Office for Nuclear Regulation

ONR Technical Advisory Panel on Accidental Aircraft Crash Hazard Assessment

Final Report - May 2015

Chief Nuclear Inspector's Foreword

It is my pleasure to present this report of the Technical Advisory Panel on Accidental Aircraft Crash Hazard Assessment. The Panel was established in 2012 to provide independent, objective, and authoritative advice to the Chief Nuclear Inspector and to explore potential improvements to existing methodologies for calculating accidental aircraft crash frequency.

The panel has deliberated over a period of two years and has called upon scientific, technical and regulatory specialists to support its deliberations so that it could fully explore the state of the art in this area.

Whilst ONR remains responsible for regulatory decisions, it takes due cognisance of any advice provided. It is in this spirit that I fully endorse the conclusions of the panel and I commit to implementing the recommendations.

I would like to express my gratitude to the panel for their commitment, professionalism and technical insight to this complex and challenging area.

Andy Hall
Chief Nuclear Inspector
Office for Nuclear Regulation

Contents

1 Introduction

1.1 Background

ONR routinely seeks advice from technical experts to support its own in-house expertise in undertaking nuclear regulatory activities. From time to time a technical issue arises where it is considered advantageous to take advice from a broad range of relevant expertise. ONR remains responsible for regulatory decisions, however it takes due cognisance of any advice provided.

In July 2012, the then Chief Nuclear Inspector took a decision to convene a Technical Advisory Panel (TAP) on the topic of accidental aircraft crash. He considered that whilst there was confidence in existing methodologies, there would be value in exploring potential improvements to the methods for calculating accidental aircraft crash frequency. The TAP was convened in order for its members to provide independent, objective, authoritative, professional scientific and technical advice to the Chief Nuclear Inspector in the area of accidental aircraft crash hazard assessment.

1.2 Purpose and Scope

The purpose of the panel was to:

- Provide independent, objective, authoritative, professional scientific and technical advice to the Chief Nuclear Inspector in the area of accidental aircraft crash hazard assessment.
- Provide relevant, state of the art advice to address the particular issues or questions that were posed to it, and to obtain specialised technical opinion as needed.
- Advise on the state of scientific and technical knowledge related to each area, highlighting implications where relevant.
- Interact in a complementary manner with other relevant scientific and technical bodies to provide expert technical advice as requested in a timely manner.
- Identify areas of uncertainty, emerging issues and knowledge gaps, and suggest research needs.

Terms of Reference (ToR) for the panel are set out in **Annex A**.

1.3 Objectives

In order to deliver the Chief Nuclear Inspector's requirements, the TAP set itself the following objectives during its first meeting:

- Provide a view on the limitations of the existing Byrne method and the practical impact of those limitations.
- Identify aspects of 'good practice' in application of the Byrne Method to reduce those limitations.
- Provide an appreciation of other extant methodologies available and their associated limitations.
- Identify those methods which would be seen as good practice and if possible best practice.
- Identify any future research needs.

1.4 Membership

The ToR set out the principles for forming the panel. The panel was required to have:

- Recognised technical leadership in the fields of:
  - Accidental aircraft crash risk assessment methodologies
  - Air crash data statistics
  - Aerodrome operations and regulation (licensing)
  - Flight operations and regulation
  - External hazards assessment methodologies
- An affiliation balance of technical expert nominees from a variety of stakeholders including academia, professional societies, non-government organisations, nuclear industry, wider industry, etc.

Letters were issued to a number of government and non-government organisations inviting them to nominate an expert member to the TAP. The following formed the basis of the organisations approached:

- Civil Aviation Authority (CAA)
- Air Accident Investigation Bureau
- Military Air Accident Investigation Bureau
- Academics Specialising in Transport Risk
- Engineering Institutions
- Consultants in the field of Aircraft Risk Assessment
- Consultants in the field of External Hazard Risk Assessment
- NGO (Lydd Airport Action Group)

- Defence Nuclear Safety Regulator
- Nuclear Industry Safety Director's forum

Nominated technical experts were required to act according to their professional discipline in line with the ToR, not as representatives of the party who nominated them. Membership of the TAP has adapted to the panel's findings and requirements throughout its lifetime (Table 1).

