# Final Project Report

| Document information | |
|---|---|
| Project Title | Improving Vertical Profiles |
| Project Number | 05.06.02 |
| Project Manager | DSNA |
| Deliverable Name | Final Project Report |
| Deliverable ID | D000 |
| Edition | 00.01.03 |
| Template Version | 03.00.04 |
| **Task contributors** | |
| *DSNA* | |


***Abstract***

Project 05.06.02 objective was to investigate ways to reach a more widespread use of optimized profiles. Two options for improvements were addressed:

1/ Design solutions by considering procedural and airspace design improvements that can be achieved with current equipment

2/ Produce an advanced concept, aimed at overcoming current limitations through the definition of new system support tools for air traffic controllers and new aircraft functions

# Authoring & Approval

| Prepared By - *Authors of the document.* | | |
|---|---|---|
| Name & Company | Position & Title | Date |
| [redacted] (DSNA) | [redacted] | See Document History |

| Reviewed By - *Reviewers internal to the project.* | | |
|---|---|---|
| Name & Company | Position & Title | Date |
| [redacted] DSNA | [redacted] | 05/08/2016 |
| [redacted] DSNA | | 03/08/2016 |
| [redacted] EUROCONTROL | | 25/07/2016 |
| [redacted] THALES AVIONICS | | 29/07/2016 |
| [redacted] IAA | | 21/08/2016 |
| [redacted] AVINOR | | 05/08/2016 |

| Reviewed By - *Other SESAR projects, Airspace Users, staff association, military, Industrial Support, other organisations.* | | |
|---|---|---|
| Name & Company | Position & Title | Date |
| [redacted] NATS | [redacted] | 18/07/2016 |
| [redacted] NATS | | 18/07/2016 |

| Approved for submission to the SJU By - *Representatives of the company involved in the project.* | | |
|---|---|---|
| Name & Company | Position & Title | Date |
| [redacted] DSNA | [redacted] | 05/08/2016 |
| [redacted] EUROCONTROL | | 05/08/2016 |
| [redacted] THALES AVIONICS | | 05/08/2016 |
| [redacted] AVINOR | | 05/08/2016 |

| Rejected By - *Representatives of the company involved in the project.* | | |
|---|---|---|
| Name & Company | Position & Title | Date |
| | | |

| Rational for rejection |
|---|
| None. |

# Document History

| Edition | Date | Status | Author | Justification |
|---|---|---|---|---|
| 00.00.01 | 26/06/2016 | Draft | [redacted] | New Document |
| 00.00.02 | 29/07/2016 | Draft | | Document updated with partners' comments |
| 00.01.00 | 05/08/2016 | Final | | Final Document for submission |
| 00.01.01 | 26/09/2016 | Final | | Updated version according to SJU's assessment |
| 00.01.02 | 15/11/2016 | Final | | Updated version according to 2nd round assessment |

| | | | | |
|---|---|---|---|---|
| 00.01.03 | 25/11/2016 | Final | [redacted] | Updated with some considerations on ODP |

# Intellectual Property Rights (foreground)

This deliverable consists of SJU foreground.

# Acronyms

| Acronym | Definition |
|---|---|
| ABAS | Aircraft-Based Augmentation System |
| A/C | Aircraft |
| A-CCO | Advanced Continuous Climb Operations |
| A-CDO | Advanced Continuous Descent Operations |
| AMAN | Arrival Manager |
| ANSP | Air Navigation Service Provider |
| AO | Airline Operator |
| AOM | Airspace Organisation and Management |
| AoR | Area of Interest |
| ATC | Air Traffic Control |
| ATCO | Air Traffic Controller |
| ATM | Air Traffic Management |
| AU | Airspace User |
| CCO | Continuous Climb Operations |
| CDO | Continuous Descent Operations |
| CONOPS | Concept of Operations |
| DS16 | Dataset 16 |
| DOD | Detailed Operational Description |
| E-OCVM | European Operational Concept Validation Methodology |
| FAF | Final Approach Fix |
| FAP | Final Approach Point |
| FL | Flight Level |
| FMS | Flight Management System |
| FTS | Fast Time Simulation |
| H/H | High Density / High Complexity |

