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Performance Comparison between Conventional and PBN Air Navigation Procedures: A Case Study on the Route Connecting Campinas Airport to Santos Dumont Airport

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Abstract- In the last decades, the popularization of the aircraft as a means of transport has raised the need for a better use of airports and airspace. To adapt to this reality, new ways to better use of airspace must be found. One of the ways found was the introduction of Performance-Based Navigation (PBN) procedures, representing a change from sensors navigation to a performance-based navigation. The implementation of this new type of procedure introduced changes in aircraft operation, the insertion of new procedures for air traffic controllers and pilots and the introduction of automation systems to support air operations. The aim of this paper is to compare the performance between Conventional and PBN air navigation procedures. The study applied fast-time simulation with the Total Airspace and Airport Modeler (TAAM) and considered nine different aircraft models in the route connecting Campinas Airport to Santos Dumont Airport. Fuel consumed is used as a performance parameter. Study results showed the benefits of applying these techniques vary according aircraft models.

Keywords- *PBN, TAAM, Performance-Based Navigation*

I. INTRODUCTION

In the last decades, the popularization of the aircraft as a means of transport has raised the need for a better use of airports and airspace. The forecast of the world's two largest aircraft manufacturers, Boeing and Airbus, is an increase of the commercial aircraft fleet. According to [1, the number of aircraft will grow on average 3.6% per year, reaching 41,240 aircrafts in the year 2032, of which 70% will be single-aisle aircraft. According to [2], the world average fleet growth will be 4.7% per year, and in emerging countries, including Brazil, there will be an increase of 6.8% per year, with this, the world aircraft fleet will double every 15 years reaching 36,556 aircrafts.

To adapt to this reality, new ways to better use of airspace must be found. One of the ways found was the introduction of Performance-Based Navigation (PBN) procedures, representing a change from sensors navigation to a performance-based navigation. The PBN concept refers to the performance requirements to be applied to air traffic route, instrument or procedure for a defined airspace.

PBN is not a new navigation system, but a set of performance specifications that an aircraft must follow. The PBN capacity of an aircraft will be varied and will be directly linked to the equipment installed in the aircraft and navigation infrastructure of the place; it will be the ability of the sensors installed on the aircraft and not a specific sensor that determines the operation of the procedure [3].

The concept is formed by the RNAV (Area Navigation) and RNP (Required Navigation Performance) procedures. The RNAV procedures are defined as "a method of navigation that allows the operation of an aircraft on any flight path in the coverage of navigational aids within the limits of coverage or a combination of both" [4]. The [5] defines as a navigation method that allows the aircraft operation on any desired trajectory within a stations cover / navigation aids or within the limits of aid capability embedded in the aircraft itself, or a combination of both. The RNP procedure can be defined as a navigation performance measure necessary for a given airspace operations.

The RNAV and RNP procedures are similar. The main difference between them, are the warning and monitoring requirements that must be embedded. When a procedure requires a warning and monitoring system it is set to RNP and when there is, no such requirement is set to RNAV. The ability of an aircraft to fly RNP will be determined by the equipment installed in the aircraft and air navigation infrastructure [4].

One of the original objectives of PBN is to permit the use of any aid available for navigation instead of being dependent on a single aid. The navigational aids transmit position information. This information is received by the sensors on board of the aircraft and is transformed into information by the navigation systems of the aircraft. The aids that are based on the ground that are used in the PBN navigation are the DME (Distance Measuring Equipment) and VOR (VHF Omni Directional Radio Range). The NDB (Non-Directional Beacon) is not considered a source of positioning for the PBN. The aids based in space are the global satellite navigation systems or Global Navigation Satellite System (GNSS). Currently, GNSS constellations in operation are GPS (USA) and GLONASS (Russia).

This equipment's precision allows aircraft flying RNP procedures a trajectory more accurately, ideal for approach procedures in mountainous regions, to bypass obstacles or to avoid over flight of certain areas. This change has had an effect an improvement in airspace efficiency, allowing an increase in air capacity allowing more flexible air routes, exits and arrivals procedures. It also allows an optimization in the air route planning in terms of fuel consumption, time, noise and decrease delays. Figure 1 shows the comparison between Conventional, RNAV and RNP routes.