Table 1: Summary of TAP membership

Name	Role/Affiliation	Meeting Attendance
Tim Allmark	Acting Chair - Office for Nuclear Regulation	1–6
Peter Ackroyd	Meeting Facilitator - Office for Nuclear Regulation	3, 4
Matt Lloyd Davies	Technical Secretary - Office for Nuclear Regulation	3–6
[redacted]	[redacted]	[redacted]
Steve Daniel	Panel Member - Magnox (Safety Director's Forum Nominee)	1
Ian Dugmore	Panel Member - UK Airprox Board (UKAB)	2, 3
Malcolm Goodwin	Panel Member - ABS Consulting	1–6
Matthew Greaves	Panel Member - Cranfield University	1, 2, 4–6
Sid Hawkins	Panel Member - Air Accident Investigation Branch	1–6
Roger Jackson	Panel Member - AMEC (on behalf of Defence Nuclear Safety Regulator)	1–6
Michael Johnson	Panel Member - EDF Energy (Safety Director's Forum Nominee)	5
David Pitfield	Panel Member - Loughborough University	2–6
Malcolm Spaven	Panel Member - Aviatica (Lydd Airport Action Group (LAAG) nominee)	1, 3–5

The CAA has provided information on request to the TAP wherever possible via Sid Hawkins.

2 Summary of activities

There were a range of activities planned to ensure that the panel was able to explore this technically complex subject as far as it deemed necessary, and fully articulate its conclusions and recommendations.

The activities centred around a series of six meetings, the details of which are summarised below.

2.1 Meetings

The TAP met six times between 15 November 2012 and 29 October 2014.

Meeting 1 – 15 November 2012 – Introductory
This meeting allowed TAP members to share their background and to identify the particular areas of knowledge/expertise of each panel member in more detail.

Meeting 2 – 1 February 2013 - Direction setting
This meeting was held to discuss what data and methods were available for assessing accidental aircraft crash hazards, and how best to move the objectives of the TAP forward.

Meeting 3 – 3 April 2013 - Technical presentations
A series of presentations were given to provide an account of the state of the art in aircraft crash hazard assessment and regulatory requirements placed on nuclear licensees for considering accidental aircraft crash. Details of the presentations are given in Section 2.2

Meeting 4 – 2 May 2013 – Workshop
The workshop session allowed panel members the opportunity for analysis and discussion of the data and information that had been presented to the TAP at the preceding meetings. Details of the workshop session are given in Section 2.3.

Meeting 5 – 13 March 2014 – Research
Research commissioned by the TAP was presented to the panel by the Health and Safety Laboratory (HSL) and Loughborough University (LU). A presentation was also made by former panel member [redacted] on a broad range of matters relating to accidental aircraft crash. Details of the presentations are given in Sections 2.2 and 2.4.

Meeting 6 – 29 October 2014 - Conclusions and recommendations
This meeting followed a consultation exercise in which panel members were asked to provide their views on the TAP's progress against its objectives, and whether or not they considered the panel to be in a position to provide conclusions and recommendations to the Chief Nuclear Inspector. The TAP concluded that it had reached the end of its deliberations and that it had an agreed set of conclusions and recommendations that it would be content to present to the Chief Nuclear Inspector.

2.2 Specialist technical presentations

Airprox brief to ONR Technical Advisory Panel

Ian Dugmore (UKAB) provided an overview of the work of the UKAB including details of its membership and the methodologies it uses to investigate Airproxs. He also provided a summary of the Board's key outputs and investigation results that were considered to be of interest to the panel. The presentation concluded that most Airproxs suffered underlying human factors causal elements, but that the limited data set made it difficult to identify any significant new or emerging trends.

As Low As Reasonably Practicable (ALARP) and numerical targets

Geoff Grint (ONR) delivered a presentation giving guidance on the principle of ALARP and the use of numerical targets as set out in ONR's Safety Assessment Principles (SAPs). The link between legal requirements, and the tools available to ONR to measure compliance with the law were detailed and it was concluded that ONR's SAPs and Technical Assessment Guide (TAG/005) were consistent with the Health and Safety at Work Act 1974 and HSE's publication *Reducing Risks Protecting People*. It was also noted that ONR uses the Tolerability of Risk framework for risk based decisions.

Modelling the frequency, location and consequences of aircraft accidents

David Pitfield (Loughborough University) provided a detailed description of the airfield risk modelling approach developed by his team at Loughborough University. Modelling accidental aircraft crashes involves three components: a frequency model, a location model and a consequences model. The results presented were the output from three doctorate studies investigating the modelling of frequency, location and consequences of accidental aircraft crash. Data was obtained from a very broad range of international sources with preliminary statistical analysis being conducted by a third party in the US. Detailed results were presented for the frequency and location models which have been developed to a greater extent than the consequences model.

Statistical modelling of crash probabilities

Guest speaker Roberto Trotta (Imperial College London) provided a summary of his work for Lydd Airport Action Group in reviewing the statistical approach used by the Byrne methodology in modelling airfield crash risks. Dr Trotta elaborated his position that the Byrne method suffers from fundamental methodological problems and proposed advanced statistical modelling techniques that he considered to be more robust and consistent.

