Potential benefits in the application of Time Based Separation concept at Lisbon Airport

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Abstract

The main goal of this work is the evaluation of the potential benefits in the application of Time Based Separation concept at Lisbon Airport. It is investigated the possibility of achieving a reduction in the separation of consecutive airplanes during the arrival process, while keeping the minimum safety required by the regulations of the International Civil Aviation Organization.

The study characterizes varied flight profiles during different wind conditions, such as the altitude, ground speed, distance and time spacing, and the buffer application derived from the separations, for standard references and particularly for the Lisbon Airport.

The variations registered in the results suggest that the optimization of the separation model can be profitable, increasing the theoretical maximum capacity especially in the peak hours.

Keywords: Time Based Separation, Separation Minima, Final Approach Speed, Headwind

1. Introduction

Between 100.000 and 200.000 flights are counted each day in the entire world. New ideas are created constantly in order to achieve new methods that are able to fill our planet with aircrafts, and at the same time avoiding all types of flight delays until the last second or economizing the fuel until the last drop [1].

Annual movements of air traffic in Lisbon FIR have increased constantly. In 2015, the total of flight records beat a new value, overcoming the 500.000 movements and exceeding the 20 million passengers in Lisbon Airport [2][3].

In fact, because of this relevant increase of air traffic, Lisbon Airport is saturating its capacity more and more every single day, which leads to further delays in both arrivals and departures [4].

It is extremely important and enormously useful in various aspects to the city of Lisbon (including economical issues), to accomplish the final goal of this study - to improve the capacity of Lisbon Airport. This project promises to aim the way how current methodologies and procedures can be adapted with the intent to contribute to a better arrivals flow.

2. State of Art

Nowadays, aircraft on final approach are separated by one fixed distance, independently of the existing meteorological conditions. The current system works in Distance Based Separation (DBS) that remains constant for each headwind (HW) circumstances.

Despite the fact that the DBS model is applied in an efficient way by the air traffic controllers, respecting the prevailing regulations, the arrivals capacity decreases when the Ground Speed (GS) of the aircrafts at the final approach decreases, due to the impact of headwinds (HW). In fact, for some airports that operate near its total capacity, the influence of
HW conditions in the airplane during arrival is an issue that requires important analysis. Maintaining the separation distances in situations with strong HW, larger time intervals are developed between arrivals when comparing with arrivals without the presence of wind. This results in various disadvantages, like fewer flights landing per hour, more air holdings, more delays or more fuel consumption [5][6].

Using a reconfiguration of the system, it is possible to reduce this negative impact caused by the wind. The modification of the DBS to a more dynamic system based in time intervals, specifically configured for certain intensities of HW, justifies a study that regards the Time Based Separation (TBS) model in the runway 03/21 (RWY 03/21) of Lisbon Airport.

2.1 Lisbon Airport

The main RWY is 03/21, which has 3805 meters of length. The second runway is RWY 17/35, which has 2400 meters of length and intersects the RWY 03/21, but this one is rarely used [7].

In international airports, it is possible to distinguish two different modes of operations: the segregated mode (common in multiple runway airports), where one runway is only used for arrivals and another runway for departures; and the mixed mode, such as Lisbon Airport, where the arrivals and departures are intercalated in the same runway – corresponding to the RWY 03/21 in Lisbon.

2.2 Lisbon Capacity

Nowadays, Lisbon Airport finds itself working on full capacity during peak hours, particularly due to the tourism sector growth and the increasing presence of low-cost companies that expanded 27% in Lisbon in 2015. Portela Airport can still support the traffic growth until 2019; however it will be needed a new long term solution from 2020 when the annual number of passengers will reach around 25 million.

During 2016, the airport functioned in a congested way – which means that it operated at least 80% of its full capacity during at least 3 hours per day.

Various solutions are pointed to respond to the lack of the airport capacity. Amongst them, the most discussed one it’s the expansion to Montijo aerodrome. However, as it will be checked along the project, one of the most important factors that establish the flow of arriving aircraft is the minimum separation demanded by International Civil Aviation Organization (ICAO), with the intent to avoid collisions or wake turbulence problems between airplanes that fly consecutively.

