Enclosure 1

(Ref. Technical Letter F063-L08-040)

MITRE

Center for Advanced Aviation System Development

Preliminary Runway Spacing Analysis of the Texcoco Area

Prepared for

Dirección General de Aeronáutica Civil
Secretaría de Comunicaciones y Transportes

6 June 2008

1.0 Introduction

MITRE performed a preliminary analysis of the lateral separation required between parallel runways in the Texcoco area in support of Mexico's Dirección General de Aeronáutica Civil (DGAC). This analysis utilized the **MITRE-developed Simultaneous Instrument Approach Model (SIAM)**, a fast-time simulation model that allows investigation of potential collision rates between aircraft on independent parallel approaches. Among other things, this model has been used to support the United States Federal Aviation Administration (U.S. FAA) in the development of requirements for independent approaches to two and three parallel runways. MITRE also uses SIAM to investigate and evaluate runway spacings at airports throughout the world in support of safety assessments.

Certain aspects of independent approaches can be affected by the design of airspace, approach procedures, and the specific runway layout. Since these factors have not yet been specified for Texcoco, this analysis should be considered preliminary. MITRE's runway spacing analysis will be finalized once preliminary runway siting, procedures design, and other supporting tasks have advanced to the appropriate stage.

2.0 Overview

This section describes the principal factors that play a role in the complex assessment of safety vs. runway spacing when independent approach procedures are being considered. Following a general description on matters of equipment, procedures and resources (such as monitor controllers), current standards are shown. However, given Texcoco's elevation and other characteristics of the area, the reader is introduced to SIAM and its origins, as the standards being presented do not necessarily apply to Texcoco. Much more detail on equipage, as well as additional SIAM work is to follow, as this is only the start of a much more comprehensive analysis.

Sufficient runway spacing and appropriate procedures and equipment are necessary to conduct independent approaches to two or three runways in Instrument Meteorological Conditions (IMC). Generally, radar-equipped controllers monitor approaching aircraft on each approach path on dedicated radar displays to ensure that the aircraft do not deviate from their respective approach paths. A No Transgression Zone (NTZ) at least 2000 ft (610 m) wide separates the parallel approach paths and is depicted on the radar display (see Figure 1). Separation between aircraft on the same approach path is also maintained by these controllers. Should these monitor controllers observe an aircraft deviating from its approach path toward the NTZ, they issue instructions to the aircraft to turn back to its final approach path. Should the controllers observe an aircraft entering or about to enter the NTZ, they then instruct any nearby aircraft on the adjacent approach paths to discontinue their approaches and turn to avoid the deviating aircraft.

For independent approaches to two parallel runways, the International Civil Aviation Organization (ICAO), in both the *Manual on Simultaneous Operations on Parallel or Near-Parallel Instrument Runways (SOIR)* [ICAO, 2004] and *Procedures for Air Navigation Services – Air Traffic Management (PANS-ATM)* [ICAO, 2007], allows independent parallel approaches to runways separated by 1310 m or more. However, for runway separations between 1310 m and 1525 m, independent approaches are allowed "when it is determined that the safety of aircraft operations would not be adversely affected."

The U.S. FAA authorizes independent approaches to two and three parallel runways [FAA, 2008] at over 30 airports, including approaches to three parallel runways at four airports: Denver International Airport (KDEN), Dallas/Fort Worth International Airport (KDFW), Cincinnati/Northern Kentucky International Airport (KCVG), and the Hartsfield - Jackson Atlanta International Airport (KATL). Outside of the U.S., only a few airports (approximately five) conduct independent approaches to two runways. MITRE has been involved in making a safety case and assisting in the implementation of these procedures at most of these airports. Independent approaches to three parallel runways only exist in the U.S. (ICAO has not issued standards yet). Therefore, a few non-U.S. airports now considering independent approaches to three parallel runways have approached MITRE for support.