| | |
|---|---|
| ILS | Instrumental Landing System |
| INAP | Integrated Network and ATC Planning |
| LoA | Letter of Agreement |
| LSD | Large Scale Demonstration |
| M/M | Medium Density / Medium Complexity |
| MET | METereological services for air navigation |
| ODP | Optimised Descent Profiles |
| OFA | Operational Focus Areas |
| OI | Operational Improvement |
| OSED | Operational Service and Environment Definition |
| PMS | Point Merge System |
| RBT | Reference Business Trajectory |
| RMT | Reference Mission Trajectory |
| RNP | Required Navigation Performance |
| RTS | Real Time Simulation |
| RWY | RunWaY |
| SESAR | Single European Sky ATM Research Programme |
| STAR | Standard Terminal Arrival Route |
| TMA | Terminal Manoeuvring Area |
| XMAN | Extended Arrival Management / Cross Border Arrival Management |

# 1 Project Overview

Within SESAR, the Project 05.06.02, aimed to improve the current situation regarding vertical profiles of flights.

By considering procedural and airspace design improvements, Project 05.06.02 contributed to the development and deployment of approach procedures to fly environmental, economic optimised profiles and routes, by contributing to Solution #11: Continuous Descent Operations (CDO) (AOM-0702-A), i.e progressive implementation of procedures for CDO in higher density traffic or from higher levels, optimised for each airport arrival procedure, assisted by airspace design which integrates arrival and departure streams.

Solution #11 identified the key factors to enable the realisation of continuous descent operations in H/H, which are the predictability of the arrival trajectory (i.e. flight crew need to be informed of the whole flight path from the En Route airspace to the Final Approach in order to compute the optimum vertical profile) and flexibility for aircraft during the descent (i.e. when there are no altitude or speed restriction during the descent, aircraft are able to use their preferred descent profile). This was validated with improved procedure design.

Considering an advanced concept definition, Project 05.06.02 also proposed a V1 maturity level concept document (according to the E-OCVM methodology, ref. [5]) that can be used as an input notably for SESAR 2020.

## 1.1 Project progress and contribution to the Master Plan

The methodology was based on 3 main steps:

- Produce an initial documentation that would provide direction and support the rationale of the improvements. This documentation is made of the "State of the Art" (D01) and the "Airborne Recommendations for Procedural Design" (D03). Those documents constituted an important reference for the project. The following steps were made of the improvements themselves.
- The improvements were made by two different steps. The first step corresponded to the procedural improvements. Those were justified by the statement that current operations could noticeably be enhanced by taking into account environmental constraints in the process of procedure design. The tools used for validations were modelled based-simulations, real time simulations and finally a live trial.
- To move beyond that, advanced system support would be required, which is what this next step was about and that can be therefore considered as a natural evolution of previous work. For defining this "advanced concept", comprising new system support tools for air traffic controllers and new aircraft functions, the intent was to overcome limitations that would possibly not being overcome with the current means.

The project 05.06.02 was **initially** aiming at contributing to deliver the following Operational Improvements (OIs):

- For the procedural improvements:
    - AOM-0702-A: Continuous Descent Operations (CDO)
    - AOM-0705-A: Continuous Climb Operations (CCO)1
- For the advanced concept:
    - AOM-0702-B: Advanced Continuous Descent Operations (A-CDO)
    - AOM-0705-B: Advanced Continuous Climb Operations (A-CCO)