As a result, new procedures and methods should be considered to improve capacity.

3. Separation Models

At Lisbon Airport, the control transfer between the Approach (APP) and the Tower (TWR) is made when the airplane is at 10 nautical miles (NM) from the threshold (THR), despite the most part of international airports is at 6-8 NM [8].

3.1 DBS - Distance Based Separation

In current operations relatively to arrivals, the separation at final approach is applied by the controller through the radar, and is expressed in NM for any wind circumstance or other atmospheric conditions. Therefore, the same distance takes longer to fly when the HW is strong and takes less to fly when the wind is calm. This results in a loss of arrival rate at the runway during peak hours in HW conditions.

The minimum separation between two aircrafts is recommended by ICAO and includes wake vortex separation criteria. This method prioritizes the definition of Wake Turbulence Categories (WTC), and allows the traffic flow depending on the weight of the airplanes. In fact, the wake turbulence is more troubling in situations where there is a significant difference between the weights of two consecutive planes, with the first one being the heaviest. Therefore, for the description of the turbulence separation, it is considered the combination of categories in which the first one is superior to the second one, with the exception of Heavy-Heavy pair. These categories are defined by ICAO function of Maximum Take Off Weight (MTOW):
WTC Light (L) – aircraft with less than 7 000 kg
WTC Medium (M) – aircraft between 7 000 kg and 136 000 kg
WTC Heavy (H) – aircraft that weight more than 136 000 kg.

The wake turbulence is the turbulence created by an airplane when it passes through the air, forming vortices behind the plane caused by the wingtips. The following table describes the minimum wake turbulence separations, in distance, that must be applied for all the planes with surveillance radar system during the approach phase.

The abbreviation MRS – Minimum Radar Separation – corresponds to the minimum radar separation at final approach. This separation is usually 3 NM (as in Lisbon) and in practice it is equivalent to the cases in which the combination of consecutive airplanes is not formulated in Table 1 and does not correspond to an intercalated departure (for this concrete situation, the separation is 6 NM). [9]

The minimum wake vortex separation is implemented for more than 40 years, so that, for certain cases, it is too rigid and too overprotective. This can lead to consequences in traffic flow, forcing the runway to hold back its full potential. These situations are augmented, in most cases, in the presence of HW so that separation becomes temporally exaggerated [9].

3.2 TBS - Time Based Separation

The TBS concept can be summarized as:
“A reduction from the final approach distance-based wake turbulence radar separation through the adoption of time base-separation. This will require specified minimum headwind conditions that are sufficiently stable over a given time-frame.” (SESAR P06.08.01, 2011, p. 61). [9]
The rules for the practice of the TBS model is derived from the DBS in low HW circumstances. In these situations, the airport capacity with the DBS is acceptable for intense traffic and congested operations. However, due to the diversity of GS profiles on final approach, directly related to HW conditions, it becomes necessary to manage the spacing between consecutive airplanes, applying TBS. The transformation of distance-based separation minima to separation time intervals is calculated basing on SESAR Project 06.08.31 by EUROCONTROL.

Given the glide path (descending arrival airway), the Indicated Airspeed (IAS) and the HW conditions, the resulting GS profile determines the separation interval on final approach. To calculate the reference separation in the new model TBS, it is used a standard profile for speed on final approach during a 5 knots (kt) HW intensity. The standard profile for speed is the stabilized reference speed for a landing. At a 6 NM distance to the threshold (6 DME), reference Indicated Airspeed (IAS) is 170 kt, reducing at a rate of -20 kt/NM until 150 kt (IAS) at 5 DME. From this distance, landing speed stabilizes at 150 kt (IAS) until the THR, maintaining a 3º glide slope angle from a 80 feet (ft) runway elevation (above mean sea level).

After a calculation process that involved the parameters mentioned above and the determination of temperature, pressure, the GS profile was obtained. Table 2 was achieved which describes TBS time intervals between arrivals.

