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PBN Hybrid Procedures as an Enabler for Airport Accessibility in Challenging Terrain

the example of Innsbruck/Austria

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Abstract—**Along with many other advantages, Performance Based Navigation (PBN) has given aviation new technological and operational standards to safely perform flights to and from airports in critical terrain [1], which under conventional navigation standards would have produced prohibitively high weather minima. Therefore, PBN clearly acts as a contributor to safety and accessibility of terrain-challenged airports [2]. However, in some cases, the design criteria for Required Navigation Performance (RNP) procedures show disadvantages over conventional criteria when it comes to the geometric layout of obstacle protection areas. In such cases, the strict separation between PBN and conventional procedures may not support the best operational solution whereas relinquishing this separation in favor of a hybrid approach to ICAO procedure standards can produce very promising results. The concrete example of the development of a hybrid procedure for one of the world's most complex airport locations will be shown in this paper to advocate the use of both PBN and conventional design criteria in a "mixed toolbox" concept to achieve even higher levels of accessibility to critical terrain airports whilst maintaining the highest levels of safety.**

Keywords – Required Navigation Performance; terrain-challenged airports; Performance Based Navigation; procedure design criteria; localizer; RNP AR; missed approach

I. INTRODUCTION

In a direct comparison between conventional procedures and modern PBN, it may at first appear that the PBN procedure options always beat their conventional counterparts in terms of navigation accuracy and thus result in smaller obstacle protection areas when looking at their underlying design criteria as defined in ICAO Doc 8168 (PANS-OPS) [3], ICAO Doc 9613 (PBN Manual) [4] and ICAO Doc 9905 (RNP AR) [5], etc..

Whilst this is true in most cases, there are various scenarios in which the angular behavior of conventional ground-based navigation aids like VORs or Localizers may show great advantages in near-station locations, whereas the position-independent navigation performance of RNP procedures (most of which are GNSS based) shows a better overall accuracy than a purely conventional navigation solution. It is now interesting to study cases where a useful combination of both PBN and conventional navigation standards can improve the overall procedure quality, which for approach procedures is oftentimes evaluated on the basis of procedure minima [6] as well as flight crew workload. If it is possible to prove that combining "the best of both worlds" (i.e. PBN and conventional criteria) in a hybrid approach can lead to higher accessibility (by means of lower procedure minima) with the same or lower levels of crew workload than provided by either a full PBN procedure (such as an RNP AR "Authorization Required" approach, for instance) or a fully conventional one, this clearly states that the existing separation between PBN and non-PBN design criteria should be given up in favor of a "toolbox philosophy" where elements of various navigation standards can be freely combined through a defined set of interface segments.

It is, of course, self-evident that all hybrid solutions (most of which, in their individual combination, are outside of ICAO criteria, so far) have to meet at least the same or better target levels of safety than the ones already established by ICAO.

A. *Background of the Example Scenario*

The scenario discussed in this paper came up at the airport of Innsbruck in the Austrian Alps and shall be used as an exemplary case to cover all relevant aspects in the design of a hybrid procedure. After covering the individual case, some general conclusions about the proposed combination of PBN and conventional design criteria will be derived.

The airport of Innsbruck in Austria (ICAO code LOWI) has a long history of flight operations in a very complex environment. Apart from the extremely mountainous terrain, the Alpine location adds to weather challenges, which tends to aggravate the situation for IFR flight operations especially during winter months. Innsbruck is a city of about 130.000 inhabitants, situated at the Inn River which flows through the narrow and winding Inn Valley. Whilst the airport was opened in 1948, it was not until the 1970s that the first navigation aids for IFR operations were installed. In the two decades before, the airport was only accessibly through visual procedures which strongly restricted its use. Like other studies have shown for different regions of the world, airport accessibility is oftentimes much more than just a flight operational parameter but rather shows considerable economic effects on a much larger scale [7]. The operational restriction at Innsbruck was therefore particularly painful during the winter months as this period has always been of great economic importance to the winter sports region of Tyrol. Since the introduction of full IFR approaches, Innsbruck has seen a constant development towards lower procedure minima in order to assure airport accessibility in IMC (instrument meteorological conditions), which - as mentioned - is a large economic factor for the region. Following an early locator (low-power NDB) approach, the second advancement was the introduction of a localizer approach (LOC/DME East RWY 26) in the 1980s, which was the best conventional option for Innsbruck as ILS systems are unusable due to the curved geometry of the valley and resulting runway alignment issues. The improvement in terms of procedure minima was tremendous, however the lowest possible minimum was still at 1410 feet AGL (above ground level) and already required an increased missed approach climb gradient of 5% (with the standard 2.5% gradient, the minimum was at 3010 feet AGL). Hence, whilst being an accessibility improvement and particularly helpful for crew workload reduction thanks to its lateral guidance inside the valley, the localizer approach still could not guarantee a stable weather-independent operation at the airport..