1 Following the recommendations in SE#3 R5, the OI steps AOM-0702-A has been updated and AOM-0705-A removed in DS16

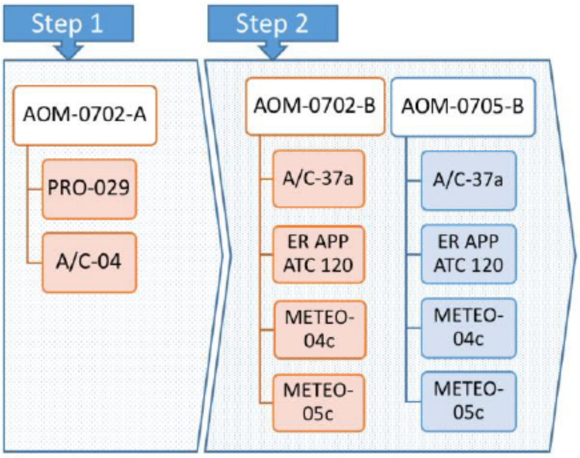
For the project, some of the enablers were mainly supporting means for the Solution while others were not addressed. Furthermore, the project did not address equally the above listed OIs.

Several exercises addressed indeed the above procedural improvements.

For AOM-0702-A, there are 2 V2 exercises and 1 V3 exercise that have been conducted, at the end of the project, AOM-0702-A was assessed at a V3 level of maturity.

For AOM-0702-B and AOM-0705-B the project focussed on providing a concept of operations for continuous descent operations and only partially addressed the matter of continuous climb operations in the context of an advanced concept with a V1 level of maturity (on the basis of the 5.2 Step 2 DOD [7], consistent with SESAR 2020 Initial Transition ConOps [8] and the position of SESAR Airspace Users on direction of research in Step 2 [10]). Furthermore, some early exercises could also be associated to AOM-0705-B: 1 V2 exercise and 1 V3 exercise (nevertheless this last exercise addresses more departures in the way they interact with arrivals more than strictly CCOs).

Therefore, the OIs/enablers actually addressed by the project can be found below:




The contribution of this project to the ATM Master Plan was to focus on the OIs below, supporting the future deployment of SESAR operational improvements and is described in the following table from DS16:

| Code | Name | Project contribution | Maturity at project start | Maturity at project end |
|---|---|---|---|---|
| AOM-0702-A | Continuous Descent Operations (CDO) | The project proposed notably a concept derived from the Point Merge concept while still partially relying on ATCOs' vectoring skills : Vectoring to Merge Point. | V1 | V3 |
| AOM-0702-B | Advanced Continuous Descent Operations (A-CDO) | The project provided a concept of operations for this OI | V0 | V1 |
| AOM-0705-B | Advanced Continuous Climb Operations (A-CDO) | As described above the project partially addressed the matter of continuous climb operations in the context of an advanced concept notably in very preliminary studies. | V0 | V1 |

## 1.2 Project achievements

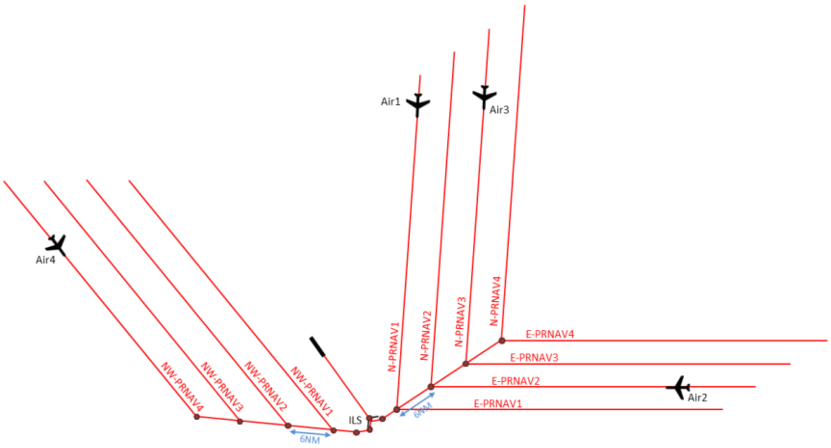
Main results for procedural improvements activities are linked to the outcome of the achieved corresponding exercises:

1) Model-based simulations were conducted in 2011, based on Stockholm/Arlanda. These simulations investigated the impact of speed constraints in the climb phase, and the potential improvements that might be gained by allowing Airspace Users to fly departure/climb speeds closer to their ‘preferred operational speed’, rather than restricting them to 250kts below FL100.