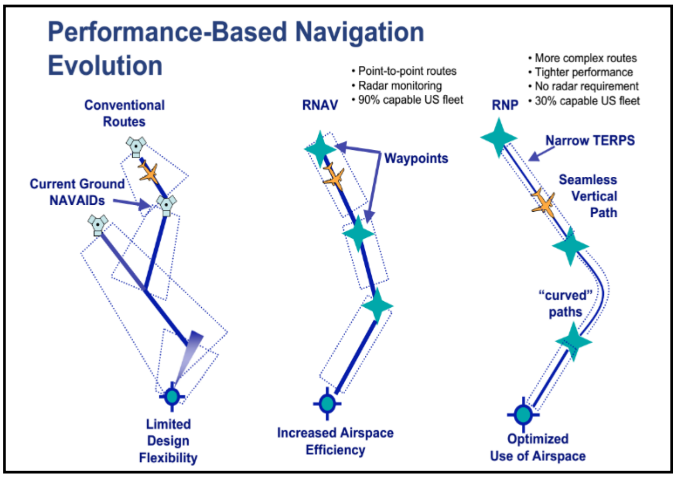

Figure 1. Comparison between Conventional, RNAV and RNP routes [6]

The navigation performance and lateral deviation necessary for RNAV and RNP procedures is part of the navigation specification determined by air authorities. For example, in a RNP 1 procedure (navigation specification), the maximum lateral deviation permitted is 1 nautical mile per each side 95% of the time and 2 nautical miles for 99% of the time, as shown in Figure 2. With this in mind, the air planner determine the separation minima and route spacing.

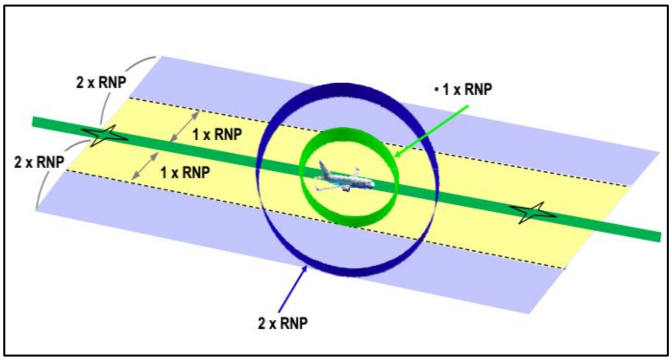

Figure 2. Navigation performance in RNP navigation [7]

The objective of this article is to measure the benefits of PBN. A case study in the route connecting Campinas Airport to Santos Dumont Airport was performed. The parameter used to measure the efficiency was the fuel. For this, it was used the fast-time simulation with TAAM (Total Airspace and Airport Modeler) software. To verify if there were differences in performance by aircraft model, it was compared the fuel consumption of nine different types of aircraft.

The academic contribution of this paper is with fast-time simulation, compare fuel consumption by conducting RNP, RNAV and Conventional procedures. The analysis was not restricted to only one type of aircraft with nine different models being analyzed.

This article is divided into six sections, including this introduction. The second section presents the air navigation history and the various type of air navigation used. The third section presents the airports operational considerations and its characteristics. Section four presents the route planning. Section five presents the results and section six presents the conclusion of this article.

II. AIR NAVIGATION HISTORY

Air navigation advances have always been connected with aviation advances. Initially, due to lack of flight instruments or systems that would help in navigation, commercial flights were limited to fly their route during the day and good weather. For guidance, pilots were required to use visual references, and did not have instruments to indicate the flight attitude of the aircraft, using the natural horizon as reference [3].

All the navigation was made using a road map. The pilot or navigator had to compare geographical terrain references and compare with the map, checking and correcting possible detours. The first air navigation charts were created in the United States in the 20. Allied to the aeronautical charts, the first instrument used for air navigation was the compass. Drawing a line that united the intended destination, the pilot could set the true course of the intended track [3].

Used until the present day, the navigation method on visual conditions (VFR) uses the information found in aeronautical chart for planning, associated with the visual references in the soil, the information on the map and flight planning time. A problem that had to be transposed was to maintain contact with the ground references and see the runway during the night. During the 20's, in the United States the first of runway lights beacon were installed, solving the problem that did not allow night operations.

