Appendix G – Summary of FAA/Boeing Taxiway Deviation Studies

ACRP 4-09 - Risk Assessment Method to Support Modification of Airfield Separation Standards

Introduction

A cooperative research study between the Boeing Company and the FAA evaluated extreme centerline deviations of large aircraft during taxiing operations on straight segments. The study was intended to gather data to define taxiway separation standards for the A-380 and B-747-800 aircraft. Two of these studies have been completed, and three additional studies are ongoing or planned for the near future. Results from the studies at Anchorage International Airport (ANC) and John F. Kennedy International Airport (JFK) (Scholz, 2003a and 2003b) were combined to arrive at a more generalized taxiway deviation model. Data from a third study at Schipol Airport (1995) in the Netherlands also were compared to integrate the findings from these studies and to obtain probability models for wingtip collision risk between taxiing aircraft and an object, as well as between two taxiing aircraft.

These lateral deviation models are the best alternative available to develop a quantitative analysis methodology for airfield separations. No other models or data are available to develop other approaches, covering a full spectrum of aircraft models as would be desirable. Moreover, collection of data from taxiway incidents has proved to be insufficient to model aircraft deviations, although the data can be used to develop frequency models for taxiway veer-offs.

Description of Taxiway Centerline Deviation Studies at ANC and JFK

The FAA/Boeing studies characterized extreme deviation behavior of B-747 aircraft as they taxi on straight 75-foot-wide taxiway segments. B-747 taxiway centerline deviation data were collected from September 24, 2000, through September 27, 2001, at ANC and from June 24, 1999, through February 17, 2000, at JFK. During this period, 9,767 deviations were recorded at ANC with a range of [−8.225, 8.863] ft, and 2,518 deviations were registered at JFK with a range of [−8.63, 7.53] ft.

The deviations at each airport were extrapolated to more extreme deviations as they could happen for significantly higher numbers of event exposures (e.g., 10^6 - 10^9 taxiway operations). Based on the extreme value limiting assumption, absolute deviations were extrapolated using the 700 most extreme deviations at ANC and the 200 most extreme at JFK.

The resulting model from the analysis was in the following general form:

$$p = 1 - \exp\left(-\frac{1}{n}\left[1 + c\left(\frac{y-\lambda}{\delta}\right)\right]^{-1/c}\right)$$

Where y is the specified threshold of exceedence, p is the probability estimate of exceeding the threshold y distance from the centerline, and λ, δ, n, and c are extrapolation parameters for the model.

To arrive at a more generalized model, data from both airports were combined. Combining the data can help to obtain more reliable models, due to the larger sample size (12,314 deviations in total). A similar modeling practice was implemented to extrapolate more extreme deviations, and the deviation risk model was developed using the 859 most extreme events from the pooled data.

Table G-1 presents the parameters of the models developed for ANC, JFK, and from the combined data. Figure G-1 depicts the taxiway centerline deviation probability at ANC, JFK, and both combined. As presented in the figure, for deviations ranging from 5 to 16 ft, probability results for JFK are higher based on the collected data.

The study also examined the extent to which the deviation at JFK agrees with that at ANC. The conclusion was that the adjusted deviations from JFK are roughly 10% more spread out than the adjusted deviations from ANC. Another analysis indicated that the distributions of the adjusted lateral deviations for ANC and JFK were very much the same in character, differing in location and scale only. Thus, it appears that the data from both airports could be combined if the JFK data were scaled by dividing them by 1.1.

Table G-1. Deviation from taxiway centerline models

Study	**Model**	**Parameters**				**Aircraft**
		n	λ	δ	c	
ANC	$p = 1 - \exp\left(-\frac{1}{n}\left[1 + c\left(\frac{y-\lambda}{\delta}\right)\right]^{-1/c}\right)$	9796	8.797	1	0.03836	B747
JFK		2518	8.398	0.926	−0.02774	B747
Combined		12314	9.073	0.9927	0.0307	B747

