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DYNCAT

DYNAMIC CONFIGURATION ADJUSTMENT IN THE TMA

This deliverable is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 893568 under European Union's Horizon 2020 research and innovation programme.

Abstract

DYNCAT aims at enabling more environmentally friendly and more predictable flight profiles in the Terminal Manoeuvring Area (TMA), namely on approach, by supporting the pilots in configuration management. Approach operations at busy airports are louder and less fuel efficient than they could be. One way to remedy this situation is to assist pilots to better handle the current restrictions and constraints as well as weather conditions. Success hinges on the pilots' skills and their access to important information like the optimised flaps sequence.

The DYNCAT Solution sets a course for more environmentally friendly and more predictable flight profiles in the terminal manoeuvring area, or TMA. It supports pilots in their energy management task during the arrival phase. By analysing the mismatch of aircraft and air traffic control procedures, it proposes improvements to on-board and ground operations. This includes the identification of the possible need of regulatory changes for ATM. The project also assesses the Solution's ecological and economical potential.

In this context, this document updates and supersedes the Preliminary System High-Level Specification (Deliverable D3.1 [3]) following the conduction of the piloted Real-Time Simulation exercise in WP4. The update's main objective is to adjust the high-level system requirements where necessary to match the DYNCAT prototype that has been implemented during the evaluation. Indeed, some modifications were brought to the Solution prototype in order to take into account the preliminary operational feedbacks and the maturity assessment of the initial requirements during the prototyping phase.

This new version of the system specification relies on the DYNCAT Function Experimental Implementation Report (Deliverable D3.3 [3]). It will support the further work beyond DYNCAT with a reliable definition of the available Flight Management System (FMS) and Cockpit Display System (CDS) prototypes.

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1 Introduction

1.1 Background

DYNCAT aims to improve the situation in the TMA related to noise exposure and fuel consumption. Part of the Work Package that in overall aims at prototyping the operational concept for further evaluations, the present activity provides a final specification based on the prototype implemented in the piloted Real-Time Simulation by the software engineers involved in DYNCAT project. Bases for this specification are the outcomes of Work Package 2, specifically the Final Operational Concept Document (Deliverable 2.4), and of Work Package 3, specifically the Preliminary System High-Level Specification (Deliverable D3.1 [3]) and the DYNCAT Function Experimental Implementation Report (Deliverable D3.3 [3]).

This document provides the extended and enhanced requirements from the Preliminary System High-Level Specification (Deliverable 3.1 [3]) based on the outcomes of the Work Packages 3 (i.e. Proof of Concept) and 4 (i.e. Environmental Benefits Quantification).

1.2 Purpose and Structure of the Document

This Final System High-Level Specification is the last deliverable of the Work Package 3 in which the DYNCAT Solution has been prototyped as a new capability of the Flight Management System (FMS).

Starting from the Operational Concept Document of the DYNCAT project, the objective of this document is to “convert” the DYNCAT concept into a high-level technical system specification, in order to reflect the prototype content used for the piloted evaluations.

This document first presents the differences between the current methods and the new operating methods proposed by DYNCAT in order to introduce the expected benefits. It presents the technical items that have been selected from the Final Operational Concept Document (Deliverable D2.5 [9]) in order to prove the feasibility and the value of the Solution. It specifies the avionics systems involved in the realisation of the prototype, namely the Flight Management System (FMS) and the Cockpit Display System (CDS).

It describes specifically the FMS and CDS systems into which the DYNCAT capability has been mapped during this project, with the technical constraints, assumptions and high-level requirements related to the implementation. However, the only product and system under test is the Flight Management System, and all the other modifications were made to support the FMS validation, including the CDS evolutions. Indeed, in this project, the CDS is “only” considered as the way to provide the pilots with the information computed by the FMS and required to support the energy management task. The objective was not to validate the way the information was presented into the cockpit, but to validate that the data computed by the Flight Management System and provided to the pilots will enable more environmentally friendly flight profiles.

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1.3 Acronyms

The following table contains a list of acronyms used in this report.

Acronym	Meaning
4D	4 Dimensions
ADS-C	Automatic Dependent Surveillance - Contract
AAL	Above Airfield Level
ALT	Altitude
AMAN	Arrival Manager system
AOC	Airline Operational Communications
ATC	Air Traffic Control
ATCO	Air Traffic Control Operator
ATM	Air Traffic Management
CDA	Continuous Descent & Approach
CDS	Cockpit Display System
CPDLC	Controller Pilot Data Link Communication
CSTR	Constraint
D<no.>	Deliverable <no.>
DECEL	Deceleration pseudo-waypoint (FMS transition from descent to approach phase)
DTD	Distance to Destination
DTG	Distance-To-Go
DYNCAT	Dynamic Configuration Adjustment in the TMA
EPP	Extended Projected Profile
ER	Exploratory Research
FAF	Final Approach Fix
FCOM	Flight Crew Operating Manual
FCU	Flight Control Unit
FMS	Flight Management System
FPLN	Flight Plan
H2020	Horizon 2020
HDG	Heading
ITA	Indicated Time of Arrival
KOM	Kick-Off Meeting
MCDU	Multiple Control Display Unit
MFD	Multi-Functions Display

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Acronym	Meaning
ND	Navigation Display
OCD	Operational Concept Document
PFD	Primary Flight Display
PJ	SESAR Project
PRT	Permanent Resume Trajectory
RTA	Required Time of Arrival
SESAR	Single European Sky ATM Research
SOP	Standard Operating Procedure
SPD	Speed
T<no.>	Task <no.>
TMA	Terminal Manoeuvring Area
VD	Vertical Display
VDEV	Vertical Deviation
VFE	Maximum flaps extension speed
VMAN	Manoeuvring speeds
VS	Vertical Speed
WP	Work Package
WPL	Work Package Leader

Table 1: Acronyms used in this report

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2 System operational service

This section is very similar to the one in the Preliminary System High-Level Specification (Deliverable 3.1 [3]) with the objective to keep a readable and understandable standalone document. It provides a short synthesis of the Operational Concept which is the major input for this technical specification. The objective is first to remind and focus on the current and desired ground and airborne practices, in order to well derive the required evolutions for DYNCAT operational implementation and correctly identify the impacts on the systems.

2.1 Previous operating method

2.1.1 Ground practices

As described in the Deliverable D2.5 [9], ATM systems are often enhanced by an Arrival Manager (AMAN) system, which provides additional information to the ATC controller with respect to the arriving flights, e.g. the expected arrival time and the arrival sequence at the TMA entry. To establish a dedicated sequence for final approach and landing, AMAN systems are capable to output a time offset for every flight in the sequence, representing time to lose or to gain while in the arrival phase. The controller is then responsible for giving appropriate and corresponding instructions to the pilots to meet the time offsets and accomplish the selected sequencing while maintaining the aircraft separation at all times.

In case ATM systems are not enhanced by an AMAN, the Air Traffic Controller (ATCO) is used to maintaining separation employing classical methods based on lateral, vertical and speed instructions.

According to Critical Analysis of Current Operations (Deliverable D2.3 [1]) document, for Zurich airport, a large fraction of flights performs descent and approach phases under high communication with the arrival controller:

- Very few flights have no lateral instruction (around 3%), whereas most of the flights receive at least 3 lateral instructions.
- The same distribution can be observed on vertical instructions: 3 or more vertical instructions are standard for the flights.

That means, for most of flights, that the FMS managed modes are not available neither on the lateral plan nor on the vertical plan. Thus, the energy management task is transferred to the pilots with very limited support from the systems.

The flight results also show that the ATCO might also provide the "track miles" or “Distance-To-Go” (DTG) which indicates to the pilot the approximate remaining distance to the runway threshold. The data analysis demonstrates that the given distance often greatly differs from the distance actually flown by the aircraft. A reason for this is that the planned sequence of inbound aircraft can change over time but the track miles are, for the majority of the flights, communicated only once. That means that the pilots do not always benefit from the latest information about the remaining distance to fly. It has also been reported that shorter DTGs than expected are sometimes intentionally given to the pilots to make them execute a descent in a more pronounced manner.

2.1.2 Airborne practices

According to Critical Analysis of Current Operations (Deliverable D2.3 [1]), safe and efficient landing operations of the individual aircraft from the pilot's view are mainly based on the procedures laid down by the operator in the Flight Crew Operating Manual (FCOM). It means following a sequence of configuration changes (extension of the high-lift system in several steps, extension of the landing gear) with associated changes in airspeed. However, these ways to operate are highly individual, depending not only on the type of aircraft, but also on its current weight, on its energy state and on the wind situation along the flight path. The management of configuration and speed regime depend on each other. The sequencing of high-lift system and landing gear is based on theoretical Standard Operating Procedures (SOPs) but also on the pilots' skills, knowledge and habits. It partly results in over-consuming flights. Indeed, pilots need to take some margins in order to avoid over-energy approaches and go-around situations, and this often includes early extension of the landing gear and use of speed brakes, which may increase the fuel consumption and the noise footprint unnecessarily.

In addition, when a lateral instruction is given by ATC, the vertical modes can no longer be managed by the FMS system with its current design. Indeed, in this situation, the FMS is no longer able to fully and properly support the pilots in the energy management task as the distance and path to the destination are unknown. The pilots have to manage the energy dissipation by themselves using the selected modes, which constitutes a hard task with few cues from the FMS, as energy is a complex compromise between speed (kinetic energy) and altitude (potential energy), which is affected by the environmental parameters and the aircraft configuration.

The track miles as an additional piece of information provided by ATC is a core value for both the pilot and the system. This value is important to plan the approach properly and to determine the top of descent, from where thrust remains at idle until the glide path interception, and the latest point to decelerate to the final approach speed. This is necessary to perform an optimal flight in terms of noise emission and fuel burn. As already mentioned above, the analysis of operational measurement data shows that the given distance might have a great deviation from the distance actually flown by the aircraft (even if the majority is in between minus 2 NM and plus 2NM), which does not allow the pilot nor the system to plan and fly an optimal approach. Indeed, an action performed to optimise the flight according to the communicated distance becomes probably under-optimised (and maybe even counter-productive) with increasing deviation from the actually flown distance.

2.2 New DYNCAT operating method

2.2.1 Ground practices

The DYNCAT concept should not impact the way the separation is performed today by the ATCOs, with or without AMAN systems, so that it will not affect the safety level of current operations. It should then be compliant with current vectoring methods (lateral instructions) that can shorten or lengthen the aircraft trajectories. However, a pre-requisite for DYNCAT ground operations is to provide to the cockpit the required information in order to be able to compute a closed trajectory when the aircraft leaves its pre-planned route (i.e. the assumed published transition). Indeed, the conventional cockpit systems provide limited crew awareness of lateral path and aircraft energy, with approximate predictions in case of radar vectoring. This is due to the general unavailability of the information to compute a continuous reliable path to the destination on one side, but also to the fact that the current on-board systems are not designed to compute a "closed" lateral path in these radar vectoring situations. Nevertheless, a reliable closed lateral trajectory can be considered as an enabler for DYNCAT vertical optimisation.