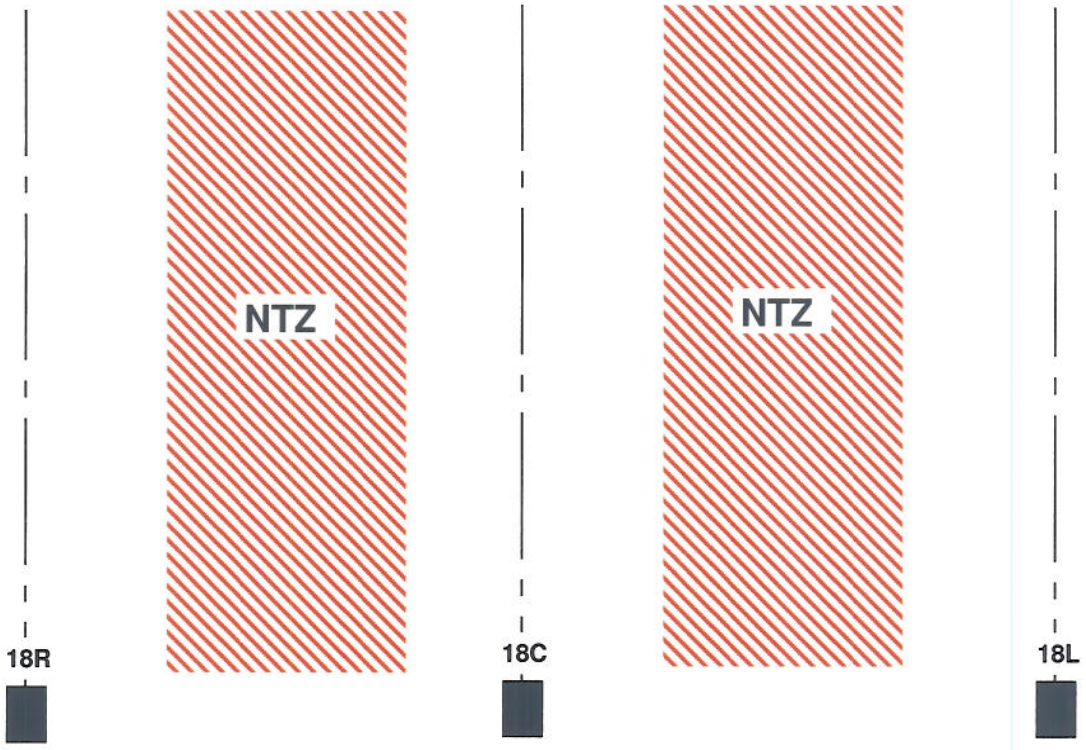

Figure 1. Independent Approaches to Three Parallel Runways

Standards for the evaluation of runway spacing for independent approaches to parallel runways depend on many factors of which the following are key:

- Type of display used by the controllers monitoring the approach
- Update interval of the radar/surveillance system
- Air Traffic Control (ATC) and aircrew procedures (e.g., reaction times)
- Training of controllers and aircrews
- Environmental conditions

In general, displays used by the monitor controllers consist of a standard display, usually a monochromatic analog or digital display, or the Final Monitor Aid (FMA) display. The FMA is a color digital display with an expanded scale orthogonal to the runways. The FMA also includes visual or aural alerts to warn the controller that an aircraft is projected to enter the NTZ between the runways, or has entered the NTZ.

Radars consist of standard Airport Surveillance Radars (ASRs) with monopulse Secondary Surveillance Radars (SSRs) that have an update interval of 5.0 seconds or less. For closely-spaced runways, a high-update-rate sensor, such as the Precision Runway Monitor (PRM) may be used. The PRM is a monopulse SSR capable of update rates as fast as one-half second (although a one-second update rate is most commonly used). Other types of high-update-rate sensors are also under consideration, such as multilateration or Automatic Dependent Surveillance-Broadcast (ADS-B). These are not currently authorized or used, however, by ICAO or the U.S. in support of independent approach procedures.