Statistical modelling of the frequency and location of accidental aircraft crashes within Great Britain

Nick Warren (HSL) provided a summary of the work undertaken by HSL to support the TAP. Further details are given in Section 2.4.

2.3 Workshop

Strengths and weaknesses of the Byrne methodology

The TAP formed two syndicates, each of which was asked to identify strengths and weaknesses of the Byrne methodology. The following list summarises the aggregated weaknesses of the Byrne methodology identified by the syndicates:

- There is a notable disparity between the amount of data in the three aircraft crash categories (background, airways, and airfield). Background and airways data are considered to be similar and there is a relative sparsity of data in these categories compared to airfield crash data.
- There is a broad range of global and local factors, and so accident rate may not be the most appropriate variable to quantify.
- The model has not evolved with time e.g. flight patterns have changed.
- There is a lack of confidence in the calculated values because there is no quantification of uncertainty.
- The methodology uses only narrow UK data sets, and data available elsewhere e.g. CAA, is not used.
- The model is quite generic and doesn’t take account of some local factors.
- There is inflexibility in the methodology e.g. a straight approach to the runway is assumed and no account can be taken of any increased risk from a curved final approach.

- The ‘type’ thresholds as defined by aircraft weight are arbitrary.
- The extent of airfield thresholds is arbitrary.
- The methodology cannot distinguish between risks in controlled and uncontrolled airspace.
- Different operational environments are not accounted for.

The following list summarises the aggregated strengths of the Byrne methodology identified by the syndicates:

- The methodology distinguishes between airfield and ‘other’ crashes.
- It is a simple method.
- It is a crude estimation tool to demonstrate low probability of occurrence.
- The methodology uses real data, which implies ‘real’ risk rather than purely theoretical risk.
- The methodology is relatively updateable.
- It is easy to perform a sensitivity analysis on the key parameters.
- It allows for different categories of accidents.

Fitness for purpose

The TAP discussed the adequacy of the Byrne methodology, initially focusing on what the Licensees’ requirements are for a methodology to determine aircraft crash hazard. The TAP identified the following as positive characteristics of a model:

- Simplicity.
- Ability to calculate and model low frequency events; frequency is important to acceptability.
- Ability to estimate target area.
- Ability to account for site specific local factors e.g. proximity to an air field.
- Acceptability of methodology to ONR.

The TAP concluded that the Byrne methodology is useful at modelling crash frequency around airports in a general way. However, there are some local factors that it does not address. For example, the issue of military aircraft crash data in the Byrne methodology is problematic; there is very little data to inform the model effectively and it is difficult to separate ‘genuine’ data from ‘outlier’ data. However, there are some sites for which the military aircraft category is a significant local factor that should be included in their crash rate model.

The TAP considered that there were no known better methods. However, it was recognised that this was possibly due to the limit of knowledge of the TAP, rather than a lack of available methods/models. It was suggested that the TAP may need to be informed by a programme of work to address this shortfall.

The TAP concluded that it could not usefully (within the limitations of time and resource available) undertake any further meaningful deliberations until targeted research had been undertaken on some aspects of the data and methods used in calculating accidental aircraft crash risk. It therefore proposed commissioning research to address the knowledge gaps identified by its discussions.

2.4 Targeted research

A detailed scope of work was prepared and invitations to tender were issued to a number of organisations. In establishing the scope of work, the TAP posed the following research questions:

1. What is the frequency of military and non-military aircraft crashes in Europe, the US and other regions considered to be representative of UK operations, over the past 10 years and what were the operational environment characteristics?
2. How can datasets be screened to identify those events that are most relevant to the UK?
3. How can the likelihood of airfield and non-airfield related crashes be statistically modelled as a function of airfield proximity and on a per km/year basis respectively?
4. What extant models are available to estimate the likelihood of accidental aircraft crash at a particular location, what are their key characteristics and what scope is there for potential further development?
5. How can the aleatory and epistemic uncertainties associated with aircraft crash data and aircraft crash models be quantified?
6. How does the Byrne methodology compare with other methodologies, and can it be enhanced with larger contemporary datasets?

Following an evaluation of the tenders received, ONR proposed a joint project between HSL and LU. Both organisations concluded their work in February 2014 and presented their findings and recommendations to the TAP during Meeting 5; a summary of the findings and recommendations is given in Section 3.2.

2.5 Consultation exercise

In June 2014, having had time to consider the findings and recommendations of the HSL/LU research report, ONR wrote to TAP members seeking their views on a proposed way forward. The panel was asked to consider the original aims and objectives as set out by the Chief Nuclear Inspector, and the progress made against them. The following questions were put to the panel with a view to seeking consensus on the current position and way forward.

