EUROCONTROL

# ‘ROCAT’ Solution

## Optimised Runway Occupancy Time Spacing for Arrivals

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| TITLE | | | |
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| **"ROCAT " Solution**<br>**Optimised Runway Occupancy Time Spacing on final approach** | | | |
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**Abstract**

This document presents an operational solution for enhanced arrival runway throughput thanks to optimised Runway Occupancy Time (ROT) spacing on final approach, also named 'ROCAT' solution

The 'ROCAT' solution, developed under the SESAR2020 programme as PJ02.08.03, defines a methodology to establish a local scheme with optimised arrival distance minima due to ROT factor.

The minima are derived on the basis of analysis of local AROT observations characterized at least per runway and per aircraft type. The conversion of these times into distance spacing minima relies on ICAO PANS ATM doc 4444 principles already applicable for reduced 2.5NM spacing.

There are several ways to operate the ROCAT for selected aircraft type pairs in view of upgrading the applied ROT-spacing: on a categorical system basis – 'ROCAT' (on a procedural basis or with automation support / ATC separation delivery tool such as for TBS-ORD solution) for quick wins, or on an individual leader aircraft type/pair-wise basis – 'iROT' or 'ROCAT-PWS' (with necessary ATC separation delivery tool), for maximising the arrival throughput benefits



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# CONTENTS

# EXECUTIVE SUMMARY

This document, developed along the SESAR 2020 Wave 2 Very Large Demonstration VLD3-W2 "SORT" project, presents the Optimised Runway Occupancy Time Spacing Minima for Approach, called ROCAT scheme.

The runway throughput in peak period is directly linked with the applicable minimum longitudinal separation between successive traffic on final approach or on departure.

Complementing various works on wake turbulence separation optimization (RECAT-EU and RECAT-Pair-Wise**),** ROCAT aims at **optimizing ROT-spacing** for part of traffic for which ROT is the prevailing spacing constraint.

The ROCAT scheme is developed in two steps.

1) Based on local surveillance observations, the ROT distribution in peak operation is characterized at least per landing runway and per aircraft type.
2) Using a reference conservative ground speed, the ROT time spacing are converted into individual distance spacing (iROT) using the average ROT of the distributions obtained in 1). That methodology relies on the condition on average ROT established in ICAO PANS-ATM doc 4444 for application of reduced Minimum Radar Separation from 3NM to 2.5 NM in final approach.

There are three ways to operate the ROCAT solutions:

- **Leader-Wise application (iROT)**, which requires automation support with an ATC separation delivery tool, which could also enable, RECAT-pair wise, time-based separation and optimum runway delivery (TBS-ORD);
- a **customized ROT-based category scheme**, defined to be an optimum for a given airport traffic mix (possibly combined with RECAT-EU);
- a procedural ROT-spacing minima enhancement for a **limited number of specific pairs** of aircraft types (or group of pairs)

Depending on the traffic mix, the runway layout and the currently applied ROT spacing minima, the benefits in runway throughput during peak periods can typically reach up to 8% and even more if combined with optimized wake turbulence schemes.

Also, at equivalent throughput, the ROCAT spacing reduction,

- ✓ supports a reduction of the overall flight time for an approach sequence of traffic, which therefore benefits to the whole traffic sequence.
- ✓ offers more flexibility for the Air Traffic Controllers to manage the traffic.
- ✓ enables more rapid recovery from adverse conditions, helping to reduce the local airport delay and eventually the ATFM delay propagated at network level.

# 1. ROCAT background principles

The applied spacing between consecutive arrivals directly drive the runway arrival throughput. Those spacings are driven by:

- The applicable separation and spacing minima, and
- The accuracy in the delivery of those minima.

The applicable separation and spacing minima between arrivals on final are dictated by the largest applicable constraint between

- MSS/MRS - Minimum Surveillance / Radar Separation,
- WT - Minimum Wake Turbulence Separation, if applicable,
- ROT - Runway Occupancy Time spacing for
    - Segregated mode (A-A), or
    - Mixed mode on single or crossing runways (i.e., gap spacings for A-D-A).

Depending on the traffic and the runway infrastructure, the ROT can become the limiting factor to arrival runway throughput, especially in case of reduced MRS and/or Wake Turbulence (WT) separation.

For surveillance separation minima, a reduced MRS to 2.5NM is authorised by EASA/ICAO under given conditions including ROT but is currently operated only at a limited number of European airports. A SESAR Solution even defines the conditions in which minimum surveillance separation is allowed to be reduced down to 2.0NM.

