UPDATE ARTICLE

The recovery of air traffic growth in the South Atlantic after the COVID-19 pandemic and air traffic flow management: calculating airspace capacity using a new mathematical model

La reanudación del crecimiento del movimiento aéreo en la pandemia del Atlántico Sur posterior COVID-19 y la gestión del flujo del tránsito aéreo: medición de la capacidad del espacio aéreo a través de un nuevo modelo matemático

A retomada do crescimento do movimento aéreo no Atlântico Sul pós-pandemia COVID-19 e o gerenciamento do fluxo de tráfego aéreo: a aferição da capacidade do espaço aéreo por meio de um novo modelo matemático

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ABSTRACT

Brazil geostrategic situation is extremely relevant in the decision-making process of development policies in South America. With the approval of theEuropean Union-Mercosur Free Trade Agreement, a considerable growth is expected in the air transportation of cargo and passengers. Although the impacts caused by the COVID-19 pandemic have been catastrophic for the global aviation, the recovery of air operations along with the stagnant growth of the industry could cause traffic congestion in the airspace. This propositional scenario could be even more severe in the oceanic airspace, where there is an air corridor that connects Europe to South America, and cause serious economic consequences for the countries of the Region. In order to ensure greater precision in the calculations to define the capacities of the airspace sectors, a mathematical model capable of measuring the capacities of the aerial portions was presented in this study, which proved to be more suitable for the international standards. The accurate results of the calculations will provide the creation of quality indicators which will guide investments in technologies, equipment and human resources, in order to improve the efficiency of the air traffic flow management system with regard to the growth of air traffic in the South Atlantic airspace.

Keywords: Capacity. Growth. Management. South Atlantic.

RESUMEN

La situación geoestratégica de Brasil es de gran relevancia en el proceso de toma de decisiones de las políticas de desarrollo en Sudamérica. Con la aprobación del Tratado de Libre Comercio entre Mercosur y la Unión Europea, se espera un crecimiento considerable de carga y pasajeros aéreos. Aunque los impactos causados por la pandemia de COVID-19 fueron catastróficos para la aviación mundial, la reanudación de las operaciones aéreas con el crecimiento de la industria represada podría causar congestión en el

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The acronyms and abbreviations contained in this article correspond to the ones used in the original article in Portuguese.

espacio aéreo. Este panorama proposicional podría ser aún más severo en el espacio aéreo oceánico, donde existe un corredor aéreo que une Europa y Sudamérica, y ocasiona graves consecuencias económicas para los países de la Región. Con el fin de asegurar una mayor precisión en los cálculos para definir las capacidades de los sectores del espacio aéreo, en este estudio se presentó un modelo matemático capaz de medir las capacidades de las porciones aéreas, el cual resultó más adecuado a los estándares internacionales. Los resultados precisos de los cálculos proporcionarán la creación de indicadores de calidad para orientar las inversiones en tecnologías, equipos y recursos humanos, con el fin de mejorar la eficiencia del sistema de gestión de flujo del tránsito aéreo en vista del crecimiento del movimiento aéreo en el espacio aéreo del Atlántico Sur.

Palabras clave: *Capacidad. Crecimiento. Gestión. Atlántico Sur.*

RESUMO

A situação geoestratégica do Brasil possui extrema relevância no processo decisório das políticas de desenvolvimento da América do Sul. Com a aprovação do Acordo de Livre Comércio entre o Mercosul e a União Europeia, espera-se um considerável crescimento do movimento aéreo de cargas e passageiros. Embora os impactos causados pela pandemia da COVID-19 tenham sido catastróficos para a aviação mundial, a retomada das operações aéreas com o crescimento represado da indústria poderá provocar congestionamentos no espaço aéreo. Esse quadro propositivo poderá ser ainda mais severo no espaço aéreo oceânico, onde há o corredor aéreo que liga a Europa à América do Sul, e causar sérias consequências econômicas para os países da Região. Com o objetivo de garantir maior precisão nos cálculos para definir as capacidades dos setores de espaço aéreo, foi apresentada neste estudo uma modelagem matemática capaz de aferir as capacidades das porções aéreas, que se mostrou mais adequada às normas internacionais. Os resultados precisos dos cálculos proporcionarão a criação de indicadores de qualidade que nortearão os investimentos em tecnologias, equipamentos e recursos humanos, para melhorar a eficiência do sistema de gerenciamento do fluxo de tráfego aéreo frente ao crescimento do movimento aéreo no espaço aéreo do Atlântico Sul.

