

# Potential Benefits of a Time-based Separation Procedure to maintain the Arrival Capacity of an Airport in strong head-wind conditions

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Picture 1. Visualisation of a Wake Vortex thanks to coloured smoke.

## Abstract

This paper describes a different approach to separating aircraft during the final approach phase. It is based on the fact that, under strong head-wind conditions ( $>15\text{kt.}$ ), the ground speed of the aircraft is reduced and so there is a loss of runway capacity. As a consequence of this, each aircraft needs more time to fly a given separation distance at the runway threshold. Under headwind conditions, the actual distance-based separation procedure may thus be not fully satisfactory. Moreover, according to current characterisation studies of wake vortices, which are the main hazards limiting capacity, the actual distance separation thresholds have been proved to be too conservative under strong wind conditions. We thus propose to replace the actual distance-based separations by time-based separations. Without reducing safety, such a process could maintain and increase runway capacity in a shorter term than the wake vortex advisory systems that will require more technology before they can be implemented. Let us note that

both tools should be used anyway to get optimal and safe separations in the future.

## 1. Introduction

This paper presents a first theoretical study of the potential benefits of a time-based separation approach procedure. We will first investigate how strong head-winds can reduce the runway capacity, and will then use these results to elaborate the time-based separation approach that will be suggested. The practical application of time-based separations will be further investigated for the Paris Charles de Gaulle (LFPG) airport in terms of a Theoretical Capacity (TC). Some procedures and tools that should be implemented to put such a process into practise will also be proposed. The framework of further studies to investigate the concept, including fast-time and real-time simulations, as well as shadow-mode trials, will also be described.

## 2. Why Time-based Separations ?

Time-based separations are not a new concept as they were the only one in use during the early days of Air Traffic Control and are still currently used to manage VFR aircraft. Some time-based separations are also recommended for runway occupancy and during approach and take-off phases at airports (§5 and §6.5.6.1 in [Ref 1]). But as radar systems became operational in many control centres, a need to visualise the safe separations standards was required. That is why the distance-based separation standards were introduced, separations that were easily identifiable and checked by the controllers on their radar displays.

But, under strong headwind conditions, there is a loss of runway capacity as aircraft need more time to travel the given separation distance than they do under no wind conditions.

To illustrate this, let  $D$  be the given separation distance, and  $T$  the time that is required to run this distance on a runway.  $T$  can be calculated from the formula:

$$D = GS \cdot T$$

where  $GS$  represents the ground speed of the considered aircraft.

In the case of head-wind conditions :

$$GS = IAS - WS$$

Where  $IAS$  represents the aircraft indicated air-speed and  $WS$  is the wind speed.

Thus, the stronger the headwind, the more  $GS$  decreases and  $T$  increases for a given separation distance  $D$ .

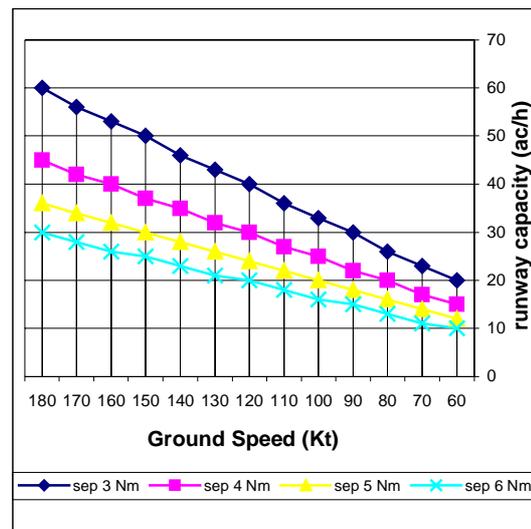
Let us consider constant distance separations and let us evaluate the time that is required to fly these distances on the runway under constant head-wind conditions of 0 knots, 15 knots and 25 knots. The results are summarised in Table 1 for a given mean  $IAS$ .

