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Improving Aircraft Accident Forecasting for an Integrated Plutonium Storage Facility

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A HIGHER EDUCATION CONSORTIUM

A Report on

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Abstract

Aircraft accidents pose a quantifiable threat to facilities used to store and process surplus weapon-grade plutonium. The Department of Energy (DOE) recently published its first aircraft accident analysis guidelines: *Accident Analysis for Aircraft Crash into Hazardous Facilities*.[1] This document establishes a hierarchy of procedures for estimating the small annual frequency for aircraft accidents that impact Pantex facilities and the even smaller frequency of hazardous material released to the environment. The standard establishes a screening threshold of 10^{-6} impacts per year; if the initial estimate of impact frequency for a facility is below this level, no further analysis is required. The Pantex Site-Wide Environmental Impact Statement (SWEIS)[2] calculates the aircraft impact frequency to be above this screening level. The DOE Standard encourages more detailed analyses in such cases. This report presents three refinements, namely, removing retired small military aircraft from the accident rate database, correcting the conversion factor from military accident rates (accidents per 100,000 hours) to the rates used in the DOE model (accidents per flight phase), and adjusting the conditional probability of impact for general aviation to more accurately reflect pilot training and local conditions. This report documents a halving of the predicted frequency of an aircraft impact at Pantex and points toward further reductions.

[1] DOE Std 3014-96, Oct 1996.

[2] *Final Environmental Impact Statement for the Continued Operation of the Pantex Plant and Associated Storage of Nuclear Weapon Components*; see **Appendix D: References** for further information.

1. Introduction

The four-factor formula of the DOE Standard[3] calculates the expected impact frequency as a product of four items:

1. The probability of an accident during a given flight activity (takeoff, landing, or general flight), calculated for each aircraft subcategory.
2. The number of such flight activities for each aircraft subcategory.
3. The probability of a specific aircraft impacting the target, given that it has a ground-impact accident.
4. The effective target area of the facility under scrutiny.

The assumptions made and values used for all of these items are extremely conservative and open to refinement. This report documents improvements for the first three factors, with concentration on adjustments to the small military crash rates. Many of these adjustments are also applicable to other aircraft subcategories; this one was chosen because of the quantity of available data, and the extensive experience in the area of one of the authors. In order to navigate between slowing down the reader intimately familiar with the material contained herein and ignoring the needs of others, several of the technical terms are elaborated upon in Appendix C, beginning on page 24. Full information on the sources of data used in the analysis is given in Appendix A, beginning on page 19. Any questions may be directed to the authors, whose e-mail addresses are given in Appendix E, page 25.

2. Small Military Crash Rates

For several reasons, the small military crash rate calculations found in the DOE Standard and its support document[4] significantly overstate current operational experience. These likely stem from a misunderstanding of the military data itself. One of these problems arises from an outright error; another comes from the inclusion of accident data from retired aircraft (and in one case, long-retired aircraft). These two issues are dealt with first, in Tables 1 through 3.

Another issue involves the misapplication of data related to the counting of landings, and this more complex problem is laid out in Tables 4 through 8. The Department of Defense (DOD) tracks aircraft accidents by measuring accidents per 100,000 flying hours. The four-factor model uses accident probability per flight segment as its first factor. The authors of the DOE Guidelines and the authors of the SWEIS both worked on this conversion factor. We see several opportunities for improving the quality of the estimated accident probability per flight segment. In this section, we document means to interpret available data in a more representative way than was used for the SWEIS.

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[3] The four-factor formula is presented in detail in Appendix B, beginning on page 23.

[4] *Data Development and Technical Support Document for the Aircraft Crash Risk Analysis Methodology (ACRAM) Standard; see* **Appendix D: References** on page 24 for more information.

2.1 Retirements of Small Military Aircraft

The accident rates for aircraft are not uniform across aircraft models. Indeed, the Class A[5] accident rates for small military aircraft range from 1.10 per hundred thousand flight hours to 13.67 per hundred thousand flight hours, as seen in Table 1 on page 5. Because of this, it is important that the overall accident rate for any category or subcategory accurately reflect the mix of aircraft which represent the current threat. Improvements in technology have reduced accident rates considerably in aircraft of more modern design, resulting in a steady decline of overall accident rates.

Unfortunately, the data which were used to calculate the accident rates given in the Standard, include data related to the long-retired T-33 (which has an extraordinarily high accident rate) and several other aircraft more recently retired from active service. The effects on the accident rates from considering only aircraft currently in active service are shown in Table 1. The top portion of this table is reproduced from Table 4.2 of the technical support document for the DOE Standard *Aircraft Crash Risk Analysis Methodology*. This document is based on data collected from accidents occurring between 1973 and 1994.

First, there is an error in the data that was used. The line labeled “F-4/RF-4” is the sum of the lines labeled “F-4” and “RF-4C,” which means that the data related to accidents for these two aircraft are counted twice. The effect of this double-counting is removed before further analysis is performed.

Next, the effects of the retirement of the T-33 are calculated. This is handled separately from the other retirements, in part because its removal is recommended by the author of the support document, but also because of the length of time since its retirement (1983) and the dramatic effect of its removal on the overall accident rates. The Class A accident rate for the small military category drops by nearly 44% when the effects of the T-33 are removed from consideration.

The retirements of the A-7 (1993), A-37 (early 1990’s), F-4 (1992), RF-4 (1995), F-5, F-106 (early 1970’s), and T-39 result in another drop of 18% in the Class A accident rate.

The impending retirement of the F-111 is shown to result in a modest additional decrease in the accident rates. The addition of data pertaining to the new T-1A also causes a very small drop in the rates. Although there have not yet been any accidents involving the T-1A, the relatively low total number of flight hours logged so far precludes a major impact as yet on the overall accident rates. (The sources for all of the data in this and all other tables are in an appendix to this report.)

The effect of all these elements on the bottom line is a 66% reduction in Class A accident rates for small military aircraft. However, the accident rates as applied in the Standard require that the data be broken down by mission phase (takeoff or landing) and impact location (on or off the runway), information to which we do not have current access. This is an area worthy of further investigation. In fact, the technical support document states explicitly[6]:

> If operations at a given location differ greatly from the overall distribution in the historical data, alternative estimates of crash frequencies, based on the appropriate mix of aircraft at the location, should be considered.

