DIRECT ROUTE SEGMENTS IN BRAZILIAN AIRSPACE

A SUSTAINABILITY STUDY

by

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A Capstone Project Submitted to Embry-Riddle Aeronautical University in Partial Fulfillment of the Requirements for the Aviation Management Certificate Program.

Embry-Riddle Aeronautical University
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This Capstone Project was prepared and approved under the direction of the
Group's Capstone Project Chair, Dr. Peter E. O'Reilly
It was submitted to Embry-Riddle Aeronautical
University in partial fulfillment of the requirements
for the Aviation Management
Certificate Program

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After eighteen months of this journey, filled with special moments, discovering new friends, and meeting old ones but writing new histories to our lives that will never be forgotten.

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AVM6 colleagues, thanks for supporting each other and making us feel we were all on the same team, doesn’t matter the company we work for, we are the best management team for the Brazilian aviation industry.

Abstract

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This research project has as its main objective to study and present the benefits that flying direct from point to point provides to several aviation stakeholders, in addition, our study suggests the implementation of this approach in Brazilian airspace. This initiative is also known as the Free Route Airspace (FRA). The model analyzed in this research has already been implemented by Eurocontrol in approximately three-quarters of Europe's airspace.

The free route airspace has proven to be efficient, bringing numerous benefits to the airlines, such as reduction of flight time, reduction of flight distance and consequently reduction of fuel consumption. All of the benefits mentioned can contribute to the possibility of increasing seat availability and/or cargo capacity.

The initiative presented also has a great impact on sustainability. The reduction of fuel consumption generated with the implementation of flying direct also reduces the amount of CO_2

emissions in the atmosphere. It would also contribute to the commitment that the airlines have signed to reduce and neutralize CO_2 emissions by the year 2050.

Benefits were also observed for the ATC (Air Traffic Control), these advantages include reducing the ATC workload, as well as decreasing the need for interaction for communication between ATC and aircraft.

To get an idea of the potential of this initiative, three routes were studied, and their respective gains were presented in detail. The benefits presented were calculated with the flight planning system currently used by one of the major Brazilian airline companies.

Table of Contents

DIRECT ROUTE SEGMENTS IN BRAZILIAN AIRSPACE

A SUSTAINABILITY STUDY

Chapter I

Introduction

Free Route Airspace (FRA) is a specified airspace within which users may freely plan a route between a defined entry point and a defined exit point, with the possibility to route via intermediate significant points without reference to the ATS route network (traditional route system - airways). The FRA method is also a way to overcome capacity and environmental challenges in the aviation sector by reducing fuel combustion and emissions while improving flight efficiency, engine uptime costs, aircraft uptime, etc. At the same time, FRA paves the way for further improvements in airspace design and ATM (Air Traffic Management) operational concepts.

The FRA concept is being implemented by Eurocontrol, a pan-European civil-military organization dedicated to supporting European aviation (*About Us*, 1963). Free route airspace projects are currently spread over more than three-quarters of Europe's airspace. As such, flight efficiency targets for the region are more readily achievable. (*Free Route Airspace*).

According to Eurocontrol, once fully implemented, compared with the current situation (traditional route system), it should allow many savings, such as the reduction of 1 billion nautical miles flown, 6 million tons of fuel saved, 20 million fewer CO_2 tons emitted, and around 5 billion euros in fuel costs savings.

The FRA was successfully deployed throughout northern, southeastern, and most central Europe. Portugal was the first country to introduce full airspace on May 7, 2009. (*Free RouBrate*

Airspace). The expectation is that most of Europe's airspace will implement the first step of FRA by 31 December 2022, and the last step by 31 December 2025. (*Free Route Airspace*).

This research project aimed to calculate CO_2 emissions for specific routes, in the traditional concept (air route network), and to calculate CO_2 emissions for the same routes, under the Free Route Airspace (FRA) concept, verify differences in terms of emissions and understand the potential benefits for the Brazilian aviation industry.

Problem Statement

Brazilian airspace extends beyond the area over its territory. It covers a total of 22 million km^2, over land and sea. Due to the size of the Brazilian airspace, it is divided into four areas called CINDACTAs (Integrated Center for Air Defense and Air Traffic Control) which are responsible for controlling and managing the airspace and for the separation between aircraft flying to and from the borders with other airspaces in Brazil. The concept of direct routes (DCTs) or Free Route Airspace depends on how the responsible CINDACTAs will manage the air traffic between those areas.

The Airspace Control Department (DECEA) is the Aeronautics Command organization responsible for controlling this area, which is divided into subdivisions called Flight Information Regions, or FIRs. There are five FIRs in Brazil (Brasília, Curitiba, Recife, Atlantic, and Manaus), over which four Integrated Air Defense and Air Traffic Control Centers (CINDACTA) operate.

The Brazilian airspace route system is the traditional concept of Air Traffic Services (ATS) with airways route network. According to Aeronautical Command Instruction (Instrução do Comando da Aeronáutica), ICA 100-12 - Rules of the Air, ATS routes are specific routes, whose purpose is to conduct the flow of air traffic according to the provision of Air Traffic Services (ATS) (Departamento de Controle do Espaço Aéreo, 2018).

With the development of new navigation and air traffic control technologies, improvements are being studied and applied. The DCT (Direct) routes concept is an evolution of the traditional ATS routes and points to permanent benefits for users of Brazilian airspace. It is an improvement that could contribute to the reduction of distances flown, decreasing costs associated with air operations, and lessening the emissions of polluting gases. The next evolution step of airspace optimization is the use of the Free Routes Airspace (FRA) concept, as established in the International Civil Aviation Organization (ICAO) Global Air Navigation Plan. So, the use of the DCT Routes in Brazil is considered a preliminary phase for the implementation of the FRA. (*Operacionalização Do Conceito de Rotas Diretas é Realidade No Brasil*)

The Airspace Management Group regarding the optimization of Brazilian airspace was to include the implementation of the DCT Routes in the Brasília and Curitiba FIRs, in the second half of 2021. It was implemented in two polygon areas (FIRs), one in the Northeast of Brazil (Recife FIR) and an area in the Southern (Curitiba FIR).

The main difference between both methods (DCT and FRA) is that once the DCT areas implemented in Brazil are allowed to fly out of airways from waypoint to waypoint, inside pre-defined polygons, and the ATC (Air Traffic Control) can manage all the flights in that area. On the Free Route Airspace, all aircraft will be flying above a pre-determined flight level plan the routes between a defined entry and exit point without any reference of the ATC network. In other words, there are no airways to be used, the point-to-point flight is always allowed.

