



The CREDOS Project

Final Activity Report

Abstract:

This document is the Publishable Final Activity Report of the CREDOS project.

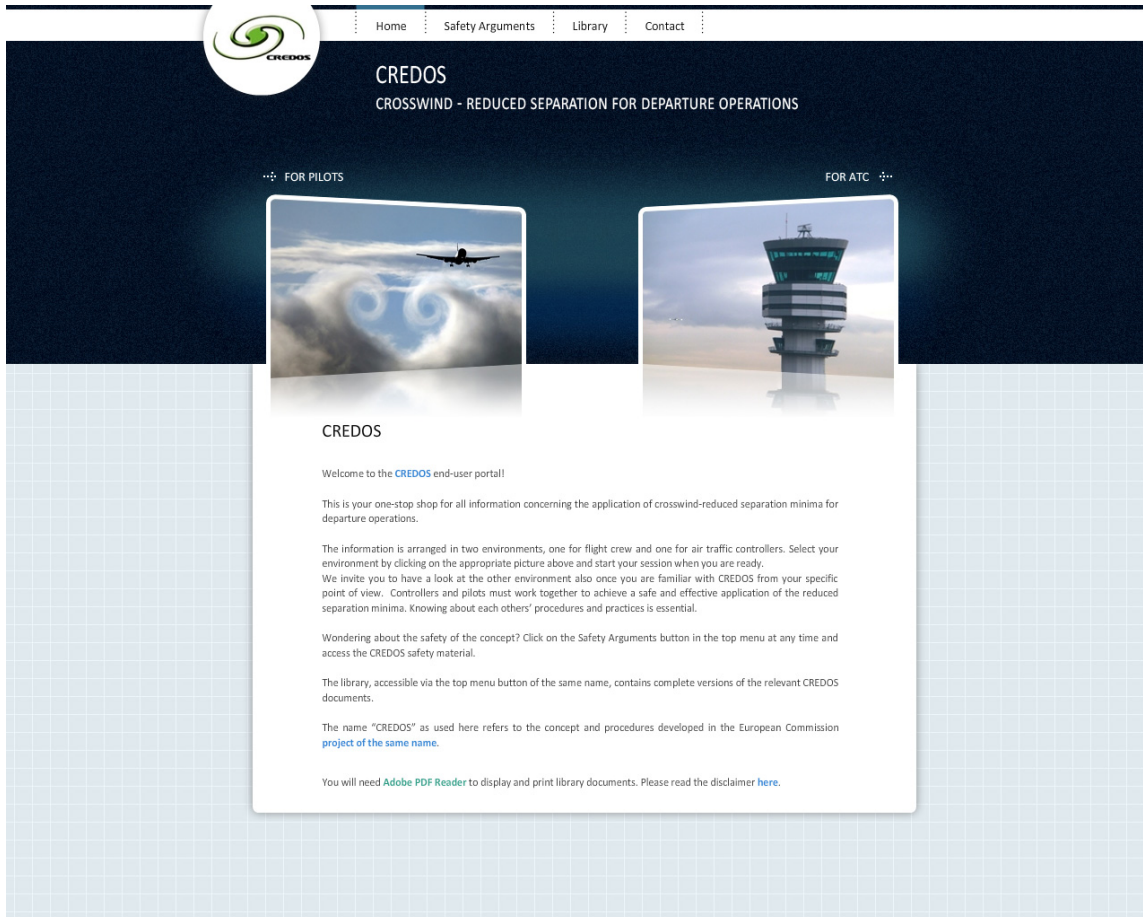
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Publishable executive summary

The CREDOS Project Website can be viewed at www.eurocontrol.int/credos

The CREDOS portal can be accessed through the following web link:
<http://credos.bluskysservices.com/>



Home Safety Arguments Library Contact

CREDOS
CROSSWIND - REDUCED SEPARATION FOR DEPARTURE OPERATIONS

FOR PILOTS FOR ATC

CREDOS

Welcome to the [CREDOS](#) end-user portal!

This is your one-stop shop for all information concerning the application of crosswind-reduced separation minima for departure operations.

The information is arranged in two environments, one for flight crew and one for air traffic controllers. Select your environment by clicking on the appropriate picture above and start your session when you are ready.

We invite you to have a look at the other environment also once you are familiar with CREDOS from your specific point of view. Controllers and pilots must work together to achieve a safe and effective application of the reduced separation minima. Knowing about each others' procedures and practices is essential.

