D27 – A PBN solution to link FRA to Final Approach

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Abstract

D27 is a proposed PBN solution linking Free Routes Airspace to Final Approach. This solution takes credit for the work undertaken by three SESAR projects and looks at linking the different phases of flight. The deliverable provides a scenario and considers the connectivity between FRA, en route and terminal operations. The deliverable identified regulatory short falls and recommends that these issues be addressed.

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This deliverable consists of SJU foreground.

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Executive summary

This P04.07.03 deliverable, D27, provides a possible PBN solution to link the Free Routes airspace, above FL310, to Final Approach in high density airspace via a set of defined and strategically deconflicted ATS routes from fixed entry points at the base of the FRA to the Final Approach Segment. The deliverable focuses on the work of three projects, P04.07.03 'Use of Performance Based Navigation (PBN) for En Route Separation Purposes', P05.07.04 'Full implementation of P-RNAV in TMA' and P05.06.03 'Approach Procedures with Vertical Guidance (APV)' and suggests one possible PBN scenario based on current published and planned European legislation. This deliverable forms part of SESAR Solution #10 and the expectation is to close out AOM-0404.

The three separate SESAR projects have investigated different phases of flight and different navigation specifications. Therefore, the European Commission's Pilot Common Project Implementing Regulation (716/2014) and EASA's Notice of Proposed Amendment 2015-01 'Performance-Based Navigation (PBN) implementation in the European Air Traffic Management Network (EATMN)' have been the primary drivers for determining which PBN navigation specifications to consider and Project 04.07.03 has created a scenario based on these to deliver the proposed PBN solution. It should be noted that this solution is not the only answer and the deliverable provides some thoughts on other applications that could equally resolve the dilemma on how to safely bring aircraft from FRA to the runway.

The project has identified what constraints there are to putting the proposed solution into the airspace and these are considered primarily to be regulatory. From the technical perspective, aircraft with the necessary functionality are flying within the European airspace today. The main key to effective PBN implementation in a fixed route environment is identified as high quality airspace design; however, the use of PBN in FRA today is limited as the aircraft's database has no airway or airport records stipulating the required performance for these operations. The strategic deconfliction of the arriving and departing flows of traffic, primarily laterally and vertically where flight paths are forced to cross, should always be the design goal and the result of well segregated flows should be the ability to provide uninterrupted continuous climb and continuous descent operations (CCO/CDO) when the traffic density allows.

D27 provides the background for the proposed PBN solution, and the supporting work undertaken by the three identified projects, provides the evidence in terms of capacity, efficiency, environmental impact and, of course, safety. The individual validation reports from the three projects need to be read in conjunction with this paper; it is not the aim of this deliverable to rewrite the existing work but instead to point to the results. All the supporting documentation is listed in the Annex.

The recommendation of this deliverable is the need to resolve a set of regulatory constraints prior to the full implementation of this proposed PBN solution.

1 Introduction

1.1 Purpose of the document

The purpose of this document is to provide a possible solution to connect the Free Routes Airspace, planned above FL310, to the approach utilising PBN capabilities. The document considers a high density traffic environment which requires flows of traffic below FL310 to be strategically deconflicted by the appropriate placement of ATS routes and the utilisation of Advanced Required Navigation performance (A-RNP) together with a consistent and highly repeatable turn performance provided by Fixed Radius Transitions (FRT) in the en-route and Radius to Fix (RF) path terminators on the instrument flight procedures (IFPs). The entry and exit from the FRA will be at defined waypoints which the ATS routes will connect to. This document is aimed to support SESAR Solution 10 which is an optimised route network using advanced RNP; this solution does not consider operations above FL310. The figure below shows the operations under consideration.

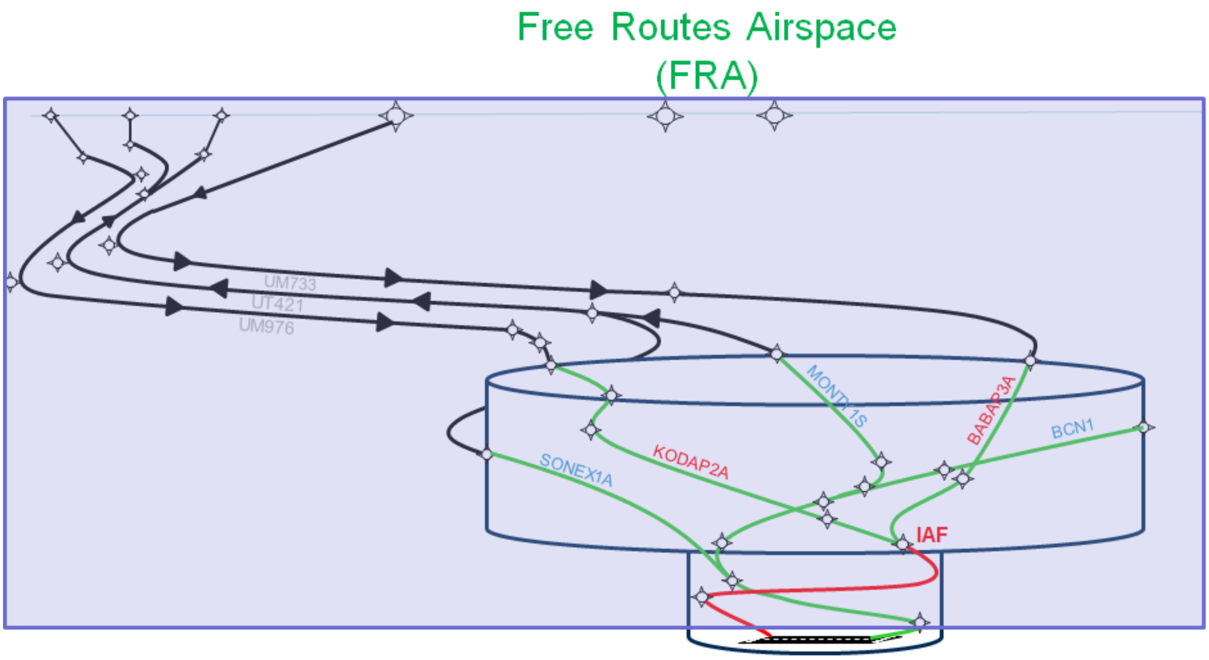

Figure 1 - Scope of Proposed Solution

Operations within high traffic volume terminal environments may be subject to delay due to the effective metering of the arrival sequence. The management of this delay may be achieve through the application of holding, radar vectoring or the by the use of Point Merge; this proposed solution considers the latter option but the operational concept for specific terminal airspace will define the most efficient way of managing that delay whilst maintaining runway capacity. Therefore, a true Continuous Descent Operation (CDO) from Top of Descent (TOD) to the runway may not always be achievable due to capacity limitations. Regardless of which technique is used to manage that delay, aircraft may be forced to interrupt the CDO whilst the arrival flow is managed. Effective metering and sequencing through the use of extended arrival managers (AMAN) at the hub airports, as identified in AF#1 of the Pilot Common Project Implementing Regulation (PCP IR - EU 716/2014), is hoped to minimise the need to interrupt the aircraft's approach and therefore enable a complete CDO. Furthermore, sequencing of the arrival flow is expected to be significantly enhanced with Time of Arrival Control (TOAC); however, this functionality is still relatively immature and has not yet been defined within the PBN manual (ICAO Doc 9613 Edition 4).

1.2 Intended readership

SESAR related projects that can be interested in this deliverable are projects in the same OFA 2.1.1, SWPs 4.2, 4.3, 4.7, 5.2, 5.3, 5.9 and 4.7.2 for consistency across these SWPs and transversal projects 16.3.x, 16.6 and B5.

1.3 Inputs from other projects

Phase 1 of Project 04.07.03 considered en-route strategically deconflicted flows of traffic closely spaced and utilising the FRT functionality; the work of Phase 1 of this project supports this solution. Project 05.07.04 investigated the full implementation of P-RNAV (lateral performance is the same as RNAV1) in TMA; however, although this project investigated the application of Point Merge, which is part of the proposed solution, the aircraft functionality did not include 'on-board performance monitoring and alerting' and radius-to-fix (RF) turn performance[1]. For the approach phase, one possible method to support these operations was investigated by Project 05.06.03. This project looked at Approach Procedures with Vertical Guidance (APV) supported by satellite based augmentation and flown to localiser performance with vertical guidance (LPV) minima. Both P05.07.04 and P05.06.03 focused on TMA operations whilst P04.07.03 only studied en route operations. Figure 2 below summaries the interaction between the three associated projects but does not highlight the connectivity issue of the different projects.

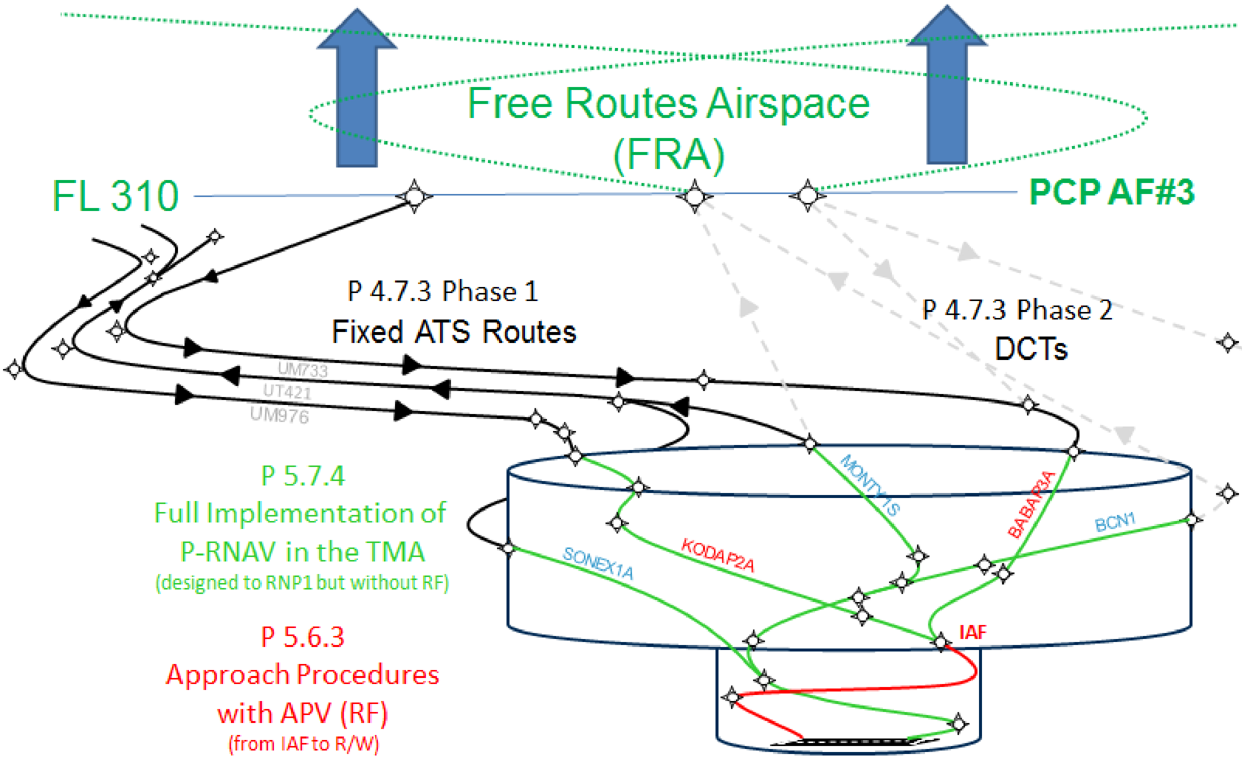

Figure 2 - Projects providing input to the proposed solution

1.4 Glossary of terms

The following terms are taken from P05.06.03 D43 Advanced Procedure Validation Report EXE792 and may not be in line with the PBN manual (ICAO Doc 9613 Edition 4):

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[1] Atterntion should be drawn to the UK CAA/NATS flight trial of RNP1 SIDs at London Standsted (EGSS) which has exercised radius to fix (RF) turns. This flight trial is not undertaken within SESAR but demonstrates successful operation of this aircraft functionality.

Glossary	
Approach Procedure with Vertical Guidance (APV)	Area Navigation (RNAV) approaches using both lateral and vertical guidance
Advanced Approach Procedure with Vertical Guidance (ADV-APV)	The Advanced APV or the Advanced LPV procedure. This comprised of three elements: A RNP approach using RF (or TF) turns for the initial and intermediate phases of the approach procedure; A CDA for vertical profile; APV down to LPV minima for the FAS i.e. an APV-SBAS FAS. Throughout this document APV may be used in graphs and text for simplicity but this refers to Advanced APV
APV Equipped	Aircraft that have APV SBAS/Baro equipment on-board in order to carry out an APV approach
European Geostationary Navigation Overlay Service (EGNOS)	The satellite based augmentation system (SBAS) developed by the European Space Agency, the European Commission and EUROCONTROL
Localiser Performance with Vertical Guidance (LPV) procedure	An APV approach based on SBAS. The phraseology "Advanced APV procedure" is equivalent to "Advanced LPV" and "Advanced LPV procedure" for the purpose of this document

1.5 Acronyms and Terminology

Term	Definition
ADD	Architecture Definition Document
AF	ATM Functionality (as identified in the PCP IR)
AMAN	Arrivals Manager
AMC	Acceptable Means of Compliance
AOM	Airspace Organisation and Management
AP/FD	Autopilot/Flight Director
APV	Approach with Vertical Guidance
A-RNP	Advanced Required Navigation Performance
ATCO	Air Traffic Control Officer
ATM	Air Traffic Management

Term	Definition
ATS	Air Traffic Services
AU	Airspace User
B-RNAV	Basic Area Navigation (RNAV5)
CCO	Continuous Climb Operation
CDA	Continuous Descent Approach
CDO	Continuous Descent Operation
CRDS	Central European Air Traffic Control Research Development and Simulation Centre
CRS	Closer Route Spacing
CS-ACNS	Certification Specification – Airborne Communications, Navigation and Surveillance
DOD	Detailed Operational Description
E-ATMS	European Air Traffic Management System
EC	Executive Controller
EGNOS	European Geostationary Navigation Overlay Service (European SBAS)
ENR	En route
E-OCVM	European Operational Concept Validation Methodology
ESSP	European Satellite Services Provider – Concession Holder of EGNOS
E-TMA	Extended Terminal Manoeuvring Area
FAF	Final Approach Fix
FAP	Final Approach Point
FAS	Final Approach Segment
FMS	Flight Management System
FRT	Fixed Radius Transition
IAF	Initial Approach Fix
IF	Intermediate Fix
IRS	Interface Requirements Specification
INTEROP	Interoperability Requirements

Term	Definition
LPV	Localiser Performance with Vertical Guidance (minima line)
OFA	Operational Focus Areas
OPMA	On-board Performance Monitoring and Alerting
OSED	Operational Service and Environment Definition
PBN	Performance Based Navigation
PC	Planning Controller
PCP	Pilot Common Project (Implementing Regulation – EU 716/2014)
PI	Performance Indicator
P-RNAV	Precision Area Navigation (≈RNAV1) certified by TGL10 Rev1
RF	Radius to Fix (ARINC424 Path Terminator)
RTS	Real Time Simulation
SBAS	Satellite Based Augmentation System
SDD	Service Definition Document
SESAR	Single European Sky ATM Research Programme
SESAR Programme	The programme which defines the Research and Development activities and Projects for the SJU.
SJU	SESAR Joint Undertaking (Agency of the European Commission)
SJU Work Programme	The programme which addresses all activities of the SESAR Joint Undertaking Agency.
SoL	Safety of Life
SPR	Safety and Performance Requirements
SUT	System Under Test
TAD	Technical Architecture Description
TF	Track to Fix (ARINC424 Path Terminator)
TGL	Temporary Guidance Leaflet (issued by the Joint Airworthiness Authority)
TMA	Terminal Manoeuvring Area
TOAC	Time Of Arrival Control
TOD	Top of Descent

Term	Definition
TPO	Tactical Parallel Offset
TS	Technical Specification
TSE	Total System Error
VALP	Validation Plan
VALR	Validation Report
VALS	Validation Strategy
VP	Verification Plan
VR	Verification Report
VS	Verification Strategy
WP	Work Package

2 AOM-0404

Description

Advanced RNP is implemented and supports enhancements of route structure. Spacing between routes is reduced where required, with commensurate requirements on airborne navigation and ground systems capabilities.