As with new technologies and processes in aviation, the FRA presents many challenges to the users. These potential impediments do not outweigh the benefits. However, it will be necessary to take the appropriate actions to get the most out of FRA in Brazil. These issues and challenges are:

- Changes to the isolation method used by Air Traffic Control (ATC). For example, direct routes are not a conflict resolution option, as most aircraft use the most direct routes available anyway.
- Vectoring an aircraft that has planned a route using points with geographic coordinates can cause problems when instructing the flight crew to resume their navigation.
- Conflicts that arise shortly after entering the ATC (Air Traffic Control) sector's responsibilities require further vigilance from the controller when handing over / accepting control. The need for a coordinated approach to the implementation of FRA – Efficiency is only achieved if the FRA is widely deployed. Appropriate measures need to be taken to prevent the airfield from becoming a bottleneck.
- The need for improved (system-based) coordination between air navigation services in case the FRA crosses state boundaries. The use of odd / even levels normally determined by each AIP (Aeronautical Publication Information) may not follow standard assignments (i.e. odd = east, even = west).
- Aircraft flying along sector boundaries from one airspace to another one (i.e., from Brasília Airspace to Curitiba Airspace), using different ATCs managing each airspace, and one depends on the other separations.
- Careful consideration must be given to the potential for loss of separation if deviating from the planned route (due to weather, etc.)

Sectorization may need to be optimized to better accommodate new traffic flows. This is a particularly difficult task for a limited-time FRA implementation. The lack of fixed routes increases the risk of blind spots both within the jurisdiction and near the border.

Goals of the Study

This study aimed to demonstrate the importance of the Free Rota Air Space in Brazil and recommend sustainable national measures. The study analyzed European free-route airspace practices to maximize the benefits of direct flights and, consequently, reduce fuel burn and carbon emissions into the environment.

The DCT Routes (Direct Routes from waypoint to waypoint) point to permanent benefits for users of Brazilian airspace, contributing to the reduction of distances flown, costs associated with air operations and emissions of polluting gases.

Direct routing in highly complex environments is intended to provide airspace users with optimized airspace volumes for direct routing networks to maximize flight planning flexibility. A significant number of direct routes is part of the complexity of the environment.

Contributions Expected

Brazil is included in the scope of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) countries and started the process of monitoring the international CO_2 emissions of its air operators in January 2019. ANAC is the body responsible in Brazil for the implementation of CORSIA and the inspection of air operators.

The implementation of Free Route Airspaces in Brazil will contribute to reducing emissions and, consequently, the amount of fuel planned and used by all Airlines operating in Brazilian airspace, contributing to aviation efficiency and sustainability.

Definition of Terms

FIR – flight information region is an airspace of defined dimensions within which flight information service and alerting services are provided.

FRA – free route airspace is a specified airspace within which users may freely plan a route between a defined entry point and a defined exit point (with the possibility to route via intermediate significant points) without reference to the ATS route network (traditional route system - airways).

List of Acronyms

ANAC	National Civil Aviation Agency
AIP	Aeronautical Publication information
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic Services
CINDACTA	Integrated Air Defense and Air Traffic Control Centers (Centro Integrado de Defesa Aérea e Controle do Tráfego Aéreo)
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CO_2	Carbon Dioxide

DCT	Direct routes DECEA Airspace Control Department (Departamento de Controle do Espaço Aéreo)
FRA	Free Route Airspace
FIR	Flight Information Region
ICA	Instruction of the Air Force Command
ICAO	International Civil Aviation Organization
OACI	Organização da Aviação Civial Internacional
OECD	Organization for Economic Co-operation and Development
NM	Nautical Miles

Plan of Study

Chapter Two: A literature review on aviation route systems, Free Route Airspace concept, and aviation sustainability.

Chapter Three: Present the research methodology used. Collect fuel consumption data on specific routes, within Brazilian airspace, through flight documentation. The researchers will use a commonly established calculation method to convert the values of the fuel consumed to values of CO_2 emissions, generated in the conventional system. The same routes will be studied a second time (in the same software, in the same conditions), using the FRA concept to acquire data regarding fuel consumption and CO_2 emissions. Statistical data of the same routes will be analyzed to understand the possible annual volume of CO_2 emissions reduction on the selected routes.

Chapter Four: Conclusions for the total amount of CO_2 emissions in both concepts will be presented and compared. Evaluation with stakeholders (Airline Operational Engineering

Departments, Air Traffic Control, and Airline Managers) to understand the positive impacts of the FRA concept in Brazil will be conducted.

Chapter Five: Based on the conclusions and evaluation of the main stakeholders, the researchers will present their recommendations and ideas for future studies.

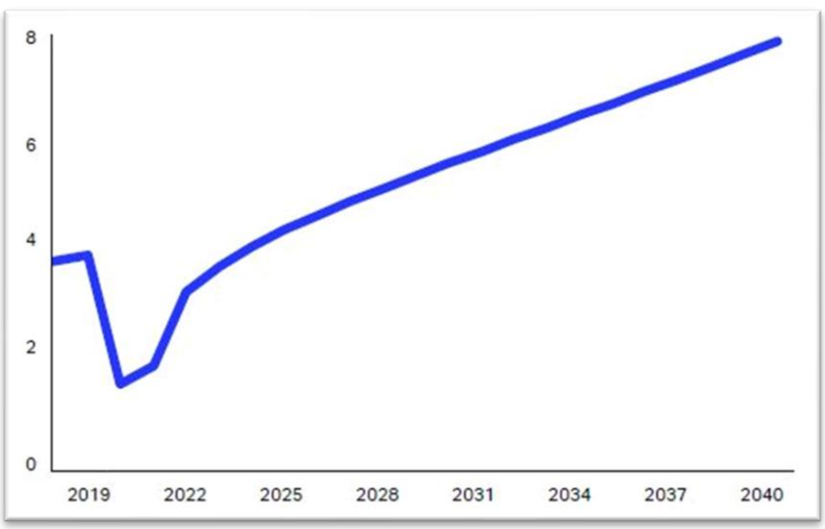
Chapter II

Review of the Relevant Literature

The aviation industry's growth is impressive, nowadays more than 100,000 commercial flights take off every day around the world. This represents more than 400 departures per hour, considering only commercial flights. According to the ICAO website study, technological improvements are needed to ensure success and sustainability (*Future of Aviation*, n.d.).

