Lisbon Airport Capacity Enhancement: Airspace capacity estimation and enhancement

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Abstract

The capacity of Lisbon Airport has been for a long time object of concern, with the airport currently operating close to its saturation limits and constrained by the capacity of its terminal area airspace. In this context, a study based on fast-time simulation techniques, which allow great flexibility in assessing the different airspaces scenarios impact, was realized. This paper describes the concepts of airport airside capacity as well as controller workload, which heavily affects capacity. Using the software RAMS Plus, the current airspace configuration of Lisbon Airport was studied and replicated in two scenarios, one for RWY 03 and another for RWY 21. Alternative scenarios were analysed having concluded that, with some modifications, it is possible to increase airspace capacity.

Keywords: Airspace, Air Traffic Control, Capacity, RAMS Plus, Simulation, Workload.

1. Introduction

All over the world, controllers are struggling to deal with more and more congested airspace, especially in the terminal areas of some busy airports. The case of Lisbon Portela Airport is no exception, expecting a traffic increase of 13% between 2014 and 2019, and currently constrained by the capacity of its terminal airspace (TMA) [1].

TMAs are connections between airports and en-route airspace. In this confined part of the airspace, and in short periods of time, aircrafts are constantly changing altitude, speed and direction before landing or after take-off. When this area gets congested, there is a strong probability it will have an impact on other parts of the ATM system, including runways blocked and traffic backlog in the feeding en-route sectors [2]. It is clear that TMAs are a complicated system to study and, regarding not only its complexity but also the various entities involved (airports, airlines, ATC, militaries, citizens around the airport, etc.), it is easily foreseen that new solutions directed to more efficient procedures are arduous to find.

2. Capacities

I – Airport Capacity

Airport capacity refers to its ability to accommodate aircraft and is expressed in number of movements (arrivals and departures), typically in the period of one hour [3]. It is conditioned by four distinct elements: airspace, airfield, terminal and ground access [4].

Despite being a commonly used term, the exact definition of "airport capacity" is disputable. The reason for that is simple: not only is it conditioned by different elements, but it also depends on various aspects such as weather conditions (wind, visibility…), traffic (type of aircraft, mixed operations...) and even the proficiency of air traffic controllers (ATCo) and pilots working at the moment. Some of these factors vary with time, making capacity time-variable, and others cannot even be measured quantitatively [5].

II – Runway Capacity

As mentioned previously for the case of an airport, runway capacity is no more than a probabilistic quantity depending on the circumstances involved. The following factors can be considered the most influent ones:

- Number and geometric layout of the runways;
- Separation requirements between aircraft imposed by the ATM system;

- Mix of movements using the runway (arrivals only, departures only or mixed), sequencing of movements as well as traffic type;
- Type and location of taxiway exits from the runway(s).

Maximum Throughput Capacity (MTC) is the fundamental measure of the capacity, simply quantifying the number of movements that can be performed in one hour if the runway is used to its maximum potential, without violation of ATM rules. It also employs some assumptions [6]:

- There is a continuous aircraft demand for arrivals and/or departures;
- Static fleet mix (i.e. runway is solicited by a similar mix of aircraft types along time);
- Procedures do not change.

All things considered, MTC gives an average capacity of a runway, independent of concerns with the level of service provided.

III – Airspace Capacity

For most airports dealing with capacity issues, but not limited by their runway(s), it is usually the airspace which constitutes a major constraint.

The capacity of an ATC sector depends on a whole chain of characteristics such as shape, connection to adjacent airspaces, the function of the airspace itself, traffic type, etc. [7] However, in areas with high traffic density, the capacity is not determined uniquely by spatial and aircraft performance constraints. Unlike road or rail transportation, the capacity of an ATC sector is also conditioned by a different factor: ATCo workload.

Taking into account that experience in Europe usually shows airspace capacities determined by ATCo workload, airspace capacity (or capacity of an ATC sector) can be defined as the maximum number of aircrafts that can be controlled in the sector during a period of time, while still allowing an acceptable level of controller workload [8]. With this in mind, ATCo tasks and procedures become the most significant factors for the analysis, although airspace characteristics cannot be neglected, since they affect the complexity of the sector

IV – Controller Workload

ATCos work in a complex person-machine environment in which they are subject to multiple demands and tasks over time. The workload in response to those solicitations will be a function of their capacities and what they must do in order to maintain a safe and expeditious traffic flow [9]. Although it can be measured and estimated, workload is affected by a complex interaction of [8]:

- Airspace situation: features of both sector and air traffic;
- State of the equipment: design, reliability, accuracy;
- State of the controller: age, mood, experience, decision making strategies, etc.