Palavras-chave: *Capacidade. Crescimento. Gerenciamento. Atlântico Sul.*

1 INTRODUCTION

Brazil geostrategic position in South America directly influences the countries of the Region in political decision-making processes for South America development, according to the National Defense Policy (BRASIL, 2020, p. 77). One of the dominant elements of this scenario, which interferes in the international relations in South American strategic environment, is the Brazilian airspace, which, according to the Department of Airspace Control (DECEA, 2021),

> [...] extends beyond its borders. It exceeds the area over its territory and reaches a significant portion of the Atlantic Ocean, totaling 22 million km², over land and sea, as agreed in International Treaties.

This range makes Brazil responsible for managing flights in the main oceanic air corridor in South America, in which commercial and cargo flights between Europe and South America pass through. There is an expectation of growth in the number of air operations, considering the approval of the Free Trade Agreement between Mercosur and the European Union for this corridor. According to Agência Brasil,

> Mercosur and European Union countries will constitute one of the largest free trade areas on the planet from the Agreement announced on June 28, 2019, in Brussels. Together, the two blocks represent about 25% of the world economy and a market of 780 million people (AGÊNCIA BRASIL, 2019).

The economic upturn, stimulated by the Agreement between the European Union and Mercosur should increase the growth of air cargo and passenger aviation in the oceanic airspace of the South Atlantic, which was affected by the COVID-19 health emergency. This prognosis raises the necessity of assessing the aircraft absorption capacity in the main oceanic air corridor in South America, under the responsibility of Brazil, in which all the air traffic between Europe and South America is addressed.

According to the Publication of Aeronautical Information (DECEA, 2020), the Brazilian airspace, due to its huge air space, is divided into smaller portions, which are called sectors. The Publication of Aeronautical Information (DECEA, 2020) also emphasizes that air traffic services in the oceanic airspace sectors are provided by Controller–Pilot Data Link Communication (CPDLC) and Automatic

Dependent Surveillance-Contract (ADS-C), without the aid of radars. As a result, there are greater inaccuracies in relation to the aircraft positions on air routes, for monitoring purposes.

Considering this operational situation, the International Civil Aviation Organization (ICAO, 2016) provides for the application of longitudinal separations of 80 nautical miles, approximately 148 km, and lateral separations of 50 nautical miles, approximately 93 km, between aircraft which occupy the same altitudes and the same flight routes. Due to these characteristics, the geographic coordinates established in the Publication of Aeronautical Information – Brazil (DECEA, 2020) define large sectors for the Brazilian oceanic airspace.

In order to manage the air traffic flow, to ensure fairness and quality in the provision of air traffic services, it is essential to establish the capacities of these sectors to achieve balance between air traffic demands and capacities. DECEA, through the Air Navigation Management Center (CGNA), developed a methodology for calculating the capacity of sectors, detailed in the ATC Sector Capacity Manual (DECEA, 2014), based on the international standards.

This model, used in Brazil, allows to assess airspace sector capacities; however, the accuracy of the measurement results is adjusted for sectors in which the mean flight times — measured from the entry to the exit of the sector aircraft — is not longer than 28 minutes. Above this time, the values may be full of discrepant effects, as admitted by the ATC Sector Capacity Manual (DECEA, 2014, p. 13-14): "The convergence factor has the function of minimizing discrepant effects in large sectors [...]".

In view of the situation and considering the importance of accurate measurement of the oceanic airspace sector capacity for the air traffic flow management, due to the growth expectation of the air traffic over the South Atlantic, this article is intended to propose a new mathematical model with the objective of nullifying the distortions caused by long flight times in the sector. Considering that the current formula cannot solve such distortions, this proposal is necessary to produce sector capacity values within the limits established in international standards.

Since this scientific investigation has already been contextualized, the research problem and the general and specific objectives will be conducted, in order to guide the development of this work.