The more the head wind blows, the longer the time it takes to fly these given distances; this has an impact on the hourly arrival rates which are consequently reduced. Figure 1 shows the reduction in runway Theoretical Capacity (TC) with ground speed, where  $TC$  represents the maximum number of aircraft per hour that can land one after the other without any other spacing in between them than the exact distance separation standards (no gaps, no buffer).

Runways for which aircraft are separated by constant distances of 3, 4, 5 and 6 nautical miles are considered.

**Table 1. The impact of wind on time separations**

Separation in N.M	3.0	4.0	5.0	6.0
<b>No Wind</b> GS = 136 kts				
Separation Time (s)	79	106	132	159
<b>Headwind 15 kt.</b> GS = 121 kt.				
Separation Time (s)	89	119	149	179
<b>Headwind 25 kt.</b> GS = 111 kt.				
Separation Time (s)	97	130	162	195



**Figure 1. Variation of Runway Capacity with GS at constant distance separation**

In order to avoid this loss of runway capacity without reducing the safety of the system, several possibilities exist.

The first one consists of flying faster to keep the same longitudinal separation as well as the same time separation. Such a solution is already partly applied, either by the controllers who can assign different speeds to the aircraft according to the meteorological conditions, or by the pilots who correct the indicated airspeed by using the ground wind speed information that can be provided by the controllers. Let us note that a speed correction is automatically performed by some Airbus flight management systems : this being called “managed speed”. But the actual procedures do not always compensate 100% of the head wind effects on the  $GS$ , especially when the correction is done thanks to the ground wind information given by the controllers and also under very strong wind conditions. In fact, the higher an aircraft flies, the stronger the wind it is subject to and the greater its  $GS$  reduction.

The second solution to avoid the loss of runway capacity under strong head wind conditions consists of reducing the longitudinal distance separation to maintain a constant time interval separation, independently of the headwind conditions: this is the time-based separation procedure that we recommend to be used and that will be described in the next sections.

In this first theoretical approach, we will not take into account the wind compensation procedures that may be applied. Nevertheless, further investigations, like fast-time and real-time simulations, will have to take these compensations into account as a realistic final operational procedure will combine both wind compensation and time-based separation processes.

### 3. Which Time-based Separations

The main hazard limiting the current separation standards between aircraft, and thus runway capacity, is the wake vortices that are generated by all aircraft and that can be a hazard for the following aircraft, especially in the case of a small aircraft meeting the wake vortex of a large preceding aircraft.

A Wake Vortex (WV) is a turbulent wake that is generated as a direct consequence of the lift that is produced to make each aircraft fly. To get such a lift, a difference of pressure has to be created between the upper and lower part of each wing: as a result of this difference, an air flow is created that generates two vortices at the wingtips (see Picture 1). The heavier the aircraft and the slower it is flying, the stronger the vortex. Vortex size also increases with wingspan, and some aircraft, eg the Boeing 757, are known to produce particularly vicious air turbulence. The vortices descend relatively slowly until they decay or reach the ground. An encounter with wake turbulence can result in severe upset to the equilibrium of an aircraft, with rapid movement in roll, pitch or both. Vortex encounters in the cruise phase represent a minority of this type of accident which usually happens in the landing phase.

Proper separation standards are essential to maintain an acceptable level of safety. These standards are reflected in Europe by the actual ICAO aircraft distance separation standards that takes into account the Maximum Take-Off Weight (MTOW) classes that were defined in the early 1970's (see Table 2). Changes in the weight categories definition and separation standards have also been brought in the USA and in the UK in the light of experience. Whenever no minimum distance separation are specified, the usual

minimum radar separation, equal to 3 or 2.5 nautical miles, is applied.

