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SAFETY AND
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A METHOD FOR THE SITE-SPECIFIC ASSESSMENT OF AIRCRAFT CRASH HAZARDS

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NUCLEAR REGULATORY COMMISSION

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1. INTRODUCTION

Most aircraft crashes make news headlines. From the crop spraying aircraft which hits telephone lines and crashes into a farmer's field, to the large airliner which ploughs into a mountainside killing a few hundred people, crashes are considered newsworthy events and arouse general interest. Hence, the public is well aware that aircraft crash, but perhaps because of the low level of individual risk associated with air travel, the aircraft crash hazard is generally perceived to be acceptable, or at least as acceptable as the hazard posed by other rare events such as lightning strikes or floods.

To an operator of a nuclear power station (or any other potentially hazardous plant), the hazard posed by crashing aircraft might be termed 'low risk-high consequence'. When choosing a site for a new plant, aircraft crashes are considered, along with other types of extreme load/external hazards in the context of nuclear safety. In Britain a siting policy was produced early in the development of a commercial nuclear power programme which recommended that nuclear power stations should not be sited close to the direct path of runways [1]. Within ten years legislation had been enacted that prohibited or otherwise restricted flying activity near certain nuclear installations [2].

The position of the non-nuclear industries with respect to concern over aircraft crash was expressed by the Health and Safety Executive (HSE) in the 1985 CIMAH guide, where in Para 113 appears the statement "A safety case may also perhaps say that the risk of an aircraft crashing on the installation is insignificant in comparison with other causes of a major accident, because the site is well separated from the nearest airport and air traffic lanes".[3]

Several countries have adopted the US frequency criterion of designing against aircraft crashes on installations where the frequency is greater than 10^{-7} per year, and then only design against the impacts of light aircraft (the most likely impacts in most places). Several European countries, however, design against aircraft crashes using a pre-defined and smoothed impulse model which is intended to represent the normal impact of a Phantom aircraft travelling at flight speed.

The three principal damage modes expected to dominate aircraft crashes are:-

(1) direct impact leading to penetration or perforation

(2) direct impact or near-misses leading to intense induced vibrations

(3) direct impact or near-misses leading to fuel fires and detonations.

These damage modes and their relative importance clearly depend upon the specific details of the impact, and upon the type of structure and type of aircraft.

2. NATURE OF THE EFFECTS

It is important to decide at the start which events count as an aircraft crash. In the UK the Civil Aviation Authority (CAA) publish annually lists of all notifiable accidents involving British registered aircraft.[4] These include all incidents occurring between the times of boarding an aircraft and disembarking from it, which result in serious injury or death, or substantial damage to the aircraft (that which would seriously affect the ability of the aircraft to fly safely). Military aircraft accidents are divided by the MOD Inspectorate of Flight Safety into five categories. Category 4 accidents necessitate major repairs to an aircraft which normally cannot be carried out locally, and category 5 accidents are so severe that it is not worthwhile repairing the aircraft. Category 1, 2 and 3 accidents are less serious.

Having defined an aircraft accident, it is necessary to decide which sub-set of these events is relevant from the point of view of crashes onto an installation. For military aircraft crashing in the UK, it is reasonable to consider only category 4 and 5 flying accidents, and also to exclude from these accidents those where significant pilot control was indicated just before impact. This exclusion is a reflection of observed "pilot avoidance" as discussed further in Section 3.1.1 (v), and tends to remove about half the total number of category 4 and 5 accidents. For civil aircraft, the selection procedure, for the UK at least, must be performed 'manually' by sorting through all the CAA accidents reports individually. From the point of view of the manager of a nuclear power station, for example,

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(commercial flights) Figure 6 compares the four airway fall off rates described above for an airway of width 10 km (Note that the relative frequency scales are not normalised which accounts for the apparent predominance of the USNRC curve) It is clear that two types of distribution are present, and that these attach different weights to the near and far field rates

In the UK, airways are typically 10 nautical miles wide, with traffic tending to be concentrated towards the centreline, and it is unusual for aircraft to fly outside airways In this case, the normal distribution seems more realistic than the prescription recommended by the USNRC At the same time, the simple exponential forms may be too narrow and their use could lead to underestimation of crash rates in some cases One method might be to use the normal distribution with a 9 km standard deviation for wide airways, whilst a narrower distribution might be chosen for non-airway flight paths, which could be at relatively low altitudes

The method chosen for implementation in PRANG is a blend of these two ideas; the standard deviation of the normal distribution for crashes below, and as a result of airways is set equal to the average flying height

Branching and bending in the airways can be treated easily with PRANG. As a result of recent modification any airway which starts and or finishes within the grid can be represented, as well as ones passing straight through Airways which have a change of course within the grid can also be modelled: the airway would then be modelled as two separate airways with the first ending and the second starting at the location of the bend. In the case of branching, e.g. where two airways merge into one, work by the CAA[24] suggests that the resultant airway can be successfully modelled as a single route carrying the total traffic of the two 'feeder' airways. The crash rate does not increase as a result of the bunching of aircraft