1.1 Research problem

The research problem aims to know how the new mathematical model will be able to reduce the discrepant effects caused by long flight times in the control sector and limit the calculated capacity values to those established in standards.

1.2 Hypothesis

It is expected that the new mathematical model will be able to nullify the discrepant effects caused by long flight times in the sector and generate capacity results that are within the limits of the regulations in force.

1.3 Objectives

1.3.1 General objective

This work aims to analyze the current and a proposed mathematical model, which are used to measure airspace sector capacity. These models are used to identify the discrepant effects of the current model and the mathematical devices created for the proposed model. The distortions of the capacity results, caused by long flight times in the sector, could be nullified.

1.3.2 Specific objectives

1) Examine the characteristics and identify the distortions of the current mathematical model adopted by DECEA, used to measure airspace capacity;

2) Detail the calculations of the current and the proposed models; and

3) Calculate the sector capacity, using the new mathematical model and real data.

1.4 Justification

The academic and professional proposal of the project is to develop a mathematical model capable of measuring the capacities of the large sectors of the airspace, since the current mathematical formula, approved by DECEA, established in the ATC Sector Capacity Manual (DECEA, 2014, p. 13-14), presents discrepant effects for sectors in which the average flight time is longer than 28 minutes.

Therefore, developing a new mathematical model, capable of nullifying the undesirable effects arising from the current formula, will contribute to the achievement of more accurate results and indicators that can guide investments in technologies, equipment, human resources and procedures for better efficiency of the flow management in the South Atlantic oceanic airspace.

1.5 Methodology

1.5.1 Approach

This study was carried out through a quantitative research method, because calculations were performed based on real data from large control sectors, using the current mathematical model and the proposed one.

1.5.2 Research objective

Starting from the objective, the research was explanatory, for real data of the operation. This procedure aimed to identify the discrepancies produced by the current mathematical model, used to calculate the capacity of the sectors. Subsequently, the same data were inserted into the new mathematical model and the results were compared.

1.5.3 Research type

This study was a documentary research. Documents from the Brazilian Aeronautics Command and the International Civil Aviation Organization that deal with this subject were chosen to comprise the documentary corpus, as well as texts that address the possible economic effects arising from the agreement between Mercosur and the European Union. These texts also emphasize the importance of the oceanic air corridor in South America, considering the growth expectation in air operations in the region.

1.5.4 Validation

Real data of the operation were collected *in loco*, at the Atlantic Area Control Center, so that the capacity values of sectors of the Brazilian oceanic airspace were calculated, by using the proposed mathematical formula. The results were carefully analyzed by the air traffic controllers of the Atlantic Area Control Center, who considered the technical operational criteria for the validation of the results with the use of the proposed model.

1.6 Research structure

This research is divided into four chapters: Introduction, Economic Development and Strategic Environment, Brazilian Airspace, Analysis of Mathematical Models for Capacity Calculation, and Conclusion.

Chapter 1 briefly discusses Brazil geostrategic position in South America and the future economic situation in the region, with regard to the agreement approval between Mercosur and the European Union, as well as the expected growth recovery in air operations.

Chapter 2 is dedicated to addressing the expected economic development in South America, the importance of recovering air operations for the countries in the strategic surroundings of South America and the impacts caused by the COVID-19 health emergency.

Chapter 3 presents the structures of the Brazilian airspace and the singularities of the oceanic airspace sectors.

Chapter 4 discusses the capacity methodology adopted in Brazil to establish the sector abilities, as well as the in-depth analyses of the mathematical models.

Finally, in the conclusion, the relevant highlights that led to deep investigations and provided enough data for the main issues raised in this research, are presented.

2 ECONOMIC DEVELOPMENT AND THE STRATEGIC ENVIRONMENT

The Free Trade Agreement approval between Mercosur and the European Union signals that the country should be prepared for strong economic growth, since, as highlighted by Agência Brasil,

> [...] the Agreement is second only to the African Continental Free Trade Area Agreement, which involves 44 countries in Africa and was signed in March 2019. Even so, the European Union and Mercosur signed the greatest Agreement among the economic blocs in history, which should strongly boost trade between the two continents. (AGÊNCIA BRASIL, 2019).

