Appendix B – Collision Risk Model
ACRP 4-09 - Risk Assessment Method to Support Modification of Airfield Separation Standards

Introduction

The Collision Risk Model (CRM) is used to estimate the probability of collision with obstacles by an airborne aircraft on an ILS approach and eventual missed approach. The original CRM developed by the FAA and ICAO is presented in this appendix and was used to estimate the risk during the airborne phase of landing.

CRM Variables

- Obstacle location (x, y, z) and dimensions
- Aircraft dimensions (wingspan, height from ILS antenna to wheels)
- Aircraft approach speed category
- Aircraft climb gradient (standard 2.5%)
- Type of approach (Cat I or Cat II)
- Elevation
- Obstacle clearance height (OCH)
- Reference datum height (RDH, standard is 15 m [50 ft])
- Localizer course (use standard of 213.36 m [700 ft])
- Distance from localizer to threshold (use standard of 3800 m [12470 ft])
- Glide path

CRM Reference Coordinates

The coordinates are represented in Figure B-1. The origin (0, 0, 0) is the runway centerline at the approach end. X is the extended runway centerline distance from the runway end, y is the lateral distance from the runway centerline, and z is the height above the runway arrival end.
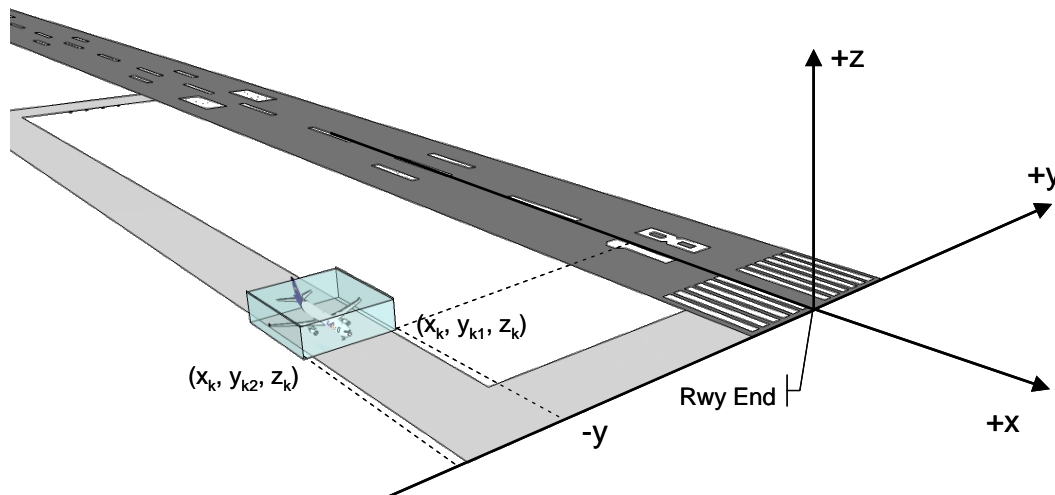
Figure B-1. CRM coordinate system

Collision Risk

During the approach phase, an aircraft may deviate from the nominal flight path for a variety of reasons, including local turbulence, wind shear, lateral wind, unstabilized approach, pilot technique, and equipment malfunction. The concept is illustrated in figures B-2 and B-3. Figure B-2 shows an aircraft during the approach to land. In the mean case, the aircraft is following its nominal flight path (location 1), and in this condition both vertical and horizontal deviations from the nominal path are nil. However, under certain conditions the aircraft may be in location 2 instead of location 1. In this situation, the aircraft has both vertical and horizontal path deviations.

Figure B-2 also shows there is a vertical deviation probability distribution, represented by the blue area in the figure. Only the distribution below the nominal flight path is shown in the figure because such are the deviations that may lead to the risk of collision during the approach. The difference between Z_{avrg} (the height in the nominal flight path) and Z_{actual} is considered the height loss or vertical deviation during the approach.