The major tasks to be performed by controllers in a sector consist of standard communications, traffic monitoring, traffic evolution prediction and detection and resolution of conflicts. In Figure 1 we have the relation of these tasks (the reader is advised to take into account that the workload values are only indicative).

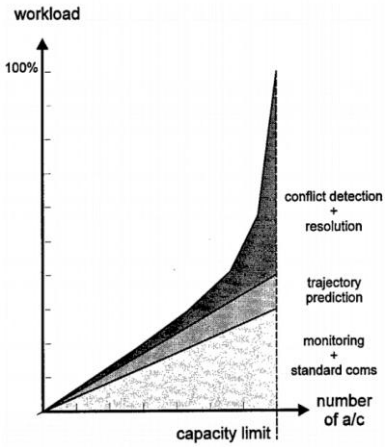

Figure 1: Controller Workload [10]

It is clear that workload associated with standard communications, monitoring and trajectory prediction is close to a linear function of the number of aircraft in sector but, when the scenario includes conflicts, the workload increases exponentially.

V – Controller Positions

Although there are differences from centre to centre, the most common configuration of ATC position implies two controllers per sector: one planning controller and one tactical controller [11].

The planning controller has to manage the aircraft entries into and exits of from his sector, coordinating with adjacent sectors. Before an aircraft enters his sector, the planning controller receives a request with an entry point and a flight level. Considering the traffic already in the sector and other aircrafts approaching it, the controller then accepts or makes a counter-proposal until agreement is attained with previous sector. Similarly, he coordinates aircrafts leaving his airspace with the subsequent sector [12][13].

The tactical controller contacts directly with pilots. He gives instructions to assure separation between aircrafts in his sector and to achieve exit conditions arranged by the planning controller [13].

3. ATC simulations, software and capacity estimation techniques

In order to estimate a sector's capacity, reproduction of the ATC environment is needed. To do that, Air Navigation Service Providers (ANSP) resort mostly on two types of simulations: Fast Time Simulations (FTS) and Real Time Simulations (RTS) [14].

I – Fast-Time Simulations (FTS) and Real Time Simulations (RTS)

To calculate controller workload and estimate sector capacities, ANSPs frequently use computer models to simulate the ATC system or, in other words, FTS techniques, which consist in an attempt to model the entire ATC system in a mathematical and logical language, describing the behaviour of all parties involved in the process [15]. This represents a cost-effective method to provide support for high-level decisions that would require longer time and greater financial costs to be simulated in real environment, making it possible to evaluate the benefits of both physical and procedural modifications on the airport and/or airspace in a relatively short period of time and at a considerable lower cost.

There are, though, some limitations about FTS, because in general it is unprovided of human aspects like judgement and thinking. There is the consciousness that workload experienced by controllers cannot be explained purely as a function of the amount of traffic they handle [11]. Due to the lack of human elements relatively to FTS, there is the need to perform RTS. As the name suggests, the simulation process takes the same time to operate as the real ATC system [15].

In RTS the operational environment is replicated as close as possible to the reality, including the new technology or procedure(s) to be tested. Professional controllers perform their functions in positions which represent the actual controller positions in the ATC system and there are even pilots available for communication.

The main disadvantage of RTS is the cost, since it requires trained personnel, equipment and significant simulation type. Nevertheless, they are fundamental to estimate with great accuracy the impact of new technologies and procedures on controller workload and capacity [1].

II – RAMS Plus

In the early nineties, EUROCONTROL started the development of a simulation tool: the Reorganized ATC Mathematical Simulator (RAMS) [16]. This software would later become a commercial product been further developed by ISA Software. Its current designation is RAMS Plus. It works as a fast-time simulation model and it is used worldwide by some of the biggest ANSPs to measure a wide variety of ATM parameters such as workload, delays, capacity of the airport and airspace [17].

RAMS works as a discrete-event simulation model of the ATC system, providing a high fidelity model. At the beginning, RAMS was a runway-to-runway simulator but, in 2003, with the release 5.00 a groundside module was added, upgrade which improved the definition of RAMS to a gate-to-gate model [18]. The most recent version is the 6.00, launched in December 2013 and its features include 4D flight profile calculation, 4D sectorization, 4D spatial conflict detection, conflict resolution process based on a rulebase, 4D resolution manoeuvring, workload assignment, time-based metering, TMA runway/holdstacks and airport ground movements [17]. With extensive outputs, it is possible to extract information about a variety of parameters. Three stand out as the most important ones: flight events, sector/controller workload and conflicts [19].