1. Has the TAP met the Chief Nuclear Inspector's aims?
2. Has the TAP met its objectives?
3. Do you agree that there are some technical areas (listed above) that the TAP has not addressed in sufficient detail?
4. Do you consider the TAP should deliberate further on all or some of those technical areas not addressed (listed above)?
5. Are there any other technical areas you consider should be investigated?
6. Has the LU/HSL research report met your expectations?
7. Do you support the report's conclusions and recommendations?
8. Do you agree there is a need for further work?
9. Do you agree with the areas proposed by ONR for further investigation?
10. Are there other areas for investigation or research questions you believe should be addressed?

The consultation responses were collated, summarised and presented to the TAP during Meeting 6 with a view to seeking consensus on the current position and agreeing the way forward. Having achieved this, the TAP agreed that it had reached the end of its deliberations and that it had an agreed set of conclusions and recommendations that it would be content to present to the Chief Nuclear Inspector. Details of the consultation output and the TAP's conclusions and recommendations are given in Section 3.3.

3 TAP Outputs

3.1 Airways Data Error

In Meeting 3, [redacted] brought to the attention of the TAP an apparent error relating to the statistical analysis of crash risk arising from airways data that had been identified in [redacted] review of *The Calculation of Aircraft Crash Risk in the UK*.[1]

ONR commissioned an independent review that revisited the in-flight reliability estimates presented in the report and found that they were a factor of 12 lower than is consistent with the data on which they are based. The data covered a 12 year period and it would appear that an erroneous reduction by a factor of 12 occurred, perhaps by use of the annualised crash rate divided by the total number of kilometres flown in the 12 year period.

Subsequently, ONR wrote to all licensees requesting them to review safety cases that reference or use results or data from the report, either directly or indirectly. For those licensees affected by the error, none of the required corrections were found to lead to a significant change in the aircraft crash frequency calculation. All licensees are now aware of the error and have committed to ensure that it is corrected within their internal arrangements.

ONR's assessment is that all licensees have provided an adequate response to the notification of the aircraft crash analysis data error and no safety cases are undermined by the error. ONR considers that the matter of the aircraft crash error is satisfactorily resolved and no further regulatory action is required.

3.2 Research findings and recommendations

The research undertaken by HSL and LU covered two broad themes: a comparison of available models, and a statistical analysis of aircraft crash rates and location distributions.

1 JP Byrne, The Calculation of Aircraft Crash Risk in the UK, AEA Technology, HSE Research Report 150/1997 (1997). TRIM 2012/340223

- Chelapati (1972)
- Hornyik (1974)
- NUREG-0800 (1975 onwards)
- Solomon (1988)
- Kobayashi (1988)
- David (1990)
- DNV (1990 onwards)
- NLR (1993 onwards)
- BERG (2011)
- LLNL (1993 onwards)
- US DOE (1996 onwards)
- Byrne (1997 onwards)
- NATS (1997 onwards)
- TÜV SÜD (2001)
- Loughborough (2001 onwards)
- Bienz (2004)
- GFL (2006)
- ENAC(2012)

Key findings: Methods

The models studied exhibit a range of strengths and weaknesses.

All of the models suffer from either an inability to consider all types of aircraft, or they do not take local flight paths into account if the site is within the vicinity of an aerodrome. Most of the methods fail to quantify the overall uncertainty in estimated crash probabilities.

The Byrne methodology is the model most commonly used in the UK nuclear industry. Its capabilities are summarised in Table 3 below.

Table 2: Strengths and weaknesses of the Byrne methodology

Does consider	Does not consider
Shadow shielding of part of a site by structures on another part of the site	Hazardous materials carried on-board the aircraft
Skidding of an aircraft onto a site	Smaller aircraft such as gyrocopters, gliders, airships, and balloons
Projectile bounce of an aircraft making its initial impact outside the site	Curved flight paths
Debris falling from aircraft	Quantification of uncertainty
Remotely piloted aircraft systems	

Two models (Loughborough (Wong) and US DOE) identified risk factors relating to meteorological conditions, which are based on data rather than an assumed causal mechanism, and are considered to be reliable for application to Great Britain.

The model with the greatest ease of application is the DOE standard model, allowing non-aviation specialists to take account of site-specific factors more easily than applying the Byrne model. The model includes a tabulated set of data that is relatively easy to apply on a site specific basis. It would also be possible to expand the concept to a Geographic Information System to highlight the aviation risk exposure over the whole of Great Britain.

It may be possible to combine the strengths of several models to understand better the risks associated with accidental aircraft crash. However, it should be cautioned that the effort involved in achieving this may not provide a significant benefit.