In the research from IATA (2022), global passenger travel is expected to return to the 2019 level of activity in 2024 and continue to expand over the next 20 years at an average rate of 3.3%, rising to 7.8 billion passenger journeys per year by 2040 (IATA, 2022) shows the world's total number of air transport passengers (commercial aviation only), in billions, from 2019 with a forecast growth until 2040. *(Figure 2.1)*

Figure 2.1 World's Air Passengers Volume, Past, and Forecast (in billions of passengers)



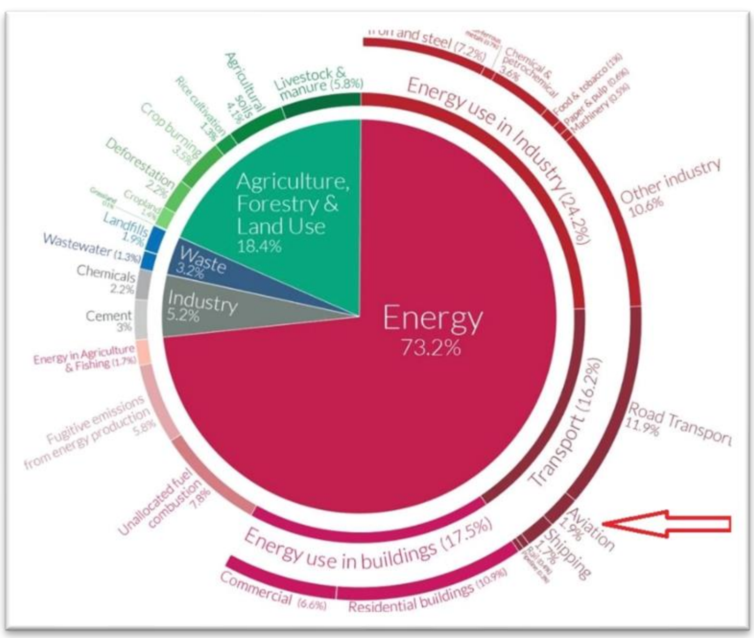
(IATA - International Air Transport Association, 2022).

In addition to the growth in aviation industry capacity, there is the challenge of sustainability. The climate is changing, and forecasts show major impacts on life on the planet. According to NASA's Global Climate Change website, "impacts such as the loss of sea ice, melting glaciers and ice sheets, sea level rise and more intense heat waves are already happening, ranges are changing, and plants and trees are flowering earlier" (Jackson, n.d.).

In research by the IATA – International Air Transport Association, about ¾ of global CO_2 emissions derive from the use of fossil energy (IATA, 2022). The air transport sector commits to net zero CO_2 emissions by 2050 (Graver et al., 2022). This commitment is of existential importance to the industry. It is also important for the prospects of realizing a future global economic model that is sustainable, inclusive, and prosperous (IATA, 2022).

Figure 2 shows global CO_2 emissions by sector. The transport sector is responsible for 15.9% of total global emissions, a relevant contribution to the total. Aviation was responsible for 1.6% of total global CO_2 emissions in 2002 (BAUMERT et al., 2002), and in 2016 this tax rose to 1.9% (IATA - International Air Transport Association, 2022) (Figure 2.2).

Figure 2.2 Global Greenhouse Gas Emissions by Sector.



(IATA - International Air Transport Association, 2022).

Aviation has a huge growth expected and, at the same time needs to reduce emissions, in this scenario. The FRA concept allows flights to be more direct, thus allowing for CO_2 and fuel consumption reductions. Only in Europe, the FRA concept is expected to reduce emissions by more than 20 million tons of CO_2 per year (*Free Route Airspace,* n.d..).

The FRA concept is very important because it can contribute to growth and sustainability at the same time.

Brazilian Airspace Structure

According to DECEA (Departamento de Controle do Espaço Aéreo – Department of Airspace Control), “the structure of Brazilian airspace consists of three subdivisions of surveillance, four integrated air defense, and air traffic control centers, a regional air traffic control service based in São Paulo, five area control centers, and 47 split approaches. In Brazil there are also 59 air traffic control towers, 79 regional airspace control sections, and over 90 air communications offices and various support sections nationwide” *(Operacionalização do Conceito de Rotas Diretas é Realidade No Brasil, 2020).*

Direct Routes

Due to the workload of the ATCs (Air Traffic Control), the CGNA (Air Navigation Management Center) has implemented the preferred routes and Route Playbook, to manage the most critical routes based on the ATC workload to separate the aircraft in safe conditions.

The “fly direct” scenario is already in testing by DECEA and CGNA authorities in the Brazilian Airspace the Direct Routes only into polygons specified in four portions located at

Amazonic FIR, Curitiba FIR, Recife FIR, Brasília FIR, and are Specified by the AIP (Aeronautical Information Publication) and can only be used if the ATC has conditions to activate these areas under the workload and specific conditions. The following items are listed below and are part of the Brazilian AIP:

- Flights departing from FIR sectors where Direct Routing is not applicable going to or crossing sectors where this concept is already available
- Flights departing from FIR sectors where Direct Routing is applicable going to or crossing sectors where this concept is not available

The distance between waypoints inserted in the flight plan shall not be greater than 300 NM" (*AIP Brasil - Publications*, n.d.).

Free Route Airspace

The concept of Free Route Airspace according to ICAO "Defined routes that allow custom planning between defined entry and exits using published intermediate waypoints independent of the ATS route network, depending on airspace availability." (*DRAFT CONOPS for Free Route Airspace (FRA) Implementation in AFI Region.*, n.d.).

The airspace complexity and air traffic management infrastructure allow aircraft to fly directly from one waypoint to the next without relying on ground equipment. This, therefore, provides an opportunity for improved efficiency in terms of reduced mileage, time, and fuel consumption, and may lead to reduced maintenance costs, since the distances are reduced due to the non-use of airways. According to Eurocontrol Free airspace projects now cover more than three-quarters of Europe's airspace, and flight efficiency targets for the region are within reach. Route growth – the difference between flight distance flown and the corresponding portion of great circle distance – reduced from 3.58% in Dec 2007 to 2.00% in Dec 2021 due to airspace design (*Free Route Airspace*, n.d.).

Summary

The aviation industry is expected to grow in the next years. Most worldwide airlines commit to sustainability and reducing CO_2 emissions (Graver et al., 2022). In research from Crownhart today, aviation accounts for about 3% of global gas emissions. Some airlines and industry groups have committed to achieving net zero emissions by 2050, but these plans often lack details on how to achieve them (Crownhart, 2022).