In addition to vertical deviations, the aircraft may have lateral deviations, as shown in Figure B-3. According to ICAO Doc 9274, the vertical and horizontal deviations are independent of each other. In this case, the probability of both vertical and horizontal deviations is the product of the probability of vertical deviation by the probability of lateral deviation.
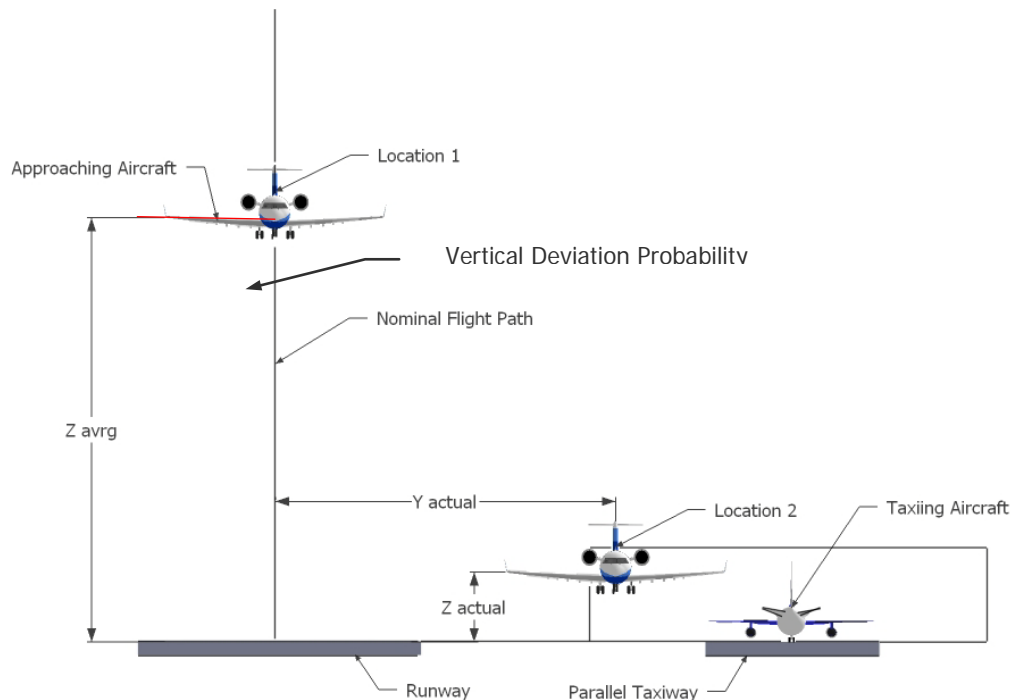

