown. In the rare case that none of the above data is available, the system assumes that the aircraft touched down perfectly (approximately 1000ft from threshold).
- The system's runway information database is used to estimate the runway distance remaining following touchdown.
- Runway remaining distances, both the actual and also that required, based on nominal longitudinal acceleration values.
- There are also measures that calculate the braking acceleration, both experienced and required.

Future Industry Implementation of these Ideas

A Supplement detailing the technical specification of the items discussed in this report will be provided to those Operators and FDM system suppliers wishing to incorporate these into their operational flight data monitoring systems. The supplement will include sufficient information to enable incorporation by both Aerobytes and other FDM system users. It is recommended that the proposed measures and events are implemented by UK Operators to complement their existing FDM programmes.

Preface

Comments from Aerobytes

As any experienced user of an FDM/FOQA system will tell you, developing theoretical high-level/low-detail 'concept' analysis solutions is easy. The challenge is to translate those 'concepts' into reliable and practical methods that will work across a range of aircraft - aircraft which won't necessarily all record the 'perfect' set of parameters.

For example, algorithms that depend upon GPS levels of accuracy for latitude/longitude or upon Radio Height sampling at unusually high rates can never gain widespread popularity. They will only ever work for a small subset of aircraft that can provide this information and not for the majority of aircraft whose 'legacy' parameter-sets are fixed in stone.

Consequently, the Aerobytes philosophy has always been to find the simplest, value-led solution to each problem and then to minimise its dependency upon 'exotic' parameters.

With that said we don't pretend that our solutions are perfect and actively welcome constructive feedback and dialogue. By sharing our work with the wider flight-data community (including other vendors) we have taken a small but significant step in helping to drive further improvements in levels of flight-safety around our planet.

After all, a good idea that might save lives should not be kept a secret.

The UK Operator

The Operator considers the 'Significant 7' risks as relevant and essential for monitoring to ensure continued safe operation. In our opinion, safety departments in all airlines are monitoring the exposure against these risks through their safety programs. However, it has been challenging to translate safety data into consistent measures against specific risks. We experienced that monitoring hundreds of FDM events and event descriptors from the Safety Reporting database can be a very time consuming exercise and may produce varied analysis. By grouping key reporting and FDM events under specific risk can prove to be an easy and consistent way of measuring exposure against key risks.

The FDM precursors project was announced at the time when we had started work in this area internally at the Operator. We were immediately interested in working with the CAA to mutually benefit from this project. The project was well planned with objectives mutually identified and agreed. We were particularly pleased that CAA led the project and the workload did not lead to any significant disruption at the safety office in the Operator.

A comprehensive analysis of the data was conducted by the CAA with operational input from the Operator. Variables and event logics were modified to confirm consistency and accuracy of the data. The sole aim of the project was to identify FDM based precursors which could easily be adopted into any FDM system, but will provide sufficient information to assess the exposure to the Runway Excursion risk. Although our FDM vendor (Aerobytes) had provided us with some very useful algorithms to monitor key values and events, this project helped in identifying some finer improvements which could further enhance the analysis of the data. Our intention is to ensure that all seven recommended values/events are correctly setup in our FDM system and provide even more accurate information through parameter interpolation. By doing this, we believe our monitoring will be more focussed and consistent in highlighting any emerging issues.

We look forward to adopting further FDM based precursors from future projects dealing with the remaining 'Significant 6'.

Glossary

AAL	Above Airfield Level
AGL	Above Ground Level
CFIT	Controlled Flight Into Terrain
DSTTO2TD	Distance 50ft AAL to T/D
FDM	Flight Data Monitoring
GPS	Global Positioning System
GS	Glideslope (ILS)
HTLFLAP	Height AAL when Landing Flap Selected
ILS	Instrument Landing System
LOC	Localiser (ILS)
Non-Precision Approach	An instrument approach and landing which utilizes lateral guidance but does not utilize vertical guidance (ICAO Annex 6, Chapter 1)
NPA	Non-Precision Approach
PA	Precision Approach
PIO	Pilot Induced Oscillation
Precision Approach	An instrument approach and landing using precision lateral and vertical guidance with minima as determined by the category of Operation (ICAO Annex 6, Chapter 1)
QAR	Quick Access Recorder
RALT	Radio Altitude
RHS	Right Hand Side
States	Approach, Landing phases etc. defined by Aerobytes
SVD	State Value Definition
T/D	Touchdown
Vapp	Final approach speed computed by Airbus aircraft (Vapp=VLS + wind correction)
Visual approach	An approach by an IFR flight when either part or all of an instrument approach procedure is not completed and the approach is executed in visual reference to terrain (ICAO Doc 4444, Chapter 1)
Vref	Reference Landing Speed
VSI	Vertical Speed Indicator

Introduction

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Participants

CAA, the UK Operator, Aerobytes signed up to a Memorandum of Understanding that outlined the objectives, methodology, and conditions surrounding this trial.

Confidentiality and Proprietary Information

The data will be held securely and not released. IPR will be respected.

FDM Data Availability

The Operator's A320 QAR data from one summer (587 flights) and one winter month (250 flights).

Description of Aerobytes System

This is a widely used FDM program (UK and international). It has traditional events plus 'composite' events that bring together a number of parameters. For example: in assessing a stable/unstable approach – configuration, speed, glideslope and localiser deviation and rate of descent.

The system breaks down each flight into a series of states – e.g. take-off, initial climb etc. These are organised in a hierarchy in which a given state will trigger the detection process for further (dependant) states. This means that the system will only detect 'level flight' after finding 'taxi to take off', 'take off', 'initial climb' and 'climb' states.

Reference points (state points) are set within each state at which various values are measured (state values). These values are retained for **all flights** and can then be used to trigger events.

In the case of this trial the Approach and Landing States are of interest. The system sets an end point at touchdown and then looks backwards through the data until the gear and flaps are up which is set as the start of the Approach State. It is also possible to restrict the approach by use of the aircraft's heading being within (say) 45 degrees of the runway heading.

The Landing State is the period between touchdown until the end of roll-out. This is defined as after 90 secs, or groundspeed is less than 50kt or there is a heading change of more than 20 degrees.

Existing Approach and Landing Analysis

The Operator's existing configuration was run against the summer month data to establish a results baseline which was analysed using Excel and SPSS. This process enabled CAA to learn more about the data and the software which produced it.

Existing System Events

The system has a comprehensive range of events, many of which are focused on the approach and landing phases and are relevant to the runway excursion trial. In an Operator's FDM system these are and will remain a focal point for their monitoring. The user is able to set the exceedence levels at which each event's severity is considered to be green, amber or red.

Special attention was given to the events that were based on 'composite' state values since these were based on parameters similar to those covered by the standard events. For example Late Initial Stabilisation, this is based on the point at which the aircraft is First Stable (see Table 1).

Table 1: Information available during approach and landing.