Key findings: Data

The following findings were made by HSL/LU when considering aircraft crash data:

- Statistical analysis of aircraft crash data for Great Britain for the period 1985 to 2006 found no evidence of a change in the background annual rate of crashes (expressed per km^2) for any of the aircraft categories considered[2].
- Statistical analysis of civil aerodrome-related crashes for Great Britain for the period 1979 to 2006 found no evidence for a change in the rate of crashes for small and large transport aircraft.
- A statistically significant increase in the accident rate for light aircraft of 4.4% and in the accident rate for helicopters of 4.7% per year was found.
- Based upon accidents between 1985 and 2006 the estimated background crash rate was greatest for England. Based upon accidents between 1979 and 2006 the estimated aerodrome-related crash rates were similar across England, Scotland and Wales, hence the Great Britain rates may be used.

A variation on the Byrne methodology, in which statistical uncertainty was taken into account, was investigated as part of the HSL/LU study. Standard statistical methods were used to derive revised crash rates and location distributions to estimate the probability of an accidental aircraft crash at a location in the vicinity of Lydd airport.

Whilst the TAP was prevented by its terms of reference from considering specific sites, the work undertaken by HSL and LU was an independent research project not bound by the same restrictions. The research team independently selected Lydd airport for its case study because data on aircraft movements were readily available for that airfield.

A comparison of the total crash frequency per year using the Byrne model with the HSL method shows that although the individual contributions from landing and take-off crashes differ, for the location being considered, the differences cancel each other out when the

2 Due to the low number of accidents in the small and large transport aircraft categories the statistical power to detect any trend over time is low.

risk from background crashes, landing movements and take-off movements are combined to give an annual aerodrome-related crash frequency.

Research recommendations

The HSL/LU report made 18 recommendations to the TAP. The TAP considered each of these recommendations and engaged in detailed discussion of each during Meeting 6. **Annex B** lists the recommendations and summarises the TAP's comments.

3.3 Review of progress against Scope and Objectives

Section 2.5 sets out the questions put to members of the TAP during the consultation exercise. In response to questions 1 and 2, relating to the TAP having met the Chief Nuclear Inspector's objectives, and its own objectives, the response was consistent. Members felt the objectives in both cases had been met. However, there were some comments provided. Some members felt the panel's deliberations could have been enhanced with representation from the military and earlier involvement of end-users. A lack of consideration of military aircraft flying patterns was cited as a potential shortfall.

Members generally agreed that the TAP had addressed the technical areas that it set out to address (Question 3), and that no further action on these areas was needed (Question 4), although some members identified additional technical areas that could be explored (Question 5). However, this was accompanied by a warning that any additional work should be considered in the context of ALARP, and should be proportionate to any potential improvements in risk evaluation methodology. The additional technical areas identified were:

- Look ahead to future aviation trends rather than focus on historical data.
- Greater consideration of local factors.
- Formal definitions of aircraft and airspace categories.
- Analysis of military aircraft data.
- Data screening methods/decision making.

All members agreed that the LU and HSL research reports met their expectations and the project specifications (Question 6). The TAP found it particularly helpful to include a measure of confidence in calculated risk values.

The TAP generally supported the report's conclusions and recommendations (Question 7). However, there was again caution that a decision on taking up the recommendations should be considered in the context of ALARP, and that any additional work should be proportionate to any potential improvements in risk evaluation methodology. Annex B summarises the TAP's comments in relation to each recommendation.

Some members identified potential areas of further work (Question 8), with the previously stated caution relating to ALARP and proportionality. These included:

- Consideration of local factors, including meteorological effects.
- Flight density around nuclear sites.
- Lateral distribution of crashes.

Identification of potential further work

From the consultation responses the TAP summarised the following areas for potential further consideration (Questions 9 and 10):

- Consideration of military aviation training activity and crash data.
- Effect of local factors, including meteorology, on crash data.
- Selection of data sources and development of screening methods to ensure the most appropriate data is used in risk calculations.

An overwhelming message from the TAP membership is that any future work, including taking up recommendations from the research report, should be considered in the context of ALARP, and that any additional work should be proportionate to potential improvements in risk evaluation methodology.

3.4 TAP Recommendations

In Meeting 6, the TAP considered the output of the consultation exercise and the research report with a view to forming a consensus on the advice and recommendations the TAP should make to the Chief Nuclear Inspector.

Throughout its discussions, the TAP was mindful of ONR's principles of enforcement, and in particular, the need to ensure that its advice and recommendations were proportionate to the risks being considered.

The TAP agreed that the Byrne methodology for quantifying accidental aircraft crash hazard was broadly acceptable. However, the panel identified a number of factors that should be considered by licensees to support the overall assessment of aircraft crash hazard, including:

- Local factors such as meteorology, aerodrome specific flight paths, local habitat etc should be considered on a site-by-site basis.