Wondering about the safety of the concept? Click on the Safety Arguments button in the top menu at any time and access the CREDOS safety material.

The library, accessible via the top menu button of the same name, contains complete versions of the relevant CREDOS documents.

The name "CREDOS" as used here refers to the concept and procedures developed in the European Commission [project of the same name](#).

You will need [Adobe PDF Reader](#) to display and print library documents. Please read the disclaimer [here](#).

Background

ICAO separation standards for landing and take-off were implemented in the 1970's to protect an aircraft from the wake turbulence of a preceding aircraft. However research has shown that the transport and persistence of wake vortices are highly dependent on meteorological conditions, so that in many cases the ICAO standards are over-conservative. By developing a full understanding of wake vortex (WV) behaviour in all weather categories, separations could be reduced under certain suitable conditions.

The CREDOS project was studying the operational feasibility of this approach by focussing on the situation for take-off under crosswind conditions. Although this represents only part of the scope of application, the methods and tools developed by this project can be later used to cover arrivals and other meteorological conditions. The project used measurements of wake vortices taken at St Louis and Frankfurt airports to develop models of wake vortex behaviour. Using Monte Carlo simulation techniques these models have been used to establish safe separations under various crosswind conditions. An operational concept for crosswind departures has been developed and validated in accordance with the Operational Concept Validation Methodology.

The CREDOS project was funded by the European Commission (DG/RTD) within the Aeronautics and Space Work Program of the 6th Framework Program.

CREDOS was coordinated by the EUROCONTROL Experimental Centre.

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The project was performed by a consortium of the following organisations:

		Partner	Country
1	ECTL	EUROCONTROL Experimental Centre	France
2	DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V.	Germany
3	AD	Airbus Deutschland GmbH	Germany
4	NLR	Stichting Nationaal Lucht- en Ruimtevaartlaboratorium	Netherlands
5	M3S	M3 SYSTEMS SARL	France
6	ONERA	Office National d'Etudes et de Recherches Aérospatiales	France
7	UCL	Université catholique de Louvain	Belgium
8	TUB	Technische Universität Berlin	Germany
9	NATS	NATS En-Route Limited	United Kingdom
10	DFS	DFS Deutsche Flugsicherung GmbH	Germany
11	INECO	Ingeniería y Economía del Transporte SA	Spain

Note that the CREDOS project was performed in close collaboration with the Federal Aviation Authority (FAA). Initial plans for the FAA to be a full partner in the Consortium had to be abandoned due to legal complications, but the spirit of a collaborative project has been retained and the FAA had to all intents and purposes the status of a partner in this project.

Objectives

- To demonstrate the feasibility of a Concept of Operations allowing reduced separations for Single Runway Departures under crosswind. This will be done through the provision of proof in the form of:
 - A Safety Case (Functional Hazard Assessment to Preliminary System Safety Assessment)
 - A Human Factors Case
 - Analysis of expected benefits at selected European & North American airports
- To provide all stakeholders with the required information to facilitate the implementation of this concept where appropriate in the near-term (pre-2012):
 - Validation of the concept and support tools
 - Outline local Safety Case
 - Guidance on Benefits Assessment
 - Recommendations on Training & Technology requirements
- To increase the body of knowledge concerning wake vortex behaviour during initial climb phase of flight.

Achievements

The work of the project was divided into five work packages (WP).

WP 1 titled "Data Collection"

Wake and Wind

The CREDOS data were mainly collected by research measurement tools deployed for the project or from systems already installed on the airport since a certain time. In addition to these research tools, operational data available at airport such RADAR data, METAR, anemometer measurements also provided relevant information for the project.

US LIDAR

The Lockheed Martin Coherent Technology (LMCT) was made available to the project by the FAA through EUROCONTROL was operated by Volpe and supported by DFS. The system was deployed south the runway 25L in order to monitor the departures from the runway 25R.

The system was collecting data only for west wind operation for nearly 6 months and tracked more than 10.000 vortices mainly from heavy departures on runway 25R.

DLR LIDAR

The DLR 2 μ m pulsed Lockheed Martin Coherent Technology (LMCT) lidar was located close to the da Vinci house in the south-east edge of the terminal area. The lidar performed vertical scans in three different planes. One plane is oriented perpendicular to the flight path; the other planes

employ viewing directions shifted by 33.5 deg and 55 deg.

