APPENDIX A

MODULE NO. B0-05: IMPROVED FLEXIBILITY AND EFFICIENCY IN DESCENT PROFILES (CDO)

<table>
<tr><td>Summary</td><td colspan="2">To use performance-based airspace and arrival procedures allowing aircraft to fly their optimum profile using continuous descent operations (CDOs). This will optimize throughput, allow fuel efficient descent profiles and increase capacity in terminal areas.</td></tr>
<tr><td>Main performance impact as per Doc 9854</td><td colspan="2">KPA-04 – Efficiency, KPA-05 – Environment, KPA-09 – Predictability, KPA-10 – Safety.</td></tr>
<tr><td>Operating environment/ Phases of flight</td><td colspan="2">Approach/arrivals and en-route.</td></tr>
<tr><td>Applicability considerations</td><td colspan="2">Regions, States or individual locations most in need of these improvements. For simplicity and implementation success, complexity can be divided into three tiers:

a) least complex – regional/States/locations with some foundational PBN operational experience that could capitalize on near term enhancements, which include integrating procedures and optimizing performance;

b) more complex – regional/States/locations that may or may not possess PBN experience, but would benefit from introducing new or enhanced procedures. However, many of these locations may have environmental and operational challenges that will add to the complexities of procedure development and implementation; and

c) most complex – regional/States/locations in this tier will be the most challenging and complex to introduce integrated and optimized PBN operations. Traffic volume and airspace constraints are added complexities that must be confronted. Operational changes to these areas can have a profound effect on the entire State, region or location.</td></tr>
<tr><td>Global concept component(s) as per Doc 9854</td><td colspan="2">AOM – airspace organization and management
AO – aerodrome operations
TS – traffic synchronization, AOM</td></tr>
<tr><td>Global plan initiatives (GPI)</td><td colspan="2">GPI-10: Terminal area design and management
GPI-11: RNP and RNAV standard instrument departures (SIDS) and standard terminal arrivals (STARS)</td></tr>
<tr><td>Main dependencies</td><td colspan="2">Nil</td></tr>
<tr><td rowspan="6">Global readiness checklist</td><td></td><td>Status (ready now or estimated date).</td></tr>
<tr><td>Standards readiness</td><td>√</td></tr>
<tr><td>Avionics availability</td><td>√</td></tr>
<tr><td>Ground system availability</td><td>√</td></tr>
<tr><td>Procedures available</td><td>√</td></tr>
<tr><td>Operations approvals</td><td>√</td></tr>
</table>

1. NARRATIVE

1.1 General

1.1.1 This module integrates with other airspace and procedures (continuous descent operations (CDO), performance-based navigation (PBN) and airspace management) to increase efficiency, safety, access and predictability.

1.1.2 As traffic demand increases, the challenges in terminal areas centre on volume, hazardous meteorological conditions (such as severe turbulence and low visibility), adjacent airports and special activity airspace in close proximity whose procedures utilize the same airspace, and policies that limit capacity, throughput, and efficiency.

1.1.3 Traffic flow and loading (across ingress and egress routes) are not always well-metered, balanced or predictable. Obstacle and airspace avoidance (in the form of separation minima and criteria), noise abatement procedures, as well as wake encounter risk mitigation, tend to result in operational inefficiencies (e.g. added time or distance flown, thus more fuel).

1.1.4 Inefficient routing can also cause under-use of available airfield and airspace capacity. Finally, challenges are presented to States by serving multiple customers (international and domestic with various capabilities): the intermingling of commercial, business, general aviation and many times military traffic destined to airports within a terminal area that interact and at times inhibit each other's operations.

1.2 Baseline

1.2.1 The baseline for this module may vary from one State, region or location to the next. Noted is the fact that some aspects of the movement to PBN have already been the subject of local improvements in many areas; and these areas and users are already realizing benefits.

1.2.2 The lack of ICAO PBN operational approval guidance material is slowing down implementation and is perceived as one of the main roadblocks for harmonization.