Regarding wake separation minima, the introduction of RECAT authorised by EASA and ICAO reduces some of the wake separations possibly making the ROT the next prevailing constraint.

The runway occupancy time is intrinsically related to the aircraft flight and to the runway infrastructure. A global definition of ROT spacing for the whole fleet landing on any runway of a given airport is thus conservative. Therefore, a more refined definition of ROT spacing provides room for optimisation between individual or group of aircraft.

ICAO PANS-ATM Doc 4444 does not explicitly define how to calculate safe ROT distance spacing minima. However, Section 8.7.3 makes an interesting link between MRS reduced to 2.5 NM and ROT.

**8.7.3 Separation minima based on ATS surveillance systems**

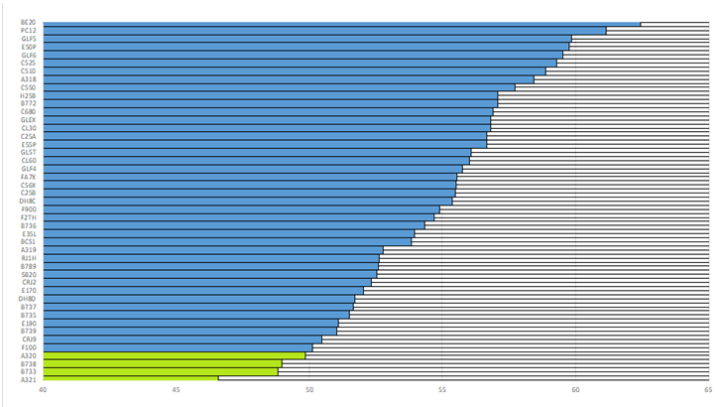
2.5 NM between succeeding aircraft which are established on the same final approach track within 10 NM of the runway threshold. A reduced separation minimum of 4.6 km (2.5 NM) may be applied, provided:

i. the average runway occupancy time of landing aircraft is proven, by means such as data collection and statistical analysis and methods based on a theoretical model, not to exceed 50 seconds;
ii. braking action is reported as good and runway occupancy times are not adversely affected by runway contaminants such as slush, snow or ice;
iii. an ATS surveillance system with appropriate azimuth and range resolution and an update rate of 5 seconds or less is used in combination with suitable displays;
iv. the aerodrome controller is able to observe, visually or by means of surface movement radar (SMR), MLAT system or a surface movement guidance and control system (SMGCS), the runway-in-use and associated exit and entry taxiways;
v. distance-based wake turbulence separation minima in 8.7.3.4, or as may be prescribed by the appropriate ATS authority (e.g. for specific aircraft types), do not apply;
vi. aircraft approach speeds are closely monitored by the controller and when necessary adjusted so as to ensure that separation is not reduced below the minimum;
vii. aircraft operators and pilots have been made fully aware of the need to exit the runway in an expeditious manner whenever the reduced separation minimum on final approach is applied; and procedures concerning the application of the reduced minimum are published in AIPs.

It thus defines the runway occupancy time criteria and conditions in which a spacing of 2.5 NM can be safely applied. However, this ROT criterion needs to be satisfied by **all traffic**, impairing benefits from MRS reduction if only some aircraft does not meet the criteria on average.

# 2. ROCAT scheme logic

ROCAT relies on individual ROT characterisation, at least per runway and aircraft types. based on local traffic data.



There is essentially three ways to operate optimised arrival runway occupancy time spacing and the corresponding modes of operations:

A. Procedural application: applying optimized (i.e., reduced) ROT distance spacings for part of the traffic defined, e.g., for some aircraft types and/or some landing runway(s).

B. With light HMI support: defining categories/groups of aircraft with corresponding applicable ROT distance-spacing. **ROCAT** defines a scheme with **categories of aircraft ROT spacing** as function of their average ROT, and associated applicable ROT distance spacing value, allowing to operate reduced ROT spacings for some part of the traffic

| Follower / Leader | Heavy | Medium (low ROT) | Medium (high ROT) | Light |
|---|---|---|---|---|
| Heavy | 4 NM | 5 NM | 5 NM | 6 NM |
| Medium (low ROT) | 2.5 NM | 2.5 NM | 2.5 NM | 5 NM |
| Medium (high ROT) | 3 NM | 3 NM | 3 NM | 5 NM |
| Light | 3 NM | 3 NM | 3 NM | 3 NM |