Phase	Event Name
Warnings	Touch & Go
	Low Fuel on Landing
	Go around
Speed	Approach Speed Low (before Go Around)
	Approach Speed High (before Go Around)
	High Tailwind Component (Approach)
	Airspeed Low at Touchdown
	Airspeed High at Touchdown
	High headwind component (landing)
	High crosswind component (landing)
	High Tailwind Component (landing)
	High Taxi Speed (after landing)
	Harsh Braking (landing)
	Unstable approach (speed variation <1500ft)
	Unstable approach (speed variation <1000ft)
	Unstable approach (speed variation <500ft)
	Approach Speed Low (<500ft)
	Approach Speed Low (<1500ft)
	Approach Speed Low (<1000ft)
	Approach Speed High (<50ft)
	Approach Speed High (<500ft)
	Approach Speed High (<1000ft)
	Approach Speed High (<1500ft)
Power	Late T/R Cancellation
	High power on approach
	Low power on approach
	Late power cut during flare
	Excessive N1 with Reverse Thrust

Phase	Event Name
Acceleration	High Lateral G on Landing
	Hard Landing
	High normal acceleration (landing)
Flight Path	Radio Altimeter 1 malfunction
	Radio Altimeter 2 malfuction
	Unstable at Low Altitude (LOC)
	Unstable at Low Altitude (GS Lo)
	Unstable at Low Altitude (GS Hi)
	Unstable at Low Altitude (VSI Lo)
	Unstable at Low Altitude (VSI Hi)
	Unstable at Low Altitude (Speed Lo)
	Unstable at Low Altitude (Speed Hi)
	Unstable at Low Altitude (Gear)
	Unstable at Low Altitude (Flap)
	Low Percent Stabilised
	Un-stabilised at Low Altitude (Ht AAL)
	Late Initial Stabilisation (Ht AAL)
	Late Stabilisation on Approach
	Long Flare
	Long Flare (duration from flare height)
	Short Flare (duration from flare height)
	Unstable approach (LOC variation)
	Unstable approach (G/S variation)
	LOC Deviation (FLY LEFT)
	LOC Deviation (FLY RIGHT)
	High rate of descent (<500ft)
	High rate of descent (<1000ft)
	Deviation above glideslope
	Deviation below glideslope
	Possible Deep landing
	High rate of descent (<1500ft)
	Excessive Heading Change (landing)

Phase	Event Name
Configuration	Autoland
	Late T/R Deployment
	T/R Not Deployed
	Late land gear
	Overweight Landing
	Late Gear Down (<300ft AGL)
	Speedbrake with excessive flap
	Late land flap (height AAL)
	Late land flap (duration)
	Reduced flap landing
	Speedbrake on approach
	Manual Landing with A/T
	Abnormal Auto-brake Setting
Attitude	Forward SS input during LDG
	Excessive Elevator post N/W TD
	Inadequate Elevator on Landing
	Excessive Elevator on Landing
	Excessive Bank on landing (below Flare Ht)
	High Pitch Rate on Landing
	Pitch Low (approach)
	Pitch High (approach)
	Unstable approach (roll)
	Unstable approach (pitch)
	Excessive bank on approach (<1000ft)
	Excessive bank on approach (<500ft)
	Excessive bank on approach (<50ft)
	Abnormal pitch landing (high)
	Abnormal pitch landing (low)

State Value Measures Examined

Approach Values		
Height AAL when:		*N1 Power:*
First Stable		Minimum 500–50ft AAL
Last Unstable		Maximum 500–50ft AAL
Established on G/S		
Landing Flap Selected		*Maximum Roll:*
Gear Selected Down		500–50ft AAL
Misc:		Below 50ft AAL
Percentage of approach Stable		
Airspeed vs Vapp:		*Maximum Sink Rate:*
Maximum below 1000ft AAL		1000-500ft AAL
Minimum below 1000ft AAL		500–50ft AAL
Airspeed Std Deviation 500-50ft AAL		

Touchdown Values
Airspeed:
At touchdown
At touchdown vs Vref
Distances:
Nominal Flare Height to T/D
50ft to T/D
Time:
T/D to Thrust Reverse

Table 2: List of state values examined.

Twenty relevant State Value measures shown in Table 2 were selected for examination. Correlations between parameters, for example - Height at Gear Down vs Height Last Unstable, were calculated. This example showed some correlation, i.e. early gear selection led to early stabilisation, but also demonstrated that some late selections were quickly followed by stability. Examples of bad data were also seen to highlight the importance of data validation.

What Does the Existing Data Analysis Show?

Airfield Differences

The system automatically identified the landing airfield and runway using a lookup table that also contained information of the approach aids. This later assisted in the recognition of the non-precision vs precision approaches. The Height Last Stable values enabled differences between airfields and, of particular interest, runways to be seen, as shown in Figure 1.