B. The RNP AR Revolution

Finally, with the advent of Performance Based Navigation in the early 2000s, Europe's first RNP AR approach was designed in Innsbruck in 2005 which revolutionized all-weather operations in the demanding environment. The minimum (published as a DH – decision height) could now be reduced to as low as 710 feet for RNP 0.3 capability and later on even 610 feet for RNP 0.15.

Whilst the beginning of RNP AR operations in Innsbruck was still particularly challenging as the navigation specification was in its infancy and not yet fully standardized by ICAO (initial designs for Innsbruck were still based on FAA TERPS [8] criteria due to a lack of guidance material from ICAO), other challenges included aircraft operator equipage and certification. It has to be stressed that the RNP AR type of approach was the first standardized approach that required direct interaction between CAA (Civil Aviation Administration), ANSP (Air Navigation Service Provider) and aircraft operators for the approval of the procedure's individual use, which needed a new level of flight operations expertise inside the IFP unit (instrument flight procedures), which is usually an entity of the ANSP.

C. More Potential in Hybrid Procedures

It can be said that the RNP AR seemed to be the "end of history" regarding the procedure evolution in Innsbruck but just when it had achieved the highest acceptance amongst aircraft operators (with more than 80% of airlines at LOWI being approved to use the procedure), a new weather phenomenon started to regularly impede Innsbruck's accessibility in the winter of 2013 and produced an alarming spike in the rate of weather-induced diversions, despite the existing RNP procedure minima. The frequent weather pattern consisted of very low ceilings (mostly around 600ft of low stratus/high fog) with good visibility underneath, but breaking the cloud cover was often impossible on the RNP AR approach and therefore oftentimes led to missed approaches and diversions. This caused the airport operator and various airlines to reach out to the ANSP requesting an enhanced procedure to further reduce minima and thereby guarantee better all-weather accessibility of Innsbruck airport. It was clear to all involved that this was a critical demand as most operators saw their winter products jeopardized (oftentimes consisting of winter charter packages for ski-weekends in the Tyrolian Alps) in case the diversion rate would not go down. For the ANSP's IFP team, however, this was an almost unrealistic demand as the most advanced procedure type (i.e. the RNP AR approach with very low minima) was already installed at the airport.

Finally, this was the starting point for something new, something that had to be innovative and go beyond the existing ICAO design criteria whilst at the same time being deeply rooted in the existing safety concept for RNP operations. It was from this scenario that Austro Control's IFP team developed Europe's first PBN hybrid procedure in a terrain-challenged environment.

II. The Conceptual Approach to Hybrid Protection Areas

In flight procedure design, the protection area is a defined geometry around an aircraft's flight path which must not be penetrated by any obstacle and oftentimes even features an additional buffer called the MOC (Minimum Obstacle Clearance) between its surfaces and the highest possible obstacle. As a matter of fact it would be more appropriate to refer to these geometries as three-dimensional protection "bodies" or "spaces" as they clearly extend in all three spatial dimensions for most procedure types. The individual geometry depends on the underlying navigation specification, the applied navigation sensors and stations, the procedure category, as well as - in certain cases - factors like speed, flight path gradients, etc.