The simulations also provided some initial insight into gains that might potentially be harvested if arrival speeds were to be more harmonised across the arrival operation – as per the Swedish/Gothenburg operation of published arrival speeds.

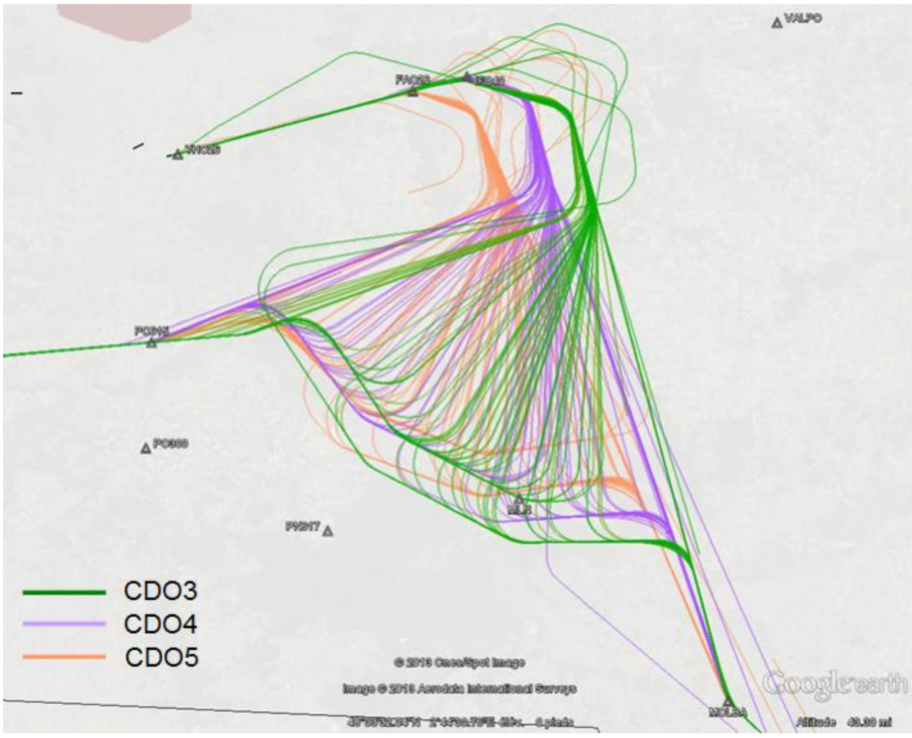
Some fuel-efficiency gains were recorded in the simulations but further analyses would be needed to confirm these initial conclusions.

2) Model-Based-Simulations on Toulouse tested a new procedural design for a M/M environment based on closed loop parallel arrival branches that can be seen below.