1.2.3 There is still some work to be done to harmonize PBN nomenclature, especially in charts and States/regional regulations (e.g. most of European regulations still mention basic area navigation (B-RNAV) and precision area navigation (P-RNAV).

1.3 Change brought by the module

1.3.1 Flight operations in many terminal areas precipitate the majority of current airspace delays in many States. Opportunities to optimize throughput, improve flexibility, enable fuel-efficient climb and descent profiles, and increase capacity at the most congested areas should be a high-priority initiative in the near-term.

1.3.2 The core capabilities that should be leveraged are RNAV; RNP where needed; CDO; where possible, increased efficiencies in terminal separation rules in airspace; effective airspace design and classification; air traffic control (ATC) flow and ATC surveillance. Opportunities to reduce emissions and aircraft noise impacts should also be leveraged where possible.

1.4 **Element 1: Continuous descent operations**

1.4.1 Continuous descent is one of several tools available to aircraft operators and ANSPs to benefit from existing aircraft capabilities and reduce noise, fuel burn and the emission of greenhouse gases. Over the years, different route models have been developed to facilitate CDO and several attempts have been made to strike a balance between the ideal of environmentally friendly procedures and the requirements of a specific airport or airspace.

1.4.2 CDO can provide for a reduction in fuel burn and emissions, while increasing flight stability and the predictability of flight path to both controllers and pilots, without compromising the optimal airport arrival rate (AAR).

1.4.3 CDO is enabled by airspace design, procedure design and facilitation by ATC, in which an arriving aircraft descends continuously, to the greatest possible extent, by employing minimum engine thrust, ideally in a low drag configuration, prior to the final approach fix/final approach point (FAF/FAP). An optimum CDO starts from the top-of-descent (TOD) and uses descent profiles that reduce controller-pilot communications and segments of level flight.

1.4.4 Furthermore it provides for a reduction in noise, fuel burn and emissions, while increasing flight stability and the predictability of flight path to both controllers and pilots.

1.5 **Element 2: Performance-based navigation**

1.5.1 PBN is a global set of area navigation standards, defined by ICAO, based on performance requirements for aircraft navigating on departure, arrival, approach or en-route.

1.5.2 These performance requirements are expressed as navigation specifications in terms of accuracy, integrity, continuity, availability and functionality required for a particular airspace or airport.

1.5.3 PBN will eliminate the regional differences of various required navigation performance (RNP) and area navigation (RNAV) specifications that exist today. The PBN concept encompasses two types of navigation specifications:

a) RNAV specification: navigation specification-based on area navigation that does not include the requirement for on-board performance monitoring and alerting, designated by the prefix RNAV, e.g. RNAV 5, RNAV 1; and

b) RNP specification: navigation specification based on area navigation that includes the requirement for on-board performance monitoring and alerting, designated by the prefix RNP, e.g. RNP 4.

2. INTENDED PERFORMANCE OPERATIONAL IMPROVEMENT

2.1 Metrics to determine the success of the module are proposed in the *Manual on Global Performance of the Air Navigation System* (Doc 9883).

Efficiency	• Cost savings and environmental benefits through reduced fuel burn. • Authorization of operations where noise limitations would otherwise result in operations being curtailed or restricted.

