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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 TMA, namely on approach, by supporting the pilots in configuration management.

Approach operations at busy airports are louder and less fuel efficient than they should 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 project will set a course for more environmentally friendly and more predictable flight profiles in the terminal manoeuvring area, or TMA. It will support pilots in their energy management during the arrival phase. By analysing the mismatch of aircraft and air traffic control procedures, it will propose improvements to on-board and ground operations. This includes the identification of the possible need of regulatory changes for ATM. The project will also assess their ecological and economical potential.

This document describes the experimental prototype of the preliminary high-level system requirements (from deliverable D3.1 [3]) into the Flight Management System (FMS) and Cockpit Display System (CDS). As a reminder, these requirements specify the key technical items that have been selected from deliverable D2.4 [2] to illustrate and validate the DYNCAT concept (major add-on compared to the current state of the art).

This experimental implementation report contributes to the project main goals that are to demonstrate the feasibility and to evaluate the benefits of the concept during the Real-Time Simulation exercise. First, it presents the experimentation context. Then, it describes the experimental prototyping in the Flight Management System and suggests possible improvements or points to further develop. Eventually, this document focuses on the test means used to validate the DYNCAT concept, i.e. the Cockpit Display System and the test bench.

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1 Introduction

1.1 Background

DYNCAT aims to improve the situation in the Terminal Manoeuvring Area (TMA) related to noise exposure and fuel consumption. Part of the Work Package 3 that in overall aims at prototyping the DYNCAT operational concept for further evaluations, the present activity provides the software implementation report. This Experimental Implementation Report is a result of the task T03.02 (Exemplary Implementation) and is based on the previously delivered system high-level specification for the prototypical Flight Management System and Cockpit Display System functionalities, and more specifically the high-level system requirements provided in Deliverable D3.1 [3]. The Validation Plan (Deliverable D3.2 [4]) is also an input for this document, as the validation scenarios did allow to refine the expected behaviour and were used to evaluate the prototype maturity.

This document will serve as an input for the Prototype Validation Report (D4.1) as well as for the Final System High-Level Specification (D3.4). It also served for the Real-Time Simulation in a more informal way, as part of the prototyped description was also used in the briefing for the pilots and controller.

1.2 Purpose and Structure of the Document

This document describes the content of the DYNCAT prototype that has been used to prove the concept feasibility and to estimate the benefits. As the prototype target was to meet the needs expressed in the high-level system requirements from Deliverable D3.1 [3], this report will also evaluate the prototype compliance to these requirements. In a more general way, this document will provide a global understanding of the prototyped DYNCAT concept, including its current limitations.

This report first reminds the context of the experimentation, both on a prototyping axis (i.e. the expected benefits of a prototype) and on a more technical one (the technical context, i.e. the starting products' baselines).

Then, this document describes the prototype content for all the functional items defined in Deliverable D3.1 [3]. For a given functional item, it reminds first the associated requirements, and provides a compliance status for each of them. Then, it details the prototype content, behaviour, and the potential limitations. At last, some possible improvements are listed for further refining of the DYNCAT concept.

The last chapter of this report provides a short overview of the integration of the prototype in its environment for the next steps, i.e. on the test bench.

The evaluation of the DYNCAT function itself concerning operational feasibility and acceptability as well as environmental benefits will be performed in the upcoming Deliverables D4.1 and D4.2, for which the present report serves as input. It will also be used to update the System High-Level Definition to its final version (D3.4).

Reminder:

The present document describes an exemplary prototype of the DYNCAT concept. In order to be able to have quantifiable and reliable results, this prototype was developed on a real Flight Management System, and will be evaluated by being compared to an A320 family Flight Management System.

However, it shall be noted that the general DYNCAT concept is not aircraft dependent, and that it could perfectly be applied to other aircraft types. Some first insight on the guidance on the transfer of DYNCAT's functionality to different aircraft types will be presented in the "Way Forward" sections of chapter 3. More and final information will be found in Final System High-Level Specification (D3.4).

1.3 Acronyms

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

Acronym	Meaning
AAL	Above Airport Level
AGL	Above Ground Level
AP	Auto-Pilot
ATC	Air Traffic Control
ATCo	Air Traffic Controller
ATM	Air Traffic Management
CDA	Continuous Descent & Approach
CDS	Cockpit Display System
CF	Course to a Fix (type of A424 leg)
CPDLC	Controller Pilot Data Link Communications
D<no.>	Deliverable <no.>
DECEL	Deceleration pseudo-waypoint (FMS transition from descent to approach phase)
DTG	Distance to Go
ER	Exploratory Research
EUROCAE	EURopean Organisation for Civil Aviation Equipment
FAF	Final Approach Fix
FCU	Flight Control Unit
FGC	Flight Guidance Computer
FMA	Flight Mode Annunciator
FMS	Flight Management System
FPLN	Flight Plan
FT	Feet
H2020	Horizon 2020
HDG	Heading

Acronym	Meaning
HMI	Human Machine Interface
IMB	Integrated Modular Bench
ITA	Indicated Time of Arrival
KCCU	Keyboard Cursor Control Unit
LOC	Localiser
MCDU	Multifunctional Control and Display Unit
MFD	Multi-Functions Display
NAV	Navigation
ND	Navigation Display
NM	Nautical Miles
ODTL	Optimum Distance To Land
PFD	Primary Flight Display
PRT	Permanent Resume Trajectory
R&D	Research & Development
RTS	Real Time Simulation
SESAR	Single European Sky ATM Research
STAR	Standard Terminal Arrival Route
T<no.>	Task <no.>
TF	Track to a Fix (type of A424 leg)
TMA	Terminal Manoeuvring Area
VCC	Characteristic speed for flaps extension
VDEV	Vertical Deviation
VFE	Maximum flaps extension speed
V/S	Vertical Speed
VSIB	Virtual Simulation Integration Bench
WP	Work Package

Table 1: Acronyms used in this report

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2 Experimentation context

This section provides first a reminder of the experimental context, in other words the objectives and expected benefits of the concept implementation as a prototype.

Then, it presents a more "technical" aspect of the experimentation context: the Flight Management System and the Cockpit Display System baselines from which the prototype is derived.

2.1 Experimentation objectives

The main objective of an exploratory research project such as DYNCAT is, quite obviously, to validate the concept under test. Here, it means validating the feasibility and benefits of the DYNCAT functionality within real avionics products, through a realistic real-time demonstration.

Additionally, exposing the functionality to pilots and controllers brings much more than a simple validation. Indeed, the user's feedback is a precious input in order to improve the concept and its sub capabilities. To that end, having a realistic experimentation, in a simulated cockpit the pilots are familiar with, is an important asset.

Moreover, using the real Flight Management System software to develop the DYNCAT prototype provides another benefit: it conduces to partly follow an "industrial-like" approach, preparing the next phase of such an exploratory research project. As the prototype has to comply with the Flight Management System architecture, rules, and even limitations, this approach enables to study the possible architectural trade-offs that can be envisioned for a future integration in an in-service Flight Management System . Even further, by sometimes leading to challenge the design choices defined in the preliminary requirements, this approach helps to refine the need.

2.2 Prototype baseline

2.2.1 PureFlyt™ FMS

As stated in deliverable D3.1 [3], the Flight Management System is a natural candidate to implement the DYNCAT function in the avionics systems: the Flight Management System already computes the expected aircraft trajectory laterally (along the planned route, and possibly along the aircraft track) and vertically (altitude and speed profiles), as well as cues for pilot awareness. Thus, improving these capabilities with the DYNCAT concept makes sense from a cockpit-design point of view.