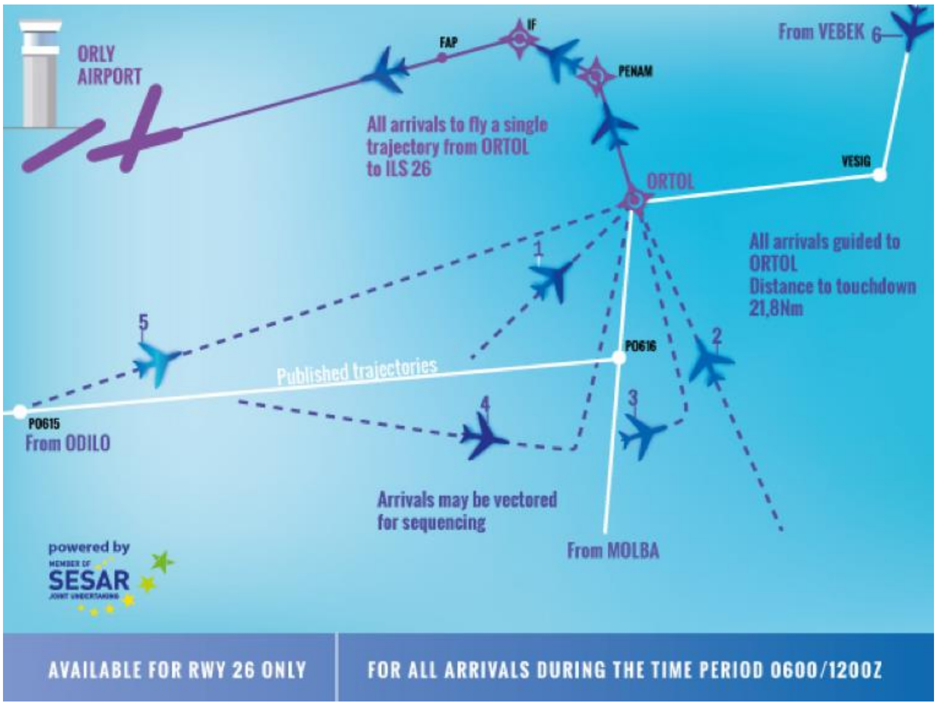

The results of those initial simulations were matured and confirmed during V3 Real Time Simulations and demonstrated several benefits compared to the baseline: reduced fuel consumption and flight time for arrivals, less potential conflicts between A/C and reduced tactical workload. The concept was well accepted by ATCOs, although it could be improved to be fully usable, notably in H/H, with the addition of new tools for ATCOs. The concept was very promising but only tested in Toulouse-Blagnac TMA. From this perspective and because no ‘integrated’ validation, especially as integration in the cockpit is concerned (indeed only qualitative feedback/recommendations are available), have been conducted, this concept variant is actually not considered fully V3 in M/M.

3) Some design options, based on a PMS principle were also tested in the context of the Paris Orly approach with the support of Real Time Simulations, principle illustrated below.




The qualitative and quantitative measurements performed were globally consistent. In terms of feasibility, the overall feedback from the core team was positive. The different CDO options were considered as providing benefits: less frequency load (up to -11%pt at the radar position compared to the baseline), increased availability (-25% of instructions in approach) and continuous descent enabled (aircraft maintained at higher level with reduced length of level off at low altitude) compared to today. According to the ATCOs, those benefits were reported as maintaining current level of safety and capacity. The capacity (runway spacing) was estimated as equivalent to today although the new procedures would require an adaptation of ATCOs' working methods to sequence aircraft: use of speed to refine spacing without or a few use of vectors. Furthermore, trajectory predictability improves ATCOs' situational awareness. The main limitations raised were the potential loss of vectoring skills and potential conflicts between arrivals and the route for eastbound departures.

4) Furthermore, the project proposed also a procedural design, still based on closed loop procedure to the ILS while allowing some vectoring. This principle is illustrated next page.




This new design, based on what the project named the Vectoring to Merge Point concept, was tested during RTS, with the objective to obtain controller acceptance before performing flight trials and to get some initial trends regarding noise impact, flight efficiency and flown trajectories. The positive corresponding early trends were confirmed during live trials. ATCOs acceptance was confirmed, notably a positive impact on situation awareness although some concerns were raised under high traffic conditions (perception of a reduced vectoring area). Furthermore, a large majority of pilot did not report any difficulty related to the procedure. The perceived level of capacity (obtained through questionnaires) in the arrival area was considered as rather deteriorated by a majority of the controllers (due to a reduced vectoring area). This should be further investigated and in particular whether this perception is linked to the current practices of a rather late sequencing combined to the lack of practice of the new technique, or to the intrinsic difficulty to further anticipate actions.