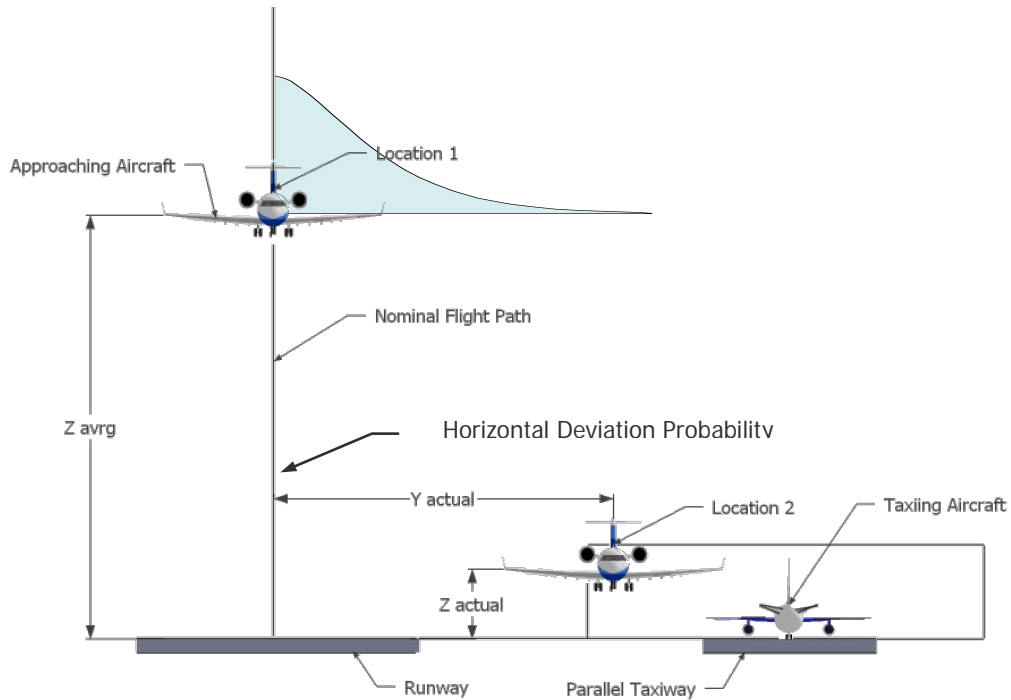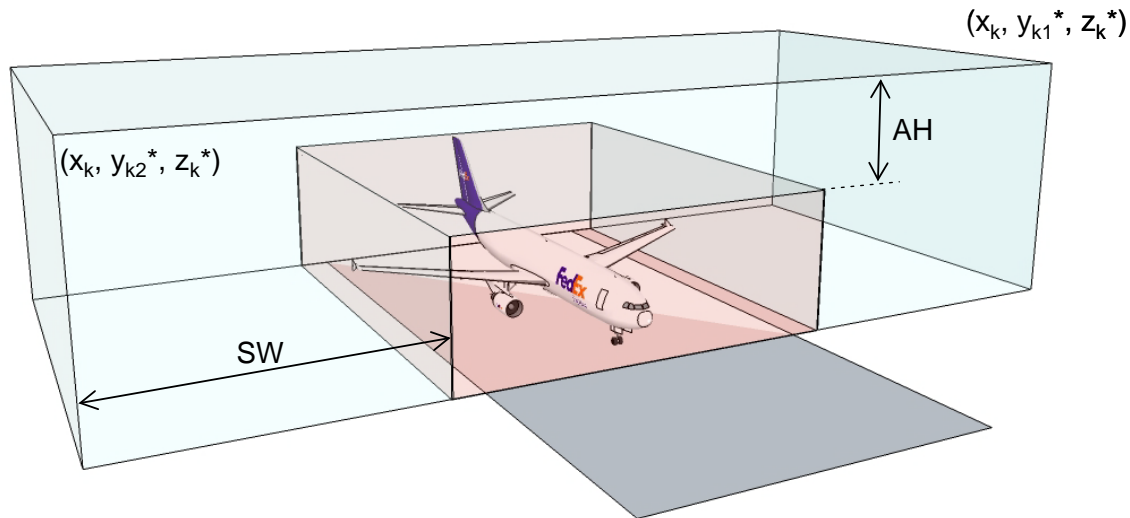Figure B-2. Vertical deviation from nominal flight path

Figure B-3. Lateral deviation from nominal flight path

When these deviations are excessive and there are obstacles in the vicinity of the runway (e.g., taxiing aircraft), as shown in Figures B-2 and B-3, there is a chance that aircraft may collide with such obstacles. The farther away the obstacle is (laterally and vertically), the lower the chances that a collision may occur.

To simplify the analysis, CRM adjusts the dimensions of an obstacle to account for the semi-wingspan of the approaching aircraft and its distance from the fuselage center to the bottom of the landing gear. This process facilitates the computation of the collision risk, as the lateral and vertical deviations from the approach path may be used directly in the analysis. When the approaching aircraft centerpoint is inside the obstacle box, a collision is assumed to occur. Figure B-4 shows the adjustments made to the ground obstacle used in the analysis. To characterize the aircraft for the purpose of this study the taxing aircraft is assumed to be located within 3 ft of the taxiway centerline and it is represented by a rectangle that is 6 ft wide and has the height of the tallest aircraft in the ADG.

- Add aircraft height (AH) from bottom of wheel to ILS glide path to height of obstacle.
- Add arriving aircraft semi-wingspan (SW) to both sides of obstacle.
- Obtain adjusted (y^*, z^*) coordinates for the obstacle.
  - $y_{k1}^* = y_{k1} + SW$.
  - $y_{k2}^* = y_{k2} - SW$.
  - $z^* = z + AH$.

Figure B-4. Adjustments to obstacle dimensions

These adjustments are made automatically by the analysis software. In the example case shown in Figures B-2 and B-3, the aircraft in location 2 has its centerline inside the box of the taxiing aircraft, and the approaching aircraft in this situation is assumed to collide with the taxiing aircraft.