The localizer only (abbreviated as LLZ or LOC) approach as described in ICAO Doc 8169, Vol2, Part II, Section 2, Chapter 1 is derived from the surfaces used in a full ILS construction and has a splayed geometry around the nominal flight path of the final approach segment. This geometry clearly reflects the physical characteristics of the localizer beam, which is interpreted on board of the aircraft by a VOR/LOC receiver. The interpretation is based on the electromagnetic field strength and radiation lobe geometry of the localizer beam which is translated into an angular deflection indication on board [9]. It is through this angular behavior that the same localizer deflection will correspond to a growing offset from the nominal track centerline the farther away from the transmitter the aircraft is positioned. This simple geometric principle is the underlying reason for the aforementioned splay in the LOC protection area which can be seen in Figure 1. One could also paraphrase this VOR and LOC specific behavior by saying that the resolution of the position information given by these navigation aids is a function of the distance to the individual ground station.

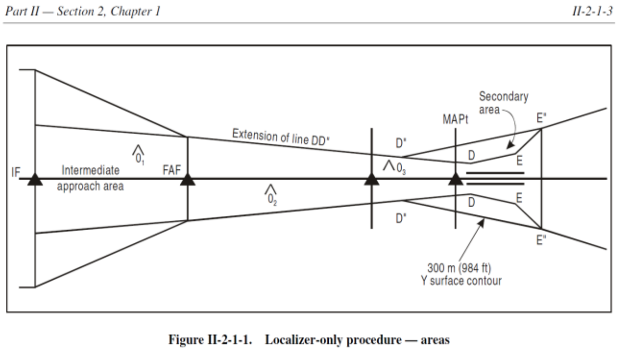

Figure 1. Protection Areas of LOC Only Procedure *(ICAO PANS-OPS)*

Compared to the rather complex geometry of the localizer or ILS surfaces, the protection areas for RNP procedure segments are very simple: they laterally extend to two times the RNP value of that segment and according to ICAO Doc 9905 the RNP value is 0.3nm in the final approach segment of a standard RNP AR approach, which makes the protection area extend to 2 x 0.3nm = 0.6nm to each side of the nominal flight track. In the vertical dimension, the final approach segment of an RNP approach features a 246 feet MOC buffer, which gives the obstacle protection geometry of a straight RNP segment a simple rectangular box shape.

Moreover, because of the dependence of RNP approaches on Global Navigation Satellite Systems (GNSS) as a primary navigation data source, the lateral accuracy of the position solution is no function of the distance to any ground station (as there is no ground station involved in the immediate navigation solution) and evidently no angular offset interpretation applies.

Considering first the lateral dimension only and assuming that the vertical MOC buffer was violated, any such penetrating obstacle which is within the 4 x RNP corridor along the final approach track would also be within the lateral boundary of the LOC protection area once it is equal or wider than the 4 x RNP width. The point at with the lateral "LOC only" protection area hits the width of 4 x 0.3nm = 1.2nm can easily be calculated with the OAS (Obstacle Assessment Surface) formulae given by DOC 8168 Vol.2, Appendix E to Chapter 1 "Calculation of obstacle assessment surface height", but it is not the only decisive factor as the so-called secondary protection area D (visible in Figure 1) is inclined and has the initial MOC of the primary area which is then linearly reduced to zero at the outer edges. In other words, an obstacle which penetrates the protection area of the RNP corridor can easily be underneath the lateral extension of the localizer protection area, as well (and, indeed, will be in almost all cases as the overall LOC surface extension is always wider than 4 x 0.3nm = 1.2nm) but still be no factor as long as it is small enough to fit under the inclined secondary surfaces.

A. The Final Approach Segment

This scenario is exactly what was found in Innsbruck which opened a window of opportunity for the use of the localizer instead of the RNP final approach segment as shown in figures 2 and 3.

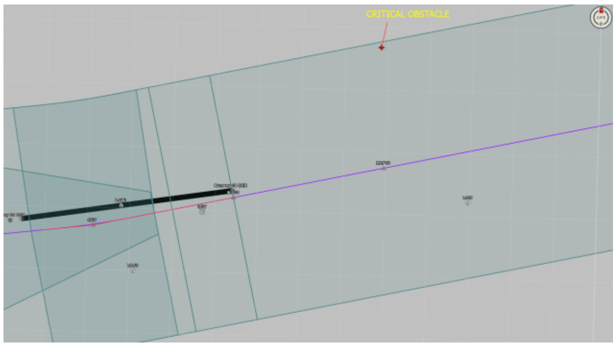

Figure 2. Critical Obstacle in RNP AR Protection Area *(FPDAM software design by Austro Control)*

Whilst Figure 2 shows the identified critical obstacle which determines the procedure minimum of the previously existing RNP AR approach, Figure 3 shows the same obstacle being located in the secondary protection area of the localizer OAS.