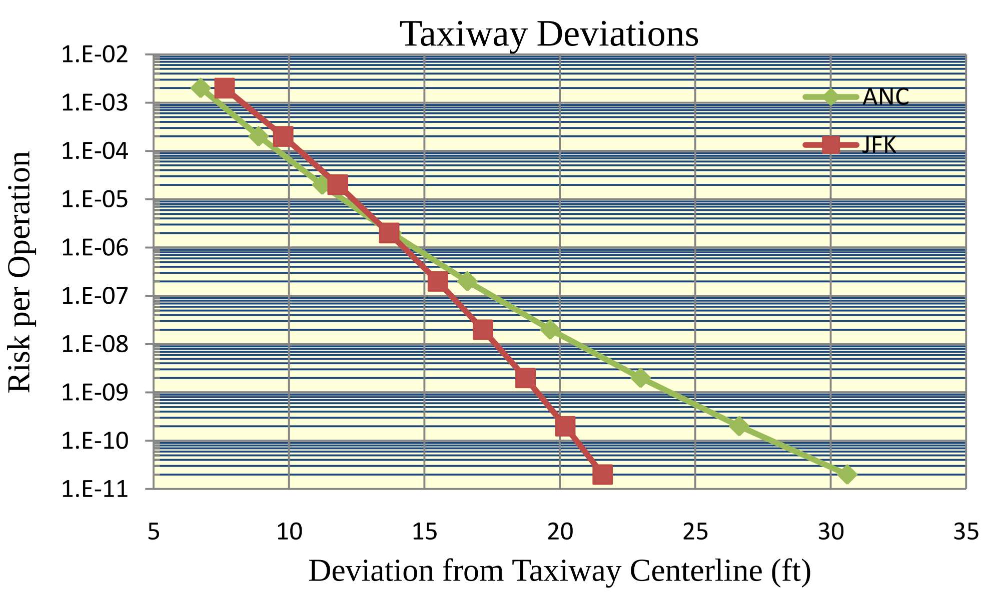

Figure G-1. Risk of B-747 centerline deviations from taxiway centerline

The ANC model was implemented to estimate the risk of veering off the edge of the taxiway for various taxiway widths recommended by the FAA and ICAO design standards for B-747, A-380, and other NLA. Figure G-2 presents the estimates for ANC airport as an example. As expected, the risk of taxiway veer-off decreased as the width of the taxiway increased.

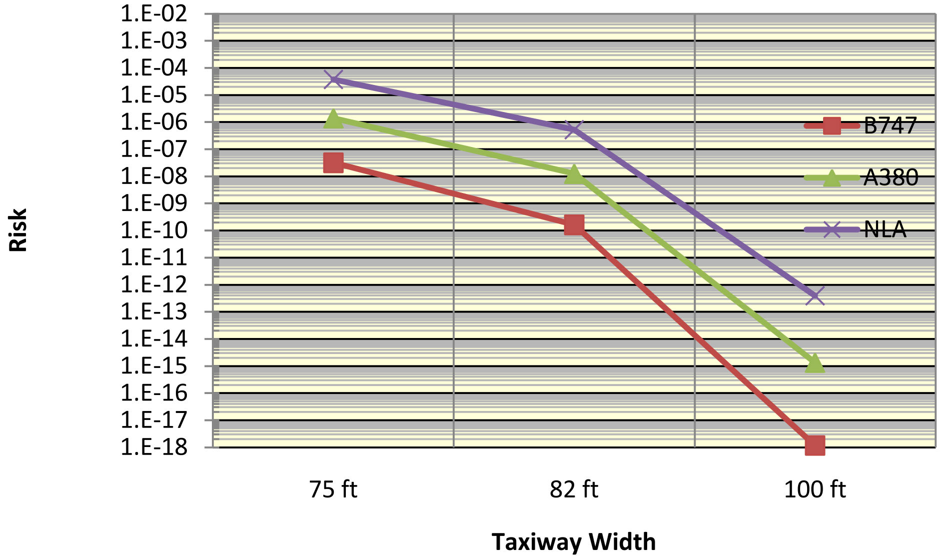

Figure G-2. Risk of veering off taxiway edge for different taxiway widths at ANC

Collision Risk for Taxiing Large Aircraft Study

Another FAA/Boeing study (Scholz, 2005) described the analysis concerning the risk of collision between two large aircraft taxiing on parallel taxiways and the risk of collision between a large taxiing aircraft and a fixed object. The data used for this study were obtained from the JFK and ANC studies.

Wingtip Collision with Fixed Object

A collision between an aircraft wingtip and a fixed object can be avoided if:

$$T > W/2 + d$$

Where T is the separation between the object and the taxiway centerline, W is the wingspan, and d is the aircraft deviation from the taxiway centerline. This situation is presented in Figure G-3.