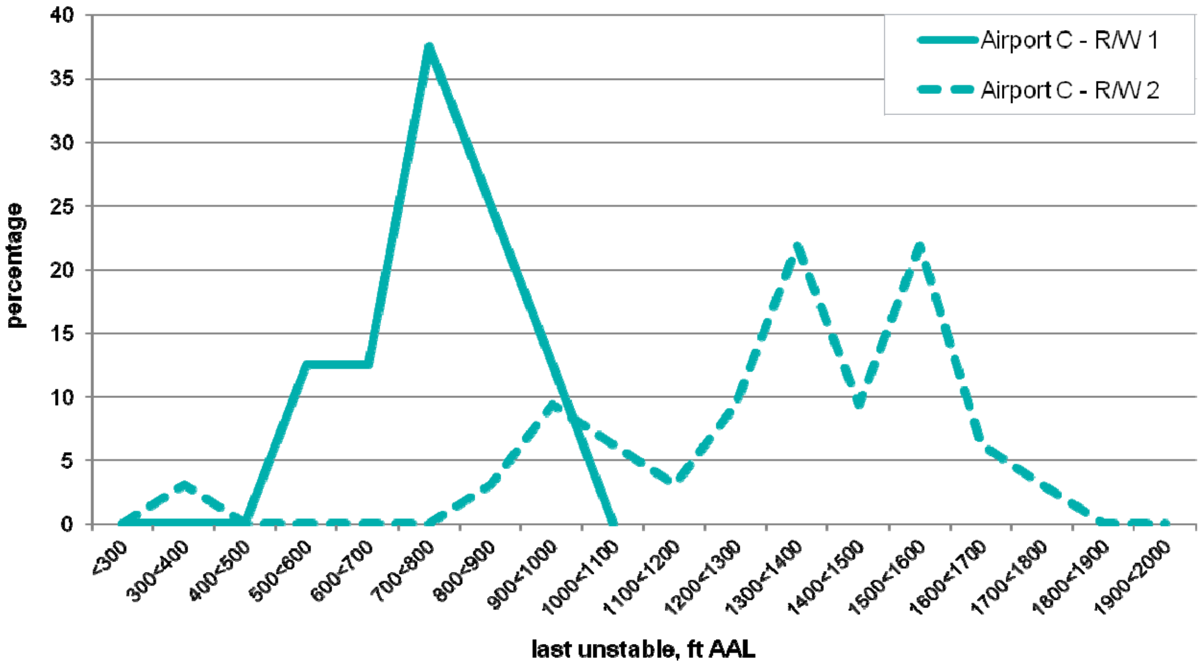


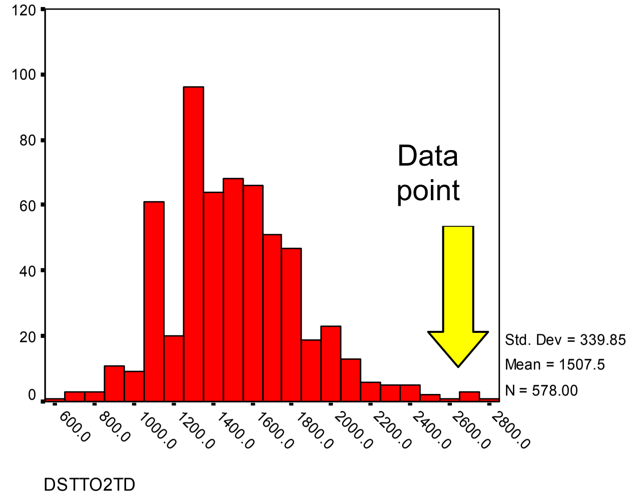
Figure 1: Comparison between the height last unstable data from different runways at the same airport.

Because of differences in the approach procedures to this airport's single runway this has resulted in a significant difference between the individual runway's frequency distributions. On one runway direction there is a straight in approach whilst in the other direction it has a non precision approach with a late final turn.

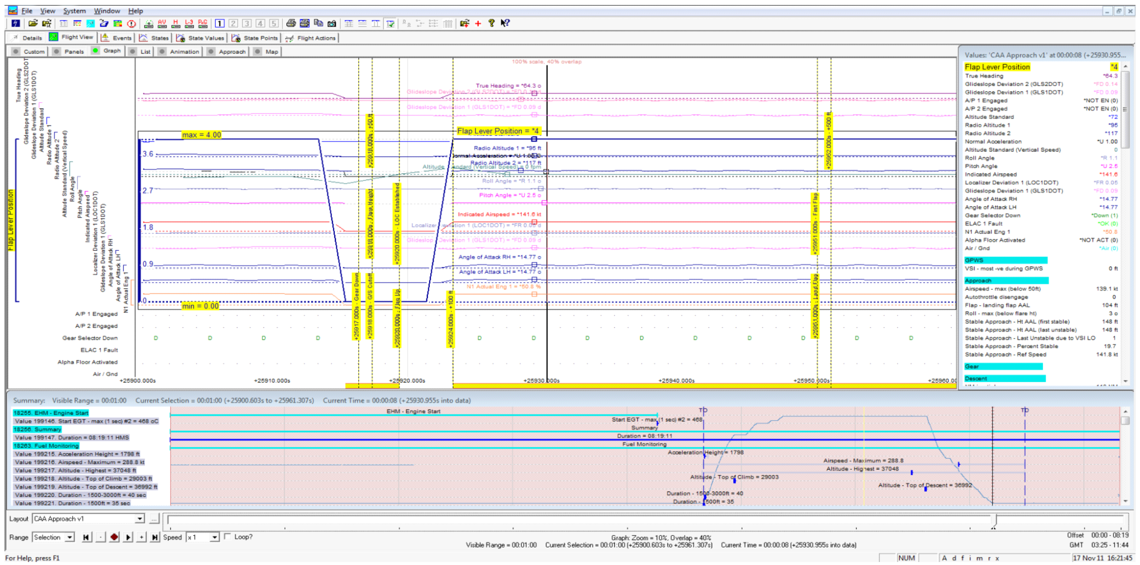
Differentiating between Valid and Invalid Data at the Extremes

This system, like others, has a low false event rate but the examples shown in Figures 2 and 3 demonstrate the care that needs to be taken when assessing extreme values. Both bad data and valid data were seen at the extremes of the distributions and this demonstrated the importance of data validation.

Figure 2 (below): An example of a valid extreme data point.



The example above shows a valid excessive distance from 50ft to touchdown caused by a PIO in the flare whereas the example below shows a late land flap setting caused by missing data. The system has since been modified to take into account this type of bad data.



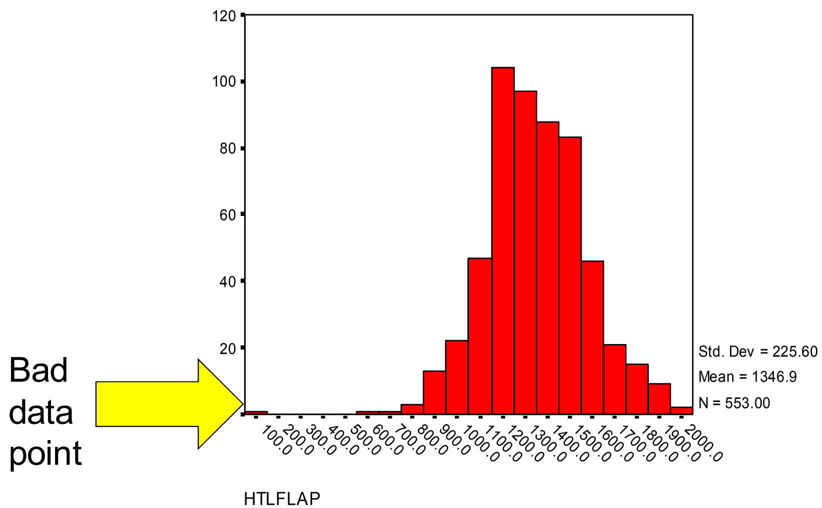


Figure 3 (above): An example of an invalid extreme data point.

Comparison between the Original vs Modified Constants' Effect on First and Last Unstable Values

As a result of the experience with the original data analysis, a number of small changes were made to the system variables to facilitate analysis.

The reader will note that Table 3 refers to two different reference speeds (Vapp and Vref). As the trial was conducted on Airbus A320 data, the speed criterion was based on the Vapp parameter. If non-Airbus aircraft are involved, speed limits could be based on Vref or selected speed (if these are recorded). This would be determined by the analysis system which uses a sensibility check to compare selected speed with an estimated average 'target speed' at around 100ft Radio Altitude from landing. That is, selected speed will not be used if it falls outside the limits defined by Selected Speed vs Airspeed hi/lo. If found to be within limits, the relevant speed parameter (Selected speed or Vref) is chosen as the speed reference (see Airspeed vs Selected or Airspeed vs Vref) depending on which is closer to the average 'target speed' at around 100ft Radio Altitude. The estimated average target speed at around 200ft-100ft Radio Altitude from landing is used as a fixed speed reference (see Airspeed vs Estimated) only if nothing better is available. Note any reference that busts the limits defined by Selected Speed vs Airspeed hi/lo won't be considered at all.

