ANALYSIS OF WINGS COLLISION RISKS DURING THE OPERATION OF B737W AIRCRAFT AT THE CONGONHAS AIRPORT APRON / SP - BRAZIL

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ABSTRACT

This article presents an estimate of a risk of two B737 aircraft wings colliding while parking in designated positions on the apron of the Congonhas Airport (São Paulo – Brazil). The movement of the aircraft around the apron was observed and analyzed during docking. The final parking position when cleared for the boarding and disembarking of passengers and luggage was monitored both at the boarding bridges and at remote locations. Statistical analysis was performed, and the results reveal the feasibility of parking these aircraft under current conditions available at the airport. This study indicates that a smaller distance will not have an adverse effect on the safety of the operations.

Keywords: wings collision risk, airport operation, B737W aircraft, Congonhas Airport, Generalized Linear Model.

1. INTRODUCTION

The current configuration of the Congonhas Airport (São Paulo – Brazil) is a result of its development history, initiated in April of 1936, when the “Campo de Aviação da Companhia de Auto-Estradas” [“Aviation Field of the Highways Company”] as formerly nominated, received its first experimental flights.

Three transverse runways with length of 1,700; 880 and 1,040 meters were planned at the end of the 1940s. The first runway was paved at the end of 1950. Subsequently, a second provisional runway was built parallel to the first, which would later become an auxiliary runway. Studies performed in 1950 demonstrated that it was no longer necessary to build transverse runways. Thus, the airport is currently composed of two parallel runways. Over a long period, the operation at Congonhas Airport proceeded with the aircraft parking in the apron at remote positions, away from the terminal building, with the passengers transported by foot or bus.

With the expressive air traffic growth in the early 2000s the improvement of the Passenger Terminal was necessary as also the adoption of a new design for the parking apron to adequate the capacity of the installations to attend the volume of passengers and aircraft movements. The terminal building was expanded and twelve new boarding bridges were installed. Today the airport has a total of thirty parking positions for commercial aircraft, twelve of which have boarding bridges. The other eighteen positions are remote, where passengers are transported by bus.

With the implementation of the new apron (with new geometry and twelve boarding bridges) and the advent of B737 New Generation (with winglet and larger wingspan), the evaluation of the safety issues in the operation of the apron becomes necessary. This is especially true for the B737-700W and 800W as the design of new apron does not allow these aircraft to utilize the boarding bridges, as the space between the wing tips of two aircraft parked next to one another is below the minimum safety distance set by the regulations.

The parking apron at Congonhas Airport can accommodate thirty commercial aircraft. Positions 1 through 12 are in front of the Passenger Terminal and have boarding bridges. The other 18 positions are remote, where passengers are transported by bus. Figure 1 shows the parking positions and separations. The separation between two adjacent positions [referred as aircraft stand lead-in lines by the International Civil Aviation Organization (ICAO)] is 39.22 m for positions 1 and 2. For position 2 through 11 the separation between two adjacent positions is 38.82 m, and for positions 11 and 12 the separation is 39.56 m. For the remote positions 13 through 23, the separation is 42 m between stand lead-in lines. Positions 25 to 30 are also remote with a separation of 35 m in the stopping lines. Positions 17 and 24 are at 45° in relation to the adjacent positions, without restrictions for any aircraft.

The largest aircraft in the apron maneuvering at Congonhas Airport are the Boeing 737 family and the Airbus 320, whose main physical characteristics are in Table 1. Figure 2 illustrates the geometric characteristics of the aircraft.

Currently, Congonhas Airport receives six types of aircraft: B737-700W; B737-800W; B737-700; B737-800; A320 and B737-300. The aircraft stand lead-in lines values (in meters) between the wing tips of two aircraft parked side-by-side are in Table 2. The most restrictive positions, that is, those that result for the smallest separations, are at boarding bridges number 2 to 11, with a separation between the aircraft stand lead-in lines of 38.82 m.

For safety reasons the ICAO (2005) recommends a separation of 4.5 m between the wing tips of two adjacent parking aircraft. Table 2 shows, for positions 2 through 11, that the side-by-side parking separations when B737-700W/800W and A320-200 are parked, may result less than the 4.5 m required by the ICAO (2005). The critical parking situations are concentrated around the front of the terminal 2 to 11 and are indicated in Figure 3. The smallest distance of 3.02 m is between two B737-700W/800W aircraft.

The objective of this study is to develop a methodology for calculating the risk of wings collision between two aircraft parked in adjacent positions. Deviation measurements in the parking position of the aircraft are taken and a generalized linear model (GLM) is adjusted for the deviation measure to identify relevant explanatory variables to explain the variability of the deviation. Results of the models provide inputs to calculate the risk of two B737 aircraft wings colliding when parked at adjacent positions. The results indicate the feasibility of the operation of B737-700W/800W aircraft at any position regardless of whether the aircraft are parked on the left or the right position. This finding constitutes a contribution to the management and planning of airports.

ICAO (2005) specifies that it is permissible to use a smaller separation at an existing airport if an aeronautical study, such as this study, indicates that a smaller distance will not have an adverse effect on the safety of the operations.

Although generalized linear model (Montgomery 2005 and 1997) is not a new feature, the application in the current context is novelty in technical and academic literature related to airport safety. Moreover, this problem is common nowadays, since the disposal area to park in airports demands long time building work to change an existent infrastructure to attend the rules to accommodate new and bigger aircraft in specified different context.

To accommodate new large aircraft (NLA) operations Barros and Wirasinghe (2003) have analyzed the passenger terminal configurations. NLA are new aircraft developments larger than the Boeing 747, like the Airbus A380. The analysis is performed individually for a single pier, several types of pier–satellites, and a set of remote parallel piers connected by an automated people mover (APM). In all cases, the best location for the NLA gate positions is sought, using analytical models. A design of experiments approach has been employed by Buxi and Hansen (2011) to determine profiles that minimize the total average costs. The average cost of the methodologies is evaluated against realized capacities to determine the benefit of the weather forecast, since the weather is a role in determining the capacity of an airport. Borille and Correia (2012) consider the explanatory variables as demand characteristics, terminal layout, the number and type of carousels, waiting time and space available to study their influence in the level of service of the operational arrival components at airports. The analysis combines user monitoring techniques, data collection, simulation models, design of experiments and linear regression. Five major international airports in Brazil are used as case studies. Atasoy et al. (2013) provide analytical evidence of the impact of a new innovative modular aircraft on the operations of an airline. The impact analysis is carried out with an integrated scheduled planning model that presents a combination of appropriate optimization and behavioral modeling methodologies. An experimental design was meant to minimize the impacts of the differences in size and to reveal to a larger extent the impact of modularity. Chiang (2011) used two-level full factorial design of experiments (DOE) to simulate the different scenarios to identify relevant factors and their interactions considered in the research to measure its impact on passenger corridor occupancy.