Rationale

With the introduction of an Advanced-RNP navigation specification, the advantages gained from P-RNAV will be further enhanced by onboard performance monitoring and alerting (OPMA) and the execution of more predictable aircraft behavior. This will enable the design of optimised routes which may include closely spaced parallel routes, Fixed Radius Transition (FRT) and Tactical Parallel Offset (TPO) functionality in en route and procedures which include Radius to Fix (RF) in the TMA.

OI Step Comments

OI - Optimised Route Network using Advanced RNP linked to aircraft performance

2.1 Navigation Specifications

The key to this proposed solution is connectivity. The aircraft will need to have a lateral performance accuracy of 1NM with OPMA and consistent and highly repeatable turn performance. This set of capabilities is met with the Advanced Required Navigation Performance (A-RNP) specification as detailed with the PBN Manual (ICAO Doc 9613 Edition 4). For this solution it is also assumed that the aircraft will also be capable of FRT and that this would be a requirement to operate on the ATS routes. The A-RNP specification was designed as an 'umbrella' specification which would incorporate RNAV5, RNAV2/1, RNP1 and RNP APCH with a single certification and operational approval. The following table details the expected lateral navigation performance in each flight phase and optional functionalities that can be associated with each PBN Navigation Specification:

Navigation Specification	Flight phase								Additional Functionalities (Required or Optional)			
				Approach								
	En route oceanic/ remote	En route continental	Arrival	Initial	Intermediate	Final	Missed[1]	DEP	RF	FRT	TOAC	Baro VNAV
RNAV 10	10											
RNAV 5[2] *AMC 20-4*		5	5									
RNAV 2		2	2					2				
RNAV 1 *Rev 1 JAA TGL 10*		1	1	1	1		1	1				O
RNP 4	4									O		
RNP 2	2	2								O		
RNP 1[3]			1	1	1		1	1	O[8]			O
Advanced RNP[4]	2[5]	2 or 1	1	1	1	0.3	1	1	R[8]	O	O	O
RNP APCH[6] *AMC 20-27 AMC 20-28*				1	1	0.3	1		O[8]			O
RNP AR APCH *AMC 20-26*				1-0.1	1-0.1	0.3-0.1	1-0.1		*Specific requirements for RF & VNAV*			
RNP 0.3[7]		0.3	0.3	0.3	0.3		0.3	0.3	O[8]			O

Note:

1. *Only applies once 50m (40m Cat H) obstacle clearance has been achieved after the start of climb.*
2. *RNAV 5 is an en route navigation specification which may be used for the initial part of a STAR outside 30 NM and above MSA.*
3. *The RNP 1 specification is limited to use on STARs, SIDs, the initial and intermediate segments of Instrument Approach Procedures and the missed approach after the initial climb phase; beyond 30 NM from the airport reference point (ARP), the accuracy value for alerting becomes 2 NM.*
4. *Advanced RNP also permits a range of scalable RNP lateral navigation accuracies – refer to the A-RNP Nav Spec in the PBN manual.*
5. *Optional – requires higher continuity.*
6. *There are two sections to the RNP APCH specification; Part A is enabled by GNSS and Baro VNAV, Part B is enabled by SBAS.*
7. *The RNP 0.3 specification is primarily intended for helicopter operations.*
8. *Refer to the RF Appendix in Volume II Part C of the PBN manual for conditions of user.*

Figure 3 - PBN Navigation Specifications with associated options permitted

2.2 Defining the aircraft path

To enable safe and efficient operations within the high density en-route airspace and the terminal manoeuvring areas (TMAs), it is expected that the flows of traffic inbound and outbound are segregated appropriately to allow aircraft to climb and descend as efficiently as possible whilst ensuring that the capacity within the airspace is not impacted. Therefore, another key to this proposed solution is the strategic deconfliction of traffic flows by effective placement, protection and management of the ATS routes; this is achieved by careful and effective airspace design. It is important that the reader understands that the lateral accuracy required along the route, together with performance monitoring and alerting and consistent turn performance can only be enabled when there is an airway or airport record coded into the aircraft's navigation database. The datahouses will only code an airways or airport record, which defines the parameters for that path, if the route, be it an airway or and instrument flight procedure (IFP), is designated as an ATS route in accordance with ICAO Annex 11 Appendix 1 or 3 and that route is listed in the State's Aeronautical Information Publication (AIP).

2.3 Concept of Operations:

To safely manage aircraft arriving out of Free Routes Airspace (FRA) into a high traffic density environment will require the aircraft placed onto defined ATS routes. There will need to be defined waypoints at the edge of the FRA, be that laterally or vertically, where the defined ATS route starts. Therefore, the ATM system will need to monitor the exit points from FRA to ensure these waypoints are not saturated by arriving traffic. The application of extended AMANs at the hub airports, as identified in AF#1 of the PCP IR, should enable capacity management and initial sequencing at these waypoints through speed management.

2.4 En-Route operations

The work undertaken by P04.07.03 in Phase 1 set out to confirm the previous EUROCONTROL Real Time Simulations (RTS) on A-RNP route spacing run at EUROCONTROL's Central European Air Traffic Control Research Development and Simulation Centre (CRDS) based in Hungary in 2009 and 2010. These RTS applied a route spacing of 7 NM in both same direction and opposite direction both on the straight and turning segments. A figure of 5NM applying A-RNP performance with FRT for consistent and highly repeatable turn performance was derived by Collision Risk Modelling however, the ATCos stated that due to sector size, radar scale and aircraft relative speeds and other human factors, the minimum separation between route centrelines that they were comfortable with was 7NM. The controllers did express that at TMA boundaries, when sector sizes are smaller and aircraft speed is reduced, the possibly a 6NM distance between route centrelines could be achieved.

Within P04.07.03, the team investigated the 7NM route spacing in more densely populated airspace to confirm the CRDS findings. The two exercises undertaken by ENAV simulated Italian airspace and envisaged the following elements which would be part of the proposed PBN solution:

a) Designing Advanced RNP routes for the EUR ARN spaced by 7 NM in the en route and possibly at the en route/terminal interface 6 NM. These ATS routes would designated in accordance with ICAO Annex 11 Appendix 1 or 3 and would be published in the AIP; (*Note:*

that terminal routes is a generic expression used to include ATS routes, instrument flight procedures or SIDs/STARs).

b) The ability to maintain a consistent spacing between Advanced RNP routes on turns due to the requirement for both RF and FRT functionalities;

c) The aircraft has been properly certified and the aircrew have been operational approval for Advanced RNP operations with FRT against EASA documentation (EASA AMC or Certification Specification (CS));

d) ATS routes with FRT are clearly designated;

e) The Advanced RNP ATS and Terminal route being flight planned by the air crew;

f) The aircraft navigating along the Advanced RNP ATS or Terminal route using an area navigation system with requirements to maintain the route centre line;

g) The aircrew manage the FMS to ensure the FRT is correctly executed;

h) ATC give the appropriate airways clearance to ensure that the aircrew manage the FMS correctly;

i) ATC monitoring the progress of the aircraft along the route and correcting any deviations from the cleared Advanced RNP ATS or Terminal route. (This does not prohibit ATC providing direct-to clearance (short cut) where appropriate).

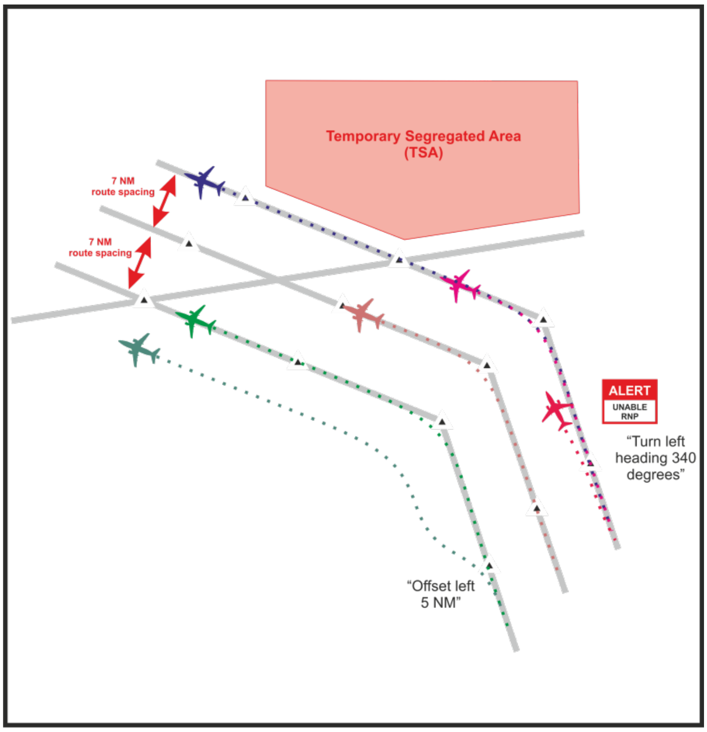

Figure 4 - Proposed closely spaced A-RNP routes for en route phase of the solution

The proposed solution of designing parallel closely spaced routes with FRT[2] at the turns would safely provide additional capacity if the ATS routes are correctly designed and aircraft operating on these ATS routes are appropriately certified and the crews operationally approved. The ATM system will need to identify those aircraft which do not have the capability and these will have to be managed differently. As the solution maintains 7NM between centrelines in the turning segments as well, aircraft which are unable to perform FRT cannot be allowed to operate along these routes. Therefore, to ensure controller workload remains manageable the ATM system will have to identify from the ICAO flight plan which aircraft should not operate on the closely spaced parallel routes. There are several current constraints to applying this solution, the ICAO flight plan does not have PBN codes for

[2] The reader should refer to the PBN manual (ICAO Doc 9613 Edition 4) Volume II, Part C Appendix 2 to understand how the FRT will calculate and action a fixed radius transition.

A-RNP or FRT; this would have to be set at regional level as a minimum. Allied to this, RTF phraseology for confirming the navigation specification and whether the aircraft has FRT needs to be developed. Finally, EASA has yet to develop certification and operational approval documentation.

The A-RNP specification requires the aircraft to have autopilot/flight director (AP/FD) and this should provide high confidence that the aircraft will maintain within 1NM of the ATS route centreline 95% of the flight time. As OPMA is also a requirement, in normal operations the probability that an aircraft exceeds 1NM from the centreline in normal operations is 10^{-7} per flight hour (one missed detection in 10 million/fh). Furthermore, in abnormal conditions when the uncertainty in position is double the RNP, the probability that the avionics fails to provide an alert to the flight crew is 10^{-5} per flight hour (one missed detection in 100,000/fh). Therefore, with the ground system's route adherence monitoring (RAM), the airspace user and controller should have high confidence that if the performance is exceeded at least someone in the system will be alerted and then mitigation can be employed. The requirement for the navigation computer to be capable of flying a parallel offset from the parent track, up to 20NM in increments of 1NM or less, will provide the controller to initiate tactical parallel offsets (TPO) to manoeuvre aircraft around one and other rather than radar vectoring. The added bonus of the parallel offset functionality is that the aircraft's offset route will inherit all the properties of the parent path; therefore, the same performance requirements will be applied to the offset as well as the ATS route.

In terms of airspace design, currently within PANS OPS (ICAO Doc 8168) there is very little guidance for the design of FRTs. Unlike procedure designers, who undergo specific training before developing instrument flight procedures, there does not appear to be such a requirement for airspace planners. This may need to be addressed, especially as the FRT radii defined in the Minimum Aviation Specification Performance Standards (MASPS) for Required Navigation Performance for Area Navigation (RTCA Doc 236C/EUROCAE ED75D) only **recommends** two values: 22.5NM above FL200 and 15NM below FL190. Guidance must be provided on designing an ATS route with FRT and what factors could make the transition 'unflyable' (this would mean that the aircraft's flight path would be unpredictable). Again, as both pilot FMS interaction and controller instructions can affect whether the computer will create the FRT or not, appropriate training and awareness material will need to be developed to support these operations. Finally, as the ATS route designator for FRT was dropped from Annex 11 in the 2008 amendment cycle, a new designation is required. The ICAO Separation and Airspace Safety Panel (SASP) initiated this action in 2012 but the Air Navigation Bureau passed the task onto the Instrument Flight Procedures Panel (IFPP) to address. This action has still to be completed.

The primary elements which prevent Europe placing parallel ATS routes closer together are considered to be regulatory rather than technical. The A-RNP specification, detailed in ICAO Doc 9613 Edition 4, requires the aircraft to have OPMA, be able to perform with a lateral track accuracy in the en route of 2 or 1NM (Europe plans to require 1NM performance) 95% of the flight time. The aircraft must be capable of executing several path terminators including RF, the aircraft must have AP/FD and the aircraft must be able to perform an RNAV hold. On final approach, the aircraft's performance is required to be +/-0.3NM 95% of the flight time. All of these capabilities are not just limited to the latest generation of aircraft but have been available for the past decade with new production aircraft. The table below is a 2010 fleet capability assessment undertaken jointly by IATA and EUROCONTROL.