The European Union-Mercosur Free Trade Agreement is expected to boost Europe and South America economies and, consequently, will foster the air transportation sector, demanded by the country parties to the agreement, in order to meet the cargo and passenger transportation growth. The COVID-19 sanitary emergency, in this context, slowed down the growth projection of air operations, in addition to decreasing air traffic in April 2020 to the equivalent to 30% of air operations in 2019, according to the Air Traffic Comparative Report (DECEA, 2021). However, with the decrease of the COVID-19 pandemic, resulting from the vaccination campaign, data from the Air Traffic Comparative Report (DECEA, 2021) which indicate the recovery of airline operations with sustainable growth since May 2021 were observed.

The post-COVID-19 recovery of air operations interest every country in the world, especially those in the South American strategic environment that will be directly influenced by the economic activity growth, arising from the European Union-Mercosur Free Trade Agreement. The future economic scenario presents characteristics that can strengthen international relations between the entities involved and arise the collaborative interest of investing in improvements to the air traffic control systems in the Region, in order to expand the air traffic in the South Atlantic.

According to the guidelines of the National Defense Policy (BRASIL, 2020, p. 17),

> at the regional level, the convergence of interests contributes to increase cooperation among South American countries, which may promote the consolidation of mutual trust and the execution of defense projects, aiming — among others goals — at technological and industrial development, in addition to strategies for solving common problems.

In this context, due to the identification of a common problem, the Brazilian oceanic airspace, responsible for the air traffic management in the corridor that connects Europe to South America, constitutes a strategic environment for the countries of the region, and the aircraft measurement capacity in the oceanic air corridor, in this sense, is extremely important to determine the technical and operational weaknesses that restrict the provision of air navigation services over the South Atlantic.

3 BRAZILIAN AIRSPACE

The Brazilian airspace, which covers the entire national territory, extends beyond its borders, including territorial and jurisdictional waters,as well as the airspace that has been included in the Regional Air Navigation Agreement. According to the Department of Airspace Control (DECEA, 2021), the Brazilian airspace

> [...]extends beyond its borders. It exceeds the area over its territory and reaches a significant portion of the Atlantic Ocean, totaling 22 million km², over land and sea, agreed in international treaties.

Due to the extensive area, DECEA divided the Brazilian airspace into smaller portions called FIR — Flight Information Region —, airspace of defined dimensions, under the responsibility of the Integrated Centers for Air Defense and Air Traffic Control (CINDACTA), as detailed in the Department of Airspace Control (DECEA, 2021).

- CINDACTA I (Brasília-DF) Responsible for FIR Brasília, which covers the central region of Brazil;
- CINDACTA II (Curitiba-PR) Responsible for FIR Curitiba, which covers the south and part of the central-south of Brazil;
- CINDACTA III (Recife-PE) Responsible for FIR Recife and FIR Atlântico, which cover the Northeast and the area over the Atlantic;
- CINDACTA IV (Manaus-AM) Responsible for FIR Manaus, which extends over a large part of the Amazon region.

The oceanic airspace, object of this study, is under the responsibility of CINDACTA III and, according to the Publication of Aeronautical Information — Brazil (DECEA, 2020), it is operationally monitored by the Atlantic Area Control Center (ACC-AO), which provides air traffic service in the area over the South Atlantic.

3.1 Brazilian oceanic airspace

According to the ATM Performance Report of the Brazilian Airspace Control System (DECEA, 2019), CINDACTA III is

> responsible for the airspace controlling and management of an area totaling 14.3 million square kilometers, with 12.2 million square meters of FIR Atlântico and 2.1 million square meters of FIR-RE.

The Brazilian oceanic airspace, due to its extension area of 12.2 million square meters, is divided into sectors, organized in the operational environment of the Atlantic Area Control Center, according to the Publication of Aeronautical Information – Brazil (DECEA, 2020).

The sectors are registered in the Integrated Air Movement Management System (SIGMA, 2020), software developed by the company ATECH for CGNA. According to research carried out by using SIGMA, the aircraft took between 1 hour and 2 hours and 40 minutes long to leave the sectors of the Brazilian oceanic airspace.