- Assessments should consider anticipated future aviation trends, rather than relying solely on historical data.
- Definitions of aircraft and airspace categories should be agreed between the nuclear industry, the aviation industry and the regulator.
- Greater consideration should be given to military aircraft combat, in particular, sourcing appropriate data.
- Decision making processes and methods for screening data should be established to produce the most reliable datasets on which to base assessments.

The TAP also agreed that whilst further effort would be required to understand the effect of local factors, flight density around nuclear sites and lateral distribution of crashes, any additional work should be proportionate to the benefit gained. To this end, the TAP advised that a group of interested parties should be convened to consider these matters in the context of the regulatory framework within which they operate.

Recommendation 1:
The Byrne methodology is considered fit for purpose and ONR should continue to accept it as an appropriate tool for supporting the overall assessment of accidental aircraft crash hazards at nuclear licensed sites.

Recommendation 2:
A forum should be established comprising representatives from the CAA, ONR, MoD and nuclear site licensees to allow the effective exchange of information on changes in flight patterns, operational activities, crash data, and other relevant topics, such that licensees are able to ensure they have taken account of current and emerging trends in aviation risk.

The TAP also advised that ONR should take account of the TAP's findings in its assessment of licensee safety documentation.

Recommendation 3:
ONR's Technical Assessment Guide on external hazards should be updated to reflect knowledge gained during the course of the TAP's deliberations.

The TAP advised that its findings and recommendations should be brought to the attention of nuclear Licensees through the Safety Director's forum.

Recommendation 4:
The outcome of the TAP should be shared with industry through the Safety Director's forum.

4 Conclusions

The TAP, through this report, offers its independent, objective, authoritative, professional, scientific and technical advice to the Chief Nuclear Inspector in the area of accidental aircraft crash hazard assessment. The TAP has deliberated over a period of two years and, as necessary, has called upon relevant scientific, technical and regulatory specialists to provide further expert advice, so that it could fully explore the state of the art in the topic.

A survey of 18 models for assessing accidental aircraft crash risk was conducted. All were found to have individual strengths and weaknesses with no one model standing out as having more favourable characteristics than the others. The Byrne model, which is the most commonly used methodology in the UK nuclear industry, was found to be at least as strong as any other in its ability to quantify accidental aircraft crash risk.

There was consensus amongst the panel that the Byrne methodology is fit for purpose but that it could be enhanced by learning from other available models, and the other factors identified by the TAP during the course of its deliberations. However, the TAP cautioned that any proposed changes or additional work must be proportionate to the benefits gained.

A statistical analysis of available crash data found there is no evidence of a change in the background annual rate of crashes for any of the aircraft categories considered, or in the rate of crashes for small and large transport aircraft. However, there has been a statistically significant increase in the accident rate for light aircraft and helicopters. Crash rates for Great Britain as a whole (rather than England, Scotland and Wales separately) can be used reliably.

The analysis also found significant uncertainty in the probability of aerodrome related crashes at large distances from the runway, due to a lack of data. Furthermore, for crashes after take-off, ignoring any correlation between lateral and longitudinal crash distances leads to an underestimation of the crash probabilities at large distances from the runway threshold and centreline.

The TAP identified a number of areas that it considers should be addressed as part of a Licensee's overall safety assessment for accidental aircraft crash risk, including but not limited to, local factors, future aviation trends, and data selection and use.

The TAP has considered the totality of evidence presented to it and makes the following recommendations to the Chief Nuclear Inspector:

1. The Byrne methodology is considered fit for purpose and ONR should continue to accept it as an appropriate tool for supporting the overall assessment of accidental aircraft crash hazards at nuclear licensed sites.
2. A forum should be established comprising representatives from the CAA, ONR, MoD and nuclear site licensees to allow the effective exchange of information on changes in flight patterns, operational activities, crash data, and other relevant topics, such that licensees are able to ensure they have taken account of current and emerging trends in aviation risk.
3. ONR's Technical Assessment Guide on external hazards should be updated to reflect knowledge gained during the course of the TAP's deliberations.
4. The Safety Director's Forum should be used as a vehicle for disseminating the findings of the TAP to nuclear site Licensees and for overseeing the group identified in recommendation 1.

The TAP considers that it has reached the end of its deliberations and that it is content for these recommendations to be presented to the Chief Nuclear Inspector as the output of its work.

Annex A

Terms of Reference

ONR Technical Advisory Panel terms of reference

The Technical Advisory Panel (TAP) is to provide independent, objective, authoritative, professional scientific and technical advice to the Chief Nuclear Inspector in the area of accidental aircraft crash hazard assessment.

The TAP shall provide relevant, state of the art advice to address the particular issues or questions that are posed to it, and to obtain specialised technical opinion as needed.