According to Bugault and Holger airlines are under pressure to achieve net zero gas emissions by 2050, airlines are experimenting with so-called sustainable aviation fuel (SAF) (Bugault & Holger, 2021). The most advanced candidate is biofuel, made primarily from edible oils, agricultural crops, and virgin wood, but scarce supply and high costs make it difficult to use on a small percentage of flights. Over the next decade, a variety of alternative fuels could make flying even cleaner. Free Route Airspace is being implemented in some countries that are expecting to reduce CO_2 emissions and fuel consumption (*Free Route Airspace, n.d*). In Brazil there is still in place the ATS model (*Departamento de Controle do Espaço Aéreo, 2018*), this is an old model. The Direct Routes in a few portions of the Airspace are seen as a first step to gathering results to become a Free Route Airspace. This would allow flight planning over a pre-determined flight level where the routes are defined. The routes would be based on waypoints disregarding the use of airways and complying with the new sustainable scenario.

Chapter III

Methodology

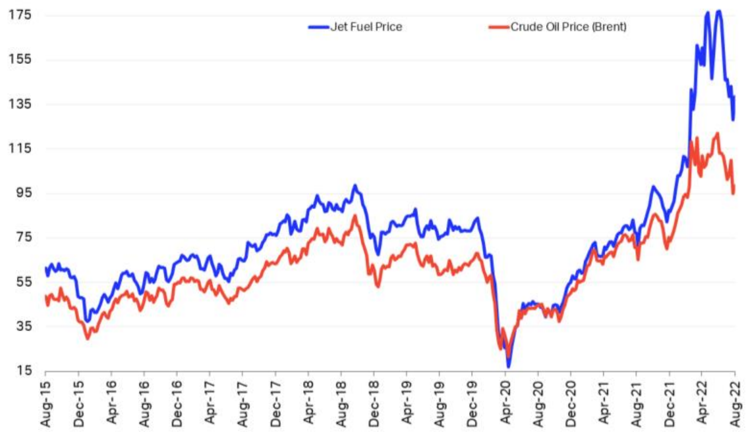
The present research was focused on analyzing the benefits of the possible implementation of the Free Route Airspace (FRA) in the Brazilian Airspace. This chapter presents the methodology that was used to understand how Free Route Airspace can reduce CO_2 emissions and, consequently, reduce costs based on the optimization of flight time, travel fuel and flight distance. In addition to scope limitation issues, this study was designed to calculate and compare three routes in Brazil that are used by all Brazilian airlines in the domestic market with flight levels above FL250 inclusive. According to ICA 100-37 (Air Traffic Services) regulation, airspace is divided into lower airspace below FL245 (inclusive) and upper airspace above FL245 (exclusive).

The airline industry in Brazil, as throughout the world, faces a challenging post-pandemic scenario, where fuel prices are above what operators are used to.

According to Yue and Byrne (2021), “as a high-intensity energy user, the transport sector is under scrutiny to adapt how to achieve CO_2 reductions, particularly relevant for airlines, as air travel from passengers produce the highest and fastest growth in individual emissions.”

Figure 3.1 shows the evolution of jet fuel prices and crude oil prices, in US dollars, per barrel (Jet Fuel Price Monitor, 2022):

Figure 3.1 – Jet Fuel Price Evolution



(IATA - International Air Transport Association, 2022).

To calculate the difference in fuel and CO_2 emissions between the real routes and the direct routes considered by the FRA model (see chapter 2 – Free Route Airspace), a Flight Plan Calculation System was used (this system is highly known and used by many airlines worldwide).

Experimental design

The researchers designed the study based on the following data:

- Choose a route for each type of distance in the Brazilian domestic market: short, medium and long.

- Define the type of aircraft based on the number of aircraft of this model operating in Brazil.

- Set the average payload.

- Collect the number of flights using the largest operator of this aircraft model in Brazil, as an example.

Data Collection

The objective based on the data collected was to understand the behavior in terms of sustainability by calculating the amount of CO_2, time and flight costs for the real route system model used in Brazil, the ATS system.

The data chosen to be analyzed were listed below:

1. Routes:

SBLO to SBGR

SBFI to SBSP

SBFZ to SBSP

2. Aircraft type:

A320-232

3. Number of flights (from 01AUG22 to 17AUG22):

SBLO SBGR: 637 flights

SBFI SBSP: 529 flights

SBFZ SBSP: 837 flights

4. Meteorological data:

Zero wind

5. Take off performance calculation:

Airbus Performance calculation software

Most used runway for origin airport

Runway Dry

26ºC OAT

Standard atmospheric pressure (1013 hPa)

6. Flight Plan Calculation Software:

Fuel Density 0.803

Maximum Zero Fuel Weight available according to performance calculation

SBGL for an alternate airport

Cost Index 15

Optimum Flight Level

All those data were chosen to calculate the same scenarios, retrieve the correct results, and have a fair comparison with no differences between the calculations.

Handling Data

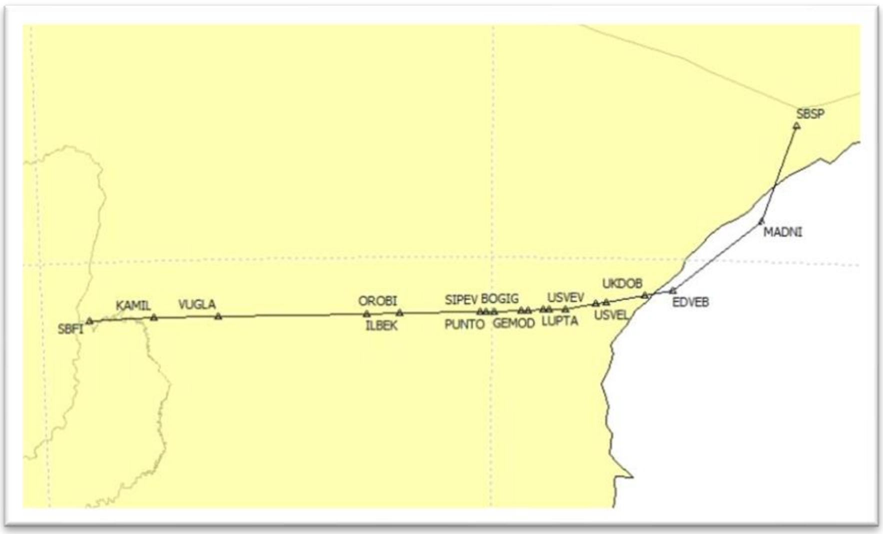
The methodology used in this study was to choose the calculation method to acquire all data from the chosen city pairs, from August 1, 2021 to August 17, 2022. Data from a single Brazilian airline was used, however the routes are identical for all airlines, because the routes are regulated by the authority. This study did not reveal the fuel prices paid by airlines, as they are confidential and because, as it is known, depending on the number of operations, the values may vary.