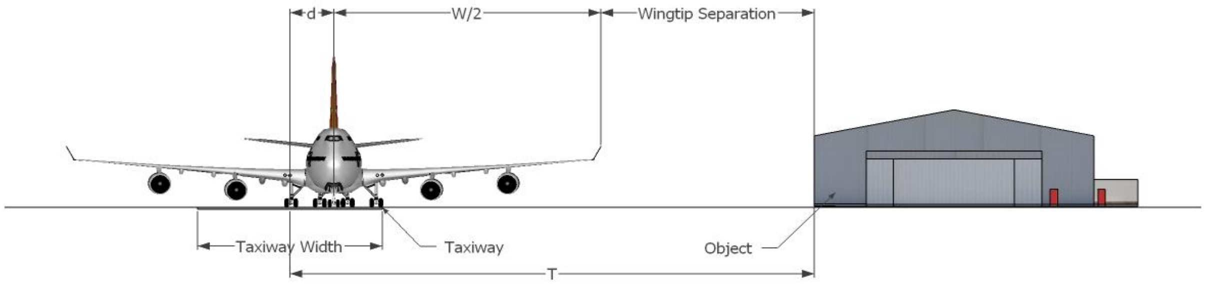

Figure G-3. Taxiway/object separation

Using the probability estimates of d from previous studies and assuming different wingspans, the required separations between the taxiway centerline and an object were calculated for ANC and JFK. Table G-2 presents the required separation for specific aircraft wingspans and associated collision risk at ANC.

Table G-2. Required separation between taxiway centerline and object for different risk levels at ANC

	Estimate ≤ T (ft)						
	collision risk p						
wingspan (ft)	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}
180	96.8	98.9	101.2	103.7	106.4	109.2	112.3
190	101.8	103.9	106.2	108.7	111.4	114.2	117.3
200	106.8	108.9	111.2	113.7	116.4	119.2	122.3
210	111.8	113.9	116.2	118.7	121.4	124.2	127.3
220	116.8	118.9	121.2	123.7	126.4	129.2	132.3
230	121.8	123.9	126.2	128.7	131.4	134.2	137.3
240	126.8	128.9	131.2	133.7	136.4	139.2	142.3
250	131.8	133.9	136.2	138.7	141.4	144.2	147.3
260	136.8	138.9	141.2	143.7	146.4	149.2	152.3
270	141.8	143.9	146.2	148.7	151.4	154.2	157.3
280	146.8	148.9	151.2	153.7	156.4	159.2	162.3

Parallel Taxiway Centerline Separation for Wingtip to Wingtip Clearance

To avoid collision between two taxiing aircrafts with W_1 and W_2 wingspans, the combined deviations need to satisfy the following equation:

$$T > (W_1 + W_2)/2 + d_1 + d_2$$

Where T is the required separation between the taxiway centerlines and d_1 and d_2 are the deviations of each aircraft, as shown in Figure G-4.

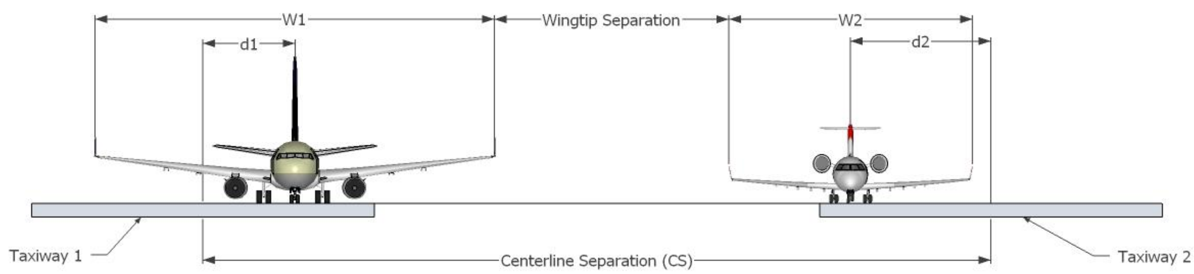

Figure G-4. Taxiway/taxiway separation

The study examined two approaches. In the first approach, deviations from ANC and JFK were split into two halves, and the deviations from the first half were randomly paired with the second half. In all, 6,157 pairs of $d_1 + d_2$ were obtained. For each set of such pairs, the extreme value extrapolation method was applied to the absolute values $| d_1 + d_2 |$ to obtain estimates of deviation probabilities. To correct for the random splitting and pairing effect, this process was repeated 500 times, and a combined estimate and confidence bound was obtained in the tabulation of the results.

The second approach looked at all pair-wise sums di + dj with $1 \leq i < j \leq 12{,}314$. There are 75,811,141 (N) such paired sums. The absolute values |di +dj | were then ordered from smallest to largest, and the top 1,000 and 10,000 were plotted against their respective tail fraction rank order on a log scale. A quadratic was fitted to the graph by the method of least squares, and this quadratic was then used to estimate the probabilities.