**Table2. ICAO Separation Standard (in NM)**

Leader	Follower		
	Heavy	Medium	Small
Heavy (MTOW>136t)	4	5	6
Medium (MTOW>6t)	-	3	4
Small (MTOW<6t)	-	-	3

Recently, some research has been performed in the USA as well as in Europe in an attempt to better characterise the Wake Vortex phenomenon in order to enable a reduction in the safe separation distances. This research has been directed towards different goals which may explain why it has remained uncoordinated and frequently unfocused for long. Nevertheless, WV detection and characterisation have now been improved thanks to new detection technologies like the LIDAR, a kind of laser radar, or the SODAR, an acoustic remote sensing system. Some progress has also been made to predict wake vortices thanks to numerical models like the Canadian VFS [Ref 2] and the VORTEX model developed by the CERFACS and STNA [Ref 3] Research is now concentrated more on wake vortex advisory systems that gather both the prediction of WV and weather forecast models and are evaluated thanks to the detection of WV means. Among those systems, one can mention the US Aircraft Vortex Spacing System (AVOSS), the French SYAGE [Ref 3] and the German Wake Vortices Warning System (WVWS). Some systems have also been developed to investigate more operational issues such as the approach on two closely spaced runways (spaced less than 2500 ft apart) like the US Simultaneous Offset instrument Approach (SOIA) and the German High Approach and Landing System / Dual Threshold operation (HALS/DTOP).

The AVOSS results from the summer of 2000 deployment in Dallas - Fort Worth (DFW) airport are particularly of interest as they give valuable information on how winds and other atmospheric conditions affect the wake vortex characteristics ([Ref 4] and [Ref 5]). AVOSS uses current terminal weather observations and short-term predictions to anticipate wake behaviour to provide safe wake spacing criteria. The subsystem integration logic applies the estimated wake behaviour to a corridor of airspace about the nominal flight path. The results prove that 61% of the wake vortices exit the corridor in less than a given minimum Runway

Occupancy Time (ROT) that is equal to 50 seconds.

On average, for each nautical mile behind an aircraft, the vortex the aircraft generates will typically have descended between 100 and 200 feet. These vortices generally persist for up to 80 seconds, but in light or calm air this period can extend up to two and a half minutes whereas it decreases under strong wind conditions.

If we compare these times to those that are required to fly these distances under no wind conditions (the first line in Table 1), the current distance separation standards may be seen to be too conservative, especially in case of strong wind conditions that reduce the duration of the phenomenon.

Under headwind conditions of more than 15 knots, we thus propose to replace the actual ICAO distance separations by their equivalent in time. In fact, the time separations will be equivalent to **the time that is required to fly the actual ICAO distance separations under no wind conditions.**

The time separations are evaluated for a common reference ground speed (GSr). A GSr of 137 kt. has been selected after examination of engine performance databases that have been found to be representative of the actual distribution of the aircraft according to the different weight classes that are defined to characterise the ICAO separation standards.

The equivalent time separation standards are given by the formula:

$$T = D / GSr$$

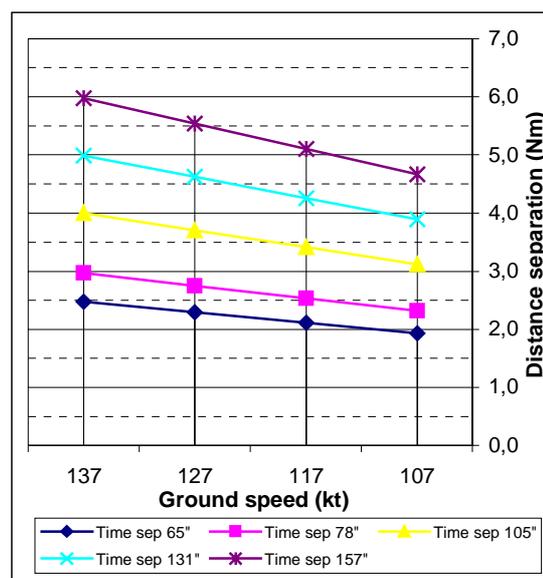
Using the ICAO distance separations per weight class (Table 2), their corresponding time-based separations are enumerated in Table 3. In the case where a 2.5 nautical miles radar separation is applied, the corresponding time interval is 66 seconds.