The survey collected four different pieces of information that helped to better understand the relevance of the present study. This information included the reduction of fuel burned, airtime, total distance from origin to destination and reduction of CO_2 emissions.

Actual route data was retrieved from official published DECEA charts, which show available airways connecting city pairs, and the route to be flown is not the best and most direct. As can be seen visually and intuitively in the figures below, it is possible to verify that there is an opportunity to reduce the trajectory. The origin and destination are not connected by a direct route and must obey the ATS route system.

The figure 3.2 shows the route from Foz do Iguaçu Airport to Congonhas Airport.

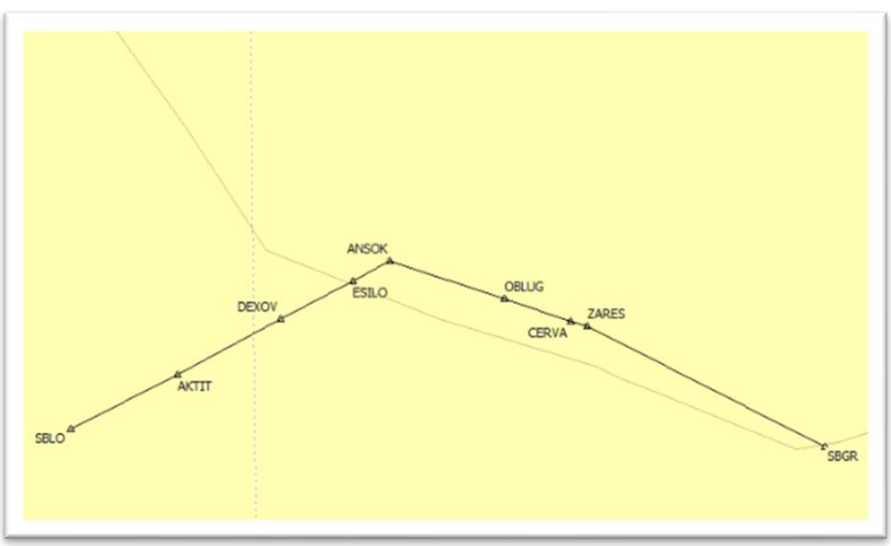
Figure 3.2 – ATS Regular Route - SBFI/SBSP



(Map retrieved from Flight plan calculation system)

The figure 3.3 shows the route from Londrina Airport to Guarulhos Airport.

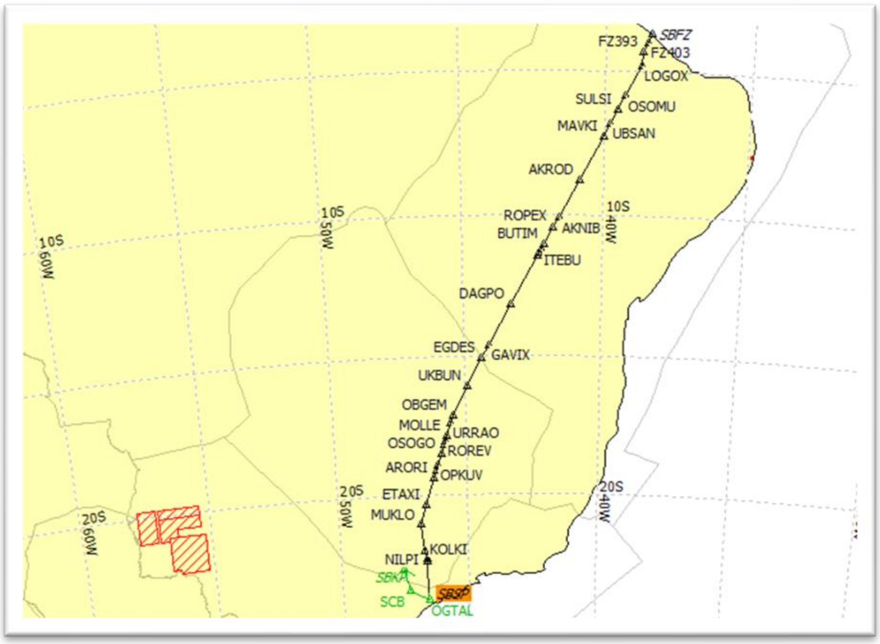
Figure 3.3 – ATS Regular Route – SBLO/SBGR



(Map retrieved from Flight plan calculation system)

The figure 3.4 shows the route from Fortaleza Airport to Congonhas Airport.

Figure 3.4 – ATS Regular Route – SBFZ/SBSP



(Map retrieved from Flight plan calculation system)

The number of flights for the city pairs studied was obtained from a specific Brazilian Airline and to obtain the mass of CO_2 emitted based on an aviation fuel CO_2 emission formula it is 3.15 kg per 1 kg of fuel.

The results considering the Free Route Airspace were calculated through a Flight Plan System, used to calculate all flights of the same airline, from which we found the total number of flights to be considered in this study and the official letters to review the published entrances and exits waypoints to the terminal areas. Terminal areas are defined as an air traffic control area, around a major airport, or airports, normally established at the confluence of ATS Routes, where there are a significant number of flights (Annex 2 Air Rules, 2005).

The first piece of information is referred to as fuel consumption (figure 3.3) because fuel is the measurable variable for calculating CO_2 emissions. The fuel information shows the fuel needed on the routes of the chosen city pair, based on the data retrieved, from the period of this study, in the current scenario, the ATS route system.

Figure 3.3 (Consumption Table)

Calculated fuel consumption, flight time and CO_2 emission data for each leg

City pair	Trip Fuel (kg)	Flight Time	CO_2 emission (kg)
SBLO - SBGR	2.949	01h04	9.289
SBFI - SBSP	3.864	01h25	12.172
SBFZ - SBSP	8.877	03h13	27.963

(Data retrieved from Flight plan calculation system)

Figure 3.4 (Number of Flights)

Quantity of legs in the observed period

City pair	N
SBLO - SBGR	637
SBFI - SBSP	529
SBFZ - SBSP	837

(Data retrieved from Company statistical database)

Analysis

The flight calculations have added to this study a great perception based on direct routes implemented by Free Route Airspace. Nevertheless, in this present study, a total of six calculation was performed. The total distance and trip fuel results were acquired from the Flight Planning Software and used to calculate the respective CO_2 emissions.