Results indicated that the quantile estimates bounds obtained from the first approach were somewhat higher than those obtained under the second approach. The researchers recommended the conservative results from the first approach.

Table G-3 presents the probability results based on the first approach, which is the one proposed for ACRP 4-09. It presents the probability of wingtip collision based on the separation between taxiways centerlines and the wingspan length, assuming two aircraft with the same wingspan.

Table G-3. Required separation *T* between taxiway centerlines for different risk levels at ANC

	Estimate $\leq T$ (ft)						
	collision risk p						
wingspan (ft)	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}
180	189.4	191.6	193.8	195.9	197.8	199.7	201.4
190	199.4	201.6	203.8	205.9	207.8	209.7	211.4
200	209.4	211.6	213.8	215.9	217.8	219.7	221.4
210	219.4	221.6	223.8	225.9	227.8	229.7	231.4
220	229.4	231.6	233.8	235.9	237.8	239.7	241.4
230	239.4	241.6	243.8	245.9	247.8	249.7	251.4
240	249.4	251.6	253.8	255.9	257.8	259.7	261.4
250	259.4	261.6	263.8	265.9	267.8	269.7	271.4
260	269.4	271.6	273.8	275.9	277.8	279.7	281.4
270	279.4	281.6	283.8	285.9	287.8	289.7	291.4
280	289.4	291.8	293.8	295.9	297.8	299.7	301.4

Cohen-Nir and Marchi (2003) conducted a separate study using the collected data from JFK and ANC. In processing the JFK deviation data, they identified some problems with collected data. Several large deviations that would have put the B-747 outside of the taxiway were recorded in a very short period of time. One of the lasers had gone out of service, and all subsequent unusually large deviations occurred with only one laser in service and no ability to measure speed, wheelbase, or direction of travel. The authors decided to eliminate these unusually large deviations from the data set.

The authors conducted several statistical analyses and used regression and Monte Carlo techniques for modeling the taxiway deviations. The study concluded that NLA operations on older airports that cannot meet the FAA ADG VI separation requirements can be conducted on straight taxiway segments, with an extremely low probability of collision. Also, the probabilities derived from taxiway deviation can be helpful to support airport requests for modifications of FAA design standards.

Considering the anomalies associated with data collected from JFK, the ACRP 4-09 research team preferred to use the ANC data and models as the basis for the methodology presented in this study.

Taxiway/Object Separation

Using the models developed by FAA/Boeing based on ANC data, Scholz (2005) derived the wingtip collision risk based on the wingtip separation to an object when the aircraft is located at the taxiway centerline. Using this approach provides more flexibility to the analysis for specific aircraft wingspans. As shown in Figure G-5, wingtip separation is the distance of the object from the centerline of the taxiway less half of the operating aircraft wingspan. Collision occurs if the deviation of the aircraft exceeds this distance to the side of the taxiway on which the object is present. One simplifying assumption is necessary: the wingtip deviation distribution is the same as the aircraft lateral deviation distribution from the taxiway centerline.

Using data from the FAA study, the research team arrived at the probability of taxiway/object collision at ANC based on the mean wingtip separation; in other words, the separation when both aircraft are located at the respective taxiway centerlines. We also used the combined data from the airports to obtain the collision probabilities. The basic assumption in this case is that lateral deviations are similar, independent of the type of aircraft. Although this cannot be proved based on existing data, the assumption is conservative because the data used to model risk were gathered for large aircraft. The standard wingtip separation based on FAA regulation for a class IV aircraft is 53 ft, as shown in Figure G-6.