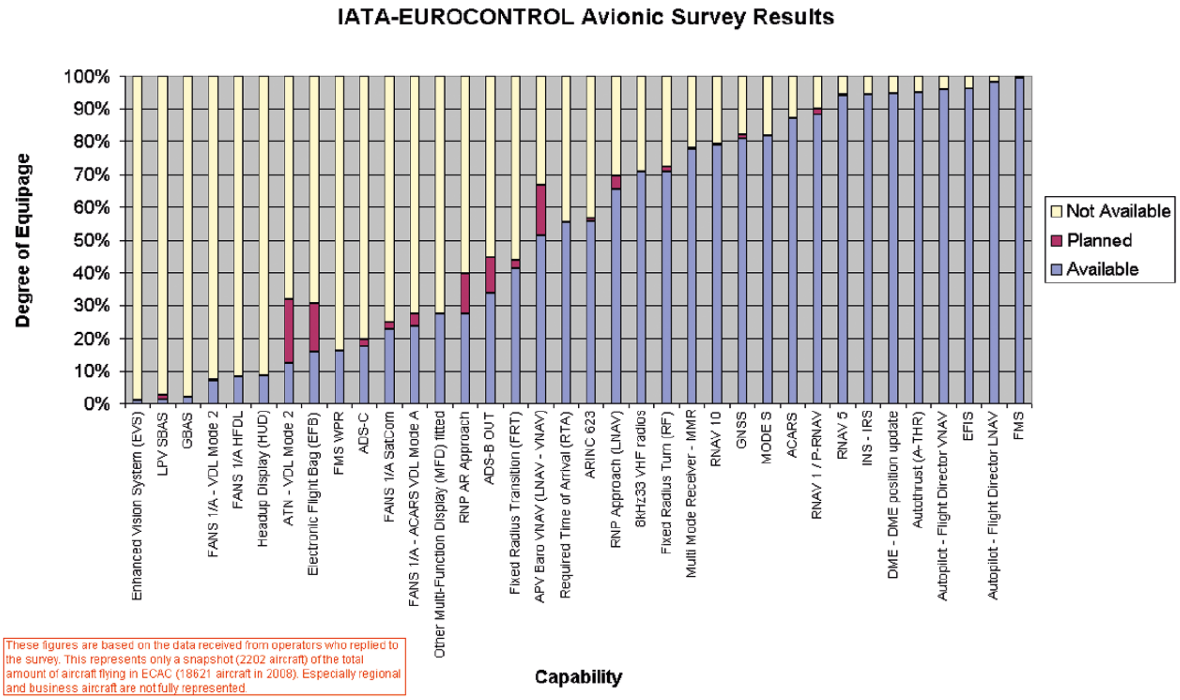

Figure 5 - 2010 IATA/EUROCONTROL Avionics Survey

Whilst this survey is over 5 years old, the table clearly shows that the requirements for A-RNP with FRT can be met by a reasonable percentage of the European fleet today. The vast majority of the fleet is equipped with GPS, which is the only sensor which automatically provides OPMA, although there will need to be a back-up infrastructure of DME/DME for at least the next decade as dual frequency will not be available until 2024 at the earliest and multi constellation probably even further into the future. Over 50% of the surveyed aircraft have RF functionality whilst approximately 30-35% of the fleet are capable of executing FRT in the en route. Therefore, a positive cost benefit analysis will need to be undertaken to clearly show that in the projected environment there will be a return on investment for the airspace users. For the proposed closely spaced parallel routes, a mixed mode operation is not foreseen. Management of aircraft 'flying by' the waypoint rather than performing a fixed radius transition (a managed turn) will negate the collision risk modelling which foresaw the Target Level of Safety (TLS) of 5 x 10^{-9} fatal accidents per flight hour (fa/fh) being met by consistent and highly repeatable turn performance. Therefore, the safety case must address how segregation of aircraft of lower performance will be undertaken and consideration given to the possibility that someone tries to 'cheat' the system by deliberately filing the incorrect codes on the flight plan to gain access to these ATS routes; this has been observed in RVSM airspace and the SASP has written to the Air Navigation Commission (ANC) about it.

2.4.1.1 The Proposed Solution – En route

For the purposes of this deliverable, the project has developed a fictitious scenario to connect the different segments of the proposed solution. This scenario has an airport with single runway (04/22) and a main flow of traffic that primarily runs North/South. Transit traffic operating above FL310 would be in Free Route Airspace and on user preferred trajectories. Access to and from the fixed route environment below FL310 would be made vertically at specified (and published) entry points. Due to the high volume of traffic, a managed, strategically deconflicted set of parallel routes has been designed and some of this traffic will be operating to and from the airport. In accordance with the SESAR Deployment Manager's Deployment Programme Family 1.2.5 (A-RNP) has been implemented and a series of closely spaced parallel routes have been designed. As there is permanent restricted airspace, there is a need for turning segments to be employed. Therefore, to restrict variability in turn performance, the region has elected to design the ATS routes with Fixed Radius Transitions; therefore, to operate safely on these ATS routes and to ensure consistent and highly repeatable turn performance, the aircraft operating on the route network above FL200 will need to be certified, and the crews operationally approved, to A-RNP with FRT; this should be indicated to

ATC through the ICAO flight plan (however, at present the codes for A-RNP and FRT do not exist). The diagram below provides the layout of the en route ATS airways:

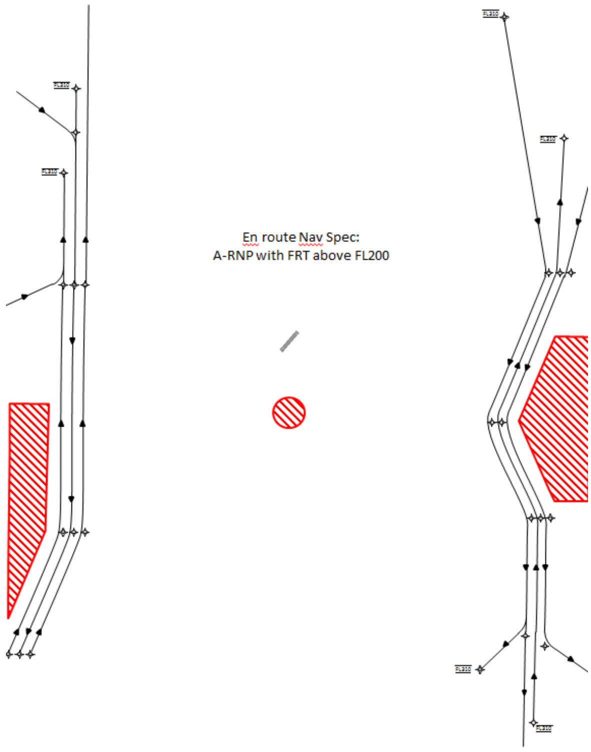

Figure 6 - En route scenario upper ATS route network

All ATS routes are designed in accordance with current guidelines (although it should be noted that design guidance for FRT is lacking). The ATS routes are designated in accordance with ICAO Annex 11, Appendix 1 (currently there is no designator for ATS routes with FRT and this is being addressed by the IFPP) and published in the State's AIP. The ATS routes have been coded up by the datahouses and are in the aircrafts' operational databases as normal airways records. Clearance to operate on these ATS routes will be given by ATC and the controllers will have been trained on issues such as the use of DCT and incorrect phraseology.

2.5 Terminal Operations

2.5.1 Transition to Final Approach

In the TMA as well as operations below FL195, we may expect to see mixed mode operations. This will allow the ATM system to manage aircraft of lower capabilities which would be cost prohibitive to retrofit to A-RNP. However within the TMA we would expect a minimum capability of RNP1, which can be achieved with a GPS receiver, and the RF path terminator as well as the other requirements for RNP1 laid out in ICAO Doc 9613 Edition 4. Aircraft with an A-RNP certification and provided the crew is equally operationally approved would fully comply with the needs of the SIDs/STARs and transitions.

The design of the SIDs/STARs and transitions are to be coordinated to ensure that the efficient flow of traffic along strategically deconflicted paths (laterally wherever possible or with good vertical separation if the paths are forced to cross) which will allow the aircraft to climb and descend unrestricted enabling CCO/CDO provided the traffic density allows. To manage capacity on the runway, RNAV holds can be designed and this functionality required by A-RNP will allow procedure designers to reduce the amount of airspace needed to protect the hold in comparison a conventional one. However, as this would be a mixed mode environment conventional holds would still need to be provided. The alternatives to the conventional hold could be to design either Point Merge arcs or 'trombones' to manage the flow and sequencing of aircraft onto the runway. Although Project 05.07.04 'Full implementation of P-RNAV in TMA' did not consider RNP1, the lateral accuracy required along the SIDs/STARs and Transitions was 1NM 95% of the flight time. Therefore, what P05.07.04 did not address was the benefit of OPMA and the availability of RF; the PBN manual does not allow RF functionality to be associated with RNAV specifications. However, flight trials in the UK at Stansted (EGSS) have demonstrated very successful RNP1 operations with RF on the SIDs from both runway 04 and 22; this trial has been so successful it has been extended for a further 6 months.

2.5.1.1 Arrivals: Extended TMA boundary to TMA Boundary

Normal Mode – High traffic density & complexity

To fully support the proposed operating method, traffic is expected to arrive at the Extended TMA (ETMA) boundary on RNP1 routes which below FL195 will be designed either as STARs with RF or ATS routes with fly by transitions to accommodate a mixed mode environment. The flow of the traffic should be appropriately metered and sequenced such that the arriving aircraft can initiate a continuous descent from the Top of Descent, or continue the descent uninterrupted if it has been initiated whilst still with the Area Control Centre (ACC). The key to enabling this is the coordinated design of arrival and departure flows routes by the careful placement of the ATS routes and consideration of building in maximum vertical separation where there are interactions thereby enabling uninterrupted climbs and descents; the EUROCONTROL TMA Design Guidelines and the Airspace Concept Handbook for PBN Implementation stress this important, and sometimes overlooked, fact.

The flows of traffic from the different directions will need to be merged and there are several means to achieve this:

- via holding stacks,
- via Point Merge Systems or
- via the simple joining of routes.

Whilst holding stacks are the traditional way of maintaining a steady arrival steam, the aircraft are unable to perform a CDO and the amount of airspace required to protect a conventional hold may force less efficient flows of traffic through the airspace. The scenario envisaged, high density traffic loads, would probably mean that merging flows of traffic, even two at a time might not meet the needs of the airspace. Once the flows are merged, then sequencing can be managed by an extended downwind path with at least one reversal; this is commonly referred to as a ‘trombone’. Alternatively, sequencing and merging can be achieved through the application of a Point Merge System. Whilst there are advantages with both designs, as has been demonstrated in P5.7.4, for this solution the decision was made to implement a Point Merge System (PMS) and meter the traffic off of the arcs.

Positioning of the PM arcs again needs careful consideration as the amount of airspace required could impact on departure operations. Logically, the PMS could be placed on along the centreline of the active runway, this would allow for the least amount of additional fuel needed to complete the full procedure. However, the primary arrival flows will probably dictate where the PMS is to be located and, due to traffic evolution, that may not always be aligned to the runway. A further consideration would be whether the PMS is to support both (or more) runway directions. In Project 05.07.04, the team investigated this possibility. Regardless of location though, careful consideration should be given to ensuring that PMS placement does not restrict departure flows, holding down aircraft until clear of the arcs; this again is good airspace design.

Operations along these STARs/transitions would be RNP1. The RF functionality could be required and it would be up to the service provider to identify whether consistent and highly repeatable turn performance is required. Whilst P05.07.04 considered PMS with a 1NM performance, this was based on P-RNAV (similar lateral performance to PBN’s RNAV1); the project did not consider RF on the SIDs/STARs or transitions[3]. RNP 1 will have the same lateral performance requirement but will

[3] The RF functionality has been in use for departure operations at Schiphol (EHAM) since 2008, however, it is applied with P-RNAV operations which is contrary to it use in ICAO Doc 9613 Edition 4 published in 2013; RF is expected to be applied only with RNP specifications. The UK CAA has been undertaking a flight trial at Stansted (EGSS) using RF with RNP1 for departures off of both runway 04 and 22.

provide the controllers with a high level of confidence that if the aircraft exceeds the 1NM performance requirement of the SID/STAR or transition, then the pilot will be alerted. It will be up to local implementation, how this unexpected occurrence will be mitigated.

Operations within the TMA are expected to be 'mixed mode' with both RNP1 and RNAV1 aircraft operating. Provided the SIDs/STARs and transitions are not designed with RF turns, then it may be possible to allow both navigation specifications to operate on the IFPs. However, there will need to be an independent surveillance capability (SSR or MLAT) to ensure that lower capable aircraft do not exceed the performance requirement of the ATS route. Furthermore, the FDPS will need to extract from the flight plan whether the aircraft is RNP1 or RNAV1 capable. The requirement for RF on the procedures will automatically exclude the RNAV1 capable aircraft and an alternative procedure, which may even be conventional, will have to be put in place; it should be noted that in the current flight plan it is not possible to identify whether an aircraft has RF functionality (except if the operator has filed RNP (AR) APCH with RF).

The primary aim of this PBN solution is to take credit for modern aircraft navigational capabilities an allow the avionics to follow an appropriately defined path that has been designed as efficiently as possible in terms of track distance, the ability to safely perform CCOs and CDOs and with the minimum environmental impact on the aerodrome's neighbours. The design of a PMS should enable the controllers to sequence the arrival flow and, when traffic densities allow, enable a CDO. Furthermore, the use of speed control once the aircraft are cleared to the merge point should allow the longitudinal spacing to be optimised prior to final approach, be that precision approach or an approach with vertical guidance (APV).

It is highly recommended that the design of the airspace involves both the main airspace users and ATC. This can assist with the eventual placement and operation of the PMS together with the addressing the challenges faced by the airspace users when fuel planning. Typically AOs are required to carry fuel from the TOD to the point where the approach is initiated taking in to account the arrival procedure; therefore, the location of the IAF can be very significant and possibly be very beneficial to be defined prior to entry to the Point Merge System. If the airline has to fuel for the full PMS then add additional fuel to account for holding time, they are carrying more fuel than required; time on sequencing leg must be considered as holding time. It is recommended that the PMS should be defined as a Transition. In the design of the PMS it is again highly recommended that the aircraft are in level flight 5NM prior to the sequencing legs; this will ensure that vertical separation (normally 1000') is achieved before the lateral separation is breached. If the PMS arcs are utilised then the flow of a CDO will be interrupted and a level section will be flown; therefore, the height of the PMS and distance from the runway will be influencing factors. Similarly, the outer arc of the PMS should always be 1000' lower than the inner arc to ensure that aircraft, when cleared to the merge point, can continue or recommence their CDOs without breaching the vertical separation minima.

Waypoints may be defined at the entry points of the sequencing to provide the controllers with the opportunity to direct traffic straight to the Point Merge arcs. When capacity allows this is when a true CDO can be supported. However, this would provide path shortening where an aircraft could descend rapidly enough and mitigate some non-nominal scenarios, such as P-RNAV equipage failure. The designer must consider the ability of the aircraft to lose all the height necessary from the shortest distance possible. Some operators may refuse to descend too rapidly for passenger comfort and this type of issue should be discussed within the implementation team during the design phase.