III – Capacity Estimation: CAPAN Method

The Capacity Analyser (CAPAN) method was developed by EUROCONTROL to evaluate sector capacities and new airspace designs. It is used integrated in RAMS Plus, with EUROCONTROL using a version of RAMS with the necessary modifications. With RAMS working as a simulation tool to determine the workload generated in a sector for a given traffic sample, CAPAN generates values expressing the loading in the simulated control positions. From the empiric experience, these values can be classified according to table 1.

According to CAPAN, the capacity of an ATC sector is considered to be the maximum number of aircraft that can enter in it, in the period of an hour, without exceeding an acceptable level of workload for the controller (i.e. the 70% threshold) [16].

Threshold	Interpretation	Working time per hour
70% or above	Overload	42 minutes +
54% – 69%	Heavy Load	32 – 41 minutes
42% - 53%	Medium Load	25 – 31 minutes
18% - 41%	Light Load	11 – 24 minutes
0% - 17%	Very Light Load	0 – 10 minutes

Table 1: EUROCONTROL workload thresholds [16]

The estimation of the capacity is obtained with the following procedure:

1. The sector and its procedures are reproduced in RAMS;

2. An appropriate[1] traffic sample is added to the simulation;
3. RAMS runs the simulations and generates traffic flows and task events;
4. Flight data and workload are registered;
5. Analysing the data, it is possible to relate workload values with the number of sector entries;
6. Plotting the values obtained for the 24 hour period and performing a regression analysis, the function $WL = F(N_{sector\ entries})$ is obtained;
7. The capacity value is obtained intersecting the obtained function with the 70% threshold.

4. Lisbon's airport and airspace

I - Runways

Lisbon airport has two crossing runways (RWY): 03/21 and 17/35. RWYs 03 and 21 are equipped with ILS (CAT I and CAT III respectively). Being impossible to operate in more than one runway simultaneously, and to enhance its capacity, the airport receives the majority of the traffic in an arrival – departure – arrival sequence.

The RWY in use is preferentially the 03/21, since operations in RWY 17/35 require coordination with some restricted areas around the airport and, consequently, depend on military conditions. In general, the active RWY is the 03, switching for RWY 21 whenever the weather justifies it. RWY 35 is occasionally requested.

The average runway occupancy times are presented in the following table [20]

	RWY 03	RWY 21
Arrival - Heavy	57.5s	52.9s
Arrival - MedJet	51.1s	49.1s
Arrival - MedProp	53.6s	42.9s
Departure - All groups	43s	43s

Table 2: Runway Occupancy Times

II – Airspace

The terminal control area comprises the airspace represented in Figure 2 (Lisboa TMA), excluding the portion of Lisboa CTR within these limits. Its vertical lower limit varies from 1000ft above ground/mean sea level to FL055, while its upper limit is FL245. Lisbon TMA has an unusual shape due to military zones constraints.

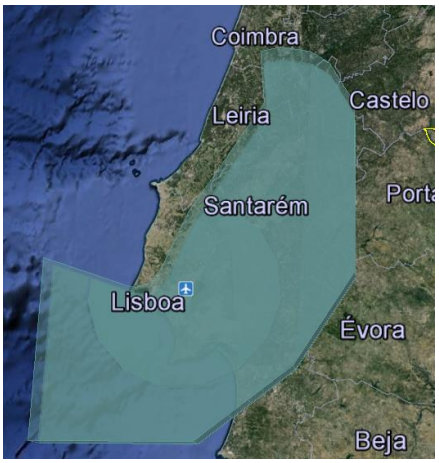

Figure 2: Lisboa TMA

Lisboa TMA, according to the Portuguese Aeronautical Information Publication (AIP) [21] can be divided in up to four sectors:

- Lisboa APP Sector 1 – An arc of circle centred on ARP with 30NM radius, from 2000ft to FL085;
- Lisboa APP Sector 2 – An arc of circle centred on ARP with 30NM radius, from 1000ft (on the first 9NM radius) or 1500ft (between 9 and 30NM radius) to 2000ft;
- Lisboa TMA Lower Sector – the area represented in Figure 2, from FL055 to FL145, excluding the portion of Lisboa APP sector within its limits;
- Lisboa TMA Upper Sector – the area represented in Figure 2, from FL145 to FL245.