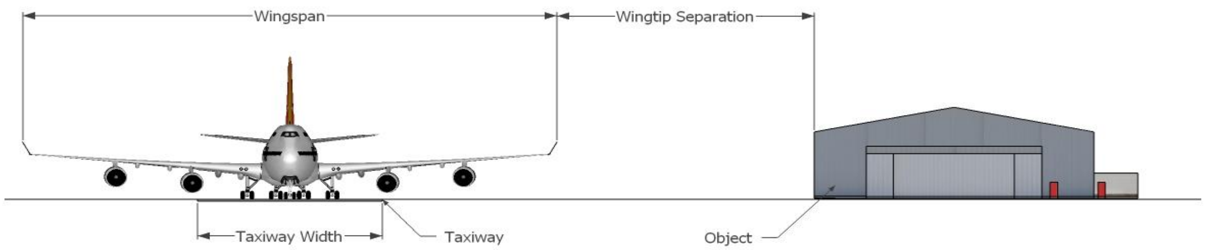

Figure G-5. Wingtip separation for a taxiway-object collision model

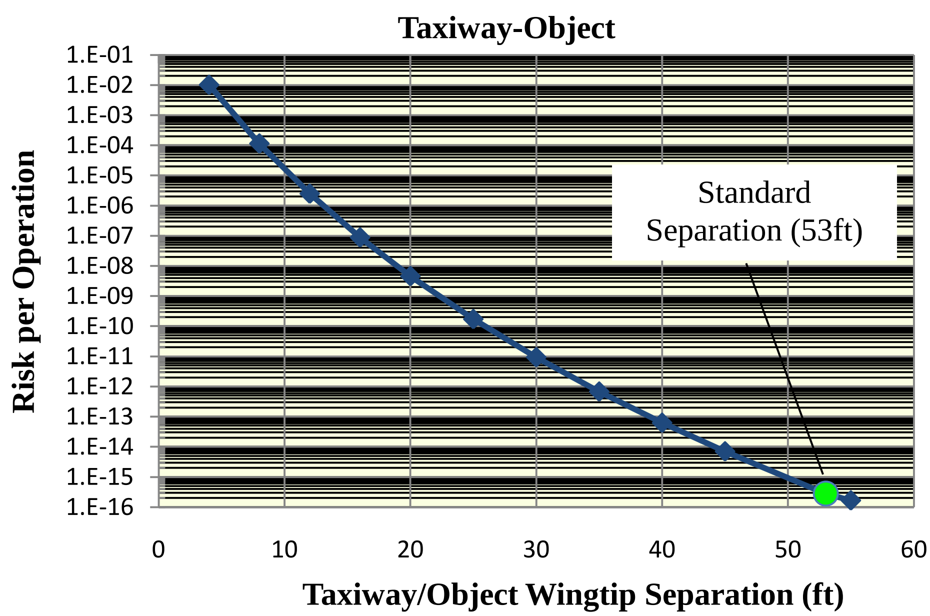

Figure G-6. Taxiway/object collision probability based on wingtip separation at ANC using data from FAA studies

Taxiway/Taxiway Separation

The results from the first approach presented in the FAA/Boeing study were implemented to develop the taxiway/taxiway collision probabilities based on wingtip separation of two B-747 aircraft on parallel taxiways. Figure G-7 presents the results in graphical format.

In the accident and incident data collected, no record was found for wingtip collisions between two aircraft in parallel taxiways; therefore, the level of protection provided by the standards may be considered very high. Looking from the point of view of risk, and based on the records of incidents and accidents, the worst credible consequence expected for wingtip collision of two taxiing aircraft is aircraft damage. In this case, acceptable risk can be significantly higher than one in ten million operations ($1x10^{-7}$). Also, standard wingtip separation for class V aircraft is 53 ft, which according to data from ANC would be very conservative.

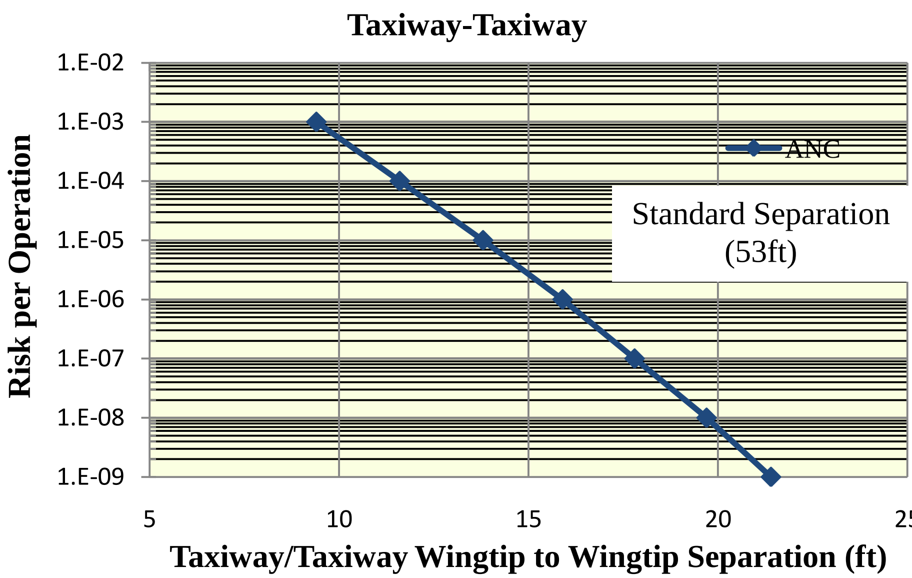

Figure G-7. Taxiway/taxiway collision probability based on wingtip separation in parallel taxiways at ANC