It was during the 20's, also in the United States, the first airway took shape. Placed at equal intervals, rotating beacons were installed outlining the path of the airway. The lights positioned on towers, rotated at a speed of 6 revolutions per minute and were located each 15 miles. As the flight took place, it was possible to see the headlights for distances over 40 miles Despite all the advances, a necessary condition for the achievement of the flights was to maintain visual flight conditions that allow the continuous display with the terrain and the rotating beacons.

Seeking the possibility of flight conditions without continuous contact with the ground, onboard instruments were created that allowed overcome this obstacle, and fly under instrument conditions (IFR). The instruments created were the attitude indicator, the heading indicator and the turn indicator. At the end of the 20's, in the United States, was created the first radio-based system allowing navigation in instrument flight conditions. It was the four-course radio range. The devices were installed at intervals in the airways, becoming world standard aid to navigation instrument.

The system just pointed heading and course information, not revealing the distance to the station. To minimize the problem, marker beacons were installed along the route. At the same time, the Non-directional Radio Beacon (NDB) was developed. The receiver in the aircraft was named DF (Direction Finder). The use of DF required a manual manipulation, which proved to be very laborious for the crew. Therefore, the DF form replaced by ADF (Automatic Direction Finder), which could, in electronic form, determine the direction for NDB station and inform it to the pilot.

Continuous improvements to the ADF navigation system made it popular among pilots. The first ADF was installed in the USA in 1924, and since then, a number of airways based on this aid. In addition, NDB were installed near the runway serving as a aid approach for the airport. Due to its low cost, this type of aid is used today in some airports around the globe.

In 1937, the Visual Aural Range (VAR) was developed, an update of the four-course radio range system. The development eliminated the reflection problems, which were encountered in previous system. VAR failed to be complete accepted by the crews and was replaced by a system emitting an infinite number of possible courses, instead of four in the previous system. The new system was called VHF omnidirectional range (VOR).

The VOR is still used as an aid to navigation for instrument flight. The VOR only provides the direction for the station, not specifying its distance to it. To solve this problem the Distance Measuring Equipment (DME) was created. The DME system uses the elapsed time of the pulse coded sent by the interrogator located in the aircraft and a transponder located in the ground station. After the pulse is received back, the distance is electronically calculated.

Seeking a greater precision for landing when approaching for landing in IFR conditions, in the 40's, the Instrument Landing System (ILS). The ILS allows the pilot a landing approach aligned with the runway centerline, providing guidance on the vertical and lateral axes. The ILS consists of three types of transmitters: the Finder, the glide slope and markers beacons.

To navigate using the VOR or NDB system, pilots need to program the route through several VOR along the route until reaching the destination. Because it is a navigation aid based on the ground, its location is restricted to the location of airports or the places where the installation was possible. As a result, most of the time, is not viable a straight navigation, causing longer flight time and fuel consumption, as shown in Figure 3.

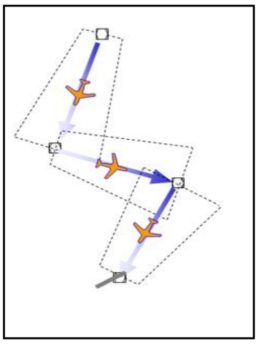

Figure 3. Route profile using navigation aid based on the ground

The way found to overcome this limitation and allow direct navigation between destinations, was the creation of Area Navigation (RNAV) procedures. The following systems are used in RNAV: Doppler radar, CLC, LORAN, LORAN-C, Inertial, VOR / DME and GNSS. However, it was with the introduction of the Global Navigation Satellite System (GNSS) that the RNAV became popular as a navigation system.

The GNSS is a constellation of satellites that provides high frequency signals conveying the information of time and distance. This information is captured by a receiver, which analyses it and indicate the location of the aircraft. Due to technological advances and the need for better use of airspace, the performance-based navigation (PBN) procedures were created.

III. AIRPORTS OPERATIONAL CONSIDERATIONS

A. *Campinas International Airport – Viracopos*

The Campinas International Airport - Viracopos, ICAO designation - SBKP, has one runway (15/33) with a length of 3,240 meters. The percentage utilization is 89% of the runway 15 and 11% of the runway 33. 78% of the operations were IFR operations [8]. Figure 4 shows the airport layout.