Stable Approach Algorithm Criteria:	Original	CAA	Notes
Stable Appr - Airspeed vs Estimated (max)	20 kt	15 kt	matches Vapp limits - Estimated speed understood to be the estimated Vapp
Stable Appr - Airspeed vs Estimated (min)	-10 kt	-5 kt	matches Vapp limits - Estimated speed understood to be the estimated Vapp
Stable Appr - Airspeed vs Selected (max)	15 kt		
Stable Appr - Airspeed vs Selected (min)	-5 kt		
Stable Appr - Airspeed vs V STABLE APP (max)	20 kt		not used in trial
Stable Appr - Airspeed vs V STABLE APP (min)	0 kt		not used in trial
Stable Appr - Airspeed vs Vapp (max)	15 kt		
Stable Appr - Airspeed vs Vapp (min)	-5 kt		
Stable Appr - Airspeed vs Vref (max)	25 kt	Not changed but could be changed to Vref +20 kt.	See Flight Safety Foundation ALAR Approach and landing Accident Reduction Tool Kit, FSF ALAR briefing Note, 7.1 – Stabilised Approach, Table 1 Recommended Elements Of a Stabilised Approach
Stable Appr - Airspeed vs Vref (min)	-5 kt		
Stable Appr - Heading Range	45 o		
Stable Appr - ILS G/S Dev (max)	1 d		
Stable Appr - ILS G/S Dev (min)	-1 d		
Stable Appr - ILS LOC Range	1 d		
Stable Appr - RALT cut-off for Airspeed	150 ft	100 ft	aligns cut-off to lowest reasonable limit
Stable Appr - RALT cut-off for ILS	200 ft	100 ft	aligns cut-off to lowest reasonable limit
Stable Appr - RALT cut-off for Vertical Speed	100 ft		
Stable Appr - Selected Speed vs Airspeed hi	10 kt		
Stable Appr - Selected Speed vs Airspeed lo	-30 kt		
Stable Appr - Sink-rate (max)	1400 fpm	1000 fpm	A higher sink rate ought to only be required for a certain few approaches. See Flight Safety Foundation ALAR Approach and landing Accident Reduction Tool Kit, FSF ALAR briefing Note, 7.1 – Stabilised Approach, Table 1 Recommended Elements Of a Stabilised Approach
Stable Appr - Sink-rate (min)	200 fpm		
Stable Appr - Window Duration	10 secs	15 secs	longer assessment period for further assurance of stability
Constant	**Original**	**CAA**	
Max ILS AAL	3000 ft	6000 ft	Max altitude that ILS parameters are looked for
***State Value Definitions:**	**Original**	**CAA**	*** names of state values were changed as appropriate after modification**
GS - established AAL*	2000 ft	6000 ft	maximum of value range increased
N1 - max (500ft to 50ft)*	Start: [Approach].[+500ft] and End: [Approach].[+50ft]	Start: [Approach].[+1000ft] and End: [Approach].[+50ft]	measurement range expanded
N1 - min (500ft to 50ft)*	Start: [Approach].[+500ft] and End: [Approach].[+50ft]	Start: [Approach].[+1000ft] and End: [Approach].[+50ft]	measurement range expanded
(CAA Test) Distance: GS Aerial to T/D		new SVD (integrates groundspeed, precision approach filter on)	
Other additions:			
_Stable Appr Debug parameter	not enabled	enabled	

Table 3: System changes made by CAA.

Effect of Changes Made on the First and Last Unstable Values

Figures 4 and 5 show the effect of changes in the stability criteria for the sink rate from 1400 to 1000FPM and qualifying time period for confirming stability, which was increased from 10 to 15 seconds. These were expected to affect the stability assessments. However, they only affected less than 10% of cases in the determination of the height first stable and less than 20% of the height last unstable values. The new criteria also resulted in a small number of cases detected at a higher altitude than the previous, apparently incorrect value.

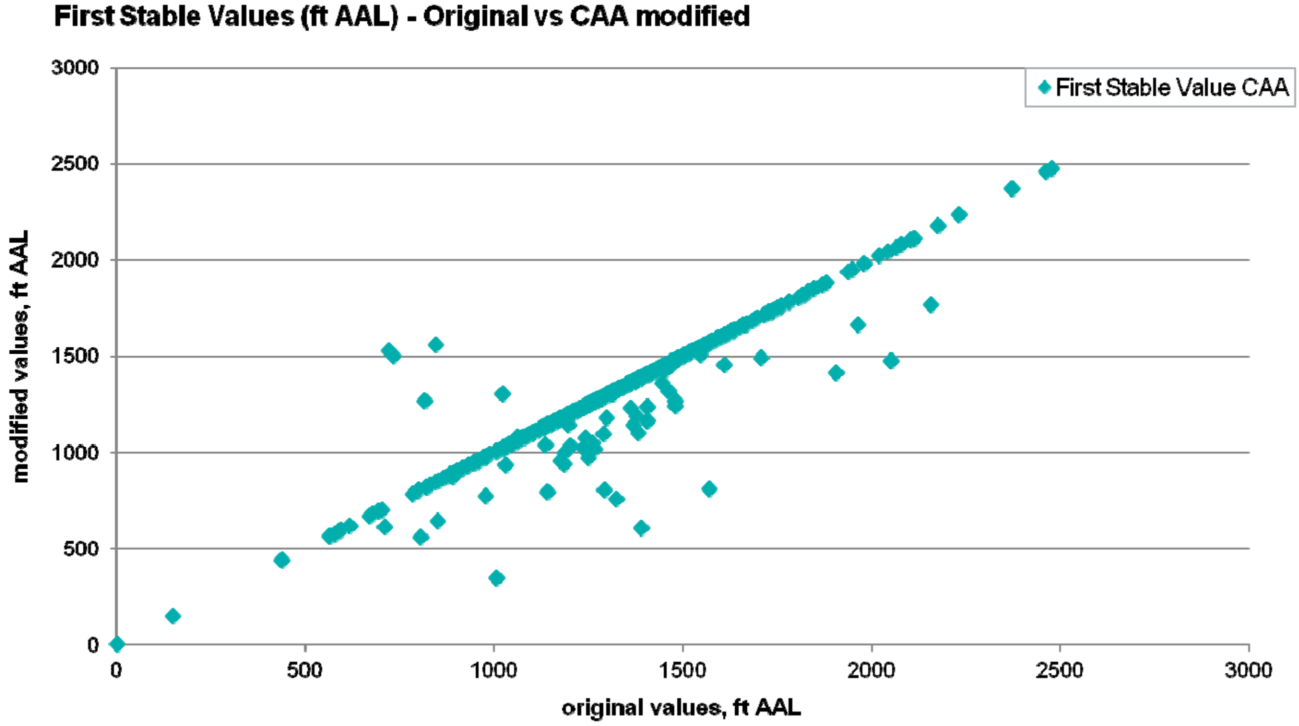


Figure 4: Cross plot of original vs modified values of height first stable.

