Appendix 11.2 Calculation of Aircraft Crash Frequency

Introduction

The distance between the nearest arrival/departure flight path for the Hong Kong International Airport (HKIA) and the LPG Store at Tuen Mun Area 44 is approximately 4.7km. The distance between the LPG Store and HKIA is about 7.5km, which is within the criteria of 5 miles (8km) for the consideration of airfield accident. At such distances, the LPG Store comes into the flight paths of the critical takeoff and landing phases and therefore the background crash rate, airway crash rate and airfield crash rate were taken into account. The frequency of aircraft crash was estimated using the methodology of the HSE (1997). The number of runway movements of aircraft N was provided by yearly statistics of the HKIA in 2009-2018. Number of movements in year 2026 and year 2031 were estimated by linear regression.

Frequency Calculation

Background Crash Rate and Airway Crash Rate

The frequency of aircraft crash of a particular aircraft type is calculated with reference to *Health and Safety Executives - The Calculation of Aircraft Crash Risk in the UK* prepared by J P Byrue in 1997, given by the following equation:

Frequency (per year) = Background Crash Rate + Airway Crash Rate

Frequency (per year) = $(A \times B_i) + (A \times N_i \times R_i \times afac/\ alt)$*, where*

- A = area of the LPG Store (in km^2)
- N_i = number of aircraft movement (for aircraft type i)
- B_i = background crash rate for aircraft (for aircraft type i, in per year per km^2)
- R_i = aircraft in-flight reliability (for aircraft type i, crashes per year per km per aircraft movement)
- alt = altitudes of airways (in km)
- afac = area factor used in airway calculation

The parameters of the above equation are listed as follows:

- Area of the LPG Store (A): 4.0×10^{-4} km^2 = $400m^2$
- Number of aircraft movement (N):
  - The forecasted annual aircraft movement in year 2026 and year 2031 are 584,399 and 710,229 respectively.
- Background aircraft crash rate (B_i):
  - The background crash rate for airliners is 2×10^{-6} per year per km^2
- Aircraft in-flight crash rate (R_i):
  - It is taken as 4.7×10^{-11} per year per km per movement
- Altitudes of airways (alt):
  - altitudes of airways is taken as 5 km
- Area factor (afac):
  - area factor (afac) is taken as 0.265 from Table 9 of Byrne (1997) with corresponding x1 = 0.94

    (x1 = x/alt where x = the minimum horizontal distance from airway/ flight path to the site which is taken as 4.7 km)

By substituting the parameters into the equation listed above, the annual aircraft crash rate can be estimated and listed as follows:

- Frequency (per year) in year 2026 = 1.38×10^{-9} per year
- Frequency (per year) in year 2031 = 1.51×10^{-9} per year

Airfield Crash Rate

The model considers specific factors such as target area of the proposed magazine site and its longitudinal (x) and perpendicular (y) distances from the runway threshold for landing and take-off movement. The aircraft crash frequency per unit ground area (per km^2) is calculated as:

$$g(x,y) = NRF(x,y) \qquad (1)$$

Where N is the number of runway movements per year; R is the probability of an accident per movement (landing or takeoff). F(x,y) gives the spatial distribution of crashes and is given by:

For aircraft landing, for x > -3.275km,

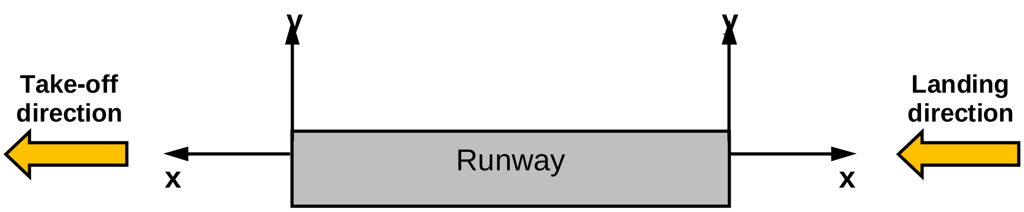
$$F_L(x,y) = \frac{(x+3.275)}{3.24} e^{\frac{-(x+3.275)}{1.8}} \left[\frac{56.25}{\sqrt{2\pi}} e^{-0.5(125y)^2} + 0.625 e^{-\frac{|y|}{0.4}} + 0.005 e^{-\frac{|y|}{5}} \right] \qquad (2)$$

For aircraft takeoff, for x > -0.6km,

$$F_T(x,y) = \frac{(x+0.6)}{1.44} e^{\frac{-(x+0.65)}{1.2}} \left[\frac{46.25}{\sqrt{2\pi}} e^{-0.5(125y)^2} + 0.9635 e^{-4.1|y|} + 0.08 e^{-|y|} \right] \qquad (3)$$

Equations (2) and (3) are valid only for the specified range of x values. If x lies outside this range, the impact probability is zero. This case applies for 07L and 07R runways for arrival flight path and 25L and 25R runways for departure flight path.

Distances between the proposed magazine and the runways are measured and transformed into longitudinal (x) and perpendicular (y) distances in the Aircraft Crash Coordinate System according to the following figure.