Point Merge Systems

There are many possible point merge options and several are depicted below:

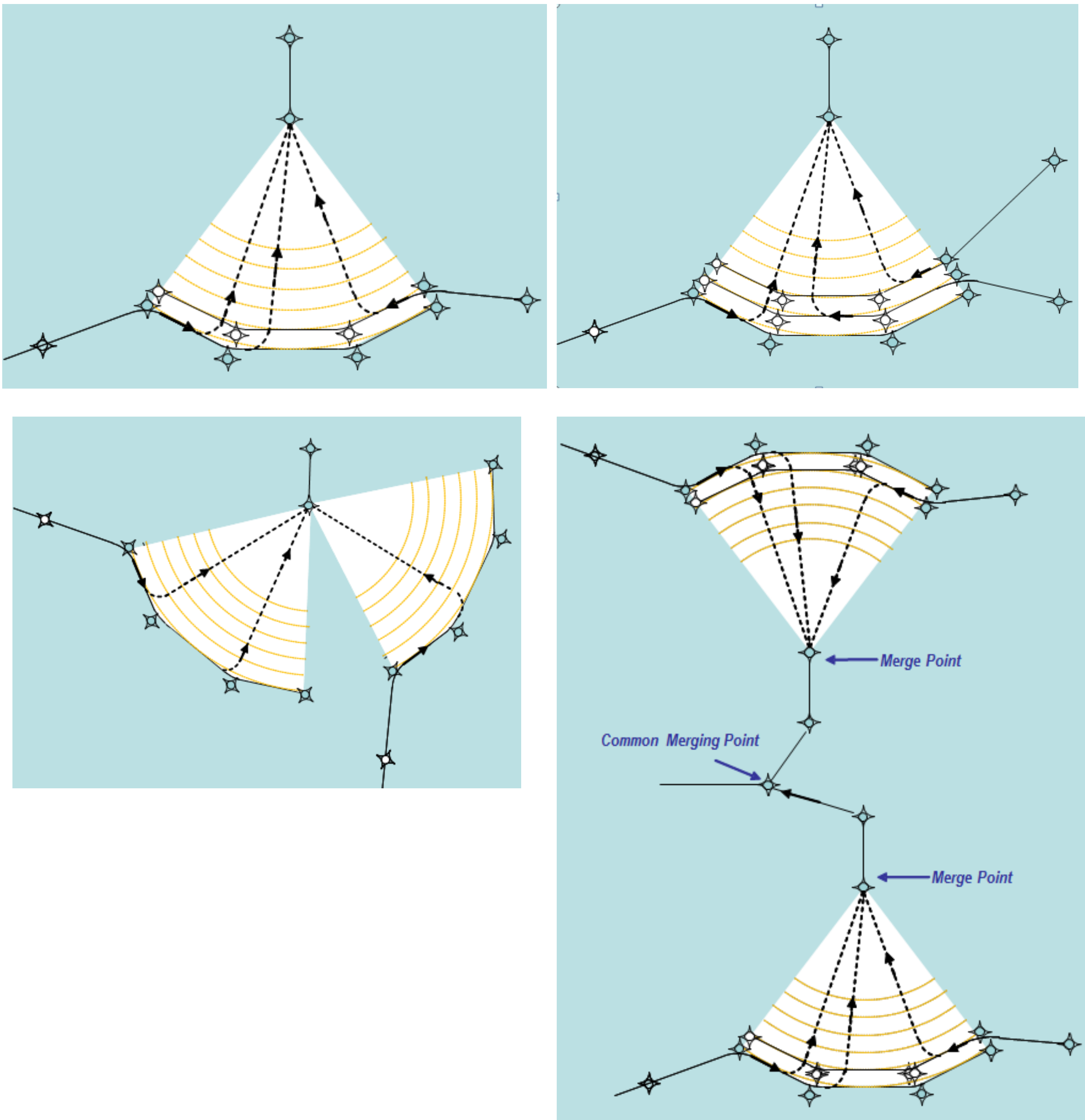

Figure 7 - Different Point Merge Options

In P05.07.04, each landing runway was fed by one or more Point Merge Systems with multiple sequencing legs, dependent upon the volumes of airspace available within which to site the Point Merge Systems and the quantity of delay absorption required.

The Point Merge System should be used for final adjustment to traffic sequencing, sequencing multiple traffic flows together (as arriving on the sequencing legs), optimising spacing of traffic delivery to either the base leg or final approach and prioritising emergencies where necessary.

There are several ways for the pilot to perform descent/approach (full managed, V/S, DES, OP DES, NAV, HDG...), which may lead to different behaviours in handling constraints and clearances. This needs to be considered when developing the operational procedures.

Point Merge Systems with multiple levels, or without level-off, on the sequencing legs are likely to provide improved descent efficiency and may be possible, but implementation within the limited airspace of a complex TMA is expected to be difficult:

- o Greater complexity for the controller to manage the sequencing legs.

- o Takes up more levels in the airspace, which could impact on potential for CCOs.

Consideration should be given to how the Point Merge Sequencing Legs are comprised:

(a) Multiple waypoints to create a pseudo arc

(b) Radius-to-Fix (RF) Turn around the Merge Point, where the sequencing leg maintains a constant radius turn around the fix.

Option (a) is better suited to cope with a mixed-equipage environment, which is highly likely – especially during a period of transition.

Option (b) may be implemented where aircraft equipage allows. The primary benefit of using RF Turns is the reduction in the number of waypoints that need to be defined for the approach route. However, consideration should be given to the entry direction and the likelihood of a rapid roll reversal at the initiation of the RF arc.

P05.07.04 identified the following in the project's OSED:

Wherever possible, the departure routes should be designed with the aim of enabling Continuous Climb (CCO) as this will realise further environmental benefits. To facilitate this, some or all of the following may be considered:

- o All departures able to out-climb arrivals or arrival and departure flows cross a short track distance from the departure end of the runway.
- o Minimise the placing of Stacks near to an airfield: move the Stacks further out and place at higher Flight Levels.
- o Minimise the number of levels in the Stacks
- o Minimise the placing of Approach routes near to other airfields within the TMA.
- o Use PBN routes as much as possible across the TMA to enhance predictability.
- o Minimise the need for level flight at low altitudes: use CDAs from a high Flight Levels to runway.

Clearly the importance of ATS route placement and instrument flight procedure design are key to delivering safe and efficient flight operations.

2.5.1.2 The Proposed Solution – SIDs/STARs and Transitions

To link our aerodrome to the fixed ATS route network, we will require SIDs and STARs. These ATS routes, designed in accordance with PANS OPS criteria (ICAO Doc 8168), designated in accordance with ICAO Annex 11, Appendix 3 and published in the State's AIP. The SIDs and STARs together with the linking 'transitions' have been carefully planned and strategically separated to allow for both continuous climb and continuous descent operations. Where it has not been possible to laterally separate the flows of traffic, the designer has created crossing points close to the runway departure points such that even with the highest rate of climb expected, the arriving aircraft will always be above the departing one. Published height restrictions have been designed to reduce controller workload.

The design of the transitions from the IAF to the IF has introduced point merge arcs to allow for a more efficient sequencing onto Final Approach. Within the State's AIP, it is clearly stated when the flight crew must carry the appropriate amount of fuel to be able to execute the full point merge arc and still have sufficient reserves to comply with normal operating procedures. In low traffic densities, the operators can expect an early 'direct to' the merge point and a true CDO can be flown. The arcs have been design to allow for CDO to be recommenced immediately the aircraft is cleared to the merge point; however, whilst on the arcs the aircraft will be in level flight to ensure that separation is maintained, aircraft on the outer arc will be held level at 11000' from 5NM prior to the PMS and remain level until cleared inbound the merging point. The arrivals manager will sequence the North and South arcs and provided that appropriate speed control in exercised, then there should be no requirement for radar vectoring.

Aircraft operating on the SIDs/STARs and transitions are to be RNP1 with RF certified and the crews operationally approved to this standard. Mixed mode operations may be possible in low traffic densities but consideration is to be given to how the controller differentiates between RNP1 with RF and RNAV1 aircraft (currently there is no way of uniquely indicating RF capability within the ICAO flight plan and no RTF phraseology has been developed for PANS ATM ICAO Doc 4444). In addition, if mixed mode is planned by ATC then the controllers must be alerted to the high possibility of variation in turn performance. Whilst in the straight segments it is expected that the controller would see little difference in lateral track performance, in the turning segments the variation could be quite pronounced and lead to safety issues. The diagram below is a proposal on how the entry and exit flows of traffic might be segregated to provide efficient, safe cost effective operations within the TMA whilst minimising the environmental impact:

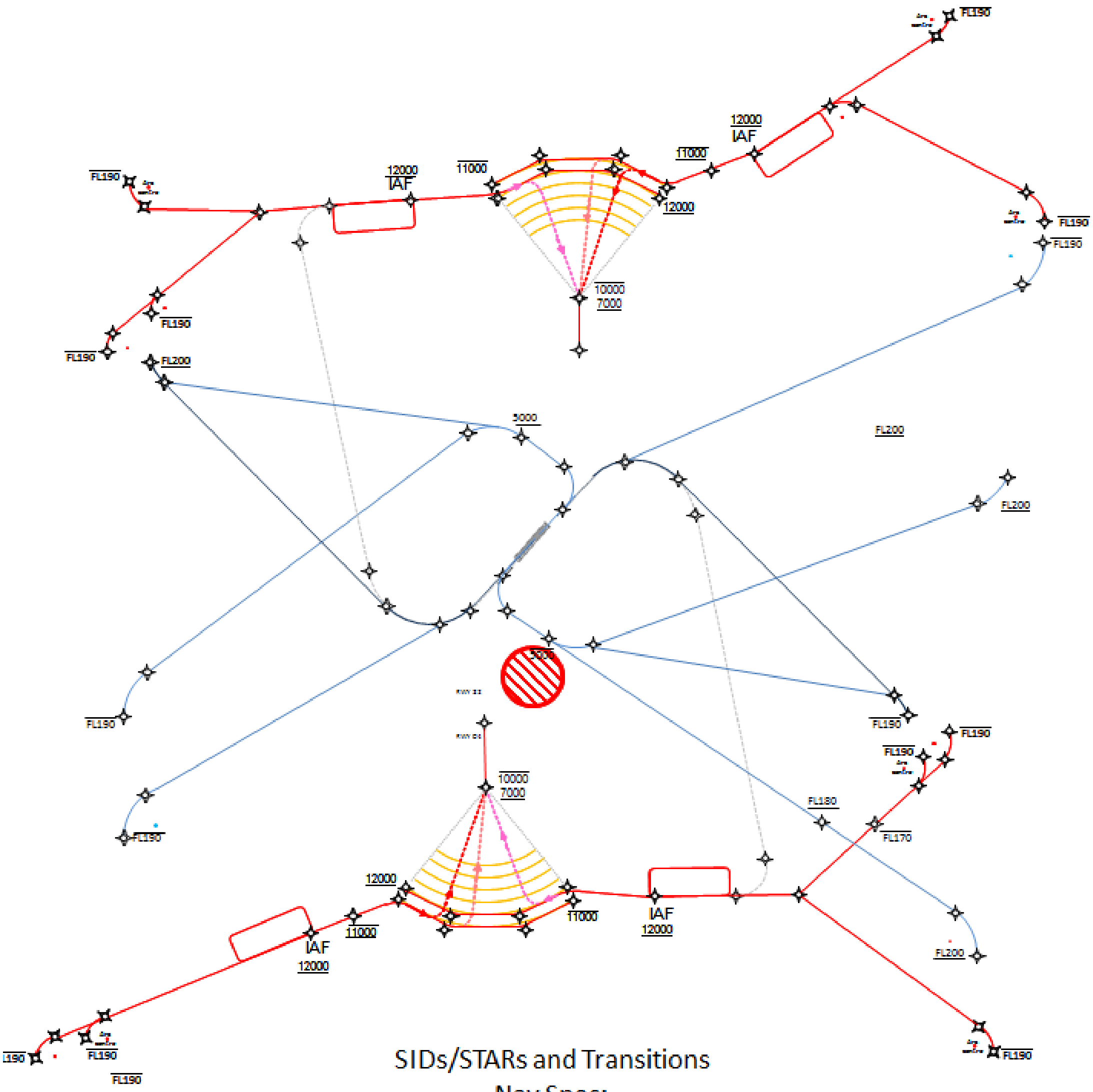

Figure 8 - Scenario SIDs/STARs and Transitions with PMS

2.6 Final Approach

From the merge point, the traffic should be adequately sequenced primarily through the use of speed control during the approach to the merging point. Therefore, there should not be a requirement for controller intervention using radar vectoring except as a contingency solution or if there is an emergency; it is expected that efficiency and capacity will be lost if the controller intervenes at this stage. This proposed solution now considers the application of a satellite-based augmentation system (SBAS) to support an APV. This is just one application to perform final approach, and it should be noted that SBAS receivers are not widely fitted on aircraft today. The primary reasons for this are that the main manufacturers did not support the SBAS solution in the early 2000s, there was concern for that the users of the service might be charged sometime in the future and finally, that once GALILEO was operational that EGNOS could be withdrawn. However, over the last decade the European Geostationary Navigation Overlay Service (EGNOS) operator has demonstrated that regional and older aircraft could benefit from the service the system provides. Therefore it is mainly on these types of aircraft that SBAS is fitted today. It should be noted, the European Commission (EC) sent a letter to ICAO in July 2011 indicating that EGNOS would be supported in the long-term and the signal from the service would be free-of-charge. The ICAO GNSS manual (ICAO Doc 9849) indicates that Airbus will be offering SBAS as an option on the A350.

Provided that there is no requirement for RF capability inside the Final Approach Segment (FAS) or in the initial or intermediate parts of the missed approach and that the performance requirement on final is only +/-0.3NM and the missed is +/-1NM then a RNP APCH can be applied; the lateral performance requirements are 1NM on initial and intermediate approach, 0.3NM on Final Approach and 1NM on the missed approach. This approach may be designed with a lateral path only (LNAV) or with a lateral and vertical path (LNAV/VNAV). Alternatively, if designed in accordance to PANS OPS 8168, the lateral path can be flown with an SBAS receiver (Localiser Performance LP) or the lateral and vertical path which is termed a Localiser Performance with Vertical guidance (LPV). The LNAV/VNAV procedure is commonly called an APV Baro and the LPV procedure is an APV SBAS.

This proposed solution considers the application of an APV SBAS and applying RF turns prior to the Final Approach Point. Again, the procedure designers should not look at individual procedures alone but always consider the interaction with the other flows, both arriving and departing. RF is not a requirement of RNP APCH and therefore, the controller will need to know whether the aircraft is capable of flying the procedure. This will entail either the ability of the ATM system to automatically identify it from the flight plan or by establishing whether the aircraft is RF capable by radio communication; unfortunately neither a RF code for the ICAO flight plan nor the appropriate RTF phraseology exists within PANS ATM today.

The design criteria for RF are established in PANS OPS (ICAO Doc 8168) although there should be clear guidance how late the roll out onto the final approach heading is to be. It is understood that the FAF/FAP can be as close as 3NM from the threshold and it is considered undesirable for the aircraft to be rolling out onto final approach from an RF turn so close to the touchdown point. APV-Baro performance is linear down the final approach segment whilst the APV-SBAS provides an angular, improving solution the closer to the runway the aircraft is. The lateral performance of a APV-Baro is 0.3NM whilst the alert limit laterally for an APV-SBAS is set at +/-40m. In the vertical, barometric guidance along the vertical path only starts at the FAF and AMC20-27 stipulates the vertical performance the aircraft must demonstrate for certification. With the APV-SBAS, geometric positioning is active all of the time, however, within the final approach segment the vertical alarm is set for +/-50m; this is APVI design criteria.

Project 05.06.03 clearly demonstrated APV-SBAS with RF. The aircraft had to be certified according to **AMC 20-28**, "*Airworthiness approval and operational criteria for RNAV GNSS approach operation to LPV minima using SBAS*".

The A-RNP specification covers the simple RNP APCH but provides an option for lateral performance of less than 1NM; this is commonly referred to as scaleability. The proposed solution aims to capture as many aircraft as possible and therefore focuses on a 1/1/0.3/1NM solution. The option for applying lower performance requirements in the initial and intermediate segments only would severely restrict those aircraft that could fly the procedure. It would also create further challenges in how the ATM system, and ultimately the controller would establish if the aircraft has the scaleability functionality to safely fly the initial and/or intermediate segments of the procedure. Furthermore, certification material (EASA AMC or CS) is still to be developed for the A-RNP specification and for scaleability.