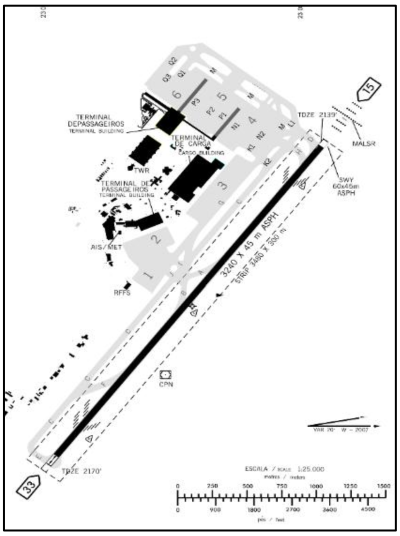

Figure 4. Campinas International Airport Layout

Considering 50% of arrivals, the IFR capacity is 45.58 movements per hour. In 2013, the total movement of domestic flights were 118,663 and international flights were 8,589. In the same year, the total domestic passengers were 9,234,514 and the international passengers were 60,835 [8].

B. Santos Dumont Airport - Rio de Janeiro

The Santos Dumont Airport – Rio de Janeiro, ICAO designation - SBRJ, has two parallel runways (02L/20R and 02R/20L) separated by one axis at a distance of approximately 80m, not allowing independent operation between runways. The 02L/20R runway has a length of 1,260 m and runway 02R/20L has 1,323 meters in length. The percentage utilization is 25% of the runway 02 and 75% of the runway 20. 89% of the operations were IFR operations [8]. Figure 5 shows the airport layout.

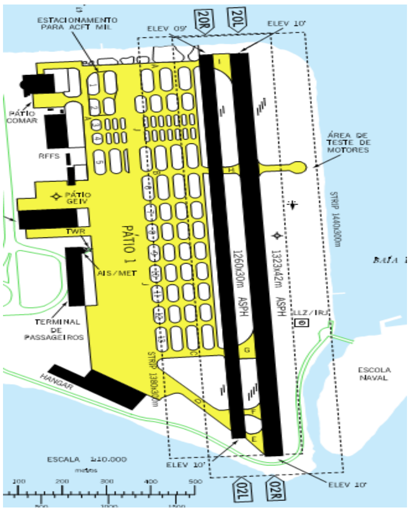

Figure 5. Santos Dumont Airport layout

Considering 50% of arrivals, the IFR capacity is 46.48 movements per hour. In 2013, the total movements of domestic flights were 127,208. In the same year, the total domestic passengers were 9,204,603.

IV. ROUTE PLANNING

Each simulated flight consists of a sum of procedures namely: takeoff, standard instrument departure procedure (SID), en-route flight, standard arrival instrument procedure (STAR), instrument approach procedure (IAC) and landing, as shown in Figure 6.

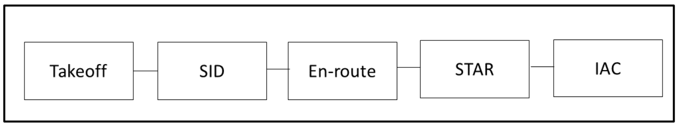

Figure 6. Route planning

The construction of the simulation took into account that the aircraft could fly only two types of procedure: Conventional or PBN, meaning that the SID, STAR and IAC should be only one of these types.

The procedures and the geographical coordinates of the fixes included in the procedure were provided by the Brazilian Department of Airspace Control (DECEA). In this article, the SID, STAR and IAC procedures were analyzed in terms of fuel consumption. The airways used followed the routes predetermined by DECEA and are conditioned to the type of procedure flown (PBN or Conventional).

The aircraft used by the Brazilian airlines in the domestic flights were simulated in the study. The Brazilian fleet in 2012 consisted of 518 aircraft, of which with a capacity between 101 and 150 passenger seats accounted for 31.47% and with capacity 151-200 seats accounted for 36.87%. Figure 7 shows the evolution in number of aircraft by manufacturer in Brazil between 2009 and 2012. Taking into account the manufacturer of the aircraft fleet of Brazilian airlines, the Boeing aircraft company accounted for 36.10%, 31.85% of Airbus and Embraer with 14.48% [9].