Other uses of statistical analysis in different problems related to airport operations are discussed in Xianfenga and Shengguoa (2012). Contributions related to airport operations can be mentioned: Ale and Piers (2000), Lee (2006), Yun (2003), Kai (2006), Gang and Jin-fu (2008 a, b), Gui-mei and Sheng-guo (2010). Hang and Gui-hong (2009) investigated airport safety and used different data analysis methodologies (groupings, scores, fuzzy logic, AHP, etc.) to assess the risk of different events related to aviation and, in particular, to airports. A single study on the “length and reference codes of runways and taxiways; runway and taxiway strips; runway end safety areas; separation distances between runways and taxiways; and definition of obstacle limitation surfaces" was developed by Eddowes et al. (2001).

This paper is organized as follows: this introduction section; section 2, the elements of the full database are described; the exploratory data analysis and generalized linear model are subject of section 3; the procedures for the determining the risk of two aircraft wings colliding when they are simultaneously boarding in neighboring boxes is the subject of the section 4; section 5 shows the final conclusions. All the technical terminologies related to the airport operations can be found in International Civil Aviation Organization – ICAO – (2013).

Table 1: Physical characteristics of critical aircraft (Boeing, 2001; Airbus, 2005)

Physical characteristics (m)/Aircraft	B737-800W	B737-800	A320-300
Wing span (P)	35.80	34.32	34.09
Length (L)	39.48	39.48	37.54
Main Gear Wheel Span (M)	7.00	7.00	8.97

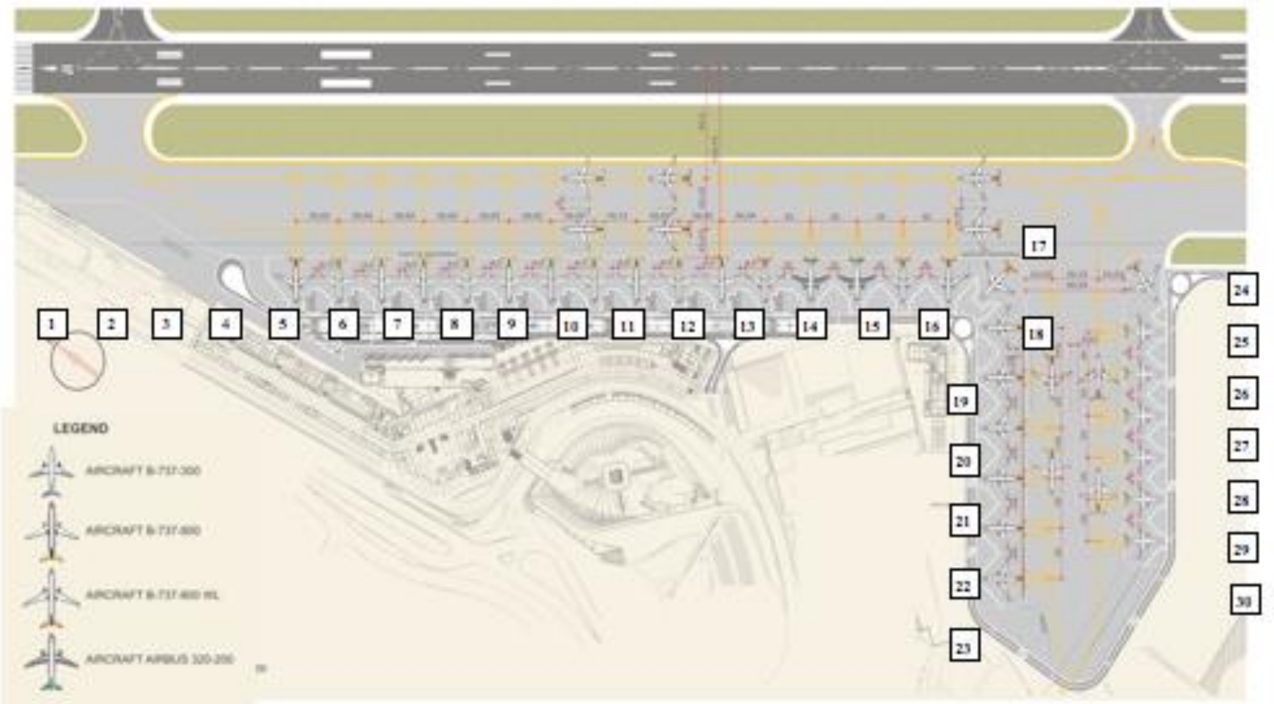

Figure 1: Parking positions and separations at the Congonhas Airport – São Paulo - Brazil

Source: SBTA's Homepage (http://www.sbta.org.br)