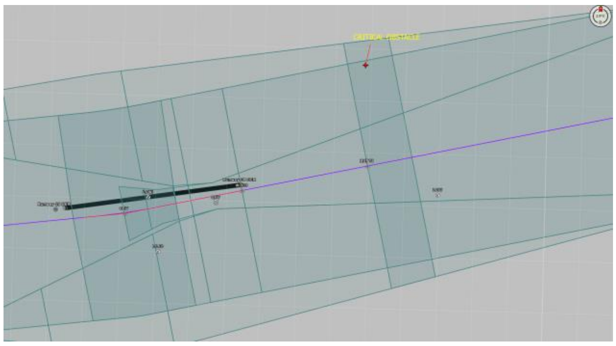

Figure 3. Critical Obstacle within but vertically below LOC Secondary Protection Surface *(FPDAM software design by Austro Control)*

It should now become evident that as long as the obstacle is low enough to remain below the inclined secondary protection surface of the LOC area, it will be no factor to the localizer approach.

At the same time it is of great importance to note that the laterally wider extension of the secondary LOC surface (as well as its splayed primary area further away from the transmitter) may potentially produce new obstacles which were no factor to the previous RNP corridor. This is exactly the comparative evaluation which has to be performed to evaluate the usefulness of a hybrid procedure, because it would be unwise to eliminate the critical obstacle of an existing procedure whilst "adding" (i.e. being forced to consider) new ones that could have even more detrimental effects on the overall procedure minimum. Thus, it is always important to carry out a comparative obstacle analysis between the different procedure segment options considered. Moreover, a certain hybrid combination may only be advantageous for one scenario whilst being useless for another.

To apply this notion to our given scenario at Innsbruck: any secondary LOC surface obstacle with a deeper penetration than the one previously found for the critical obstacle of the RNP AR approach would have rendered the concept of combining a localizer final approach segment with an RNP AR missed approach impractical, as no gain in accessibility through better procedure minima could have been achieved.

This clearly reflects the very nature of a toolbox concept where procedure segments of different navigation standards can be merged: there is no standard combination which can provide a "one size fits all" solution to approach procedures. This also implies that the flexibility provided by such a modular approach is an advantage over rigid design criteria for complete approach types of only one navigation specification.

B. The Missed Approach

Looking at the Innsbruck scenario so far, it appears that the analysis is simply stating that a LOC approach can have obstacle protection advantages over an RNP AR approach which seems hardly credible and inevitably leads to the question why one does not merely revert to the existing localizer approach which has been in use for several decades. The reason why the LOC approach at LOWI yields a minimum which is at best around 700 feet higher than the RNP AR is the conventional character of its missed approach. Generally speaking, conventional missed approaches have much wider protection areas than RNP AR procedures, esp. when it comes to turns where the AR concept allows for the use of RF (Radius-to-Fix) path terminators to fly rigidly contained high precision turn segments. It is therefore no coincidence that the use of RF functionality in the final and missed approach segments is amongst the fundamental elements that constitute the RNP AR approach classification, together with the onboard monitoring and alerting regime of the RNP concept.

The actual breakthrough from LOC to RNP AR at Innsbruck therefore came from better procedure design options in the missed approach segment, which due to the high accuracy, continuity and integrity of RNP operations enables very tight obstacle protection even in turns - some truly revolutionary progress for flight operations in challenging terrain!