For departures on runway 07L the lidar was used for vortex characterization needed in CREDOS. For this purpose the lidar scanned perpendicular to flight direction and collected vortices generated at a nominal altitude of 170 m. This generation height assumes a rotation point after 3000 m and a climb angle of 7 deg. Since these values vary in broad bands, near ground effect (NGE) cases could also be expected. For the evaluation of wake-vortex properties, an interactive four-stage data processing algorithm was applied. First profiles of vortex tangential velocities were estimated from which vortex positions and circulations are derived. The error for vortex core position was determined to about 4.5 m in the vertical and 6.5 m in the horizontal direction and for circulation to 13 m²/s. Eddy dissipation rate can be determined from the second order structure function based on 5 min averages and a vertical resolution of 5 m.

ONERA LIDAR

The new ONERA wake vortex lidar results from research completed within ONERA/DOTA on 1.5 µm fiber lasers. This new technology makes it possible to consider more compact and less expensive systems. It is eye safe and out of visible range. The scanner sweeps space in a vertical plane according to a programmed sector. It is necessary to add to this unit a computer which controls the lidar and carries out signal processing.

During CREDOS EDDF1 campaign, 187 departures were measured by ONERA lidar during 8 days.

Weather

DFS WTR/RASS

The wind-temperature radar with radio acoustic sounding system, WTR/RASS, of DFS has been deployed in May 2004 as part of the development of DFS' wake vortices warning system, WVWS, at Frankfurt airport.

Every two minutes the WTR/RASS delivers 3-dimensional wind- and temperature profiles together with additional information about data quality, turbulence and other system related items. Normally wind profiles are available in the height band from 60 m up to 1500 m above ground level in 30 m increments. Due to technical restrictions the range of the temperature measurements ends around 1000 m AGL on average.

For the purpose of CREDOS a dedicated campaign was started in June 2006, until July 2007.

DLR SODAR

A Sodar with a RASS extension (METEK DSDPA.90-24, MERASS 1274 MHz) provides vertical profiles of the three wind components, vertical fluctuation velocity, and virtual temperature. The vertical resolution is adjusted to 20 m and the averaging time to 10 minutes. The lowest measurement height is 40 m and the instrument reaches maximum heights between 160 m and 300 m. Based on the assumption of isotropy, the rms value of turbulence can be calculated from the vertical fluctuation velocity. The Brunt-Väisälä frequency can be derived from the virtual temperature profiles. The Sodar/RASS system is complemented by a sonic anemometer with a sampling frequency of 20 Hz mounted on a 10 m mast which provides the three wind components, turbulent kinetic energy, and virtual temperature. Eddy dissipation rate can be determined from longitudinal spectra and structure function (2nd & 3rd order). Both instruments are operated permanently and are situated close to the DWD station in the middle between runways 25L and 25R (see Figure 2 in section 2.1.2).

Vertical profiles of the three wind components and temperature have been measured by SODAR/ RASS each 10 minutes from December 2006 to March 2007.

DFS METAR and weather data

Deutscher Wetterdienst, DWD, the German meteorological service provider is responsible for the provision of standardised meteorological data, such as METAR, TAF and SIGMET. For this purpose DWD operates anemometers, ceilometers, pressure- and visibility sensors on the airfield. The data, which is updated every ten seconds is sent to the responsible ATS-units, e.g. Frankfurt Tower and Frankfurt Approach. On June 10th 2006 DFS R&D unit started to store these data for subsequent analysis within the CREDOS project. The CREDOS data collection was conducted until July 2007.

The dataset contains wind-direction and –speed measured at three different locations. QNH, QFE, several runways visual range measurements complete the set of surface observations.

Aircraft Information

DFS Radar Data

For a reliable prediction of the areas where wake turbulence might constitute a risk for following traffic rather precise information about actually flown aircraft trajectories, including rotation point, initial climb rate, airspeed etc. is needed.

DFS Deutsche Flugsicherung GmbH has been collecting such surveillance data. For security reasons the data was retrieved through DFS' Test-RadNet, a system similar to the operational RadNet which collects the data from all Radars and distributes it to the concerned ATS-units. Due to its very nature, the test system has not such a high-redundancy and fail-safe layout as the operational RadNet. Nevertheless experience showed that periods where no data could be retrieved were rare.

Radar data have been collected for more than a year, i.e. from June 2006 until July 2007

US LIDAR data and radar data, WTR/RASS, METAR and other weather information were merged by DFS and constituted the main EDDF2 output.