Usually, Lisboa TMA works with the Configuration of two sectors (Lisboa TMA and Lisboa APP sectors). In periods of low traffic demand, the sectors may be collapsed into a single one (Lisboa TMA). Presently, the configuration of four sectors is very rarely used.

There are several military areas around Lisbon, being Lisbon Airport mainly affected by Alcochete, Montijo, Sintra and Monte Real (Figure 3). They influence the design of the airspace, as well as the approach and departure routes. The area of Montijo also conditions the use of RWY 35, due to its proximity to the beginning of the RWY.

[1] A traffic sample consistent with the traffic observed in the sector: arrivals, departures, aircraft types, etc. Ideally a real traffic sample.

Figure 3: Most significant military areas around Lisbon

Given the configuration of the referred airspace, a good collaboration and an effective coordination between both authorities is fundamental.

III – Routes

There are SIDs and STARs published for, respectively, traffic departing from and arriving at Lisbon.

RWYs 03 and 35 share the standard procedures. More information about these procedures can be obtained in the Portuguese AIP [21].

5. Simulations

The following table presents the list of scenarios that will be studied and their main characteristics.

Scenario Name	RWY	Purpose
Reference Scenario 03	03	Reproduce the current situation and model calibration
LPPT_03_B	03	Analyse eventual benefits of this sectorization
LPPT_03_C	03	Calculate the impact of the routes and holdstack pending on military activity.
LPPT_03_D	03	Evaluate the impact of a reduction in RWY occupancy times
LPPT_03_E	03	Decrease the separation between departures from 2 to 1 minute
LPPT_03_F	03	New sectorization with approach and departure sectors
Reference Scenario 21	21	Reproduce the current situation and model calibration
LPPT_21_B	21	Analyse eventual benefits of this sectorization
LPPT_21_C	21	Calculate the impact of the routes and holdstack pending on military activity.
LPPT_21_D	21	Evaluate the impact of a reduction in RWY occupancy times
LPPT_21_E	21	Decrease the separation between departures from 2 to 1 minute
LPPT_21_F	21	New sectorization with approach and departure sectors

Table 3: Scenarios resume

I – Reference Scenarios

The reference scenarios (one for RWY 03 and another for 21) are the reproduction of the current terminal airspace of Lisbon Airport, as well as its operating mode. The, routes and procedures are replicated as close as possible to the ones published in the Portuguese AIP, with the most commonly used sectorization of two sectors (Lisboa APP and TMA). The traffic sample used is from the 1st of July of 2013 (RWY 03) and 12th of July 2013 (RWY 21). Both traffic samples were increased using RAMS' traffic generation tool to reach sector saturation.

The analysis of these scenarios indicated an airspace saturated by the sector "Lisboa APP". The capacity was not constraint by the sector "Lisboa TMA".

The following graphics present the results obtained, as well as an estimation of the capacity using the CAPAN method.