**Table3. ICAO Separation Standard – Time equivalence in seconds, GSr=137knots**

Leader	Follower		
	Heavy	Medium	Small
Heavy (MTOW>136t)	105	131	158
Medium (MTOW>6t)	-	79	105
Small (MTOW<6t)	-	-	79

Under head wind conditions, the use of time-based separations will reduce the longitudinal distance

separation (see Figure 2), but will help to maintain a constant runway capacity.



**Figure 2. Variation of Distance Separation at Constant Time Interval**

Let us note that such a reduction in the distance separations will have to be subject to further acceptance by the ICAO when it comes to reducing the distance separations below the 2.5 nautical miles threshold, the minimum radar separation, that is usually considered as the minimum acceptable distance separation to maintain a reasonable level of safety.

#### 4. Potential Benefits of a Time-based Procedure on a Real Traffic Sample

To further illustrate the impact of using time-based procedures, we consider their potential benefits in terms of Theoretical Capacity on actual traffic samples at one major European airport. The Paris - Roissy Charles de Gaulle (LFPG) airport has been chosen.

For this airport a day during which the traffic was operated normally was considered. One peak hour was then chosen during this day to give the best possible information about the distribution according to the ICAO weight classes of the aircraft landing at LFPG.

Considering the traffic sample that has landed at the airport during that hour, the theoretical capacities (TC) of the considered runways are evaluated : either when ICAO distance-based separations under 0 knots, 15 knots, and 25 knots headwind conditions, or time-based separations are applied.

**When time-based separations are applied, TC is independent of the headwind strength** and is constantly equal to the TC when the ICAO distance separations are applied under no wind conditions. This should help to reduce the delays due to some weather conditions and thus should bring economical benefits to the Airlines thanks to a better optimisation of the ground operations.

To evaluate the theoretical capacity, we compute the time that is required to have all the aircraft land on their respective runways one after the other, with no separation between them other than the exact considered type of separation (no gaps, no buffer).

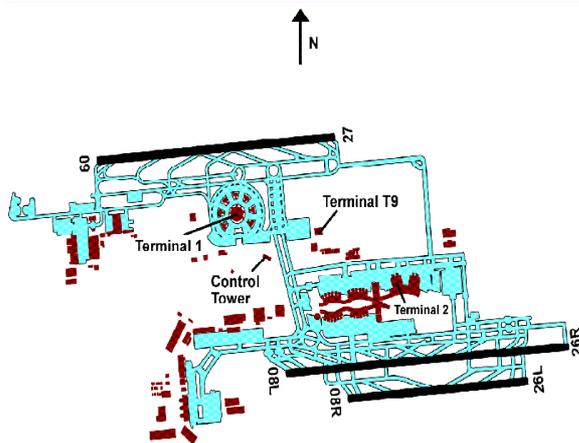
The TC is then calculated by deducing the number of aircraft that can land during a one hour period of time by simple proportional considerations according to the traffic sample analysis (the time required to manage the number of aircraft that have landed during the considered hour).

For example, N aircraft (a/c) have landed on a given runway. The time required to manage these aircraft with no other separation in between than the exact considered separations is equal to  $T_s$ .

We have :

$$N \text{ a/c} \rightarrow T_s \text{ seconds}$$

$$TC = N \times 3600 / T_s \text{ a/c} \rightarrow 3600 \text{ seconds}$$



**Figure 3. Paris Roissy LFPG Airport Configuration**

The reference day chosen was 28<sup>th</sup> June 2002. The runway configuration was West all day and the two runways dedicated to the arrivals (named 26L and 27L, see Figure 3) were considered. Both runways are sufficiently spaced (>2500 feet) to manage their arrivals in an independent way.

The arrivals between 9:00 am and 10:00 am were focused on. To perform the calculations, the reference Ground Speed GSr of 137 knots was still considered as the average IAS of all the aircraft at the runway threshold.