ATC and pilot procedures are established for independent approaches, and training is required for both controllers and aircrews. For example, the U.S. conducts training using simulation as a part of controller qualification for monitoring independent approaches. Pilot training, consisting of viewing a video, is required before pilots can execute independent approaches when a PRM is in use. Information is also published in pilot flight publications and is required to be read before independent approaches are conducted. Table 1 shows the current ICAO and U.S. standards for independent approaches to parallel runways.

Environmental factors should also be considered. **The U.S. FAA [FAA, 2008] requires additional analysis for independent approaches to three runways at airports with elevations over 1000 ft Mean Sea Level (MSL).** In general, consideration for airport elevation and temperature is prudent for approaches to both two and three runways, since high-elevation/density altitudes generally require aircraft to fly at a faster true air speed (TAS), which reduces time available for controllers to separate aircraft in case of a deviation. Also, some airspace configurations can increase the difficulty of separating

aircraft in case of a deviation on final approaches, and this can affect runway spacing. **This analysis of the Texcoco area preliminarily accounts for these factors.**

Table 1. ICAO and U.S. Standards for Independent Approach Procedures

Number of Runways	Runway Spacing	Display	Radar (Maximum Update Interval)	Aircrew Training	Remarks
2 (U.S. only)	915 m (3000 ft)	FMA	PRM (1.0 sec)	Required	≥2.5° localizer offset
2 (U.S./ICAO)	1035 m (3400 ft)	FMA	PRM (2.4 sec)	Required	
2 (U.S./ICAO) or 3 (U.S. only)	1310 m (4300 ft)	FMA	ASR (4.8/5.0 sec)	Not Required	Note 1
2 (U.S./ICAO) or 3 (U.S. only)	1525 m (5000 ft)	Standard	ASR (4.8/5.0 sec)	Not Required	Note 1

Note 1. Airports with 1000 ft or higher elevation require an aeronautical analysis for independent approaches to three runways. (U.S. standards). The U.S. standard for an ASR is 4.8 seconds, while the ICAO standard is 5.0 seconds. This report will assume that ASRs with a 5.0-second update rate are used.

The U.S. FAA performed extensive testing during the development of independent approach procedures. This testing was a combination of human-in-the-loop (HITL) testing and fast-time simulation testing. For a general description of this work, spanning many years, see [Massimini, 2006].

The HITL testing consisted of simulations using trained controllers monitoring parallel approach paths using realistic surveillance displays and communications equipment. Position and altitude data from approved flight simulators flown by trained airline pilots was presented on the controller displays in a realistic manner, along with position and altitude information from computer-generated aircraft. During the simulation, certain aircraft were directed by the Test Director to "blunder", or deviate from one final approach path towards another (without the controller or other pilots knowledge). The simulation measured how fast controllers and pilots reacted to avoid a collision, and how close aircraft came to each other during the blunder event. Other measures were also recorded, such as the number of penetrations or near-penetrations of the NTZ during normal (i.e., non-blunder) approaches. These penetrations often necessitated that the controller instruct the aircraft to break off the approach and be re-sequenced into the traffic flow to the airport. These breakouts were referred to as nuisance breakouts.

Although the HITL testing lasted several weeks for each test conducted, enough results could not be collected to assure a sufficient level of safety. Therefore, fast-time simulation models were created that use input and human performance data from the HITL testing. These fast-time models could simulate hundreds of thousands of blunder events and refine the estimate of projected performance of equipment, procedures, pilots and controllers during independent approaches. MITRE developed SIAM for use during this phase of the program [Gladstone and Friedman, 1995].

The U.S. FAA used a combination of results from the HITL and fast-time simulation testing to approve standards. The criteria for approval were:

- The nuisance breakout rate observed in the simulation. This is the percentage of approaches where a non-blundering aircraft had to be corrected because of straying too close to or into the NTZ.