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[5] See **Appendix C: Terminology** on page 24.

[6] Page 4–2; see **Appendix D: References** on page 24 for further information.

Table 1: Revision of Table 4.2 of the DOE Standard Support Document. This revision of the referenced table shows the effects of the error in the data, the removal of the T-33 and other retired aircraft, the removal of the F-111 (which will be retired within a year), and the addition of the new T-1A. The amounts labeled "Decrease" refer to percentage decrease from the original value over the final value. Thus the original Class A accident rate is nearly three times the final value after removal of retired aircraft. *All accident rates are per 100,000 flight hours.

Aircraft Model	*Class A Number*	*Class A Rate**	*Class B Number*	*Class B Rate**	*Number Destroyed*	*Destroyed Rate**
A-7	101	5.71	24	1.36	102	5.77
A-10	79	2.62	44	1.46	78	2.58
A-37	36	4.92	6	0.82	32	4.38
F-4/RF-4	593	5.75	387	3.76	516	5.01
F-4	468	5.80	308	3.82	411	5.09
F-5	39	8.82	16	3.62	40	9.05
RF-4C	125	5.59	79	3.53	105	4.69
F-15	83	2.74	127	4.19	80	2.64
F-16	201	5.06	24	0.60	191	4.81
F-106	151	9.35	61	3.78	118	7.31
F-111	113	6.23	94	5.18	94	5.18
F-117	1	2.01	2	4.03	1	2.01
T-33	2,351	13.67	589	3.43	1,189	6.92
T-37	131	1.15	31	0.27	129	1.13
T-38	183	1.57	90	0.77	180	1.54
T-39	29	1.10	21	0.80	12	0.45
T-41	7	1.16	5	0.83	3	0.50
Totals	4,691	5.82	1,908	2.37	3,281	4.07
Decrease due to overstatement resulting from double-counting for F-4/RF-4:						
Reduction	593		387		516	
Adj. Total	4098	5.83	1521	2.16	2765	3.93
Decrease	**13%**	**0%**	**20%**	**9%**	**16%**	**3%**
Decrease due to retirement of T-33:						
Reduction	2,351		589		1,189	
Adj. Total	1,747	3.29	932	1.75	1,576	2.97
Decrease	**50%**	**44%**	**31%**	**17%**	**36%**	**24%**
Decrease due to retirement of A-7, A-37, F-4, F-5, RF-4, F-106, T-39:						
Reduction	949		515		820	
Adj. Total	798	2.24	417	1.17	756	2.12
Decrease	**20%**	**18%**	**27%**	**25%**	**25%**	**21%**
Decrease due to impending retirement of F-111:						
Reduction	113		94		94	
Adj. Total	685	2.03	323	0.96	662	1.96
Decrease	**2%**	**4%**	**5%**	**9%**	**3%**	**4%**
Effect of addition of T-1A:						
T-1A Values	0	0	0	0	0	0
Adj. Total	685	2.00	323	0.94	662	1.94
Decrease	**0%**	**0%**	**0%**	**0%**	**0%**	**1%**
Net Total	685	2.00	323	0.94	662	1.94
Total Decrease	**85%**	**66%**	**83%**	**60%**	**80%**	**52%**
Overstatement Ratio	**6.8**	**2.9**	**5.9**	**2.5**	**5.0**	**2.1**

2.2 Small Military Aircraft Classes

As stated previously, accident rates are not uniform across aircraft models; the accident rates for the attack/fighter class of small military aircraft are approximately three times the rates for trainer aircraft. (See Table 2 and 3 below for a breakdown of the remaining small military craft by class.) The current model could be substantially refined by calculating separate accident rates for these two classes and applying them individually to the traffic at Amarillo Airport. This need not represent significantly more effort to accomplish than the further analysis recommended in regards to retired aircraft. The total estimated small military aircraft traffic at Amarillo Airport (divided into takeoffs and landings) need only be apportioned into percentage of attack/fighter craft and percentage of trainer craft.

Table 2: Accident Rate Analysis for Attack/Fighter Aircraft, Showing Effect of Impending Retirement of F-111. The overstatement ratio is the ratio of the original value to the final value. *All accident rates are per 100,000 flight hours.

Aircraft Model	*Class A Number*	*Class A Rate**	*Class B Number*	*Class B Rate**	*Number Destroyed*	*Destroyed Rate**
F-111	*113*	*6.23*	*94*	*5.18*	*94*	*5.18*
A-10	*79*	*2.62*	*44*	*1.46*	*78*	*2.58*
F-15	*83*	*2.74*	*127*	*4.19*	*80*	*2.64*
F-16	*201*	*5.06*	*24*	*0.60*	*191*	*4.81*
F-117	*1*	*2.01*	*2*	*4.03*	*1*	*2.01*
Total Attack/Fighter	*477*	*4.01*	*291*	*2.45*	*444*	*3.73*
Effect of impending retirement of F-111 on Attack/Fighter Values:						
Reduction	*113*		*94*		*94*	
Adj. Total	*364*	*3.61*	*197*	*1.96*	*350*	*3.47*
Decrease	***24%***	***10%***	***32%***	***20%***	***21%***	***7%***
Effective Overstatement	***1.3***	***1.1***	***1.5***	***1.3***	***1.3***	***1.1***

Table 3: Accident Rate Analysis for Trainer Aircraft. *All accident rates are per 100,000 flight hours.

Aircraft Model	*Class A Number*	*Class A Rate**	*Class B Number*	*Class B Rate**	*Number Destroyed*	*Destroyed Rate**
T-37	*131*	*1.15*	*31*	*0.27*	*129*	*1.13*
T-38	*183*	*1.57*	*90*	*0.77*	*180*	*1.54*
T-41	*7*	*1.10*	*5*	*0.80*	*3*	*0.45*
T-1A	*0*	*0*	*0*	*0*	*0*	*0*
Total Trainer	*321*	*1.33*	*126*	*0.52*	*312*	*1.29*

2.3 Incorrect Calculation of Landing and Takeoff Crash Probabilities

The accident rates in the DOE Standard are based upon calculation of the numbers of crashes divided by the number of takeoffs and landings, while the military source data specify the crash rate per 100,000 flight hours. The support documentation shows that due to misinterpretation of the military data, the rates are being applied incorrectly. From discussions with Science Application International Corporation (a contractor to DOE involved in development of the Standard) and others who are familiar with the data, it is clear that there is a significant discrepancy between how the data were collected and reported in the Standard and its intended use in the Standard.

