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SECOND WORKSHOP / GROUP MEETING ON IMPLEMENTATION SAM (SAM/IG/2)
REGIONAL PROJECT RLA/06/901

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Agenda
Item 4: Implementation of the air traffic flow management (ATFM) in the SAM Region

METHODOLOGY USED BY BRAZIL FOR THE RUNWAY CAPACITY CALCULATION

(Submitted by CGNA - Air Navigation Management Center of Brazil)

Summary

This paper aims to submit to ICAO, the methodology adopted by Brazil for the runway capacity calculation.

Reference:

- Doc 8168 – ICAO – Aircraft Operations.

1 Introduction

1.1 The saturation of the runway operational capacity for arrivals and departures have been seen as one of the biggest problems for domestic and international airports. In order to maintain the air traffic flow near the optimal conditions, avoiding possible overflow in the system, the Brazilian Air Navigation Management Center (CGNA) applies standard proceedures for runway capacity calculations. These procedures help to follow the changes in demand/capacity at the airports, to find parameters which support recommendations to the airports of interest in advance and to keep the overall operation in harmony.

According to the evolution of the air traffic at airports, the runway capacity calculation will take into account not only the runway occupancy time, but also other factors which can significantly interfere in the runway operational capacity.

1.2 To determine the capacity of a runway or a set of runways, the following factors are considered:

a) planning factors; and
b) factors related to the landing and takeoff operations.

1.2.1 Planning Factors

The planning factors are elements used to simplify the mathematical models, or the operational aspects, which influence the determination of the runway capacity. The most common are:

a) Optimal conditions for aircraft sequencing and air traffic coordination;

b) All operational teams are considered with the same capacity and same operational performance; and

c) All radio-navigation and visual-aid are considered, technically and operationally, unrestricted, and all communication equipment (VHF/telephony) are considered operational.

1.2.2 Factors Related to the Takeoff and Landing Operations

a) Average runway occupancy time;
b) Aircraft Mix ;
c) Thresholds percentage of use;
d) Final approach segment length;
e) Standardized minimum separation between the aircrafts for landing;
f) Runways and taxiways configuration, and
g) Final approach speed.

2 Analysis

The mathematical model for calculating the theoretical runway capacity used by DECEA is described in the following sections. In some of the steps, the aircraft classification is used by grade (A through E), according to the Doc 8168 (Table III-1-2).

2.1 MATHEMATICAL MODEL FOR THE THEORETICAL RUNWAY CAPACITY

STEP 1
COLLECTION OF DATA FROM THE AIRPORT:

1º) The runway occupation time at takeoff (TOPD): time taken by the aircraft during the takeoff operation or the time measured from the moment when the aircraft leaves the “hold short of” position until the it flyies over the opposite threshold;

2º) The runway occupation time at landing (TOPP): time spent from the point at which the aircraft crosses the threshold of the runway during the landing operation until it leaves the runway; and

3º) Flight time from the outer marker (or FAF) to the threshold of the runway (T): time taken by the aircraft during the final approach, from the moment when the aircraft crosses over the outer marker (or FAF) until it crosses the threshold of the runway or, in the absence of an outer marker, when it starts the final approach segment until it crosses the threshold of the runway. The aircraft category is considered in the time mesurement process.

Obs.: The times previously described are classified by the aircraft category and are taken in the control tower of the airfield. These times will be recorded on special forms (Annexes 1 and 2, respectively). It is important to explain that during the time mesurement, will be watched the "Modus Operandi" of the ATC Organs in the studied airfield.

STEP 2

AVERAGE RUNWAY OCCUPANCY TIME (MATOP)

Average runway occupancy time will be calculated for each runway threshold; due to the fact that each runway has its own configuration. This leads to different average time of runway occupancy in each threshold.