- The results of a collision risk analysis showing if the target level of safety was met for the simulation

- An operational evaluation by the members of the Technical Working Group that conducted the simulations

Most of the standards contained in Table 1 were developed using the above methodology.[1] While standards for runway spacing, surveillance equipment, and procedures are important, the published standards do not always encompass all requirements. For example, analysis of operations at KDEN indicates that the higher approach speeds that result at higher elevations lead to a need for additional runway spacing [Ozmore and DiMeo, 1994]. Since the Texcoco elevation is even higher than KDEN, standard runway spacing requirements do not apply.

MITRE's preliminary analysis of runway spacing at Texcoco used the SIAM fast-time computer model combined with human performance data gathered during the U.S. FAA's HITL testing. Since the procedures, equipment, and general practice of independent approaches will be similar in Texcoco to those tested by the U.S. FAA, the application of fast-time modeling should be sufficient to validate runway spacing, equipment, and procedural requirements for Texcoco. Appropriate adjustments are included to account for airport elevation, percentage of different types of traffic, etc. For example, MITRE analyzed recent operational statistics from 2006 and 2007 (through October) for Mexico City International Airport (AICM), provided by Servicios a la Navegación en el Espacio Aéreo Mexicano (SENEAM) [SENEAM, 2007].

Furthermore, it is important to note that at this early stage of the project, MITRE had to make assumptions regarding the design of approach procedures, runway threshold

[1] Independent approaches to two runways spaced 1310 m (4300 ft) apart using a standard surveillance display were developed prior to the use of this methodology.

locations (e.g., non-staggered runways were assumed), and other factors. Other important assumptions are the positioning of the Outer Markers (OMs), which are used by pilots to identify the final approach fix and to assist in determining their location along the final approach path, and the length of the final approach paths. For planning purposes, MITRE positioned the OMs approximately 5 NM from the approach end of the runways and assumed long final approach paths. These assumptions generally require increased runway spacing to maintain the required level of collision avoidance. More detailed procedures design work to be conducted later will allow MITRE to determine the positioning of the OMs and the length of the final approach paths with more accuracy and, as a result, refine its runway spacing analysis. **It is in this regard that the results of this paper should be considered strictly preliminary and should not be utilized for major decisions on final runway siting**.

3.0 Path-Following Errors

For independent approach paths to parallel runways, there is some concern that normal path-following errors of aircraft about the final approach path centerline, due to flight technical or other errors, could cause aircraft to stray close to or into the NTZ (see Figure 2). If this were to happen, the controller would be required to correct the heading of the wandering aircraft. Also, the controller may be required to break out the wandering aircraft and possibly the aircraft on the adjacent approach path. Controller workload could become excessive, and subsequent breakouts of aircraft could negate some of the capacity-enhancing effects of independent approaches. However, the path-following errors on final approach are well known and have been measured during a number of data collection efforts. See, for example [PRM Program Office, 1991]. In general, the errors are centered on the approach path and have magnitudes that increase with the distance from the runway threshold. Note that path-following errors that occur before aircraft reach the glide slope do not result in a loss of separation, since aircraft maintain 1000 ft of altitude clearance until beginning to descend down the glide slope.

Table 2 gives the probability of an aircraft entering the NTZ due to path-following errors on a normal approach (i.e., no blunder occurs), using the distribution of path-following errors of [PRM Program Office, 1991], mentioned above. Note that this distribution can also be affected by the width of the NTZ.