In the final EIS, the crash rates per aircraft landing or takeoff are applied to all approaches and all departures, including touch-and-go operations, low-approach operations, and full-stop landings. The crash rate data (as collected from the Air Force) is based upon an accident rate per 100,000 flying hours and the total number of landings and takeoffs for the aircraft fleet. However, the Air Force records only landings in which the wheels actually touch the runway.[7] This is done as a practical matter, because the number of landings is used to determine when tires should be replaced and as an indicator of aircraft fatigue. In most U.S. Air Force practice approaches, the wheels never touch the ground, even though a landing practice approach and subsequent simulated takeoff is performed. These simulated approaches and departures are not included in the crash rate data supplied by the Air Force. However, the DOE Standard requires that the crash rate be applied to traffic data which includes these operations.

In Table 4.7 in the DOE Standard support document, the numbers of landings were stated for each type of aircraft, as well as the number of crashes on and off the runway per takeoff and per landing. If the flight hours of Table 4.2 are applied to the numbers of landings found in Table 4.7, the column of landings per flight hour can be calculated for the aircraft specifically mentioned.

Based on Dr. McNerney's personal experience with trainer and fighter aircraft, average sortie length for T-37 and T-38 aircraft is approximately 1.2 to 1.3 hours. With an expected four landings (including low approaches) per sortie, the number of landings per flight hour should be around 3.0 rather than the 1.2–1.3 shown in Table 4 on page 8. For F-4 sorties, the average sortie length should be around 1.3 to 1.6 hours, and the average number of landings (including low approaches) per sortie should be between 2 and 2.3. Therefore the expected number of landings per flight hour for the F-4 (and most other fighter aircraft) should be between 1.25 and 1.75 landings per flight hour, rather than the 0.55 calculated.

[7] In fact, the Air Force regulation for fighter and attack aircraft prohibits practice landings (but not practice approaches) unless an instructor pilot is on board the aircraft. In operational squadrons, it would be the rule that most pilots would fly for months without an instructor pilot being on board, therefore several low approaches are flown, but only one landing would be logged per flight.

As Table 4 illustrates, this application of data leads to a suspicion that the number of landings are significantly underestimated for both the fighter and trainer aircraft. Consequently, the landing and takeoff crash rates used in the Standard must either be recalculated based upon the estimated total numbers of operations (including low approaches), or the current crash rate data should be applied only to traffic counts of actual landings and takeoffs, excluding all low approaches.

Table 4: Calculated Landing per Flight Hour Based upon Supplied Data. The low crash rates per landing based upon data supplied by the military do not include low approaches. However, in the EIS, they are applied to numbers, which do include low approaches, resulting in overstatement of the expected number of impacts.

Aircraft Model	Landings	Flight Hours	Landings per Flight Hour	Expected Operations per Flight Hour
A-7	940,000	1,768,958	0.53	1.25–1.75
A-10	1,738,000	3,020,198	0.58	1.25–1.75
F-4	4,462,000	8,066,975	0.55	1.25–1.75
F-15	2,235,000	3,031,730	0.74	1.25–1.75
F-16	2,818,000	3,971,946	0.71	1.25–1.75
F-111	891,000	1,814,333	0.49	1.25–1.75
T-37	14,147,000	11,439,050	1.24	3.00
T-38	15,118,000	11,664,996	1.30	3.00

To find out the approximate understatement of operations, a series of weighted analyses was performed. For each model of aircraft, a conservative increase factor was calculated. The increase factor is the ratio of all operations (including low approaches) to the number of actual landings reported by the Air Force. For example, the data showed an approximate 0.53 landings per flight hour for the A-7, while at least 1.25 landings per flight hour were expected. Thus, the increase factor for the A-7 is 1.25/0.53 = 2.35. The total number of operations for the A-7 (including low approaches) is then estimated to be $940{,}000 \times 2.35 = 2{,}211{,}198$. Table 5 summarizes the results for this first (and most conservative) round of estimation.

Table 5: Calculation of the Revision Factor of the Most Conservative Estimate of Landings which include Low Approaches. The increase factor is calculated by dividing the more appropriate value for operations per flight by the original value, which is given in the table. In this case, the more appropriate value is assumed to 1.25 operations per hour for attack/fighter craft and 3.0 operations per hour trainer craft.

Aircraft Model	Landings	Flight Hours	Landings per Flight Hour	Increase Factor	Estimated Number of Operations
A-7	940,000	1,768,958	0.53	2.35	2,211,198
A-10	1,738,000	3,020,198	0.58	2.17	3,775,248
F-4	4,462,000	8,066,975	0.55	2.26	10,083,719
F-15	2,235,000	3,031,730	0.74	1.70	3,789,663
F-16	2,818,000	3,971,946	0.71	1.76	4,964,933
F-111	891,000	1,814,333	0.49	2.55	2,267,916
T-37	14,147,000	11,439,050	1.24	2.43	34,317,150
T-38	15,118,000	11,664,996	1.30	2.31	34,994,988
Totals	42,349,000				96,404,813
Most Conservative Revision Factor: 96,404,813/42,349,000 = 2.3					

This procedure is applied to each aircraft model, and the total estimated number of small military aircraft operations is calculated. The ratio of this estimated total number of operations to the original number of landings then quantifies the inflation factor. That is, the accident rate used in the DOE Standard (and thus the Pantex SWEIS) is 2.3 times as large as the data support.

Performing the analysis in this manner (instead of merely averaging either landings per flight hour or increase factors) allows for a weighting scheme based on flight hours per aircraft model, and thus more closely reflects the reality of the operational fleet. To obtain full accuracy for the EIS, it will be necessary to obtain model-by-model counts in Amarillo air space.

By way of sensitivity analysis, this procedure is repeated for two less conservative values for the expected numbers of operations per hour, resulting in revision rates ranging from 2.3 to 2.5. (See Tables 6 and 7 on page 10.) These represent reductions in the accident rates between approximately 56% and 61%. (See Table 8 on page 10 for a summary of the results.)