**Table 1: Illustration of ROCAT scheme enabling reduced MRS**

C. For application with separation delivery tool support:
   a. **iROT/ROCAT-Pairwise (i.e., leader-wise)** defines a scheme with **individual ROT spacing behind aircraft types** as function of their average ROT, and associated applicable ROT distance spacing value, allowing to operate reduced ROT distance spacings for some part of the traffic.

| | Heavy | A320 | A319 | B738 | BCS3 | E190 | DH8D | … | Light |
|---|---|---|---|---|---|---|---|---|---|
| **Heavy** | **4.0** | **5.0** | **5.0** | **5.0** | **5.0** | **5.0** | **5.0** | **…** | **6.0** |
| **A321** | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | … | 5.0 |
| **B738** | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | … | 5.0 |
| **A319** | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | … | 5.0 |
| **BCS3** | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | … | 5.0 |
| **GLF5** | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | … | 5.0 |
| | … | … | … | … | … | … | … | … | … |
| **Light** | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | … | 3.0 |

**Table 2: Illustration of iROT / ROCAT-PWS scheme enabling reduced MRS and aircraft leader-wise ROT spacing (notional) values**

b. **Dynamic iROT/ROCAT-Pairwise** uses Machine Learning ROT predictor to determine dynamic **individual ROT spacing for each pair** as function of various input features (e.g., runway, leader type, airline, origin airport, wind conditions, etc.) and associated applicable ROT distance spacing value, allowing to operate optimized ROT spacings tailored per flight.

# 3. ROCAT minima determination

The Optimized ROT distance spacing solution (ROCAT) relies on a conversion of the individual ROT characterization combined with a conversion to distance based on ICAO PANS-ATM Doc 4444.

## 3.1. Initial ROCAT setting

### 3.1.1. Local ROT definition

The Runway Occupancy Time (ROT) is defined as the difference between the time the aircraft is observed to overflight the runway threshold and the time it has vacated the runway.

Moreover, some airport may apply Reduced Runway Separation Minima (RRSM) as prescribed in ICAO PANS-ATM doc 4444.

**7.11.7 Reduced runway separation minima which may be applied at an aerodrome shall be determined for each separate runway.**

The separation to be applied shall in no case be less than the following minima:

Note *Category 3 aircraft:* all other aircraft (> 7 tons / Jets)

a) landing aircraft:

…

3) a succeeding landing aircraft may cross the runway threshold when a preceding Category 3 aircraft:

i. has landed and has passed a point at least 2 400 m from the threshold of the runway, is in motion and will vacate the runway without backtracking; or
ii. is airborne and has passed a point at least 2 400 m from the threshold of the runway;

If RRSM is applicable, the ROT value to be considered is then the minimum between the ROT based on runway vacation and RRSM.

The definition of runway vacation may vary depending on the airport. Therefore, the accurate ROT definition has to be provided by the local ANSP in agreement with the local Regulation Authority, and in particular:

- the conditions on the flights (e.g., speed, heading, distance on the runway exit) to consider it has vacated the runway, and
- the application (or not) of RRSM and the application conditions (e.g., visibility), if any.

### 3.1.2. Individual AROT characterization

Based on the locally defined ROT, the first step in ROT spacing optimization is the characterization of the ROT for each flight. The analysis shall cover at least a full year (4 seasons) of representative operations and all runways for which ROT spacings are intended to be optimized. The analysis shall be performed based on data provided by the local airport. Two sort of data can be provided:

OPTION #1: processed ROT data (together with the other features of interest, see list below)

OPTION #2: Surveillance data (e.g., A-SMGCS) providing for each flight latitude/longitude, altitude, groundspeed evolution over time and allowing:

- Detection of landing runway
- Detection of runway vacation (according to local definition + coordinates of runway exits)
- Calculation of ROT

Using either option, a complete arrival dataset shall be built containing at least the following features:

- Aircraft type
- Landing Runway
- Date and time at runway threshold
- Date and time of runway vacation
- ROT

Additional optional features can be used for finer ROT characterization and prediction (e.g., if using Machine Learning prediction, see below)

- Call sign (or at least aircraft Operator)
- ADEP
- Surface wind (anemometer) at landing time
- Visibility
- METAR data

From this dataset, a characterization of the ROT shall be performed:

- Level #1: per landing runway and per aircraft type;
- Level #2: per landing runway, per aircraft type and per aircraft operator;
- Level #3: using a Machine Learning (ML) algorithm allowing more accurate prediction of ROT from a set of input features (Note that a coverage function shall also be then introduced to define in which conditions the ML predictor can be safely used). Level #3 is further detailed in Section 4.

