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Human Factor Analysis When Implementing Performance-Based Navigation Procedures in Aviation

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***Abstract*-**The increased use of airplanes as a means of transportation in recent decades has encouraged the pursuit for better airspace use. One alternative was to abandon sensor-based navigation and implement Performance-Based Navigation (PBN) procedures. The PBN concept encompasses the Area Navigation (RNAV) and Required Navigation Performance (RNP) procedures. It is a fundamental factor for the modernization and optimization of the Air Traffic Control environment. This paper aims to investigate the human factors related to the introduction and use of PBN procedures in aviation. We examined the academic literature focusing on the main factors related to flight safety and operating in a PBN environment. The article primary interest is how the introduction of a new concept can impact the operational environment and affect safety. The academic gain of the present paper is made by the analysis of the safety factors that can affect air traffic and airworthiness when using the PBN procedures. Because PBN procedures represent something in development and in the implementation phase, academic studies should focus not only on the economic aspects and optimization of their use but also on the safety aspects related to the human factor of the operation that can be considered the weakest part while using a modern system.

Keywords- *PBN, Safety, Navigation Procedures*

I. Introduction

In 15 years, the total commercial fleet is forecast to double and some cities are supposed to accumulate air demand with long-hauls and regional traffic creating global hubs. Delay is one aftereffect of this flight concentration and because of capacity constraints, there is a growing necessity for changes in the air traffic system to accommodate the increased traffic demand [1]. The developed use of airplanes as a mechanism of transportation has reinforced the pursuit for better airspace use. One alternative was to abandon sensor-based navigation and implement Performance-Based Navigation (PBN) procedures. This response was only permitted because of significant improvements in air navigation infrastructure that occurred in the last decades that allowed better aircraft location and permit a plane to fly an established course without relying on ground-based aids. The PBN concept encompasses the Area Navigation (RNAV) and Required Navigation Performance (RNP) procedures. It is a fundamental factor for the modernization and optimization of the ATC environment [2]. It is associated with its airworthiness certificate, operating systems, and air navigation infrastructure availability. The equipment installed in an aircraft and the air navigation infrastructure will determine its ability to operate in this environment. PBN procedures brought fundamental changes in aircraft operation, pilot procedures, and flight controllers, and introduced new aircraft-based equipment [3].

Air traffic controllers have favored from the modifications brought in. They can support a higher volume of flights since they are no longer susceptible on radar vectoring and speed commands in the approach operations for landing on the Terminal area. These advances are feasible through the reduction in the number of communications between the airplanes and ground control stations and a better organization of the airspace. Other gains are the upgrade of air safety in regions with high topography and a decrease in aeronautical noise [3]. This combination of factors has resulted in more complex flight paths [4].

This paper aims to investigate the human factors related to the introduction and use of PBN procedures in aviation. The academic literature focusing on the main factors related to flight safety and operating in a PBN environment is examined. The article primary interest is how the introduction of a new concept can impact the operational environment and affect safety. The academic gain of the present paper is made by the analysis of the safety factors that can affect air traffic and airworthiness when using the PBN procedures. Because PBN procedures represent something in development and in the implementation phase, academic studies should focus not only on the economic aspects and optimization of their use [5], but also on the safety aspects related to the human aspects of the operation, that can be considered the weakest part while using a modern system.

II. LITERATURE REVIEW AND ANALYSIS

Because of its innovative characteristics these are the studies that address human error and PBN procedures. Barhydt and Adams [3] conducted the first study of this type. They executed an exploratory study using the Aviation Safety Reporting System Database (ASRS) covering the period of 2000 until 2005 from seven airports from the United States. As a result, 124 reports were analyzed, and they clustered the results into four categories: air traffic control procedures; airline operations; aircraft system´s capacity air procedure layout. Butchibabu, et al. [4] complemented the study, expanding the search period, from 2004 to 2009. They analyzed 285 reports using the same methodology. [5-14] integrated these studies but did not rely on flight safety database. The knowledge produced shows the factors that can influence human error and increase the safety of operations air transport.

One of the initial safety aspects is that the aircrew must be certified, trained and being familiar with the PBN procedures. For its complexity and requirements, the aircraft and its embedded system must be certified. In all the analyzed studies, the following aspects were identified as contributing factors air traffic operation, procedure interpretation and automation by the pilot, and procedure layout.