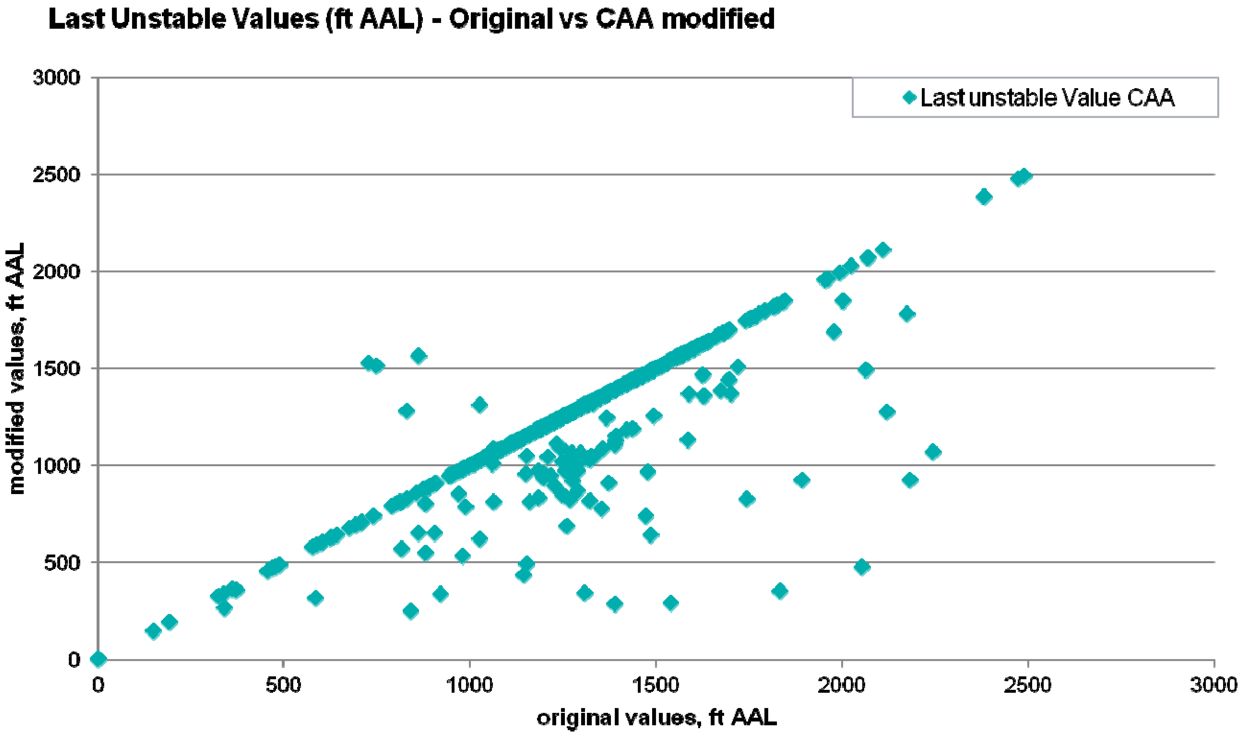


Figure 5: Plot of heights at first stable vs those at last unstable.

Discussion of Modified Analysis Results of First Stable Point

Height AAL at which First Stable - Indicating those which became unstable later in approach

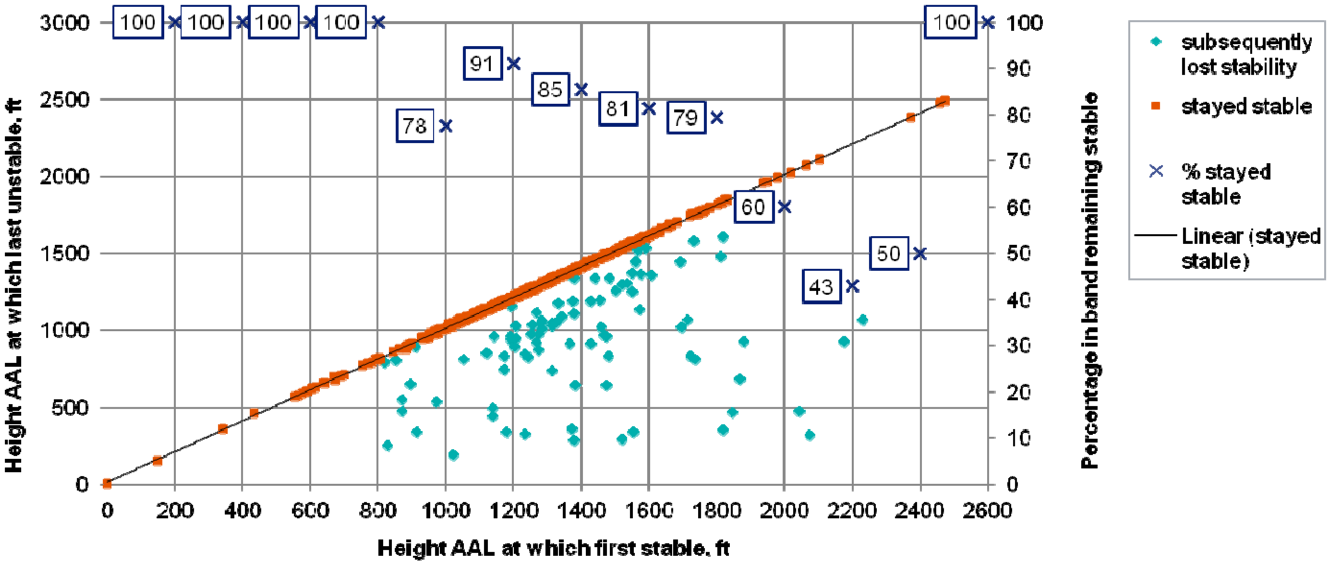


Figure 6: Plot of heights at first stable vs those at last unstable.

Figure 6 shows the height at which each flight first became stable plotted against the height at which it was last unstable. Those points on the diagonal line (573 approaches or 84%) remained stable throughout the approach after the first stable point. This height varied from 2500ft AAL down to the cut-off – so some were obviously candidates for a late stabilisation event.

Those points that lay under the diagonal line (90 approaches or 16%) indicate that after the First Stable point the approach again became unstable. While some of these regained stability at an acceptable height others were again candidates for a late stabilisation event.

Assessing Precision vs Non-Precision Approaches (NPA) and Other types of Approach

It is acknowledged that there are significant differences in the consistency of non-precision vs Precision approaches that have led to past runway excursion accidents. Therefore it is important to (a) determine the type of approach being flown and (b) obtain comparable metrics from both types of approach. For this exercise precision approaches were simply defined as those where the system returned a value for glideslope established height AAL. It should be noted that this results in visual approaches also being counted under the generic title of 'NPA'.

Figure 7 shows the breakdown of the heights at which precision (light columns) vs non-precision approaches (dark columns) were last unstable. This demonstrates that a greater proportion of precision approaches become stable at higher altitudes than non-precision.