Chapter IV

Conclusions

This chapter has been structured to provide a clear and objective understanding of the results of this study. For this purpose, a division into three subsections was adopted, to be treated independently.

All the conclusions of this study are presented, initially, in a very objective way, highlighting the main aspects in bullet points. In the sequence, we approach each aspect in more detail, followed by graphs that are presented below.

Conclusion 1 – Economy in Fuel, Flight Time, and CO2 emissions

Based on the three routes, object of study in this research, around S$ 40,000 could be saved by consuming 250 tons less of emissions through the "Free Route Airspace Method". The predicted overall savings would be even more significant (over US$1 million) if more routes were included in this same method.

Data Collection Method

All data collected for Conclusion 1 was retrieved using points 1, 2, 3, 4 and 5 (listed below) to calculate actual and direct routes using the FRA (Free Route Airspace) method as described in Chapter 3.

Data chosen to be analyzed:

1 – Routes

2 – Type of aircraft

3 – Meteorological data

4 – Take off performance calculation

5 – Flight plan calculation software

Results

The collected data, calculated in the flight planning system mentioned in Chapter 3, show the results of Fuel Consumption, Flight Time and CO2 Emissions for real routes (Figure 3.3 Consumption Table) per flight and the results obtained for the same routes calculated with the FRA method (Figure 4.1 Table of FRA Consumption Routes).

The results show that it is possible to reduce all the terms of this work by calculating the same routes using the FRA method according to the Comparative Table (Figure 4.2 Comparative Table of Consumption), which shows the differences per route and per flight.

The routes were calculated taking into account SID/STAR (departure and arrival procedures were used with the same distance and flight levels to avoid differentiation between the compared routes) comparing the real routes and the FRA method (Figures 4.3 Route Comparison SBFZ SBSP, 4.4 Route Comparison SBFI SBSP, and 4.5 Route Comparison SBLO SBGR) where actual routes are shown in blue and direct routes are shown in black.

Conclusion 1

Based on the studies performed by Eurocontrol, as well as on the data collected and the results obtained from the flight planning system, the FRA (Free Route Airspace) model proves to be efficient and can significantly reduce carbon emission and generate savings by decreasing flight time and fuel consumption, if implemented in Brazil.

According to the calculations made and extrapolated to the number of flights studied per route in the defined period, in terms of sustainability and savings in carbon emissions, they reduce an average of US$ 50.00 per ton of CO_2 emitted (True Cost Carbon Pollution, n.d.).

The total monetary savings (based on just the three routes), considering the carbon savings of 789 tonnes using the Free Route Airspace method, is around US$39,489. This value took into account the estimated fuel savings of 250 tons, only on the three routes in this study. Such savings can be even greater if more routes are added to the study.

See Recommendation 1 in Chapter Five.

Conclusion 2 – Better Aircraft Utilization and Fleet Optimization

Data Collection Method

All the data collected for Conclusion 2 was retrieved using the data collection method from conclusion 1, to calculate the actual and the direct routes, based on FRA Method as described in Chapter 3.

Results

The Free Route Airspace concept is based on users planning their flights freely within a specific airspace, allowing direct flights, by the shortest route, reducing the flight time (Free Route Airspace).

The results and data collected show a reduction of two minutes on the SBLO/SBGR route, three minutes on the SBFI/SBSP route and five minutes on the SBFZ/SBSP route, for each sector. This reduction in flight time can contribute to increasing aircraft utilization, as they will be more available.

Conclusion 2

The Free Route Airspace concept can contribute to increasing the use of aircraft per day, one of the main measures of aircraft productivity (Massachusetts Institute of Technology, s.d.), which contributes to a greater number of passengers transported. The use of aircraft is one of the key factors for the success and profitability of an airline (Belobaba et al., 2009), therefore, the FRA concept can contribute to the sustainability of the industry.

See Recommendation 2 in Chapter Five.

Conclusion 3 – Increased Predictability for Air Traffic Control and Contributions to Fewer Radio Communication Interactions

Data Collection Method

All the data collected for Conclusion 3 was retrieved using the data collection described on conclusion 1, to calculate the actual and direct routes, using the FRA (Free Route Airspace) Method as described in Chapter 3.

Results

The Free Route Airspace concept is based on users planning their flights freely within a specific airspace. In this concept, aircraft will fly the shortest and most direct route. As such, it should contribute to the decrease in requests for aircraft to air traffic control to fly direct, as it is already foreseen under the FRA. This planned condition, with no route changes during flight, increases predictability for Air Traffic Control and reduces radio communication interactions as a consequence.

Conclusion 3

The Free Route Airspace concept can contribute to increasing Air Traffic Control predictability and reduce radio communication interactions, which according to the U.S. Department of Transportation (n.d.), can lead to misunderstandings, delays, and radio channel congestion that leads to noisy or blocked transmissions.

See Recommendation 3 in Chapter Five.

Conclusion 4 – Increased Available Payload Optimization

Data Collection Method

The data collected for Conclusion 4 was retrieved using the data collection described on conclusion 1, to calculate the actual and direct routes, using the FRA (Free Route Airspace) Method as described in Chapter 3.

Results

The Free Route Airspace concept is based on the users freely planning their flights inside specific airspace. In this concept, the aircraft are going to be flying the shorter and more direct route. The expected results would contribute to decrease the minimum fuel required to comply with all regulated fuel calculations, using the FRA method. This planned condition, without route changes during the flight, increases the available payload optimization. This would be due to reducing fuel once the routes were planned directly. The fuel weight could be used for cargo or passengers, depending on the aircraft type used in the citypair (same origin and destination).

Conclusion 4

The Free Route Airspace concept can contribute to increasing payload availability and reduce the minimum fuel requires which could be exchanged for cargo or passengers.

See Recommendation 4 in Chapter Five.

Description of Conclusions

Conclusion 1 – Economy in Fuel, Flight Time, and CO2 emissions

Data Collection Method

According to the calculations comparing the routes, the result of fuel reduction, distance, and carbon emission could be optimized if the FRA method were implemented by the authority in Brazilian Airspace.