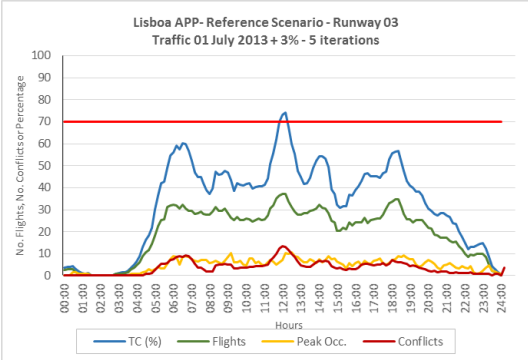

Figure 4: Key indicators - Reference Scenario RWY 03

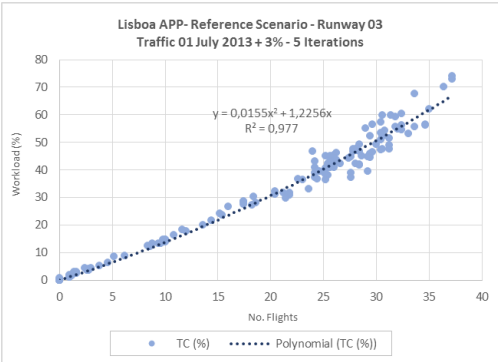

Figure 5: Capacity Estimation - Reference Scenario RWY 03

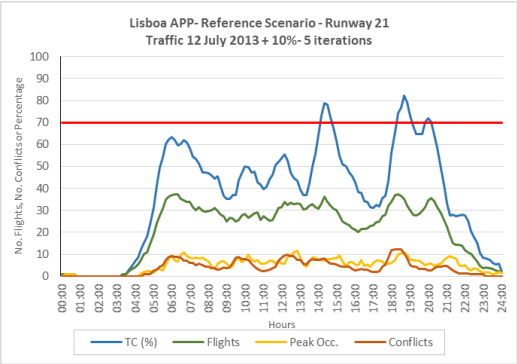

Figure 6: Key indicators - Reference Scenario RWY 21

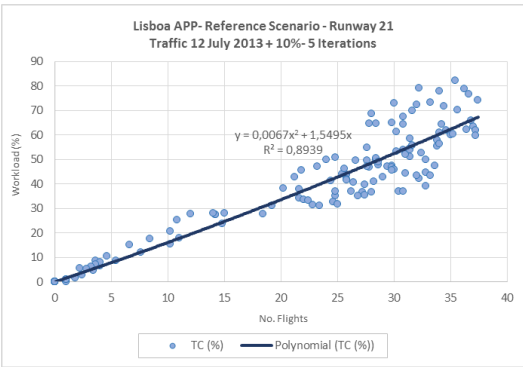

Figure 7: Capacity Estimation - Reference Scenario RWY 03

For both scenarios, the capacity is estimated in 38 movements per hour.

II – Airspace with four sectors

This scenario introduces a new sectorization, using all the four sectors presented in 4-II, with the vertical profile presented in figure 8.

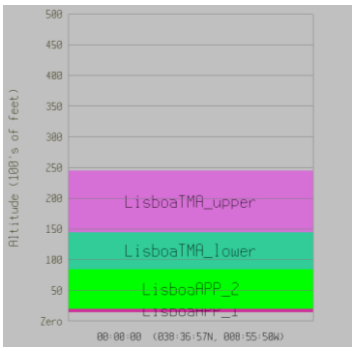

Figure 8: Vertical profile of four sectors configuration

The results obtained for these scenario were close to the ones from reference scenario. The capacity of Lisboa APP Sector 1, which in fact receives the same traffic as Lisboa APP in the previous scenario, is the limiting sector and its capacity remains unchanged in the 38 movements per hour.

III – Configuration including alternate STARs and holdstacks in restricted areas

This scenario pretended to evaluate the impact of the resticted areas around Lisbon Airport. Relatively to the reference scenario, this simulation introduces the holdstack UMUPI and the alternate STARs BUSEN2D, GAIOS2D, LIGRA2D, NAKOS2D, TROIA2D, UNPOT2D and XAMAX4D for RWY 21, as well as XAMAX4C for RWY 03, all conditioned by eventual military activities.

Overall, these new STARs lead to a reduction on the number of flights sent to holdstacks and improved the separation inside TMA. Despite the complexity reduction, the capacity remains in 38 movements per hour, conditioned by the APP sector. It is possible to notice a small reduction in the workload, but it is not sufficient to increase the capacity of the sector. The STARs in the restricted areas may help and ease traffic separation, but do not lead to an increased capacity.

IV – Scenario with reduced occupancy times

The aim of this scenario was to evaluate the effects of a reduction in the runway occupancy time. The new times are presented in table 4.

	RWY 03	RWY 21
Arrivals - Heavy	54s	49s
Arrivals - MedJet	48s	46s
Arrivals - MedProp	51s	40s
Departures	40s	38s

Table 4: New runway occupancy times

Overall, this reduction only had a strong impact in the average stack holding times, reducing significantly the time on hold. It did not have effects in the capacity of the airport, since it is constraint by the airspace and not because of the runway and thus the capacity is still 38 movements per hour.

V – New departure routes

In this scenario, the standard departure procedures were modified. At this moment, all traffic taking off in Lisbon Airport must have a minimum time separation of two minutes since there are no departure procedures with tracks diverging 45º or more. Here in this scenario, the aim was to introduce new routes that would accomplish the requests of Doc. 4444 [22] to operate departures with one minute separation.

There were concerns related with the restricted area of Alcochete (for RWY 03) and Montijo (RWY 21) which may interfere with this procedures.

For RWY 03, with some reorganization of the current SIDs, it was possible to introduce the alternatives without conflicting with the military areas, as presented in detail in where the restricted areas are marked in brown. Although the departure routes cross the area of Montijo, the aircrafts have an altitude higher than the 2000ft of vertical limit imposed while flying over that area.