Height at which last unstable (AAL ft) for precision vs non-precision approaches

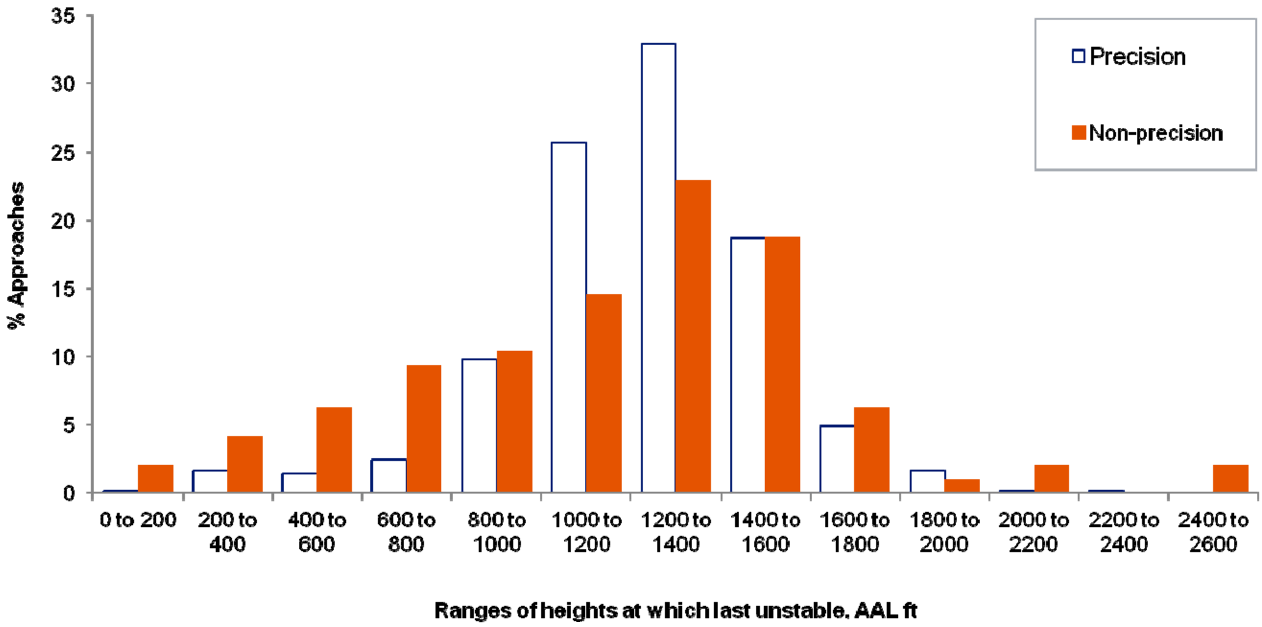


Figure 7: Comparison between heights at which last unstable for precision vs non precision (including visual) approaches.

Landing Distance Measures

The analysis considered three basic measures of distance during the flare and landing phases.

1. Distance from the nominal threshold crossing height of 50ft RALT to touchdown.
2. Distance from nominal flare height to touchdown (20ft RALT for A320).
3. Distance from passing the glideslope aerial to touchdown.

Glideslope signal and radio height (i.e. below 200ft AGL) are used to calculate the distance from passing the glideslope aiming point to touchdown. This method will not however be available on a NPA.

During the initial analysis 225 flights returned a value for the glideslope aiming point to touchdown distance. Figure 8 shows a comparison of the values against the distances from 50ft to touchdown.

Comparison of methods for measuring landing distance: 50ft RADALT to TD distance vs GS Aerial to TD distance

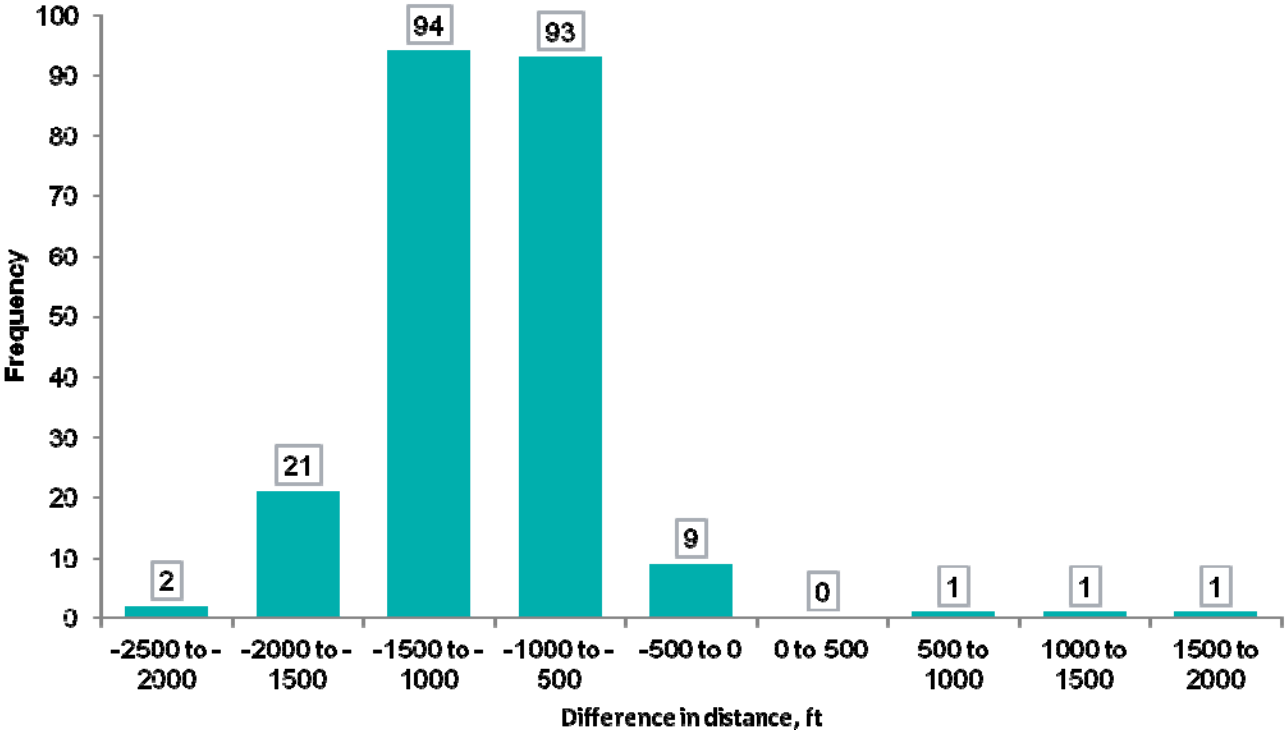


Figure 8: Histogram of differences between glideslope aerial and 50ft AGL to touchdown distances.

This data shows a good relationship between the 50ft and glideslope aerial to touchdown distances. The three positive data points (on RHS of chart) were all found to be due to a false high on glideslope indication. But this aspect has now been improved and is now reliable and has subsequently been used to more accurately detect the runway threshold.

Five examples of apparent deep landings were examined in detail and showed to be valid in four cases but the fifth did not return an excessive glideslope aerial to touchdown distance. This indicates that the 50ft or flare heights, while generally valid, may not be 100% reliable as a datum for landing distances but rather should be used to initiate further investigation.