It is also assumed that a 60 seconds separation is enough for the leader aircraft to execute the touchdown (moment when an airplane touches the ground) and leave the runway [9].
<table>
<thead>
<tr>
<th>Leader</th>
<th>Follower</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy (H)</td>
<td>98s 122s 145s</td>
</tr>
<tr>
<td>Medium (M)</td>
<td>60s 60s 122s</td>
</tr>
<tr>
<td>Light (L)</td>
<td>60s 60s 60s</td>
</tr>
</tbody>
</table>

The TBS spacing is applied since the follower aircraft is on final approach, until the leader aircraft crosses the runway threshold. The separation can also be understood as the ideal time interval between the touchdown of the leader and the touchdown of the follower [8].

4. Implementation

In order to successfully develop this project, it is crucial to study the current procedures in Lisbon Airport, and explore the key-points that allow an improvement in the application of separations, optimizing the practices. In this chapter it is described the characterization and performances of important factors related to arrivals, during a certain real time period.

4.1 Data Characteristics

To accomplish this study, various surveillance radar data, processed by the Air Traffic Management Surveillance Tracker and Server (ARTAS) and provided with permission by Navegação Aérea de Portugal (NAV), were analyzed, with records saved between the 2015 February 28th and March 11th.

During this 12 days period that was studied, a total of 2215 airplanes landed on RWY 03/21. Speed, position and altitude data were analyzed for Lisbon Airport arrivals over the time period mentioned. Such data was correlated with wind data, which was also studied to analyze separations.

4.2 Approach Area

For every flight, it was available the position (latitude and longitude), speed, time and altitude (FL – flight level) in a 5 second time interval. Data related to the position was converted into distance to the THR of the RWY 03 or RWY 21, depending on the cases. In this phase, it is focused the verification of the separation on final approach. Therefore, it is calculated the straight line that extends from both sides of the runway, and that corresponds to the straight descent airway that the airplane flies on final approach – the glide path.

![Figure 1 - Representation of the glide path](adapted from [9])

In order to center the studies on occasions of intense traffic, it was selected airplanes that shared simultaneously the same final approach zone from the last 6 NM until the THR of each runway. The reason of being 6 NM is that for certain aircrafts during their arrivals (specially for RWY 03), they only enter their glide paths at distances too close to the runway – it is common to find cases where that distance is 4 DME, instead of the Flight Approach Point.

All the following analysis in this abstract are related to RWY 03, since the number of movements in this runway (2111) is clearly higher than RWY 21 (104) in the 12 days period studied.
Observing Figure 2, there are only cases where the airplane makes the final path in the last 10 NM individually or simultaneously with another plane on final approach.

4.3 Wind and HW conditions

In order to correlate the surveillance radar data with the HW, wind files were collected concerning the studied time. Despite the absence of wind-altitude data on final approach zone, there are recordings of surface wind observations at Lisbon Airport – particularly at both thresholds of RWY 03 and RWY 21, where anemometers are situated and monitored by the Meteorological Observation Integrated System (SIO) of Lisbon Airport. This wind data was provided by Instituto Português do Mar e da Atmosfera (IPMA) for this work, and forms a plausible assumption of the real wind that an aircraft faces during the landing process.

Figure 3 - HW intensity [kt] at the touchdown for RWY 03

In Figure 3, it is clear that during arrivals, RWY 03 was certainly the most recommendable runway for most of the considered 12 days time period, because it is where the HW has generally positive values – with intensity between 0 and 10 kt.

4.4 Altitude Profile

Figure 4 represents the mean altitude profile relatively to the decreasing distance to the RWY 03, during the 12 selected days. The mean values for each WTC, as well as the standard deviation and the 5/95\textsuperscript{th} percentile are represented. The altitude profile at final approach is clearly similar between all types of airplanes, which leads to the overlap between the profiles in the graph, and consequently, the low values of standard deviation (which begins at 300 ft at 8 DME and decreases continually until 50-100 ft at the THR), and a 5/95\textsuperscript{th} percentile with a low amplitude (approximately 1000 ft at 8 DME and, just like standard deviation, decreases until 200 ft at THR).

At the last 8 NM, it is verified that the general altitude profile converges to an 3\(^{\circ}\) angle – usually called the glide slope angle – as the profile decreases 5 FL per 1.5 NM, or 150 meters per 2780 meters.