Figure 4.1 (Consumption FRA route Table)

Calculated fuel consumption, flight time and CO_2 emission data for each leg with FRA

City pair	Trip Fuel (kg)	Flight Time	CO2 emission(kg)
SBLO - SBGR	2.861	01h02	9.012
SBFI - SBSP	3.746	01h22	11.800
SBFZ - SBSP	8.719	03h08	27.465

(Data retrieved from Flight plan calculation system)

Figure 4.2 (Consumption comparative Table)

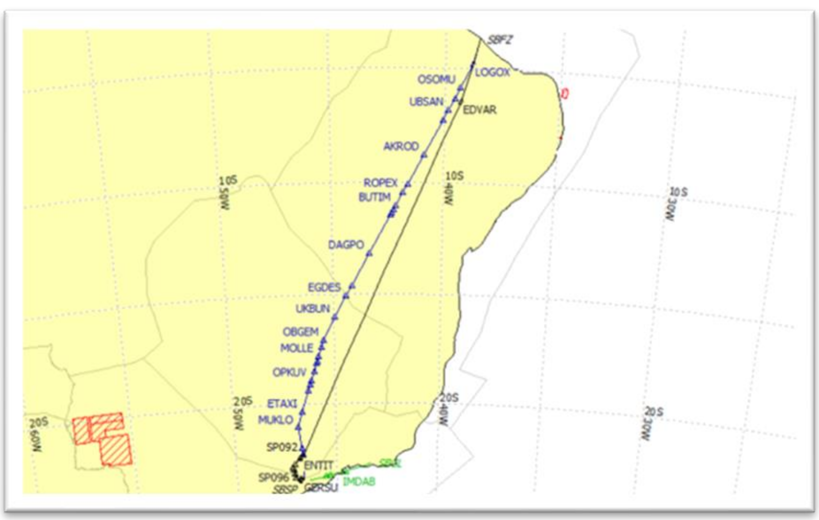
Comparative fuel consumption, flight time and CO_2 emission data for each leg with FRA

City pair	Difference in Trip Fuel (kg)	Difference in Flight Time	Difference in CO_2 emission(kg)
SBLO - SBGR	-88	-00h02	-277
SBFI - SBSP	-118	-00h03	-372
SBFZ - SBSP	-158	-00h05	-498

(Data retrieved from Flight plan calculation system)

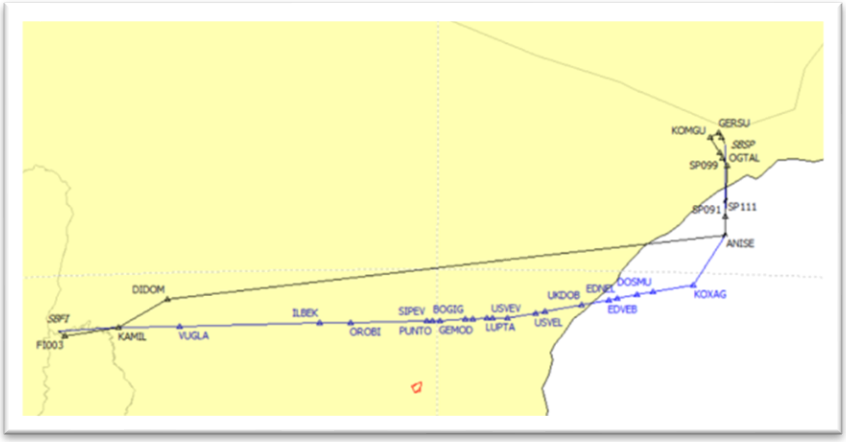
According to the results, the planned routes using the FRA Method, if implemented by the Brazilian Authorities, can reduce the distance between the origin and destinations. As described in the Conclusion 1 results, the images below show the comparison between actual routes, in blue, and the proposed routes, in black.

Figure 4.3 (Route SBFZ SBSP Comparing)



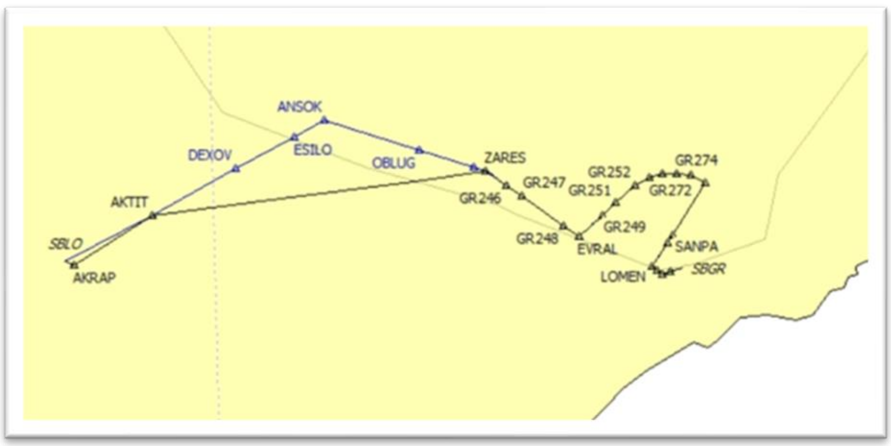
(Map retrieved from Flight plan calculation system)

Figure 4.4 (Route SBFI SBSP Comparing)



(Map retrieved from Flight plan calculation system)

Figure 4.5 (Route SBLO SBGR Comparing)



(Map retrieved from Flight plan calculation system)

Conclusion 2 – Better Aircraft Rotation Utilization and Fleet Optimization

The FRA method can increase aircraft turnover with more economical and direct routes by reducing flight time and can also adjust crew regulations to keep flights in-chain and On Time Performace (OTP) as planned. In other words, the method will avoid an increase in aircraft speed to follow the schedule and keep all flights on time. It reduces flight delays and costs for all airspace users and limits the environmental impact of aviation, no matter how demand for air travel grows.

Conclusion 3 – Increased Predictability for Air Traffic Control and Contribute to Fewer Radio Communication Interactions

Data Collection Method

During the research, the air/ ground / air communication was verified when the absence of airways and waypoints, the ATC and the crew will only have normal communications when entering and leaving the FIR (Flight Information Region) to only one information, and the workload can be reduced once the ATC and the crew keep focused on the flight plan and the aircraft separation.

Conclusion 4 – Increase Available Payload Optimization

Data Collection Method

The Free Route Airspace full implementation, according to the conclusion 1 (Fuel, Flight Time, and CO2 emissions) reducing the minimum fuel required, keeping the focus on the safe environment, the availability to accommodate more cargo and/ or passengers can be reverted to a more profitable flight, mainly departing from smaller airports where the performance can be decreased due to the environmental factors as shorten runways, obstacles and other factors that force to reduce the number of passengers and cargo.

Chapter V

Recommendations, Limitations of the Study, Future Research, and Lessons Learned.

Given all the data collected and the analysis performed, the researchers found sufficient evidence to support the conclusions and recommendations. We believe that these recommendations will bring benefits in fuel economy and flight time, keeping the Brazilian airspace environment safe. Each recommendation refers to at least one conclusion presented in Chapter IV of this study.