Moreover, one of the main inputs of the DYNCAT Work Package 3 is the D2.3 [1] document and the flight records analysed in this report. These data were retrieved from A320 aircraft. As the objective was to use part of the records to define the validation scenarios, having an environment, including a Flight Management System, representative of the A320 family was necessary.

From the drivers stated here above, Thales proposed to derive the prototype from the PureFlyt™ Flight Management System. This product indeed offers the "basic" lateral and vertical capabilities already listed, but also the capacity to be integrated on a bench that match the characteristics of an A320-family aircraft (e.g. characteristic speeds as the flaps extension speeds O/S/F) as well as its functional behaviour (same pseudo-waypoints displayed, same behaviour when the aircraft is on heading, …).

Furthermore, this real Flight Management System software can be used as a prototype basis, meaning that it can be modified as specified in D3.1 [3] and then run on a representative simulation bench. It is also compatible with the new generation of Cockpit Display System mentioned in the chapter here-below.

At last, the PureFlyt™ Flight Management System is a candidate (ongoing call) to be the Flight Management System of the future Airbus aircraft, and/or to be retrofitted to existing ones, making it a realistic and representative choice to evaluate the DYNCAT concept.

Figure 1: PureFlyt™ FMS HMI used for DYNCAT prototype

2.2.2 System HMI: the CDS

The Flight Management System and the Cockpit Display System are closely linked: the Cockpit Display System is needed for the pilot to interact with the DYNCAT function, by providing the inputs (e.g. Distance-to-Go) to the system, and obviously to observe the DYNCAT outputs. Nevertheless, in the WP3, the Cockpit Display System update is only a means to validate the concepts and is not part of the system under test, which is only the Flight Management System as stated in the previous deliverables.

A new generation of Display System has been used for DYNCAT experimentation, with the objective to facilitate the evolutions and thus, to permit a rapid prototyping and an early validation phase. It is particularly adapted to DYNCAT context in which new energy management cues will be experimented with prior to being potentially integrated into a flying product.

This Cockpit Display System is configured in a “classical” way, in order to provide to the pilots the same information they are accustomed to. In particular, the display contains:

- a Primary Flight Display (PFD), containing, among others, information related to the aircraft attitude, evolution (altitude, speed, etc.) and state (speed brakes, flaps, etc.),
- a Flight Mode Annunciator (FMA),
- a Navigation Display (ND) picturing the aircraft trajectory,
- a Multi-Function Display (MFD).

Figure 2: Focus on the Cockpit Display System new generation

3 Prototype details

This section provides details on the prototype content and behaviour, and assesses the compliance to the specification from the deliverable D3.1.

For all the functional items identified in D3.1, a compliance assessment is provided, and the prototyping is described more in depth (possibly by picturing the implementation result in the Flight Management System/on the Cockpit Display System). Then the prototype limitations (where applicable) are listed. At last, some potential improvement ideas are proposed, based on the questions and remarks raised during the development phase.

3.1 Lateral path determination

This section contains the technical requirements that drive the prototyping of the lateral path construction, specifically when the aircraft flies in selected modes.

Air Traffic Control provides the Distance-To-Go (DTG) or the Indicated Time of Arrival (ITA) coupled with a HDG instruction, and possibly the waypoint on which to capture the Flight Plan (FPLN). Indeed, the Air Traffic Controller (ATCo) might anticipate and provide the Flight Plan waypoint on which a DIRECT TO will be required; the Final Approach Fix (FAF) will be considered otherwise.

On the Flight Management System side, in selected lateral mode, a Permanent Resume Trajectory (PRT) is computed (see chapter 3.1.2). The Flight Management System will compute the turning point to comply with the provided Air Traffic Control data, either the Distance-To-Go or the Indicated Time of Arrival.

3.1.1 Associated requirements and prototype status

Requirement		Status
Identifier	REQ-DYNCAT-FMS-0008	**Fully prototyped**
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, possibly associated to a capture waypoint, information in order to compute the lateral path	
Identifier	REQ-DYNCAT-FMS-0009	**Fully prototyped**
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 information in order to compute the lateral path.	

Identifier	REQ-DYNCAT-FMS-0010	**Fully prototyped**
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.	
Identifier	REQ-DYNCAT-FMS-0011	**Fully prototyped**
Title	Flight plan lateral capture	
Requirement	When the aircraft is in lateral selected mode, the FMS shall compute a PRT that captures the flight plan at the provided capture point when available, at the FAF otherwise.	

Table 2: Lateral path determination requirements and associated prototype status

3.1.2 Prototype overview

The lateral path determination uses a version of the Permanent Resume Trajectory function issued from SESAR PJ01 (see e.g. [6]). The Permanent Resume Trajectory capability allows, when in lateral selected mode, to display a trajectory that joins the Flight Plan, starting from the aircraft and following the current heading. The length of the trajectory segment following the current heading and the way of joining the Flight Plan can be adapted in order to comply with the provided Air Traffic Control information (either Distance-To-Go or Indicated Time of Arrival).

Upon Distance-To-Go entry, the Flight Plan by the Permanent Resume Trajectory is performed as a DIRECT TO the Final Approach Fix. Upon Indicated Time of Arrival entry, the capture of the Flight Plan by the Permanent Resume Trajectory is performed as a DIRECT TO the point on which is set the Indicated Time of Arrival (limited to the Final Approach Fix : the capture cannot be located after the Final Approach Fix). The choice to perform a DIRECT TO has been “inherited” from the SESAR PJ01-08B2 solution, in the intent to match the way Air Traffic Control clears the aircraft back on route. Moreover, the reason for the choice of the Final Approach Fix as default capture point was to reduce the Air Traffic Control and pilot workload by avoiding the need to transmit this information from the ground and to enter it into the Flight Management System. The Final Approach Fix capture also leads to the shortest possible trajectory which is a way to ensure that the indications for energy management along the Permanent Resume Trajectory are computed with the hypothesis of the maximum excess of energy (for a given set of Air Traffic Control instructions). Indeed, as the flown trajectory can only be longer, this capture minimises the risk to have an excess of energy in a critical phase.

However, if a capture point is set manually (see chapter 3.5), the Flight Management System will consider it for the lateral path determination, as required.

The Permanent Resume Trajectory computation is performed by doing several iterations in which the distance along the current heading track is adapted to find the best solution [7]. This enables to provide a stable solution while ensuring an acceptable computation time according to Flight Management System standards.

An example of lateral path determination using the Distance-To-Go is shown here-below: upon Distance-To-Go entry, the Flight Management System computes a Permanent Resume Trajectory along the current track, with the expected length, and capturing the Final Approach Fix.

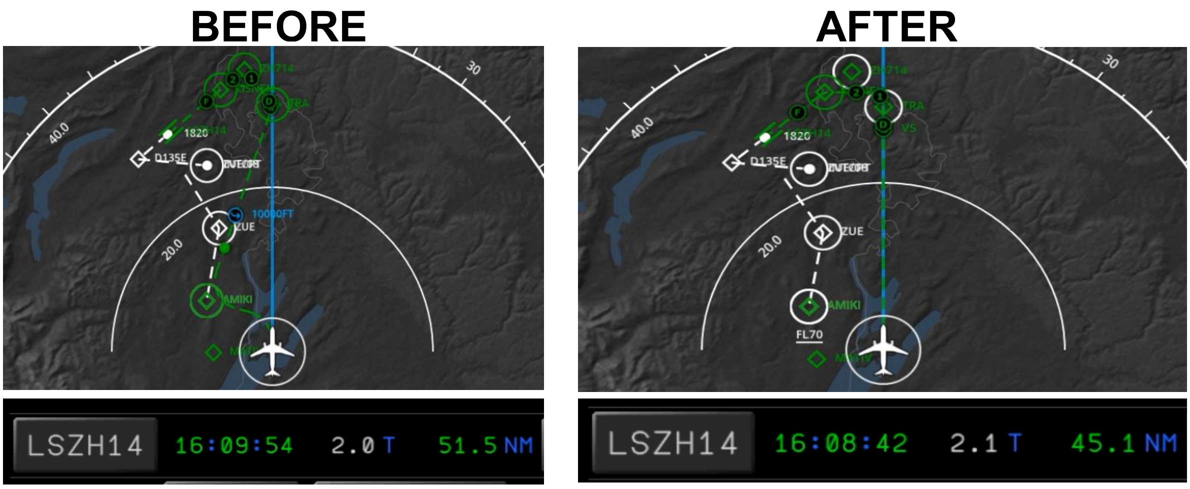

Figure 3: Effect of Distance-To-Go entry (value: 45 Nautical Miles) on the Permanent Resume Trajectory