4.5 Speed Profile

Figure 5 shows the GS profile from 8 DME for RWY 03. As it was expected from Chapter 3.1, it is observed that at 8 NM from the THR, GS is around 180 kt, decreasing to 160 kt at 5 DME, until it finally converges, maintaining a Flight Approach Speed (FAS) equal to 130 kt in the last 2 NM before the touchdown.

By the other hand, the standard deviation is around 20 kt at 8 DME, and decreases the amplitude until noticeably 10 kt at the end. The 5/95\% confidence interval varies sensitively in the exact same way, starting with a total...
amplitude of 80 kt and ending at the THR with a 35-40 kt amplitude.

In Figure 6 it can be found the general distribution for all the planes, undifferentiated for all categories, and the tendency line represented with red color. After the suspicion that the 2111 GS values at 2 DME (in this phase it really corresponds to FAS) were close to a normal distribution, the situation was studied and concluded that it was, indeed, true. Effectively, the normal distribution would have the mean and variance as \( N (\mu =132.85, \sigma^2 =10.625) \) for this GS distribution, and would be identical to the red line in Figure 6.

The following figure shows similar information to the RWY 03, but takes into account the HW. Analyzing the graphic, it is patent the HW effect in the GS – for all categories, the mean GS at 2 DME decreases as the HW increases.

5. DBS to TBS and respective results

The procedure applied to transform DBS spacing to TBS intervals for Lisbon Airport is the same as in Chapter 3.2, with the only difference that it was not necessary to execute all the transformation to GS, because the speed included in the original ARTAS files represents the ground speed. Therefore, it is also not needed reference values for HW.

Table 3 - TBS separations applied to Lisbon Airport

<table>
<thead>
<tr>
<th>HW conditions [kt]</th>
<th>[0-40]</th>
<th>[40-80]</th>
<th>[80-120]</th>
<th>[120-160]</th>
<th>[160-200]</th>
<th>[200-240]</th>
<th>[240-280]</th>
<th>[280-320]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy (H)</td>
<td>105 s</td>
<td>129 s</td>
<td>150 s</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium (M)</td>
<td>81 s</td>
<td>81 s</td>
<td>129 s</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light (L)</td>
<td>81 s</td>
<td>81 s</td>
<td>81 s</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Regarding Table 3, it can be noted that TBS separations at Lisbon Airport are larger than the ones from standard values on Table 2. In fact, due to a lower GS regarding this situation when compared with Chapter 3.2, it is normal for time intervals to increase for Lisbon Airport.

5.1 Spacing and Buffer

For this project, the spacing between consecutive arrivals was calculated through the distance and time intervals that separate two aircrafts. For the distance spacing, the
calculation was achieved through the definition of the geometric coordinates found in ARTAS files, and filtered for the paired aircrafts at the last 6 NM. The calculation for spacing obtainment is represented as a straight line between the two consecutive planes arriving to RWY 03. On the other hand, time spacing was calculated knowing the previously interpolated time in reference points situated each 0.5 NM along the glide path, and after some unit conversions, it is recorded the exact time interval that the second plane took to reach the same reference point previously flown by the leader.

The mean distance and time spacing registered in consecutive arrivals that share simultaneously the last 6 NM is in Figure 8 and Figure 9.

![Figure 8 - Mean distance separation profile](image1)

![Figure 9 - Mean time separation profile](image2)

Observing Figure 8, it is noticed a descending tendency along the glide path until the THR, particularly in the last 4 NM. This distance spacing compressing effect results from the GS decrease of the leader airplane relatively to the following plane. However, the time spacing does not suffer from the same effect, because, generically speaking, the speed profile of the follower aircraft along the airway is identical to the speed profile of the leader airplane.

Regarding the mean distance spacing, the profile is similar for each HW condition and the compression effect gradient is the same for every wind circumstance. Still, for an HW higher than 10 kt (red line), it is noticed a slightly bigger spacing when compared to the other wind conditions. In spite of the distance being fixed between consecutive airplanes for DBS practices, independently of the HW, this can be explained due to the wind impact that reduces GS and increases temporarily the distance to the leader aircraft, until eventually the second aircraft recovers the loss. This larger spacing for a strong HW implies, logically, larger time spacing when compared to other HW conditions, and results in a 10 second time difference relatively to a low HW.