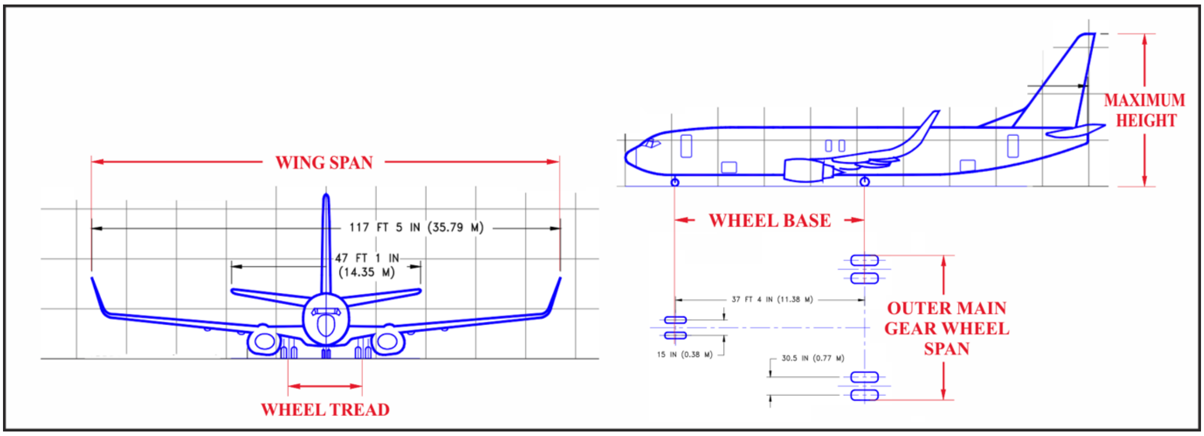

Figure 2: Geometric characteristics of the aircraft

Table 2: Wing tip separation (in meters) parking of the aircraft combinations at the Congonhas Airport for the boarding bridges 2 to 11.

Aircraft	B737-700W	B737-800W	B737-700	B737-800	A320	B737-300
B737-700W	3.02					
B737-800W	3.02	3.02				
B737-700	3.76	3.76	4.50			
B737-800	3.76	3.76	4.50	4.50		
A320	3.88	3.88	4.62	4.62		
B737-300	6.48	6.48	7.22	7.22	7.34	9.94

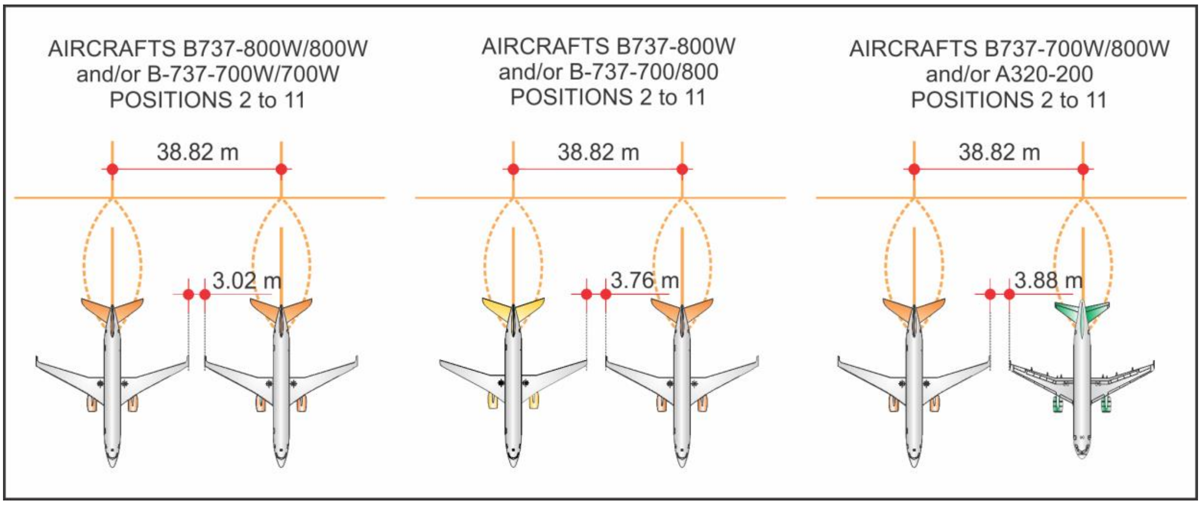

Figure 3: Critical parking situations at Congonhas Airport

2. DATABASE

For the determination of the effective aircraft position in relation to the aircraft stand lead-in lines (painted on ground), three measurements are taken at different positions in the landing gear. These measurements determine accurately the position of the aircraft in relation to the stopping line painted on pavement, as well as the resulting separation from the other neighboring aircraft:

a) The deviation or relative distance from the axis of the nose gear and that of the stopping T position in the longitudinal direction to the movement;

b) The deviation or distance from the axis of the nose gear and that of the aircraft stand lead-in line position in the direction transverse to the movement;

c) The distance from the axis of one leg of the main landing gear and the aircraft stand lead-in line position.

The scheme provided in Figure 4 depicts the location of the measurements. Using these measurements, the deviation between the axis of the main landing gear and the parking position axis, and the deviations, longitudinal and transversal, of the nose gear are determined.

The deviation measurements are collected in seven positions with boarding bridge (positions from 6 to 12) and in eight remote positions (position from 15 to 23, except the position 17) around two weeks (from the last week of October to the first week of November in 2008). Due to the operational restrictions, the deviations are taken only for the aircraft B737-300, B737-700 and B737-800 totaling 196 observations.

Two measurements are obtained to determine the location of the nose gear. One is the deviation or distance from the landing gear to the stopping line (longitudinal direction of the aircraft). In addition to this measurement, the position of the nose gear before (-) and after (+) the T-stopping line is also noted.

Deviations in relation to the “T” after the determination of the painted line are obtained with the metal bracket positioned on the axis of the nose gear. This position is marked on the ground and the difference between the mark and the painted line is recorded.

Deviations of the nose gear in relation to the aircraft stand lead-in line are obtained in the following manner:

- Determination of the center axis of the nose gear with the laser device;
- Recording of the nose gear axis position on the ground;
- Measurement of the distance between the nose gear axis position and the painted line. Both deviations are recorded to the left and to the right in the longitudinal direction.

And additionally deviations in the main landing gear with respect to the aircraft stand lead-in line are obtained using the location of the painted line in the following manner:

- Determination of the axis for a set of wheels in the main landing gear using a laser device
- Recording of the position of the main landing gear axis position on the ground;
- Determination of the line perpendicular to the aircraft stand lead-in line position up to the axis of the main landing gear projection using an aluminum ruler;
- Measurement of the distance between the position of the axis of the main landing gear and the painted line.

Although many measurements are in database, in this paper the statistical analysis concerns on the deviations in the main landing gear with respect to the aircraft stand lead-in line as the risk of wings collisions depends on such deviation and this is the subject of the next sections.