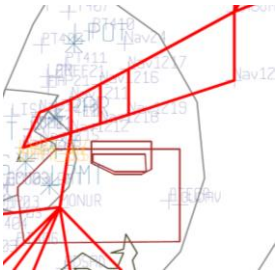

Figure 9: New SIDs RWY 03

For the case of RWY 21, the aircrafts departing in the new routes have to fly over the restricted area of Montijo in an early stage of the flight, making it necessary to apply performance restrictions in these routes to avoid entering the restricted area.

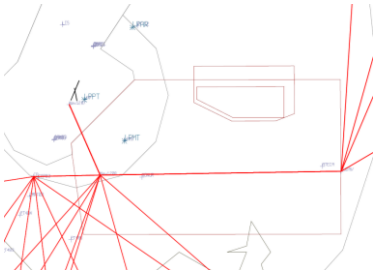

Figure 10: New SIDs RWY 21

In respect of RWY 03, the capacity of the APP sector in this scenario decreases to 37 movements per hour, due to the complexity added with the new design applied in the departure routes, which include two merge points. The strength of this configuration lies on the low delays occurred with departures, with an average of 1.1 minutes only considering the late takeoffs.

Because of the experience of RWY 03, it was decided not to submit this scenario into a deeper analysis for RWY 21.

VI – Scenario with approach and departure sectors

This scenarios present a new airspace configuration. Since the sector Lisboa APP limits the capacity, it will be divided in North and South sectors.

The new sectorization predicts an Approach Sector (APP South for RWY 03, APP North for RWY 21) and a Departure Sector (APP North for RWY 03, APP South for RWY 21), as presented in figure 11.

Figure 11: Lisboa APP North and South

When RWY 03 is in use, some aircrafts departing for the south side of the TMA, namely those with lower climbing performances, may enter in the APP Sector South, in this case working as the approach sector. Since that occurs in a very brief period of time (usually less than half a minute) in the transition between Lisboa APP North and Lisboa TMA, a “sector clip” was introduced here. As a result, if a departure flight enters in South Sector and will exit in less than a minute, instead of being handed to the control of this sector, it is handed off straight to the control of Lisboa TMA. Also, although the North Sector is supposed to work as the departure sector, it is still crossed by part of the traffic approaching Lisbon via STARs INBOM and XAMAX. Because the workload of the departure sector is low, there is enough margin to deal with these flights without constraints.

With this new configuration, the approach sectors do not constraint the capacity, presenting a workload far from the threshold. The sector that reaches saturation in these scenarios is Lisboa TMA, which remain unchanged relatively to the original sector. Its estimated capacity is of 48 movements per hour for RWY 03 and 44 for RWY 21.

6. Discussion

The reproduction of the current terminal airspace in Lisbon and the calibration of the scenario allowed to obtain a reference scenario with a capacity of 38 movements, consistent with the declared values of the airport.

The division of the airspace into the four sectors declared in AIP, as done in the scenarios LPPT_03_B and LPPT_21_B, only increases the capacity of the TMA sector. Although it splits the saturated APP sector into two, the APP Sector 2, being only between 1000ft and 2000ft, is practically unused and only departing traffic with low climb performance enters it for a very short period of time. For arrival aircrafts, being the FAP assigned to an altitude of 3000ft or 4000ft depending on the RWY, this sector is never used. In fact, the “new” APP Sector 1 has exactly the same work as the former and saturated APP sector. This division exists due to former procedures related

with Cascais Aerodrome (LPCS) and is currently outdated, not adding capacity to the airspace.

The introduction of the alternative STARs using restricted airspace is more relevant in the case of RWY21, as the higher number of routes of this type could suggest. When operating RWY 21, these alternatives received an average of 15% of the traffic entering the TMA via STARs with alternatives pending on military exercises. Although the estimated capacity remains in the 38 movements, the reduction in the number of conflicts monitored suggests a decrease in the complexity of the airspace. It is possible to notice a reduction on the total workload of the tactical controller. Despite not being the solution for a capacity enhancement, these routes may play an important role and provide a useful alternative to the narrow air corridor between the airport and the military area of Sintra. In the scenario using RWY 03, the new alternative route received only one flight. The holdstack UMUPI receives considerable traffic, but mostly because of its location.