Airline data analysis

Common indicator for wake turbulence encounters is a sudden upset of the aircraft's attitude with a speed, altitude or heading deviation as result. In most cases corrective actions are performed manually by the flight crew.

It is noticed that almost twice as many wake turbulence incidents are reported during the arrival phase than during the departure phase. During the departure phase aircraft mostly encounter wake turbulence from aircraft of the same ICAO wake turbulence category. Application of wake turbulence separation minima provides a low percentage of incidents with medium aircraft taking off behind heavy aircraft. During the arrival phase wake turbulence separation minima apply for medium aircraft landing behind heavy aircraft, but still a high percentage of incidents occur with this aircraft combination.

Possible cause is that aircraft are lined up in the same approach sequence with minimum separation under unfavourable weather conditions for wake turbulence. Reports of light aircraft encountering wake turbulence are not found in the dataset. During climb, descent, approach and landing, medium aircraft suffer more or less the same from similar aircraft as from heavy aircraft.

WP 2 titled "Data Analysis and Models"

Two measurement campaigns for wake vortices generated by departing aircraft at Frankfurt airport

have been carried out and the databases were provided through WP 1. The campaign EDDF-1 focused on aircraft departing from runway 07L where the measured 147 wake vortices were generated in a height range from 100 m to 400 m. The EDDF-2 long-term campaign measured 10,442 wake vortex tracks generated by aircraft departing from runway 25R. Due to the vortex generation height range from the ground up to 150 m, most vortices were generated in ground effect or descended into ground effect. The meteorological conditions spanned a wide range in terms of wind conditions, turbulence, and temperature stratification.

The crosswind thresholds obtained from the data analysis based on EDDF-1 and EDDF-2 depend on assumptions of the corridor width that has to be cleared from wake vortices to decrease separations. Assuming a corridor width of 200 m crosswinds of 3.9 – 4.4 ms⁻¹ are necessary to clear the corridor for a 60 s separation from wake vortices on a 95 % probability. However, these values can not be taken as they are, since no safety requirements or risk assessment is taken into account to make sure that present safety standards can be assured. Reducing aircraft separation from 120 s to 60 s under favourable crosswind conditions might result in less but more intense wake vortex encounters. The reason is that in the case of higher crosswinds there are less wake vortices in the area of interest but those which are still there are stronger since only 60 s old compared to 120 s within ICAO. Therefore the crosswind thresholds obtained in WP 2 have to be used in WP 3 and WP 4 to address safety and risk considerations.

Wake vortex prediction skill has been investigated for a number of model versions employing a scoring procedure which evaluates deviations between vortex predictions and measurements. The scoring results indicate good prediction skill if the onset of rapid decay out of ground effect is delayed by one time unit. As expected the scoring results confirm that crosswinds measured by lidar yield superior prediction skill of lateral transport compared to other wind measurement devices situated further away. Peculiarities of wake vortex behaviour during departures could not be identified. A very consistent view of lateral vortex transport measured by lidar and predicted by D2P could be achieved.

This indicates that the statistics of measured lateral transport are well suited to derive crosswind thresholds sought-after in CREDOS. It further indicates that the D2P model should be well applicable for the prediction of lateral vortex transport in the Monte Carlo simulation environment WakeScene-D which is used to support the definition of crosswind thresholds for reduced aircraft separations and to contribute to the CREDOS safety case.

The prediction models of UCL, i.e. the Deterministic/Probabilistic wake Vortex Models (DVM/PVM), also using a two-phase decay, were both assessed, and on both the EDDF-1 and the EDDF-2 databases. The DVM and PVM simulations were run using inputs as close as possible to the measurement conditions, and also using the “declared” measurement uncertainties. The results were compared with the provided experimental data, and quantified comparisons on the wake vortex positions and circulations were provided and discussed using statistical means.

The difference between the LIDAR processed Γ_{5-15} circulation (as provided in the EDDF-1 database) and the LIDAR processed total circulation Γ_{tot} (as provided in the EDDF-2 database) is also highlighted. In that respect, the influence of the distinction between the Γ_{5-15} circulation and the Γ_{tot} circulation on the prediction results (i.e., altitude and circulation DVM predictions) is further studied using the EDDF-1 database. Also studied is the influence, on the DVM results, of the extrapolation of the met. data, when not available. Finally, and for completeness, the “benchmark procedure” is also applied to the whole EDDF-1 database (in fact 138 cases out of the 147 cases that have enough data to make meaningful comparisons). Considering the quite high variability of the present data, the agreement between the DVM predictions and the measurements data is considered as quite good.