4 MATHEMATICAL MODEL ANALYSIS FOR CAPACITY CALCULATION

4.1 Brazilian model for sector capacity calculation

The ATC Sector Capacity Manual (DECEA, 2014) used for calculating the airspace sector capacity was established by DECEA, based on the air traffic controller workload. This variable will comprise all the tasks performed by the controllers in the air traffic control service provision. According to the ATC Sector Capacity Manual (DECEA, 2014, p. 9), workload

> is the time used by the air traffic controller to process all the tasks that a control position requires, in a specific period of time, to keep the traffic safe and orderly.

Air traffic controllers perform communication tasks with pilots, make telephone contacts with other control agencies and use the air traffic control system tools for data entry and planning. Statistical data are periodically collected by CGNA, in accordance with the ATC Sector Capacity Manual (DECEA, 2014) on: the mean time of communication between controllers and pilots (Tcom); the mean time of secondary tasks (TTS), which represent telephone contacts with other control agencies and the use of system tools; and the mean time of ATC stay in the sector (T), which corresponds to the time in which the aircraft remain in the sector. These data are collected in loco, in the control agency, considering the actual operation and, after that, the variables are entered into the Brazilian mathematical model adopted for the sector capacity calculation, according to the ATC Sector Capacity Manual (DECEA, 2014, p. 13), as shown in Table 1.

$$Nref = \frac{(T \times \alpha n)}{(Tcom + TTS) \times 1,30}$$

According to the ATC Sector Capacity Manual (DECEA, 2014, p. 13), the Number of Reference (Nref) is

> the optimal number of aircraft in simultaneous control that a given ATC sector is able to maintain for a period of time, without causing work overload for the air traffic controller. It should be noted that the calculated capacity of a sector is the Nref.

The Cognitive Factor, according to the ATC Sector Capacity Manual (DECEA, 2014, p. 14), represented by the constant 1.30

> is the addition of 30% of the time spent on TCom and TTS tasks. It refers to the air traffic controller thinking state (cognitive factor) during the time spent in the planning, traffic organization and radar surveillance functions.

The Convergence Factor (αn) presented in the modeling was created in order to restrain the accelerated growth of the linear function, when the mean times of aircraft stay in the sector are longer than 900 seconds. αn is defined by the ATC Capacity Manual (DECEA, 2014, p. 13) as

> a factor of mean time reduction of the traffic stay in the sector (*T*). The convergence factor has the function of minimizing the discrepant effects in large sectors so that the Nrefis not greater than 18 traffics.

Application of the convergence factor, according to the ATC Sector Capacity Manual (DECEA, 2014, p. 14), reduces the discrepant effects of capacity values for sectors where the mean flight times do not exceed 1700 seconds (approximately 28 minutes). Over this time, there is a considerable increase in the calculation margin of error, which makes the convergence factor unable to adjust the mathematical model for flight times longer than 1 hour, so that the capacity values do not exceed the limits established in the regulations.

Table 1 – Parameters of the mathematical model.

Nref	Calculated ATC Sector Capacity
T	Mean time of aircraft stay in the sector (in seconds)
Tcom	Average time of the controller communication (transmission and reception) with the aircraft (in seconds)
TTS	Average time spent by the controller in secondary tasks (in seconds)
αn	Convergence factor
1,30	Cognitive factor

Source: DECEA (2014).

The sector capacity studies carried out in Brazil were fundamental for the establishment of important time parameters to be considered in the development of the Brazilian methodology of the sector capacity analysis. However, the country, as an ICAO signatory, confirmed the capacity limits established by the Manual on Collaborative Air Traffic Flow Management (ICAO, 2018, p. 133).

> The formula is based on two hypotheses: first, sectors work better when they do not manage more than 25 aircraft during a 15-minute period; and, second, sectors work better when they manage a maximum of 18 aircraft during a one-minute period. The 25 aircraft hypothesis led to the determination that each aircraft requires 36 seconds of a controller work time.

Although Brazil adopts the same sector capacity limits defined by ICAO, due to the peculiarities of the Brazilian airspace, the ATC Sector Capacity Manual (DECEA, 2014) establishes a methodology for collecting the time allocated to tasks performed by air traffic controllers. This is a point of divergence between Brazil and ICAO in terms of the Manual on Collaborative Air Traffic Flow Management (ICAO, 2018).