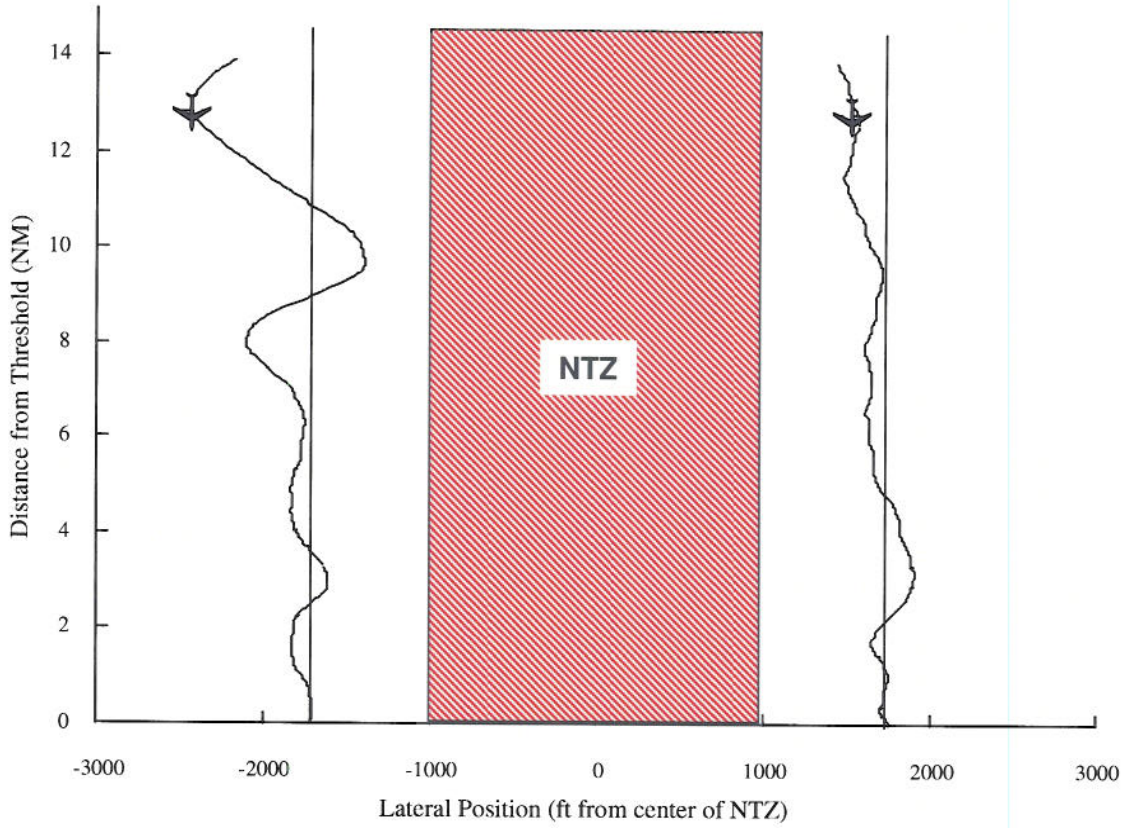

Figure 2. Example of Path-Following Errors during Independent Approaches

Table 2. Probability of an Aircraft Entering the NTZ Due to Path-Following Errors when 10 NM from the Runway Threshold in Texcoco

Number of Runways	Runway Spacing	P(Enter NTZ)
2	1220 m (4000 ft)	~0.02
2	1585 m (5200 ft)	~0.00

There are no standards established for the maximum number or percentage of aircraft entering the NTZ. Aircraft entering or getting close to the NTZ can increase controller workload, since these aircraft must usually have course corrections issued. Also, some aircraft may have to be broken out from the approach due to NTZ entries, and this requires re-sequencing the broken-out aircraft back into the traffic flow, increasing workload and reducing capacity. However, the rates shown in Table 2 are sufficiently low that MITRE believes that path-following errors will not present any difficulties for the three-runway configuration envisioned for Texcoco. A two-runway configuration using a PRM with very long final approach paths could have some difficulties with path-

following errors and may require some special airspace design. MITRE will consider this when refining airspace designs in the Texcoco area.

4.0 Collision Risk

An area of serious concern during independent approaches is the occurrence of blunders. A blunder is a deviation of an aircraft from one approach path towards an adjacent approach path. A blunder is distinguished from a path-following error as follows. A path-following error is part of a normal approach, and will be corrected by the aircrew without controller intervention (although perhaps not before entering the NTZ and losing required separation). A blunder, on the other hand, is a more severe deviation that probably would not be corrected by the aircrew without controller intervention.