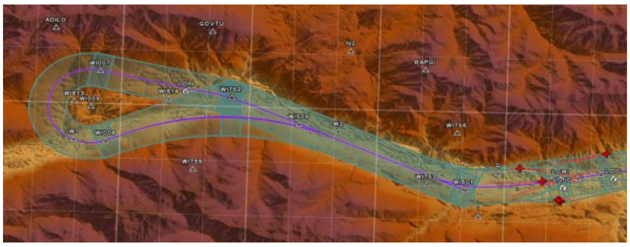

Figure 4. RNP Missed Approach Procedure Protection Area *(FPDAM software design by Austro Control)*

As shown in Figure 4 the RNP missed approach makes use of the tight 4 x RNP protection corridor which retains its small width even in turns through the use of RF path terminators, thereby considerably reducing protection areas over conventional wind spiral turns which have to account for inadvertent track overshoots and therefore show a characteristic protection "bulge" to the outside of the turn. An example wind spiral construction from ICAO Doc 8168 Vol.2, Part II, Section 3, Chapter 1, Appendix A is shown in Figure 5.

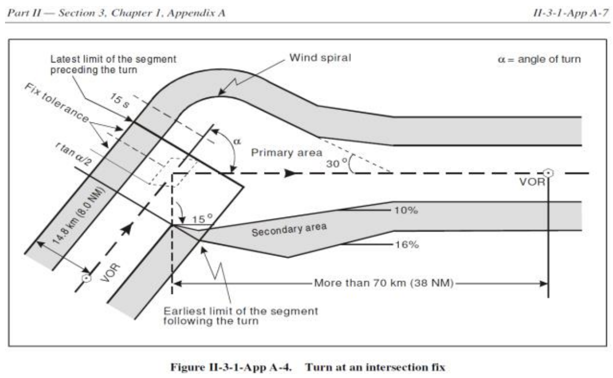

Figure 5. Wind Spiral Construction Example *(ICAO PANS-OPS)*

With the narrow and curved geometry of the Inn Valley to the west of the airport, a conventional missed approach that fits into the given orographic contours is simply impossible with conventional procedure design criteria given by PANS-OPS. Thus the localizer approach itself relies on a small visual segment as a means to enable the aircraft to return to localizer tracking on an opposing outbound flightpath. Whilst strongly reducing airport capacity (as any following traffic has to hold before starting an approach until a successful completion of the preceding landing is confirmed by ATC), this dual use of the same localizer (inbound and outbound) is the only way to provide sufficient track guidance in all phases of the approach. The connection between the inbound final approach phase and the opposite-direction outbound approach phase on the same LOC station, however, requires a 195° turn to re-intercept the localizer (180° + 15° intercept angle) and cannot be protected by conventional criteria, with ICAO wind spiral protection extending far beyond the available space in the narrow valley. Thus, in order to make it work, some sort of visual turn resembling a circling procedure (and being obstacle protected in a similar way) was designed, which obviously has a detrimental impact on the LOC procedure minimum. The procedure chart can be seen in figure 6.

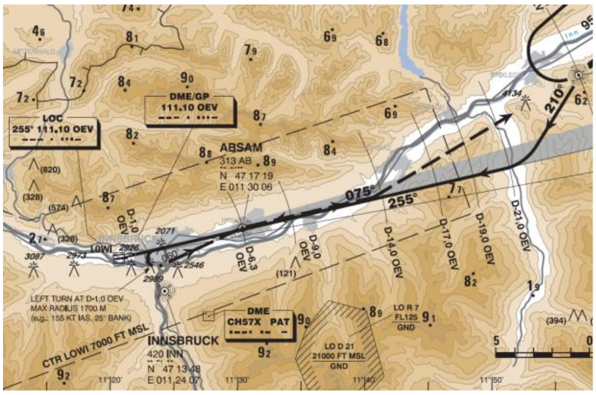

Figure 6. LOC/DME East Procedure LOWI *(AIP Austria, Austro Control)*

This is where the classic RNP AR approach paved new ground with the possibility of a tightly protected missed approach procedure that initially follows the curved valley and, after reaching a certain altitude, even allows for a fully protected turn inside the valley. The latter was achieved by using the aforementioned RF path terminator, which provides the same RNP lateral protection as in straight segments (i.e. 2 x RNP to each side of the nominal track) and thereby makes use of the full potential of this advanced approach specification.