Note that the characterization shall be performed for peak operations, during which aircraft tend to vacate the runway earlier due to higher traffic pressure.

The characterization shall at least cover the average ROT but can also consider quantiles (e.g., p95).

### 3.1.3. Individual AROT distance spacing calculation

The conversion of individual time-based ROT into distance-based ROT spacing relies on the link, established in ICAO PANS-ATM doc 4444, between reduced MRS and ROT.

In that document, it is stated that MRS= 2.5 NM can be safely applied provided that the average ROT does not exceed 50 s. It thus establishes a direct link between average ROT and associated distance spacing. In order to convert a time separation of 50 s into a distance separation of 2.5 NM, a (ground)speed of 180 kts is used as 50 [s] x 180 [kts]/3600 = 2.5 [NM].

This reference speed of 180 kts is obviously conservative as no aircraft traveled the last 2.5 NM down to landing threshold at such a high speed during peak operations. It therefore introduces a buffer in the distance-spacing calculation accounting for uncertainty on:

- Leader ROT that can be larger than the average, and
- Follower flight speed that varies from one flight to another.

The here-proposed methodology extends this logic on two aspects:

1. Rather that considering the average ROT of the whole traffic, the average ROT is computed for subsets of the traffic (defined at least per runway and per aircraft type for Level 1 and also per operator for Level 2)
2. Rather than setting a ROT threshold to apply 3 or 2.5 NM spacing, the individual ROT spacing is computed directly from the individual average ROT and the reference 180 kts groundspeed:

iROT distance behind type Z on RWY XX (OP YY) [NM] =

average $ROT_{\text{type Z, RWY XX (OP YY)}}$ [s] x 180 kts/3600

For example, on runway XX

- 2.6 NM of ROT spacing can be applied behind aircraft type Z if its average ROT is 52s
- 2.8 NM ROT spacing can be applied behind aircraft type Y since if average ROT is 56s.

The final results of individual ROT spacing (iROT) is thus a table providing per runway and per aircraft type (and possibly per airlines), the applicable ROT distance spacing applicable behind that flight.

Note that for rarer aircraft types or less frequently used runway(s), the ROT might not be characterized with sufficient statistical relevance. For those cases, the ROT spacings shall correspond to the surveillance separation or any other larger ROT-based spacing currently applied locally.

### 3.1.4. Other AROT characterisation and spacing strategies

The methodology proposed in Section 3.1.3 relies on the average ROT characterization. However, other strategies of ROT spacing determination can be also implemented using a more conservative ROT prediction (e.g., using 95$^{th}$ quantile per runway and per type) and then converted to a distance using a much less conservative reference speed (i.e., probably closer to the actual speed of the follower aircraft). This methodology is not developed in this document.

## 3.2. ROCAT scheme Maintenance

Without change to the runway infrastructure, the optimized ROT spacings must only be maintained on a regular basis in order to:

- Verify no major change in the ROT behaviour for existing aircraft types (Safety),
- Improve the ROT characterization by, for instance, integrating new or more rare aircraft types in the list covered by iROT (Performance).

In case of **significant change to the runway infrastructure** (e.g., change to runway exit), the **ROT characterization shall be re-performed** based on new measurements or based on theoretical studies relying on historical data and comparison of new configuration compared to old one. For instance, if a new RET is built, all ROTs are expected to be reduced or unchanged. Therefore, the previously established iROT distance-spacing can be safely applied.

## 3.3. EUROCONTROL CCPM service for ROT analysis and ROCAT maintenance

The Continuous Capacity and Performance Monitoring (CCPM) Application provides the main airport stakeholders with a comprehensive operational view and a continuous (24/7) capacity and performance monitoring.

The application is based on the concept of an automated data collection and allows automated ROT data collection that can then be used for ROCAT scheme definition and maintenance.

More information are available through https://www.eurocontrol.int/service/airport-capacity-and-performance

# 4. Enhanced solution using Machine Learning-based AROT prediction (ref. SESAR Sol PJ.02-W2-14.10)

The ROCAT solution can be further enhanced by using a finer AROT prediction based on more input features hence requiring the use of Machine-Learning (ML).