Analysis has shown [Higgins and Massimini, 1996] that blunders are rare events, but do occur. In the case of a blunder, intervention by the monitor controllers may be required to prevent a collision. A number of factors affect the chance of a collision in the case of a blunder. For example, the severity of the blunder (i.e., how quickly does the blundering aircraft proceed towards an adjacent runway) may affect how quickly the controller and pilot observe the deviation and correct it. The speed of the controller reaction, either to correct the deviation by the blundering aircraft or to instruct the aircraft on other approach paths to break out, is important. Also, the speed at which pilots react to controller instructions is critical. Communication blockages, misunderstandings, and phraseology can also be factors. Approach path separation, type of radar, display equipment, and controller/pilot training can also be factors.

The U.S. FAA has conducted extensive testing to quantify the chance of a collision during independent approaches [Massimini, 2006]. By agreement with industry, union, and government participants, for testing purposes a collision is considered to have occurred if aircraft pass within 500 ft slant range of each other. This testing has included pilot and controller reaction testing, real-time simulation, and fast-time simulation [PRM Program Office, 1991], [Ozmore and Morrow, 1996].

SIAM can accept a variety of parameters, including runway and approach path configuration, path-following information, and different types of aircraft on the independent approaches (i.e., this type of analysis is performed on an airport-by-airport basis, since elevation and fleet mix can affect results). SIAM then simulates a large number of blunders to determine the chance of a collision given that a blunder occurs. Reaction times of pilots and controllers are usually modeled from statistical distributions of reaction times observed in the U.S. FAA HITL testing using qualified controllers and qualified pilots.

SIAM, and other testing done by the U.S. FAA, gives a measure of the chance of a collision given that a blunder occurs—a "conditional" probability. However, the most important consideration is not how often a collision might occur given that a blunder occurs, but how often a collision might occur during independent approaches—an

"unconditional" probability. In order to ensure that independent approaches do not contribute to an increased accident rate, the U.S. FAA determined a maximum allowable probability of a collision, given that a blunder occurs, in order for a procedure to be authorized. These maximum probabilities are shown in Table 3. The conditional probabilities in Table 3 are equivalent to an overall unconditional probability of one accident per 25 million approaches. See [PRM Program Office, 1991], [Ozmore and Morrow, 1996], and [Massimini, 2006] for a more complete discussion of how this probability was derived.

Table 3. Maximum Acceptable Probability of a Collision Given that a Blunder Occurs

Independent Approaches to	Maximum P(Collision|Blunder)
Two Runways	0.004
Three Runways	0.003

Note that independent approaches to three runways require a lower conditional collision rate than approaches to two runways. This is due to the additional risk of blunders from the center runway. This reduced collision rate often results in larger runway spacing for three-runway systems than for two-runway systems. The unconditional collision rate is the same for both two- and three-runway systems (i.e., less than 1 accident per 25 million approaches).

5.0 Airport Elevation/Aircraft Speed

The ability of the monitor controllers to separate aircraft after a deviation is primarily dependent on the surveillance display, the update rate of the radar, and the procedures and communications requirements specified by ICAO and/or the U.S. FAA for independent approaches.

During testing, the U.S. FAA found that airport elevation could have a significant effect on the ability of monitor controllers to separate aircraft, primarily due to the higher aircraft TAS that results from the higher altitudes being flown during the approaches. For this reason, as previously mentioned, the U.S. FAA imposed a maximum elevation of 1000 ft MSL for independent approaches to three runways unless additional analysis was performed. Although airport elevation applies equally to approaches to two runways, the U.S. FAA standards for two runways were never changed to incorporate elevation. ICAO also did not limit airport elevation for independent approaches to two runways. (Recall that ICAO has not published standards for independent approaches to three runways.)

As previously mentioned, notwithstanding the lack of U.S. FAA or ICAO standards, MITRE believes that elevation should be considered in the safety analysis of *all*

independent approach procedures. Accordingly, the analysis conducted by MITRE for this paper has adjusted speeds based on the elevation and temperature of Texcoco.