Tables B-1 and B-2 present the values normally used for these adjustments by the FAA and ICAO.

Table B-1. FAA aircraft design groups and dimensions

Design Group	Semi-Wingspan (SW) ft (m)	GP Wheel/ Antenna Height (ft)	Aircraft (Tails) Height (ft)
I	SWS < 24.5 (7.5)	6	< 20
II	24.5 (7.5) ≤ SWS < 39.5 (12)	12	20 to < 30
III	39.5 (12)≤ SWS < 59 (18)	15	30 to < 45
IV	59 (18) ≤ SWS < 85.5 (26)	17	45 to < 60
V	85.5 (26) ≤ SWS < 107 (32.5)	19	60 to < 66
VI	107 (32.5) ≤ SWS < 131 (40)	19	66 to < 80

Table B-2. ICAO aircraft categories and dimensions

Aircraft Category	Wing Semi-Span (m)	GP Wheel/ Antenna Height (m)
A	30	6
B	30	6
C	32.5	7
D	32.5	7
E	40	8

The CRM Approach

CRM is used to estimate the probability of collision between an approaching aircraft and existing obstacles. The CRM approach is illustrated in Figure B-5. The model represents only the non-visual portion of the ILS approach (Cat I, Cat II Flight Director, and Cat II Autopilot) and the missed approach portion, if applicable.

ICAO Doc 9274 provides the probabilities for lateral and vertical deviations for both the ILS and missed approach phases. The mean vertical path and standard deviations are given for different distances from the runway end and for glide paths of 2.5, 3.0, and 3.5 degrees. The mean lateral path is assumed to have no deviation ($Y = 0$), and the mean vertical path is assumed to be the nominal flight path.
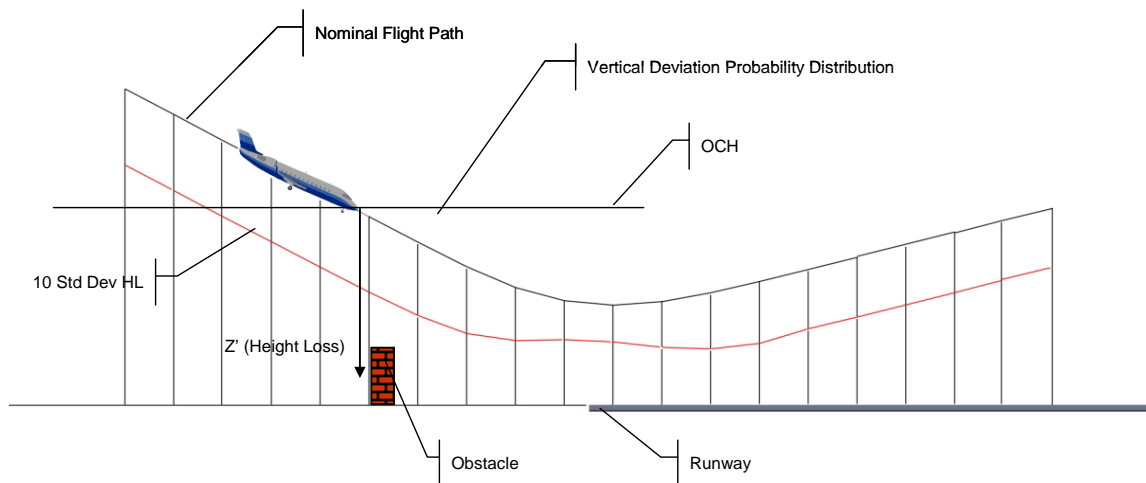

Figure B-5. CRM approach (not to scale)

The CRM does not account for the probability associated with the stage of flight prior to intercepting the ILS beams or after the straight missed approach altitude. Moreover, it cannot estimate the probability of deviations during the visual descent below the OCH or during the rollout phase of landing (veer-offs).

The CRM also provides the approach to consider multiple obstacles and shadowing to estimate the total risk of collision. For some conditions, ICAO Doc 9274 provides tables with probabilities of lateral and vertical deviations, and in other cases it provides the mean path and associated standard deviations when a normal probability distribution, with or without transformations, can be used to estimate probabilities.