Table 6: Calculation of the Revision Factor for the Moderately Conservative Estimate of Landings which includes Low Approaches. The increase factor is calculated by dividing the more appropriate value for operations per flight hour by the original value, which is given in the table. In this case, the more appropriate value is assumed to be 1.5 operations per hour for attack/fighter craft and 3.0 operations per hour for trainer craft.

Aircraft Model	*Landings*	*Flight Hours*	*Landings per Flight Hour*	*Increase Factor*	*Estimated Number of Operations*
A-7	*940,000*	*1,768,958*	*0.53*	*2.82*	*2,653,437*
A-10	*1,738,000*	*3,020,198*	*0.58*	*2.61*	*4,530,297*
F-4	*4,462,000*	*8,066,975*	*0.55*	*2.71*	*12,100,463*
F-15	*2,235,000*	*3,031,730*	*0.74*	*2.03*	*4,547,595*
F-16	*2,818,000*	*3,971,946*	*0.71*	*2.11*	*5,957,919*
F-111	*891,000*	*1,814,333*	*0.49*	*3.05*	*2,721,500*
T-37	*14,147,000*	*11,439,050*	*1.24*	*2.43*	*34,317,150*
T-38	*15,118,000*	*11,664,996*	*1.30*	*2.31*	*34,994,988*
Totals	*42,349,000*				*101,823,348*
Moderately Conservative Revision Factor: 101,823,348/42,349,000 = 2.4					

Table 7: Calculation of the Revision Factor the Least Conservative Estimate of Landing which includes Low Approaches. The increase factor is calculated by dividing the more appropriate value for operations per flight hour by the original value, which is given in the table. In this case, the more appropriate value is assumed to be 1.75 operations per hour for attack/fighter craft and 3.0 operations per hour for trainer craft.

Aircraft Model	*Landings*	*Flight Hours*	*Landings per Flight Hour*	*Increase Factor*	*Estimated Number of Operations*
A-7	*940,000*	*1,768,958*	*0.53*	*3.29*	*3,095,677*
A-10	*1,738,000*	*3,020,198*	*0.58*	*3.04*	*5,285,347*
F-4	*4,462,000*	*8,066,975*	*0.55*	*3.16*	*14,117,206*
F-15	*2,235,000*	*3,031,730*	*0.74*	*2.37*	*5,305,528*
F-16	*2,818,000*	*3,971,946*	*0.71*	*2.47*	*6,950,906*
F-111	*891,000*	*1,814,333*	*0.49*	*3.56*	*3,175,083*
T-37	*14,147,000*	*11,439,050*	*1.24*	*2.43*	*34,317,150*
T-38	*15,118,000*	*11,664,996*	*1.30*	*2.31*	*34,994,988*
Totals	*42,349,000*				*107,241,883*
Least Conservative Revision Factor: 107,241,883/42,349,000 = 2.5					

Table 8: Summary of the Aggregate Small Military Accident Rate Factors from Tables 5, 6, and 7. Since the application of the rates in the Standard requires the inclusion of low approaches in the numbers of operations, the accident rate must be adjusted accordingly. (The calculated accident rates are based on 86 takeoff accidents and 154 landing accidents, each with the impact point off-runway. Accidents where the final impact is on the runway were excluded.) The overstatement ratio (the ratio of the original estimate to each revised estimate) is the same as the revision factor in this case.

Estimate	*Revision Factor*	*Estimated Number of Operations*	*Takeoff Accident Rate (10^{-6} per year)*	*Landing Accident Rate (10^{-6} per year)*	*Decrease*
Original	*1*	*46,922,000*	*1.833*	*3.28*	*0%*
Most Conservative	*2.3*	*106,814,958*	*0.805*	*1.44*	*56%*
Intermediate	*2.4*	*112,818,606*	*0.762*	*1.37*	*58%*
Least Conservative	*2.5*	*118,822,254*	*0.724*	*1.30*	*61%*

3. Impact Frequency Calculations

The crash rates used in calculations are not as informative as the final calculated value itself, the impact frequency. It is important to note that the impact frequency is ***not*** a probability, even though the Pantex SWEIS incorrectly labels it as one in more than one instance. It is a *mean*, an altogether different type of quantity. What the DOE Standard calls an impact frequency is the expected number (a more technical — and accurate — term for the mean) of impacts per year. An expected number can be a fraction, as will certainly be the case with rare events. In such a situation, calling it an event frequency is not misleading. The issue of terminology, however, is ***not*** a minor one. It can easily be demonstrated mathematically that the expected number of impacts per year is larger (and perhaps *much* larger) than the *probability* of one or more impacts in a year. That is, if the impact frequency is being mistaken for an impact probability, then the likelihood of impact in a given year is being perceived as much greater than it actually is.

The impact frequency calculations are divided into those related to takeoffs and landings and those related to non-airport operations. This is because the fundamental way in which these are calculated is somewhat different, despite the fact that the four-factor formula is the same for both. We restrict our attention to Zones 4 and 12, as these are the only two zones where plutonium is stored.

Boldface numbering within the tables throughout this section is used to identify those values which have been changed. A reference value (showing what the result would have been had no changes been made) is presented for comparison. The important thing to note is that very few components have been changed (and most quite conservatively), yet the impact on the bottom line is profound.

3.1 Contribution from Takeoffs and Landings

The number of operations per year was decreased by 25% for small military aircraft for both takeoff and landing. The reduction is based partly upon the closure of Reese AFB and its potential effect on the traffic at Amarillo airport.

This reduction in numbers of operations and the most conservative reduction in small military off-runway accident rates were applied to the four-factor formula of the Standard in order to calculate the revised contribution to overall impact frequency of near-airport operations. These calculations are presented in detail in Table 9 on page 12 (for Zone 4) and in Table 10 on page 13 (for Zone 12). The reduction is approximately 47% for Zone 4 and 42% for Zone 12.

Additionally, there is concern about the accuracy of the operational data for the general aviation categories, although no changes were made for these categories. Specifically, the number of operations for turbojets looks high relative to the other categories of general aviation aircraft. This is a topic for future research.