P05.06.03 identified that AMC 20-28 could be considered as including the SESAR A/C-06 enabler, "*LPV approach based on SBAS*". The project went on to stipulate that the flight management and guidance must allow:

- Performing RF legs at the same time that CDA technique is applied (automatic or with manual intervention).
- Moving directly from an RF leg CDA flown, or from a straight leg CDA flown, into an APV SBAS FAS.

- Transitioning generally from CDA to SBAS vertical guidance without level segment.
- Using RF legs in the missed approach (final phase).
- Flying the shortest *possible* final approach segment.

Project 05.06.03 'Approach with Vertical Guidance (APV)' had a Concept of Operations which was entitled **Advanced APV**. This concept focused on the RF functionality to enhance the approach performance but prior to the FAP. The Advanced APV concept did not aim to change current controller roles, responsibilities or operations. Although, this solution is based on a SBAS capability, provided that the procedure was designed in accordance with PANS OPS for barometric operations as well, then aircraft and flight crews which are certified and the crew operationally approved to AMC20-27 (or equivalent) **and** RF could equally fly these 'advanced' operations. It should be noted, however, that a mixed mode of traffic (RNAV1/RNP1/RNP APCH with and without RF) will be exceptionally challenging for ATC to handle without clear indications within the flight plan and displayed to the controller on either an electronic flight strip or on the radar. If the controller has to manage mixed mode operations without technical support, then the RTF load would increase substantially and this would impact capacity and efficiency; it should be noted that currently there is no defined RTF phraseology within PANS ATM for identifying RF capability.

As the proposed solution for the Final Approach Segment (FAS) is an APV SBAS, the aircraft and flight crew must be certified according to **AMC 20-28** and have also certified the RF functionality; this is not covered in the aforementioned AMC and EASA is yet to publish a dedicated certification standard for it.

If the aircraft and operator holds an A-RNP certification and operational approval to EASA CS-ACNS and IR-OPS (yet to be published) then the aircraft will be fully compliant with the RF requirement but may not have the SBAS functionality. Therefore, to capture as many aircraft as possible, it would be in the ANSP's best interest to design the procedure as both an APV-SBAS and APV-Baro; therefore, applying both sets of design criteria to the approach. It is also recognised that the A-RNP specification offers the option of 'scaleability' in the design of the initial and intermediate approach phases but as this functionality appears not to be harmonised between the manufacturers yet it is not promoted in this solution. Furthermore, certification material (EASA AMC) still has to be developed for this capability and further consideration is needed to ensure that only aircraft with the appropriate 'scaleability' capabilities fly these specifically designed procedures.

Lateral guidance on the approach is provided by GNSS standalone navigation equipment (TSO 146) or by an RNAV computer (e.g. FMS) using GNSS sensor (TSO 145) outputs. The lateral guidance is linear during the initial and intermediate segments and this is expected to change to angular when the FAS is captured. In an APV Baro, the final segment will be linear at 0.3NM leading to some of the differences in design criteria for the APV SBAS versus the APV-Baro. Lateral full scale deflection (FSD) is to change to Final Approach 2NM prior to the FAP/FAF. For the SBAS FAS lateral full scale deflection may change according to the aircraft type.

Vertical reference when flying the CDO during from an initiation point on the PMS and through the initial and intermediate segments is based on barometric altimetry and is not defined against a vertical path. Vertical **guidance**, based on SBAS, is provided using angular deviations when the FAS is captured; this guidance is provided with respect to a geometrically defined path. The vertical full scale deflection (FSD) may change according to the aircraft type.

It is expected that the FAS course will be captured at the FAP at the very latest. Then, throughout the FAS, angular lateral and vertical deviations of the aircraft with respect to the intended flight path are presented to the pilot in an ILS 'look-alike' normally on the same instrumentation as used for precision approach; however, this will vary due to aircraft type and whether a standalone SBAS receiver is being used.

The FAS is loaded directly into the navigation computer from data held in the computer's navigation database; this data is to be kept up-to-date in accordance with the AIRAC cycle as detailed in ICAO Annex 15. Not all of the data contained in the FAS will be displayed to the Flight Crew; however, some specific information must be visible and available for the pilots to enable cross checking of information.

Whilst the pilot can manually fly the CDO and manage the vertical path without assistance from the FMS, albeit that care will be required, this is not the case for the lateral path. For lateral navigation using RF-legs, the FMS (or a GNSS standalone navigator including such functionality) is required together with an autopilot/flight director (AP/FD) with at least “roll-steering” capability with performance driven by the required RNP; use of manual control with a CDI only is not allowed (Ref. PBN Manual – Volume II Appendix 1 to Part C – Radius to Fix (RF) Path Terminator).

In order to fly the RF legs the aircraft must use an Autopilot or Flight Director (AP/FD) The aircraft must have an electronic map display. The chart should identify that the RF is required and the navigation system (or Flight Crew procedures) should prohibit the loading of any procedure that requires RF functionality if that aircraft does not possess it; one way of achieving this is by the navigation data-houses excluding any procedure an aircraft is not eligible to execute (Ref. PBN Manual – Volume II Appendix 1 to Part C).

Therefore, aircraft and operators which are RNP APCH certified but **without** RF functionality (RF is an optional feature with this specification – see Figure 3) will not be permitted to accept procedures which are designed with a RF leg; there will be no mixed mode operations. All aircraft and operators with A-RNP certification by default will have RF functionality; however, the caveat on the proposed solution is that the aircraft is fitted with an SBAS receiver.

The P05.06.03 ‘Advanced APV’ concept considers the use of RF legs within the RNP APCH or A-RNP navigation specification. Therefore, the applicable airworthiness certification and operational approval material consists in AMC 20-28, 20-27 as well as additional AMCs (to be developed by EASA) to address the use of RF legs and A-RNP.

The navigation system must have the capability to execute leg transitions and maintain a track consistent with an RF leg between two fixes. The lateral total system error must be within ±1xRNP of the path defined by the published procedure for at least 95% of the total flight time for each phase of flight (Ref. PBN Manual – Volume II – Part C – App-1).

2.6.1.1 Before Approach (Terminal area up to IF)

Prior to commencing the descent to the destination airport, the Flight Crew will check the expected approach and runway in use and request the STAR, transition and approach procedures accordingly. However, it is acknowledged that commonly today the inbound clearance is received after ToD; however, this is expected to be changed in the future with the SBT/RBT/ABT/EBT.

The Flight Crew will then call out the STAR, transition and RNP approach from the navigation database and ensure there are no ‘route discontinuities’. A gross navigation error check as well checks of the Instrument Approach Procedure (IAP), such as a check of the loaded procedure and SBAS availability, are to be carried out by the Flight Crew prior to the IAF and in preparation for flying the PMS and the approach.

It is expected that once the aircraft is cleared for the procedure, the aircraft will be allowed to follow the published route from the initial approach point, through the PMS and onto the RNP APCH without the controller needing to intervene tactically. It is expected that through the point merge system and the judicious use of speed control that ATC will sequence the flow of traffic whilst allowing each aircraft the ability to fly a CDO. However, for contingency and in emergencies, radar vectoring is always an option available to the ATCo. Furthermore, ATC can tactically intervene in the terminal area by:

- providing ‘direct to’ clearances which by-pass the initial legs of an approach; however, the controller must understand the possible impact on the vertical profile and that by providing a ‘short cut’ there might not be enough track distance for the aircraft to ‘bleed off’ it’s height.,
- request interception of an initial or intermediate segment of an approach.

A CDA is expected to be flown from ToD initially to the IAF which will be a minimum of 5NM before the PMS. From here and whilst established on the PMS arc, the aircraft is expected to be in level flight. Following a clearance from ATC, the CDA should then be initiated again once the aircraft is cleared direct to the merge point.

Furthermore, where RF legs have been designed into the procedure, and this could also be for the PMS arcs, the controllers must understand the impact of issuing Direct-To clearance to a waypoint beginning a RF leg or a vector to intercept an RF leg as the aircraft must be established on the inbound track to the RF leg prior to it being sequenced.

From a flight deck perspective, crews are not allowed to manually create a waypoint by coordinate insertion and the crew should also be aware of the implications that:

a) 'Direct to' clearances may be accepted to any waypoint prior to FAP, except for a waypoint beginning a RF, and in particular to the Intermediate Fix (IF) provided that the resulting track change at the IF does not exceed 45º.

b) 'Direct to' clearance to FAP is not acceptable (Ref. PBN Manual – Volume II B.5.3.4.4.2).

For contingency operations, it may be noted that the aircraft approved APV SBAS have the capability to intercept the final approach track from a radar vector (this is a requirement for APV SBAS as detailed in AMC 20-28). However, ATC will have to know if the aircraft is APV SBAS capable and this information is not necessarily provided to ATC.

Finally if ATC does vector the aircraft, this does not imply termination of CDA though tactical ATC vectoring will, most likely, sub-optimise the CDA. (Ref. ICAO Doc 9931 – 1.2.1)

2.6.1.2 From IF up to Final Approach intercept

In the proposed solution, to establish the aircraft on the final approach course the pilot by default follows the STAR, transition and Intermediate approach segments as published. The use of radar vectoring is not anticipated except in contingency operations.

The approach interception is understood as the switch from RNAV (LNAV) guidance to xLS lateral guidance (the switch to the xLS vertical guidance does not usually occur at the same time as the switch to xLS lateral guidance). To be noted that different aircraft could have different behaviours for this interception.

If in the design of a RF leg, the procedure designer has imposed a speed restriction to ensure that the turn is 'flyable' then ATC shall not explicitly give a speed which exceeds that constraint. It is expected that ATC will be familiar with RF leg benefits and their limitations e.g. DCT and speed and there are specific ATC training requirements that are to be complied with as detailed in the PBN Manual (Ref. PBN Manual, Volume II, Appendix 1 to Part C: RF Path Terminator, section 3.3 ATC coordination).

From an Airspace User's point of view, a procedure design without any constrains is the most preferable, i.e. aircraft envelope is the constraining factor. In that case, ATC would have to know all the different aircraft performance limitations. Though, so far, when RF legs have been designed (e.g. within RNP AR operations) the procedure designers are quite conservative and typically put a speed limitation on the RF procedure to limit the possibility to exceed the RF leg criteria. However this is a very conservative method as the aircraft capability, generally, is well within limits to conduct an RF leg, especially in a non-demanding environment (i.e. no terrain).

If an aircraft system failure results in the loss of capability to follow an RF turn, the Flight Crew should maintain the current bank and roll out on the charted RF exit course, even manually. Flight Crews should advise Air Traffic Control as soon as possible of the system failure (Ref. PBN Manual – Volume II – Part C – App-1).

Along the initial and intermediate approach segments, the CDA is flown as described previously.

2.6.1.3 From Interception to FAP (transition to FAS)

The transition to FAS includes the possibility of an RF leg ending directly at the FAP as well as the change from barometric to geometric vertical guidance without a level segment.

During the transition, the RNP corridor of the RF (or straight) leg should be respected until the FAP and the Flight Crew should ensure that the glide path (APV SBAS FAS) is captured.

The transition to an xLS final segment with an RF leg finishing at the FAP has been studied in P09.09; the deliverable P09.09.D05 describes the transition from an aircraft and crew perspective, and details two possible scenarios to manage the transition. To ensure that the RNP corridor is respected until the FAP in case of an RF leg finishing at the FAP:

- The transition to LPV mode can be delayed until the FAP; in LNAV mode, it is ensured that the RNP corridor is respected. But this may change the current operating procedures and may induce Human Factors issues.

- The transition to LPV mode is not delayed; the aircraft will finish the RNP corridor in LPV mode, but it would be ensured (by analysis, simulations etc.) that in all conditions the RNP corridor is respected, and some monitoring of the RNP corridor could be done.

Depending on the flight guidance laws, there may be issues to engage the LPV lateral and vertical guidance modes when the aircraft is parallel to the LPV FAS; the "nominal" capture case for the guidance laws being generally a lateral path converging to the final FAS, and a level off.

- On the lateral part, with an RF leg finishing at the FAP, if the transition to LPV lateral mode is delayed until the FAP, the lateral path will be quite parallel to the LPV FAS lateral track, or even slightly non-converging (in case of overshoot during the RF leg).
- On the vertical part, with a transition from a CDA, the vertical path of the aircraft can be quite parallel to the LPV FAS glide path.

These transitions will require further study for safety, operational and avionics issues.

Furthermore, flying a CDA with an RF leg onto the FAP will require an assessment of Flight Crew workload to see whether the transition to the final LPV segment is acceptable. It is possible that the Flight Crew may have to monitor both the LPV lateral and vertical guidance modes engagement as well as monitoring the RNP corridor in the RF leg while flying the CDA and thus they may not have enough time to prepare for LPV final segment (for example to check that the LPV deviations are consistent, to cross-check the deviations, etc.). P05.06.03 sought to find some evidence of workload on a RF leg flown with a CDA and transitioning to a convention ILS and there is no pilot feedback indicating an increased workload.

2.6.1.4 Final Approach Segment (from FAP to DA/H)

Although this segment is to be carried out as a straight-in segment it is possible that an RF leg can join directly at the beginning of a short FAS. Within P05.06.03, an analysis of the applicable **stabilised approach criteria** was undertaken to try to gauge what FAS leg length is acceptable.

The general criteria are that an aircraft expected to be stabilised at the latest when reaching 1000ft above runway threshold. Therefore, within the Advanced APV concept, if an RF leg is directly connected to the FAS, the FAP must be at or above 1000ft AGL. For a typical 3 degree slope this means that FAS cannot be shorter than 3.0nm.

There was doubt within P05.06.03 initially regarding the meaning of "stabilised" and the fact that with an RF leg directly connected to the FAS, at the FAP the bank angle would be close to the bank angle during the RF turn. The project studied global and regional standards and regulations (e.g. PANS OPS ICAO Doc 8168, EASA OPS and associated AMCs) for clarification. They found that whilst the documents draw attention to the aircraft being in the correct landing configuration, speed and control of the flight path, they provided no precise criteria about the due attitude (e.g. ALAR Briefing Note 7-1 refers to "excessive bank angle" provided the aircraft is flown in a controlled and appropriate manner). It was further noted that in some flight manuals stabilised criteria includes a reduced back angle (near "Wings Level"), but this was considered understandable as these documents refer to straight in approaches including long final segments.

Following significant discussion with project members and the AUs, reported in the P05.06.03 OSED Version 3), the project concluded that the **applicable stabilised approach criteria** should not include a predefined max bank angle criterion. Furthermore, it is expected that Flight Crew flying the 'Advanced APV' procedures would be appropriately trained for this type of operation and will have their own judgment about whether they can easily maintain the correct flight path.

Furthermore, the project concluded that this was in line with the EUR OPS definition: "*stabilised approach (SAp)' means an approach that is flown <u>in a controlled and appropriate manner</u> in terms of configuration, energy and control of the flight path from a pre-determined point or altitude/height down to a point 50ft above the threshold or the point where the flare manoeuvre is initiated if higher*;"

2.6.1.5 Visual segment

It is expected that the decision for the Advanced APV will be taken barometrically and that appropriate temperature correction has been applied to the DA/DH. The decision to fly missed approach or to continue visually is no different for any other form of APV or precision approach.