In this context, it is observed that the first limit established by the Brazilian methodology is called number of reference (Nref), which is defined as the "optimal number of aircraft in simultaneous control within an ATC sector" by the ATC Sector Capacity Manual (DECEA, 2014, p. 9). The second limit adopted in Brazil is called number of picoof the ATC sector (Npico), which, according to the ATC Sector Capacity Manual (DECEA, 2014, p. 100),

> is the simultaneous control capacity that a given ATC sector is able to maintain, for a maximum of 19 (nineteen minutes) in one hour, continuous or not, in order to meet an increase of short-term demand.

To find the N*pico*, it is necessary to calculate the standard deviations of T, T*com*, and TTS, so that the following variables are created for N*pico* calculations:

T_{max} = *T* mean added to the standard deviation;

TTS_{min} = *TTS* mean subtracted from the standard deviation; and

$Tcom_{min}$ = *Tcom* mean subtracted from the standard deviation.

The values of these variables are usedin this mathematical modeling for N*pico* calculation.

$$Npico = \frac{Tmax}{(Tcom_{min}+TTS_{min})\times 1,30}$$

Another important measure that must be calculated is the Hourly Sector Capacity (HSC), which, as recommended by the ATC Sector Capacity Manual (DECEA, 2014, p. 15),

> [...] is the number of aircraft to which a sector is capable of providing air traffic control service during one hour. It is calculated by using the following formula:

$$HSC = \frac{3600\times(0,683\times Nref+0,317\times Npico)}{T}$$

This formula is currently used for *HSC* calculations; however, as it can be seen, this mathematical model operates, in a Cartesian way, the *Nref* and N*pico* values, without taking into account the interval between these numbers. For this reason, the calculation results may be overestimated.

4.2 Mathematical models proposed for sector capacity calculations

The convergence factors of the current model operate in the reduction of the flight times growth in the sector (T), in order to avoid that sector capacity values are above those established in standards. It is stated by the ATC Sector Capacity Manual (DECEA, 2014, p. 13) that the calculation results may be contaminated when the current mathematical model is used to calculate the capacities of large airspace sectors.

In view of the problem, this article is intended to proposea new mathematical model that could reduce the discrepant effects caused by long flight times in the control sector, and limit the calculated capacity values to those established in standards, by means of a continuous but controlled growth with the aid of the logarithmic function.

In the proposal, Nref calculations will be performed with the Basic Formula (Bf), which is a linear function, and with the Logarithmic Formula (Lf), as shown below:

$$Nref = Bf = \frac{T}{(Tcom+TTS)\times 1,30},$$

equation used for sectors with mean time of stay ofup to 900 seconds.

$Nref = Lf = Bf' + \log_n (T - 840)$,

where B' is equal to $\frac{900}{(Tcom+TTS)\times 1,30}$ and base n is equal to $8160^{1/(18-Bf')}$, which is an equation used for large sectors. The number 8160 (adjustable) of base n will be used to ensure that *Nref* will reach its maximum value of 18 aircraft for the mean time of stay in the sector (*T*) equal to or longer than 9000 seconds. Thus, model 1 which was proposed for calculating the Number of Reference for large sectors is:

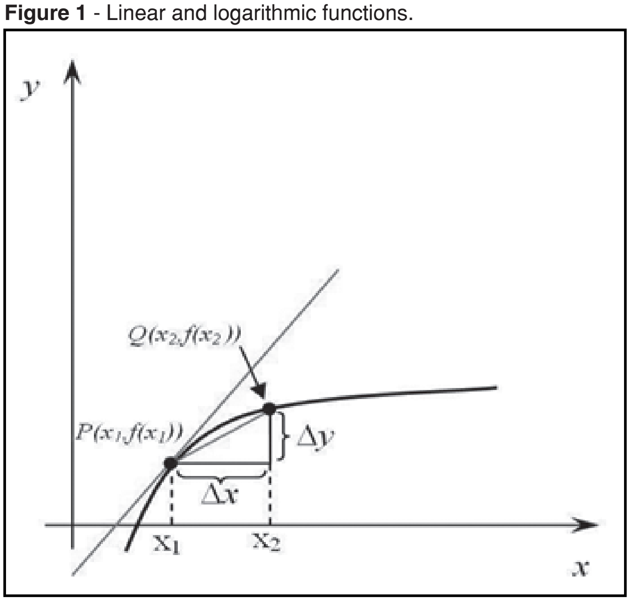
Model 1 - *Nref* Calculation.

$$Nref = \frac{900}{(Tcom + TTS)\times 1,30} + \log_n(T - 840)$$

Source: The author.