Table 9: The Effects on the Near-Airport Operations Portion of the Impact Frequency Estimate for Zone 4 of the Most Conservative Reduction in the Accident Rates for the Small Military Subcategory. Operations per year for these two subcategories were also reduced due the closure of Reese AFB. All takeoffs are from runway 04, with a corresponding (x,y)-value of (10.77, -1.71). All landing are at runway 22, with a corresponding (x,y)-value of (-10.77, 1.71). The changed values are in boldface. The overstatement ratio is the ratio of the original estimate to the final estimate.

Aircraft Subcategory	*Operations per Year*	*f(x,y) (per mile²)*	*Crash Rate P (per year)*	*Effective Area for Zone 4 (mile²)*	*Adjusted Impact Frequency (10^{-6} per year)*	*Reference Impact Frequency (10^{-6} per year)*
Commercial:						
Air Carrier Takeoff	2,365	1.2×10^{-5}	2.0×10^{-7}	0.2893	0.002	0.002
Air Carrier Landing	4,222	1.7×10^{-4}	2.6×10^{-7}	0.2893	0.079	0.079
Air Taxi Takeoff	1,614	1.2×10^{-5}	1.0×10^{-6}	0.2290	0.005	0.005
Air Taxi Landing	2,881	1.7×10^{-4}	2.3×10^{-6}	0.2290	0.379	0.379
Subtotals	11,082				0.465	0.465
Military:						
Large Aircraft Takeoffs	2,422	9.8×10^{-4}	5.7×10^{-7}	0.2138	0.062	0.062
Large Aircraft Landing	4,325	8.3×10^{-5}	1.6×10^{-6}	0.1344	0.014	0.014
Small Aircraft Takeoff	**3,306**	1.5×10^{-3}	$\mathbf{8.05 \times 10^{-7}}$	0.0577	**0.037**	0.110
Small Aircraft Landing	**5,903**	2.6×10^{-3}	$\mathbf{1.44 \times 10^{-6}}$	0.0855	**2.256**	6.884
Subtotals	**15,956**				**2.369**	7.069
General:						
Single-engine Piston Takeoff	2,072	0	1.1×10^{-5}	0.0376	0.000	0.000
Single-engine Piston Landing	3,700	5.6×10^{-4}	2.0×10^{-5}	0.0376	1.391	1.391
Multi-engine Piston Takeoff	936	0	9.3×10^{-6}	0.0370	0.000	0.000
Multi-engine Piston Landing	1,672	5.6×10^{-4}	2.3×10^{-5}	0.0370	0.711	0.711
Turboprop Takeoff	806	0	3.5×10^{-6}	0.0430	0.000	0.000
Turboprop Landing	1,440	5.6×10^{-4}	8.3×10^{-6}	0.0430	0.257	0.257
Turbojet Takeoff	916	0	1.4×10^{-6}	0.0383	0.000	0.000
Turbojet Landing	1,635	5.6×10^{-4}	4.7×10^{-6}	0.0383	0.147	0.147
Subtotals	13,177				2.507	2.507
Grand Totals	***40,215***				***5.341***	10.042
Decrease					47%	
Overstatement Ratio					1.9	

Table 10: The Effects on the Near-Airport Operations Portion of the Impact Frequency Estimate for Zone 12 of the Most Conservative Reduction in the Accident Rates for the Small Military Subcategory. Operations per year for these two subcategories were also reduced due the closure of Reese AFB. All takeoffs are from runway 04, with a corresponding (x,y)-value of (10.77, -1.71). All landing are at runway 22, with a corresponding (x,y)-value of (-10.77, 1.71). The changed values are in boldface. The overstatement ratio is the ratio of the original estimate to the final estimate.

Aircraft Subcategory	*Operations per Year*	*f(x,y) (per mile²)*	*Crash Rate P (per year)*	*Effective Area for Zone 12 (mile²)*	*Adjusted Impact Frequency (10^{-6} per year)*	*Reference Impact Frequency (10^{-6} per year)*
Commercial:						
Air Carrier Takeoff	2,365	1.2×10^{-5}	2.0×10^{-7}	0.2794	0.002	0.002
Air Carrier Landing	4,222	1.7×10^{-4}	2.6×10^{-7}	0.2794	0.052	0.052
Air Taxi Takeoff	1,614	1.2×10^{-5}	1.0×10^{-6}	0.2351	0.005	0.005
Air Taxi Landing	2,881	1.7×10^{-4}	2.3×10^{-6}	0.2351	0.265	0.265
Subtotals	11,082				0.323	0.323
Military:						
Large Aircraft Takeoffs	2,422	9.8×10^{-4}	5.7×10^{-7}	0.2379	0.322	0.322
Large Aircraft Landing	4,325	8.3×10^{-5}	1.6×10^{-6}	0.1504	0.086	0.086
Small Aircraft Takeoff	**3,306**	1.5×10^{-3}	$\mathbf{8.05 \times 10^{-7}}$	0.0847	**0.338**	1.008
Small Aircraft Landing	**5,903**	2.6×10^{-3}	$\mathbf{1.44 \times 10^{-6}}$	0.1074	**2.377**	7.252
Subtotals	**15,956**				**3.123**	8.668
General:						
Single-engine Piston Takeoff	2,072	0	1.1×10^{-5}	0.0577	0.000	0.000
Single-engine Piston Landing	3,700	5.6×10^{-4}	2.0×10^{-5}	0.0577	2.391	2.391
Multi-engine Piston Takeoff	936	0	9.3×10^{-6}	0.0571	0.000	0.000
Multi-engine Piston Landing	1,672	5.6×10^{-4}	2.3×10^{-5}	0.0571	1.230	1.230
Turboprop Takeoff	806	0	3.5×10^{-6}	0.0634	0.000	0.000
Turboprop Landing	1,440	5.6×10^{-4}	8.3×10^{-6}	0.0634	0.424	0.424
Turbojet Takeoff	916	0	1.4×10^{-6}	0.0585	0.000	0.000
Turbojet Landing	1,635	5.6×10^{-4}	4.7×10^{-6}	0.0585	0.252	0.252
Subtotals	13,177				4.297	4.297
Grand Totals	**40,215**				**7.743**	13.288
Decrease					42%	
Overstatement Ratio					1.7	

3.2 Contribution from Non-Airport Operations

Another factor of note is the assumption within the DOE Standard that the impact point for an aircraft is purely random. The glide ratio of 11:1 for a Cessna 172 and 13:1 for a T-37 presents pilots who have some remaining control of the aircraft the ability to avoid impacting built-up structures. This is especially true in the area around the Pantex Plant, which is both relatively flat and sparsely populated. Consequently, the NPf(x,y)[8] values for in-flight accidents were decreased by two-thirds for small military and all general aviation subcategories. The effects of this change for Zone 4 are shown in Table 11. The results for Zone 12 are given in Table 12. The net result is a 64–65% decrease in the contribution of non-airport operations to impact frequency.