The TAP shall advise on the state of scientific and technical knowledge related to each area, highlighting implications where relevant.

The TAP shall interact in a complementary manner with other relevant scientific and technical bodies to provide expert technical advice as requested in a timely manner.

The TAP shall identify areas of uncertainty, emerging issues and knowledge gaps, and suggest research needs.

Discussions and advice provided by the TAP may be released under the government's principles of freedom of information, subject to security review and classification.

The TAP will be chaired by ONR Chief Nuclear Inspector or the Deputy Chief Nuclear Inspector.

The composition of the TAP shall reflect:

- Recognised technical leadership in the fields of:
  - Accidental aircraft crash risk assessment methodologies
  - Air crash data statistics
  - Aerodrome operations and regulation (licensing)
  - Flight operations and regulation
  - External hazard assessment methodologies
- An affiliation balance of technical expert nominees from a variety of stakeholders including academia, professional societies, NGOs, nuclear industry, wider industry, etc (technical experts nominated would be required to act according to their professional discipline

in line with these Terms of Reference not as representatives of the party who nominated them);

- Independence from government

Panel members are expected to act as individuals and to provide objective, independent advice.

Panel members should:

- Conduct themselves with integrity and honesty and not misuse their position on the TAP or information acquired in the course of their participation to further their personal interest or those of others.
- Not receive benefits of any kind which others might reasonably see as compromising their personal judgement or integrity. They should not, without authority, disclose information which has been communicated in confidence or received in confidence from others.
- When talking to the media as an expert in their own right must not claim their views are representative of the TAP or allow that impression to be created.

Proposed Technical Areas and Sub Topics

- Methodologies for the prediction of accidental aircraft crash risk
- Current practice and the state of art;
- Case studies for the definition of public safety zones and precedents set;
- Limitations of the Byrne methodology;
- Influence of local aerodrome operations;
- Influence of local flight paths;
- Influence of local environmental features;
- Influence of target area and target area projections;
- Consideration of skidding;
- Confidence and treatment of uncertainties;
- Application to random site location;
- Application to site located near to airfield.

Base Crash Data

- Data sources;
- Data screening;
- Data limitations and uncertainties;
- Data application.

Annex B

Research (HSL/LU) recommendations and TAP comments

Recommendation		TAP comments
1	All operators of licensed nuclear sites should undertake a site-specific hazard identification exercise in relation to the aviation-specific external threats to ensure that their safety arguments were complete and had not omitted any hazardous scenarios from consideration.	This is considered routine business for ONR as it forms part of the licensing regime. However, ONR should review TAG 013 to reflect TAP output and recommendations. ONR should provide a copy of the TAP's report to the CNI.
2	The geographic spread and time space of aircraft accident data should be expanded because of the sparse nature of accident data for crashes onto GB.	Caution should be exercised when considering use of historical data. The relevance of data should be considered alongside the quantity, and it should be relevant to UK aviation. ONR TAG/013 should be updated to include guidance on data selection.
3	The operators of licensed nuclear sites, and other government agencies, should consider special measures to protect against "beyond design case" events from aviation-related activities.	This is beyond the scope of the TAP and is captured under other ONR and regulatory requirements e.g. extendibility of emergency plans.
4	The operators of licensed nuclear sites should be responsible for conducting local flight surveys to ensure that the number and type of flights operating in the vicinity of the licensed nuclear site is compatible with the assumptions used in the calculation of aircraft accident frequency.	The TAP considered this to be prescriptive and onerous. The focus should be to ensure Licensees use appropriate data and that they can justify their data selection.
5	The operators of licensed nuclear sites should ensure that local operating conditions that may modify the probability of a flight suffering an accident significantly are taken into account.	The TAP fully supported this recommendation.
6	The significant number of general aviation accidents away from the aerodrome of departure and intended arrival may allow for a more site-specific model to be derived rather than the current generalised Byrne distribution.	The TAP questioned whether the benefit was sufficient to justify the burden of generating a site specific model. It was recommended that Licensees should use site specific data and if practicable a site specific model, but normal regulatory judgement should be applied to ensure compliance with the principles of enforcement.