3.1.3 Limitations

In this prototype, the capture of the Flight Plan by the Permanent Resume Trajectory is only available for Track to a Fix (TF) and Course to a Fix (CF) A424 legs. For other leg types, the DIRECT TO capture may work, but should probably be further developed. This limitation is fully acceptable considering the Zurich approach procedure under test (which does not contain other leg types).

To compute the first turn of the Permanent Resume Trajectory, a fixed speed value has been used (for turn stability). This may lead to overshoot the turn when flying with a higher speed.

The DIRECT TO logics might also be challenged and improved by considering the flights leading to the final axis interception, and during which the radar vector is not ended with a DIRECT TO a Flight Plan waypoint.

In addition, the Indicated Time of Arrival is considered as a punctual indication only, meaning that it will not lead to speed adaptation as a classical time constraint. Combined with the fact that the Permanent Resume Trajectory length is computed only once, when the Indicated Time of Arrival is set into the system (as for the Distance-To-Go), and will not be adapted in case of speed profile revisions for instance, the Indicated Time of Arrival status might become missed in certain conditions.

3.1.4 Way Forward

The Permanent Resume Trajectory capturing the route on the Final Approach Fix waypoint by default is acceptable for the prototype, as the lateral path is only a “support” for the optimised vertical path in the DYNCAT concept, and the winds were very limited in the evaluation scenarios. However, this default behaviour will probably have to be reworked: when refining the evaluation scenario thanks to the first results, it became clear that this solution was not fully satisfying. Even though having a default capture point alleviates the pilot’s task, the choice of this point can be improved. Indeed, capturing at the Final Approach Fix is “too late”, specifically from the Air Traffic Control (ATC) point of view, as the aircraft should be aligned at least 1 Nautical Miles (and up to 3 Nautical Miles for certain approach types such as non-precision approaches) earlier. A DIRECT TO ALIGN (on a real earlier point - e.g. a waypoint on the STAR - or on a virtual point) or an earlier capture of the final axis may better fit the Air Traffic Control expectations or the pilot actions when capturing a final approach leg. This would however raise two main points to solve:

- These captures do not correspond to the classical actions possible via the Flight Management System interface. If the computed Permanent Resume Trajectory is then activated by engaging the NAV lateral mode, it will work, but if the pilot performs a DIRECT TO instead (when cleared by the Air Traffic Control), the engaged trajectory will not correspond exactly to the computed Permanent Resume Trajectory. This would then require other changes in the Flight Management System for a global consistency from the operational point of view: the Flight Management System should offer the possibility to perform the exact same capture as the Permanent Resume Trajectory (e.g. a DIRECT TO ALIGN on a waypoint).
- From the Flight Management System standpoint, such DIRECT TO ALIGN captures present a higher risk of instability/toggling (more complex geometry), specifically when the aircraft get closer to the axis.

Moreover, the fixed speed value for the Permanent Resume Trajectory first turn has to be replaced by a refined speed value. This refined speed value has to be defined in a way that ensures that the turn is flyable along the predicted path, but with enough margin to guarantee the Permanent Resume Trajectory length stability (there may be, in deceleration situations, an interdependency between the speed and the Permanent Resume Trajectory length).

Another point to consider is the relevance of the Distance-To-Go information: how long does it remain valid, and how fast shall it be entered in the Flight Management System to remain relevant? It is entered directly by the pilot in the prototype upon voice transmission, but other means could be envisioned, like a transmission from the ground by Controller Pilot Data Link Communications (CPDLC). Even allowing time for a confirmation from the pilots, the reference would be the aircraft position at time of reception.

Eventually, the Permanent Resume Trajectory final turn might be linked to the Localiser (LOC) capture in certain scenarios. However, in these cases, the Flight Management System representativeness is not sufficient as the Permanent Resume Trajectory roll authority is based on the NAV (Navigation) mode one, different from the Localiser one which is only an Auto-Pilot mode, unknown to the Flight Management System. This might generate some small gap between the predicted length and the real distance flown.

3.2 Dynamic pseudo-waypoints

This section describes the way the Flight Management System dynamically computes the flaps and landing gears pseudo-waypoints position.

3.2.1 Associated requirements and prototype status

Requirement		Status
Identifier	REQ-DYNCAT-FMS-001	Fully prototyped
Title	DECEL, "1", "2" and "F" dynamic positions computation	
Requirement	The FMS shall compute dynamically the position of the DECEL, "1", "2" and "F" configuration pseudo-waypoints to ensure the aircraft energy stabilization at 1000 ft AGL gate.	
Identifier	REQ-DYNCAT-FMS-002	Fully prototyped
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).	
Identifier	REQ-DYNCAT-FMS-003	Fully prototyped
Title	Configuration pseudo-waypoints operational limitations	
Requirement	The FMS shall compute 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.	
Identifier	REQ-DYNCAT-FMS-004	Partially prototyped (DECEL is not shifted)
Title	Approach pseudo-waypoints anticipation	
Requirement	The FMS shall shift the position of DECEL, "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.	
Identifier	REQ-DYNCAT-FMS-005	Fully prototyped
Title	Configuration pseudo-waypoints position stabilization	
Requirement	The FMS shall trigger the DECEL, "1", "2" and "F" pseudo positions update when the aircraft energy stabilization at 1000 ft AGL gate is not met, using a hysteresis (value TBC).	

Table 3: Dynamic pseudo-waypoints requirements and associated prototype status

3.2.2 Prototype overview

The Flight Management System computes the positions of "DECEL", "1", "2" and "F" pseudo-waypoints and, depending on the energy situation, the pseudo-waypoints can be moved along the trajectory in order to find the best solution in terms of energy management.

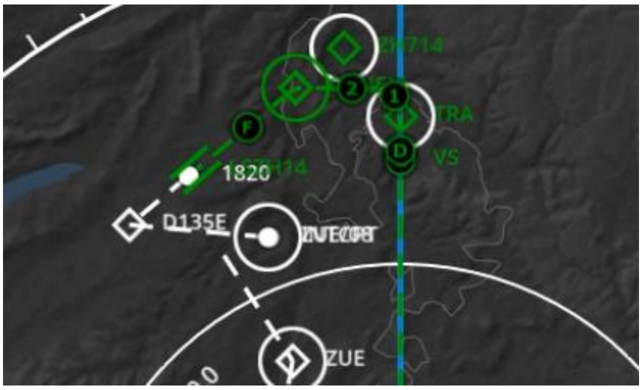

Figure 4: Computed "DECEL", "1", "2" and "F"

The configuration sequence adaptation is performed through the adaptation of the VCC which can be incremented or decremented when an over or under energy situation is detected. This detection is performed by checking the speed and altitude deviations.