Table 11: Revised Impact Frequencies from Non-Airport Operations for Zone 4. (Boldface numbering indicates changed values. All impact frequencies are in terms of 10^{-6} impacts per year.)

Aircraft Subcategory	*Reference NPf(x,y) (per year × mile²)*	*Adjusted NPf(x,y) (per mile²)*	*Effective Area for Zone 4 (mile²)*	*Adjusted Impact Frequency (10^{-6} per year)*	*Reference Impact Frequency (10^{-6} per year)*
Commercial: Air Carrier	6.0×10^{-8}	6.0×10^{-8}	0.2725	0.016	0.016
Commercial: Air Taxi	4.0×10^{-7}	4.0×10^{-7}	0.2209	0.088	0.088
Military: Large Aircraft	1.0×10^{-7}	1.0×10^{-7}	0.2738	0.027	0.027
Military: Small Aircraft	5.0×10^{-6}	$\mathbf{1.7 \times 10^{-6}}$	0.1108	***0.185***	0.554
General: Single-engine Piston	3.1×10^{-5}	$\mathbf{1.0 \times 10^{-5}}$	0.0394	***0.407***	0.535
General: Multi-engine Piston	1.4×10^{-5}	$\mathbf{4.7 \times 10^{-6}}$	0.0394	***0.184***	0.109
General: Turboprop	1.2×10^{-5}	$\mathbf{4.0 \times 10^{-6}}$	0.0455	***0.182***	0.093
General: Turbojet	1.4×10^{-5}	$\mathbf{4.7 \times 10^{-6}}$	0.0394	***0.184***	0.107
Totals				***1.274***	1.530
Decrease				64%	
Effective Overstatement				2.8	

Table 12: Revised Impact Frequencies from Non-Airport Operations for Zone 12. (Bold numbering indicates changed values. All impact frequencies are in terms of 10^{-6} impacts per year.)

Aircraft Subcategory	*NPf(x,y) (per year × mile²)*	*Adjusted NPf(x,y) (per mile²)*	*Effective Area for Zone 12 (mile²)*	*Adjusted Impact Frequency (10^{-6} per year)*	*Reference Impact Frequency (10^{-6} per year)*
Commercial: Air Carrier	6.0×10^{-8}	6.0×10^{-8}	0.2670	0.016	0.016
Commercial: Air Taxi	4.0×10^{-7}	4.0×10^{-7}	0.2292	0.092	0.092
Military: Large Aircraft	1.0×10^{-7}	1.0×10^{-7}	0.2759	0.028	0.028
Military: Small Aircraft	5.0×10^{-6}	$\mathbf{1.7 \times 10^{-6}}$	0.1270	***0.212***	0.635
General: Single-engine Piston	3.1×10^{-5}	$\mathbf{1.0 \times 10^{-5}}$	0.0597	***0.617***	0.811
General: Multi-engine Piston	1.4×10^{-5}	$\mathbf{4.7 \times 10^{-6}}$	0.0597	***0.279***	0.165
General: Turboprop	1.2×10^{-5}	$\mathbf{4.0 \times 10^{-6}}$	0.0661	***0.264***	0.135
General: Turbojet	1.4×10^{-5}	$\mathbf{4.7 \times 10^{-6}}$	0.0597	***0.279***	0.162
Totals				***1.785***	2.043
Decrease				65%	
Effective Overstatement				2.9	

[8] See **Appendix C: Terminology** on page 24.

3.3 Summary

The cumulative effects of these changes are summarized for Zone 4 in Table 13 and for Zone 12 in Table 14. These tables bring together the components of impact frequency due to takeoffs (i=1 in the four-factor formula), landings (i=2 in the formula), and non-airport operations (i=3 in the formula) for each of the two zones. The effect on total impact frequency is further summarized in Table 15 on page 16.

Table 13: Summary of Impact Frequency Values for Zone 4

Aircraft Subcategory	*Takeoff: RW04 (10^{-6} per year)*	*Landing: RW22 (10^{-6} per year)*	*Non-Airport (10^{-6} per year)*	*Adjusted Impact Frequency (10^{-6} per year)*	*Reference Impact Frequency (10^{-6} per year)*
Commercial: Air Carrier	*0.002*	*0.079*	*0.016*	*0.098*	*0.098*
Commercial: Air Taxi	*0.005*	*0.379*	*0.088*	*0.473*	*0.473*
Military: Large Aircraft	*0.062*	*0.014*	*0.027*	*0.103*	*0.103*
Military: Small Aircraft	***0.037***	***2.256***	***0.185***	***2.477***	*7.547*
General: Single-engine Piston	*0.000*	*1.391*	***0.407***	***1.798***	*2.613*
General: Multi-engine Piston	*0.000*	*0.711*	***0.184***	***0.895***	*1.263*
General: Turboprop	*0.000*	*0.257*	***0.182***	***0.439***	*0.803*
General: Turbojet	*0.000*	*0.147*	***0.184***	***0.331***	*0.699*
Total	***0.105***	***5.235***	***1.274***	***6.614***	*13.598*
Decrease				*51%*	
Overstatement Ratio				*2.1*	