No improvements were obtained from the reduction of RWY occupancy times apart from a reduction in the average time of flights in holdstacks. These results are consistent with the declared capacities of the airport, where is stated that it is constrained because of the TMA and not because of lack of RWY capacity.

The new SIDs created to reduce time separation between departures, only analysed for the case of RWY 03, did not contribute to improve the airspace. Instead, the extra complexity generated by the new routes brought the capacity down to the 37 movements. The conflicts caused by the merging of some departure routes could be easily avoided introducing altitude restrictions, but this would create the need to stop the climb of some flights, with obvious economic and environmental consequences. Furthermore, because of the dominant type of operation performed in Lisbon Airport (arrival – departure – arrival), the reduction of the separation to one minute would not bring gains during most periods of high demanding. The excellent average departure delay presented is obtained from the periods with less arrivals and more departures, reducing their time in departure queues. Typically, these are not periods of peak workload.

The new sectorization, introduced in scenario LPPT_03_F and LPPT_21_F, divides the APP sector in two. Although the sectorization is imposed in a geographical basis, it has in mind a functional sectorization, creating an approach sector and a departure sector. In this case, the constraint caused by the baseline sectorization is eliminated and the capacity of the airspace is enhanced. The sector limiting the airspace capacity is now Lisboa TMA, with 48 movements for RWY 03 and 44 for RWY 21. Studying the configuration of the airspace, the cause for the different capacities is easily identified. Unlike in the configuration for RWY 03, the most used holdstack for RWY 21 is in the TMA sector, creating more workload for its controller team.

For RWY 03, the considerable increase in the average stack holding time, together with an apparent incapability to deal with all the flights entering in the APP sectors, with peaks up to 47 movements combining the two sectors, is an evidence of a RWY saturation. To confirm it, a quick estimate was done.

The total cycle time, i.e., the typical time interval for each landing and takeoff cycle, of a runway operating in mixed mode consists in three factors [23]:

1) Time needed to guarantee a minimum separation of 3NM between an aircraft starting the takeoff roll and an approaching flight;

2) ROTA;

3) ROTD.

Considering a speed of 160kt on final approach, and a ROTA calculated with 80% of medium jets, 15% of heavies and 5% of medium propellers, the following capacities are estimated:

RWY 03 with normal occupancy times: 44 movements;

RWY 21 with normal occupancy times: 45 movements;

RWY 03 with reduced occupancy times: 46 movements;

RWY 21 with reduced occupancy times: 46 movements

Thus, it is confirmed that runway is saturated in simulation LPPT_03_F.

7. Design Proposal

From the previous scenarios, the most benefic change was the new sectorization, with the former APP sector being divided in approach and departure sectors. As far as RWY 03 is concerned, this would generate airspace capacity sufficient to keep up with the capacity of the RWY, even if the reduction of average occupancy times analysed in scenario LPPT_03_D was attained.

The same was not verified for RWY 21 where, although the new sectors would raise the airspace capacity for a value close to the one estimated for the runway with the present occupancy times, an eventual future reduction in those times would, once again, put the airspace capacity below the runway capacity. The main reason for this limitation is the location of the most used terminal holdstack of RWY 21, which is positioned in the TMA, unlike the holdstacks of RWY 03 which are located in the APP sector. Because of that, the TMA presents a lower capacity when RWY 21 is operating. To solve this, the first alteration considered was to increase the diameter of the APP sector in order to include the RINOR holdstack. However, this would imply the APP sectors to apply different separations inside the sector, since the Lisboa Airport Radar Vectoring Area is confined to the 30NM distance. As an alternative, the RINOR holdstack was replaced by a new holdstack in the waypoint Nav221,

already inside the APP sector and about 3.5NM away from the original RINOR holdstack.

The alternative STARs using restricted areas studied in LPPT_03_C and LPPT_21_C, although not leading to a capacity increase, allowed a better traffic sequencing and reduced the number of conflicts, as well as the use of holdstacks, particularly in RWY 21. A good operational coordination is necessary in order to, for example, liberate this portion of airspace to be used by civil aviation during peak traffic demand periods and restricting it for military activities in the remaining time. These routes were also included in this scenario.

The RWY occupancy times used in this simulation consider the reduction studied in LPPT_03_D and LPPT_21_D to explore at the maximum the capacity of this scenario.

Overall, these changes allowed to remove the constraints created by the airspace in the current design and gave enough margin to deal with eventual reductions in runway occupancy times and the consequent runway capacity increase obtained.