The adaptation mechanism adjusts the VCC within the range [manoeuvring speeds F/S/O; operational envelope limitations VFE – 5 knots]. When the VCC is at the lowest bound of this range, the strategy is called "smooth"; at the upper bound, the strategy is called "aggressive". By adjusting the VCC, the "DECEL" pseudo-waypoint position is mechanically moved: the speed defining the "DECEL" is reached closer from the runway in aggressive strategy.

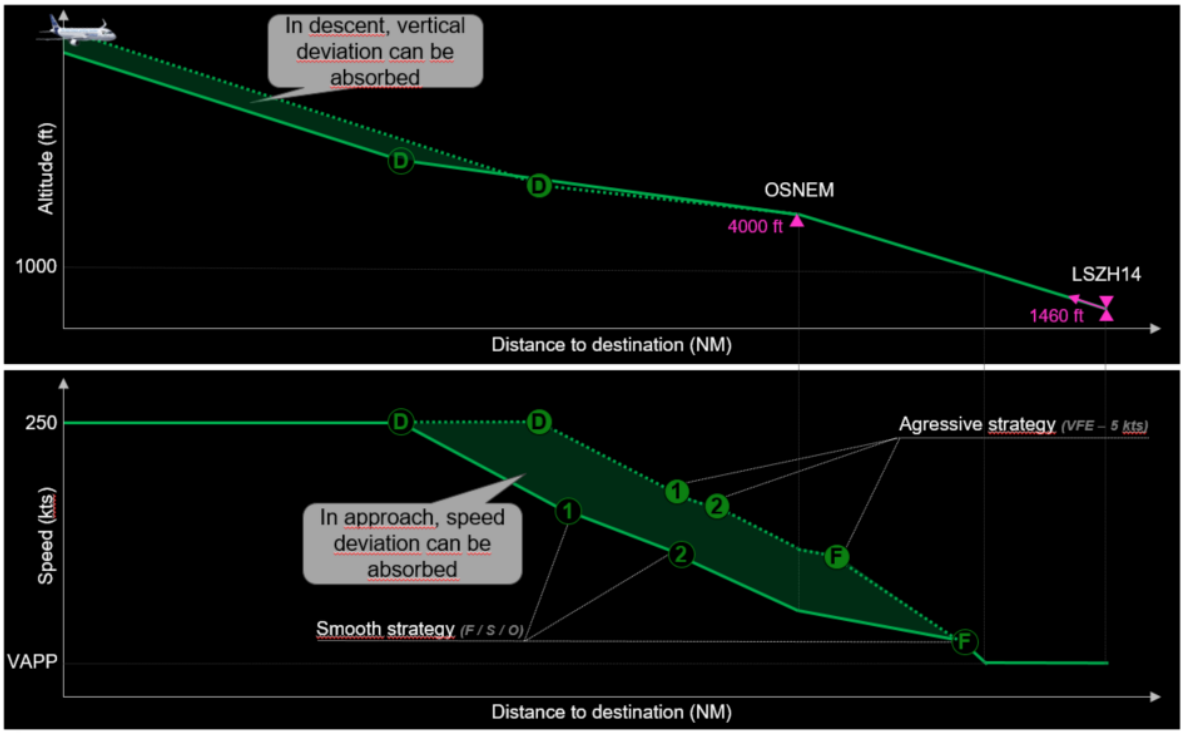

Figure 5: Configuration sequence adaptation principle, and impact on DECEL position.

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In this prototype, only “F” and “2” can be adapted, “1” will be mechanically moved accordingly. The adaptation of configuration “1” is not performed here (smooth strategy O is always applied), as, in the A320 family, configuration “1” is the less efficient configuration to dissipate energy, thus spending the least time possible in configuration “1” can be considered as the most efficient strategy. Note that the Figure 5 here-above presents the general adaptation principle, thus considering that any point of the flaps configuration sequence can be adapted.

As specified, in this prototype, “3”, “Full” and the landing gear are grouped under the “F” pseudo-waypoint (“F” for “Final”). The boundary used to define the aggressive strategy for “F” is VFE_{Full} – 5 kts: to ensure that the resulting speed profile remains in the normal flight envelope, the most constraining speed is used.

The picture below presents the effect of the VCC adaptation: in this example, upon over-energy detection, the whole configuration sequence is adapted and becomes aggressive. This allows to dissipate part of the initial over-energy, represented here by the Vertical Deviation: the aggressive strategy permits to dissipate around 700 feet of VDEV here, from +2300 ft to +1600 ft.

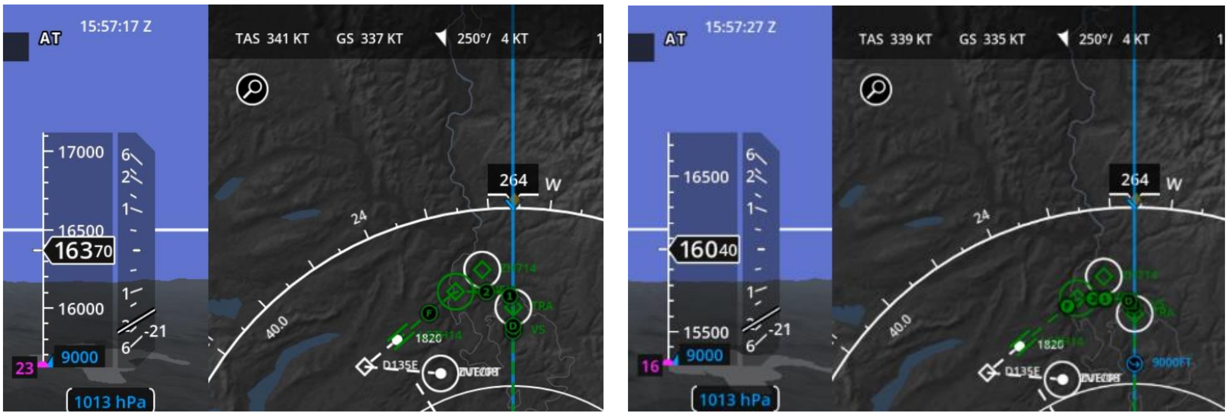

Figure 6: Adaptation from smooth strategy (left) to aggressive strategy (right) and effect on vertical deviation

Furthermore, in order to avoid any additional thrust and to take into account the flight dynamics, pseudo-waypoints “1”, “2” and “F” are shifted upstream by a fixed time value, meaning the pseudo-waypoints are displayed *x seconds before* the configuration change predicted position, as shown in Figure 7. This *shift* (corresponding to REQ-DYNCAT-FMS-004) applies in addition to the configuration sequence *adaptation* (for which the main requirement is the REQ-DYNCAT-FMS-001).

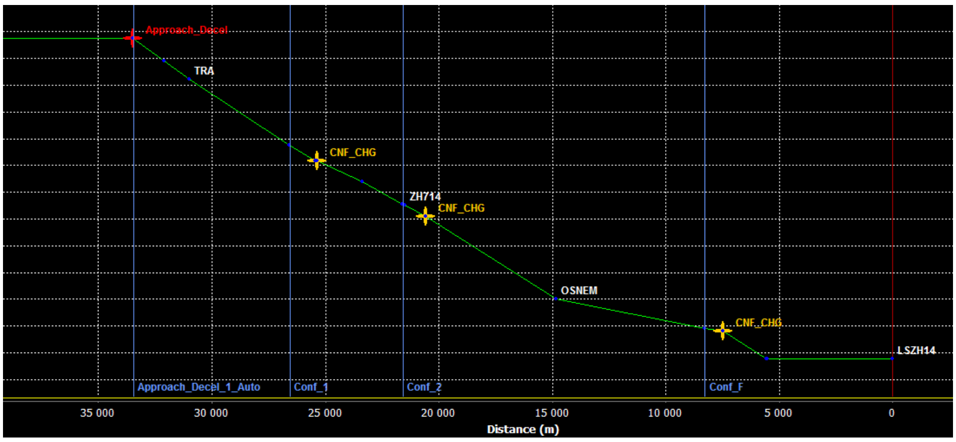

Figure 7: Displayed pseudo-waypoints positions (in blue) time-shifted from flaps extensions predicted positions (in yellow). Vertical axis shows the Indicated Airspeed.