The time separations corresponding to the ICAO distance separations, that is to say the time required to fly the separation distances (3, 4, 5 and 6 nautical miles) at the runway threshold at a ground speed of 137 knots, are those written in Table 3 which are respectively equal to 79, 105, 131 and 158 seconds. A minimum radar separation of 3 nautical miles was used where no Wake Vortex safety distance separation was required.

Table 4 summarises all the results for the TC calculation.

**Table 4. Evolution of the Theoretical Capacity for different separation procedures.**

	Number of ac in traffic sample		Duration (s)		TC (ac/h)	
	26L	27L	26L	27L	26L	27L
No wind (Distance and Time)	34	23	2785	1945	44	43
15 knots headwind (Distance)	34	23	3128	2184	39	38
25 knots headwind (Distance)	34	23	3407	2379	36	35

These results show that under strong head-wind conditions, the total TC of both runways 26L and 27L can be reduced from 87 ac/hour to 71 ac/hour, which represents a reduction of 16 aircraft or 18%. This is quite significant especially when such strong head winds happen at peak hours during which they will more likely create delays that will affect the whole flow management process during the next hours.

Table 5 also summarises some statistics about the number of days in 2001 that have had strong wind conditions at some peak hours for the LFPG airport.

**Table 5. Number of days in 2001 with strong wind at peak hours**

Wind strength	Time of the day (from h to h+1)			
	6 am	9 am	12 am	3 pm
15 to 20 kts	29	41	58	47
20 to 25 kts	3	2	6	9
≥ 25 kts	0	1	0	0

In 2001, there were in fact 97 days, which represents 27% of the days in the year, during which there was at least one peak hour with winds stronger than 15 knots (wind speed evaluated in LFPG at a 33 feet, 10 meters, altitude). These 97 days were also days for which the runway Theoretical Capacity could have been increased by at least 10 aircraft.

In fact, let us note that when one peak hour is affected by strong wind conditions, these conditions usually also concern the other peak hours of the day: this was the case of 56% of the 97 days which means that the impact on maintaining the runway capacity would have been more important than just adding 10 aircraft to only one hourly arrival rate.

A time-based separation procedure has an impact on the runway capacity when strong head-winds are blowing. The stronger the wind, the more effect the time-based separations will have to maintain capacity. As the wind is usually stronger at upper altitudes than on the ground (a measured wind speed of 15 knots in LFPG corresponds to an average wind speed of around 25 knots at a 1000 feet altitude), the real impact of using time-based separations will be certainly more important than what is presented thanks to the ground wind measurements, and more than 27% of the days in a year could benefit of such a procedure. This will be up to the fast-time and real-time simulations to precise the expected benefits.

## 5. Conclusions & Recommendations

In this paper, we have shown how strong head winds can affect the runway theoretical capacity of the Paris-Charles de Gaulle airport and how, during such weather conditions, the use of time-based separations would contribute to prevent a reduction of the runway capacity for a significant number of days.

Of course, these results need to be further analysed under more realistic conditions (wind conditions at higher altitude, speed of aircraft, real traffic sample corresponding to current or future demand) and fast-time and real-time simulations, as well as shadow-mode trials, are scheduled to take place during the next few months.

Time-based separations will continue to be investigated for the three major European airports: Paris-Charles de Gaulle, London-Heathrow, and Frankfurt. These studies should investigate the benefits in more **operational** terms such as evaluating the achieved landing rates, the delays,

the controller workloads and investigating the safety implications.

It is planned to use accurate weather modelling and forecasts to get more accurate wind conditions, especially to simulate the increase of wind with altitude. Vertical wind shear will be simulated to investigate the potential hazards of such events as well as the possible procedures that would be implemented to restore safe separations, such as extracting aircraft from the arrival sequence. The impact of re-inserting these extracted aircraft later in the arrival sequence will also be studied.