So, while complying with the ATM separation requirements, the ground practices should evolve to provide a sufficient set of information so that each aircraft will be able, when equipped with DYNCAT function, to compute a lateral path that reflects the controller's intent.

As a matter of fact, different sets of data would permit the Flight Management System to compute a closed lateral path that reflects the controller intent to achieve the required sequence and separation, and so, to support the pilots' operations to achieve an energy-optimised vertical profile.

Two favourite practices were studied in this project to convert the controller intent into a closed trajectory. Both of them are compliant with voice exchanges or datalink communications, depending on the available systems (as equipped communication systems may be different among the aircrafts landing to a given airport). It can be noticed that the ground practice #2 has been inspired by the work done in the PJ01 solution 8 thread B2 from SESAR 2020, as it is based on a Permanent Trajectory adapted according to a time indication.

Ground practice #1: no AMAN available

This practice is adapted to the ATC centres that are not equipped with AMAN systems, and in which the Air Traffic Controllers use classical heading instructions and radar vectoring methods.

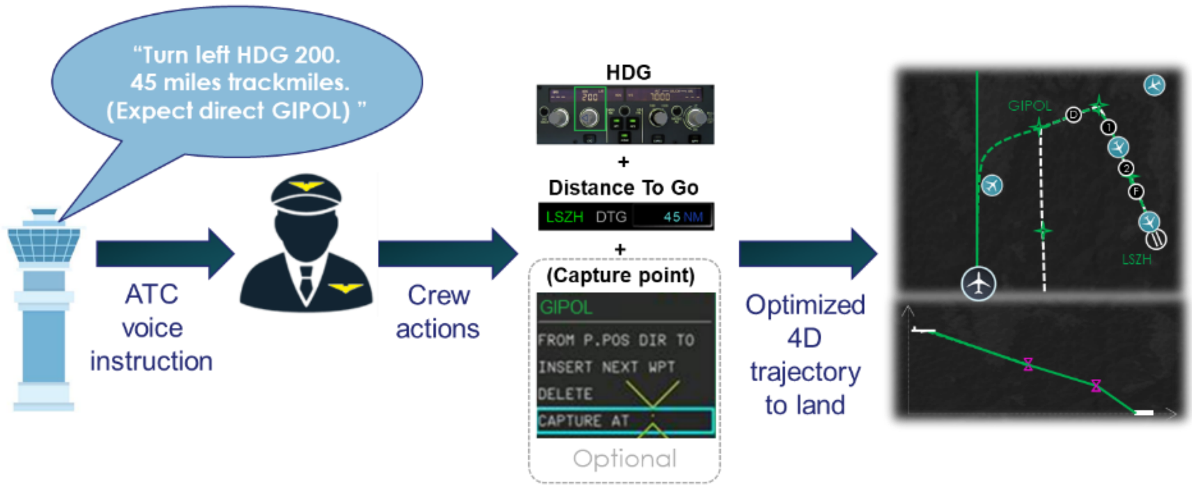

Figure 1: Ground practice #1 data exchange example

In that case, the set of data exchanged from the controller to the pilot is the following:

- ✓ A **lateral instruction**
  For instance, "Turn left HDG 200".
- ✓ An optional **capture waypoint** (when one unique heading instruction is expected and when the capture waypoint is different from the Final Approach Fix)
  For instance, "Expect direct GIPOL".
- ✓ An **indicative Distance-To-Go** (mandatory at first lateral instruction or upon ATC strategical change)
  For instance, "Expect 45 miles to touchdown".

The lateral instruction could be a heading or a track and needs to be completed by a Distance-To-Go (DTG) that corresponds to the distance to destination to be flown. This information might be completed by a capture point on which the aircraft will return on the initial pre-planned route (flight plan).

When this point is not provided, the inherent assumption is that the aircraft will be cleared to join the final axis, so that the capture waypoint can be considered as the Final Approach Fix by default. All this information can be seen as the transcription of the controller intent into the system language, but can also be provided to the controller by a dedicated separation assistance tool whose study is not part of DYNCAT project.

This first practice is quite resilient to multiple lateral instructions as long as the remaining distance to the runway threshold does not change. Indeed, the DTG given at the first instruction is the most important information. It is really the parameter that needs to be as accurate as possible as it will be used to build an optimised vertical profile and energy dissipation strategy. The geographical lateral path itself impacts the vertical profile "only" through the corresponding wind and induced turns, and even if it is not negligible, this is a second order impact compared to the Distance-To-Go.

In the case that this indicative distance to the runway threshold is shorter than the one that will be flown, the pilot will need to add some energy (thrust) to the system, thus increasing the fuel consumption. On the opposite, if the distance is longer than the one that will be flown, the pilot will need to dissipate more energy, by anticipating flaps, landing gear extension or by using speed brakes.

In the case the controller already provided a Distance-To-Go with the first heading instruction, it is not absolutely needed to provide it again with each heading (or track) update unless there is a change in the separation strategy or arrival sequence that causes this distance to be modified.

<u>**Ground practice #2: AMAN available**</u>

This practice is adapted to the ATC centres equipped with AMAN systems. It could be reasonably considered as a standard for future ways of working on ground. Thus, this practice relies on these systems to work directly in time separation, avoiding the time to distance conversion.

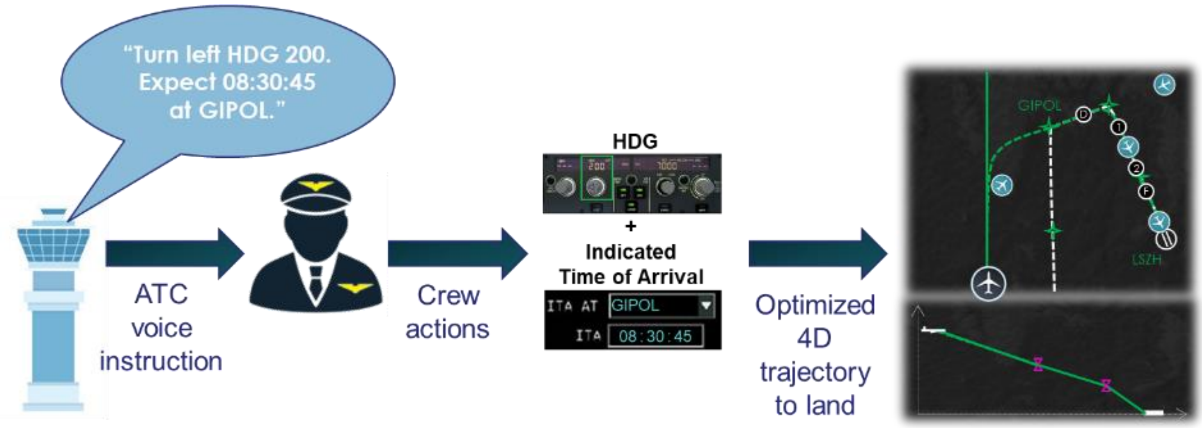

Figure 2: Ground practice #2 data exchange example

In that case, the set of data exchanged from the controller to the pilot is the following:

- ✓ A **lateral instruction**
  For instance, "Turn left HDG 200".
- ✓ An **indicated time of arrival on a capture waypoint** (mandatory at first lateral instruction or upon ATC strategical change)
  For instance, "Expect 08:30:45 at GIPOL".

As for the first practice (without an AMAN system), the lateral instruction could be a heading or a track but needs to be completed by an indicated time of arrival at a designated capture point (i.e. on which the aircraft will return onto the initial pre-planned route). Both are required to build a continuous representation of the lateral path that is intended by the controller. This second practice is also quite resilient to multiple lateral instructions as long as the indicated time of arrival at the capture waypoint does not change. Indeed, the expected time given at the first instruction is the most important datum. In this case, it is really the parameter that needs to be as accurate as possible as it will be used to build an optimised vertical profile, speed schedule and energy dissipation strategy.

2.2.2 Airborne practices

As for the ground practices, DYNCAT should support the energy management on-board without affecting neither the safety level nor the pilot workload. On the contrary, it aims to increase the situation awareness by providing to the pilots some cues, in both selected and managed modes, specifically the flaps and landing gear sequence. Based on the information provided by the ground, either from practices #1 or #2 previously described, the Flight Management System will compute a continuous and Permanent Resume Trajectory (PRT) [11]along which will be presented the optimised landing sequence. This PRT capability permits to display a trajectory from the aircraft that joins the FPLN, with the objective to reflect the most probable path to be flown.

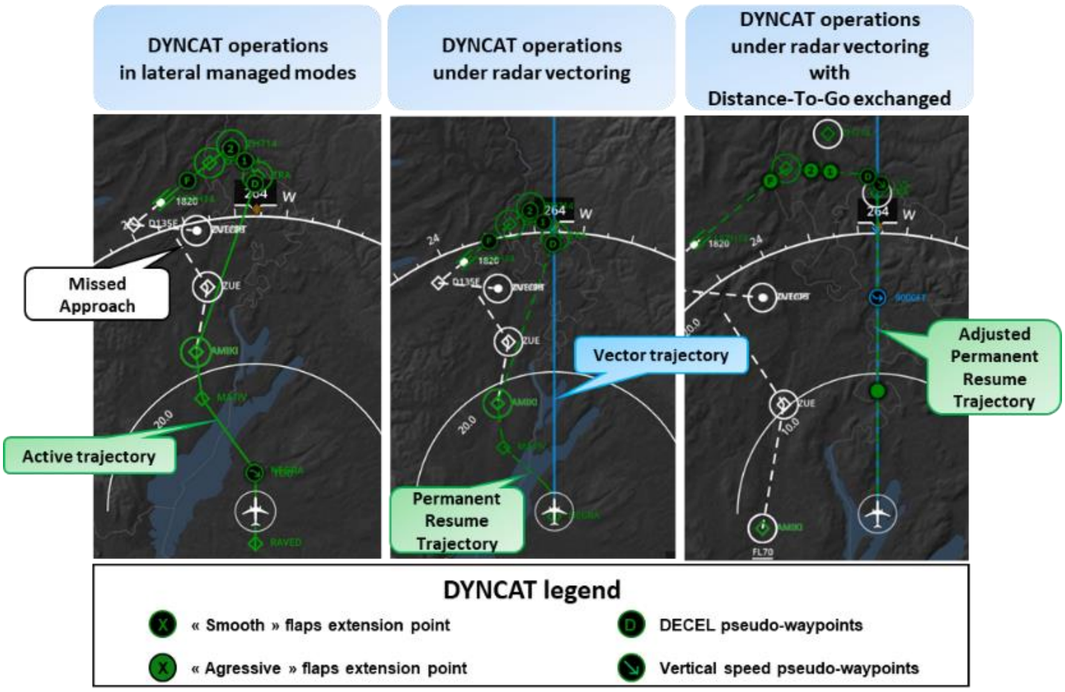

Figure 3: Cockpit representation of the ATC radar vectoring impact with DYNCAT

The Permanent Resume Trajectory coupled with Dynamic Configuration Adjustment in TMA (DYNCAT) alleviates the increase of workload due to the radar vectoring and helps to reduce the environmental impact. Both capabilities aim at improving situation awareness and aircraft manual guidance, in the lateral plan for the PRT and in the vertical plan for the DYNCAT concept. Thus, these new functions will constitute a major progress and an enabler towards greener operations.