After taking the runway occupancy time, the arithmetic average of the runway occupancy time (MATOP) is calculated separatelly by aircraft category, as follows:

$$\textbf{MATOPA} = \frac{\textbf{TOPDA+TOPPA}}{\textbf{2}}$$

$$\textbf{MATOPB} = \frac{\textbf{TOPDB+TOPPB}}{\textbf{2}}$$

$$\textbf{MATOPC} = \frac{\textbf{TOPDC+TOPPC}}{\textbf{2}}$$

$$\textbf{MATOPD} = \frac{\textbf{TOPDD+TOPPD}}{\textbf{2}}$$

$$\textbf{MATOPE} = \frac{\textbf{TOPDE+TOPPE}}{\textbf{2}}$$

STEP 3

AIRCRAFT MIX (MIX)

Aircraft Mix is the fleet configuration operating at the studied airport. According to Doc 8168, the aircraft are subdivided into five categories, depending on the runway threshold crossing speed, which must be 130% of the value of the stall speed with the landing configuration (full flaps, gear down). Therefore, the aircraft are classified as follows:

CAT "A" speed less than 90 kt
CAT "B" Speed between 91/120kt
CAT "C" Speed between 121/140kt
CAT "D" speed between 141/165kt

CAT "E" Speed between 166/210kt

The percentage by aircraft category (Mix) will be calculated from the total daily movement. To obtain this number, the data sample should be taken in the period of one week. The choosen week should contain the day selected to collect the data for calculating the runway occupation time.

The table below shows an example of aircraft mix calculation:

	MONDAY		TUESDAY		WEDNESDAY		THURSDAY		FRIDAY	
CAT	**ACFT**	**PERC**	**ACFT**	**PERC**	**ACFT**	**PERC**	**ACFT**	**PERC**	**ACFT**	**PERC**
A	32	8.42%	29	7.63%	25	6.51%	39	9.68%	25	6.31%
B	55	14.47%	57	15.00%	61	15.89%	73	18.11%	66	16.67%
C	283	74.47%	283	74.47%	286	74.48%	282	69.98%	297	75.00%
D	6	1.58%	11	2.89%	11	2.86%	8	1.99%	8	2.02%
E	4	1.05%	0	0.00%	1	0.26%	1	0.25%	0	0.00%
TOTAL	**380**	**100%**	**380**	**100%**	**384**	**100%**	**403**	**100%**	**396**	**100%**

Arithmetic mean	
CAT	***Mix***
A	7.71 %
B	16.03 %
C	73.68 %
D	2.27 %
E	0.31 %
TOTAL	**100 %**

STEP 4

WEIGHTED AVERAGE TIME OF RUNWAY OCCUPATION (TMOP)

It is the weighted average time of the arithmetic average of the runway occupation time (MATOP) by category of aircraft, taking into account the mix of aircrafts.The average time should be calculated for each threshold in the aerodrome, because the different configurations of the taxiways for each threshold in use.

$$TMOP = \frac{MIX_A \times MATOPA + MIX_B \times MATOPB + MIX_C \times MATOPC + MIX_D \times MATOPD + MIX_E \times MATOPE}{\sum MIX}$$

STEP 5

FINAL APPROACH SPEED(VA)

It is the speed needed to go through the segment of final approach (**SAF**) for landing. This velocity comes from the division of the approach segment length by the flight time (**T**) from the outer marker (or FAF) until the runway threshold.

$$VA_A = \frac{SAF}{T_A}$$

$$VA_B = \frac{SAF}{T_B}$$

$$VA_C = \frac{SAF}{T_C}$$

$$VA_D = \frac{SAF}{T_D}$$

$$VA_E = \frac{SAF}{T_E}$$

STEP 6

AVERAGE SPEED IN THE FINAL APPROACH (VM):

Weighted average of the final approach speeds, taking into account the mix of aircraft.

$$VM = \frac{MIX_A \, x VA_A + MIX_B \, x VA_B + MIX_C \, x VA_C + MIX_D \, x VA_D + MIX_E \, x VA_E}{\sum MIX}$$

STEP 7

DETERMINATION OF SAFE SEPARATION (SS):

The study considers the occurrence of a takeoff between two consecutive landings, but without affecting the regulatory minimum separation (SMR), which is established in rules of ICA 100-12 in the case of Brazil. With this aim, it is necessary to calculate a safe distance to be added to the regulatory minimum separation between aircrafts on approach, in order to allow the take off of an aircraft, after the landing of the first approaching aircraft, but without compromising the regulatory separation to the second approaching one.