2.6.1.6 Missed Approach

If the required visual reference to continue the approach has not been established at the DA/DH, the Missed Approach is initiated to be initiated as for an APV or PA operation. The Missed Approach must be flown in accordance with the published procedure. Whilst a conventional missed approach could be considered in this phase of flight, the proposed solution does not consider that this would be applicable. Therefore, the RNP1 missed approach would be published and it would be expected that all aircraft will be certified to either RNP1 or A-RNP to support this operation.

It is expected that when the Go-Around (GA) is initiation, the lateral navigation would switch to Track or Heading hold or directly to LNAV depending on the aircraft avionics capability. Therefore, should RF legs be included in the final phase of the missed approach, the possible loss of capability to follow an RF is to be considered.

2.6.1.6.1 The Proposed Solution – APV SBAS

In our proposed PBN solution, we have considered the transition to finish at the Intermediate Fix (IF) and it is at this point the operator will fly an RNP APCH. As has been previously stipulated, this proposed scenario looks at a late turn onto the Final Approach Point (FAP) and therefore appropriate training will be required for both the flight crew and the controllers. To exercise a localiser performance with vertical guidance (LPV) approach the aerodrome must be within the APV SBAS service area as defined by the EGNOS service provider in the SoL Service Definition Document. The aircraft must be fitted with a satellite-based augmented receiver (TSO145/146) and this can be indicated in the ICAO flight plan in Item 10A (the LPV code is 'B'). This information may be transparent to the controller and is slightly different to how other PBN related information is notified in Item 18 of the ICAO flight plan. In addition, the ANSP must have put in place an appropriate monitoring system to alert the controller when the SBAS service is not available; this is normally done through an EGNOS working agreement (EWA) signed between the ESSP and the Service Provider in which such things as NOTAM proposals will be defined.

It should be noted that an aircraft fitted with a normal GPS receiver (TSO129A/196) feeding to the navigation computer and with RF will provide the same navigation performance along the RNP APCH; however, although the performance in the FAS is 0.3NM, performance monitoring and alerting is linear down the approach whilst with an APV SBAS this is designed and integrated as an angular performance resulting in the appearance that the closer the pilot gets to the runway the more sensitive the lateral deviation indicator becomes. Furthermore, whilst vertical positioning only takes place within the FAS, the positioning on the vertically defined path is geometric with the APV SBAS whilst it would have to be done barometrically with the 129A/196 receivers; this then also brings in the issue of temperature compensation. Therefore, even if an aircraft is certified for RNP APCH against AMC 20-27 and with a certified RF capability, there would be an issue of allowing it to fly the Advanced APV procedure. Outside of the LPV code in Item 10 of the ICAO flight plan there are currently limited codes for Item 18 to identify RNP APCH with Baro or SBAS and with RF or not. The option to place this information as free text in Item 18 does not assist ATC as most FDPs are not able to read this information. Therefore, if the controller needs to know the capabilities how can this be provided? Furthermore, there is no RTF phraseology defined to allow the controller to elicit if the aircraft is APV SBAS capable and even if there were this would lead to significant increases in workload for both the pilot and controller.

The diagram below shows the design of two APV SBAS onto our fictitious runway, with provision from both the North and South on to the active runway end. There is a height restriction designed on both downwind legs to ensure that departing traffic on the SIDs (no shown here) is vertically separated from the arriving flows. These vertical restrictions can be explicitly cancelled by the controller when there is no confliction with the departures. The vertical separation at the crossing point has been calculated using a generic climb/descent chart as shown in Figure 7. This example is taken from the EUROCONTROL Airspace Concept Handbook for PBN Implementation Edition 3 the expected separation at the crossing point when the departure has travelled 7NM is expected to be between 4-5000' (with a 10% climb gradient whilst the arrival traffic still has 18NM track miles to run to touchdown, so the minimum altitude for a 3° glideslope would be 6000'. RTS would provide data on possible nuisance TCAS alerts (which might be an issue with high performance climbers) and the sequencing of the North/South flows onto the final approach segment.

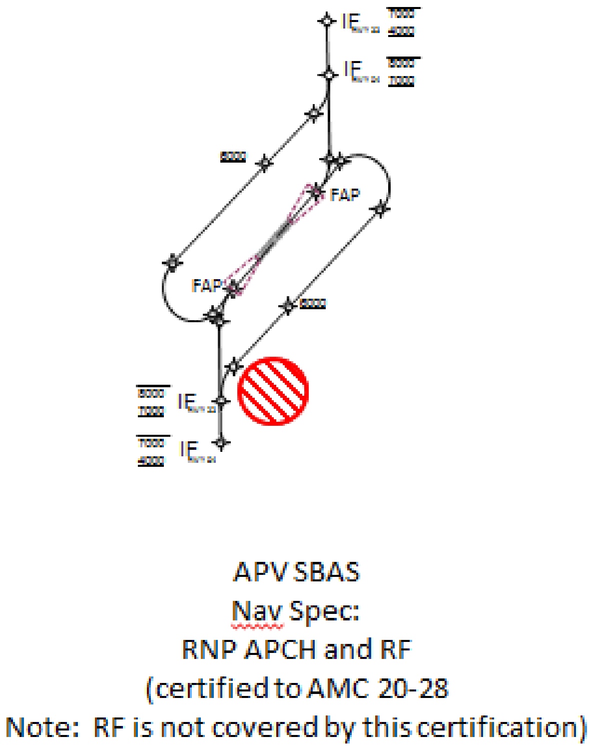

Figure 9 - APV SBAS[4]

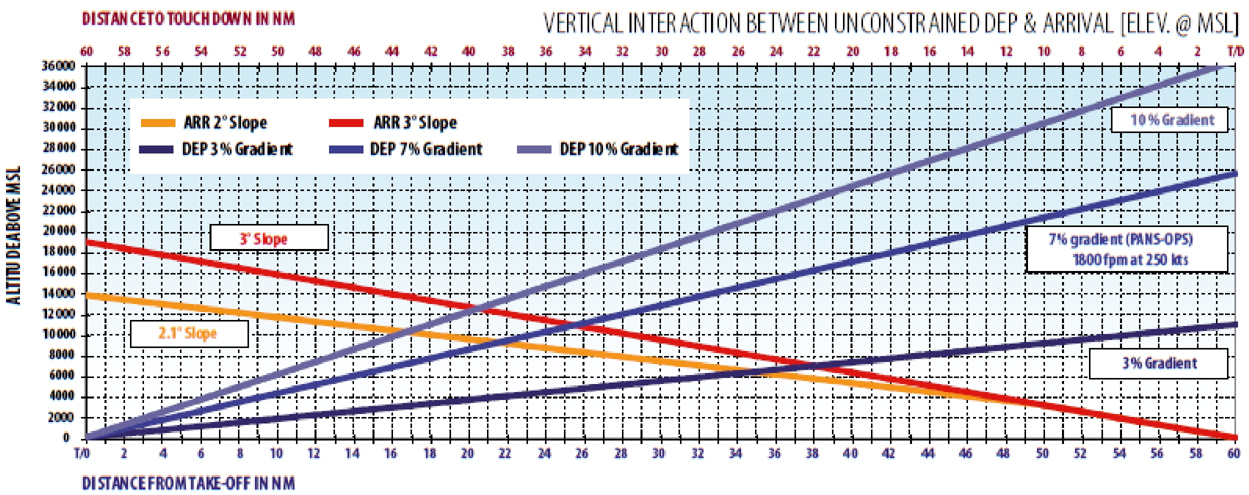

Figure 10 - Sample Climb and Descent Profiles

Finally, although the proposed solution for the RNP APCH only starts at the IF, it could start at the IAF as well. AMC20-28 covers operations in the Initial and Intermediate segments and the required

[4] The two IFs relate to the runway direction and is not a printing error.

navigation performance in both segments is 1NM. Therefore, the Point Merge could form the initial part of the RNP APCH, as depicted below. Pont Merge as an operation does not require its own certification; it is just one way of designing the PBN routes. As the only requirement is to have a lateral track performance meeting the needs of the ATS route, then if the APV SBAS is published from the IAF rather than the IF, aircraft with AMC 20-28 could operate on the PMS as well as deliver the Advance APV. Consideration would still need to be given on the STAR segment linking from the airway to the IAF. Here RNP1 certification with RF would be required or alternatively certification to A-RNP.

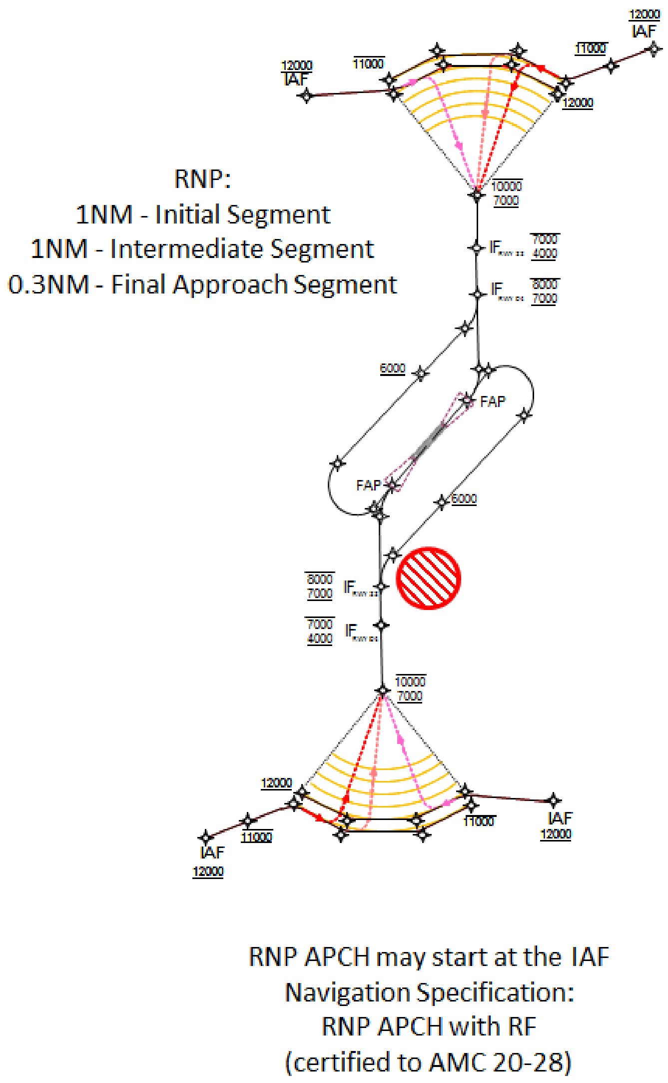

Figure 11 - PMS as part of the RNP APCH

The final point to raise here, and it is again a design consideration, is the use of RF arcs for the point merge. In the design of the arcs in this scenario, consideration was given to using RF arcs with the arc centre located at the merge point. However, the designer will need to consider flyability and it was considered with the entry angles proposed to enter the arcs, there would at least be a roll reversal and the danger of the aircraft overshooting the arc whilst initiating the fixed radius path. Simple software tools, such as the RNAV Validation Tool (RVT) would provide the designer initial clues as to whether with this PMS design RF arcs could replace the waypoints around the arc.