The new function growth graph will be formed by the intersection of linear and logarithmic functions graph, as shown in Figure 1.

Figure 1 - Linear and logarithmic functions.



Source: Stewart (2005).

With the new mathematical model, Npico capacity calculations will be performed with the Basic Formula (*BF*) and with the Logarithmic Formula (*LF*), as shown below:

$$Npico = BF = \frac{Tmax}{(Tcom_{min}+TTS_{min})\times 1,30},$$

equation used for sectors with mean time of stay of up to 900 seconds.

$Npico = LF = BF' + \log_n (T_{max} - 840)$,

in which *BF'* is equal to $\frac{900}{(Tcom_{min}+TTS_{min})\times 1,30}$ and capacity of base n is equal to $9960^{1/(25-BF')}$, which is an equation used for large sectors. The number 9960 (adjustable) of base n will be used to ensure that *Npico* will reach its maximum value of 25 aircraft for the mean time of stay in the sector (*T*) equal to or longer than 10800 seconds.

Thus, model 2, which was proposed for the PicoNumber capacity calculation for large sectors is:

Model 2 - *Npico* Calculation.

$$Npico = \frac{900}{(Tcom_{min} + TTS_{min})\times 1,30} + \log_n(T_{máx} - 840)$$

Source: The author.

In order to reduce the overestimated hourly sector capacity values (HSC) generated by the current formula established in the ATC Sector Capacity Manual (DECEA, 2014, p. 15),

$$HSC = \frac{3600\times(0,683\times Nref + 0,317\times Npico)}{T},$$

and considering that the Number of Reference (*Nref*) expresses the optimal number of aircraft in simultaneous control in the sector, model 3 below, was proposed for HSC calculation.

Model 3 - *HSC* Calculation.

$$HSC = \frac{3600\times Nref}{T}$$

Source: The author.

4.3 MATHEMATICAL MODEL VALIDATION

In order to validate the proposed mathematical models, real data were used from Tcom, TTS and T, and were collected *in loco*, at ACC-AO, by CGNA team, from March 12 to 23, 2018. At that time, the capacity values of the group of sectors S2B/S2C/S3, with the new models, which constitute part of the air corridor that connects Europe to South America were calculated. These values were validated through the Operational Board, formed by CGNA team and by CINDACTA III air traffic controllers.

4.3.1 Data collected by CGNA for *Nref*calculation

TTS = 135,65 seconds;

$Tcom$ = 105,43 seconds; and

T = 6987,6 seconds.

$$Nref = \frac{900}{(Tcom+TTS)\times 1{,}30} + \log_n (T - 840) ,$$

in which base n is equal to $8160^{1/(18-Bf')}$, with

$$Bf' = \frac{900}{(Tcom+TTS)\times 1{,}30} .$$

Therefore, *Nref* = 17. The capacity value is within the limit established by the ATC Sector Capacity Manual (DECEA, 2014, p. 13) and by the Manual on Collaborative Air Traffic Flow Management (ICAO, 2018, p. 133).

Order to use the current mathematical model for the calculations, the convergence factor (*an*), for $T >$ 1700 seconds, is 0.65, as highlighted by the ATC Sector Capacity Manual (DECEA, 2014, p. 14). Thus, the following result is:

$$Nref = \frac{T \text{ x } \alpha n}{(Tcom+TTS)\times 1{,}30} .$$

Therefore, *Nref* = 22, which is a value above the limit established in standards.

4.3.2 Data collected by CGNA for Npico calculation

TTS_{min} = 70,98 seconds;

$Tcom_{min}$ = 24,16 seconds; and

T_{max} = 9290,4 seconds

$$Npico = \frac{900}{(Tcom_{min}+TTS_{min})\times 1{,}30} + \log_n (T_{max} - 840) ,$$

in which base n is equal to $9960^{1/(25-FB')}$,

with $Bf' = \frac{900}{(TCom_{min}+TTS_{min})\times 1{,}30}$. Therefore, Npico = 21.