Other considerations for Touchdown position and landing distances

An accurate GPS derived touchdown position would be ideal for both PA and NPA, especially if then used to determine remaining distance from runway length tables. However, such data is not available on most current aircraft and is therefore a longer term objective. Finally, if this distance could then be related to the predicted braking performance the difference would be an estimate of the safety margin. Finally, a measure of braking deceleration could be used to infer how marginal the crew believed the available distance was.

Investigation into Inclusion of Roll and Power Parameters in the Stability Criteria

To investigate the effect of including Roll and Power in the stable approach algorithm the instantaneous maximum value of roll and the maximum and minimum of N1 were obtained.

In the absence of detailed performance data the stable state trigger values were chosen statistically (outside 2 standard deviations) for N1 were 65% and 30%. Nominal roll angles were selected according to altitude: - above 1000ft (10deg), between 1000 and 500ft (8deg), below 500ft (6deg).

By looking at these parameters during the 15 second stability assessment period it was determined that 30% 158 out of 510) of the first stable points above 1000ft AAL would be changed, 60% (35 out of 59) between 1000 and 500ft, and 25% (1 out of 4) below 500ft.

Changes due to Power or Roll:

limit	first stable (ft):	not changed	changed due to N1/Roll	% changed
N1/Roll	>1000	352	158	30.98
N1/Roll	<=1000>500	24	35	59.32
N1/Roll	<=500	3	1	25.00
N1/Roll	Total	379	194	33.86

Table 4. Changes in First Stable Height due to inclusion of Roll and Power criteria.

Table 4 shows the effect of the inclusion of a power / roll monitor on the first stable points. Low power breaches account for the majority of these changes. If included in a production system it is recommended that an average over a period of seconds would help reduce the nuisance triggers in turbulence. This aspect is still under discussion as to its practicality and reliability. However it is recommended that these aspects are monitored by Operators using applicable pre-existing FDM events (for example, such as those shown in Table 6).

Focusing FDM Oversight onto 'Significant' Precursor Events

It is recommended that events based on each measure should be set to trigger at a significant magnitude such as those shown in Table 5.

It should be remembered that when using the full distributions, bad data may infiltrate them so care must be taken. Therefore these significant events must be fully validated so as to remove false events. In this way the workload associated with each measure will be minimised, whilst assuring data quality.

Condition	**Event Boundary/Limit**	**Notes**
Unstable Approach	below 1000 feet AAL and below 500 feet AAL	Lowest height AAL at which the approach was unstable.
Long Flare	Distance > 2100 feet	From flare height (set at 20ft for A320) to touchdown
Long Landing	Distance > 2500 feet	From runway threshold to touchdown
Fast Landing	CAS > Vapp + 0 knots or Vref + 5 knots	Vapp is used as this trial used Airbus data. Vref would be used on other types. Note event limits may need adjustment.
Runway remaining at Touchdown	< 4000 feet remaining	(Runway length) – (Distance from runway threshold to touchdown)

Table 5. Proposed FDM Precursor Limits.

Role of Routine FDM Events

It is important to note that, in addition to precursors, 'normal' FDM events from current systems are still a key element and should be reviewed to maximise their effectiveness. Table 6 shows a typical list of these events.

Phase	Event Name	Phase	Event Name
Attitude	Abnormal pitch landing (low)	Flight Path	LOC Deviation (FLY LEFT)
Attitude	Excessive bank on approach (<1000ft)	Flight Path	LOC Deviation (FLY RIGHT)
Attitude	Excessive bank on approach (<500ft)	Flight Path	Long Flare (duration from flare height)
Attitude	Excessive bank on approach (<50ft)	Flight Path	Unstable approach (GS variation)
Attitude	Excessive Bank on landing (below Flare Ht)	Flight Path	Unstable approach (LOC variation)
Attitude	Excessive Elevator on Landing	Power	Excessive N1 with Reverse Thrust
Attitude	Inadequate Elevator on Landing	Power	High power on approach
Attitude	Unstable approach (pitch)	Power	Late power cut during flare
Attitude	Unstable approach (roll)	Power	Low power on approach
Configuration	Abnormal Auto-brake Setting	Speed	Approach Speed High (<1000ft)
Configuration	Late land flap (duration)	Speed	Approach Speed High (<1500ft)
Configuration	Late land flap (height AAL)	Speed	Approach Speed High (<500ft)
Configuration	Late land gear	Speed	Approach Speed High (<50ft)
Configuration	Late T/R Deployment	Speed	Approach Speed Low (<1000ft)
Configuration	Manual Landing with A/T	Speed	Approach Speed Low (<1500ft)
Configuration	Overweight Landing	Speed	Approach Speed Low (<500ft)
Configuration	Reduced flap landing	Speed	Harsh Braking (landing)
Configuration	T/R Not Deployed	Speed	High crosswind component (landing)
Flight Path	Deviation above glideslope	Speed	High Tailwind Component (Approach)
Flight Path	Deviation below glideslope	Speed	High Tailwind Component (landing)
Flight Path	Excessive Heading Change (landing)	Speed	Unstable approach (speed variation <1000ft)
Flight Path	High rate of descent (<1000ft)	Speed	Unstable approach (speed variation <1500ft)
Flight Path	High rate of descent (<1500ft)	Speed	Unstable approach (speed variation <500ft)
Flight Path	High rate of descent (<500ft)		

Table 6. Examples of other events to be monitored. Those closely related to proposed measures are highlighted.

A combination of the statistical elements of the precursor measures and the contextual/causal information from these events will best enable the assessment of risk and then target remedial actions.

Summary Data

Once the standardised precursor measures have been implemented thought must be given to the aggregation, analysis and presentation of the results.

For example:

- Measures of exposure by airfield, runway, fleet
- Frequencies/probabilities of events by airfield and runway
- Values and context data (e.g. airfield, runway, type of approach) for each event

This data should be output in a standard database/spreadsheet format to allow further analysis and also aggregation with other operators' data if agreed. Table 7 gives an example of one potential layout.

Individual Events	Airfield	Runway	NPA or PAPP	Aircraft type	Ht First Stable	Ht Last Unstable	Flare Distance	Landing Distance	Touchdown Speed
Unstable Approach Below 1000ft AAL									
Long Flare									
Long landing									
Fast Landing (vs Vapp or Vref)									

Operating Statistics	Airfield	Runway	NPA or PAPP	Aircraft type	No of Deps

Overall Event Rates	All Airfields	All Aircraft Types	NPA or PAPP	Aircraft type	Rate per 1000 flts
Unstable Approach Below 1000ft AAL					
Long Flare					
Long Landing					
Fast Landing (vs Vapp or Vref)					

Overall Event Rates	Airfield	Runway	NPA or PAPP	Aircraft type	Rate per 1000 flts
Unstable Approach Below 1000ft AAL					
Long Flare					
Long Landing					
Fast Landing (vs Vapp or Vref)					

Table 7. Examples of Potential Summary Reports.