In such an approach, the expected AROT is not only characterized per runway and aircraft type but predicted using a ML model also accounting for additional features such as:

- Flight surveillance data (e.g., from RADAR)
  - Airlines
  - Week of year, day of week, hour of the day
  - Departure airport, its ICAO area and its country
- Wind data (e.g., from runway surface anemometer)
  - Average head – and cross-wind speed
  - Variance of head – and cross-wind speed
- Other met data (e.g., from METAR)
  - Pressure
  - Temperature
  - Dew point
  - Visibility
  - weather flags: rain, brume, shower, fog, snow, storm, drizzle, haze, convective clouds
  - weather events intensity (strong or weak)
  - ceiling clouds altitude

Note that the ML model shall be trained, validated and used at inference stage based only on input features that are operationally available at the time a ROT distance spacing indicator has to be calculated by a separation delivery tool. Typically, depending on the local arrival procedure, the considered prediction time horizon ranges from 5 to 10 minutes before landing time. Therefore, for instance, the final approach speed measured at 2-3 NM from runway landing threshold cannot be used as this would not be available at decision time (i.e., time of calculation of the distance spacing).

Note also that the ROT ML-predictor shall be accompanied by some coverage description providing in which conditions (based on type, runway, wind, etc.) the model can be reliably used. For the other conditions, no ROT distance spacing shall be applied.

Once the AROT ML-predictor is built and validated, corresponding ROT distance spacing can be calculated using a similar logic as that described in Section 3.1.2 but using the ML AROT predictor in place of the “naïve” AROT estimator (i.e., the average per runway and aircraft type). In particular, the AROT-based distance spacing is computed for each aircraft pair using the leader AROT ML-prediction and a reference speed, corresponding to Level #3 described in Section 3.1.2.

However, if such a finer AROT characterization, because of the higher accuracy in AROT prediction, the reference groundspeed used to convert time into distance spacing can be safely reduced from 180 kts to a value leading to the same probability of under-spacing as the Level 1 solution. Indeed, since the AROT ML prediction is more accurate than the naïve predictor, if using the same reference speed as for the naïve approach, the risk of provision of separation delivery below actual ROT is decreased. Therefore, the reference speed can be decreased (e.g., from 180 kts to 175 kts) while maintaining the same level of risk of loss of runway separation compared to the naïve approach, which allows further separation reductions and hence runway capacity.

The assessment of the risk of under-spacing shall be performed based on historical surveillance data of peak operations based on observed leader ROT and follower time-to-fly in three steps.

First, the AROT naïve (i.e., average per aircraft type and runway) and ML predictors have to be built based on a training dataset taken as a subpart of the complete database.

Then, based on an independent validation dataset (e.g., the part of the database not used for training), the risk of under-spacing is assessed if using

- the naïve AROT predictor and a reference speed of 180 kts
- the ML AROT predictor with multiple reference speeds decreased from 180 kts by steps of 1 kts.

For that purpose, for each leader-follower aircraft pair of the validation database, the time separation that would have been obtained if delivering the follower exactly at the predicted naïve ROT distance spacing or ML ROT spacing is computed. Those time separations $T_{sep,naïve}$ and $T_{sep,ML}$ are computed using the ROT distance spacings values (function of the leader flight) and the measured follower time-to-fly profile (i.e., the observed time required to travel the computed spacing distances). In order to increase the number of pair data samples, artificial aircraft pairs are built assuming that each aircraft flight could have been the leader (i.e., preceding aircraft) of any other aircraft flight landing within +/- 5 minutes. This approach allows us to increase the number of pairs in the sample (and hence to better cover rare cases) while still combining pairs observed in similar conditions.

Finally, for each pair, the time separations $T_{sep,naïve}$ and $T_{sep,ML}$ are compared to the actual AROT measured for the leader flight. The results are then quantified in terms of: (i) error rate defined as the fraction of pairs with separation delivery below the actual observed ROT; (ii) mean time separation.

The reference speed used to convert the ML AROT prediction into distance spacing is then determined as that leading to same or lower error rate as the naïve approach.

For example, if when applying Level 1 solution (i.e., ROT spacing calculated from average ROT per runway and per type and using reference speed of 180 kts), the fraction of pairs obtained with an under-spacing (i.e., time separation smaller than actual ROT) if all pairs would have been spaced at ROT spacing minima is 2%, the reference groundspeed for Level 3 solution (i.e., based on ML ROT prediction) can be reduced (maybe to, say 175 kts or 170 kts) until it reaches a obtained fraction of under-spacing of 2% if all pairs would have been spaced at ML-ROT spacing minima.

Note that the obtained error rates shall not be interpreted as actual probability of loss of runway separation since we here consider that all aircraft would be delivered exactly at the minima and without accounting for any ATC action which will not be the case operationally. In reality, most of the pairs would indeed be delivered with a separation buffer which would significantly reduce the risk of under-spacing.