The cruise altitude were 28,000 ft for the jet engine and 18,000 ft for the Turboprop aircrafts. For the fuel consumption and performance calculation, the TAAM uses as database the BADA (Base of Aircraft Data). The BADA is an aircraft performance model developed by Eurocontrol for use in air traffic simulations.

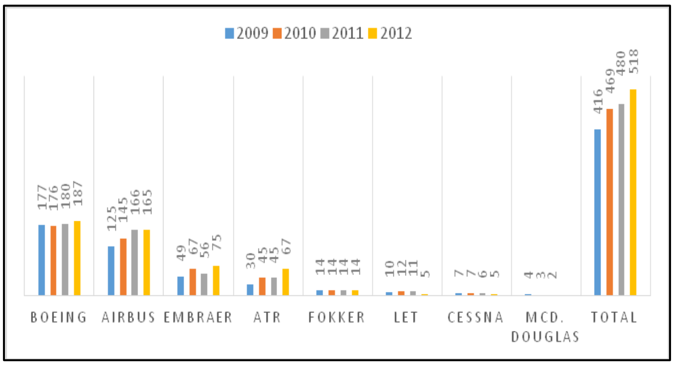

Figure 7. Number of aircraft by manufacturer in Brazil between 2009 and 2012

Due to differences in performance, the aircraft were divided into two types: jet engine and turboprop, as shown in Table 1.

TABLE I. AIRCRAFT UTILIZED IN THE STUDY

Jet Engine	**Turboprop**
A319; A320; A321; B-733; B-737; B-738; F-100; EMB 145; EMB 190	AT-72

In the simulations, the random function has been disabled. The aim was that all flights having the same driving techniques, allowing a better comparison of fuel consumption of the aircraft.

Since the goal is to check the consumption of fuel in the realization of the procedures, it was not considered in the simulation the time and the consumption during aircraft taxiing. The data started to be computed from the beginning of the take-off and stopped when the aircraft came to a complete stop after landing.

V. RESULTS

The results showed that performance of aircraft flying Conventional or PBN procedures must be analyzed for each airport. Each airport has a different reality, when it comes to flight procedures. Similarly, the aircrafts do not behave the same performance.

To find out, in percentage, which procedure presented more economy when compared to other one, the gain metric was used. The X / Y gain is the economy, in percentage, the fuel consumption of the X procedure when compared to the Y procedure. For the purpose of analysis, it was compared the RNP, RNAV and Conventional (CNV) procedures. The positive gains occur when the completion of the procedure X is most beneficial compared to the procedure Y. It is negative when the completion of the procedure Y is more beneficial. The absence of representation means that there was no difference in fuel consumption between the procedures.

A. From Campinas Airport to Santos Dumont Airport

1) Total Consumption on the route

The TAAM with existing features in the software failed to simulate the landing of Foker-100 aircraft in SBRJ. The software considered that the aircraft would not be able to land on the runway and the terminated the flight.

Until the beginning of the approach procedures for landing (IAC), the PBN and Conventional routes are overlapping. Except for the RNP W procedure, all other procedures simulated in SBRJ are defined path, meaning that after reaching the minimum decision height (MDA), an aircraft must have visual references with the ground for landing.

The direct consequence is that the minimum ceilings of this procedure are higher when compared to other procedures for instrument at other airports. Because TAAM does not make the calculation of this type of path alone, flight paths were created to simulate the visual traffic of the aircraft. Figure 8 shows the fuel consumption for the route.