The DVM can thus also be used as part of the Monte-Carlo simulation environment WakeScene-D. For the PVM, using both databases, it appears that the predicted envelopes, obtained using the declared measurement uncertainties, are also quite reliable, again considering the high variability of

the provided circulation data. In order to obtain "better" predicted results (yet of course larger envelopes), one should rerun the PVM using input uncertainties which better reflect the true uncertainty of the provided data.

In the "benchmarking exercise" results of the two deterministic wake vortex prediction models, the DVM of UCL and the D2P of DLR, are compared for a small subset of the EDDF-1 database. Model input values are taken from the mean experimental values corresponding to the time of over-flight, and here considered as the "true" reference. For reference 16 cases, out of the 147 cases of the EDDF-1 database have been chosen.

For the benchmarking exercise, both wake vortex models (D2P and DVM) are computed from identical initial conditions specified by Airbus and based on aircraft and LIDAR data. The predicted vortex characteristics, i.e., lateral and vertical positions and circulation, of both models are confronted to the LIDAR measurements, comparing the running average of vortex characteristics (predicted by both models and "measured") and computing the rms deviation between the predictions and the measurements. An assessment depending on crosswind and headwind categories is also performed and reported.

It is noted that the sample size is really not sufficient for robust conclusion. However, for both models, the vortex predicted characteristics are in the range of the LIDAR data, under the given challenging atmospheric conditions. It is concluded that the wake vortex models (DVM and D2P) both represent the wake vortex transport and decay. From the data, an opportunity is indicated that the models could be used for the transport prediction under crosswind conditions, together with the appropriate probabilistic versions (PVM and P2P) or using an appropriate safety margin to be defined and applied (a proposition being also reported).

A Wake Vortex Detection Algorithm 'WAVENDA' was adapted for the detection of aircraft Wake Vortex Encounters (WVE), both for arriving and departing aircraft, using flight data recording data (FDR). The wake vortex detection algorithm was implemented using classification functions, based on the results of a discriminant analysis applied to a set of landing cases obtained in a previous project. These cases had been visually inspected for the occurrence of a WVE. Based on the results obtained and limited performance tests it is recommended to further explore the wake vortex detection classification by including other parameters, e.g. the product of vorticity and signal-to-noise ratio SNLR, so as to hopefully increase the successful detection rate from about 78% to at least 90%.

WP 3 titled "Risk Modelling & Risk Assessment"

The aim of this work package was to provide a simulation environment for the assessment of wake vortex hazard under different crosswind conditions and apply it to the departure situation used in the CREDOS concept.

The simulation environment should address the probability of a wake encounter as well as the severity of it. A risk analysis consisting of suitable simulation scenarios should support the definition of safe reduced separation distances for crosswind departures.

The necessary additional models were developed, while in sub-WP 3.2 several weather scenarios were simulated that allowed discovering different effects of wind on wake encounter risk during departure and giving an indication of the crosswind needed to allow safe reduced spacing.

A trajectory generation model has been developed to generate realistic distributions of departing aircraft's flight paths for Monte Carlo simulations using the tool WakeScene-D. This trajectory model has been validated with aircraft track data delivered by DFS during the project.

Piloted simulator tests of wake vortex encounters in two flight simulators were conducted with a number of licensed commercial pilots to gain experience about wake encounters during departure. Those tests generated a large database of simulated wake encounters flown with an A320 and an A330 flight simulator during departure that can be exploited for model development and validation. The data was used within CREDOS for development and validation of a pilot behaviour model for wake encounters during departure based on a Neural Net architecture and advanced severity criteria for assessment of the severity of wake encounters.

These additional models were integrated into the two simulation tools WakeScene and VESA providing a powerful simulation platform for risk assessment of wake encounters during take-off and departure. The new versions of these tools are referred to as WakeScene-D and VESA-D. They allow determining how many encounters are likely to happen in a certain scenario and how severe they are for the encountering aircraft. Relative assessments were made between a reference scenario and defined reduced separation scenarios.

Operational scenarios have been defined in WP 3 with input by the partners from other work packages Ref.: CREDOS Deliverable D3-11 to determine the simulation scenarios that needed to be assessed. The wake encounter probability and severity was then computed using WakeScene-D and VESA-D. Extensive analyses have been conducted on the simulation results regarding the influence of parameters like wind direction and magnitude or aircraft routing on encounter frequency and severity. The analyses revealed a significant effect of the veering of the wind with altitude, the so-called Ekman spiral, on encounter risk. This leads to the fact that crosswinds coming from the left of the departure runway on the ground generally lead to higher encounter probability above a certain altitude than crosswinds coming from the right (valid on the northern hemisphere).