This distance comes from the multiplication of the weighted average speed in the final and the weighted average of the runway occupation time.

$$SS = VM \times TMOP$$

STEP 8

DETERMINATION OF TOTAL SEPARATION BETWEEN TWO CONSECUTIVES LANDINGS (ST):

By calculating the distance traveled by the second aircraft on final approach, during the time that the runway stays busy and adding the calculated distance to the regulatory minimum separation adopted, we get the necessary separation between two consecutive landings.

The total separation comes from the summation of the safe separation distance (SS) with the regulatory minimum separation, as follows:

$$ST = SMR + SS$$

There are cases where the SS can be disregarded. Usually this can happen at the airports that have two or more runways, improoving the dynamism of the operation and enabling an aircraft to line up and wait on a runway during the landing of other aircraft on another runway.

STEP 9

DETERMINATION OF WEIGHTED AVERAGE TIME BETWEEN TWO CONSECUTIVES LANDINGS (TMST):

The weighted average time used for the total separation between two consecutive landings is obtained from the total separation distance length divided by the weighted average speed of the aircraft mixing, as follows:

$$TMST = ST/VM$$

STEP 10

DETERMINATION OF THE NUMBER OF LANDING AIRCRAFT IN ONE HOUR (P):

The possible number of landings with the proposed separation within a time interval of one hour is obtained dividing the interval of one hour by the weighted average time used for the total separation between two consecutive landings, as follows:

$$P = 1Hora(sec)/TMST(sec)$$

STEP 11

DETERMINATION OF THE NUMBER OF DEPARTURE IN ONE HOUR (D):

Applying the calculated total separation it is possible to have one departure between two consecutive landings. Decreasing one aircraft of the total number of landings, we get the possible number of departure in the interval of one hour.

D = P-1

STEP 12

DETERMINATION OF THE RUNWAY CAPACITY (CP):

The runway capacity comes from the addiction of the number of landings with the number of takeoffs, as folows:

CP=P+D

STEP 13

PERCENTAGE OF RUNWAY USAGE (PU):

The runaway usage percentage is calculated from the total monthly movement, obtained from a one year data sample.

In order to achieve the required precision in the calculations, the last twelve months data of the control tower management systems are analysed to measure the usage percentage of each runway of the aerodrome.

The tables below show an example the runaway usage percentage calculation:

RUNWAY	% RUNWAY OCUPATION
A	**86**
B	**14**
TOTAL	**100**

MES	RWY A	RWY B	MONTHLY MOVEMENT
ENE	7622	2631	10253
FEB	6364	3229	9593
MAR	9239	2409	11648
ABR	9965	1184	11149
MAY	10811	896	11707
JUN	11280	291	11571
JUL	11637	620	12257
AGO	12145	263	12408
SET	11687	273	11960
OCT	9177	2184	11361
NOV	7765	2936	10701
DIC	7487	3665	11152
TOTAL	**115179**	**20581**	**135760**

STEP 14

CAPACITY OF A RUNWAY SET

The runway capacity of a runway set is the full sustainable capacity, in the operational point of view, considering the runway usage percentage of each runway. The runway set capacity is the weighted average of each runway capacity, considering the respective runway usage percentage, as follows:

$$CA = \frac{PU_1 x CP_1 + PU_2 x CP_2 + \ldots\ldots PU_N x CP_N}{PU_1 + PU_2 \ldots\ldots PU_N}$$

2.2 Practicable Runway Capacity

The practicable runway, or runway set, capacity can be choosen between 80% and 100% of the theoretical runway capacity.

It is recommended to use values closed to 80% of the theoretical runway capacity to reduce the possibility of delays during the operation when some external factor, like weather, operational delays of the companies, etc., interferes in the normal airdrome operation. When the practicable runway capacity value is closed to 100%, it becomes difficult to recover delays caused by external factors.

3 **Action suggested**

3.1 The meeting is invited to:

a) Analyze the information presented in the Working Paper.

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APPENDIX A

DEPARTURE TIME OF RUNWAY OCUPPATION

Airdrome: ____ **Date:** _____ **RWY:** ____

Time of beginning: _____ **Time of ending:** _____

Aircraft	Category	Time	Obs

OBS.: In the fields below is the average time of runway occupation by aircraft category.