The permanent trajectory provides the crew with an explicit and adjusted path computed consistently with the controller lateral instruction, completed either by a track miles information or by a time indication. The FMS algorithm extrapolates the current aircraft state in order to capture the active flight plan in the most likely way according to the operational context.

This is necessary to ensure an appropriate preparation for landing with the adequate approach speed, configuration and required fuel reserve. This permanent trajectory is then the lateral reference for the vertical descent profile computation. It supports the piloting tasks by enabling a display of the FMS's underlying assumptions.

It might also be used for automatic guidance in the future, assuming that it will be provided to the ground via the Automatic Dependent Surveillance - Contract (ADS-C) / Extended Projected Profile (EPP) in order to get an FMS trajectory clearance. The EPP contains the updated FMS predictions that include, for example, the predicted speeds along the route. The ground systems might then enable controllers to display the downlinked route on the radar screen and to automatically cross-check whether this route is consistent with the traffic management requirements.

Thanks to the PRT capability, the FMS is able to optimise the flight strategy even in lateral selected mode. The DYNCAT concept includes an adaptation of the vertical segments (that can be flown with existing autopilot modes), of the deceleration point, of the flaps change points and speed brakes segments.

Whereas the current vertical reference is computed with a fixed backward strategy, DYNCAT will adjust the "energy path" to find, when possible, a solution that joins the airport and the aircraft current energy state. This solution will be much more fuel and noise efficient than the current one as it enables to permanently propose the best strategy on the display systems to the pilots through dynamic adjustments in real time (e.g. to account for uncertainties in the wind profile or deviations from the optimum aircraft energy state).

It eases the understanding while helping to minimise fuel consumption, thus CO_2 emissions, and to reduce the noise footprint. Compared to conventional FMS, the underlying assumptions are presented to the pilots in order to make them able to follow the FMS suggestions.

At any time, lateral and vertical managed modes can also be engaged along the permanent trajectory to automatically capture the flight plan in the way presented on the display, with a totally safe and continuously verified seamless trajectory.

In the case the pilot decides to engage the managed mode, upon an ATC clearance for instance, the lateral and vertical paths will be kept, providing an operational continuity. In that case, the system manages the guidance of the aircraft and it allows the crew to focus on the energy monitoring and the management of the flaps, landing gear and possibly speed brakes (if required).

In order to determine the best trajectory for the on-board system, the pilot needs to enter the required parameters to adjust the trajectory in accordance with the controllers' indications. Depending on the ground practices, there are different ways to enter the information.

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Airborne practice #1: DTG indication management

This practice is adapted to the ATC centres that are not equipped with AMAN systems, and thus to the ground practice #1, in which the Air Traffic Controllers use classical heading instructions and radar vectoring methods.

The pilot should be able to enter into the system the following data with the following interactions means:

- ✓ A **lateral instruction**
  The pilot enters the instruction on the FCU, for instance, "HDG 200".

Figure 4: FCU pilot entry example for heading instruction

- ✓ A **capture waypoint**
  The pilot defines the capture waypoint on the MFD FPLN page (or equivalent means), by clicking on the waypoint that needs to be designated as the capture one, for instance "Capture AT ZH714".

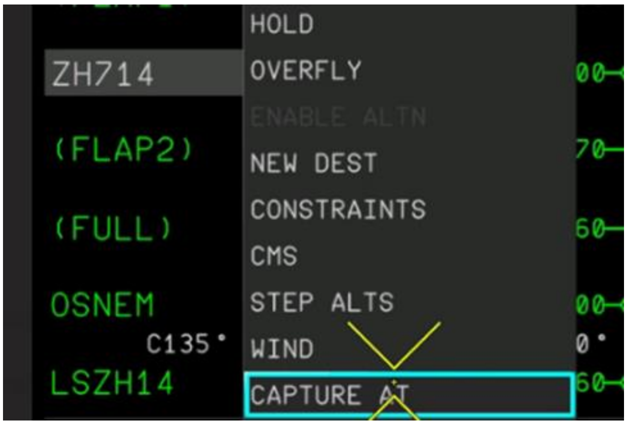

Figure 5: MFD pilot entry example for capture waypoint designation

This option could also be available from an interactive Navigation Display (ND) (or any equivalent means).

- ✓ An **indicative Distance-To-Go**
  The pilot can enter the distance to touchdown on the MFD, by clicking on the destination and entering for instance a "45 NM" after selecting a new "Distance-To-Go" parameter.

This option could also be available from an interactive ND (or any equivalent means).

Airborne practice #2: Time indication management

This practice is adapted to the ATC centres that are equipped with AMAN systems, and thus to the ground practice #2, in which the Air Traffic Controllers work directly in time separation, avoiding the time to distance conversion.

The pilot needs to enter into the system the following data:

- ✓ A **lateral instruction**
  As for the airborne practice #1, the pilot enters the instruction manually on the FCU as it is done today, for instance, "HDG 200".

- ✓ An **indicated time of arrival on a capture waypoint**
  The pilot enters the indicated time of arrival and defines the capture waypoint by one unique operation on the MFD FPLN page (or equivalent means), by clicking on the waypoint that needs to be designated as the capture one, and entering for instance "08:30:45" as a new "Indicated Time of Arrival" parameter.
  Therefore, the pilot may also modify the capture waypoint. This situation corresponds to an alternative practice, in which the indicated time of arrival is set on the destination waypoint (to meet ATC time separation needs) whereas the capture point is located upstream in the flight plan.

  This option could also be available from an interactive ND (or any equivalent means).

  Note: The practice here is subject to discussion. This topic is also discussed, for example, in SESAR PJ01 solution 8 thread B2 [10]. Current controller practice is to monitor time separation at a certain point depending on the procedures and runways considered.

2.2.3 Perspectives

The worldwide traffic growth reinforces the ATCO need for predictability to maintain safety levels with more and more aircraft in the sky. This increase also leads to an increase of the vectoring practice that comes with a major impact on traffic foreseeability and flight efficiency.

Nevertheless, ATCO general feedback confirmed the need to use radar vectoring for both sequencing and separation reasons. In this context, the permanent trajectory with DYNCAT must be a solution that assists in real time not only the crew but also the controller. It will constitute a key capability to take up the challenge to enhance the vectoring manoeuvres.

From the cockpit point of view, as presented before, it provides a clear and adjustable vision of the system trajectory and assumptions to join the flight plan and predict future aircraft state. It helps notably to fly an optimised and fuel-efficient profile in lateral selected mode thanks to an adjusted vertical reference.

From the ground point of view, thanks to the Automatic Dependent Surveillance - Contract (ADS-C), and more specifically to the Extended Projected Profile (EPP) downlink from the aircraft to the ground, data accuracy is improved on the ATCO side. The most reliable trajectory prediction is the one computed by the FMS, even more so considering a permanent trajectory coupled with DYNCAT concept, so that it is adjusted to match the controller intent, keeping the pilot in the loop. Indeed, the flight path computed by airborne means is based on reliable aircraft performance and environmental data. Its transfer to the ground segment will build confidence on the ATCO side, and could end-up with

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a PRT/DYNCAT clearance, or could even be used by ground tools to support the sequencing and separation operations.

Another interesting option would be, according to the Final Operational Concept Document (Deliverable D2.5 [9]) document, to develop a new ground de-confliction tool that could provide a full flight plan to the FMS, thus describing the manoeuvre(s) to be done in order to lose or gain time. This would reduce the controller workload and avoid any misunderstanding between the ground and the airborne segments. In a first step of implementation and to ensure a sufficient situational awareness for all the actors, this new route can be pre-validated on the ground by the controllers, keeping a human intervention in-the-loop before the uplink. Then, the acknowledgment from the pilot would act as an acceptation confirmation, in addition to the EPP frame that would permit an automatic monitoring on the ground side. However, in the DYNCAT project, focus was on the airborne side, and so to keep some independence with the ground systems evolutions, the proposed solution minimises the relative impact.

3 System technical specification

First, this section reminds the assumptions considered for the DYNCAT prototype and that the project mainly focuses on the airborne system evolutions, relying on other SESAR solutions as for example SESAR PJ01 solution 8 thread B2 where ground topics (Distance-To-Go, Indicated Time of Arrival, etc.) are used to improve traffic management in TMA. Then, it presents the high-level system requirements that were implemented in order to demonstrate the concept feasibility.

3.1 Technical scope

This section presents the way the operational concept has been used to define the prototype used as a proof of concept. It provides an overview of the functional items included in the DYNCAT prototype to validate the solution feasibility and operability during the Real-Time Simulation test campaign with pilots and controller. These items were mainly extracted from the Operational Concept Document, but some modifications and additions were identified during the maturity phase.

The prototype contains the following improvements, applying particularly to the approach phase, along the flight path:

- **Dynamic** computation of the **flaps/slats extension** and DECEL pseudo-waypoints according to the current aircraft state to ensure the stabilisation at 1000 ft AAL.

  Note: *Only lever position on 0, 1, 2 and final configuration are considered. For instance, in case of Final configuration=FULL, lever position on 3 is not considered. Landing gear is assumed to be linked to final configuration.*

- **Dynamic** computation of an **optimised continuous descent vertical profile** from a fuel and noise point of view according to the current aircraft energy state.
- Display of specific **cues** to understand and be aware of the **system assumptions**.
- Display of specific **cues** to alert about an **over-energy situation**.
- Possibility to fly the proposed trajectory in **selected or managed modes**.

When the aircraft is out of its flight plan due to ATC heading instruction, some valuable additions are provided:

- **Permanent Trajectory** considering the expected track miles to the destination threshold or the indicated time of arrival to a specific waypoint to compute and display a consistent closed trajectory.

As stated in chapter 2.2.2 Airborne practices, the waypoint holding the indicated time of arrival and the capture waypoint may be different.

Upon indicated time of arrival insertion on a waypoint, the capture waypoint is automatically set on this waypoint. This choice is driven by simplicity (minimise the number of actions to define the lateral path). However, the pilot is able to set another capture point afterwards. Note that any indicated time of arrival change will reset the capture point though.