Furthermore the simulations have shown that the routing of the aircraft in the departure corridor has a significant impact on wake encounter risk. Depending on how the departure routes are laid out, a crosswind with respect to the runway can become a headwind after a turn, increasing encounter probability, or it can transport vortices from one route into a neighbouring one.

All results however indicate that for a scenario with straight-out departure routes a crosswind of 8 kt is needed to sufficiently reduce wake encounter risk when reducing the departure spacing between Heavy and Medium type aircraft from 120s to 60s. For a realistic departure route layout additional constraints are needed. For the Frankfurt example used in the simulations a crosswind of 6-8 kt could be sufficient if it is made sure it is coming from the right of the runway. Alternatively a restriction to using only the northerly departure routes would have a similar effect than departing straight-out, allowing a crosswind threshold of 8 kt as well.

WP 4 titled "CREDOS Operational Concept and Validation"

The aim of this work package was:

The definition of the concept of operations, the refinement of this concept based on the CREDOS modelling and validation results, and requirements for the system (the procedures, user requirements, and system requirements).

The development of the validation strategy and plan, the execution of the different validation cases (business case, environmental case, safety case, and human factors case) and other activities necessary for safe introduction of CREDOS.

The validation of the concept of operations and Human Machine Interface requirements through the use of real-time simulation (with support of intermediate recommendations resulting from the human factors and safety activities).

The basic idea behind CREDOS is that, for departures, the wake turbulence separation criterion

may be relaxed on the runway and for the first part of the climb path when the crosswind is such that the wake turbulence generated by the preceding aircraft will have been blown out of the departure track of the succeeding aircraft. The benefits of the proposed concept would be a temporarily increase of the departure runway throughput in such a way that it absorbs capacity peaks or reduces departure delays. This increase occurs only when an aircraft of lighter wake category directly follows a heavier one and the CREDOS criteria are met. Only in such cases is there a potential for reducing the spacing between that aircraft pair compared to the wake turbulence separation that would otherwise have to be applied. The actual benefits would then also be dependent on traffic composition, usage of the runway and the SID structure. The safe application of CREDOS separation suspension would require new information to be considered by controllers. CREDOS is a wind-dependent concept. Consequently, the safe application of the concept requires the wind conditions to be monitored in the area surrounding the aircraft departure path. The range of the concept applicability is thus dependent on the wind monitoring capabilities of the airport (wind measurements, wind nowcast and/or forecast). At this stage, the CREDOS concept has been kept as generic and as simple as possible. The concept is thus to be considered rather as guidance material than as a description of one particular endorsed solution. A number of improvements are also envisaged for the future. The different validation cases have shown that, although there is clear potential from a Business Case, Environmental Case and Human Factors point of view, further work in the area of safety is needed. It is also concluded that the next step for crosswind concept validation should be aimed at performing one or more local implementation cases.

WP 5 titled "Stakeholder Communications & Marketing"

The aim of this work package was to manage all the mechanisms used by the project to effectively communicate the CREDOS concept to the full range of interested parties. The task began with a detailed stakeholder segmentation analysis and was followed by more specific actions for communicating with each identified group.

This work package also covered the main instruments of internal communication within the project, namely the project website, OneSky Teamsite and the VDR.

Information requirements of all stakeholders were considered and it was ensured that they were kept fully aware of the development of the CREDOS Concept and were sufficiently involved in its validation.

Two information packages, one for Air Traffic Controllers (ATCOs) and one for the pilots have been developed. Both information packages are presented in one single portal to encourage and facilitate the interest both the controllers and the pilots have for each others working environment. The CREDOS portal can be accessed through the following web link: <http://credos.bluskyservices.com/>

A Case Study of the implementation of CREDOS at Madrid-Barajas airport, showing the expected benefits, local safety measures, procurements, training and transition requirements, was provided.

A CREDOS project website was constructed and maintained, to be used for both internal and external communication of the projects achievements. It can be accessed at http://www.eurocontrol.int/eec/credos/public/subsite_homepage/homepage.html

A Validation Data Repository (VDR) as a means for monitoring the progress of the CREDOS concept validation was established.

Alignment of the work of the CREDOS project with developments in SESAR was monitored.