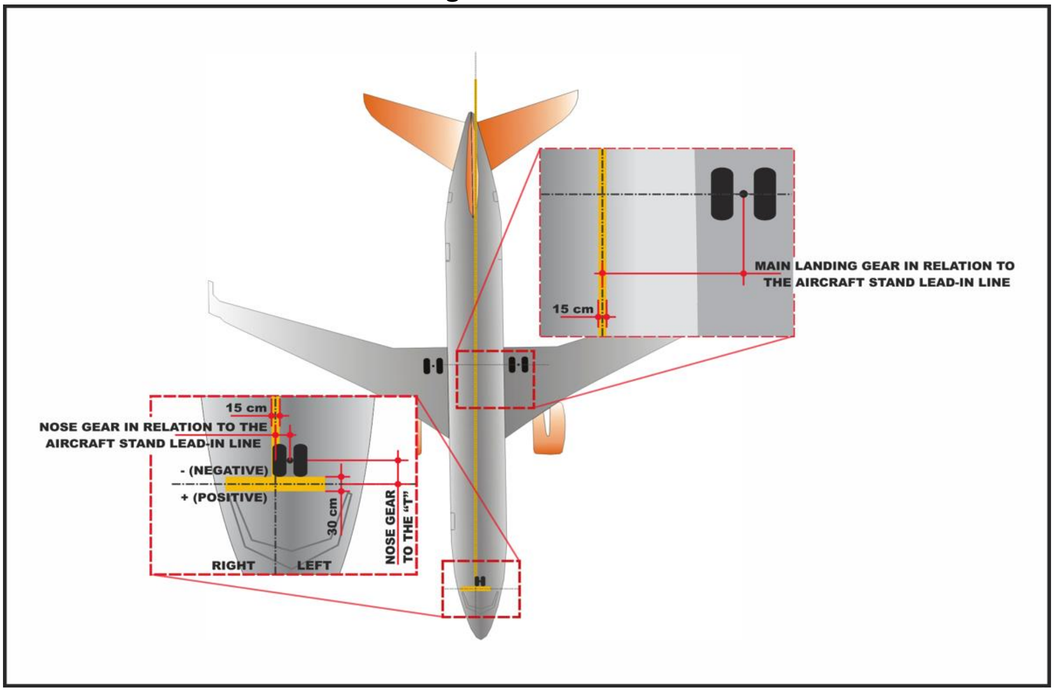

Figure 4: The location of measurements

3. DATA ANALYSIS

In this section, the statistical data analysis is presented. Notations used hereon are introduced. Let be

D= the distance from the main landing gear to the aircraft stand lead-in line**.**

The explanatory variables considered to the statistical data analysis to explain the variability of the deviation measurement D are:

- Types of parked aircraft ("aircraft"): B737-300, B737-700 or B737-800;
- Type of the localization ("type") boarding bridge or remote;
- The number of the position ("box"): the box number 6 to 12 if the position is a boarding bridge or the box number 15 to 23, except 17 if the position is remote;
- The driven direction to put the aircraft into the box ("direction"): the aircraft turns to the left or to the right hand.

Table 3 presents some descriptive statistics of D (average, standard deviation - SD and median) by each of the explanatory variables. Tables 4-7 present the same descriptive statistics but concerning to two explanatory variables at each time, specifically: Table 4: type x direction; Table 5: type x aircraft; Table 6: aircraft x direction; Table 7: type x box number. Note that the average values of D in any table are negative, representing an average deviation to the left side of the reference line. Analyzing the tables, some interesting observations can be noted. From Table 3, (absolute) larger values of D are observed for aircraft B737-300 and 800 but when analyzed together with type of position, the behavior differs a lot (see Table 5). For the boarding bridges, the larger (absolute) average differences are observed for the B737-300 aircraft and the smaller differences for the B737-800 aircraft but for the remote locations, the opposite trend is observed, that is, smaller differences for the B737-300 aircraft and largest differences for the B737-800 aircraft. Such fact suggests that an interaction effect of the type of aircraft and type of parked position is active. From Table 7, the average deviations depend on the box number. For the boarding bridges, the boxes located in the center position (9 and 10) exhibit the greater level of deviation. The same observation is valid for the remotely located boxes, where the deviations are higher for the center boxes. These results demonstrate that the boxes cannot be considered homogeneous (in sense of equal behavior relative to distances). Note also the lowest average deviations are observed for the last box of each type of position, but also largest standard deviations (box number 12 and 23, respectively for boarding bridge and remote position).

In order to identify which explanatory variables are more significant to explain the variability of D, a generalized linear model is proposed. The k-th observation of D can be expressed as:

$$D_k = \beta_0 + \sum_{i=1}^{2}\beta_{1i}X_{1i} + \beta_2 X_2 + \beta_3 X_3 + \sum \beta_{4j(X_3)}X_{4j(X_3)} + \sum_{i=1}^{2}\gamma_{1i}X_{1i}X_3 + \varepsilon_k \qquad (1)$$

with

β= ($\beta_0;\beta_{11};\beta_{12};\beta_2;\beta_3;\beta_{41(1)};\ldots;\beta_{46(1)};\beta_{41(-1)};\ldots;\beta_{47(-1)};\gamma_{11};\gamma_{12}$**)**

the vector of the parameters to be estimated: β_0, a constant; $\beta_{11};\beta_{12}$, are the effects related to the different types of aircraft; β_2 is related to the direction which the aircraft takes to be parked in the box; β_3, to the type of parked position (boarding bridge/remote); $\beta_{41(1)};\ldots;\beta_{46(1)}$, the effects of the position of boxes at boarding bridges; $\beta_{41(-1)};\ldots;\beta_{47(-1)}$, the effects of the position of boxes when the aircraft parked in remote position; $\gamma_{11};\gamma_{12}$ the interaction effects of the types of aircraft and type of parked position.

e_k is the random error and assumes that follows a normal distribution (0; σ^2). The explanatory variables used in these analyses assume the following values:

X_{11}=1; X_{12}=0 for the aircraft B737-300;
X_{11}=0; X_{12}=1 for the aircraft B737-700;
X_{11}=-1; X_{12}=-1 for the aircraft B737-800;

X_2=1 for the aircraft parked in the box by the right hand direction;

X_2=-1 for the aircraft parked in the box by the left hand direction;

X_3=1 for the aircraft parked in boarding bridges;

X_3=-1 for the aircraft parked in remote position.