It must be stressed, however, that the Innsbruck scenario is so challenging that even the standard RNP value of 1nm for an RNP AR missed approach proved to be too large for the given orographic geometry. Hence, the procedure design applied an exception granted by ICAO Doc 9905 (page 4-36, section 4.6.2c) to reduce the RNP AR missed approach protection to a value lower than 1nm (in our case 0.3nm as in the final segment) for as long as the inertial reference unit (IRU) drift is assumed to contain the aircraft within this value based on very conservative assumptions on IRU drift rates of eight degrees per hour (page 4-42f, section 4.6.18). This provides for the critical case of GNSS loss at the missed approach point (where the aircraft would continue to "coast" on IRU navigation only) and ensures sufficient obstacle protection throughout the subsequent missed approach. Hence, only with the use of a 0.3nm RNP missed approach including the RF leg in the valley, the successful reduction of the approach minimum from 1410 feet on the LOC approach to 710 feet on the RNP AR were achieved.

C. *Merging the "Best of Both Worlds"*

Having presented both the advantages of close range LOC protection (i.e. in the vicinity of the transmitter station) over the RNP final segment and the advantages of an RNP missed approach over conventional options, it may become clear to the reader that a merged combination of both may prove to be a solution that surpasses the results achieved by any of the two options alone. It is this reasoning for the given Innsbruck scenario that created Europe's first hybrid approach, which was named "LOC R" approach (read Localizer Romeo Approach – where the identifier "R" stands for RNP, see chart in figure 8). The result is a merged protection area from the localizer to the RNP missed approach which in the given obstacle and terrain scenario could exclude the critical obstacle of the original RNP AR final approach segment without including new and more constraining ones further away from the LOC station. It was therefore possible to further reduce the procedure minimum from 710 feet on the RNP AR 0.3 (and 610 feet on the even more advanced RNP AR 0.15) down to an astonishing 360 feet minimum for the LOC R approach. Figure 7 once again summarizes the conceptual basics of the idea in a graphic representation.

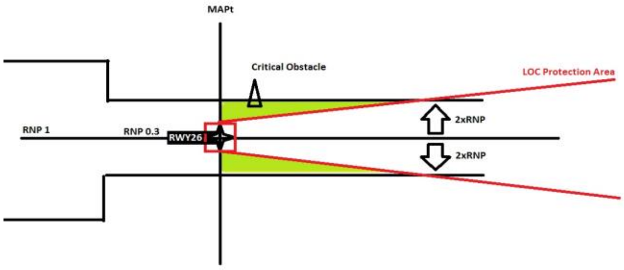

Figure 7. Critical Obstacle Avoidance by Application of the LOC Protection Area *(author's own work)*

In the development of this hybrid procedure one of the issues was the absence of any guidance material on merging conventional localizer and PBN based RNP AR procedure segments (i.e. their protection area geometry) which was addressed by a simple geometric linkage between the two procedure surfaces, since no other logic could be derived from given ICAO material. The more challenging issue, however, was the question of flyability. With most concepts for PBN hybrid procedures focusing on RNP final approach segments leading into conventional missed approaches, this was the reverse concept where a conventional station tracking would have to transition into a Flight Management System (FMS) guided RNP missed approach upon activation of the go-around mode of the aircraft. It was therefore clear from the beginning that this concept would have to be rigorously tested in a simulator environment and with real flight crews to verify aircraft system acceptance, flyability, workload and to also derive tailored crew handling procedures for this type of approach.

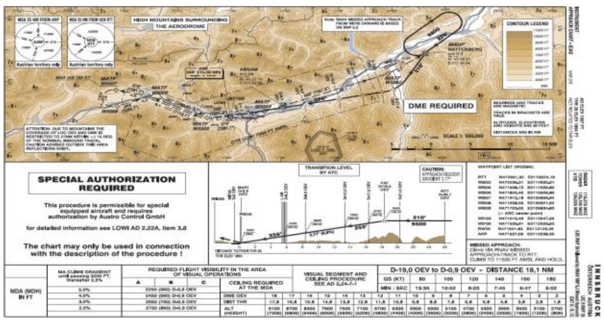

Figure 8. LOC R Hybrid Approach LOWI *(AIP Austria, Austro Control)*

III. FLYABILITY AND CREW WORKLOAD

The concept of PANS-OPS implies that whenever the standards of these criteria are observed, the issue of flyability is covered. For this purpose, ICAO has defined aircraft categories and clearly considers physical limitations of aircraft turn and climb performance, for instance. Whenever certain parameters have to be met which cannot automatically be expected from all aircraft of a given category, the required parameters are indicated (e.g. speed limitations, climb gradients, etc.)[10]. However, once the procedure takes place outside the given ICAO criteria, it enters the realm of "special procedures" where flyability is a key element which has to be analyzed as part of the design process and especially the safety assessment. For some procedure types (esp. RNP AR procedures as described in ICAO Doc 9905) there is already a mandatory flyability evaluation in place, which is oftentimes referred to as a Flight Operational Safety Analysis (FOSA).