Moreover, the Flight Management System will automatically activate the approach phase when switching to V/S mode near the DECEL. By removing the manual action of approach activation, this capability helps reducing the pilot's workload, while avoiding the corresponding engine spool-up.

Note: the approach activation upon switch to V/S mode was not specified in deliverable D3.1 [3] as it has been identified during the maturity phase. A requirement shall be added in D3.4 Final System High-Level Specification.

3.2.3 Limitations

The main limitation for this functional item is the partial prototyping of requirement REQ-DYNCAT-FMS-004.

Indeed, unlike the configuration pseudo-waypoints, the "DECEL" pseudo-waypoint is not shifted in this prototype. However, the approach phase is also activated upon switching to V/S mode near the DECEL pseudo-waypoint. The approach phase activation results in the managed target speed switching to manoeuvring speed (here: green dot). This anticipation of the DECEL phase allows to limit the engine spool-up when changing into V/S mode, which was the objective of the pseudo-waypoint shift. (See chapter 3.7 for VS cue relative position). So this partial prototyping will not affect the RTS final results (no impact on fuel consumption nor on noise).

3.2.4 Way Forward

As explained above, it was chosen not to adapt configuration "1" as it is not efficient for the A320 family. However, to be compliant to any aircraft, the Flight Management System could find the best adaptation strategy by determining which configuration adaptation is efficient according to its capacity to dissipate energy.

Moreover, to have an even more efficient energy management, another improvement would be to have three separate pseudo-waypoints for configurations "3" and "F" and for the landing gear (as a reminder, in this prototype, "3", "F" and the landing gear are grouped under the "F" pseudo-waypoint). It would enable to propose different sequence orders to the pilot, not only the classical one (e.g. 1 ➔ 2 ➔ gear down ➔ 3 ➔ full). Finally, the following point should be discussed: from a noise point of view, what is the best compromise between the use of the landing gear and the use of the speed brakes to dissipate energy?

At last, the question of shifting the DECEL (as initially specified) could be studied: if the prototype solution (activating the approach phase upon switch to V/S mode) is retained, no additional shift of the DECEL will be needed; on the other hand, if the chosen design does not prevent from engines spool up, a shift will probably be needed.

3.3 Optimised vertical profile

This section contains the technical requirements that drive the prototyping of the optimised continuous descent and approach vertical path in order to optimise both fuel and noise.

3.3.1 Associated requirements and prototype status

Requirement		Status
Identifier	REQ-DYNCAT-FMS-006	**Fully prototyped**
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.	
Identifier	REQ-DYNCAT-FMS-007	**Not prototyped** **(not required for the RTS scenario)**
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.	

Table 4: Optimised vertical profile requirements and associated prototype status

3.3.2 Prototype overview

The Flight Management System on which the prototype is based already allows to compute a CDA vertical profile. For the deceleration segments which are free of altitude constraints, a vertical slope of -500 ft/min is now considered.

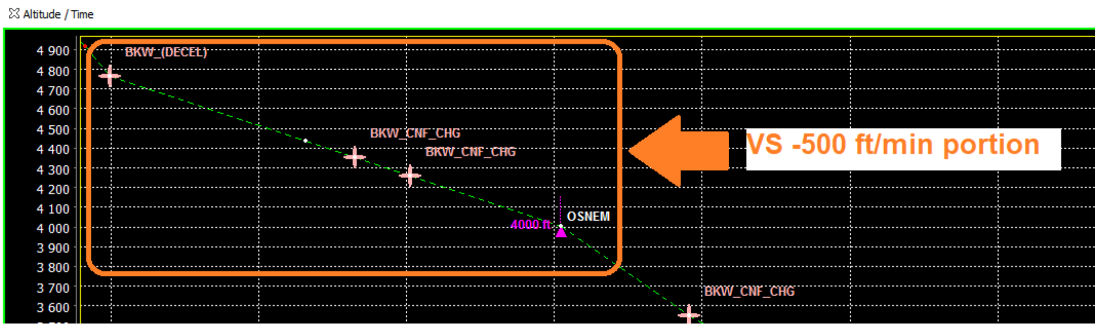

Figure 8: Profile portion at 500 ft/min

A deceleration segment is considered as free of altitude constraints when there is no AT altitude constraint and when any AT OR ABOVE or AT OR BELOW altitude constraint on this portion is respected using a vertical slope of -500 ft/min.

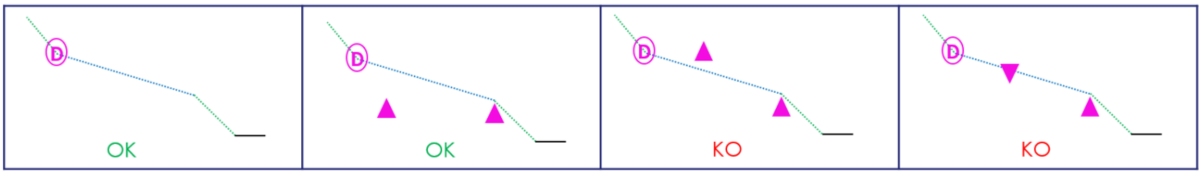

Figure 9: "Free/not free of altitude constraint" examples

Moreover, in order for the Flight Management System to compute an *optimised* vertical profile, a DYNCAT factor has been introduced for the approach to reduce the conservatism of the current Performance Database (A320 legacy Performance Database). It allows to have a computed profile that better fits the real aircraft capabilities. This factor can be tuned, if needed (see chapter 3.8). More specifically, it permits to tune the Flight Management System theoretical deceleration capability in final approach in order to match the real (or simulated) aircraft performance. It is mandatory to correctly predict the deceleration in order not to be stabilised too late or too early but at 1000 ft AAL. The default value has been set to 1.4, meaning it virtually increases the theoretical deceleration of the aircraft by 40% along the considered segments in the Flight Management System predictions.

Note: the DYNCAT Factor was not specified in deliverable D3.1 [3]. One requirement shall be added in D3.4 Final System High-Level Specification.

3.3.3 Limitations

The optional (as defined in D3.1 [3]) requirement REQ-DYNCAT-FMS-007 has not been prototyped. It is not required for the RTS scenario: as the test procedures do not contain speed restrictions, the vertical profile does not contain constant speed segments in approach. Thus, not prototyping this requirement will not affect the RTS final results.

3.3.4 Way Forward

As mentioned above, prototyping the capability described by the requirement REQ-DYNCAT-FMS-007 (Vertical mode for constant speed segment in approach) could allow to cover more situations. To target an industrial implementation of the DYNCAT concept into a Flight Management System, this development would be mandatory.

Moreover, having a V/S part in CDA profiles is not currently part of the Flight Management System high-level specification. As the Continuous Descent Operations topic is still evolving, particular attention could be paid, in the future, to the compliance of the Flight Management System high-level specification with a V/S segment on this portion.

The use of V/S could also be challenged: would Open mode be relevant for deceleration in approach? During the internal validation tests, we identified a risk with the use of V/S, as it "adds" a task for the pilot (switch to V/S and then monitor/adjust it), increasing the workload in a busy phase of the flight.

At last, the use of the DYNCAT factor could be studied to define the optimum values to use depending on the target aircraft (with its associated Performance database, which may be more or less optimised depending on the manufacturer) and on the desired aggressiveness of the DYNCAT function.