On the other hand, if the HW decreases (green line that represents an HW lower than 5 kt), it turns into a lower time spacing and the arrival rate will increase, while keeping the same separation distances.

During the final approach paths, it is usual a buffer application between consecutive arrivals: the spacing buffer is defined as the distance in NM between actual spacing at a certain point and the separation minimum, and will gain importance when the compression effect occurs (generically at the last 4 NM of the glide path of the leader airplane) [10].

The buffer application, just like the separations, belongs to the responsibility of the TWR controller, and most of the time depends on his experience. Various factors interfere as well in this spacing addition, such as wind and visibility conditions or air traffic.

In the following Figure 10, it is represented the general buffer for every paired aircraft that landed at RWY 03. For those cases where the WTC combination implies the turbulence separation, it is assumed the ICAO recommendations on Table 1. In the rest of the cases, it is assumed the minimum 3 NM radar separation that is usually used at Lisbon Airport (these are the cases of the most frequent combination Medium-Medium).

Finally, when it comes to intercalated departures, the reference separation is 6 NM at Lisbon Airport.
Figure 10 - Spacing buffer profile

Generally, distance spacing reduces along the glide path until the touchdown: at 6 DME the buffer is 2 NM, and keeps reducing until 1.5 NM at the THR, as a result of the speed reduction along the final approach airway. This compression effect becomes quite predictable if it is considered coherent speed variations for all airplanes, dictated by the control related to arrival procedures. Another cause for the buffer reduction can be explained by the tolerance given by controllers when the second airplane is no longer in danger of an encounter with the first one, relieving in a certain way the separation rigidity and accelerating the landing process, while keeping safety levels [11].

It should also be noticed that between 3 and 2 DME, there is a slightly buffer increase, due to a more abrupt GS reduction of the leader aircraft comparing to the follower. However, this increment is temporary and it only extends for 0.5 NM, returning right after the compression effect again.

5.2 Benefits of the TBS for real samples

In order to demonstrate the impact of using TBS at Lisbon Airport, it is analyzed the Theoretical Capacity (TC) for real samples. Peak hours are selected to collect the best information possible on TBS method, taking into account the minimum separations and WTC categories.

During the studied days, traffic peak hours occurred in the morning, at midday and at late evening – mainly between 7h and 9h; 12h and 14h; and 17h and 19h. During these periods, the total number of landings can be around 20 per hour. Taking into account the wind variations, the TC is evaluated for an HW lower than 5 kt, between 5 and 10 kt and higher than 10 kt.

The first step consists in recording real samples, related to different HW conditions, and obtain the time interval taken by the airplanes to land in the runway one after another – ideally without any spacing despite the minimum radar or wake turbulence separation, because these are peak hour samples. In other words, real samples selected have ideally a buffer close to zero. It is then deduced the number of aircrafts that landed during one hour period, using a proportion of separation distances correspondent to the peak periods. Finally, TC is estimated and represented as the movements per hour - by deducing the number of planes that can land during one hour with the correct proportions of separation types (turbulence, radar or intercalated departures separations) [11].

As it was mentioned before, all the analysis in this abstract are related to RWY 03. For the following calculations, it was assumed the speed profile and time separation in Lisbon, presented in Chapter 5 and defined by Table 3, respectively.

Therefore, considering the TC for a HW lower than 5 kt, between 5 and 10 kt and higher than 10 kt:

- HW < 5 kt

  The sample for the traffic peak in this case was elaborated on March 9th. Between 7:43:40 and 8:40:38, 25 aircrafts landed and 11 took off, resulting in a rate of 37 movements per hour (total TC).

- 5 < HW < 10 kt

  The sample for the traffic peak in this case was elaborated on March 5th. Between 7:34:06 and 8:25:26, 20 aircrafts landed and 16 took off, resulting in a rate of 41 movements per hour (total TC).