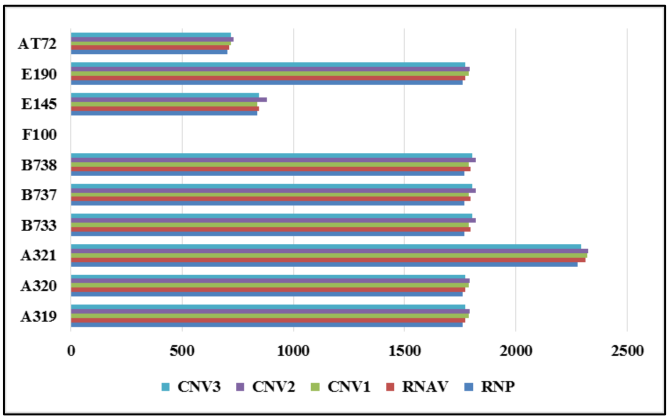

Figure 8. Fuel consumption (kg) for the route

RNP route proved to be the most economical when compared to the RNAV routes, CNV1, CNV2 and CNV3. Figure 9 show the gains.

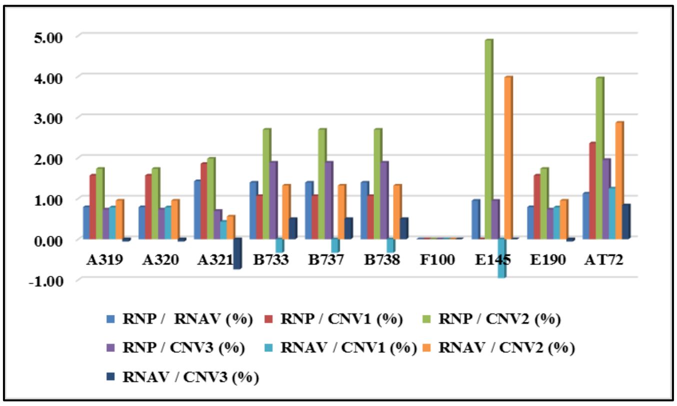

Figure 9. Gains (%) for the route

Total gains were different by aircraft model. RNP gains when compared to the RNAV are between 0.79% and 1.43%. Aircraft models A321, B733, B737 and B738 presented the best performance. The gains of RNP when compared to the Conventional are between 0.73% and 4.89%. Aircraft model E145 presented the best gain with 4.89%. RNAV gains when compared to the Conventional are between -0.96% and 3.98%. Aircraft model B733, B737, B738 and E145 presented better performance when performing CNV 1 procedures.

The aircrafts performed the RNP routes faster. The gains were on average one minute when compared to the RNAV, CNV1e CNV3 and three minutes compared with the CNV2.

2) Total Consumption on the Arrival and Landing Procedure

Figure 10 shows the fuel consumption when it is analyzed just the arrival (STAR) and landing (IAC) procedure. For calculation purposes, consumption is calculated from the first point of the STAR until the aircraft stopped on the runway.

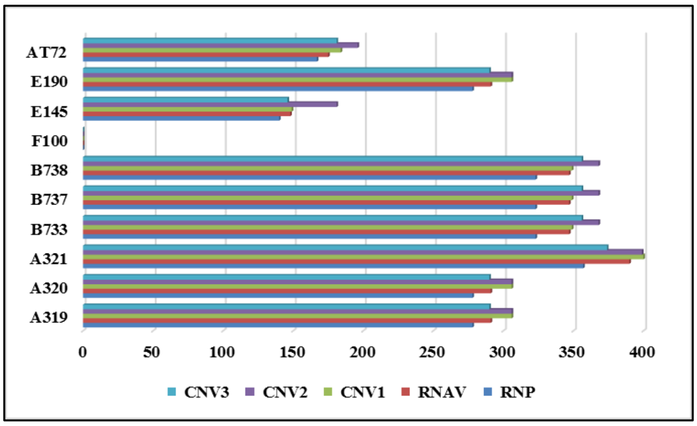

Figure 10. Fuel consumption (kg) for the arrival and landing procedure

RNP procedures proved to be the most economical when compared with the other procedures. Figure 11 show the gains.