Table 14: Summary of Impact Frequency Values for Zone 12

Aircraft Subcategory	*Takeoff: RW04 (10^{-6} per year)*	*Landing: RW22 (10^{-6} per year)*	*Non-Airport (10^{-6} per year)*	*Adjusted Impact Frequency (10^{-6} per year)*	*Reference Impact Frequency (10^{-6} per year)*
Commercial: Air Carrier	*0.002*	*0.052*	*0.016*	*0.070*	*0.070*
Commercial: Air Taxi	*0.005*	*0.265*	*0.092*	*0.361*	*0.361*
Military: Large Aircraft	*0.322*	*0.086*	*0.028*	*0.436*	*0.436*
Military: Small Aircraft	***0.338***	***2.377***	***0.212***	***2.926***	*8.895*
General: Single-engine Piston	*0.000*	*2.391*	***0.617***	***3.008***	*3.202*
General: Multi-engine Piston	*0.000*	*1.230*	***0.279***	***1.508***	*1.395*
General: Turboprop	*0.000*	*0.424*	***0.264***	***0.689***	*0.560*
General: Turbojet	*0.000*	*0.252*	***0.279***	***0.530***	*0.414*
Total for Zone 12	***0.666***	***7.077***	***1.785***	***9.528***	*15.332*
Decrease				*48%*	
Overstatement Ratio				*1.9*	

Table 15: Summary of Final Results

	Adjusted Impact Frequency	*Reference Impact Frequency*
Zone 4	6.6×10^{-6}	13.6×10^{-6}
Zone 12	9.5×10^{-6}	18.4×10^{-6}
Totals	16.1×10^{-6}	32.0×10^{-6}
Decrease	*50%*	
Overstatement Ratio	*2.0*	

4. Conclusions

Realistic site-specific aircraft accident analysis for the Pantex facilities shows numerous opportunities to improve the estimates of accident rates:

1. The accident rate factors for small military aircraft have been adjusted to reflect the mix of currently operational aircraft models, deleting accidents involving older, more accident-prone, and non-operational models. This reduced the predicted accident rate for small military aircraft by more than 60%. However, further research (involving access to source data) is needed to calculate the specific effect on the accident ratios used in the Standard. Subdividing the small military subcategory into attack/fighter craft and trainer craft would also result in substantial refinement of the estimated impact frequency, and should be investigated.

2. The conversion factor from military accident rates (accidents per 100,000 hours) to DOE guideline accident rates (accidents per mission) has been adjusted to reflect the way the USAF and the FAA count missions, landings, approaches and departures. This reduced the predicted accident rate for small military aircraft by more than 55%.

3. The accident rate for small military trainers and general aviation aircraft has been reduced by approximately 65% to reflect pilot training to crash on flat fields (when impact is imminent) rather than into congested areas such as the Pantex facilities.

These last two adjustments together reduced the estimated overall accident rate by more than half. It is anticipated that similar planned adjustments to the large military, air carrier and air taxi categories will produce a similar additional decrease in overall accident rates. We are seeking necessary source data for those adjustments.

5. For Further Research

First, accident and operations data need to be gathered on the mix of military aircraft currently in use, for the purpose of developing accident rates based on the aircraft representing a current threat to the facility. This can be done for both small and large military aircraft.

Second, it is suggested that separate accident rates be developed for attack/fighter and trainer aircraft in the small military subcategory, and these be applied separately to the traffic data at Amarillo International Airport.

Appendix A: Sources for Data in the Tables

There are two primary sources for the data included in the tables, which are designated by [A] and [B].

The [A] refers to the support document for the DOE Standard *Accident Analysis for Aircraft Crash into Hazardous Facilities* (DOE-STD-3014-96, October 1996). The following tables within it are used as sources of data.

1. Table 4.2 Summary of Small (High-Performance) Aircraft Mishap History (Mishap Rates per 100,000 Flight Hours), p. 4–7.

2. Table 4.7 Crash Data and Estimates of Crash Frequencies Based on the Minuteman III Mishap Database — Takeoff and Landing, on page 4–10.

The [B] refers to the *Final Environmental Impact Statement for the Continued Operation of the Pantex Plant and Associated Storage of Nuclear Weapon Components, Volume II* (November 1996), also from the DOE. The following tables within it are used as sources of data.

1. *Table E.2.1–1 — Aircraft Crash Rates*, page E–39
2. *Table E.3.1.2–1 — Amarillo International Airport Flight Operations by Aircraft Category*, page E–42
3. *Table E.3.1.4–2 — Zone 4 Aircraft Operational Data: Take-off, In-flight, and Landing*, page E–43
4. *Table E.3.1.4–3 — Zone 4 Aircraft Crash Location Probabilities: Runway 22*, page E–43
5. *Table E.3.1.4–4 — Zone 4 Aircraft Crash Location Probabilities: Runway 04*, page E–44
6. *Table E.3.1.5–3 — Zone 12 Aircraft Operational Data: Take-off, In-flight, and Landing*, page E–50
7. *Table E.3.1.5–4 — Zone 12 Aircraft Crash Location Probabilities: Runway 22*, page E–50
8. *Table E.3.1.5–5 — Zone 12 Aircraft Crash Location Probabilities: Runway 04*, page E–51

Details for each table are given below.

Table 1. This is taken directly from [A1]. The column giving the numbers of flight hours was not reproduced.

Table 2. These data are a subsidiary of that in Table 1.

Table 3. These data are a subsidiary of that in Table 1.

Table 4. The numbers of landings come from [A2]. The flight hours are taken from [A1].

Table 5. The landings and flight hours are repeated from Table 4. The increase factor is calculated as 3.0/(landings per flight hour) for the T-37 and T-38 and as 1.25/(landings per flight hour) for all other models. The estimated numbers of operations are obtained by multiplying the flight hours column by the increase factor.

Table 6. The landings and flight hours are repeated from Table 4. The increase factor is calculated as 3.0 divided by the landings per flight hour for the T-37 and T-38 and as 1.5 divided by the landings per flight hour for all other models. The estimated numbers of operations are obtained by multiplying the flight hours column by the increase factor.

Table 7. The landings and flight hours are repeated from Table 4. The increase factor is calculated as 3.0 divided by the landings per flight hour for the T-37 and T-38 and as 1.75 divided by the landings per flight hour for all other models. The estimated numbers of operations are obtained by multiplying the flight hours column by the increase factor.

Table 8. The revision factors are brought forward from Table 5, Table 6, and Table 7. The base number of operations (46,922,000) is from [A2]. Each estimated number of operations is obtained by multiplying the base number of operations by the appropriate revision factor. The figures of 86 takeoff accidents impacting off-runway and 154 landing accidents impacting off-runway are taken from [A2] also. The takeoff accident rates are then calculated as 86 divided by the appropriate estimated number of operations. The landing accident rates are calculated as 154 divided by the appropriate estimated number of operations.