The probability of an accident per movement R is interpreted from NTSB data for fatal accidents in the U.S. involving scheduled airline flights during the period 1986-2005. The 10-year moving average suggested a downward trend with recent years showing a rate of about 2×10^{-7} per flight. There are only 13.5% of accidents associated with the approach to landing, 15.8% associated with take-off and 4.2% are related to the climb phase of the flight. Thus, it is assumed that the accident frequency for the approach to landings is taken as 2.7×10^{-8} per flight and for take-off is 4.0×10^{-8} per flight.

The number of runway movements of aircraft N is provided by yearly statistics of the Hong Kong International Airport in 2009-2018. Number of movements at year 2026 and year 2031 were estimated by linear regression respectively for landing and take-off cases. The movement number adopted in the calculation were divided by 4 to take into account that only a quarter of landing or take-off use a specific runway.

The aircraft crash frequencies were finally obtained by multiplying g(x,y) to target area which was estimated to be 4×10^{-4} km^2 for the LPG Store.

The calculations are presented in **Table 1** and the airfield crash frequency per year in both construction stage (year 2026) and operational stage (year 2031) are summarised in **Table 2**.

Table 1 **Calculation for Aircraft Crash Frequency**

Year	Runway	x (km)	y (km)	F(x,y)	N (per year)	R (per flight)	Crash frequency (per unit area)	Target area (km^2)	Crash Frequency (per year)
2026	25R Landing	7.0	3.4	2.7E-05	73057	2.7E-08	5.4E-08	4.00E-04	2.1E-11
2026	25L Landing	8.2	2.9	1.9E-05	73057	2.7E-08	3.8E-08	4.00E-04	1.5E-11
2026	07L Landing	-10.6	7.5	0	73057	2.7E-08	0.0E+00	4.00E-04	0.0E+00
2026	07R Landing	-11.9	7.5	0	73057	2.7E-08	0.0E+00	4.00E-04	0.0E+00
2026	07L Take-off	7.0	3.4	2.2E-05	73043	4.0E-08	6.6E-08	4.00E-04	2.6E-11
2026	07R Take-off	8.2	2.9	1.6E-05	73043	4.0E-08	4.7E-08	4.00E-04	1.9E-11
2026	25R Take-off	-10.6	7.5	0	73043	4.0E-08	0.0E+00	4.00E-04	0.0E+00
2026	25L Take-off	-11.9	7.5	0	73043	4.0E-08	0.0E+00	4.00E-04	0.0E+00
2031	25R Landing	7.0	3.4	2.7E-05	88788	2.7E-08	6.5E-08	4.00E-04	2.6E-11
2031	25L Landing	8.2	2.9	1.9E-05	88788	2.7E-08	4.6E-08	4.00E-04	1.8E-11
2031	07L Landing	-10.6	7.5	0	88788	2.7E-08	0.0E+00	4.00E-04	0.0E+00
2031	07R Landing	-11.9	7.5	0	88788	2.7E-08	0.0E+00	4.00E-04	0.0E+00
2031	07L Take-off	7.0	3.4	2.2E-05	88769	4.0E-08	8.0E-08	4.00E-04	3.2E-11
2031	07R Take-off	8.2	2.9	1.6E-05	88769	4.0E-08	5.7E-08	4.00E-04	2.3E-11
2031	25R Take-off	-10.6	7.5	0	88769	4.0E-08	0.0E+00	4.00E-04	0.0E+00
2031	25L Take-off	-11.9	7.5	0	88769	4.0E-08	0.0E+00	4.00E-04	0.0E+00

Table 2 **Total Aircraft Crash Frequency**

	Total Crash Frequency (per year) (Year 2026)	Total Crash Frequency (per year) (Year 2031)
Landing	3.7E-11	4.4E-11
Take-off	4.5E-11	5.5E-11
Total	8.2E-11	9.9E-11

Total Aircraft Crash Rate

The total frequency of aircraft crash at the LPG Store was calculated as:

- Aircraft crash frequency (per year) in year 2026 = 1.51×10^{-9} per year
- Aircraft crash frequency (per year) in year 2031 = 1.61×10^{-9} per year

The total frequency of aircraft crash at year 2031 was used in the FTA to calculate the failure frequencies of various LPG release scenarios.

Probability of LPG Equipment Failure due to Aircraft Crash

It was assumed that when there is an aircraft crash, the LPG liquid-line pipework (i.e. 'liquid inlet pipeline to storage vessel' will definitely fail (i.e. probability = 1).

For failure of road tanker, it was assumed that the probability of 'road tanker rupture' and 'road tanker partial failure' given that there is an aircraft crash are 1 and 0 respectively. This assumption is to address in case of aircraft crash to a road tanker, the only possible result is catastrophic failure of the road tanker. For failure of storage vessel, as the LPG storage vessels are protected by a concrete chamber, it was assumed that the probability of 'storage vessel rupture' and 'storage vessel partial failure' given that there is an aircraft crash are 0.01 and 0.09 respectively.