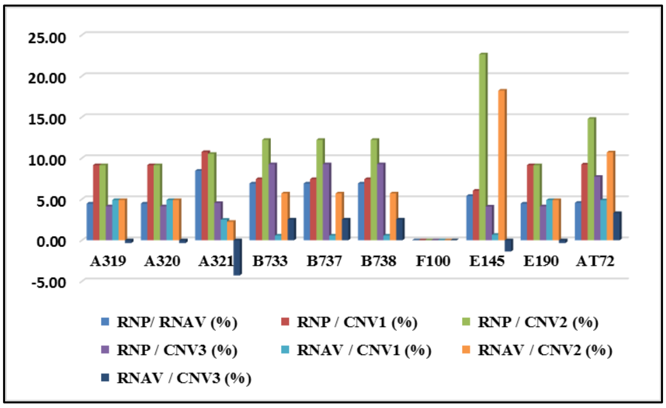

Figure 11. Gains (%) for the arrival and landing procedures

Analyzing the total gain for the RNP procedure enabled fuel savings, with rates of 4.47% to 8.46%. Analyzing the RNAV procedures, for the aircraft models A319, A320, A321 and E145 the CNV3 procedure was economic.

B. From Santos Dumont Airport to Campinas Airport

1) Total Consumption on the route

Because the differences imposed by DECEA, aircraft flying PBN (RNP or RNAV procedures) and Conventional fly different routes. In this route, RNAV and Conventional procedures have their trajectory overlapped. Figure 12 shows the fuel consumption for the route.

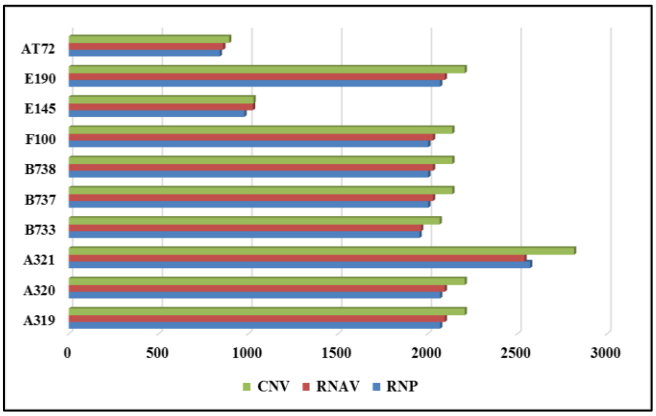

Figure 12. Fuel consumption (kg) for the route

Analyzing the RNP and RNAV procedures, except for the A321, all aircraft had lower consumption with the use of RNP route. Figure 12 show the gains.

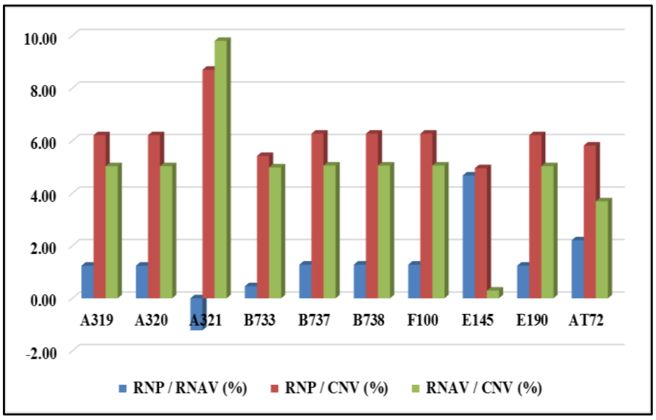

Figure 13. Gains (%) for the route

All aircraft presented an fuel efficiency smaller than 1.3%., except for the E145 that presented 4.67% and the ATR-72 with a 2.21% economy. Comparing the RNP routes with the Conventional, the differentiation imposed by the regulator brought gains of up to 9.8%, with an average of 5%.

The PBN procedures were faster than conventional three minutes on average. Among the PBN procedures, RNAV proved to be the fastest, but the difference was never more than a minute.

2) Total Consumption on the Arrival and Landing Procedure

Figure 14 shows the fuel consumption when it is analyzed just the arrival (STAR) and landing (IAC) procedure.