As the number of the box is nested of type of parked position, so for the boarding bridges (X_3=1) the explanatory variables X_{4j} assume the following values:

X_{41}=1; X_{4j}=0; 2≤ j ≤6 for box #6;
X_{42}=1; X_{4j}=0; j ≠2; 1≤ j ≤6 for box #7;
X_{43}=1; X_{4j}=0; j ≠3; 1≤ j ≤6 for box #8;
X_{44}=1; X_{4j}=0; j ≠4; 1≤ j ≤6 for box #9;
X_{45}=1; X_{4j}=0; j ≠5; 1≤ j ≤6 for box #10;
X_{46}=1; X_{4j}=0; j ≠6; 1≤ j ≤6 for box #11;
X_{4j}=-1; 1≤ j ≤6 for box #12;

And for the remote positions (that is, X_3= -1) the values of variables X_{4j} are:

X_{41}=1 and X_{4j}=0; 2≤ j ≤7 for box #15;
X_{42}=1 and X_{4j}=0; for j ≠2; 1≤ j ≤7 for box #16;
X_{43}=1 and X_{4j}=0; for j ≠3; 1≤ j ≤7 for box #18;
X_{44}=1 and X_{4j}=0; for j ≠4; 1≤ j ≤7 for box #19;
X_{45}=1 and X_{4j}=0; for j ≠5; 1≤ j ≤7 for box #20;
X_{46}=1 and X_{4j}=0; for j ≠6; 1≤ j ≤7 for box #21;
X_{47}=1 and X_{4j}=0; for j ≠7; 1≤ j ≤7 for box #22;
and X_{4j}=-1; 1≤ j ≤7 for box #23.

The null hypothesis $H_{01}: \beta_{11} = \beta_{12} = 0$ (the deviations D for the different types of aircraft are equal) is rejected as it yields a p-value of 0.05. The null hypothesis $H_{02}: \beta_2 = 0$ (the deviations D of the aircraft parked in the box by the right hand and left are equal) is also rejected (p-value of 0.023). But the null hypothesis $H_{03}: \beta_3 = 0$ (the average deviations D of the aircraft parked at boarding bridges and remote position are equal) is not rejected (p-value of 0.23). This explanatory variable: type of localization (X_3) is not active alone and usually it would be discarded from the model. But in this case, it interacts with other explanatory variables producing active effects. Note that the box number (X_{4i}) depends on the type position (X_3) (if the aircraft is parked at boarding bridges, the box numbers go from 6 to 12; if parked in the remote terminals, the box number are from 15 to 23, except for 17) and its respective coefficients are significant with a p-value of 0.002 by the rejection of the null hypotheses:

$$H_{04}: \beta_{41(1)} = \dots = \beta_{46(1)} = \beta_{41(-1)} = \dots = \beta_{47(-1)} = 0$$

Additionally, $H_{05}: \gamma_{11} = \gamma_{12} = 0$ (null interaction of the types of aircraft: X_1 and type of parked localization X_3: boarding bridge and remote position) is not true (p-value of 0.001). Due to these reasons, the explanatory variable X_3 is kept in the final model. Estimates of the coefficients of the model 1 are obtained by Minitab Statistical Software and put in Table 8.

Table 3: Descriptive Statistics of D by aircraft, type and direction

		Average	SD	Median
Aircraft	B737-300	-32.48	20.43	-36.30
	B737-700	-9.75	17.57	-11.00
	B737-800	-26.87	30.03	-25.00
Type	Boarding bridge	-14.05	18.38	-13.90
	Remote	-17.41	28.40	-12.90
Direction	Right	-13.53	24.56	-9.40

	Left	-18.87	17.75	-18.90

Table 4: Descriptive Statistics of D by type and direction

Type	Direction	Average	SD	Median
Boarding bridge	Right	-10,70	17.67	-10.00
	Left	-17.92	18.58	-16.30
Remote	Right	-16.41	29.86	-9.10
	Left	-25.59	7.61	-27.15

Table 5: Descriptive Statistics of D by aircraft and type

Type	Aircraft	Average	SD	Median
Boarding bridge	B737-300	-35.60	15.36	-36.30
	B737-700	-11.55	16.11	-12.20
	B737-800	-2.63	25.74	2.05
Remote	B737-300	-9.10	46.24	-9.10
	B737-700	-4.64	20.58	-3.90
	B737-800	-31.02	29.01	-30.00

Table 6: Descriptive Statistics of D by aircraft and direction

Direction	Aircraft	Average	SD	Median
Right	B737-300	-29.23	23.64	-30.45
	B737-700	-5.38	16.66	-5.30
	B737-800	-27.21	31.00	-26.65
Left	B737-300	-37.13	15.23	-36.30
	B737-700	-16.34	16.99	-15.90
	B737-800	-22.53	14.94	-23.80

Table 7: Descriptive Statistics of D by aircraft and type and box number

Type	Box Number	Average	SD	Median
Boarding bridge	6	-14.66	15.16	-12.80
	7	-6.89	23.55	-7.40
	8	-12.47	13.37	-11.70
	9	-20.78	18.81	-16.00
	10	-21.86	16.84	-19.55
	11	-16.95	11.94	-15.90
	12	-2.25	20.09	4.80
Remote	15	-24.14	14.71	-29.70
	16	-15.84	12.49	-19.50
	18	-31.35	34.37	-34.50
	19	-16.12	36.04	-9.60
	20	-16.74	28.93	-10.80
	21	-7.07	14.86	-11.20
	22	-13.26	31.47	-12.90
	23	-2.22	29.03	8.70

Table 8: Descriptive Statistics of D by aircraft and direction

Direction	Aircraft	Average	SD	Median
Right	B737-300	-29.23	23.64	-30.45
	B737-700	-5.38	16.66	-5.30
	B737-800	-27.21	31.00	-26.65

The goodness of fit of the model (1) can be confirmed by residual analysis. Figure 5 shows four residuals plots. By these plots, the standardized residuals follow a normal distribution as also a random pattern, showing no tendencies and few unusual residuals.