Deviations during the ILS Phase

During the ILS phase, CRM provides probabilities of vertical and lateral deviations for three different ranges from the runway approach end: 7800 m, 4200 m, and 1200 m. The range of interest for this study is 1200 m because the obstacles of interest are located in the vicinity of the runway.

The CRM assumes for the ILS portion of the flight that the lateral deviation probabilities depend on the approach category but do not depend on the glide path angle. For the vertical deviations, it depends on the type of approach category, on the glide path angle, and if the approach was assisted with the flight director or autopilot.

Lateral deviations are adjusted for the localizer course width (standard was 213.36 m) and localizer to threshold distance (standard was 3800 m). The vertical distributions were derived for a standard ILS configuration with the glide path intercept located 350 m from the runway arrival end, and the model adjusts for any differences relative to the standard value used.

Table B-3. Standard deviations of aircraft displacement during an ILS approach (ICAO Doc 9274) for ranges less than 1200 m

ILS Category	Lateral Displacement, m	Vertical Displacement, m		
		2.5^o Glide Path	3.0^o Glide Path	3.5^o Glide Path
Cat I	16.4	4.9	5.8	6.8
Cat II Flight Director	11.4	4.5	5.3	6.1
Cat II Autopilot	11.4	3.7	4.4	5.1

Deviations during the Missed Approach Phase

When making an ILS approach, the aircraft descends on the glide path toward the runway touchdown aiming point. When reaching a predefined OCH without a proper visual reference to complete the descent, or when the aircraft is incorrectly aligned, the pilot must initiate a missed approach. Therefore, the vertical path is defined by the glide path down to OCH and thereafter by a missed approach model that is based on aircraft performance. Laterally, the mean path is defined by the extended runway centerline with variations due to weather conditions, instrument accuracy, pilot technique, and other factors.

When reaching OCH, the pilot may initiate a missed approach to pull the aircraft out of the descent path and to attain an ascending trajectory. During this process there is some height loss, and a point of lowest descent (see Figure B-6) is estimated using the height loss equation. Both the height loss and the range for the point of lowest descent are estimated with the model.
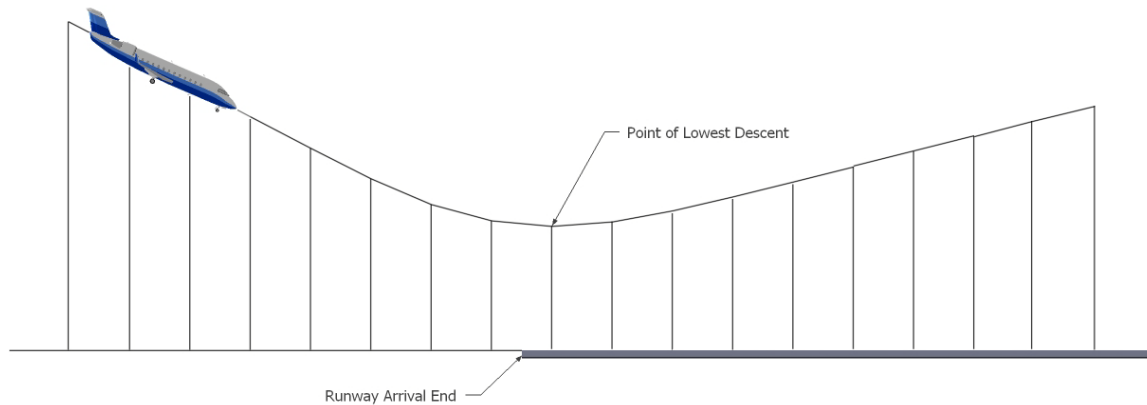

Figure B-6. Missed approach – point of lowest descent

The missed approach path lateral and vertical deviations depend on a number of factors, including the following:

- Glide path angle (2.5 degrees, 3.0 degrees or 3.5 degrees).
- ILS RDH.
- OCH.
- Aircraft maximum approach speed when crossing the threshold (Cat A - 100 knots, Cat B - 120 knots, Cat C - 140 knots, or Cat D - 160 knots).
- Airport elevation.
- Cat I approaches to an OCH of 200 ft.
- Cat II approaches to an OCH of 100 ft (Flight Director and Autopilot).