Whilst the two individual elements of the hybrid approach (i.e. the LOC and the RNP segment) have been used in previous procedures and are therefore fully validated, the critical flyability issue of the hybrid "LOC R" approach is the transition from LOC tracking to an RNP missed approach by engaging the so-called Take-Off/Go-Around (TOGA) mode in case of a discontinued approach. This could only be tested and verified by including various technical pilots from different operators flying different aircraft types and using different avionics systems. With initial simulator runs and later on actual flight trials in visual meteorological conditions (VMC), these studies consistently showed that the transition could be performed by the various aircraft and systems and did not increase flightdeck workload compared to a standard RNP AR approach. The key to the transitioning phase is the fact that the LOC R procedures has to be fully coded (including a final segment, e.g. with the help of coded waypoints based on DME distances on the LOC track). This final segment would then transition into the RNP missed approach which would be activated by the TOGA mode. A key difference to the standard RNP approach, however, is the fact that the final approach must not be flown from the coded FMS data source (e.g. in LNAV/VNAV or FINALAPP mode, depending on aircraft system architecture and nomenclature) but rather from a direct localizer tracking. Conceptually, this was the most difficult part to convey in initial training sessions with flight crews, because the full procedure is coded but only the missed approach procedure will be flown from the coded source, whereas the final approach segment is flown in a direct LOC sensor tracking mode (like any standard LOC approach that has no approved coded waypoint overlay). The reason, however, why a full procedure has to be coded lies in the database consistency requirements (as defined by ARINC 424 [11]), which stipulate that a missed approach coding is to be connected to a final approach procedure segment in order to be accepted in the database. Moreover, a missed approach activation also requires the database to have passed a final approach phase, which is why this segment will run in "idle mode" (i.e. not in an input mode to the flight director/autopilot system) in the background during the LOC tracking and only become an active data source to the flight guidance system once the missed approach mode is engaged.

Initially the question was often raised why one cannot fly the full coded approach from the FMS data source, which would make this a "classic" RNP AR approach. The reason is simple: if a localizer protection area is considered for the procedure construction (and the obstacle assessment) which eventually determines the procedure minimum, the localizer must also be the selected navigation source when flying the procedure segment. Using a coded RNP data input from the FMS database whilst having calculated the protection areas on the basis of a localizer would protect the segment for the wrong sensor and therefore be invalid (and clearly a safety risk!).

Thus, the procedure handling basically consists of the approach selection from the database (as in any FMS based approach) and the arming of the LOC tracking mode (incl. LOC frequency selection, as in any normal LOC approach). When transitioning to a missed approach (which happens latest at the Missed Approach Point (MAPt), the flight crew then engages the TOGA mode which laterally reverts the avionics to an LNAV tracking based on the coded missed approach procedure. This functionality is called "TOGA to LNAV" and is required by EASA's AMC 20-26 (Airworthiness Approval and Operational Criteria for RNP AR Operations) [12] for RNP missed approaches with RNP < 1nm, which is the case in Innsbruck. The idea behind this functionality is that the aircraft does not inadvertently go into a "heading select" or "wings level" mode when initiating the missed approach which could potentially result in a wrong flight director/autopilot guidance in a critical high-workload situation.

To sum up, the hybrid LOC R approach only affects the cockpit procedures by requiring both the selection of the FMS based RNP approach and the parallel setup of the LOC approach. When transitioning to the missed approach, an automatic switch-over from LOC to LNAV tracking has to be confirmed and in case of failure manually engaged by the flight crew. These two minor crew handling adaptations could be introduced on all aircraft and avionics systems involved in the validation and will always be part of the approval process of this "Authorization Required" (AR) type of hybrid approach to verify the flyability on each aircraft individually. None of the involved test crews noticed any increase in cockpit workload from standard procedures but rather attributed the non-standard items to a supplementary checklist which has to be completed for any RNP AR approach in any case and thereby does not alter the workflow on the flight deck.