4. DETERMINATION OF RISK OF WINGS COLLISIONS

The procedures for the determination of the risk of two aircraft wings colliding when they are simultaneously boarding in neighboring boxes are the subject of this section. We are concerning to determine the risk only for box numbers with access by boarding bridges. For box number at the remote positions similar procedure can be adopted with few adjustments.

The maximum absolute allowable distance (W) is defined for situations when wings collision would be possible, using 38.8 m (this value is the most common among the positions with boarding bridges- boxes 2 through 11) as the distance between positions and the wing spans of each type of aircraft. It consists of two portions: D (the distance from the main landing gear to the aircraft stand lead-in line) and a clearance value between the wing tips, depending on the type of aircraft. Considering two neighboring boxes, a wings collision will occur if simultaneously the aircraft in the box on the left moves to the right more than D + (19400-0.5 x 100P) cm (values of P, for the different types of aircraft, in Table 1) and the aircraft in the box on the right moves to the left more than (19400-0.5 x 100P) - D cm.

Figure 7 illustrates an example for two B737-300 aircraft. A wings collision will occur if simultaneously the aircraft in the box on the left moves to the right more than D + 500 cm and the aircraft in the box on the right moves to the left more than 500 - D cm. For two neighboring boxes with B737-700/800 aircraft, a wings collision will occur if the aircraft on the left moves to the right more than D + 224 cm and the aircraft on the right moves to the left a more than 224 - D cm.

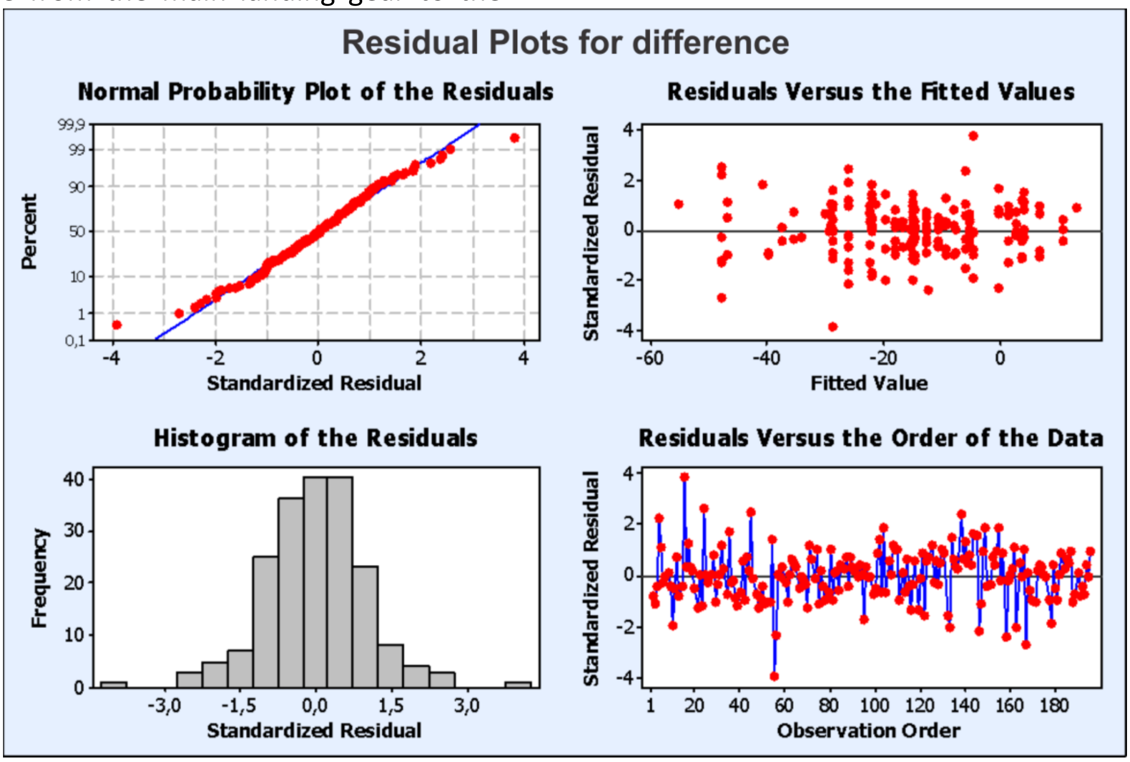

Figure 5: Residual Analysis of the Model (1)

Table 9: Estimates of the coefficient of the model (1)

Coefficient	Estimate	SE	T	P-value
β_0	-16.039	3.133	-5.12	0
β_{11}	0.505	5.373	0.09	0.925
β_{12}	8.347	3.212	2.6	0.01
β_2	-3.711	1.616	-2.3	0.023
β_3	-3.697	3.07	-1.2	0.23
$\beta_{41(1)}$	-1.962	5.37	-0.37	0.715
$\beta_{42(1)}$	10.133	4.326	2.34	0.02
$\beta_{43(1)}$	1.863	3.931	0.47	0.636
$\beta_{44(1)}$	-7.799	4.092	-1.91	0.058
$\beta_{45(1)}$	-7.516	3.861	-1.95	0.053
$\beta_{46(1)}$	-3.292	4.277	-0.77	0.443
$\beta_{41(-1)}$	-20.803	8.463	-2.46	0.015
$\beta_{42(-1)}$	-7.295	6.583	-1.11	0.269
$\beta_{43(-1)}$	-14.303	5.046	-2.83	0.005
$\beta_{44(-1)}$	4.846	5.262	0.92	0.358
$\beta_{45(-1)}$	7.488	5.225	1.43	0.154
$\beta_{46(-1)}$	4.62	6.036	0.77	0.445
$\beta_{46(-1)}$	13.785	7.94	1.74	0.084
γ_{11}	-16.578	5.38	-3.08	0.002
γ_{12}	0.434	3.201	0.14	0.892
σ^2	356.7			

And similarly, for two neighboring boxes with B737-700W/800W aircraft, a wings collision will occur if the aircraft parked on the left moves to the right more than D+150 cm and the aircraft parked on the right moves to the left more than 150-D cm. Other combinations of two neighboring boxes can be considered in a similar manner.