The perceived level of safety (obtained through questionnaires) was considered as equivalent. The noise footprints calculated by using radar tracks show a slight reduction of the number of inhabitants exposed to noise. Compared to the baseline scenarios considered, the analysis of radar tracks with the model used showed equivalent fuel consumption and associated $CO_2$ emission per aircraft in the approach area. The slight increase of distance flown (+0.9NM or +2.1%) being compensated by the increase of altitude (+523ft or +7.0%) thus leading to a neutral value of the fuel efficiency indicator (-0.7%).

For the advanced concept:

The project proposed a concept based on advanced operations, on the basis of the 5.2 Step 2 DOD and consistent with SESAR 2020 Initial Transition ConOps, where A-CDOs are facilitated in medium and high density/complexity environments at the strategic and pre-tactical planning horizons respectively. The facilitation is achieved through a process/service referred as an A-CDO Enabling Process either integrated within the scope of the RBT reconciliation process or operating as a subsequent process on a RBT already impacted by several preceding processes. Regarding the issue of process concurrency, it was suggested that the A-CDO Enabling Process could be under the supervision of INAP. The project produced a document that details the corresponding operational concept.

## 1.3 Project Deliverables

The following table presents the relevant deliverables that have been produced by the project.

| Reference | Title | Description |
|---|---|---|
| D01 | Step 1 State of the art | The deliverable reports on current practices, addresses the outcomes of projects dealing with the issue of vertical profiles, identifies needs and blocking points and proposes initial propositions of improvements (procedures and systems) |
| D03 | Step 1 Airborne Recommendations on Procedures Design | This deliverable proposes recommendations from the airborne side to be considered in ground procedure design, in order to take more efficiently into account aircraft constraints and operations |
| D33 | Procedural Improvements final OSED | This deliverable takes into account the results from both fast time simulations and real time simulations and propose recommendations on procedural improvements |
| D31 | CDO at Orly OSED | This deliverable corresponds to the CDO at Orly OSED |
| D32 | CDO at Orly VALR | This deliverable synthesis results from simulation activities (FTS and Mock Up) and propose recommendations on procedural improvements for the Orly TMA. Corresponds to PMS for Orly. |
| D34 | Procedural Improvements Validation Report | This deliverable proposes the Validation Report of the Procedural Improvements Step 1 V3. This deliverable corresponds to Parallel Legs concept. |
| D57 | CDO at Orly RTS support assessment Validation Report | This deliverable synthesis results from simulation activities designed to support the flight trials for the Orly TMA. This deliverable corresponds to Vectoring to Merge Point. |
| D48 | CDO at Orly Live Trials Validation Report | This deliverable synthesis results from preliminary/simulation activities (FTS and RTS) and the live trials, it also proposes recommendations on procedural improvements for the Orly TMA |
| D46 | CDO Step 1 OSED | This deliverable corresponds to the OSED at Solution #11 level |
| D47 | CDO Step 1 SPR | This deliverable corresponds to the SPR at Solution #11 level |
| D07 | Parallel Legs Concept Variant | This document gathers the Safety and Performance Requirements relating to the concept defined for the improvement of the vertical profile in medium traffic density environment through closed loop flight procedure and operating method: Parallel Legs |
| D58 | Step 2 Concept of Operations for Improving Vertical Profiles | This document details the operational concept corresponding to the advanced concept. |

## 1.4 Contribution to Standardisation

Standardisation considerations are mainly covered by Project's partners' involvement:

- AIRBUS: ICAO 9931, PARC…
- THALES: EUROCAE/RTCA WG78/SC214

... and Airspace Users involvement:

- Constraints in Procedure Design
- Aircraft Performance Capabilities (For example Bank angle limitations, statistical methods for wind scenarios…)
- ICAO Procedure Design

Furthermore, the Project organized coordination with the C.3 project (Maintain Standardization and Regulatory Roadmaps) concerning standardization.
As a matter of fact, some early operational requirements expressed by the project were considered relevant for international standardisation.
Two activities were notably identified in which the project could have contributed:
- Update of ICAO Doc 9931 for Continuous Descent Operations (CDO)
- Continuous Climb Operations (CCO) Manual (under development)