IV. SAFETY CONSIDERATIONS

With the flight technical and crew related aspects covered, the final issue before releasing the procedure was the question of specific safety considerations. It was thereby clear from the beginning that the hybrid approach would be treated as an AR procedure as it contains the RNP AR missed approach segment. Moreover, the specific safety requirements laid out by ICAO for AR procedures should be applied as a minimum, such as the aforementioned FOSA, specific crew training, aircraft performance evidence, etc.. The remaining question was whether or not it was necessary for the release of the hybrid approach to go beyond the safety management specifics of the standard RNP AR procedure.

This question was answered in the safety assessment which is a standardized process within an ANSP for ATM system changes. It quickly became obvious that the inclusion of the LOC-RNP transition had to be added as a check item in the approval process of the procedure. Thus, each individual operator applying for its use has to prove that the specific airframe/avionics combination is capable of supporting the seamless mode change from a full localizer tracking to an FMS based RNP AR missed approach. Moreover, the adapted cockpit procedures also have to be trained as part of the specific crew training required for AR procedures.

Finally, it can be stated that the certification and safety management umbrella of ICAO's RNP AR standard provided an excellent basis to cover approach specific safety elements as part of the operator approval process and thus allow for a standardized mitigation of operational challenges encountered in this hybrid PBN approach.

V. SUMMARY AND OUTLOOK

This paper shows a concrete example of a successful merge of conventional PANS-OPS criteria and the PBN based RNP AR navigation specification in the form of a hybrid LOC-RNP approach to Innsbruck airport in the Austrian Alps. By describing the motivation, reasoning and design considerations that made this approach a great success in guaranteeing higher accessibility to the airport in inclement weather and thus adding to safety and capacity, the paper strongly advocates the further development of PBN/non-PBN merge criteria that could open up the somewhat strict separation of these design standards and create a powerful toolset for location-specific procedure optimization. The example for Innsbruck also shows that there is no generic approach to a useful combination of PBN/non-PBN elements but the individual solution for lower minima very much depends on local terrain and obstacle conditions. The conclusion drawn from this recognition is that ICAO procedure design standards should provide maximum flexibility for combining procedure elements and corresponding criteria and should move away from a "one size fits all" philosophy. Moreover, the outdated notion of the old and obsolescent world of conventional procedures being fully replaced by PBN should also be cast aside in favor of a more comprehensive approach to the various technical and procedural opportunities provided by both concepts.

During the preparation of this paper it became clear that ICAO, indeed, starts to follow a similar path to PBN/non-PBN hybrid procedures which is reflected in the latest amendment 7 to ICAO Doc 8168 (PANS-OPS), applicable since November 2016. Thus, the criteria for Precision Approaches based on ILS/MLS are provided with options for RNP based lead-in segments (initial approach segments) and/or RNP based missed approach segments. Since the case of non-aligned LOC procedures with RNP AR missed approaches (including the use of RF path terminators, as discussed in this paper) is not yet covered, there is still room for further development but the general concept of a hybrid PBN/non-PBN toolbox has clearly been adopted by ICAO to the great satisfaction of procedure designers, especially those confronted with a challenging terrain and obstacle environment. In essence, it is scenarios like Innsbruck - where procedure minima are the key driver to airport accessibility - that deliver progress and further development of ICAO design criteria to finally use the full potential of a comprehensive and non-exclusive approach to conventional and PBN procedure standards.

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The author would like to thank the entire procedure design team of Austro Control, as well as the air traffic control unit Innsbruck for their great contribution to this innovative accomplishment of designing Europe's first PBN hybrid approach in a very complex terrain environment. Moreover, the author expresses his great gratitude for the enormous support and enthusiasm shown by airlines flying to Innsbruck who dedicated many simulator trials to this approach in order to ensure its validation and line acceptance. Without a joint effort of the entire aviation community this step forward in terrain-critical flight operations would not have been achieved.

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