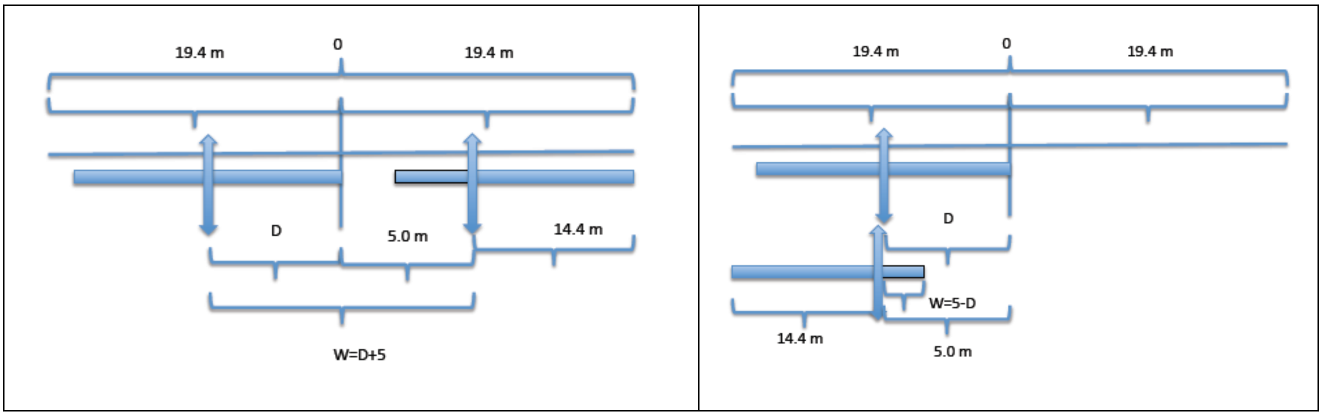

Figure 6: Maximum allowable distance for B737-300 aircraft

The predicted values (PD) of D as a function of box number, aircraft and direction considering the coefficients are in Table 9. Consider two neighboring boxes: i and (i+1). A possible wings collision will occur if simultaneously the aircraft in box i parks at a distance greater than (PD+19400-50P) cm (displacement to the right hand) and the aircraft in box i+1 parks at a distance greater than (19400-50P-D) cm (displacement to the left hand).

For example, consider two neighboring boxes 6 and 7 with both B737-300 aircraft parked from the right-hand. The B737-300 aircraft in box 6 parks at an average distance of 34.06 cm from the left of the center of the box (hence the negative value in Table 8), whereas the B737-300 aircraft in box 7 parks at an average distance of 21.97 cm to the left of the center of the box (also negative value). If simultaneously the aircraft in box 6 parks at a distance greater than 534.06 cm (displacement to the right hand) and the aircraft in box 7 parks at a distance greater than 478.04 cm (displacement to the left hand) there is a situation of a possible wings collision.

To calculate the probability, average value of the normal distribution equal to PD values in Table 9 is used and the standard deviation as 18.5565 (see Table 8). For this example, it is equal to P (Z > 28.28) x P (Z < -25.31) (see Table 9) which probabilities are respectively put in the last two columns of Table 9. Or alternatively if simultaneously the aircraft in box 6 parks at a distance greater than 465.94 cm (displacement to the left hand) and the aircraft in box 7 parks at a distance greater than 521.97 cm (displacement to the right hand). Other combinations of aircraft, direction and neighbored boxes can be evaluated in the same manner.

Table 9: Values obtained from the Adopted Model

				Maximum Distance (cm)		Standardized maximum distance (Z)		Probability	
"position"	Aircraft	Box	PD	Right	Left	Right	Left	Right P(Z>z)	Left P(Z<-z)
Right	300	6	-34.06	534.06	465.94	28.28	24.67	0.00E+00	1.11E-134
		7	-21.97	521.97	478.04	27.64	25.31	0.00E+00	1.21E-141
		8	-30.24	530.24	469.77	28.07	24.87	0.00E+00	7.28E-137
		9	-39.90	539.90	460.10	28.59	24.36	0.00E+00	2.19E-131
		10	-39.61	539.61	460.39	28.57	24.38	0.00E+00	1.52E-131
		11	-35.39	535.39	464.61	28.35	24.60	0.00E+00	6.30E-134
		12	-23.53	523.53	476.48	27.72	25.23	0.00E+00	9.79E-141
Right	700	6	-9.21	233.21	214.79	12.35	11.37	0.00E+00	2.85E-30

				Maximum Distance (cm)		Standardized maximum distance (Z)		Probability	
"position"	Aircraft	Box	PD	Right	Left	Right	Left	Right P(Z>z)	Left P(Z<-z)
		7	2.89	221.11	226.89	11.71	12.01	0.00E+00	1.51E-33
		8	-5.38	229.38	218.62	12.15	11.58	0.00E+00	2.75E-31
		9	-15.04	239.04	208.96	12.66	11.06	0.00E+00	9.40E-29
		10	-14.76	238.76	209.24	12.64	11.08	0.00E+00	7.95E-29
		11	-10.54	234.54	213.46	12.42	11.30	0.00E+00	6.38E-30
		12	1.33	222.67	225.33	11.79	11.93	0.00E+00	4.09E-33
		6	-10.70	160.7	139.31	8.6600	7.5073	2.07E-17	3.02E-14
		7	1.40	148.6	151.4	8.0080	8.1589	4.74E-15	1.40E-15
		8	-6.87	156.87	143.13	8.4536	7.7132	1.21E-16	6.11E-15
Right	800	9	-16.53	166.53	133.47	8.9742	7.1926	1.30E-18	3.18E-13
		10	-16.25	166.25	133.75	8.9591	7.2077	1.48E-18	2.84E-13
		11	-12.03	162.03	137.98	8.7317	7.4357	1.11E-17	5.21E-14
		12	-0.16	150.16	149.84	8.0920	8.0748	2.41E-15	2.77E-15
		6	-41.48	541.48	458.52	28.67	24.28	0.00E+00	1.69E-130
		7	-29.39	529.39	470.61	28.03	24.92	0.00E+00	2.38E-137
		8	-37.66	537.66	462.34	28.47	24.48	0.00E+00	1.20E-132
Left	300	9	-47.32	547.32	452.68	28.98	23.97	0.00E+00	2.96E-127
		10	-47.04	547.04	452.96	28.96	23.98	0.00E+00	2.07E-127
		11	-42.81	542.81	457.19	28.74	24.21	0.00E+00	9.36E-130
		12	-30.95	530.95	469.05	28.11	24.84	0.00E+00	1.86E-136
		6	-16.63	240.63	207.37	12.74	10.98	0.00E+00	2.39E-28
		7	-4.53	228.53	219.47	12.10	11.62	0.00E+00	1.62E-31
		8	-12.80	236.80	211.20	12.54	11.18	0.00E+00	2.49E-29
Left	700	9	-22.47	246.47	201.54	13.05	10.67	0.00E+00	6.97E-27
		10	-22.18	246.18	201.82	13.03	10.69	0.00E+00	5.93E-27
		11	-17.96	241.96	206.04	12.81	10.91	0.00E+00	5.19E-28
		12	-6.09	230.09	217.91	12.18	11.54	0.00E+00	4.26E-31
		6	-18.12	168.12	131.88	9.0599	7.1069	5.99E-19	5.93E-13
		7	-6.02	156.02	143.98	8.4078	7.7590	1.78E-16	4.33E-15
		8	-14.29	164.29	135.71	8.8535	7.3133	3.80E-18	1.30E-13
Left	800	9	-23.95	173.95	126.05	9.3741	6.7928	3.31E-20	5.50E-12
		10	-23.67	173.67	126.33	9.3590	6.8079	3.81E-20	4.95E-12
		11	-19.45	169.45	130.55	9.1316	7.0353	3.12E-19	9.94E-13
		12	-7.58	157.58	142.42	8.4919	7.6749	8.75E-17	8.33E-15