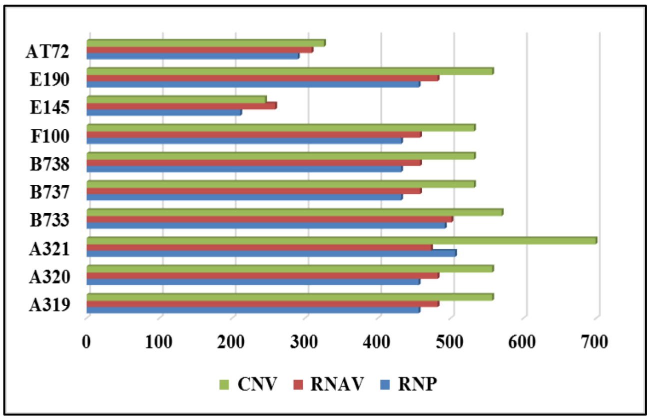

Figure 14. Fuel consumption (kg) for the arrival and landing procedure

Analyzing the procedures, the only aircraft that RNAV had the most economical consumption when compared to RNP was the A321. Figure 15 shows the gains.

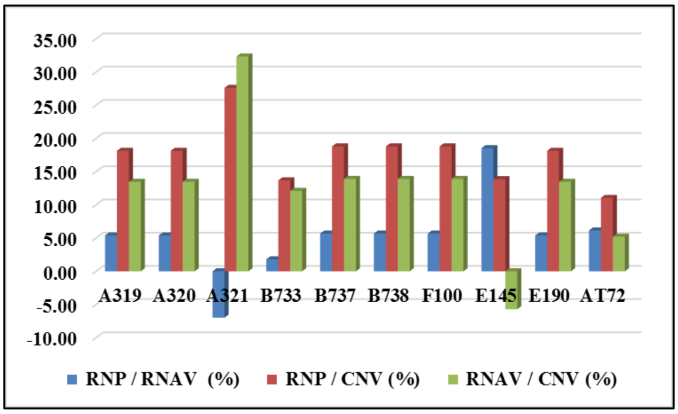

Figure 15. Gains (%) for the arrival and landing procedures

On average, all aircrafts presented an approximate gain of 6% as compared with the RNAV and 14% when compared to the Conventional procedure.

VI. CONCLUSION

In the last decades, the popularization of the aircraft as a means of transport has raised the need for a better use of airports and airspace. To adapt to this reality, new ways to better use of airspace must be found. One of the ways found was the introduction of Performance-Based Navigation (PBN) procedures, representing a change from sensors navigation to a performance-based navigation.

The implementation of this new type of procedure introduced changes in aircraft operation, the insertion of new procedures for air traffic controllers and pilots and the introduction of automation systems to support air operations.

Aircraft performance and measurement of the benefits of performance-based navigation (PBN) should be analyzed individually by aircraft model, with a view to their performance characteristics and the vertical and lateral profile of the designed instrument procedure.

Each aircraft had a specific performance by route, and on some routes, a single differentiation on the vertical limit was able to influence the total fuel consumption. This article showed that the performance and fuel economy are directly linked to the profile of the procedure and aircraft characteristics. Depending on the type of procedure and the aircraft, savings approximately 40% are observed.

New scenarios should be analyzed by comparing fuel consumption in performing PBN procedures at other airports. As well as the verification of consumption levels with air traffic interaction, with several aircraft arriving and departing at the airport at the same time, assessing whether the operational gains when aircraft are flying in isolation will be maintained when aircraft are in a normal air traffic situation.

In an environment marked by airlines competition and constant search for profitable and secure ways of operation, the search for more economical procedures is a necessity. The verification procedure that best suits the fleet and route network is essential to the survival and continuity of the airlines worldwide.

REFERENCES

[1] BOEING. “Current market outlook 2013 – 2032”. Estados Unidos. 2013

[2] AIRBUS. “Global Market Forecast. Future Journeys 2013 – 2032”. 2013.

[3] NOLAN, M. S. “Fundamentals of air traffic control”. Cengage Learning. 2010.

[4] ICAO – International Civil Aviation Organization, “DOC. 9613 Performance-Based Navigation (PBN) Manual”. ICAO, Quebec, Canada 2013.

[5] FAA – Federal Aviation Agency, “United States Standard for Performance Based Navigation (PBN) Instrument Procedure Design”. USA. 2007.

[6] TARBERT, B. “Area Navigation (RNAV) and Required Navigation Performance (RNP). 2006.

[7] NAKAMURA, D; ROYCE, W. “Operational Benefits of performance-based navigation”. Aero, 2008.

[8] MCKINSEY COMPANY. Brazilian study in the Air Transportation Sector. Rio de Janeiro 2010.