The Indicated Time of Arrival respect is only managed through trajectory length without any impact on the speed schedule. When the controller aims to make the aircraft lose some time, the system always finds a solution to respect its intention and the energy constraint. Indeed, lengthening the trajectory is always possible and favourable for energy, by increasing the DTG or the flight time.

On the contrary, when the controller aims to shorten the aircraft trajectory, through a DTG or flight time decrease, it might cause an issue. On the one hand, the trajectory cannot be shorter than a "DIRECT TO" trajectory, which may still remain too long to respect the controller intention. On the other hand, the computed trajectory may become too short regarding the energy dissipation capability of the aircraft.

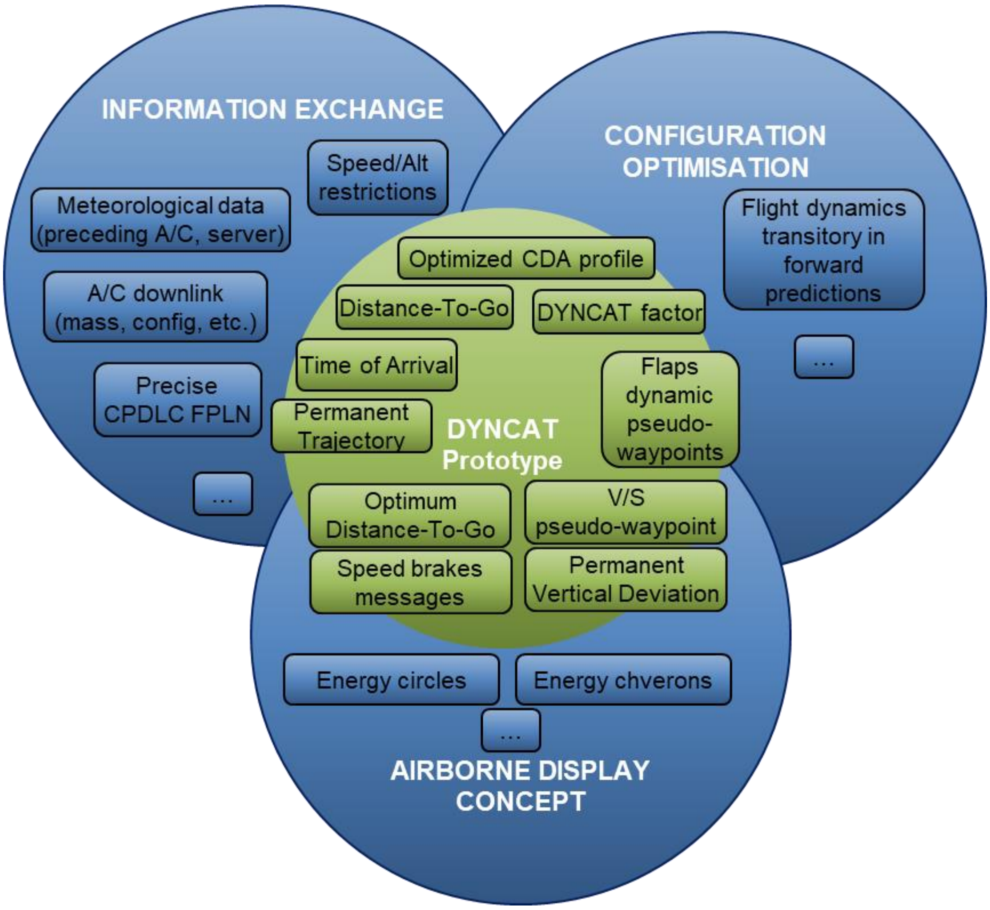

Figure 6: Prototype scope within the full operational concept

As explained before, to get an efficient FMS flight profile, some new data are mandatory when the aircraft is vectored. In addition to the heading instruction, the Distance-To-Go (with possibly a capture waypoint) or the Indicated Time of Arrival are required. These data are, in the prototyped solutions, the core data allowing the ground/airborne co-operation and mutual understanding.

In the solution prototype, when no capture waypoint is explicitly associated to the Distance-To-Go, the system assumes to capture the active flight plan at the Final Approach Fix (FAF). When an indicated time of arrival on a procedure point is given, the system assumes to capture the active flight plan at this point. As a matter of fact, the more reliable these transmitted data, the more efficient the trajectory computed by the system.

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3.2 Impacts on the avionics systems

This section provides an overview of the avionics principles and architecture, with a focus on the Flight Management System and the Cockpit Display System that are the main ones involved in the DYNCAT concept. It presents the functional analysis and breakdown that supports the implementation of each sub-capability into the existing systems.

3.2.1 DYNCAT in FMS context

The chapter presents the basic functionalities that a system has to provide to be named as a Flight Management System, and explain the main principles of such a system, aiming to clearly describe why and how the DYNCAT concept is allocated to this avionics system.

Figure 7 highlights the main FMS functions that permit to convert a flight plan into a trajectory on which the aircraft can be guided. With DYNCAT aiming at improving the aircraft trajectory, the FMS naturally embraces this capability.

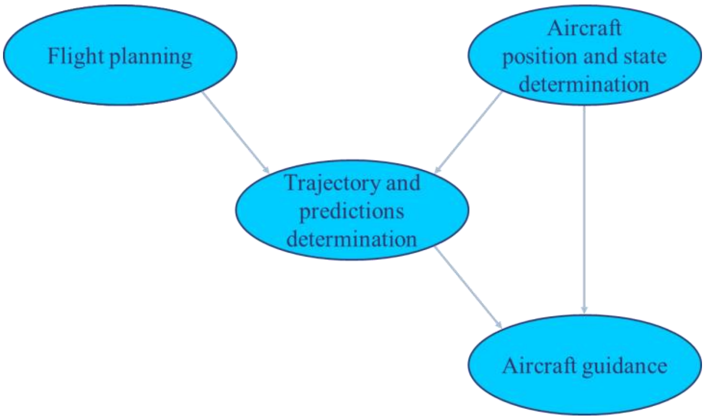

Figure 7: Main FMS functions

In order to fulfil the required capacities, basic functions shall be associated to technical functions (cf. Figure 8).

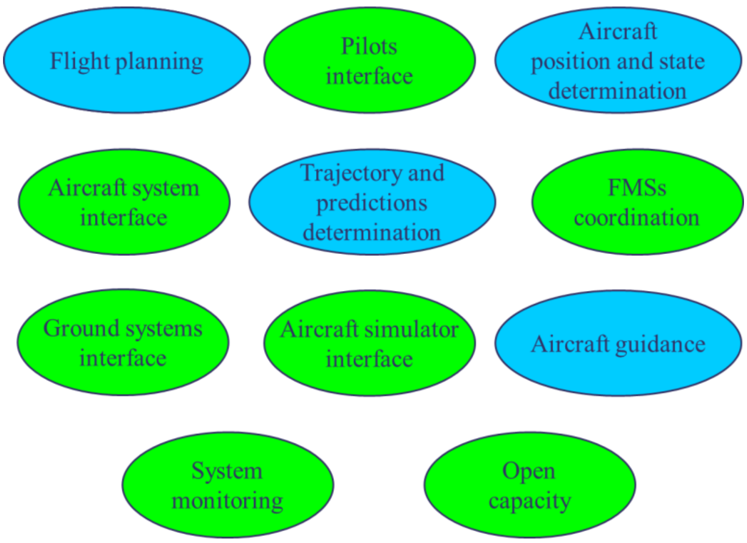

Figure 8: FMS Main Functions (in blue) and Main Technical Functions (in green)

Through the pilot interface, the FMS will receive some instructions and provide information, cues and results of its computations such as the 3D trajectory and the associated predictions

The aircraft system interface provides the position sensors (IRS, GPS, RADIO) data for the position computation, the auto-pilot modes and target for the aircraft guidance, the engine status and the fuel on board for the trajectory and predictions computation.

A coordination between the FMSs is required when more than one FMS is fitted in the aircraft. It consists in a synchronisation of the different FMS devices in order to reduce the crew workload. (A modification on one instance is automatically replicated on the others). Another capacity is the re-synchronisation that is used to initialise an instance that has lost all of its context (following an electric cut for example).

The ground systems interface covers the interface with the on-board routers that manage interface with ground actors ATC and AOC. FMS provides the require data such as aircraft position, Controller Pilot Data Link Communications (CPDLC) response filling, and Flight Plan (FPLN) exchanges to or from ground actors.

The aircraft simulator interface represents the capacity involved on the flight simulator. The FMS being an important but complex on-board system, requires steady training for the crews. To facilitate this long-time training, the FMS enables the operator to reallocate the aircraft to a chosen position or to fly faster (up to 4 times faster compared to real-time) to reach a position.

Similar to all the on-board systems, the FMS shall contribute to the aircraft maintenance. Being connected to several on board systems, the FMS is able to detect numerous outside systems failures. As an on-board system, the FMS shall implement its own monitoring to detect its own failures. All the detected outside and inside failures shall be communicate to the on-board maintenance systems. The FMS has also to store them in a non-volatile memory to allow failure analysis at the ground repair station.

The open capacity is a more recent capacity that is concomitant with the introduction of open world in the cockpit. This offers to the aircraft external systems or to any open world applications to receive some FMS data (aircraft vector, navigation database information, computed trajectory and predictions), or even to provide data (flight plans for instance).

In this context, the DYNCAT concept implementation will impact the following FMS functions (cf. Figure 9):

- Trajectory and predictions determination will compute dynamically the new extension pseudo-waypoints “1”, “2” and “F”, resulting in a dynamic DECEL pseudo-waypoint
- Trajectory and predictions are the most impacted functions as they implement the DYNCAT concept through the dynamic computation of the extension pseudo position and the optimised continuous vertical profile
- Aircraft guidance will provide guidance cues and alerts to support energy management
- Pilots interface will be modified to:
    - allow entering of DTG, ITA and capture point
    - display permanent trajectory and associated predictions
    - display guidance cues and alerts

The guidance component will manage messages and alerts to alert the crew when in over-energy situation. It will also provide cues to help crew to follow the vertical profile in selected mode.

The DYNCAT implementation will not impact guidance targets as it will rely on existing auto-pilot modes.