5. CONCLUSION

The statistical analysis conducted to evaluate the risk of two B737 aircraft wings colliding when parked at adjacent positions at the Congonhas Airport indicates the feasibility of the operation of B737-700W/800W aircraft at any position regardless of whether the aircraft are parked on the left or the right-hand. ICAO (2005) specifies that it is permissible to use a smaller separation at an existing airport if an aeronautical study, such as this study, indicates that a smaller distance will not have an adverse effect on the safety of the operations.

The expected outcome of this work is the development of similar studies that will be performed under different conditions to improve the existing airport legislation and allow for better use of existing facilities. Most of the assumptions and hypothesis used in the design of experiments are detailed constituting a valuable reference for flexible transportation systems to be designed in the future.

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REFERENCES

Atasoy, B.; Salani, M.; Bierlaire, M.; Leonardi, C. (2013) Impact Analysis of a Flexible Air Transportation System. EJTIR 13(2), pp. 123-146 128.

Airbus (2005) A320: Aircraft Characteristics Airport and Maintenance Planning.

Ale, B. J. M. and M. Piers (2000) The Assessment and Management of Third Party Risk Around a Major Airport. Journal of Hazardous Materials, v. 71, n. 1-3, p. 1-16.

Barros A. G., Wirasinghe, S.C. (2003) Optimal terminal configurations for new large aircraft operations. Transportation Research Part A 37, 315–331.

Boeing (2001) 737-600/700/800/900 Airplane Characteristics for Airport Planning.

Borille, G.M.R.; Correia, A. R. (2013) A method for evaluating the level of service arrival components at airports. Journal of Air Transport Management 27, 5-10.

Buxi, G.; Hansen, M. (2011) Generating Probabilistic Capacity Profiles from weather forecast: A design-of-experiment approach. Ninth USA/Europe Air Traffic Management Research and Development Seminar (ATM2011)

Chiang. P-N (2011) A decision support system for assessing conveyance options and modeling passenger flow in airport terminals. A Dissertation presented to the Graduate School of Clemson University. All Dissertations. Paper 709.

Eddowes, M.; J. Hancox and A. MacInnes (2001) Final Report on the Risk Analysis in Support of Aerodrome Design Rules. A report produced for the Norwegian Civil Aviation Authority. File reference RD02325. Report number AEAT/RAIR/RD02325/R/002.Report status Issue 1.

ICAO (2004) Annex 14: Aerodromes. Volume I: Aerodrome Design and Operations (4th ed).

ICAO (2005) Doc 9157-AN/901 Aerodrome Design Manual - Part 2: Taxiways, Aprons and Holding Bays (4th ed.).

Gang, L. and Z. Jin-fu (2008a) A Grey Hierarchy Risk Evaluation for Civil Airport Operation Security and Safety. Chinese Journal of Ergonomics, v. 14, n. 3, p. 1-4.

Gang, L. and Z. Jin-fu (2008b) Based on FTA and Dynamic Gray Correlation Method Analysis for Apron Human Factor Error, Chinese Journal of Ergonomics, v. 14, n. 2, p. 22-25.

Gui-mei, X. and H. Sheng-guo (2010) Runway Incursion Risk Assessment Model Based on HRA. Science Technology and Engineering, v. 10, n. 19, p. 4715-4719.

Hang, L. and Z. Gui-hong (2009) Early Warning Model of Airport Safety Based on Extension Theory. Computer Engineering and Applications, v. 45, n. 14, p. 238-244. 2009.

International Civil Aviation Organization – ICAO – (2013) Annex 14, Aerodromes — Volume I, Aerodrome Design and Operation. Sixth Edition. July 2013.

Kai, G. (2006) Research on a Forewarning Management Method for Civil Aviation Airport Disaster. Wuhan: College of Management, Wuhan. University of Technology.

Lee, W-K. (2006) Risk Assessment Modeling in Aviation Safety Management. Journal of Air Transport Management, v. 12, n. 5, p. 267-273.

Montgomery, D. C. Design and analysis of experiments. 6a edition. Arizona: John Wiley & Sons, Inc., 2005.

Montgomery, D. C. Introduction to Statistical Quality Control, John Wiley & Sons, New York, 1997.

Xianfenga, L. and H. Shengguoa (2012) Airport Safety Risk Evaluation Based on Modification of Quantitative Safety Management Model. Procedia Engineering, v. 43, n. 2012, p. 238–244. Special Issue from International Symposium on Safety Science and Engineering in China, 2012 (ISSSE-2012).

Yun, P. (2003) Research on Safety Forewarning Management System for Civil Aviation Airport. Wuhan: College of Management, Wuhan University of Technology.