(iv) **Areas of intensive military flying**

Throughout the UK there are many regions which may be termed 'special flying zones', within which it is likely that the crash rate will be significantly greater than the rate which would be calculated if the zone did not exist. In many instances, the increased rate is due to military manoeuvres, such as pilot training low flying practice, etc. These areas are termed 'areas of intense air activity' (AIAA), and occupy well-defined portions of airspace The distribution of AIAA's in the UK is given in Fig 7 Further evidence of their effect is available from studying crash locations of military aircraft in the UK, which show, in most cases, clear concentrations under AIAA's (although it would not be true to say that military training takes place entirely within these areas) In the US, recognition has been given to the potential influence of military training activities on aircraft crash rates, particularly when these involve intensive low level training or practice bombing [19,24] A relatively simple method has been proposed for the assessment of military aircraft crash rates not in AIAAs within the UK, with particular reference to Sizewell in East Anglia.[5] This method approximates the areas as having the independently calculated background crash rate outside them, and an increased crash rate within them, with no graduation between the two rates. The proposed increase in crash rate is effective only for military combat aircraft although the rates for other aircraft are altered slightly (Table 2) Using PRANG, the procedure is to calculate the crash rate for each cell in the mesh as influenced by airfields, airways, etc. and then if the cell is contained within an AIAA, the calculated rate is increased according to the figures in Table 2.

(v) **Restricted flying zones**

It is very difficult to quantify the effect on the ground impact rate that the imposition of a restriction or prohibition of flying in the area concerned might have.[5,22] Certainly such prohibitions do result in a dramatic reduction in flying activity and, although the requirements may be difficult to enforce, incursions into such zones are infrequent However, prohibited or restricted zones are sometimes only sufficiently extensive to influence flying patterns (and hence crash rates) of low-flying aircraft. It has been judged that a prohibition on local low-flying leads to a reduction in crash rates of ten times for military aircraft crashing at low impact angles.[5]

For higher impact angle crashes, this effect is less well understood. In PRANG the chosen method is to calculate the crash rate in a cell of interest due to all the effects mentioned above, and then multiply this rate for any cell corresponding to ground below a restricted or prohibited

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region, by a factor F_c. In this context, an urban area also corresponds to a restricted area. Flying over such built up areas is governed by general flight rules which prohibit dangerous flying, low flying, flying closer than 500 ft of any object on the ground, and flying within 1500 ft. of the highest fixed object in a built-up area.

There are several pieces of evidence which suggests that a value of 0·5 would be a reasonable estimate for F_c, i.e. that an average urban area in the UK is about half as likely to suffer an aircraft impact as an average rural area of equal size. Analysis of category 4 and 5 military air crashes has shown that in roughly 50% of non-airfield related crashes the pilot retains enough control of the aircraft to have some influence over the crash-landing site. These crashes are ones which result in severe damage to the aircraft and stem from failures such as loss of power. It does not seem realistic at this stage to use a value of F_c lower than 0·5 because it appears that about half the military aircraft crashes arise from causes which effectively prevent any pilot control. One would expect a very small percentage of these controlled crashes to result in the impact of a structure. This is consistent with the views expressed by the CEGB in their submission on aircraft crash made in support of the Sizewell 'B' safety case.[3] For civil aircraft the screening process removes 'controlled' crashes but flying activity for light aircraft which fly generally at low altitudes is reduced over built up areas (because of the General Flight Rules) to roughly 50% of the average over other regions. In the case of airliners, F_c for en-route crashes should perhaps be closer to unity. However, screening will err on the conservative side for these very rare accidents so putting F_c = 0·5 in these cases seems reasonable. In the US, a study by NASA[23] indicated that 42% of all severe impacts involving civil transport aircraft (covering a wide range of masses) occurred in an uncontrolled fashion. Investigation of the CAA annual reports regarding crashes of aircraft registered in Britain[4] revealed that in the period 1972-1982 there were 66 non-airfield related crashes, of which 48 occurred in rural areas, 3 in urban areas and the locations of the remaining 15 could not be determined from the reports. However, the fact that no mention of, for example, a building strike was made, implies that no impact was on to a building. Studies of the total percentage of urban land use in the UK[24] indicate that built up areas occupy around 7.5% of the total for the whole of the UK, rising to around 10% if one includes only England and Wales. The distribution of airfields in the UK implies that the majority of flying (and hence crashing) in the UK takes place over England and Wales, so we would therefore expect to get about 10% of 66 = 6·6 crashes onto urban areas in this period of time. Since only 3 appear to have been recorded, this lends further weight to the case for using F_c = 0·5. PRANG uses a default value of 0·5 for F_c; alternatively, one can set a different value if circumstances suggest such a modification. For example, there are regions of airspace where flying is prohibited for only part of the time, e.g. when an Army firing range is active, and unrestricted at other times. In such cases, it may be felt after due investigation that a value of $0 \cdot 5 \leq F_c \leq 1 \cdot 0$ would be more appropriate.

3.2 The PATH code

PATH is a computer code developed at SRD as an alternative method of calculating crash hazards.

In assessments where the considered site is very close to a well-defined flight path or air route (say within 2 km), the method of assessment employed in the code PATH can be used. This program calculates the crash rate of aircraft on to one or more specific target structures due to aircraft travelling along one or more flight paths. Each target structure is modelled as a cylinder with a given height and radius. For structures which are not actually cylinders, the 'target-area' presented to a given crash trajectory will be modelled by several cylinders whose geometry is tailored to give the best approximation for the trajectory being considered. The program therefore allows each structure to be modelled by up to 36 different cylinder combinations each being applicable to a different range of views of the structure.

Each flight path is represented by a series of (x, y, z) co-ordinates, indicating the end position of up to 50 'steps' in the flight path. These steps need not be of equal length, for instance they may be reduced in size to more accurately model a bend in the path. At each stage along the flight path it is assumed that the aircraft's velocity vector is directed towards the next co-ordinate point. The code allows up to ten separate flight paths, and up to ten different aircraft types on each