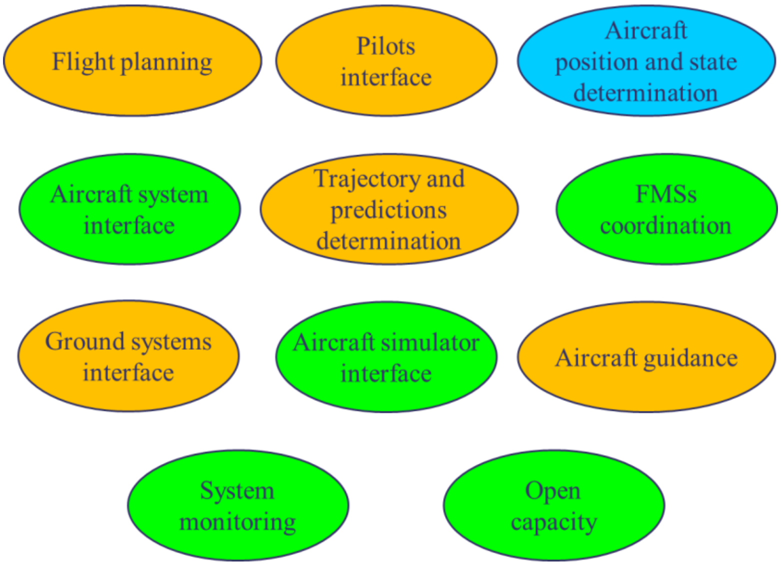

Figure 9: FMS Functions impacted by DYNCAT (in orange)

It can be noticed that ground system interfaces could be used to get the ATC restrictions through existing CPDLC messages. However, it has been agreed for the evaluation that the ATC speed and altitude restrictions will not be covered in a first step and that any ATC restrictions will be transmitted through voice exchange between the controller and the pilots.

3.2.2 Functional breakdown analysis

The following proposed functional breakdown analysis is consistent with DYNCAT functional sub-capabilities identified previously. The objective is to split the global and high-level DYNCAT capability into smaller items, each one providing an operational value to be demonstrated through the prototype.

- Dynamic pseudo-waypoints
  - FMS impacts

The current FMS already computes a profile that optimises the fuel consumption. But the document Critical Analysis of Current Operations (Deliverable D2.3 [1]) has demonstrated that there is a room for improvement, specifically in approach phase and when the aircraft is out of the pre-planned situation. In this flight phase, the configuration changes are required to reduce the minimum speed and to allow the aircraft deceleration and stabilisation for landing. The configuration changes increase both, the drag and the noise immission on ground.

The FMS will compute dynamically the optimised positions of the configuration changes for “1”, “2” and “F” resulting in a dynamic DECEL pseudo-waypoint (cf. Figure 10).

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- Cockpit Display System (CDS) impacts

The CDS will display the required cues to support the configuration extension in arrival phase.

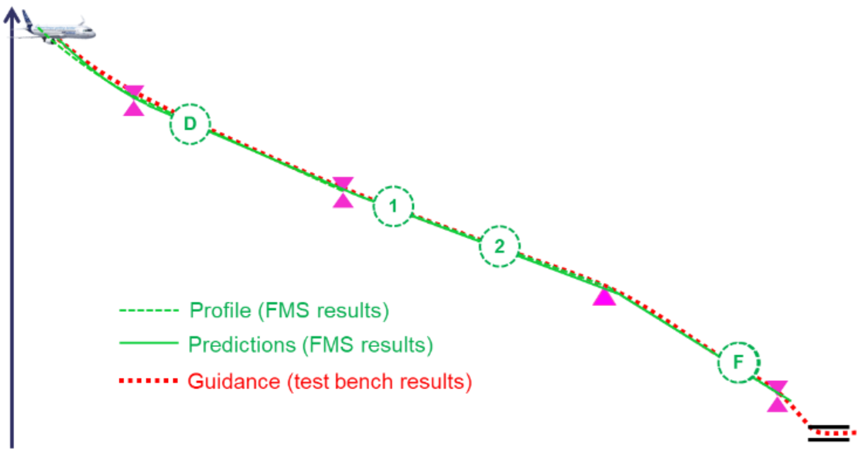

Figure 10: DYNCAT dynamic pseudo-waypoints representation

- Lateral path determination
  - FMS impacts

In the TMA, the controller uses vector commands to manage the traffic separation. The most commonly used command is a lateral vector, which leads to the loss of the auto-pilot lateral and vertical managed modes. In this situation and without the ability to compute a permanent trajectory, the FMS uses a basic hypothesis to capture the flight plan, which is not realistic.

The Permanent Resume Trajectory (PRT) function has two advantages. The first one is that the FMS assumption is shown to the crew (cf. also Figure 11). The second one is that the capture conditions are more realistic and consistent with the controller intent.

A capture waypoint in the flight plan shall be defined in order for the FMS to provide a closed lateral path consistent with the controller's intent. If the intended capture point is missing in the instruction, the default choice will be to capture the flight plan at the Final Approach Fix (FAF).

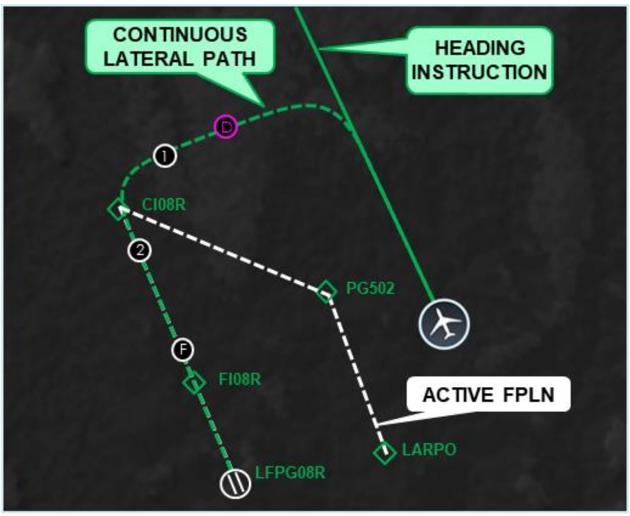

Figure 11: FMS Lateral Path construction example

- CDS impacts

The CDS will provide an input field for the pilot to enter the DTG when provided by the controller, possibly with the associated capture point.

The CDS will also provide an input field for the pilot to enter the ITA on a waypoint (that will be considered as the capture point by the FMS) when provided by the controller. It can be noticed that the ITA will not be managed as a time constraint (called Required Time of Arrival (RTA) in current FMS) but as a time indication that will be respected by adapting the trajectory length only, without impacting the speed strategy. The FMS determines a turning point on the current vector where the aircraft should turn to match the ITA waypoint, and provides to the CDS the information required for a graphical representation of the corresponding trajectory.

Finally, the CDS will display the permanent lateral path computed by the FMS (see Figure 11).

- **Optimised vertical profile**

  - FMS impacts

The DYNCAT concept introduces a new vertical profile computation with the objectives to fit with the existing operations and Auto-Pilot modes, in both managed and selected modes.

This vertical profile shall be optimised according to two objectives:

- Reduction of fuel consumption
- Reduction of noise emission

This optimisation leads to remove any level-off (cf. Figure 12) that is not imposed by the procedure and replace it by a vertical speed segment considered as the best compromise for efficient deceleration while reducing both fuel and noise effects. It can be noted that in addition to this compromise, two alternative solutions could consist in optimising the fuel only on the one hand, and the noise only on the other hand. Similar methods to modify the quality criterion of the optimisation exist today (e.g. to trade off flight economy versus passenger comfort).

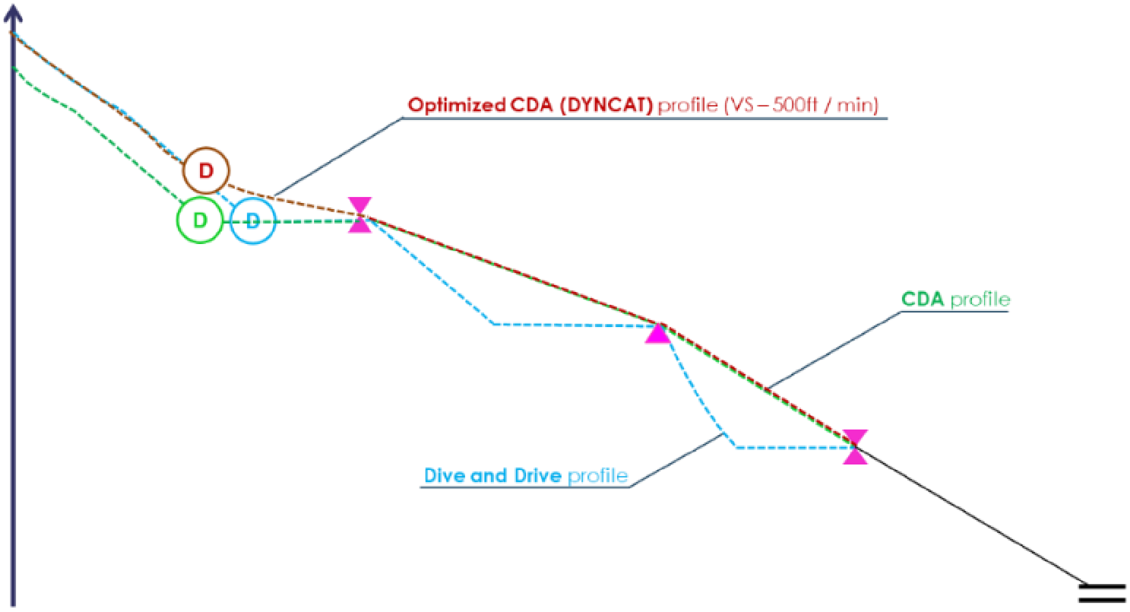

Figure 12: New DYNCAT vertical path option

- CDS impacts

The CDS will display the required cues to support the manual guidance (i.e. with selected modes) along the optimised vertical path.

- **Energy management cues**
  - FMS Impacts

The FMS will identify the over energy situations in order to be able to alert the pilot about any energy issue.

- CDS Impacts

The configuration extension pseudo “1”, “2” and “F” will be displayed on the Navigation Display and on the FPLN page on the MFD, including an energy status through a dedicated graphical code.

To identify and evaluate the over-energy situations, the FMS might possibly display the portions of the speed brakes segment with a different format, or trigger dedicated messages to warn the pilot that speed brakes extension or retraction is required.

In the opposite, i.e. under-energy case, the FMS might possibly display the segments on which the thrust is greater than IDLE with a different format. It might also locate a release point, which will be a start of descent or a deceleration point in front of the aircraft until which the current altitude or the speed, possibly linked to an ATC restriction, can be maintained without affecting the stabilisation at 1000 feet AAL.

In addition, the FMS might compute and display the optimum distance to land, and the associated margin in nautical miles compared to the active trajectory length. This margin could be displayed in green when there is no energy issue, even when it is negative (meaning that the approach will not be optimal but not have an energy issue), in amber otherwise. This information allows the pilot to better evaluate the situation, by providing him with a "reference".

Any change relative to the guidance mode required to follow the optimised vertical profile will be indicated to the crew when a lateral selected mode is engaged, through a specific and explicit symbol along the Permanent Resume Trajectory.

- **Altitude and speed restrictions**

The ATC lateral instructions were the only ones implemented in the RTS as the altitude and speed restrictions were out of the scope of the RTS scenarios.