CAT	Average time
A	

CAT	Average time
B	

CAT	Average time
C	

CAT	Average time
D	

CAT	Average time
E	

APPENDIX B

ARRIVAL TIME OF RUNWAY OCCUPATION

Airdrome:_____ **Date:_____** **RWY:_____**

Time of beginning:_____ **Time of ending**

Aircraft	Category	Time	Obs

OBS.: In the fields below is the average time of runway occupation by aircraft category.

CAT	Average time
A	

CAT	Average time
B	

CAT	Average time
C	

CAT	Average time
D	

CAT	Average time
E	

APPENDIX C

ARRIVAL TIME BETWEN OM AND THR

Airdrome:_____ **Date:_____** **RWY:_____**

Time of beginning:_____ **Time of ending:_____**

			VELOCIDAD(KT)				
AIRCRAFT	**Type**	**Category**	**Average speed**	**OM**	**THR**	**wind(KT)**	**OBS:**

OBS.: In the fields below is the average time of runway occupation by aircraft category

CAT	Average time
A	

CAT	Average time
B	

CAT	Average time
C	

CAT	Average time
D	

CAT	Average time
E	

APPENDIX D

ABBREVIATIONS

ARR	Arrival
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
CAT	Category
CFP	Actual Runway Capacity
CTP	Hypothetical Runway Capacity
CT	Time Counting
CGNA	Air Navigation Management Center
DEP	Departure
FAA	Federal Aviation Administration
IEPV	Brazilian Aeronautical Forms
OM	Outer Marker
FAF	Final Approach Fix
FPL	Filed Flight Plan
IMC	Instrument Meteorological Conditions
RWY	Runway
SAS	Situation Analysis System
SEP REQ	Required Separation
SGTC	Control Tower Management System
TARIS	Terminal of radar presentation with synthetic image
TG	Touch-and-Go
TOP	Runway Occupancy Time
THR	Threshold
TPH	Typical Peak Hour

APPENDIX E

DEFINITIONS

a) ACTUAL RUNWAY CAPACITY

The possible maximum number of operations during sixty minutes, taking into account the runway occupancy time***.*** ***(t_{op}).***

b) HYPOTHETICAL RUNWAY CAPACITY

The runway capacity calculated during sixty minutes, taking into account the average time of runway occupancy and the legislation concerning aircraft separation, including the specific rules and procedures adopted to the local operations.

c) AEROPLANE CATEGORY

Classification of aeroplanes subdivided into five groups (a, b, c, d, e), defined according to the indicated airspeed at threshold which must be equal to 130 per cent of the stall speed, with a landing configuration (full flaps, gear down).

d) AIRCRAFT MIX

Percent distribution of the aircraft fleet in operation in the analyzed airport, according to the aeroplane category.

e) PERCENTAGE BY AEROPLANE CATEGORY

Calculated index considering the total daily aircraft movement, reported in the IEPV 100-34 form (Aircraft Movement in Aerodromes) or collected from the Control Tower Management Systems. This index is equal to the percent mean of one year sample, based on weekdays (except Saturdays, Sundays and holidays).

f) PERCENTAGE OF RUNWAY UTILIZATION AT AN AERODROME

Calculated index considering the total daily aircraft movement. This index is equal to the percent mean of one year sample in order to approve the confidence on the data.

g) SATURATION

Situation on which the air traffic demand is higher than the airport capacity or than a certain control sector.

h) RUNWAY OCCUPANCY TIME FOR DEPARTING AIRCRAFT

Runway occupancy time for departing aircraft based on the moment that the aircraft leaves the holding point until the moment it crosses the opposite threshold.

i) RUNWAY OCCUPANCY TIME FOR ARRIVING AIRCRAFT

Runway occupancy time for arriving aircraft based on the moment that the aircraft crosses the threshold until the moment it vacates the runway.

j) AVERAGE RUNWAY OCCUPANCY TIME TAKING INTO ACCOUNT EACH AEROPLANE CATEGORY

Arithmetic mean, considering each aeroplane category, between the runway occupancy time for departing aircraft and the runway occupancy time for arriving aircraft.