The documents produced by the project and considered relevant from this perspective were shared with the people in charge of the implementation of the standards and regulatory management process within SESAR.
The progresses made on this matter would need more coordination in order to be clarified and further needs and/or work to be identified. At the time this report was completed, there were indeed no further specific discussions and feedbacks made on the material provided. To go a step further it would be relevant to propose the latest recommendations regarding procedure design and phraseology to the standardisation groups for consideration.

## 1.5 Project Conclusion and Recommendations

The project made a synthesis of the existing blocking points and issues that prevent a large deployment of CDO in context of high traffic density. The uncertainty associated to the flight profile of the aircraft when flying in Continuous Descent is the main blocking point that avoids widespread deployment of CDO operation in high traffic density. Therefore, the project highlighted the difficulty to satisfy at the same time the airborne needs (i.e. freedom regarding vertical profile and speed) and the ATC needs (i.e. reduction of uncertainty regarding altitude and speed of the aircraft in order to ensure sequencing and separation). These two needs are contradictory and consequently, in high traffic load, ATCO tend to reduce the freedom (through tactical intervention) in order to reduce uncertainty.

The project proposed procedure design concept variants based on the following features:

- Arrival procedures (STAR) design that facilitates sequencing with fewer tactical interventions.
- Procedure design that is optimised to support separation of departure and arrival flows with fewer tactical interventions.
- In addition to these new procedures, appropriate operating methods are implemented to facilitate the realisation of Continuous Descent Operations.

Main recommendation on airborne side in order to perform Continuous Descent Operations concerns the predictability of the trajectory, i.e. be informed as early as possible of the ATC-planned constraints for the arrival and approach trajectory, possibly including AMAN planned time, and expected vertical constraints foreseen by ATC for the flight.

In case an altitude restriction is necessary (for separation or sequencing purpose), to prefer “flexible” altitude restrictions. This recommendation is applicable for both procedure design (for strategic restrictions) and operating method (for tactical restrictions). In case a speed restriction is necessary (for separation or sequencing purpose), to define them as close as possible to the FAF/FAP.

Those considerations are of course a lot more detailed in the OSED at Solution level ([24]), notably by detailing procedural design options. As each and every TMA is different, so is its corresponding constraints, use cases defined in this document give a better view of the projects’ propositions. Furthermore, the project acknowledge the fact that the an initial documentation produced (State of the Art [12] and Airborne recommendations for procedural design [14]) would need to be updated in order notably to take into account evolutions of FMS capabilities and behaviour.

For the advanced concept, the operational concept proposed by the project is in its early stage of maturity and would need further investigation to improve in maturity. The concept is notably based on assumptions which are expected to be matured to operational requirements within SESAR2020 that still remains to be verified. Furthermore, a need for closer attention at V2 level in a number of hotspots or problem areas has also been identified.

Furthermore, project 05.06.02 and LSD.01.02 Optimised Descent Profiles (ODP) share many considerations such as the fact that vertical profile optimisation should be part of every initiative affecting procedure design or airspace reorganisation, even though in densely used airspaces optimum profiles might not be achievable most of the time. Principles highlighted by the ODP demonstration are endorsed by project 05.06.02 (keeping the procedure as simple as possible with as few restrictions as possible, as many as necessary and leaving room for the flexibility required, etc.) and both highlighted that specific solutions could only be negotiated locally. In both cases a trade-off is identified in high density traffic areas between fully optimised trajectories and capacity in the current airspace structure. In addition to some recommendations, shared with project 05.06.02, ODP identified some specific ones that could be interesting (additional elements can be found in [11]) notably regarding flexible LoA procedures (e.g. seasonal handover conditions, RWY dependent handover conditions) and the need to develop adapted tools dedicated to the calculation of vertical flight efficiency.