Operationally, the ML-based ROT distance spacing reductions can only be applied with a separation delivery tool, providing, at least, for pairs with not applicable wake turbulence separation minima, a static chevron attached to the leader and at a distance corresponding to the applicable ROT spacing for the considered leader.

# 5. How ROCAT can be operated?

There are three ways ROCAT can be operated:

1. On a procedural basis, allowing ROT-spacing minima enhancement for a limited number of specific pairs of aircraft types
2. On a category/grouping basis defining reduced ROT distance spacing minima based on a grouping of the individual ROT spacing list established in Section 3.1.3.
3. On a leader-wise basis considering for each pair of flight the ROT spacing corresponding to that established in Section 3.1.3.

## 5.1. Procedural application with no HMI support

The first option to apply optimized ROT distance spacing is to define reduced ROT spacings for part of the traffic on a procedural basis.

Those aircraft types (and associated landing runway) shall be determined based on the ROT distance spacing found in the iROT distance spacing table. Some rounding of the spacing might be found necessary to allow delivery without additional separation tool.

## 5.2. Category-based application with light HMI support

The second option to apply optimized ROT distance spacing is to define a category-based **ROCAT** scheme defining **categories of aircraft based on their average ROT**, and associated applicable ROT distance spacing value, allowing to operate reduced ROT spacing for some of those categories.

Those categories shall be established based on a grouping of aircraft. For each group, the ROT distance spacing shall be taken as the largest ROT distance spacing found for that group of aircraft in the iROT distance spacing table.

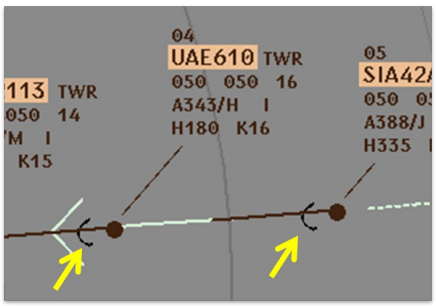
Some rounding of the spacing might be found necessary to allow delivery without additional separation tool.

A light HMI adaptation might be found necessary to provide new ROCAT categories in the flight labels.

Note that the categories can also correspond to WT categories (e.g., RECAT-EU categories).

## 5.3. Application with separation delivery tool support

iROT defines a scheme with individual ROT distance spacing behind aircraft types (for each runway) as function of their average ROT characterization. If a separation support tool is available (e.g., the TBS-ORD tool), a third option to apply ROCAT solution is to directly apply those distance-based ROT spacing minima can be, provided that they are displayed on the Controller Working Position through a chevron (the Final Target Distance-FTD- in the TBS-ORD tool) attached to the leader aircraft and at a distance corresponding to the applicable ROT spacing. This chevron can be complemented by another indicator supporting the Controller for the anticipation of compression effect between leader and follower before leader deceleration to final approach speed.




Note that those iROT minima can also serve as basis to define time-based minima from equivalent follower time-to-fly the iROT distance-based minima in low wind conditions following the TBS principle already developed and approved for wake turbulence separations.

# 6. ROCAT scheme examples

The benefits related to the used of ROCAT solution will vary depending on:

- The currently applied ROT spacing minima
- The potential for ROT distance spacing reduction (i.e., fraction of the traffic allowed to have reduced minima and amount of reduction)
- The way the minima are applied (i.e., procedural, category-based or iROT)

Some typical exemplary use cases are here provided.

## 6.1. Procedural part of traffic at 2.5 NM

For airports currently applying 3NM MRS and for which the surveillance capability allows for MRS reduced down to 2.5 NM, for pairs with no prescribed wake turbulence separation minima, a reduction of MRS from 3NM down to 2.5 NM can be allowed for part of the fleet.

For instance, if the runway exit locations are such that the lightest of ICAO MEDIUM WTC (e.g., CRJ7, CRJ9, E145, E170, E75S, E75L, E190, E195) are taking on average an earlier exit and hence have a lower average ROT below 50 s, 2.5 NM can be applied behind those aircraft flights. This could be applicable to all or part of the arrival landing runways depending whether this condition is satisfied or not for all of them. This would result in the definition of a ROCAT scheme combining ICAO WTC minima and optimized ROT distance spacing, provided in Table 3.

| Follower / Leader | SUPER | HEAVY | MEDIUM | LIGHT |
|---|---|---|---|---|
| SUPER | 4 | 5 | 7 | 8 |
| HEAVY | 3 | 4 | 5 | 6 |
| MEDIUM | 3 | 3 | 3 | 5 |
| CRJs/ERJs | * | * | * | 5 |
| LIGHT | * | * | * | * |

**Table 3: Example of ROCAT scheme with MRS reductions for CRJs and ERJs and with ICAO WTC scheme**

In another airport, it could be that because of their larger landing speed, the ROTs are on average lower for the heaviest of the ICAO MEDIUM WTC (e.g., A320 family, A220 family, B737 family) and below 50 s. 2.5 NM can then be applied behind those aircraft flights. This could be applicable to all or part of the arrival landing runways depending whether this condition is satisfied or not for all of them.