The flight trajectory in an RNP procedure results in a more complex trajectory, when compared to other types of IFR procedures, with multiple segments and transitions and because of the accuracy and workload characteristics will be flown in the autopilot engage mode in coordination with the FMS, to meet the speed, altitude and lateral deviation requirements, as shown in Figure 1.

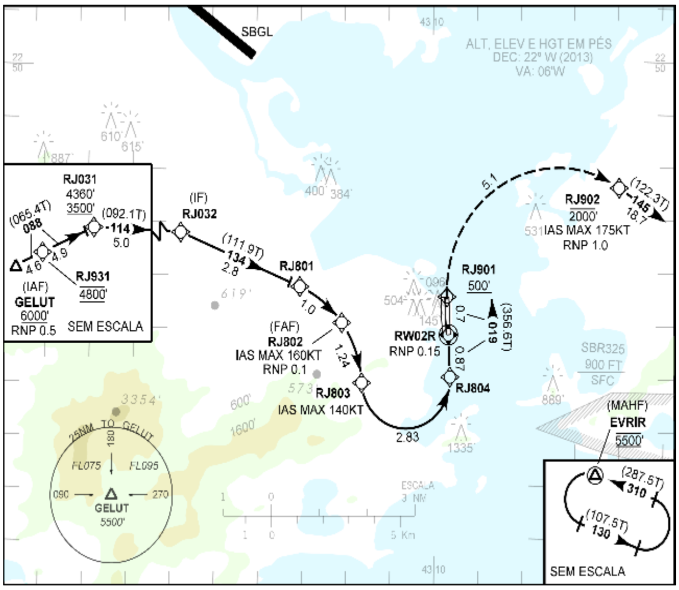

Figure 1. Flight trajectories for RNP procedures

Entzinger, et al. [11] pointed out that curved approach procedures although typically performed by the autopilot, human pilot still need the situational awareness and skills to take over control in rare-event scenarios to guaranty flight safety. Mental effort presented different levels between good and bad visibility cases, for different training levels, and in different flight phases.

These new procedures, due to their greater preciseness in a flight trajectory, require more attention and standardization of procedures by pilots and flight controllers. Due to the automation required performing the flight procedures, correct FMS programming becomes essential. Errors in the procedural or runway programming may lead to safety occurrences, as well as reprogramming errors due to changes in flight conditions, such as changes in wind direction and consequently the modification in the activated runway [3].

Consideration should be turned to updating the FMS database. The database contains the aeronautical fix that will be used in air traffic procedures. They must always be updated so that the correct flight path is followed. An incorrect fix or its absence may lead to a greater workload for the pilots with the manual insertion on the FMS of the missing data [3]. Barhydt and Adams [12] point out that last-minute change by flight controllers can affect flight safety. Although sometimes imperative, these changes can lead to incorrect FMS programming or erroneous procedure briefing by the crew. As a safety recommendation, airlines must adequate their training program for this new situation.

Butchibabu, et al. [4] identified operational issues related to PBN procedures and which human factors were linked to performing procedures those described events in-flight safety reports. During the execution of a Standard Instrument Departure (SID) or a Standard Terminal Arrival Route (STAR), the main errors reported were vertical, lateral, and speed deviations; problems in the procedure layout; lack of understanding by the aircrew for which profile to be followed predicted in the procedure's layout. Most of the situations occurred during the departure phase of the flight, followed by the arrival and the instrument approach procedure stages. The most common problem encountered was the crew's inability to follow all the fix constraint assigned in the IFR procedure. The article highlights the errors occurred during the procedure's interpretation. Most times, the pilots were lost, and did not know which profile to follow.

Most commercial aircraft and a part of general aviation fleet have, nowadays, displays and electronic systems on the cockpit panel that provide flight information. During the flight, the pilot checks the information provided by the chart and the database that appears on the FMS, and verify if the aircraft is performing the same predicted flight profile. Problems occur when the aircraft does not stick to the predicted flight profile, presenting trajectory deviations in the lateral or horizontal axes and non-compliance of the predicted velocity restrictions.

Kasim [10] complemented Butchibabu, et al. [4] study. Procedural deviations created most of the situation anomalies. Complex arrivals reported being sensitive to pilot deviations and errors. The results from the study indicated that there were significantly fewer reported event deviations with the use of PBN procedures contrasted to non-PBN ones.