3.4 Speed and altitude restrictions

This section describes the way the Flight Management System is required to manage the altitude and speed restrictions coming from Air Traffic Control. As **this part is optional** (as defined in D3.1 [3]) in a first step of the project, the following requirements might be deeply refined in the next steps based on the DYNCAT prototype progress.

3.4.1 Associated requirements and prototype status

Requirement		Status
Identifier	REQ-DYNCAT-FMS-012	Prototyped (but not required for the RTS scenario)
Title	ATC speed restriction	
Requirement	When in selected speed mode, the FMS shall maintain the current selected speed until the start of deceleration to satisfy the next restrictive descent speed.	
Identifier	REQ-DYNCAT-FMS-013	Prototyped (but not required for the RTS scenario)
Title	ATC altitude constraint	
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.	

Table 5: Speed and altitude restrictions requirements and associated prototype status

3.4.2 Prototype overview

This optional part has been prototyped but will not be exercised during the RTS phase. Constraining speed and altitude restrictions coming from Air Traffic Control are not included in the exercise set-up at Zurich airport.

3.4.3 Limitations

N/A

3.4.4 Way Forward

The envisioned requirements could be further implemented. The final goal of this functional item is to be able to compute a vertical profile matching the controller intent: the way this intent is transformed in Air Traffic Control constraints and the way these constraints are transmitted on board are still to be defined. For example, it could be entered directly by the pilot upon voice transmission, but other means could be envisioned, like a transmission from the ground by Controller Pilot Data Link Communications (CPDLC).

3.5 Controller intent entry

This section describes the required interaction so that the pilot will be able to operate DYNCAT concept easily (e.g. Distance-To-Go or Indicated Time of Arrival inputs), considering the controller intent.

3.5.1 Associated requirements and prototype status

Requirement		Status
Identifier	REQ-DYNCAT-CDS-001	**Fully prototyped**
Title	Distance To Go (DTG) entry	
Requirement	The CDS shall provide to the crew the capability to enter the DTG.	
Identifier	REQ-DYNCAT-CDS-002	**Prototyped (but not required for the RTS scenario)**
Title	Capture point entry	
Requirement	The CDS shall provide to the crew the capability to enter the capture point when no ITA is defined.	
Identifier	REQ-DYNCAT-CDS-003	**Fully prototyped**
Title	Indicated Time of Arrival (ITA) entry	
Requirement	The CDS shall provide to the crew the capability to enter the awaited ITA on a downstream waypoint which is assumed to be the PRT capture point.	

Table 6: Controller intent entry requirements and associated prototype status

3.5.2 Prototype overview

All interactions to operate DYNCAT considering the controller intent are performed on the MFD:

- the Distance To Go is entered through the Flight Number field (usually used to enter the aircraft callsign) in order to simplify the prototyping and limit the impacts on the Cockpit Display System product:

Figure 10: Distance-To-Go entry

- the Indicated Time of Arrival is entered through the Time Constraint page in order to simplify the prototyping and limit the impacts on the Cockpit Display System product:

Figure 11: Indicated Time of Arrival entry

- the capture point is selected through the dedicated "Capture At" menu (note that the "Capture At" is prototyped but not used for the RTS):

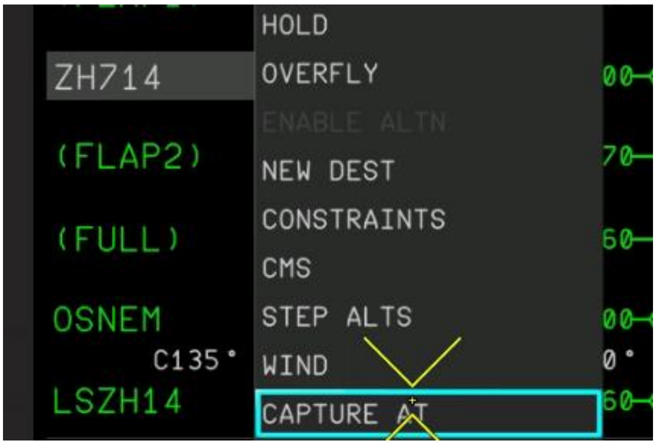

Figure 12: "Capture At" selection

No specific robustness has been added for the "Capture At". As a consequence, it is possible to select a capture point even when an Indicated Time of Arrival is already defined.

3.5.3 Limitations

In order to simplify the prototyping and limit the impacts on the Cockpit Display System product, existing MFD fields have been reused, and no specific fields nor pages have been created on MFD to enter the Air Traffic Control instructions.

3.5.4 Way Forward

In order to operate the DYNCAT function considering the Air Traffic Control instructions, dedicated fields for pilot entries such as Distance-To-Go or Indicated Time of Arrival should be defined in an appropriate page. It could be, for example, the PROGRESS page of MCDU (or equivalent means), or a dedicated page. This should be studied in order to be applicable to different aircraft (with possibly different HMI).

Moreover, the Flight Management System logics upon such entries should be refined: should these revisions result in a Temporary Flight Plan, or do they directly modify the Active one? A Temporary Flight Plan, which shall be inserted to become *Active*, prevents from erroneous entries, but requires more attention from the pilots and slightly increases the workload in the cockpit.

3.6 Strategic energy management cues

As a strategic information, the optimum distance to land (ODTL) is the only information for display that has been identified as required in the cockpit for the DYNCAT prototyping phase.

3.6.1 Associated requirements and prototype status

Requirement		Status
Identifier	REQ-DYNCAT-CDS-004	**Fully prototyped**
Title	Optimum distance to land display	
Requirement	The CDS shall provide to the crew the optimum distance to land in nautical miles.	
Identifier	REQ-DYNCAT-CDS-005	**Fully prototyped**
Title	Optimum distance to land margin display	
Requirement	The CDS shall provide to the crew the optimum distance to land margin in nautical miles, in green when there is no energy issue, in amber otherwise.	

Table 7: Strategic energy management cues requirements and associated prototype status

3.6.2 Prototype overview

The optimum distance to land represents the minimum distance to land with stabilised conditions at final stabilisation altitude (1000 ft AAL) assuming a default descent profile from the current aircraft altitude to the destination runway. This distance is computed using, in particular, the following assumptions:

- No speed brakes usage.
- The nominal configuration sequence is used (i.e. not the adapted configuration sequence to absorb over-energy defined in chapter 3.2)
- The deceleration segment from the descent speed, located before the final slope segment, is flown in Vertical Speed -500 ft/min.

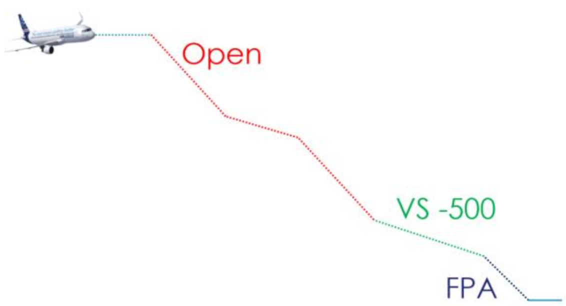

Figure 13: ODTL default descent profile

The ODTL margin, computed as the difference between the Permanent Resume Trajectory length and the optimum distance to land, is displayed in green while there is no energy issue, in amber otherwise. An energy issue is detected when the aircraft will not be stabilised at 1000 ft AAL gate while a full aggressive strategy on configurations is already applied.

The ODTL and its margin are displayed on the Navigation Display.