This would result in the definition of another ROCAT scheme combining ICAO WTC minima and optimized ROT distance spacing, provided in Table 4.

| Follower / Leader | SUPER | HEAVY | MEDIUM | LIGHT |
|---|---|---|---|---|
| SUPER | 4 | 5 | 7 | 8 |
| HEAVY | 3 | 4 | 5 | 6 |
| A220A320 B737NG-MAX | * | * | * | 5 |
| MEDIUM | 3 | 3 | 3 | 5 |
| LIGHT | 3 | 3 | 3 | 3 |

**Table 4: Example of ROCAT scheme with MRS reductions for A320 family, A220 family and B737 family and with ICAO WTC scheme**

## 6.2. Procedural part of traffic from 4 to 3 NM

For airports currently applying 4NM MRS, a reduction of MRS from 4NM down to 3 NM can be allowed for part of the fleet, provided that the ROT allows it and that no larger separation minima is prevailing (e.g., wake turbulence).

For instance, if it can be showed that, because of their larger landing speed, the ROTs are on average lower for the heaviest of the ICAO MEDIUM WTC (e.g., A320 family, A220 family, B737 family) and below 60 s, 3 NM can then be applied behind those aircraft flights. This could be applicable to all or part of the arrival landing runways depending whether this condition is satisfied or not for all of them.

This would result in the definition of a ROCAT scheme combining ICAO WTC minima and optimized ROT distance spacing, provided in Table 5.

| Follower / Leader | SUPER | HEAVY | MEDIUM | LIGHT |
|---|---|---|---|---|
| SUPER | 4 | 5 | 7 | 8 |
| HEAVY | 4 | 4 | 5 | 6 |
| A220A320 B737NG-MAX | 3 | 3 | 3 | 5 |
| MEDIUM | 4 | 4 | 4 | 5 |
| LIGHT | 4 | 4 | 4 | 4 |

**Table 5: Example of ROCAT scheme with MRS reductions from 4 to 3NM for A320 family, A220 family and B737 family and with ICAO WTC scheme**

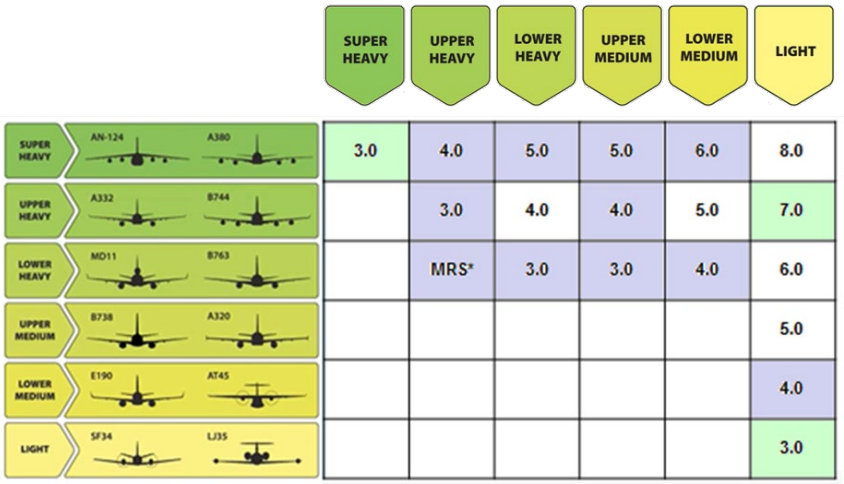
## 6.3. Combined ROCAT / RECAT-EU Categories

The ROCAT schemes can also be combined with the aircraft categories defined in RECAT-EU. The RECAT-EU categories are defined through:

- A split of the HEAVY category in two parts
  - UPPER HEAVY (e.g., A330, A340, A350, B747, B777, B787)
  - LOWER HEAVY (e.g., A300/A310, B767, DC10, MD11, B757)
- A split of the MEDIUM category in two parts
  - UPPER MEDIUM (e.g., A320 family, B737 family, A220 family, MD80/90)
  - LOWER MEDIUM (e.g., CRJ7/9, DH8D, E135/145, E170, E75S E75L, E190, F2TH)
- An increase of the LIGHT category to include all types with MTOM below 15 tons (instead of 7 tons in ICAO LIGHT WTC).