Conclusions

Flight Data Monitoring (FDM) is the systematic, pro-active and non-punitive use of digital flight data from routine operations to improve aviation safety. CAA's long experience with FDM derived information has shown it to have great potential as a reliable information source when considering exposure to aviation risk scenarios. By developing a set of targeted, reliable and consistent measures the CAA seek to contribute to direct Operator action to mitigate against real risks.

The significant seven safety issues, identified by CAA and widely acknowledged by industry, cover the main categories of occurrence identified in aviation accidents that result in potentially catastrophic outcomes: Airborne Conflict, Airborne and Post-Crash Fire, Controlled Flight Into Terrain (CFIT), Loss of Control, Ground Handling, Runway Excursion and Runway Incursion/Ground Collision. Specifically, FDM lends itself well to monitoring issues related to Airborne Conflict, Controlled Flight Into Terrain (CFIT), Loss of Control and Runway Excursion. This work focuses on one element of Runway Excursions, identified by industry as one of the priority issues at the Safety Conference in 2010. It is intended that other significant seven safety issues will be looked at through further work in the future.

The objectives of this Project are to:

1. Demonstrate the effectiveness of a standardised FDM module to help Operators, individually and as a group, better monitor and act upon identified high risk issues, in this case that of Landing Runway Excursions, through their SMS;

2. Encourage the use of such FDM analysis techniques by the wider UK Industry to monitor and address these issues; and

3. Gain an FDM overview of high risk issues through co-operation with Operators using such techniques on Runway Excursions.

Current, highly capable FDM analysis tools can be improved to produce reliable measures that will help Operators track their risks including in this case those relating to landing runway excursions, one of the CAA's significant seven issues.

The FDM system is a complex matrix of system and user set conditions and constants that can have significant consequences on the output. The trial showed that there were a number of issues with this particular implementation that initially affected the data from the approach analysis but which were addressed by program changes and adjusted constants.

Starting from the Aerobytes FDM system it is recommended that Operators use the following measures (state values) and implement the event limits (see Table 5) and stable approach criteria suggested below:

- Height First Stabilised
- Height Last Unstabilised and parameter last outside stability limits
- Distance from 20ft AGL to Touchdown
- Distance from runway threshold to touchdown
- Speed at Touchdown vs Target Approach Speed (Airbus: Vapp or Other: Vref)
- Ground Speed at Touchdown
- Runway distance remaining (Runway length minus T/D distance)

Stable Approach Algorithm Criteria	Limit
Stable Appr - Airspeed vs Estimated (max)	15 kt
Stable Appr - Airspeed vs Estimated (min)	-5 kt
Stable Appr - Airspeed vs Selected (max)	15 kt
Stable Appr - Airspeed vs Selected (min)	-5 kt
Stable Appr - Airspeed vs Vapp (max)	15 kt
Stable Appr - Airspeed vs Vapp (min)	-5 kt
Stable Appr - Airspeed vs Vref (max)	20 kt.
Stable Appr - Airspeed vs Vref (min)	-5 kt
Stable Appr - Heading Range	45 deg
Stable Appr - ILS G/S Dev (max)	1 dot
Stable Appr - ILS G/S Dev (min)	-1 dot
Stable Appr - ILS LOC Range	1 dot
Stable Appr - RALT cut-off for Airspeed	100 ft
Stable Appr - RALT cut-off for ILS	100 ft
Stable Appr - RALT cut-off for Vertical Speed	100 ft
Stable Appr - Selected Speed vs Airspeed hi	10 kt
Stable Appr - Selected Speed vs Airspeed lo	-30 kt
Stable Appr - Sink-rate (max)	1000 fpm
Stable Appr - Sink-rate (min)	200 fpm
Stable Appr - Window Duration	15 secs

To support the measures, both airport and runway movement statistics should be retained to differentiate between various types of approaches e.g. Precision and Non Precision.

A combination of the statistical elements of the precursor measures and the contextual/causal information from these events will best enable the assessment of risk and then target remedial actions.

In the future, higher resolution GPS data on touchdown points should be used to develop measures of safety margins e.g. length of runway remaining.

Finally, while expanding the application to other types for both measures and events it would be helpful if aircraft manufacturers could add insight into braking performance estimation so as to bring a risk assessment measure within reach.

Software Developments Subsequent to Initial Analysis

Following the initial analysis a number of useful improvements and refinements were incorporated into the system:

- The detection of false glideslope signals and of the glideslope aerial position has been enhanced.
- A nominal three degree 'virtual' glideslope has been added as a derived parameter to help monitor the flight path of non-precision approaches.
- The system's glideslope detection together with the use of a runway database enables the system to indicate which type of approach was flown Precision, RNP, ILS, NPA or visual.
- To improve the accuracy of the analysis of basic numeric parameters user configurable linear interpolation has been added.

A series of landing distance measures have been incorporated into the system to enhance understanding of the potential for a landing overrun:

- A more robust distance measure has been developed. If the runway supports ILS and the glideslope signal is sufficient to detect the glideslope aerial then the system will use this point on the ground as a physical reference and calculate distance from the aerial until touchdown plus the distance of the aerial from the threshold. Otherwise the system will attempt to lookup the threshold crossing height for the runway and calculate the distance from the point the aircraft passes through that altitude (corrected PALT is used if RALT is not recorded) to touchdown. In the rare case that none of the above data is available, the system assumes that the aircraft touched down perfectly (approximately 1000ft from threshold).
- The system's runway information database is used to estimate the runway distance remaining following touchdown.
- Runway remaining distances, both the actual and also that required, based on nominal longitudinal acceleration values.
- There are also measures that calculate the braking acceleration, both experienced and required.

Future Industry Implementation of these Ideas

A Supplement detailing the technical specification of the items discussed in this report will be provided to those Operators and FDM system suppliers wishing to incorporate these into their operational flight data monitoring systems. The supplement will include sufficient information to enable incorporation by both Aerobytes and other FDM system users. It is recommended that the proposed measures and events are implemented by UK Operators to complement their existing FDM programmes.

Publications for Further Consideration

Report no. NLR-TP-2005-498: 'Running out of Runway Analysis of 35 years of landing overrun accidents' [G.W.H. van Es, National Aerospace Laboratory NLR, August 2005]

DOT/FAA/AR-07/7: 'A Study of Normal Operational Landing Performance on Subsonic, Civil, Narrow-Body Jet Aircraft During Instrument Landing System Approaches' Final Report [FAA, March 2007]

Report no. NLR-TP-2009-280: 'Development Of A Landing Overrun Risk Index' [G.W.H. van Es, K. Tritschler (Germanwings), M. Tauss (University of Applied Sciences Bremen), NLR Air transport Safety Institute Research and Consultancy, June 2009]

'Runway Excursion Risk Assessment Diagram' - prepared for the FSF 64th annual IASS, Singapore, November 2011 [Pere Fabregas Camara, Flight Data Analysis/Safety Department, Vueling Airlines S.A.]