In addition to the release point previously described, a further idea is to integrate the speed and altitude restrictions as "temporary" constraints, with a dedicated segment of application within the FMS trajectory. However, it will lead to major FMS and CDS modifications so that it has been decided not to prototype these complex restrictions within DYNCAT project at this stage, but to focus on all the previous items.

3.2.3 Impact on architecture

This section describes the impacts on the avionics architecture, giving the allocation of each sub-capability to the avionics systems.

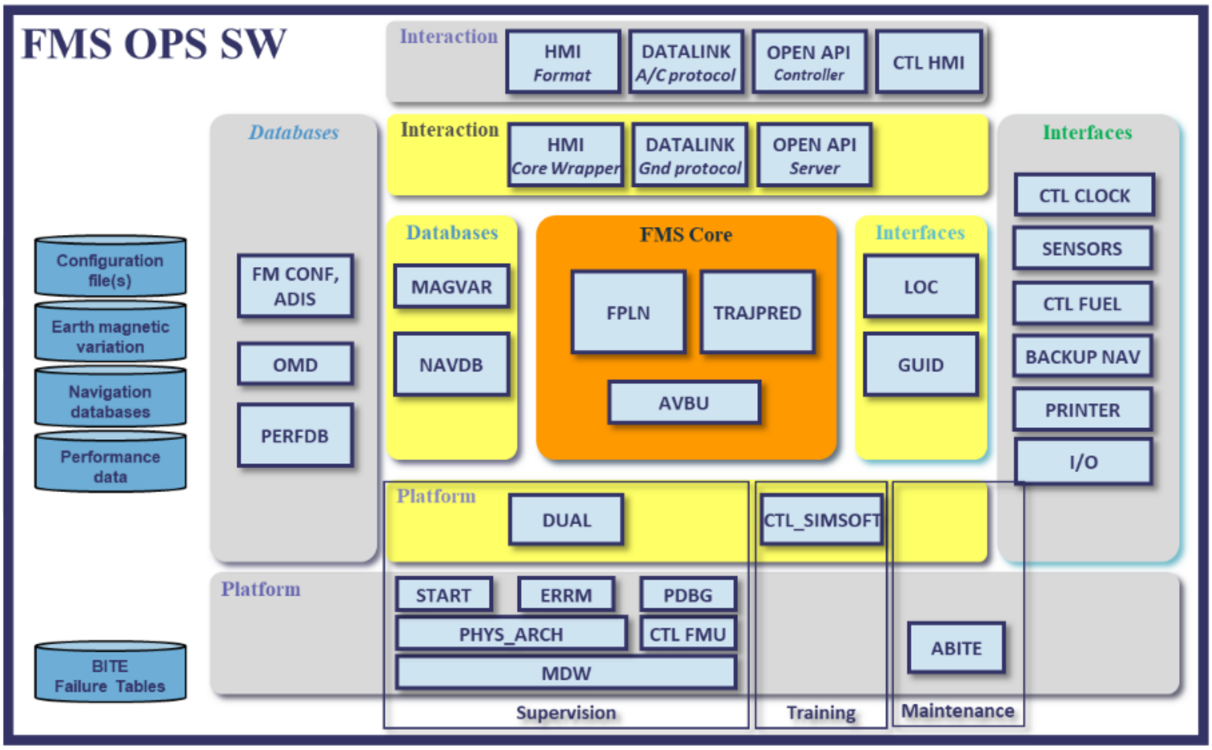

Figure 13: A320 family FMS Functions architecture

The DYNCAT prototype will be integrated on an A320–like system environment (cf. Figure 13 for the FMS architecture).

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This environment will be used as a reference to determine the architecture impacts, specifically regarding the FMS and CDS products. Practically, the FMS basis will be Thales PureFlyt™ product which is the next generation of FMS for Airbus aircraft.

The functional items required to demonstrate the DYNCAT capability are all compliant with the reference FMS architecture. As a result, this architecture principles will not be impacted and the functional items will be added to the existing components.

Here below are listed the main overall impacts, for each functional item:

- **Dynamic pseudo-waypoints**

  The configuration extension points are currently static (computed at fixed speeds), but their computation will be improved, as the extension speeds will be adjusted dynamically, considering the flight context and to ensure an optimised stabilisation. In addition, they will be displayed on the ND to help the pilot with the aircraft energy management.

- **Lateral path determination**

The proposed solution to adapt the lateral path (in order to comply with an indicated Distance-To-Go or Time of Arrival) complies with the reference architecture, but is not implemented in any state-of-the-art FMS. The DYNCAT prototype will rely on and extend the Thales PureFlyt™ PRT capability, previously exposed in SESAR project, to adapt the trajectory length to meet:

  - An expected DTG (to be fully developed)
  - An indicated time of arrival (presents some commonalities with SESAR 2020 PJ01 solution 8 thread B2 solution [10])

- **Optimised vertical profile**

The considered FMS already proposes different vertical profile options. A new one is needed to comply with the Final Operational Concept Document (Deliverable D2.5 [9]) definition (cf. Figure 12: New DYNCAT vertical path option).

- **Energy Management cues**

This item contains several new sub-capabilities:

  - Speed constraint status will be added for configurations pseudo-waypoints.
  - Cues aiming at sharing the FMS strategy with the pilot will be displayed.
  - Over-energy management cues (and possibly messages) will also be improved.

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3.3 High-level system requirements

This section describes the DYNCAT high-level requirements applicable to each avionics system involved in DYNCAT operations.

In this project, the DYNCAT solution impacted both the Flight Management System and the Cockpit Display System. Nevertheless, **the only product and system under test was the Flight Management System**. Further modifications were made to support the FMS validation, including the CDS evolutions that were not part of the test. Indeed, the CDS was "only" considered as the way to provide the pilots with the information computed by the FMS and required to support the energy management task.

The objective was not to validate the way the information is presented into the cockpit, but to validate that the data computed by the Flight Management System and provided to the pilots enable more environmentally friendly flight profiles.

Furthermore, DYNCAT new capability aims to be generic and thus might be ported to different types of aircraft, on which different interfaces might be used according to each aircraft manufacturer's wishes, habits and thus, Cockpit Display System specification. The general DYNCAT concept is not aircraft dependent and could perfectly be applied to other aircraft types. Through the Airbus A321 example of implementation, the final objective is to demonstrate that the FMS outputs are sufficient and relevant to alleviate the pilot workload and to permit to fly an optimum path compared to today's operations, thus providing fuel and noise benefits.

3.3.1 Flight Management System (FMS) requirements

This section describes the DYNCAT high-level requirements applicable to the FMS, with a chapter dedicated to each sub-capability (cf. 3.2.2 Functional breakdown analysis).

Figure 14: PureFlyt™ FMS and MFD used for DYNCAT prototype

3.3.1.1 Dynamic pseudo-waypoints

This section describes the way the Flight Management System shall compute the flaps and landing gear pseudo-waypoints.

Identifier	REQ-DYNCAT-FMS-001	
Title	"1", "2" and "F" dynamic positions computation	
Requirement	The FMS shall compute dynamically the position of the "1", "2" and "F" configuration pseudo-waypoints, resulting in a dynamic DECEL pseudo-waypoint, to ensure the aircraft energy stabilisation at 1000 ft AAL gate.	
Status	**Validated**	
Rationale	Pseudo-waypoints dynamic positions will help the pilot in the management of aircraft energy.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Dynamic pseudo-waypoints

Table 2: "1", "2" and "F" dynamic positions computation requirement

Identifier	REQ-DYNCAT-FMS-002	
Title	"F" final pseudo-waypoint definition	
Requirement	"F" final pseudo-waypoint shall group the landing configuration and the landing gear extensions, with the landing configuration as defined by the pilot(s).	
Status	**Validated**	
Rationale	Landing Gear is considered as linked to final flaps position that could either be 3 or FULL on A320 family. These items are grouped to be consistent with the existing performances databases to avoid any evolution and facilitate a short-term implementation.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Dynamic pseudo-waypoints

Table 3: "F" pseudo-waypoint definition requirement

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Identifier	REQ-DYNCAT-FMS-003	
Title	Configuration pseudo-waypoints envelope	
Requirement	The FMS shall compute the position of “1”, “2” and “F” configuration pseudo-waypoint within limited speed ranges, respectively lower limited by the corresponding manoeuvring speed and upper limited by the operational flight envelope.	
Status	**Validated**	
Rationale	To be realistic and usable, the pseudo-waypoints shall be within the flight envelope, and the extension speed shall be resilient to a possible gust. *Note: the manoeuvring speed is considered as the minimum speed for configuration extension by the current FMS that considers the managed mode flight envelope as its reference. Nevertheless, a lower speed target would be possible considering the selected mode limitation, and would even be more relevant, specifically for flaps 2 extension with heavy aircraft.*	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Dynamic pseudo-waypoints

Table 4: Configuration pseudo-waypoints envelope requirement

Identifier	REQ-DYNCAT-FMS-004	
Title	Configuration pseudo-waypoints anticipation	
Requirement	The FMS shall shift the position of “1”, “2” and “F” configuration pseudo-waypoints upstream to be consistent with the flight dynamics transitory and avoid any additional thrust, without exceeding the operational speed limitations.	
Status	**Validated**	
Rationale	The anticipation enables to cover: • the pilots’ response time • the flaps extension times • the speed capture time and so avoids as much as possible the engine use that increases noise, fuel and might even lead to a pitch-up vertical manoeuvre.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Dynamic pseudo-waypoints

Table 5: Approach pseudo-waypoints anticipation requirement

Identifier	REQ-DYNCAT-FMS-005	
Title	Configuration pseudo-waypoints position stabilisation	
Requirement	The FMS shall trigger the DECEL, "1", "2" and "F" pseudo positions update when the aircraft energy stabilisation at 1000 ft AAL gate is not met, and release them in case of low-energy situations.	
Status	**Validated**	
Rationale	These updates are required to have the pseudo-waypoints consistent with the flight context, and may be triggered using adapted thresholds for stability purpose. Pseudo-waypoint dynamic positions shall remain as stable as possible over time (no toggling) in order to be reliable and not to negatively affect the situational awareness.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Dynamic pseudo-waypoints

Table 6: Configuration pseudo-waypoints position stabilisation requirement

Identifier	REQ-DYNCAT-FMS-006	
Title	Vertical pseudo-waypoints computation	
Requirement	The FMS shall compute the vertical pseudo-waypoint(s) required to track the DYNCAT optimised vertical profile in vertical selected mode.	
Status	**Validated**	
Rationale	These cues are required to support the crew in the vertical selected modes management, with the objective to permit the aircraft guidance along the DYNCAT optimised vertical profile. For instance, a V/S pseudo waypoint is required where the pilot is supposed to switch from OPEN to V/S mode.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Dynamic pseudo-waypoints

Table 7: Vertical pseudo-waypoints computation requirement

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3.3.1.2 Optimised vertical profile

This section contains the technical requirements that drives the implementation of the optimised continuous descent and approach vertical path with regards to both fuel and noise.