- HW > 10 kt

  The sample for the traffic peak in this case was elaborated on March 6th. Between 7:25:11 and
8:32:24, 23 aircrafts landed and 21 took off, resulting in a rate of 38 movements per hour (total TC).

Table 4 - TC evolution for different HW conditions and for TBS

<table>
<thead>
<tr>
<th>Traffic Sample</th>
<th>Sample Time (s)</th>
<th>TC per hour</th>
<th>Total TC</th>
</tr>
</thead>
<tbody>
<tr>
<td>HW &lt; 5 kt</td>
<td>25</td>
<td>11</td>
<td>3418</td>
</tr>
<tr>
<td>5 &lt; HW &lt; 10 kt</td>
<td>20</td>
<td>16</td>
<td>3068</td>
</tr>
<tr>
<td>HW &gt; 10 kt</td>
<td>23</td>
<td>21</td>
<td>4033</td>
</tr>
<tr>
<td>TBS</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

For one hour period, the number of movements obtained at Lisbon Airport with TBS corresponds to a total TC of 43, so that there is an augmentation of 16.2%, 4.65% and 13.2% in the capacity of movements for a HW lower than 5 kt, between 5 and 10 kt and higher than 10 kt, respectively. It can be concluded, therefore, that despite the increase of only 1 to 6 movements per hour, Lisbon Airport capacity has potential to improve, and TBS shows benefits mainly in the landing rate at RWY 03. However, it can be stated that the advantages are not only observed during the short peak periods that only last 2-3 hours a day; despite the importance of the situation being notorious during peak times, HW creates delays that affect all the arrival management and origins a chain reaction for the rest of the day. It was inclusively demonstrated during studies at Charles de Gaulle Airport, that when one peak hour is affected by a strong HW, these conditions also affect the following peak hours of the same day [12].

6. Conclusions

In this way, it is proved theoretically the potential benefit on TBS method at Lisbon Airport, to the detriment of DBS. However, some factors that represent influence in TBS performance, and are more difficult to analyze, include all the human nature that studies cannot analytically measure. Amongst them, there is the difference in controllers or cabin crew work methods and practices, or the impact in airlines and its users [9].

6.1 Advantages

- The number of movements increases – when there is HW, the landing rate is the same as if there was no wind.
- Recuperation of capacity, especially at days with intense traffic.
- Reduction of airborne holding, and consequently reduction of delays.
- Reduction of fuel consumption and CO2 emissions (and other polluting gases).
- Reduction of flight cancellations, meaning economic benefits.
- Benefits related to safety in tailwind conditions.
- More predictability for controllers, air space users, and airport staff, which improves situational awareness and safety.
- Better precision in the segmentation of glide path, with constant vectorization and separation indicators [9].

6.2 Disadvantages

- Possible increase of go-arounds if the separation becomes too short or if an unexpected situation happens.
- Possible increase of wake vortex encounters during HW conditions, if the method is not applied rigorously.
- Controllers workload can become harder, which can have an impact on safety [9].

6.3 Limitations

TBS application has a great impact on capacity during the presence of strong HW: in fact, the stronger the HW, the bigger is the difference between TBS and the current DBS model. However, wind data used for this project corresponded to surface measures, and in fact, the wind normally has a stronger intensity at higher altitudes. Therefore, the real impact can
be much more important than the one concluded in this work, due to the lack of wind data related to altitude. Especially during summer season, where the wind intensity is the strongest of all year and traffic is congested most of the day, TBS effect would be considerably more significant than during the days selected in this study (which, inclusively, corresponded to the lowest intensity winds of the year). Thereby, a proposal for a future work would be a meteorological simulation relatively to altitude, based on numerical models to detail the expected benefits of TBS.

The differences between the conclusions of this work and other results concerning different airports illustrate even more the importance of the analysis on local conditions and particular benefits that each airport can accomplish.

A wiser comprehension about the aviation performance, concretely for intense traffic situations on final approach to congested airports, represents a gracious impact for the predictability of operations and avoidance of risks and accidents. The airspace optimization must always be developed proportionally to its utilization - that has increased to extreme levels of exigency - so that it can guarantee (or at least improve) the safety for all its users.

References