	Recommendation	TAP comments
7	The significant number of general aviation accidents in the vicinity of the aerodrome of departure or intended arrival may allow for a more site-specific model to be derived rather than the generic models in current use. The use of the DOE standard as an improved method prior to the development of a new model should be considered.	The TAP questioned whether the benefit was sufficient to justify the burden of generating a site specific model. It was recommended that Licensees should use site specific data and if practicable a site specific model, but normal regulatory judgement should be applied to ensure compliance with the principles of enforcement.
8	The Byrne model should be improved for the calculation of crash frequency distributions in the vicinity of an aerodrome. The use of a third generation model, such as NLR, should be considered as a short term replacement until a model that is available includes normalisation, use of normal operations data, consideration of aerodrome design factors and consideration of aircraft performance factors.	The TAP recognised that the Byrne model contains deficiencies and could be improved. However, it also recognised that only one site would be affected by local aerodrome operations and then only for a relatively short period of time. The TAP also noted that results reported in the HSL/LU report, comparing three different methodologies, concluded that Byrne was the more conservative estimate of crash risk. The TAP concluded that redevelopment of the Byrne model was not warranted. However, the TAP recommended that Licensees take account of local factors to ensure the methodology remains relevant to the site.
9	The cross-track lateral accident location for all phases of flight would benefit from additional research to validate, or otherwise, the current assumptions within crash location models.	The TAP questioned the benefit of additional research into cross-track lateral accident location modelling. It noted that it was aware of the issues around this but the scarcity of data would hinder development of a model. However, it recommended that TAG 013 should be updated to highlight the issue.
10	The grouping of aircraft into different mass and kinetic energy groups should be reconsidered with the objective of removing the inconsistencies present within the Byrne model. Operations by ex-military aircraft could be considered for grouping with current military aircraft. Operation of civilian aircraft but on military and state activities could be considered for grouping with current military aircraft.	The TAP noted that neither it nor ONR would be able to influence categorisation of aircraft as this is the responsibility of other National and International bodies. It commented that end-users should be aware of differences in categorisations, thereby addressing the inconsistency in Byrne. The TAP disagreed with the statement that "Operation of civilian aircraft but on military and state activities could be considered for grouping with current military aircraft.". In any case, this would be a very minor contribution to the overall data set.
11	The modelling of military aircraft accidents could be improved and associated with actual flight paths intended to be flown as well as forecast loss rates for new aircraft types.	The TAP reiterated its earlier recommendation that relevant stakeholders e.g. MoD, CAA etc., should be consulted when establishing the data sources and other inputs to calculation of aircraft crash risk.

Recommendation		TAP comments
12	The Byrne model could be improved through the local application of a hazard analysis to consider the licensed nuclear site acting as an obstacle to an otherwise safe flight.	There was some question over the intent of this recommendation. However, the TAP felt it would be captured as a local factor when assessing aircraft crash risk.
13	The Byrne model could be improved by updating the assumptions relating to aircraft impact models, skidding friction factors, projectile bounce factors and projectiles dropping from aircraft.	The TAP recognised that these factors contribute to the overall event, but it was judged that no real benefit would be seen by undertaking further work. However, the TAP recommended that TAG 013 should be updated to provide regulatory guidance on these supplementary contributors to aircraft crash risk.
14	The Byrne model should be extended, if required to comply with consequence analyses implications, to include the hovering phase of helicopter operations, the operation of gyrocopters, gliders, airships, gas-lifting balloons and hot-air balloons. The use of the DOE standard as a substitute would be an acceptable intermediate step until a more specific GB model could be developed.	The TAP considered that there was no benefit in doing this as the consequences from these aircraft types are negligible.
15	Operations by unmanned aerial vehicles should be considered in greater detail in time.	This issue is being addressed by a cross-government programme of work. In any case it is unlikely to have a significant effect on nuclear sites.
16	Any future model developed for use in the vicinity of an aerodrome should consider the correlation between lateral and longitudinal crash distances; the use of a gamma distribution; the normalisation of the data including aircraft performance factors and flight performance factors and the use of normal operations data. The significance of the variation in weather conditions experienced across GB could be tested in a sample analysis in order to determine if such factors had to be considered at all locations of licensed nuclear sites.	This recommendation is linked to recommendation 8. The TAP noted that it affected one site for a limited period of time.
17	If any model is to be developed beyond the Byrne model for use in GB then the usability could be improved by changing to look-up tables such as published in the DOE standard model or through a risk map being published for the whole of GB.	The TAP considered that this was a matter of usability and was not within the scope of the TAP's deliberations. However, the TAP noted that any improvement in the usability of modelling should be encouraged provided there was no loss in model/data integrity, and that there was still visibility to the underlying methodology.

Recommendation		TAP comments
18	Any modelling of aircraft accident frequencies at a specific location should include the consideration of confidence intervals and the 95% confidence interval upper bound should be used in safety arguments to demonstrate that a licensed nuclear site does not suffer from excessive risk associated with aviation-related hazards.	Regulatory expectation is that Licensees should use a 95% confidence interval for design basis events and a 50% confidence interval for beyond design basis events. A 95% confidence interval for beyond design basis events is considered to be unnecessarily conservative. The TAP supported inclusion of a measure of confidence in risk quantification. TAG 013 should be updated to reflect this position.

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