Identifier	REQ-DYNCAT-FMS-007	
Title	Vertical mode for deceleration segment in approach	
Requirement	The FMS shall consider a vertical slope of -500 ft/min for any deceleration segment in approach that is free of altitude constraint.	
Status	**Validated**	
Rationale	Noise footprint in descent is reduced if A/C is continuously descending without flying any level segment. Then, VS mode is preferred as it corresponds to a selected vertical mode available when the aircraft is vectored in HDG mode on lateral axis, which is the most common use case.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Optimised Vertical Profile

Table 8: Vertical mode for deceleration segment in approach requirement

Identifier	REQ-DYNCAT-FMS-008	
Title	Vertical mode for constant speed segment in approach	
Requirement	The FMS shall consider an open idle thrust segment for any constant speed segment in approach that is free of altitude constraint.	
Status	**Not assessed (not required for the RTS scenario)**	
Rationale	Noise in descent is reduced if A/C is continuously descending without any level segment to decelerate. At constant speed, VS segments would not be as fuel and noise efficient as an adapted open idle segment.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Optimised Vertical Profile

Table 9: Vertical mode for constant speed segment in approach requirement

Identifier	REQ-DYNCAT-FMS-009	
Title	Approach phase automatic activation	
Requirement	When in the active phase is Descent and the pilot switches to V/S mode without a too high vertical deviation at the beginning of the theoretical approach phase, the FMS shall activate the Approach phase automatically.	
Status	**Validated**	
Rationale	The approach phase automatic activation is required to alleviate the pilot workload in a very demanding phase. However, the approach should not be engaged if the V/S mode has been engaged not to decelerate but to capture the profile from above through a slope increase for instance.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Optimised Vertical Profile

Table 10: Approach phase automatic activation requirement

Identifier	REQ-DYNCAT-FMS-010	
Title	Performance model tailoring	
Requirement	The FMS shall provide a way to adjust the performance computation in approach in order to make the performances theoretical model match the real aircraft performance.	
Status	**Validated**	
Rationale	Any gap between the FMS theoretical performance model and real (or simulated) aircraft model will result in a loss of efficiency on the one hand, or in a late stabilisation that might lead to a Go-Around on the other hand. The tuning of the deceleration in approach (through a dedicated factor) is required to evaluate the full potential of the DYNCAT solution.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Optimised Vertical Profile

Table 11: Performance model tailoring requirement

Identifier	REQ-DYNCAT-FMS-011	
Title	Optimum Distance-To-Go computation	
Requirement	When in lateral selected mode, the FMS shall compute the optimum Distance-To-Go in nautical miles as the best compromise for both fuel and noise, with nominal flaps and landing gear settings without using speed brakes, and considering only the runway and Final Approach Point constraints.	
Status	**Validated**	
Rationale	The optimum Distance-To-Go will allow the pilots to set the aircraft to its optimum energy state as early as possible during the arrival phase, supporting the discussion with the controller. This computation is done without aggressive flaps strategy nor speed brakes that are noise producers. Procedural constraints are ignored except at FAF/RWY to match with the most common ATC practices in radar vectoring.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Optimised Vertical Profile

Table 12: Optimum Distance-To-Go computation requirement

Identifier	REQ-DYNCAT-FMS-012	
Title	Optimum Distance-To-Go margin computation	
Requirement	When in lateral selected mode, the FMS shall compute the optimum Distance-To-Go margin in nautical miles as the difference between the active Permanent Resume Trajectory length and the Optimum Distance-To-Go.	
Status	**Validated**	
Rationale	This optimum Distance-To-Go margin will allow the pilots to set the aircraft to its optimum energy state as early as possible during the approach, supporting the discussion with the controller.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Optimised Vertical Profile

Table 13: Optimum Distance-To-Go margin computation requirement

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Identifier	REQ-DYNCAT-FMS-013	
Title	Optimum Distance-To-Go margin status computation	
Requirement	When in lateral selected mode, the FMS shall set the optimum Distance-To-Go margin status to "Over-energy" when the active FPLN trajectory is too short to ensure the stabilisation at 1000 ft AAL while considering an aggressive flaps strategy and half speed brakes during the full arrival phase.	
Status	**Validated**	
Rationale	This optimum Distance-To-Go margin status will allow the pilots to take a corrective action when required and thus, to avoid an over-energy situations that might lead to a Go-Around.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Optimised Vertical Profile

Table 14: Optimum Distance-To-Go margin status computation requirement

Identifier	REQ-DYNCAT-FMS-014	
Title	Speed brakes messages computation	
Requirement	The FMS shall request the speed brakes extension when an excess of total energy (i.e kinetic energy and/or potential energy) is predicted at the entry point of the approach phase in vertical selected mode while considering half speed brakes, and request the speed brakes retraction otherwise when they are already extended.	
Status	**Validated**	
Rationale	The speed brakes are considered as the last line of defence to be in the correct conditions at the entry of the approach phase, leading to be in the expected conditions at the glide interception in order to be correctly stabilised at 1000 ft AAL.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Optimised Vertical Profile

Table 15: Speed brakes messages computation requirement

3.3.1.3 Lateral path determination

This section contains the technical requirements that drives the implementation of the lateral path construction when the aircraft flies in selected modes. In these cases, the controller should complement the first HDG instruction with the expected DTG (or ITA) and possibly the waypoint on which to capture the FPLN, the FAF being considered by default otherwise. On the FMS side, in selected lateral mode, a Permanent Resume Trajectory (PRT) is computed with the turning point to comply with the provided ATC data, either the DTG or the ITA.

Identifier	REQ-DYNCAT-FMS-015	
Title	Distance-To-Go (DTG) information retrieval	
Requirement	When the aircraft is in lateral selected mode, the FMS shall be able to receive and process the Distance-To-Go indication in order to compute the lateral path, possibly with a capture waypoint.	
Status	**Validated**	
Rationale	The Distance-To-Go (possibly with a capture waypoint) is possibly provided to the aircraft either by voice or datalink in order to permit the computation of an optimised vertical profile consistent with the controller intent.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Lateral Path Determination

Table 16: Distance-To-Go (DTG) information retrieval requirement

Identifier	REQ-DYNCAT-FMS-016	
Title	Indicated Time of Arrival (ITA) information retrieval	
Requirement	When the aircraft is in lateral selected mode, the FMS shall be able to receive and process the Indicated Time of Arrival on a capture waypoint in order to compute the lateral path.	
Status	**Validated**	
Rationale	The ITA and the associated capture waypoint are possibly provided to the aircraft either by voice or datalink in order to permit the computation of an optimised vertical profile, consistently with the controller intent.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Lateral Path Determination

Table 17: Indicated Time of Arrival (ITA) information retrieval requirement

Identifier	REQ-DYNCAT-FMS-017	
Title	Flight plan lateral capture	
Requirement	When the aircraft is in lateral selected mode with a DTG or an ITA provided, the FMS shall compute a PRT that captures the flight plan at the provided capture point when available, at the FAF otherwise.	
Status	Validated	
Rationale	The FMS should help pilot to manage the total energy of the aircraft when in lateral selected mode, consistently with the controller intent.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Lateral Path Determination

Table 18: Flight plan lateral capture requirement

Identifier	REQ-DYNCAT-FMS-018	
Title	Lateral path length	
Requirement	When the aircraft is in lateral selected mode, the FMS shall compute a PRT with a lateral path length consistent with the ITA or DTG constraint when available, or that joins the FPLN in the most likely way otherwise.	
Status	Validated	
Rationale	The FMS should help pilot to manage the total energy of the aircraft when in lateral selected mode, consistently with the controller intent when the information is available, consistently with the pre-planned route otherwise.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Lateral Path Determination

Table 19: Lateral path length requirement

EUROPEAN PARTNERSHIP

Co-funded by the European Union

3.3.1.4 Speed and altitude restrictions

This section describes the way the Flight Management System is required to manage the altitude and speed restrictions coming from ATC. As **this part is optional** in a first step of the project, the following requirements might be deeply refined in the next steps based on the DYNCAT first prototype validation results.

Identifier	REQ-DYNCAT-FMS-019	
Title	ATC speed restriction management	
Requirement	When in selected speed mode, the FMS shall maintain the current selected speed until the start of deceleration to satisfy the next restrictive speed constraint.	
Status	**In progress (prototyped but not assessed by the RTS scenario)**	
Rationale	The FMS speed profile supports the energy management to ensure the aircraft stabilisation at an altitude of 1000 ft AAL, considering the operational speed restrictions.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Speed and altitude restrictions

Table 20: ATC speed restriction requirement

Identifier	REQ-DYNCAT-FMS-020	
Title	ATC altitude restriction management	
Requirement	When in altitude selected mode, the FMS shall maintain the current selected altitude until the start of descent to satisfy the next restrictive altitude constraint.	
Status	**In progress (prototyped but not assessed by the RTS scenario)**	
Rationale	The FMS vertical profile supports the energy management to ensure the aircraft stabilisation at an altitude of 1000 ft AAL, considering the operational altitude restrictions.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Speed and altitude restrictions

Table 21: ATC altitude restriction requirement

EUROPEAN PARTNERSHIP

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3.3.2 Cockpit Display System (CDS) requirements

This section describes the additional information, introduced by DYNCAT concept of operations that are provided to the pilot. It also specifies the way the pilot shall interact with the system in order to maximise the operational efficiency.

Figure 15: Overview of DYNCAT energy management cues in the arrival phase

3.3.2.1 Controller intent entry

This section describes the required inputs from the pilot to operate efficiently the aircraft with the DYNCAT concept, accordingly to the ATCO intent.

Identifier	REQ-DYNCAT-CDS-001	
Title	Distance-To-Go (DTG) entry	
Requirement	The CDS shall provide to the crew the capability to enter the Distance-To-Go (DTG).	
Status	**Validated**	
Rationale	The FMS needs to retrieve the DTG in order to adapt the PRT.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Controller intent entry

Table 22: Distance-To-Go (DTG) entry requirement

Identifier	REQ-DYNCAT-CDS-002	
Title	Capture point entry	
Requirement	The CDS shall provide to the crew the capability to enter the capture point.	
Status	**In progress (prototyped but not assessed by the RTS scenario)**	
Rationale	The FMS needs to retrieve the capture point in order to adapt the PRT with regard to the controller intent, with the capture point being the point on which the aircraft will come back on its pre-planned route (point on is expected a DIRECT TO instruction).	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Controller intent entry

Table 23: Capture point entry requirement

Identifier	REQ-DYNCAT-CDS-003	
Title	Indicated Time of Arrival (ITA) entry	
Requirement	The CDS shall provide to the crew the capability to enter the Indicated Time of Arrival (ITA) on a downstream waypoint.	
Status	**Validated**	
Rationale	The FMS needs to retrieve the ITA and the associated capture point in order to adapt the PRT with regards to the controller intent.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Controller intent entry

Table 24: Indicated Time of Arrival (ITA) entry requirement

3.3.2.2 Strategic energy management cues

This section describes the mid-term information provided in the cockpit and required to implement the DYNCAT solution. These data, such as the optimum Distance-To-Go and the release points, are intended for strategic flight management.