6.0 Preliminary Results

Table 4 provides the results of the simulations of independent approaches to two and three runways in the Texcoco area using SIAM. To assist in the eventual design of the airport in Texcoco, minimum spacing is provided for combinations of independent approaches to both two and three runways. The results include the use of high-update-rate radars, such as the PRM.

The probability of collision given that a blunder occurs is less than specified in Table 3 for each of the runway spacings in Table 4, which implies that the overall level of accident rate from collisions is less than 1 in 25 million arrivals. This analysis is similar to those performed during the approval process for independent approaches in the U.S.

As discussed earlier, these results will be verified after more detailed runway placement, approach procedures, and airspace design has been completed.

Table 4. Minimum Runway Spacing for Approaches to Parallel Runways in Texcoco (Preliminary Analysis)

Number of Runways	Minimum Runway Spacing	Display	Radar (Maximum Update Interval)
2	1585 m (5200 ft)	FMA	ASR (5.0 sec)
2	1220 m (4000 ft)	PRM	PRM (1.0 sec)
3	1768 m (5800 ft)	FMA	ASR (5.0 sec)
3	1372 m (4500 ft)	PRM	PRM (1.0 sec)

Note: runways are assumed to be evenly spaced in 3-runway configurations.

7.0 Observations

This report provides a preliminary analysis of runway spacing at Texcoco, and includes information on additional equipment necessary to safely conduct independent approaches. However, this should not be considered an aeronautical safety assessment. Such a study would involve identifying all risks associated with independent approaches and the mitigations, if any, of those risks.

References

FAA, 2008, *Air Traffic Control*, FAA Order JO 7110.65S, Washington, D.C., U.S.A.

Gladstone, C.X., and M.S. Friedman, 1995, *Simultaneous Instrument Approach Model (SIAM) Version 2*, MTR 95W0000117, The MITRE Corporation, McLean, Virginia, U.S.A.

Higgins, M.K., and S.V. Massimini, 1996, *Aircraft Blunders During Simultaneous Instrument Approaches*, Air Traffic Control Quarterly, Vol. 3(4), pp. 261–276, Alexandria, Virginia, U.S.A.

ICAO, 2004, *Manual on Simultaneous Operations on Parallel or Near-Parallel Instrument Runways* (SOIR), Document 9643, 1st edition, Montreal, Quebec, Canada.

ICAO, 2006, *Procedures for Air Navigation Services: Aircraft Operations, Volume II, Construction of Visual and Instrument Flight Procedures,* Document 8168/OPS611, 5th Edition, Montreal, Quebec, Canada.

ICAO, 2007, *Procedures for Air Navigation Services – Air Traffic Management* (PANS-ATM), Document 4444, 15th edition, Montreal, Quebec, Canada.

Massimini, S.V., 2006, *Simultaneous Independent and Dependent Parallel Instrument Approaches*, MP 06W0000127, The MITRE Corporation, McLean, Virginia, U.S.A.

Ozmore, R. & DiMeo, K., 1994, *Simulation of triple simultaneous parallel ILS approaches at the new Denver International Airport using the final monitor aid display and a 4.8 second radar update rate* (DOT/FAA/CT-94/36), FAA Technical Center, Atlantic City International Airport, New Jersey, U.S.A.

Ozmore, R. E. and S. L. Morrow, 1996, *Evaluation of Dual Simultaneous Instrument Landing System Approaches to Runways Spaced 3000 ft Apart with One Localizer Offset Using a Precision Runway Monitor System,* DOT/FAA/CT-96/2, Federal Aviation Administration, William J. Hughes Technical Center, Atlantic City International Airport, New Jersey, U.S.A.

PRM Program Office, 1991, *Precision Runway Monitor Demonstration Report*, DOT/FAA/RD-9115, FAA Research and Development Service, Washington, D.C., U.S.A.

SENEAM, 2007, *Estadística Operacional IFR en el Aeropuerto Internacional de la Cd. de México,* México, D.F., México.