The fact that aircraft fly at different speeds according to their type and weight classes, as well as according to their altitude will also be taken into account. The adjustment process of the aircraft speed during strong head wind conditions will also have to be considered, at least for the real-time simulations.

The time-based separation process will also have to be implemented in the arrival manager systems (AMAN) that are currently in use in order to optimise the flow management and sequencing of the arriving aircraft. AMAN systems like MAESTRO (used at Paris-Charles de Gaulle), COMPASS (used at Frankfurt Airport) and FAST (used at London-Heathrow) are planned to be worked on.

In order to implement real-time simulations, the operational concepts that will help the time-based separation procedure to be put into practice will also have to be elaborated. There will be a need for the controllers to visualise the time-based separations in terms of distance: intelligent speed vectors displaying the required minimum distance separation from the previous aircraft could be used, or target “ghost” positions could be displayed on the controllers’ radar screens.

Let us note that some “ghosting” process is already used for the Converging Runway Display Aid (CRDA) system [Ref 6] that is used to coordinate arrivals as well as to allow a reliable release of departures. Such a system has already been proved to help maintain accurate small separation distances, increase airport capacity and reduce arrival delay [Ref 7]. The kind of spacing tools that we plan to implement should thus also enhance the runway capacity to values closer to the theoretical capacity ones.

This gives more operational significance to the theoretical results that have been presented in Section 4: time-based separations will both help maintain constant runway capacity independently of the wind conditions and also increase the runway capacity. Time-based procedures should thus

considerably reduce the delays and produce all the economical benefits that are linked to a better coordination of the ground operations.

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## Authors' Biographies

Elsa Freville is a Research Engineer working for Eurocontrol at the Experimental centre for two years. She has been involved in real-time and fast-time design and analysis. She has a Ph.D. degree in Mathematical Science from the French University Pierre et Marie Curie, Paris VI. Her degrees are in Statistical Analysis and Modelling.

Jean-Pierre Nicolaon is graduated from the French ENAC (National School for Civil Aviation) in 1962. Air Traffic Controller in Paris ACC/UAC during 16 years, he is fully licensed and was head of a team of 25 people. Ingénieur des Etudes et de l'Exploitation de l'Aviation Civile in 1976, and

Head of Paris Operation during 11 years, he is now Senior operational advisor for various R&D projects conducted in the Eurocontrol Experimental Centre. He is a member of the I-Wake users' group and a WakeNet2 participant as FAA-EC coordinator.

Antoine Vidal is graduated from the French ENAC (National School for Civil Aviation) in 1969. Air Traffic Controller in Paris ACC/UAC during 15 years, he is fully licensed and was head of a team of 25 people. Ingénieur des Etudes et de l'Exploitation de l'Aviation Civile in 1983, he was Head of the Operation Room of the French Air Traffic Management Cell and Head of the Studies Subdivision in Paris-Orly. He is an expert at the EUROCONTROL Experimental Centre since 1990:

- Project leader for Fast-time simulations (1990-1995),
- Project manager for ATFM studies and simulations (1996-2000)
  - Involved in Wake vortex since 2001
  - Project Manager for ATC-Wake project
- S-Wake participant as reviewer and WakeNet2 participant as task owner on Wake vortex risk assessment validation.
- Member of the I-Wake users' club

After graduating from London University with a B.Sc. (Eng) (Honours) degree, Peter Crick worked for 6 years with the Marconi Company, UK before joining Eurocontrol in 1972. He spent 6 years at the Karlsruhe ATC Centre working on the KARLDAP 1 system before joining the Fast Time Simulation Group at Eurocontrol Headquarters in Bruxelles where he stayed for three years. In 1984 the activity was moved to the Eurocontrol Experimental Centre. From 1989 Mr. Crick developed the Simplified Fast Time capability at the Centre and at one time led a team of 17 employing this simulator on behalf of member states. He has recently become interested in Wake Vortex phenomena and their impact on ATM and is currently the Time Based Separations project leader.