The corresponding wake separation minima are provided in Table 6.

An analysis of the average ROT for each aircraft type of each RECAT category can be performed to show for which category a reduced ROT distance spacing can be applied.




| | SUPER HEAVY | UPPER HEAVY | LOWER HEAVY | UPPER MEDIUM | LOWER MEDIUM | LIGHT |
|---|---|---|---|---|---|---|
| SUPER HEAVY | 3.0 | 4.0 | 5.0 | 5.0 | 6.0 | 8.0 |
| UPPER HEAVY | | 3.0 | 4.0 | 4.0 | 5.0 | 7.0 |
| LOWER HEAVY | | MRS* | 3.0 | 3.0 | 4.0 | 6.0 |
| UPPER MEDIUM | | | | | | 5.0 |
| LOWER MEDIUM | | | | | | 4.0 |
| LIGHT | | | | | | 3.0 |

**Table 6: RECAT-EU wake separation minima**

## 6.4. Deploying iROT with separation delivery tool

In case a separation delivery tool is used for approach, the iROT full solution can be deployed, hence delivering full benefits. For each leader flight, the tool will consider as ROT-spacing the iROT minimum. The tool will then display this spacing distance in the final target distance indicator (FTD in the TBS-ORD tool) provided that no larger constraint is applicable (e.g., wake turbulence).

The benefits related to full iROT deployment lie in the fact that

- no rounding up of the minima to the upper 0.5 NM has to be performed (2.6 NM or 2.8 NM instead of 3NM can be applied)
- no alignment of the spacing on the largest ROT spacing of the category has to be applied (e.g., each member of the A320 family could have different ROT spacing minimum).

## 6.5. Arrival Runway Throughput Benefits

Depending on the traffic mix and the ROT spacing constraint, the application of ROCAT or iROT (with spacing aid) can support up to 6-8% increase in arrival throughput in peak.

If combined with RECAT-EU, and with ORD spacing optimisation tool (enabling application of pair-wise separation), the gains can extend to beyond 10%.

# 7. ROCAT deployment considerations

The following elements should be considered when deploying an optimized ROT-spacing solution ROCAT minima:

- Ensuring traffic spacing **compatibility with other applicable separation and spacing constraints** and in particular
  - Wake turbulence separation minima
  - Surveillance minima
  - Gap spacing for mixed mode operations
- Ensure **correct aircraft type data filed into flight plans**
- Ensuring Air Traffic Controllers **appropriate training** on
  - ROCAT scheme and associated spacing minima if applying ROCAT category-based scheme
  - ATC automation support and separation delivery tool for managing increased complexity if applying iROT
- Ensuring **Aircraft Operators and Flight Crews awareness** of
  - Locally applicable ROT spacing based on ROCAT/iROT.
  - Operations at or close to spacing minima is associated to “High-Intensity Runway Operations” (e.g. minimizing runway occupancy time)
- Ensuring safety and in particular ROT monitoring in operations
- Regular **maintenance of iROT matrix** and particularly required if change in
  - Runway infrastructure
  - Traffic fleet

# ABBREVIATIONS

| | |
|---|---|
| ANSP | Air Navigation Service Provider |
| ATC | Air Traffic Control |
| ATM | Air Traffic Flow Management |
| ATS | Air Traffic Services |
| CAT | Category |
| EASA | European Aviation Safety Agency |
| EUROCONTROL | European Organisation for the Safety of Air Navigation |
| ICAO | International Civil Aviation Organisation |
| iROT | Individual Runway Occupancy Time |
| MRS | Minimum Radar Separation |
| MSS | Minimum Surveillance Separation |
| MTOM | Maximum certificated Take-Off Mass |
| MTOW | Maximum Take-Off Weight |
| NDA | Non-Disclosure Agreement |
| NM | Nautical Mile |
| NMD | EUROCONTROL Network Management Directorate |
| ORD | Optimum Runway Delivery |
| PWS | Pair-Wise Separation |
| R&D | Research and Development |
| RECAT | Re-categorisation |
| RMC | Roll Moment Coefficient |
| ROCAT | Re-categorisation based on ROT |
| ROT | Runway Occupancy Time |
| TBS | Time-Based Separation |
| WT | Wake Turbulence |

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