Table 9. Operations per year are taken from [B2]. The original values for the small military subcategory (4,408 for takeoffs and 7,870 for landings) were reduced by approximately 25% to obtain the results in the table. The values for f(x,y) for takeoffs are from [B5]. The values for f(x,y) for landings are from [B4]. The small military takeoff and landing crash rates are brought forward from Table 8. The remaining values for the crash rate P are taken from [B1]. The effective area values are from [B3]. The adjusted impact frequency is the product of the previous four columns, following the four-factor formula of the DOE Standard, Section 5.1, pages 38–39. The reference impact frequency is calculated the same, except for the small military takeoffs and landings. There, the original numbers of operations given above and the crash rates from [B1] were used.

Table 10. Operations per year are taken from [B2]. The original values for the small military subcategory (4,408 for takeoffs and 7,870 for landings) were reduced by approximately 25% to obtain the results in the table. The values for f(x,y) for takeoffs are from [B8]. The values for f(x,y) for landings are from [B7]. The small military takeoff and landing crash rates are brought forward from Table 8. The remaining values for the crash rate P are taken from [B1]. The effective area values are from [B6]. The adjusted impact frequency is the product of the previous four columns, following the four-factor formula of the DOE Standard, Section 5.1, pages 38–39. The reference impact frequency is calculated the same, except for the small military takeoffs and landings. There, the original numbers of operations given above and the crash rates from [B1] were used.

Table 11. The values for NPf(x,y) are from [B3]. The values for the revised NPf(x,y) for the commercial and large military subcategories are the same as the unmodified values. The small military and general aviation quantities were reduced by two-thirds. The in-flight effective areas are from [B3] also. The adjusted impact frequency is the product of the revised NPf(x,y) column and the effective area column. The reference impact frequency is the product of the unrevised NPf(x,y) column and the effective area column.

Table 12. The values for NPf(x,y) are from [B6]. The values for the revised NPf(x,y) for the commercial and large military subcategories are the same as the unmodified values. The small military and general aviation quantities were reduced by two-thirds. The in-flight effective areas are from [B6] also. The adjusted impact frequency is the product of the revised NPf(x,y) column and the effective area column. The reference impact frequency is the product of the unrevised NPf(x,y) column and the effective area column.

Table 13. The values for the impact frequencies from takeoffs and landings are brought forward from Table 9. The values for the impact frequencies from in-flight operations are brought forward from Table 11. The revised impact frequency column is the sum of the previous three columns.

Table 14. The values for the impact frequencies from takeoffs and landings are brought forward from Table 10. The values for the impact frequencies from in-flight operations are brought forward from Table 12. The revised impact frequency column is the sum of the previous three columns.

Table 15. The values in this table are brought forward from Table 13 and Table 14.

Appendix B: The Four-Factor Formula

The following is taken verbatim from the DOE Standard, Section 5.1, pages 38–39.

$$F = \sum_{i,j,k} N_{ijk} \cdot P_{ijk} \cdot f_{ijk}(x,y) \cdot A_j,$$

where

F = estimated annual aircraft crash impact frequency for the facility of interest

N_{ijk} = estimated annual number of site-specific aircraft operations (*i.e.*, takeoffs, landings, and in-flights) for each applicable summation parameter (no./y);

P_{ijk} = aircraft crash rate (per takeoff or landing for near-airport phases and per flight for the in-flight (non-airport) phase of operation) for each applicable summation parameter;

$f_{ijk}(x,y)$= aircraft crash location conditional probability (per square mile) given a crash evaluated at the facility location for each applicable summation parameter;

A_{ij} = the site-specific effective area for the facility of interest that includes skid and fly-in effective areas (square miles) for each applicable summation parameter, aircraft category or subcategory, and flight phase for military aviation;

i = (index for flight phases): i=1, 2, and 3 (takeoff, in-flight, and landing);

j = (index for aircraft category or subcategory): j=1, 2,…, 11;

k = (index for flight source): k=1, 2, ..., K (there could be multiple runways, and non-airport operations);

$\sum$ = $\sum_{kji}$; and

ijk = site-specific summation over flight phase, i; aircraft category or subcategory, j; and flight source, k.

Appendix C: Terminology

Class A accident[9]: A mishap in which the resulting total cost of property damage, injury, and illness is $1,000,000 or greater; or an Air Force aircraft is destroyed; or a fatality occurs.

Class B accident[9]: A mishap in which the resulting total cost of property damage, injury, and illness is $200,000 or more, but less than $1,000,000.

Destroyed[9]: Uneconomical to repair, defined by the number of man-hours estimated as needed to repair the aircraft. Repair time varies depending on the type of aircraft.

Non-airport operations: Operations not directly related to takeoffs or landings.

NPf(x,y): The distribution of impacts from non-airport operations is considered to be uniform across the United States. Therefore, N, P, and f(x,y) are assumed constant across all regions for a given aircraft subcategory, and it is unnecessary to present each one individually; rather the product of the three is specified for each aircraft subcategory. Thus, the four-factor formula is then merely a product of this quantity and the effective target area.

Appendix D: References

1. *Data Development and Technical Support Document for the Aircraft Crash Risk Analysis Methodology(ACRAM) Standard*, UCRL-ID-124837 Draft Revision 1 (August 9, 1996). Authors: Andrew B. Barto, Ronald E. Glaser, Timothy A. Haley, Chris Y. Kimura, Tom Lin, Richard W. Mensing, and Martin A. Stutzke.

2. DOE Standard *Accident Analysis for Aircraft Crash into Hazardous Facilities*, DOE-STD-3014-96 (October 1996), U.S. Department of Energy, 1000 Independence Ave., Washington DC 20585

3. *Final Environmental Impact Statement for the Continued Operation of the Pantex Plant and Associated Storage of Nuclear Weapon Components*, DOE/EIS-0225 (November 1996), U.S. Department of Energy, 1000 Independence Ave., Washington DC 20585

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[9] This is quoted directly from the technical support document, page 4–3.

Appendix E: Contact Information

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