- **Recommendation One:** Due to the economic and sustainability benefits, Brazilian authorities should analyze and consider the implementation of the Free Route Airspace in Brazil, where with just these three routes, around US$ 39,489 and 250 tons of fuel.
- **Recommendation Two:** Implement Free Route Airspace, due to better use of aircraft and an increase in the number of passengers and cargo transport.
- **Recommendation Three:** Brazilian ATC will reduce workload and communication interactions.
- **Recommendation Four:** Airlines will improve their cargo and seating offerings by reducing the minimum fuel requirement.

Description of Recommendations (Background).

Recommendation One

The Brazilian aviation Authorities (DECEA, ANAC, Air Navigation Center (CGNA)), should evaluate and analyze the implementation of the Free Route Airspace method, as some other authorities from Europe have already implemented it. The FRA method must have a clear concept and process requirements to facilitate the ATC controllers, pilots, flight dispatchers, and airline managers to understand the economic and workload benefits of implementing this airspace environment. However, the new method must be supported by the direct flights and segments concept, which was already identified by the CGNA and DECEA literature review.

In this context, the Eurocontrol official SESAR Concept of Operations (CONOPS 2019) documentation declares that "In order to guarantee access to airspace to all Airspace Users (and additionally support airspace capacity performance objective), but also to facilitate air-ground communication, some published waypoints have to be maintained in FRA, and can be used at Airspace Users' convenience and ATCOs´ needs" (SESAR, Concept Overview, 2.1.2). Nevertheless, Eurocontrol has published the expected economic and sustainable results. According to the Eurocontrol Journal "The move from routes to free route airspace availability offers significant opportunities to airspace users.

Once fully implemented at the European level, these improvements should allow the following savings, compared with the current situation: "**1 billion nautical miles, 6 million tons of fuel, 20 million fewer CO2 tons, and 5 Billion Euros in fuel cost savings"** (Free Route Airspace at Maastricht UAC, n.d.).

Recommendation Two

According to Federal Aviation Administration, in 2018 aircraft were utilized for 9.8 hours (9 hours and 48 minutes) per day on average (Aircraft Capacity and Utilization Factors, n.d.). The average utilization in the second quarter of 2022 was 10.9 hours (10 hours and 54 minutes) (Average Daily Aircraft Utilization Definition, n.d.). The research showed a time reduction of five, three and two minutes in the routes studied, these reduced end-route minutes, accumulated over the course of the day, added across the entire flight network, can show significant gains in increasing aircraft utilization per day. The increase in aircraft use contributes to the increase in the number of transported passengers.

It is recommended that the Brazilian airlines, deepen the study by extrapolating the results to their complete network, identifying opportunities to increase the efficiency of their operations and fleet utilization, and finally, profitability.

Recommendation Three

Air traffic is increasing year after year and airspace capacity improvement is one of the barriers to this improvement. “The performance of the air traffic flow and capacity management relies on the accuracy of air traffic predictability” and “the enhanced predictability can result in enhanced capacity” (Tobaruela et al., 2014). Many authorities are studying ways and manners to improve the predictability of air traffic and reduce uncertainty, improving safety as a consequence (Traffic Prediction Improvements (TPI), 2018).

Another barrier to the improvement in capacity and in safety is radio communication, “conventional voice conversations over radio can lead to misunderstandings, delays, and radio channel congestion that leads to noisy or blocked transmissions” (Improving Communications

Between Pilots and Air Traffic Controllers, n.d.). The FRA concept can increase predictability because the route is already direct and as a consequence, can reduce radio communication interactions because pilots are not going to request route changes to fly direct.

It is recommended the Brazilian aviation Authorities (DECEA, ANAC, Air Navigation Center (CGNA)), should evaluate and analyze the implementation of the Free Route Airspace method, as a way to improve airspace capacity due to improved predictability and less radio communication, improving as a consequence the safety of Brazilian aviation.

Recommendation Four

The FRA method implementation in Brazilian Airspace as a consequence of the reduction of the minimum fuel required raises the cargo and available seats at non-restricted airports by performance or obstacles that impact payload directly.

Limitations of the Study

Considering that Brazilian airlines have a wide variety of aircraft types and different subtypes, it was not possible to accurately calculate possible fuel and CO_2 emissions. In addition, the number of possible routes published and not published in an Authorities manual due to all possible city pairs used by Airlines on scheduled and/or non-scheduled flights, must be calculated with different Flight Planning Systems and a wider payload range.

The price of fuel is also difficult to be precise, as there are also differences between fuel suppliers, taxes and contracts between operators. The results are estimated using an aircraft's time, weather conditions, payload and routes that the researchers assumed were the best example for this study.

The workload of air traffic controllers is also extremely difficult to obtain, as the necessary information would take into account the precise value of the number of hours each controller spends, divided by air traffic areas and FIRs, due to the variety of the number of flights in each one, at different times of the year, days of the week and peak hours, which can be managed in minutes at a specific station or, number of planes at that service time.

Future Research

- The researchers believe that future research and studies should be conducted to assess the benefits of more aircraft subtypes, engines manufacturer, and payload restrictions to all Brazilian airlines.
- For a better result and overview, more routes should be added to complete an analytic study to retrieve results for different aircraft subtypes in order to increase the economic scenario for airline operators.
- Although, to develop studies for Brazilian airlines to increase the aircraft and crew rotation, the Cost Index and the availability of airport slots need to be taken into consideration, the Free Route Airspace method reduces the distance flown between origin and destination airports and the flight time.
- Future studies should analyze the workload for Air Traffic Controllers and the flight crew due to the radio communication reduction, which can be measured and optimized.

Lessons Learned

- The main learning point from this work is that there is a strong and safe economic and sustainable scenario. The active DECEA and CGNA participation in the new airspace structure to accommodate the Free Route Airspace can be economically beneficial to Brazilian airline operators

- Regarding the study of the routes, the preferred routes published in a route playbook issued by the authorities, comparing the Free Route Airspace method, can have more benefits than only fuel economy.
- Air traffic controllers can reduce the workload from radio communications and optimize the Flight Information Region to maintain safe airspace.
- It is not the purpose of this study to propose a replacement of the existing airspace division and preferential routes due to air traffic congestion in some areas that have a high number of flights and a large absorption of flights in certain peak periods.
- It is possible to analyze new methods to increase the airline’s economic health.
- Possibility to act directly into the environment reducing the carbon emission.

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