2.6.1.6.2 Proposed Solution – FRA to Final Approach for Runway 22

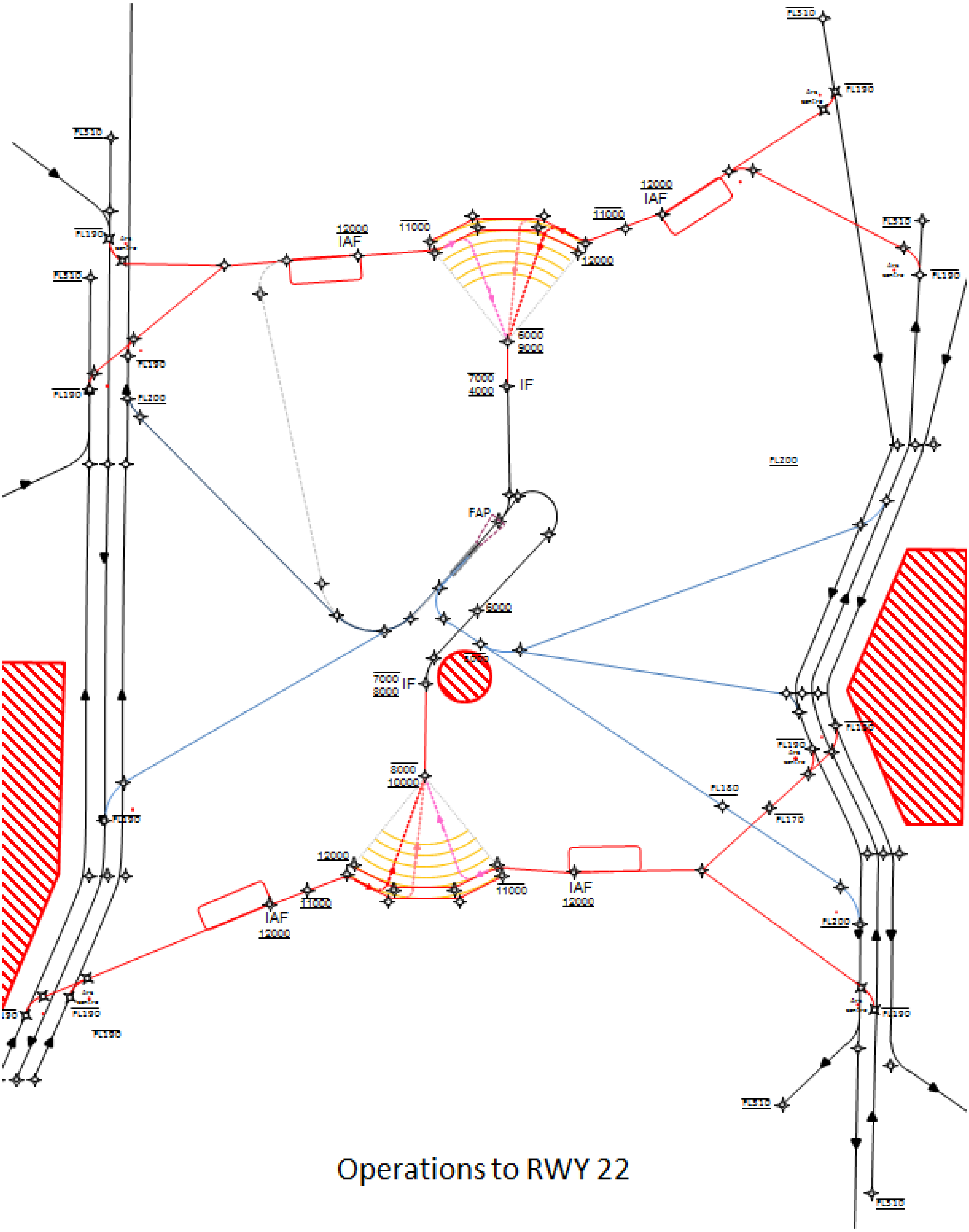

Figure 12 - Proposed PBN Solution

2.6.1.6.3 Proposed Solution – FRA to Final Approach for Runway 04

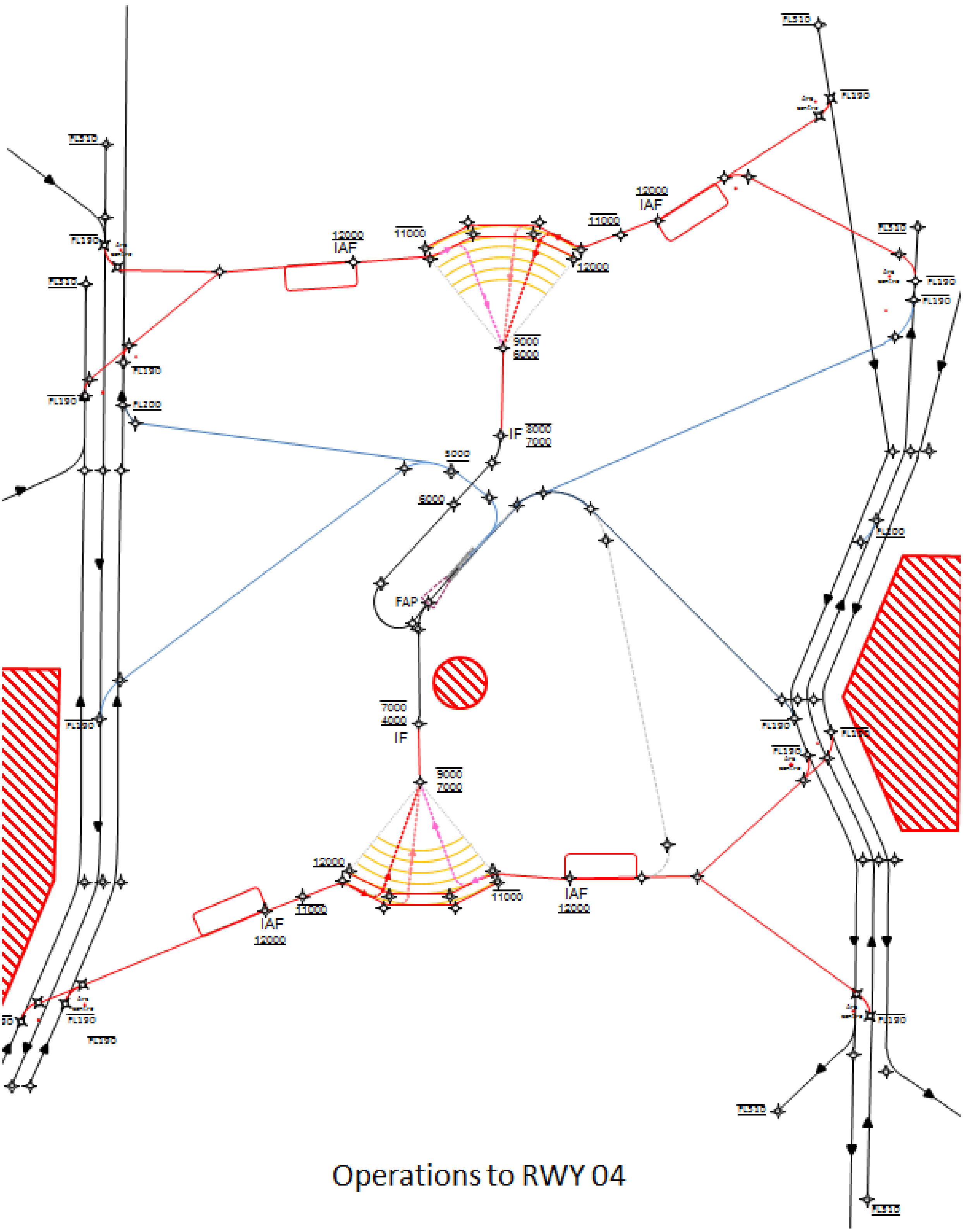

Figure 13 - Proposed PBN Solution

2.7 Tasks undertaken by P04.07.03, 05.06.03 and 05.07.04

Actions taken to prove the proposed concept of operations:

- P04.07.03 in Phase 1 of the project considered closely space parallel ATS routes with FRT and undertook two RTS: Ex194/195. Furthermore, the project undertook a FRT data collection exercise which provided initial empirical data on FRT performance.
- P05.07.04 was a terminal operations project which considered RNAV1 (similar to P-RNAV) for the Instrument Flight Procedures (IFPs) – specifically SIDs, STARs and Transitions. This project considered the application of Point Merge to sequence the traffic.
- P05.06.03 was another terminal area project which concentrated on instrument approach procedures (IAPs). Specifically this project considered a RNP APCH designed as a 3D path and guided both laterally and vertically using a satellite-based augmented receiver; this is called an APV SBAS. The project also looked at late turns onto the final approach segment (FAS) but before the Final Approach Point (FAP); this operation the project named an 'Advanced APV' and utilised RF functionality to ensure a consistent and highly repeatable turn performance. It should be noted that with the exception of AMC20-26, which provides certification and operational approval for RNP (AR) APCH (and this was not considered in any of the above projects), RF functionality is not covered by any current European certification document.

2.8 Output from combined work undertaken within SESAR

The list below provides references to the qualifying data and performance indicators reported in the VALRs for the different exercises run by the three projects mentioned above:

- 04.07.03_D06_Consolidated validation report & updated OSED – 01/11/2012
- 04.07.03_D07_Case for operational deployment – 03/12/2012
- 04.07.03_D30_Step 1 (AOM-0404_V3) VALR – 16/11/2015
- 05.07.04_D05_Final OSED for Point Merge in Milan TMA - 09/07/2012
- 05.07.04_D07_SPR for Point Merge in Milan TMA - 09/07/2012
- 05.07.04_D06_Final OSED for Point Merge in London TMA - 03/09/2012
- 5.07.04_D08_SPR for Point Merge in London TMA - 09/07/2012
- 05.07.04_D13_Integrated OSED - 03/09/2012
- 05.07.04_D14_Final Business Case and Transition Feasibility Report - 06/08/2012
- 05.06.03_D24_Advanced Procedure Validation Report - EXE-05.06.03-225 (VALR) – 05/03/2014

- 05.06.03_D25_Advanced Procedure Validation Report - EXE-05.06.03-VP-353 (VALR) – 21/02/2014

- 05.06.03_D26_Advanced Procedure Validation Report - EXE-05.06.03-VP-623 (VALR) – 02/02/2013

- 05.06.03_D27_Advanced Procedure Validation Report - EXE-05.06.03-482 (VALR) – 03/07/2014

- 05.06.03_D28_Advanced Procedure Validation Report - EXE-05.06.03-483 (VALR) – 25/09/2014

- 05.06.03_D38_V3 SPR_07/07/2015

- 05.06.03_D40_V3 OSED_25/09/2014

What is very obvious is that good design philosophy is key to maximising the benefits that PBN can deliver. Whilst it is clear that procedure designers are trained to design IFPs, in European in accordance with PANS OPS (ICAO Doc 8168), and there are established guidelines for these design of ATS routes within the terminal area, the same cannot be said for en route airspace design. The common turn performance both en-route and in the TMA is to fly by the waypoint. With altitude, the variation in turn performance becomes significantly more marked and this is the reason why a regional safety case for less than 9NM route spacing for RNAV1 is the best that can be achieved. With A-RNP and with the consistency of turn performance offered by FRT, a safety argument for a 7NM route spacing is possible. However, as the FRT radii are only recommended by industry, it is possible that States (or planners) decide on different values. If the radius selected is too small then this would lead to the FRT being unflyable and the aircraft transitioning as a fly by with all the variation that is normally observed. In addition, with IFPs we undertake validation activities to ensure the operation is both safe and flyable. What will be the requirements for en-route when the safety case for the route spacing is based on consistent and highly repeatable turn performance? It is clear that appropriate design guidance for the FRT is required. Finally, for both the RF and FRT turn performance can be influenced by actions taken on the flight deck and by ATC instructions given to the crew. There are specific training requirements in both appendices within the PBN manual and it is important that these are fully understood. To that end, both training and awareness material must be developed to support the successful application of both types of turn performance.

2.9 Lessons Learnt

Within FRA as there are no ATS routes, there is no PBN functionality. The only requirement within FRA is that the aircraft is capable of flying area navigation and this is enabled by having an area navigation computer which is capable of flying from point to point along a geodesic path (great circle).

Within PBN the key enabler is the aircraft’s ability to fly area navigation. However, within PBN we can associate performance requirements to defined paths created by the navigation computer. These performance requirements are coded into the navigation computer’s database. The data which is coded is taken from the States’ AIPs and converted into computer code by professional datahouses and then written in binary form, or ‘packed’, by the original equipment manufacturers (OEMs).

The State will define its performance requirements for their ATS routes based on national and/or regional needs and having demonstrated that these performance requirements are safe. To translate these requirements into the navigation database, the information must be made available to the data chain. Therefore, the State will normally publish the routes within the AIP or sometime within the Route Availability Document (RAD). All ATS routes and this includes IFPs, together with any and all performance requirements are coded as airways records for en route operations and airport records for terminal operations. The datahouses will only create airways records and airport records for ATS routes designated in accordance with ICAO Annex 11, Appendix1 and 3 and published in the State's AIP. If a route does not have a recognised ATS route designator or is not published in the AIP, then the datahouses will not code up that route. For FRT there is no route designator within ICAO Annex 11, Appendix 1 today.

The transition from a free route to fixed route environment also needs to be considered. The airspace planners are expected to design the fixed ATS routes to be as efficient as possible. However, as that design will probably be where the majority of the aircraft wish to flow, there is the danger of capacity overload at the published entry/exit points, be they lateral or vertical. The European Airspace Concept Handbook for PBN Implementation Edition 3, Attachment 4 details considerations for the transition between fixed and free route environments and it is recommended that this should be further investigated in SESAR 2020.

In addition, due to the immaturity of TOAC, which is not yet detailed within the PBN manual Edition 4, the OFA was unable investigate large scale TBO in SESAR1. The use of RTA with A-RNP is expected to support accurate time based operations in the future. This will become increasingly important as the introduction of AF#1 of the PCP IR will demand accurate time keeping to ensure the extended AMANs of the 25 top ECAC airports are successful. Time to lose/time to gain will start to be issued up to 200NM from the arrival airport and this will impact aircraft which will still be in the FRA before top of descent.

In all three projects, the ability for the controller to know the capability of the aircraft was considered. None of the projects considered a mixed mode environment, where aircraft of differing capabilities are all trying to follow the published ATS routes. To achieve a single level of capability will require a mandate or other form of legal tool to ensure all airspace users have the same equipage. Whilst this is the preferred option for the ANSP it is not for the airspace user. The airspace users would much prefer to fit their aircraft with the necessary capabilities when necessary and in this environment there could be a wide range of aircraft performances and functionalities. In a mixed mode environment it may be necessary for ATC to identify and segregate aircraft that do not have the performance capabilities to operate on the ATS routes. This may be done through flight data processing or it could, according to workload, be done by RTF. Unfortunately, whilst the syntax changes of the ICAO flight plan in PANS ATM (ICAO Doc 4444) made in 2012 introduced the PBN navigation specifications, these codes for Item 18 only addressed the original 8 NAV specs. The Field 18 PBN flight plan suffixes do not include the codes for A-RNP, FRT or the RF functionality other than in RNP (AR) APCH. If ATC needs to be know which aircraft are capable of flying the published routes or procedures then further work needs to be agreed at global level, through ICAO, to standardise these new flight plan codes. Furthermore, if this information is to be made available to ATC then it would probably require modifications on some flight plan processing systems.

Finally, although not a technical aspect, the key to any PBN implementation whether it be in en route or terminal airspace is effective and efficient airspace design. In a fixed route environment strategically deconflicting the flows of traffic should reduce controller workload which, in turn, may lead to a safe increase in capacity. PBN provides the airspace planner and procedure designers the ability to place routes where they wish (and not tied to the conventional navigation aids as historically we have been). Furthermore, by defining a performance requirement along the ATS routes enables the designer to place routes parallel to each other at closer distances than previously possible based on aircraft functionalities and appropriate safety cases.

2.10 What is missing

The en route section of the three projects considered the use of A-RNP with FRT to enable reduced ATS route spacing. The terminal operations considered SIDs and STARS, designed with RNAV 1 and employing Point Merge operations. There was no consideration for RF turn performance; all waypoint transitions were considered fly-by. Furthermore, for these operations a mixed mode environment was permitted with the use of radar vectoring to manage aircraft of lower capabilities. The approach phase was managed with an APV SBAS and RF. Although consideration for the RNP APCH was considered down to the Final Approach Point, only angular guidance was considered inside the FAS as provided by SBAS. An APV Baro, which covers the top end of the fleet, does not provide angular guidance but linear performance in the FAS.

Therefore, whilst the A-RNP specification covers both RNAV1 and RNP APCH specifications together with the requirement of RF, no project considered RNP SIDs and STARs with RF. Furthermore, for the approach it appears that no consideration was given to the APV Baro inside the Final Approach Fix (FAF), which is the more common capability on most aircraft.

All projects identified that the current flight plan lacks the tools for the ATM system to identify A-RNP, FRT and RF functionality. Furthermore, although P05.07.04 considered mixed mode ops in the TMA, it must be recognised that RNAV5 was never considered good enough to bring the aircraft below MSA/MFA/MRVA whichever is the highest and therefore is not expected to be used within 30NM of the arrival aerodrome. Similarly, although all four specifications A-RNP, RNAV5, RNAV1 and RNP APCH are possible with an IFR certified SBAS receiver complying with ETSO 145/146, there does not appear to be any mention in the P05.06.03 OSED that APV-SBAS approaches are only possible within the service area of LPV as defined in the EGNOS Service Definition Document (SDD). Furthermore, as previously stated, equipage of SBAS is not very high within the European fleet as can be seen in the IATA/EUROCONTROL survey of 2010 as discussed in para 2.3.1.