The capacity value is within the limit established by the Manual on Collaborative Air Traffic Flow Management (ICAO, 2018, p. 133).

In order to use the current mathematical model for calculations, the convergence factor (αn), for $T_{max} >$ 1700 seconds, is 0.65, as highlighted by the ATC Sector Capacity Manual (DECEA, 2014, p. 14).

$$Npico = \frac{Tmax}{(Tcom_{min}+TTS_{min})\times 1{,}30} .$$

Therefore, Npico = 49, a value above the limit established in international standards.

After the presentation of the values calculated by both mathematical models, the Operational Board of CINDACTA III decided to approve, in minutes of meeting, the capacity values expressed by the new mathematical models, which are currently used by ACC-AO.

4.4 Mathematical Model Implementation

In order to implement the use of the new formulas, the equations, available in the following tutorial (DOUTORES DO EXCEL, 2020), can be entered into an Excel spreadsheet to carry out the conditional tests and generate results, according to the following syntax.

IF(logical_test;value_if_true;value_if_false).

4.4.1 Nref Calculation

$$Nref = SE\left(T>900; \frac{900}{(Tcom+TTS)\times 1{,}30} + \log_n (T - 840); \frac{T}{(Tcom+TTS)\times 1{,}30}\right) ,$$

in which base n is equal to $8160^{1/(18-Fb')}$, with

$$Bf' = \frac{900}{(Tcom+TTS)\times 1{,}30} .$$

4.4.2 *Npico* Calculation

$$Npico = SE\left(T>900; \frac{900}{(Tcom_{min}+TTS_{min})\times 1{,}30} + \log_n (T_{max} - 840); \frac{T_{máx}}{(Tcom_{min}+TTS_{min})\times 1{,}30}\right),$$

in which base n is equal to $9960^{1/(25-FB')}$, with

$$FB' = \frac{900}{(Tcom_{min}+TTS_{min})\times 1{,}30} .$$

5 CONCLUSION

The opening of international borders, enabled by the reduced intensity of the COVID-19 health emergency, and the expected economic growth from the approval of the Free Trade Agreement between Mercosur and the European Union create an optimistic scenario for the international air transport industry, especially for users that plan to increase their air operations in the oceanic corridor, under the responsibility of Brazil, which is traversed by air traffic demands in the Europe/South America axis.

In view of the geostrategic importance of the Brazilian airspace for the countries around the South American region, it is in the interest of the region that the capacity of the main oceanic air corridor in South Atlantic is adequate for the air operation growth in the coming years. To this end, measuring the capacities of the Brazilian oceanic airspace sectors with some precision is extremely important to create indicators, which can guide investments in technologies, equipment, human resources and procedures to improve air traffic control systems, making air traffic flow management in the oceanic airspace more efficient.

The air traffic flow management service is not limited to congested airspaces. Accordingly, in order to use the South Atlantic airspace to the fullest extent possible, it is necessary that the Air Navigation Service Providers (ANSP) in the region know the capacities of their respective airspace sectors, so as to ensure the balance between demand and sector capacity.

According to the ATC Sector Capacity Manual (DECEA, 2014, p. 13), Brazil has developed a mathematical model to calculate airspace sector capacity; however, the ATC Sector Capacity Manual (DECEA, 2014, p. 13) states that the results, by using the current model, may present inconsistencies for large sectors. Due to this weakness, a new mathematical model was developed, by the joints of linear and logarithmic functions. During the validation process, such joint proved to be efficient and, definitely, eliminated the discrepant effects caused by long flight times in the sector, generating the referential capacities, peaks and schedules of the sectors, adequate and adjusted according to the standards. This is a response for the concern of the research problem.

With improved calculation of the oceanic airspace sector capacities, air traffic flow management specialists will be able to adopt the most optimized measures to ensure that air traffic volumes are compatible with the capacities declared by the competent authorities and to promote studies aimed at expanding airspace sector capacities and enhancing the aerospace power of the region.

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