Figure 14: ODTL and associated margin

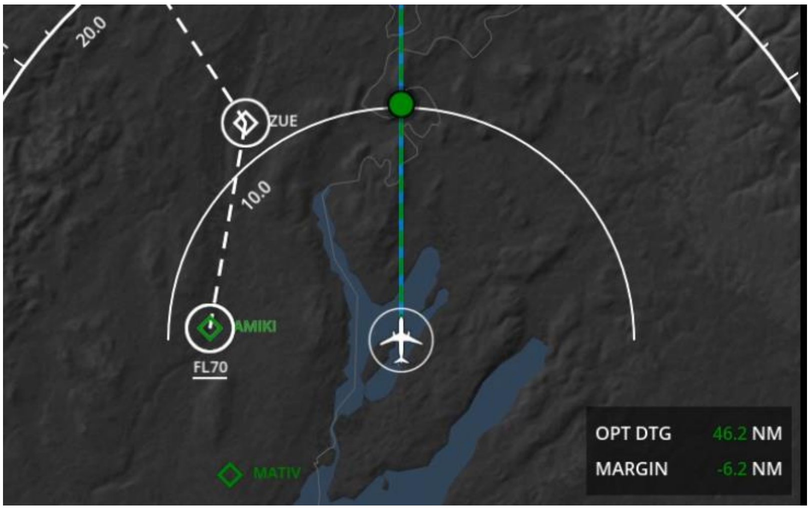

Figure 15: ODTL and margin location on the Navigation Display

Note: the definition of the ODTL and of its margin were not specified in deliverable D3.1 [4] as it has been refined during the prototyping phase. One or several requirements shall be added in D3.4 Final System High-Level Specification.

3.6.3 Limitations

No limitation identified.

3.6.4 Way Forward

In order to have a relevant ODTL, it is crucial to have accurate weather data (wind and temperature) between the aircraft and the runway, even when the aircraft does not fly along the planned route. This point is linked to the “Wind Information exchange” topic already identified in Deliverable D3.1.

An open point linked to the ODTL topic concerns the computation strategy of this profile. In the current prototype, it is static but a dynamic adaptation linked to the flaps strategy applied in the active profile might be interesting to make the understanding easier. Indeed, a negative green margin is currently absorbed by flaps and speed brakes, but the exact contribution of each one is unknown. Adapting the flaps strategy of the ODTL profile would permit to exclude the flaps from the margin.

3.7 Tactical energy management cues

This section describes the short term required information provided in the cockpit and required for DYNCAT concept prototyping, used for tactical flight management such as short-term messages, speed cues, deviations, etc.

3.7.1 Associated requirements and prototype status

Requirement		Status
Identifier	REQ-DYNCAT-CDS-006	**Fully prototyped**
Title	Approach pseudo-waypoints display on ND	
Requirement	The CDS shall display on the ND the DECEL and “1”, “2” and “F” configurations pseudo-waypoints, along the active FPLN trajectory.	
Identifier	REQ-DYNCAT-CDS-007	**Fully prototyped**
Title	Vertical pseudo-waypoints display on ND	
Requirement	The CDS shall display the information required to fly manually the DYNCAT optimized vertical profile in vertical selected mode, on the ND, and along the PRT lateral path.	
Identifier	REQ-DYNCAT-CDS-008	**Fully prototyped**
Title	Energy awareness cues	
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 there is an energy issue, in white otherwise (TBC).	

Table 8: Tactical energy management cues requirements and associated prototype status

3.7.2 Prototype overview

The Cockpit Display System displays on the navigation Display the positions of "DECEL", "1", "2" and "F" pseudo-waypoints, along the Permanent Resume Trajectory.

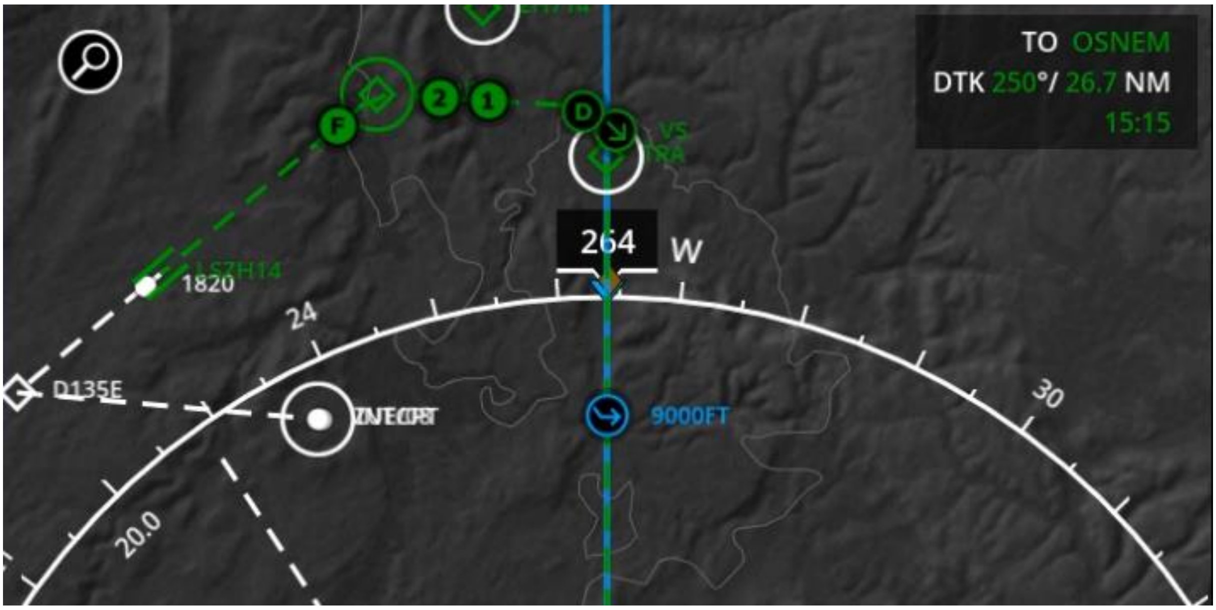

Figure 16: Computed "DECEL", "1", "2" and "F"

The look of the "1", "2" and "F" pseudo-waypoints changes according to the used strategy (see chapter 3.2 for strategies definition): as long as the strategy is not "aggressive", these pseudo-waypoints are filled in black, and they become filled in green when the strategy switches to "aggressive". Note that this does not concern the DECEL, which is not adapted.

Figure 17 : Configuration pseudo-waypoints display according to the strategy

The colour of the waypoint also changes when the Flight Management System predicts an energy issue (the speed predicted at this waypoint is too high to extend the flaps). In this case, the pseudo-waypoints are displayed in amber.

Figure 18 : Over-energy case: amber pseudo-waypoint

In order to allow the pilot to manually fly the optimised vertical profile, three different cues are displayed:

- The V/S pseudo-waypoint is displayed on the ND. This waypoint corresponds to the point where the V/S portion of the vertical profile starts, shifted by a small distance towards the current aircraft position (to cover the vertical capture transition and the pilot reaction time)

Figure 19 : V/S pseudo-waypoint

- A message requesting to extend or retract the speed brakes is displayed on the PFD. This message is displayed at the last possible moment required to reach the approach without over-energy (correct altitude and speed at the DECEL point). This choice of using this message as a "last line of defence" has been performed in order to let the pilots free to use the speed brakes earlier if they wish to do so, but also to avoid any toggling due to aircraft performances and weather uncertainties.

Figure 20: Extend Speed Brakes message on the PFD

- The VDEV symbol is displayed on the altitude scale of the PFD. This point is a direct benefit from having a Permanent Resume Trajectory and an associated vertical profile: as there is a profile, the Flight Management System and the Cockpit Display System are able to compute and display a Vertical Deviation value.

Figure 21: VDEV symbol on the PFD

Note: the need to display the Extend/Retract Speed Brakes message when in Selected vertical mode was not specified in deliverable D3.1 [4] as it has been identified during the maturity phase. A requirement shall be added in D3.4 Final System High-Level Specification.