2.11 Conclusions

Project 04.07.03 has reviewed the three projects that have supported AOM-0404 and has drawn the following conclusions:

1. EASA's Performance-Based Navigation (PBN) implementation in the European Air Traffic Management Network (EATMN), NPA 2015-01 has indicated that all ATS routes introduced after 2019 are to be RNP1. Together with the PCP IR AF#1 which impacts the top 25 ECAC aerodromes and the requirement to have RNP1 SIDs/STARs with RF together with APVs by 1 January 2024, would lead the project to the logical conclusion that at a minimum RNP1 with RF would be the correct navigation capability to design to. The SDM has published the Deployment Programme V1 and in the AF#1 family it has also now identified A-RNP (1.2.5). To maximise efficiency and to enable additional capacity in the en route, the logical would be to reduce the spacing between routes where traffic densities demand it. To enable a safe reduction in route spacing en route would then require a consistent and highly repeatable turn performance; this turn performance is provided by FRT.
2. Therefore, designing upper ATS route to A-RNP with FRT and limiting operations to only those aircraft appropriately certified should return capacity benefits. Aircraft of lower capabilities would need to be handled differently, either at lower altitudes or in less populated airspace, which may be less efficient for the airspace user. Airspace planners need to understand the design issues when planning to call for FRTs along the airway and design guidance is lacking today. Controllers and pilots will need to understand how they can influence the construction, or not, of the FRT. ATC will want to know whether the airspace users are properly equipped to operate on these A-RNP routes and PBN codes for the flight plan are required. Finally, ATS route designators for FRT are needed in ICAO Annex11, Appendix 1.
3. For terminal operations, A-RNP certified aircraft will be able to operate on RNP1 SIDs, STARs and transitions and will be able to fly a RNP APCH. These aircraft will automatically have RF functionality as it is a requirement of the navigation specification. Today, there is no certification or operational approval for A-RNP although it is understood that this will be available with the new EASA CS-ACNS. Aircraft that are not A-RNP capable will need to reach RNP1 certification and, in line with the PCP and EASA rule, have RF functionality. There is currently no certification document or operational approval for RNP1 in Europe. It is considered that aircraft with RNAV1 certification against AC90-100A or the P-RNAV standard TGL10 Rev1 based on a GNSS sensor should find it relatively easy to achieve this standard for the straight segments. The challenge will be for the turning segments and the certification of RF. The current RF functionality calls for AP/FD with a minimum of roll steering. This requirement will automatically exclude aircraft that have certification with a TSO146 receiver (stand-alone SBAS receiver) unless there is some connection to the aircraft's avionics. Some low end aircraft will equally have RNP APCH certification for APV SBAS through AMC20-28. Again, this certification as well as AMC20-27 which covers RNP APCH and barometric operations does not require RF. Therefore, if consistent and highly repeatable turn

performance is needed then the challenge will be certifying RF for all instrument flight procedures.

4. Looking at the equipage levels (Figure 5), based on the 2010 EUROCONTROL/IATA avionics survey of the European fleet, the percentage of RF capable aircraft was in the 70s, the FRT capability was lower but about 45%. The number of aircraft that were RNAV1/P-RNAV capable is about 90% and the number of aircraft GNSS capable was in the 80s; GNSS is the only sensor that will definitely provide on-board performance monitoring and alerting which enables RNP1. For APVs, the 50-60% of the scheduled ECAC operators were capable of flying an APV-Baro whilst only 5% of those who answered the survey had APV SBAS capability. It should be noted that not all operators responded to the survey and these figures may not represent business and regional aviation; however, it is more likely that these airspace users are more likely to find benefits with SBAS. This survey is now five years old and so the numbers will only have increased as older aircraft are replaced with new generation capabilities. That said, the business case will need to clearly define why those columns need to be 100% and how quickly that investment, made by the airspace users, will be returned.

5. For the APVs, the proposed solution only considered the APV SBAS and operating to a LPV minima line. However, an APV SBAS is just one of four operations that make up RNP APCH. Accepted that we wish to provide a lateral and vertical 3D path for the pilot to fly to improve on safety and reduce CFIT, why should the approach phase not consider the APV Baro as well? Although the aircraft would fly to a LNAV/VNAV minima line and the design criteria are different to that of the APV SBAS, more aircraft would be able to fly the approach although the APV Baro would have higher minima. The 'Advanced APV' based on SBAS and ILS like performance possibly allowed late turns onto the FAP and vertical guidance capture, transitioning to barometric vertical guidance may need to take place at a higher altitude and therefore the Final Approach Fix would have to be further away from the threshold supporting a higher height for that capture.

6. The Project considers that the aircraft capabilities have been available for a decade already. The team acknowledges that not all aircraft have the performance required but European legislation is driving towards RNP1 with RF and APV capability. A-RNP with FRT would cover en route to approach operations in one certification and operational approval standard. To get the true benefits of PBN, the fixed route flows must be adequately separated to enable CCO and CDO to take place. Therefore, good, efficient airspace design is a key enabler.

7. What is lacking appears to be the global level standards and regional level certification documentation:

   - ATS route designator(s) for FRT
   - FRT design criteria and guidance material on FRT use
   - Awareness campaign on FRT and how the controller and pilot can influence its application
   - ICAO flight plan codes for A-RNP, FRT and RF plus amendments to current codes.
   - Validation criteria for FRT design.
   - RTF phraseology to cover FRT/RF capabilities

   At the regional level, the requirements are for certification and operation approval documentation:

   - Certification and operational approval for RNP1
   - Certification and operational approval for RF
   - Certification and operational approval for A-RNP
   - Certification and operational approval for FRT

2.12 Recommendations

Project 04.07.03 has the following recommendations to enable the proposed solution.

At the global level ICAO should:

- Reintroduce into ICAO Annex 11, Appendix 1 the ATS route designator(s) for FRT
- The IFPP should provide clear FRT design criteria and guidance material on FRT use
- Within PANS OPS and PANS ATM provide guidance material to the airspace users and the controllers on the different types of waypoint transitions. Specifically with the FRT and RF, this guidance material should explain how the controller and pilot can influence their application
- PANS ATM should be amended to provide new ICAO flight plan codes for A-RNP, FRT and RF plus amendments to current codes.
- IFPP should provide guidance on how the ANSP will validate newly designed FRTs.
- ICAO should review its RTF phraseology in PANS ATM and provide new phraseology to cover FRT/RF capabilities

At the regional level, EASA should provide:

- Certification and operational approval for RNP1 as detailed in ICAO Doc 9613 Edition 4; this will enable AF#1 to be achieved.
- Clarification on how operators who already have RNAV1 certification can migrate to RNP1
- Certification and operational approval for RF as detailed in ICAO Doc 9613 Edition 4; this will enable AF#1 to be achieved.
- Clarify **if** and how aircraft without AP/FD could qualify for operations requiring RF[5]
- Certification and operational approval for A-RNP as detailed in ICAO Doc 9613 Edition 4.
- Certification and operational approval for FRT as detailed in ICAO Doc 9613 Edition 4.
- If a global change to the flight plan is not forthcoming, develop flight plan code for RF functionality to enable AF#1 of the PCP.

At State level:

- Qualified designers design the ATS routes to match the flows of traffic and to strategically deconflict laterally wherever possible. Where not, deconflict with as much vertical separation as is possible to minimise controller workload. Design the operations involving both ATCos and AOs.
- Undertake PBN implementation as a team exercise and follow the recommended practices promoted in the Manual on the Use of Performance-based Navigation (PBN) in Airspace Design (ICAO Doc 9992) and EUROCONTROL's European Airspace Concept Handbook for PBN Implementation Edition 3.
- Establish an EGNOS working agreement with the ESSP for LPV operations (provided the State is within the Service Area of the APV; this is defined in the Service Definition Document (SDD), latest edition published September 2015.
- Ensure all ATS routes are correctly designated and are published within the AIP.
- Train controllers and pilots in all applicable operations and requirements.
- Provide oversight on non-nominal events, record, analyse and communicated.

[5] The RF appendix clearly requires AP/FD but there is on-going discussion on this.

3 References

The following documents were used to provide input/guidance/further information/other:

[1] ICAO **ANNEX 10**, Aeronautical Telecommunications, Volume I, Radio Navigation Aids.

[2] ICAO **ANNEX 11,** Air Traffic Services.

[3] ICAO **ANNEX 15** - Aeronautical Information Services (AIS).

[4] ICAO **DOC 4444** - Rules of the Air and Air Traffic Services.

[5] ICAO **DOC 8168** - **PANS-OPS** vol. I and vol. II.

[6] ICAO **DOC 9613** - Performance Based Navigation (**PBN**) Manual 4th edition, 2013.

[7] ICAO Global ATM Operational Concept Doc 9854

[8] ICAO Doc 9573, Manual of Area Navigation (RNAV) Operations, First Edition.

[9] ICAO Document 9694.

[10] ICAO **DOC 9931**- Continuous Descent Operations (CDO).

[11] EUROCAE ED75D/RTCA DO236C Minimum Aircraft System Performance Standards: Required Navigation Performance for Area Navigation

[12] EUROCAE **ED 76A/**RTCA **DO-200A** - Standards for Processing of Aeronautical Data.

[13] RTCA MOPS **DO-229D**, Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment.

[14] ED-78A Guidelines for Approval of the provision and use of Air Traffic Services supported by Data Communications.

[15] Common Rules for the Flexible Use of Airspace, European Commission Regulation (EC 2150/2005)

[16] COMMISSION IMPLEMENTING REGULATION (EU) No 716/2014 of 27 June 2014 on the establishment of the Pilot Common Project supporting the implementation of the European Air Traffic Management Master Plan

[17] COMMISSION REGULATION (EC) No 859/2008, (This refers to European Union (EU) regulations specifying minimum safety and related procedures for commercial passenger and cargo fixed-wing aviation) **EU-OPS 1.430** Aerodrome operating minima — General.

[18] EASA NPA 2015-01: Performance-Based Navigation (PBN) implementation in the European Air Traffic Management Network (EATMN)

[19] EASA **AMC 20-27** - Airworthiness Approval and Operational Criteria for RNP APPROACH (RNP APCH) Operations Including APV BARO-VNAV Operations.

[20] EASA **AMC 20-28** - Airworthiness Approval and Operational Criteria for RNAV GNSS approach operation to LPV minima using SBAS.

[21] EASA **AMC** 20-26 - Airworthiness Approval and Operational Criteria for RNP Authorisation Required (RNP AR) Operations.

[22] General Acceptable Means of compliance for Airworthiness of Products, parts and Appliances for B-RNAV EASA AMC 20-4

[23] JAA TGL 10 Rev1 – Certification and operational approval for Precision Area Navigation

[24] FAA **AC 90-105** Approval Guidance for RNP Operations and Barometric Vertical Navigation in the U.S. National Airspace System.

[25] FAA **AC 20-138C**, Airworthiness Approval of Positioning and Navigation Systems.

[26] **ETSO-C145** - Airborne Navigation Sensors using the Global Positioning System (GPS) Augmented by the Satellite Based Augmentation System (SBAS).

[27]**ETSO-C146** - Stand-Alone Airborne Navigation Equipment using the Global Positioning System (GPS) Augmented by the Satellite Based Augmentation System (SBAS).

[28]**ETSO-C129** - Airborne Supplemental Navigation Equipment using the Global Positioning System (GPS).

[29]**ETSO-C-196A** Airborne Supplemental Navigation Sensors for Global Positioning System Equipment Using Aircraft-Based Augmentation.

[30]EUROCONTROL "Point Merge Integration of Arrival Flows Enabling Extensive RNAV Application and Continuous Descent OSED" V2.0, 19/07/10, CND/COE/AT/AO.

[31]EUROCONTROL Airspace Planning Manual Volume 2, Section 5 – Terminal Airspace Design Guidelines, Ed 2.0 -Amendment 1, 17.01.2005.

[32]EUROCONTROL Guidance Material for the Design of Terminal Procedures for Area Navigation (DME/DME, B-GNSS, Baro-VNAV & RNP-RNAV), Ed. 3.0, March 2003.

[33]Point Merge Integration of Arrival Flows Enabling Extensive RNAV Application and Continuous Descent - Operational Services and Environment Definition, EUROCONTROL CND/COE/AT/AO, Version 2.0, 19th July 2010

[34]European Airspace Handbook for PBN Implementation (Edition 3 published April 2013)

[35]EUROCONTROL "Point Merge Integration of Arrival Flows Enabling Extensive RNAV Application and Continuous Descent OSED" V2.0, 19/07/10, CND/COE/AT/AO

[36]European Airspace Management Handbook (EUROCONTROL-GUID-136 Edition 3.0)

[37]2015 Airspace Concept and Strategy for the ECAC States and Key Enablers, Edition 2 (EUROCONTROL 28 February 2008)

[38]Safety Assessment of RNP1-RNAV Route Spacing, Rev 1 Report, EUROCONTROL September 2005

[39]Guidance to States on Basic RNAV Route Spacing, EUROCONTROL September 2001

[40]Review of P-RNAV Route Spacing Safety Assessment, DNV for EUROCONTROL October 2005

[41]Operational Focus Areas Programme Guidance, SJU, Edition 02.00.00, 15th April 2011

[42]SESAR B4.2 Actors- Roles and Responsibilities, Edition 00.01.04, 15th December 2010.

[43]DLT-0612-222-02-00_D3_Concept of Operations, SESAR Consortium, 2007

[44]B4.1 Methodology for Allocating Targets and Performance Requirements at the Appropriate Levels, Edition 00.01.00, 27th July 2010.

[45]SESAR European ATM Master Plan, Draft Edition 2, March 2012

[46]SESAR Safety Reference Material.
https://extranet.sesarju.eu/Programme%20Library/Forms/Procedures%20and%20Guidelines.aspx

[47]SESAR P9.40 D01 (improvements in vertical profiles) "State of the Art study" (Edition 00.00.04).

[48]SESAR P05.06.03 D36 - Advanced Procedures Identification Report (V2 OSED).

[49]SESAR P5.6.2_D03_Airborne Recommendations for CDA Procedure Design recommendations for CDO procedure design (Edition 00.01.00).

[50]SESAR "The VINGA Project Final Report" (Edition 04.00, ref D2011-019555).

[51]SESAR P5.6.2 D01(improvements in vertical profiles) " State of the Art Report_Step 1" (Edition 00.01.00).

[52]SESAR P05.02-M315 ed 00.01.05 : WP 5 TMA Step 1 Detailed Operational Description (DOD).

[53]WP16.6.X-B5 Guidance on Scenarios & Assumptions for Primary Project Validation
https://extranet.sesarju.eu/Programme Library/SESAR Guidance Scenarios Assumptions for Primary Project Validation Exercises Step 1.doc

[54]Advanced Required Navigation Performance Real-Time Simulation No 2 CRDS/SIM/RTS-10565-FEU dated 04.02.2011

[55]OATA Operational Scenario and Use Case Guide V1.0

[56]Manual of Air Traffic Services Part 1, UK CAA CAP493, June 2011

[57]OATA Operational Scenario and Use Case Guide V1.0.

Appendix A Support Documentation

A.1 Project 04.07.03

A.1.1 En route Reports

SESAR P04.07.03 Validation Report 1- EXE-04.07.03-194 (VALR) –D04

SESAR P04.07.03 Consolidated Validation Report and Updated OSED – D06

Fixed Radius Transition (FRT) Flight Data Collection Report, EUROCONTROL October 2013.

A.2 Project 05.07.04

A.2.1 SID/STAR and Transitions Reports

SESAR P05.07.04 WS2 Validation Report (VALR) – London TMA, Edition 00.01.00, February 2012.

SESAR P.05.07.04 Point Merge in Complex TMA – London & Milan (OFA) Safety Assessment Report (SAR), v00.01.00, March 2012

A.3 Project 05.06.03

A.3.1 Validation Reports

SESAR P05.06.03 D24 - Advanced Procedure Validation Report - EXE-05.06.03-225 (VALR).

SESAR P05.06.03 D25 - Advanced Procedure Validation Report - EXE-05.06.03-VP-353 (VALR).

SESAR P05.06.03 D26 - Advanced Procedure Validation Report - EXE-05.06.03-VP-623 (VALR).

SESAR P05.06.03 D27 - Advanced Procedure Validation Report - EXE-05.06.03-VP-482 (VALR).

SESAR P05.06.03 D28 - Advanced Procedure Validation Report - EXE-05.06.03-VP-483 (VALR).

SESAR P05.06.03 D43 - Advanced Procedure Validation Report - EXE-05.06.03-VP-792 (VALR).

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