A fixed climb gradient of 2.5 degrees is assumed during the missed approach.

Collision Risk for Individual Obstacles

Individual probabilities (vertical and lateral) are calculated for the range where the obstacle is located.

Vertical Deviations

Three different vertical probabilities are applicable to different range intervals from the runway end, and these are combined to obtain the vertical probability for the given range. The three probabilities are the approach probability, the height loss probability, and the missed approach climb-out probability.

The approach probability is calculated using the ILS approach vertical distributions, using exponential interpolation when necessary for a given range. For the missed approach, the

vertical probability is assumed to be one. When the obstacle in the approach phase lies below the specified OCH level, the probability obtained must be multiplied by the height loss probability. This adjustment ensures that the distributions will reflect that a missed approach will be initiated when the aircraft reaches the OCH.

The height loss probability is the probability that the aircraft is below the obstacle height at the lowest point of its missed approach, and it is assumed to be independent of the range. The climb-out probability is based on the missed approach path distributions derived from the height loss model. Cat I missed approach distributions are assumed to be Gaussian (i.e., normally distributed), and for Cat II approaches the distribution needs to be transformed according to a Johnson SU distribution. The Johnson SU (unbounded distribution) is a transformation of the Gaussian distribution and is defined by the specification of four parameters (Gamma, Delta, Lambda, and Qui). These parameters are provided for different ranges (150 to -950 m) of the extended runway centerline and are used to calculate the probabilities.

The combined approach/height loss probability, the height loss probability, and the climb-out probability are compared, and the smallest probability applies at the given range.

Adjustments should be made to the vertical distributions to add the actual wheel height from the aircraft centerline to calculate the difference between the specified OCH and the nominal OCH to the distribution means.

Lateral Deviations

The mean of the lateral distributions is considered to match the nominal flight path. The lateral standard deviations during the approach are provided in Table B-3 for each type of ILS approach.

The lateral deviations for the missed approach phase are based on actual flights and simulation studies conducted in the United States and other countries. The distribution shapes are those used for the 1200 m range during the ILS approach.

For lateral deviations, it is necessary to make adjustments to account for the difference between the actual OCH range and a range of 409.86 m (OCH of 100 ft, wheel height of 6m, ILS RDH of 15 m, and glide path angle of 3 degrees).

During the missed approach phase, the probability distributions of lateral deviations are assumed to have the shape used during the ILS approach for the 1200 m range; however, the standard deviation changes according to each range, as shown in Table B-4.

Table B-4. Lateral standard deviations during the missed approach

Range (m)	Standard Deviation (m)
300	12.57
200	12.07

100	12.06
-100	13.30
-200	15.03
-300	17.11
-600	24.65
-900	34.23
-1200	43.93

Missed Approach Rate

The individual risk is associated with the approach, and subsequent missed approach is adjusted because only a small percentage of flights require the missed approach maneuver. To estimate the risk for obstacles located in the missed approach range, a missed approach rate needs to be multiplied by the estimated risk.

The original model uses the rate of one missed approach per 100 flights (1%); however, recent studies (FAA, 2008) have indicated that a conservative value for this rate is one in 500 flights. This proportion is applied only to obstacles located in a range after the missed approach initiation point.

Collision Risk for Multiple Obstacles

The overall risk for a group comprised of n independent (well separated from each other) obstacles is calculated using the following equation:

$$P(C) = 1 - \prod_{k=1}^{n}\left[1 - P\left(O_k^*\right)\right]$$

Where:

P(C) is the probability of a collision during the approach/missed approach maneuver.
$P(O_k^*)$ is the probability of collision with obstacle k modified to account for shadowing.

Shadowing

The equation to calculate the risk for multiple obstacles assumes that the obstacles are well separated from each other. When obstacles are closer, the risk of one may affect the risk of the obstacle behind due to a shadowing effect.

Depending on the flight direction, an individual obstacle may be decreased because of the presence of other obstacles in front or partially in front of them. The solution is to apply a shadowing angle in both the lateral and vertical dimensions. The process is explained in detail in ICAO Doc 9274 and is calculated automatically using the CRM analysis software.