By removing the RINOR holdstack from the TMA sector, the capacity of the airspace under operation of RWY 21 increased from the 44 movements of LPPT_21_F up to 48 movements, equaling the capacity estimated for the airspace when RWY 03 is operating.

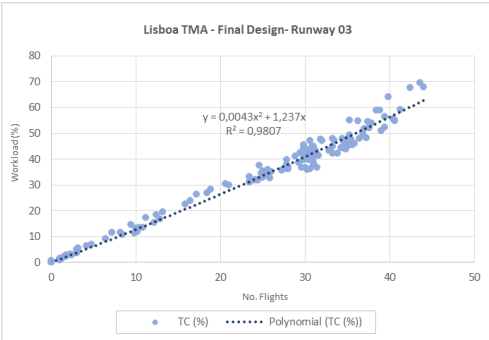

Figure 11: Regression analysis – Lisboa TMA – Final design RWY 03

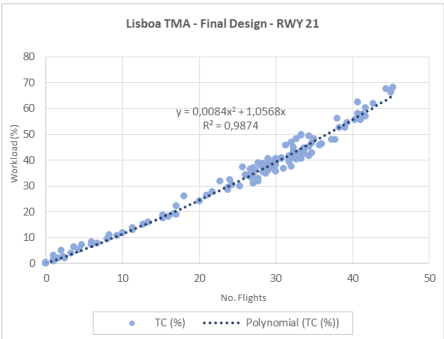

Figure 12: Regression analysis – Lisboa TMA– Final design RWY 21

The APP sectors in both cases are far from the saturation. The workload of the two approach sectors, the most demanded, is presented in the following graphics, where is possible to verify that they are far from saturation.

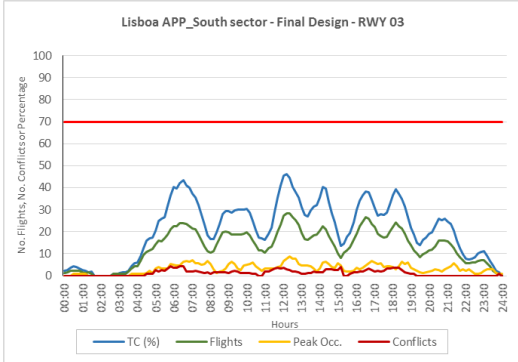

Figure 13: Key indicators - Lisboa APP_South- Final Design RWY 03

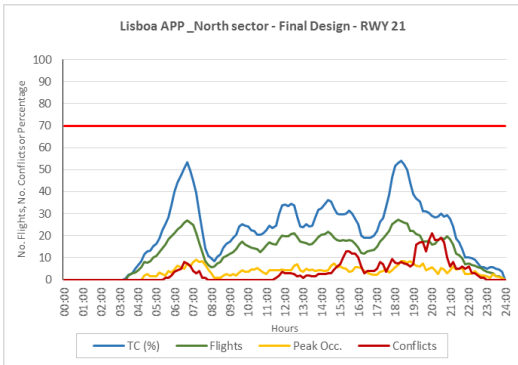

Figure 14: Key indicators - Lisboa APP_North - Final Design RWY 21

8. Conclusions

From the several new scenarios created, it was possible to verify what they would, or would not, add to the reference scenario. The division in four sectors did not improve in any way the airspace and nor did the new SIDs since the few benefits obtained did not overcome the additional complexity created. The use of the routes and holdstacks in the military areas could simplify and reduce the complexity of the work of the ATCo but, alone, did not demonstrate capability to add capacity to the airspace. The reduction in RWY occupancy times was useful to reduce delays but, having the RWYs a capacity higher than the airspace, there was no logic (nor significant results) on applying it without improving the airspace. The most successful change analysed was the division of the APP sector in two, applying an implicit functional sectorization.

The final design gets together the different measures that were determined as advantageous to improve the capacity of the airspace. Together with a reduction of the runway occupancy times, it boosts the airspace capacity to forty eight movements, ten more than the current declared capacity and more than the runway can deal with realistic occupancy times.

The workload calculation in RAMS is determined by the task list. Therefore, the design of a task list and the estimations of each task duration (weight) requires great precision and shall be based on observation of controllers during performance in a RTS environment [24]. Because of that, the values of the new capacities shall be carefully treated. Although the model was calibrated with the reference scenario, the weighing between standard tasks and extra workload created by conflict resolution may not have been accurately determined. Nevertheless, the analysis has the merit of accessing the scenario relative changes impact to the workload.

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