3.7.3 Limitations

As explained in chapter 3.2.2, the aggressive speed for “F” is VFE_{Full} – 5 kts; this speed may be used to define the position of the “F” pseudo-waypoint. This is not consistent with the VFE displayed on the PFD, which considers the VFE related to the next configuration: when in flaps 2, the displayed VFE is VFE_3. This inconsistency may be a hindrance for the pilot to correctly assess the possibility to extend the flaps when reaching “F”. Indeed, in some cases, it may also lead to a situation where the pseudo-waypoint “F” is displayed in amber whereas the current speed is below the displayed VFE.

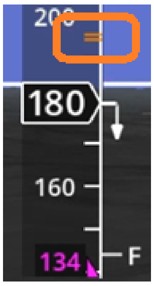

Figure 22: Displayed VFE on PFD

Some spurious displays of the Speed brakes message might occur when the pilot retracts the Speed Brakes near the DECEL pseudo waypoint with still some small vertical deviation. This limitation is due to the conditions used to display the message, which should be refined.

3.7.4 Way Forward

As stated in chapter 3.2.4, an improvement to have an even more accurate and efficient energy management would be to have three separate pseudo-waypoints for configurations “3” and “F” and for the landing gear. These pseudo-waypoints would then have to be displayed on the ND.

The “Extend/Retract speed brakes” message computation performed by the Flight Management System uses the actual speed brakes extension status. To transfer this part of the DYNCAT concept to other aircraft, particular attention shall be paid to the availability of this data for the Flight Management System on the target aircraft.

As stated above, some spurious displays of the speed brakes message might occur upon early speed brakes retraction: this problem shall be further analysed and fixed.

3.8 DYNCAT capability management

This section describes the way the Cockpit Display System and Flight Management System will manage the DYNCAT capability activation/deactivation.

3.8.1 Associated requirements and prototype status

Requirement		Status
Identifier	REQ-DYNCAT-CDS-009	**Fully prototyped**
Title	DYNCAT option activation	
Requirement	The CDS shall propose a means to activate/de-activate the DYNCAT capability.	

Table 9: DYNCAT capacity management requirements and associated prototype status

3.8.2 Prototype overview

DYNCAT capability activation/de-activation is done by entering specific codes in the flight number field (usually used to enter the aircraft callsign). The possible values for these codes are:

Code	Description
DYNREF	Activates the current FMS functional behaviour of an A32x aircraft.
DYNCAT	Activates the DYNCAT capability, except for ITA instructions.
PRTRTA	In addition to DYNCAT cheat code, activates the capability to compute a Permanent Resume Trajectory according to an Indicated Time of Arrival instruction.
FACTxxx	Enables to change the value of the DYNCAT FACTOR. E.g. enter FACT140 to set the DYNCAT Factor to 1.4.

Table 10: List of codes for DYNCAT activation/de-activation

This capability will allow to manage, with a unique Flight Management System software, all the experiments that have to be conducted during the RTS: the reference flights, the "main" DYNCAT flights and the "Indicated Time of Arrival" DYNCAT flights (performed for brainstorming/discussions). Furthermore, the DYNCAT factor tuning capability will be available in order to perform "free/tuning flights" (in addition to the RTS flights) if the pilots wish to do so.

3.8.3 Limitations

N/A

3.8.4 Way Forward

N/A

4 Experimentation test means

In order to support the DYNCAT internal validation and the RTS, the prototype had to be deployed on a representative and realistic test bench.

Figure 23: Flight Test Simulation bench (with focus on CDS and FCU)

The research test bench is a Virtual Simulation Integration Bench (VSIB) with a hybrid configuration. Its customisation is adapted to the rapid prototyping phase, meaning that new Flight Management System or Cockpit Display System versions can be deployed quickly to ease the continuity between the specification and the early validation steps. The infrastructure is based on EUROCAE Vistas Standard [5] to simulate communications between the systems. The bench is modular and includes some real equipment such as an A320 FCU or an A350 KCCU, and some simulated items (real software run on computers) such as the Thales Flight Management System PureFlyt™ (as already stated above) or the A321 FGC (Flight Guidance computer).

This bench allows to put the pilots in a familiar environment and thus to get more realistic behaviours.

Figure 24: Focus on Flight Controls required for DYNCAT

During the integration phase, particular attention has been paid to the communication between the new Cockpit Display System generation in order to ensure that the pilots get the same feedbacks on their actions (to avoid disturbing their handling during the trials) as on the real A320 Cockpit Display System.

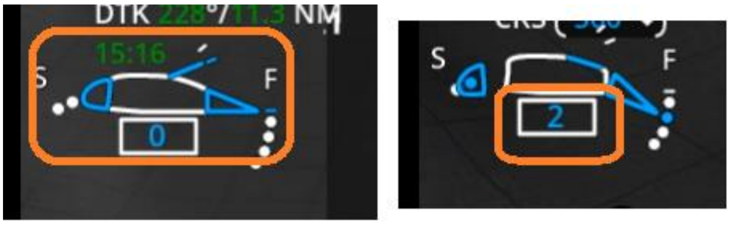

Figure 25: Display of speed brakes (left) and flaps (right) extension after bench integration

Moreover, still for validation and RTS purpose, the Flight Management System *Open Capacity* has been deployed on the test bench in order to benefit from the Flight Management System PureFlyt™ connectivity. The *Open Capacity* is a future capability that is concomitant with the introduction of the “open world” in the cockpit. This offers to the aircraft external systems or applications to get some Flight Management System data (aircraft vector, navigation database information, computed trajectory and predictions), or even to provide data to the avionics (flight plans for instance). In our context, this capacity is used as a tool to quickly initialise the flight plan and some associated parameters (e.g. between each scenario of the RTS) in order to save time on the bench and to keep the focus on the experimentation.

At last, the recording tools described in D3.2 [4] have been customised or checked for DYNCAT:

- The TOCATA engineering tool, allowing the recording of the lateral and vertical profiles, has been adapted to record information specific to the Flight Management System prototype content.
- The second tool is, as a reminder, a recorder of the VSIB simulation, enabling to record any signal that transits the IMB (Integrated Modular Bench), which is the heart of the simulation. This IMB module is a gateway that confers to the bench its modularity by enabling the interconnection of real or simulated products and systems from different generations and/or different aircraft (cf. D3.2 [4]). It permits to record the Flight Management System signals (as well as the AP ones, the environment parameters, etc…). Thus, after the Flight Management System integration onto the test bench, the Flight Management System signals observability has been verified.

5 Summary

The main objective of this SESAR Exploratory Research on DYNCAT concept is to demonstrate through a prototype the added value and the potential of the proposed solution. This document details the content of the prototype and assesses its compliance to the high-level system requirements written at earlier stages of the project.

Starting from new generation of Flight Management System and Cockpit Display System, a prototype that implements the expected requirements has been developed, including all the mandatory functional items. The system computes and display a continuous lateral path corresponding to the controller intent, allowing the computation of an optimised vertical profile. Dynamics pseudo-waypoints are computed, adapted to the current energy state of the aircraft and displayed along this profile, as well as others cues enhancing the pilot awareness to support the energy management task. A few optional items have not been treated, and some non-blocking limitations still exist, but they do not put the RTS at risk.

This prototyping phase has also highlighted some elements or concepts that can be further improved (e.g. lateral path determination…), as well as the need to develop and add other sub-functionalities (e.g. meteorological conditions uplink) in order to be able to use the DYNCAT concept at its fullest. On a more pragmatic point of view, this prototype will also allow to refine and enrich the Final System High-Level Specification (D3.4), and to get a basis for the next steps of the DYNCAT concept life.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

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

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