Even though flight efficiency improvements were limited, ODP is seen as a significant first step for future optimisation efforts:

- It continued to establish awareness about flight efficiency for ANSP daily work.
- It showed the importance for collaboration between airlines and ANSPs: an optimised design should take constraints and needs of both parties into account: ATC (separation) and cockpit crews (FMS behaviour, potential weather impact). In some cases, although new STARS, based on higher handover levels and thus optimised descent calculations have been implemented, Airline Operators (AOs) observed some negative impact on flight efficiency compared to purely tactical improvements.
- It launched the work on the connection between CDO and current AMANs in use. Long-term development of future XMANs involving AOs is an important enabler to allow more and better CDOs.

# 2 References

[1] SESAR Programme Management Plan, Edition 03.00.01

[2] European ATM Master Plan

[3] Multilateral Framework Agreement ("MFA") signed between the SJU, EUROCONTROL and its 15 selected members on August 11, 2009, amended on 14 June 2010, 19 October 2010 and 2 July 2012

[4] 'Deployment Programme 2015", SESAR Deployment Manager, 26th November 2015

[5] European Operational Concept Validation Methodology (E-OCVM) - Latest version

[6] SESAR B01 D84 IR Dataset16 Release Note - Consolidated deliverable with contribution from B.04.02 and B.04.03, 16/06/2016, Ed. 00.01.01

[7] SESAR B04.02 D105 SESAR Concept of Operations Step 2 Edition 2014, Ed 01.01.00, 2014/12/16

[8] SESAR B.04.03 D74 ADD Step 1, Edition 2013, Ed 00.01.13, 04/07/2014

[9] SESAR D68 Initial Transition ConOps SESAR 2020, Edition 2015, Ed 00.01.00, 07/12/2015

[10] SESAR Airspace Users Office "Airspace Users vision on additional SESAR Research and Innovation on Fuel Efficiency", V1.0, May 2015

[11] SESAR LSD.01.03 –D03- Demonstration Report, 14/10/2016

[12] Project_05.06.02-D01 - State of the Art, 26/01/2012

[13] Project_05.06.02-D02 – Validation Plan Step1 V2, 27/07/2011

[14] Project_05.06.02-D03 - Step 1 Airborne Recommendations on Procedures Design, 31/01/2012

[15] Project_05.06.02-D07 - Parallel Legs Concept Variant, 05/07/2016

[16] Project_05.06.02-D22 - Validation Plan Step 1 V3, 24/01/2012

[17] Project_05.06.02-D25 - Preliminary OSED, 30/04/2012

[18] Project_05.06.02-D30 – Validation Plan CDO at Orly, 21/06/2012

[19] Project_05.06.02-D31 - CDO at Orly OSED, 29/06/2012

[20] Project_05.06.02-D32 - CDO at Orly VALR, 21/03/2014

[21] Project_05.06.02-D33 - Procedural Improvements final OSED, 04/06/2013

[22] Project_05.06.02-D34 - Procedural Improvements Validation Report, 16/04/2014

[23] Project_05.06.02-D45 – Validation Plan CDO at Orly Live Trials, 08/09/2015

[24] Project_05.06.02-D46 - CDO Step 1 OSED, 22/04/2016

[25] Project_05.06.02-D47 - CDO Step 1 SPR, 27/06/2016

[26] Project_05.06.02-D48 - CDO at Orly Live Trials Validation Report, 02/03/2016

[27] Project_05.06.02-D49 – Initial D05 "Step 2 Advanced Concept of Operations", 15/09/2014

[28] Project_05.06.02-D56 - Validation Plan CDO at Orly RTS Support, 23/10/2015

[29] Project_05.06.02-D57 - CDO at Orly RTS support assessment Validation Report, 27/10/2015

[30] Project_05.06.02-D58 - Step 2 Concept of Operations for Improving Vertical, 22/04/2016

**-END OF DOCUMENT-**