Identifier	REQ-DYNCAT-CDS-004	
Title	Optimum Distance-To-Go display	
Requirement	When in lateral selected mode, the CDS shall provide to the crew the optimum Distance-To-Go in nautical miles.	
Status	**Validated**	
Rationale	The optimum Distance-To-Go will allow the pilots to set the aircraft to its optimum energy state as early as possible during the arrival phase, supporting the discussion with the controller.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Strategic energy management cues

Table 25: Optimum Distance-To-Go display requirement

Identifier	REQ-DYNCAT-CDS-005	
Title	Optimum Distance-To-Go margin display	
Requirement	When in lateral selected mode, the CDS shall provide to the crew the optimum Distance-To-Go margin in nautical miles in amber when the FMS Optimum Distance-To-Go margin status is set to “Over-energy”, in green otherwise.	
Status	**Validated**	
Rationale	The optimum Distance-To-Go margin will allow the pilots to set the aircraft to its optimum energy state as early as possible during the arrival phase, supporting the discussion with the controller.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Strategic energy management cues

Table 26: Optimum Distance-To-Go margin display requirement

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Identifier	REQ-DYNCAT-CDS-006	
Title	Speed release point display	
Requirement	When selected speed is engaged, the CDS shall provide to the crew the point where the speed should be released to satisfy the next restrictive speed constraint.	
Status	**In progress (prototyped but not assessed by the RTS scenario)**	
Rationale	The CDS supports the energy management task considering the operational speed restrictions.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Strategic energy management cues

Table 27: Speed release point display requirement

Identifier	REQ-DYNCAT-CDS-007	
Title	Altitude release point display	
Requirement	When altitude mode is engaged and the aircraft is flying a level, the CDS shall provide to the crew the point where the altitude should be released to satisfy the next restrictive altitude constraint.	
Status	**In progress (prototyped but not assessed by the RTS scenario)**	
Rationale	The CDS supports the energy management task considering the operational altitude restrictions.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Strategic energy management cues

Table 28: Altitude release point display requirement

3.3.2.3 Tactical energy management cues

This section describes the short-term information provided in the cockpit and required for DYNCAT concept implementation. These data, such as short-term PFD messages, speed cues, deviations, etc., are intended for tactical flight management.

Identifier	REQ-DYNCAT-CDS-008	
Title	Configuration pseudo-waypoints display	
Requirement	The CDS shall display the “1”, “2” and “F” configuration pseudo-waypoints on the ND along the active FPLN trajectory, and on the MFD on the FPLN page.	
Status	**Validated**	
Rationale	As the aircraft configuration extensions require pilot actions, these cues need to be displayed to make visible the FMS underlying assumption. As on the A350/A380, the ND and the MFD have been retained to improve crew awareness and enable crew anticipation for flaps extensions.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Tactical energy management cues

Table 29: Configuration pseudo-waypoints display requirement

Identifier	REQ-DYNCAT-CDS-009	
Title	Configuration pseudo-waypoints status	
Requirement	The FMS shall warn the pilot when a configuration pseudo-waypoint is predicted to be missed due to an over-energy situation, by displaying the pseudo-waypoint in amber when it is predicted to be sequenced in over-speed, in green otherwise.	
Status	**Validated**	
Rationale	The over-energy information is required to help the crew for the energy management task, and to permit an operational anticipation of any energetic issue, thus, minimising the go-around cases.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Tactical energy management cues

Table 30: Configuration pseudo-waypoints status requirement

Identifier	REQ-DYNCAT-CDS-010	
Title	Vertical pseudo-waypoints display	
Requirement	The CDS shall display all the information related to the Auto-Pilot management that are required to track the DYNCAT optimised vertical profile in vertical selected mode along the active FPLN trajectory on the ND.	
Status	**Validated**	
Rationale	These cues are required to support the crew in vertical selected mode for guiding aircraft along the DYNCAT optimised vertical profile. For instance, a V/S pseudo waypoint is required where the pilot is supposed to switch from OPEN to V/S mode.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Tactical energy management cues

Table 31: Vertical pseudo-waypoints display on ND requirement

Identifier	REQ-DYNCAT-CDS-011	
Title	Permanent Vertical Deviation display	
Requirement	The CDS shall permanently display the vertical deviation computed by the FMS in both vertical managed and selected modes in the arrival phase.	
Status	**Validated**	
Rationale	The CDS supports the energy management task by providing the information of the deviation between the optimised FMS profile and the aircraft altitude. This information becomes relevant at any time with the introduction of the Permanent Resume Trajectory coupled with the computation of an optimised dynamic profile.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Tactical energy management cues

Table 32: Permanent Vertical Deviation display requirement

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Identifier	REQ-DYNCAT-CDS-012	
Title	Speed brakes messages display	
Requirement	The CDS shall display the extension and retraction request messages on the PFD, respectively "EXTEND SPD BRK" and "RETRACT SPD BRK", accordingly to the FMS logics, in both vertical managed and selected modes.	
Status	**Validated**	
Rationale	The CDS supports the energy management task by providing the speed brakes request as the last line of defence to be in the correct conditions at the entry of the approach phase, leading to be in the expected conditions at the glide interception in order to be correctly stabilised at 1000 ft AAL.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	Tactical energy management cues

Table 33: Speed brakes messages display requirement

3.3.3 DYNCAT capacity management

This section describes the way the CDS and FMS will manage the DYNCAT capability activation/deactivation.

Identifier	REQ-DYNCAT-CDS-013	
Title	DYNCAT option activation	
Requirement	The CDS shall propose a means to activate/de-activate the DYNCAT capability.	
Status	**Validated**	
Rationale	The FMS and CDS will manage the DYNCAT capability as an option in order to facilitate the evaluations and comparisons with and without DYNCAT for ER phase.	
Category	<Functional>	
Relationship	**Linked Element Type**	**Identifier**
<SATISFIES>	<SESAR Solution>	DYNCAT
<SATISFIES>	<OCD>	DYNCAT D2.5 - Final Operational Concept Document
<ALLOCATED_TO>	<Function>	DYNCAT Capacity management

Table 34: DYNCAT option activation requirement

4 Summary

In this very first step of SESAR Exploratory Research on DYNCAT concept, the main objective was to demonstrate through a prototype the added value and the potential of the proposed Solution. Keeping that in mind, this technical high-level system specification extracts and presents the major add-on from the Operational Concept Document, and allocates each evolution to the most relevant avionics systems in order to document the prototyping phase.

The DYNCAT concept involved both ground and airborne segments and the communication between both can either be done through direct voice exchanges (between the pilots and the controllers) or by datalink. At this stage of the project, the voice communication will be considered as the favourite option as it is mainly done today, and partly because of the nature of the consortium members, but also to limit the impact on the ground simulation. Thus, it avoids the use of new ground tools or any evolutions of the existing communication standards, facilitating the implementation in the current operations.

Chapter 2 describes the practices evolutions that would permit an implementation of the DYNCAT concept. The major enabler is the capability on board the aircraft to understand the controller intention through some key data analysis. This information is consistent with the current practices so that there is no revolution compared to today's ways of working, but only a generalisation of the good practices. Practically, it consists in sharing by voice communication an accurate Distance-To-Go (DTG) or an Indicated Time of Arrival (ITA). However, in a further Industrial Research phase, some datalink communication means could be tested and replace the voice exchanges to reduce the workload, avoid any misunderstanding and limit the impact on the radio bandwidth. Some instructions could first be uplinked and then be interpreted by the system automatically before downlinking some data such as the Extended Projected Profile (EPP) in order, for instance, to enable a complex clearance on the optimised 4D trajectory (i.e. lateral, vertical and speed profiles).

Regarding the airborne capability, the avionics architecture analysis in this specification demonstrates that the DYNCAT concept implementation will impact only the FMS and the CDS systems. In addition, a functional breakdown analysis has been performed in order to define the DYNCAT sub-capabilities, each one of them contributing to an expected operational added value such as a fuel consumption decrease or the noise footprint reduction.

Finally, this document provides the requirements that the airborne systems shall implement to cover each sub-capability of the DYNCAT solution. The major design items compared to the A320 state of the art are the capabilities to dynamically compute the flaps sequence in approach phase and to optimise the vertical profile along a permanent trajectory in selected mode, while considering the ATC restrictions and the current flight context. The FMS will need to retrieve and process new data (i.e. new inputs) in order to compute a trajectory compliant with the ATCO intent. It will be supported by the CDS that will manage and process the pilots' entries in the cockpit in case of voice communication.

As a conclusion, this final system high-level specification reflects the prototype that has been developed for the piloted Real Time Simulation exercise that took place on a Thales research simulation bench in March 2022. It is intended to evolve in the next research phase (i.e. Industrial Research phase), including the analysis from the Advanced CDO Recommendations and Roadmap document (Deliverable D5.1 [8]).

5 References

[1] DYNCAT Deliverable D2.3, "Critical Analysis of Current Operations", 31st March 2021, Edition 01.00.00

[2] DYNCAT Deliverable D2.4, "Initial Operational Concept Document", 23rd April 2021, Edition 01.00.00

[3] DYNCAT Deliverable D3.1, "DYNCAT D3.1 - Preliminary System High-Level Specification", 30th June 2021, Edition 01.00.00

[4] DYNCAT Deliverable D3.2, "DYNCAT D3.2 – Implementation Validation Plan", 25th November 2021, Edition 01.00.00

[5] DYNCAT Deliverable D3.3, "DYNCAT D3.3 – DYNCAT Function Experimental Implementation Report ", 30th April 2022, Edition 01.00.00

[6] DYNCAT Deliverable D4.1, "DYNCAT D4.1 – Prototype Validation Report" , 31st May 2022, Edition 01.00.00

[7] DYNCAT Deliverable D4.2, "DYNCAT D4.2 – Environmental Benefits Report", 31st May 2022, Edition 01.00.00

[8] DYNCAT Deliverable D5.1, "DYNCAT D5.1 – Advanced CDO - Recommendations and Roadmap", under preparation

[9] DYNCAT Deliverable D2.5, "Final Operational Concept Document", under preparation

[10] PJ.01 W2 EAD - D3.1.021 - PJ.01-W2-08B V2 Interim TS/IRS, Edition 01.00.00

[11] Boyer J. and Dacre-Wright B. Permanent Resume Trajectory: an Innovative Flight Management System Functionality for Greener and Seamless Operations. Aerospace Europe Conference 2020, Bordeaux / France, 25th – 28th February 2020, paper no. AEC2020_493.