Chandra and Grayhem [6] studied how the correct design and content of an air procedure chart, RNAV and RNP procedures, could cause accidents and influence the air navigations safety. The procedure chart allows the graphical representation of the path an aircraft will follow that and assist the pilot. It should have an easy-to-understand layout. The procedural chart covers various flight procedures, including RNAV and RNP procedures. Mainly, with introducing the RNP procedures and its complexity, a greater amount of information and detail will be necessary. Therefore, much information in a small space can cause understanding problems for the crew. For the authors, the problem can be solved by implementing the Electronic Flight Bags and the use of flight charts in digital format.

Display clutter is a significant problem for airplane pilots monitoring modern flight deck displays. The main challenge is to determine the ideal middle ground between excessive data and insufficient information [13]. Butchibabu, et al. [14] introduce a de-cluttering technique to reduce the representation of visually complex RNAV and RNP procedures by diminishing the number of paths shown on an individual chart page. Employing data from 28 airlines and 19 pilots, the results indicated that pilot response times were substantially enhanced with the recommended approach in different procedures (approach and departure), pilot types (airline and corporate), and chart manufacturers.

Chandra, et al. [7] studied how the PBN instrument chart layout, representation, convenience, and information capacity can contribute to the aircrew error. RNAV and RNP procedure charts may be visually different from traditional procedure charts such as ILS and VOR. ILS procedures have a direct path to the runway in a funnel-shaped, with the trajectory width increasing as it moves away from the runway. The RNAV procedure shows a trajectory with a constant width and the RNP procedure maintains the constant width with multiple trajectories and curved segments.

Because of the various forms of chart layout, the PBN procedures can bring confusion and misunderstanding to the pilots and air traffic controllers. Chandra and Herschler [5] show that the main challenge for the graphical representation of an RNAV and RNP procedure is that there is a large variation between layout procedures for different locations. Differences in topography, airspace types and other factors determine these differences. Crews may request more time to understand and correctly follow the navigation layout.

Chandra and Markunas [9] interviewed 45 professional pilots in limited groups to figure out what causes Instrument Flight Procedures (IFPs) complex from the context of commercial pilots. They pointed out that IFP design parameters, as the number of transitions and flight path constraints, are the major driver for personal complexity for line pilots. Unusual IFP designs can produce in unique chart representations that are unfamiliar and more difficult to use.

Schaad [8] describes the implementation of a combination of both PBN and conventional navigation standards procedures (hybrid procedures) at Innsbruck airport, a terrain-challenged airport. In special procedures, where flyability is a major component, it is mandatory to evaluate the safety assessment, in a process called Flight Operational Safety Analysis (FOSA). For the specific FOSA, the regulators included several pilots from different operators flying different aircraft types and using different avionics system to verify if the new procedure would increase flightdeck workload. It was necessary that each operator proved that the specific imbedded equipment could support the requirements, and the aircrew should also be specific trained for this new type of procedure.

III. CONCLUSION

The adoption of PBN procedures have enabled point-to-point navigation without limiting to ground-based navigation aids. Being a human activity, it is subject to errors. When thinking about a system, such as the air traffic system, becomes much more productive when analyzing and understanding the causes of failure, seeking to make the whole process safer. In this article, we identified the main human factors that can influence air navigation safety when using PBN procedures. Although requiring a higher level of automation for their execution, procedures require that crew and flight controllers work more and in tune. Human intervention will be necessary to stop deviations from execution.

Although there are few works in the area, the existing studies call attention to some important factors for the correct operation of the air traffic system. Because they are procedures that require a degree of automation to be performed, attention must be given to the embedded equipment and the constant updating of the database. Although automated, the role of the pilot becomes important for navigation procedures.

Erroneously, we can have the impression that the pilot, with all the automation, has a passive row. This is not true. In fact, the crew should be totally focused on the navigation procedures and when deviations occur, act quickly to avoid accidents.

In addition, the insertion of data and the correct choice of procedures will also be up to the crew and flight controllers. Incorrect scheduling or choice of a procedure in place may have serious consequences. The correct understanding of what was requested and what is expected to be performed is important in the interaction between the flight controller and aircrew. Doubts and erroneous interpretations can lead to accidents. Introducing automated procedures does not detract from the importance of this interaction.

The layout procedures deserve special attention with the complexity and quantity of data to be inserted in the navigation chart for pilot monitoring. The worst-case scenario in these cases is an incorrect interpretation of the pilot or total inability to know what is expected to be executed.

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