	• Reduction in the number of required radio transmissions. • Optimal management of the top-of-descent in the en-route airspace.
Environment	As per efficiency
Predictability	• More consistent flight paths and stabilized approach paths. • Less need for vectors.
Safety	• More consistent flight paths and stabilized approach paths. • Reduction in the incidence of controlled flight into terrain (CFIT). • Separation with the surrounding traffic (especially free-routing). • Reduction in the number of conflicts.
Cost Benefit Analysis	The following savings are an example of potential savings as a result of CDO implementation. *It is important to consider that CDO benefits are heavily dependent on each specific ATM environment.* Nevertheless, if implemented within the ICAO CDO manual framework, it is envisaged that the benefit/cost ratio (BCR) will be positive. Example of savings after CDO implementation in Los Angeles TMA (KLAX): a) CDOs RIIVR2/SEAVU2/OLDEE1 and 4 ILS: 1) implemented 25 September 2008, and in use full time at KLAX; b) about 300 - 400 aircraft per day fly RIIVR2/SEAVU2/OLDEE1 STARs representing approximately half of all jet arrivals into KLAX: 1) fifty per cent reduction in radio transmissions; and c) significant fuel savings – average 125 pounds per flight. 1) 300 flights/day * 125 pounds per flight * 365 days = 13.7 million pounds/year; and 2) more than 2 million gallons/year saved = more than 41 million pounds of CO2 emission avoided. The advantage of PBN to the ANSP is that PBN avoids the need to purchase and deploy navigation aids for each new route or instrument procedure. The advantage to everyone is that PBN clarifies how area navigation systems are used and facilitates the operational approval process for operators by providing a limited set of navigation specifications intended for global use. The safety benefits to PBN are significant, as even airports located in the poorest areas of the world can have runway aligned approaches with horizontal and vertical guidance to any runway end without having to install, calibrate and monitor expensive ground-based navigation aids. Therefore, with PBN all airports can have a stabilized instrument approach that will allow aircraft to land into the wind, as opposed to a tail wind landing.

3. NECESSARY PROCEDURES (AIR AND GROUND)

3.1 The ICAO *Continuous Descent Operations (CDO) Manual* (Doc 9931) provides guidance on the airspace design, instrument flight procedures, ATC facilitation and flight techniques necessary to enable continuous descent profiles.

3.2 It therefore provides background and implementation guidance for:

a) air navigation service providers (ANSPs);

b) aircraft operators;

c) airport operators; and

d) aviation regulators.

3.3 The ICAO *Performance-based Navigation (PBN) Manual* (Doc 9613) provides general guidance on PBN implementation. This manual identifies the relationship between RNAV and RNP applications and the advantages and limitations of choosing one or the other as the navigation requirement for an airspace concept.

3.4 It also aims at providing practical guidance to States, ANSPs and airspace users on how to implement RNAV and RNP applications, and how to ensure that the performance requirements are appropriate for the planned application.

3.5 The management of the top-of-descent (TOD) with CDO in en-route airspace (especially in the context of free-routing) will have to be analyzed because CDO will imply an imposed TOD.

4. NECESSARY SYSTEM CAPABILITY

4.1 Avionics

4.1.1 CDO is an aircraft operating technique aided by appropriate airspace and procedure design and appropriate ATC clearances enabling the execution of a flight profile optimized to the operating capability of the aircraft, with low engine thrust settings and, where possible, a low drag configuration, thereby reducing fuel burn and emissions during descent.

4.1.2 The optimum vertical profile takes the form of a continuously descending path, with a minimum of level flight segments only as needed to decelerate and configure the aircraft or to establish on a landing guidance system (e.g. ILS).

4.1.3 The optimum vertical path angle will vary depending on the type of aircraft, its actual weight, the wind, air temperature, atmospheric pressure, icing conditions and other dynamic considerations.

4.1.4 A CDO can be flown with or without the support of a computer-generated vertical flight path (i.e. the vertical navigation (VNAV) function of the flight management system (FMS)) and with or without a fixed lateral path. However, the maximum benefit for an individual flight is achieved by keeping the aircraft as high as possible until it reaches the optimum descent point. This is most readily determined by the onboard FMS.

4.2 Ground systems

4.2.1 Within an airspace concept, PBN requirements will be affected by the communication, surveillance and ATM environments, the NAVAID infrastructure and the functional and operational capabilities needed to meet the ATM application.

4.2.2 PBN performance requirements also depend on what reversionary, non-RNAV means of navigation are available and what degree of redundancy is required to ensure adequate continuity of functions. Ground automation needs initially little changes to support CDO: potentially a flag on the display. For better integration the ground trajectory calculation function will need to be upgraded.

5. HUMAN PERFORMANCE

5.1 Human factors considerations

5.1.1 The decision to plan for RNAV or RNP has to be decided on a case by case basis in consultation with the airspace user. Some areas need only a simple RNAV to maximize the benefits, while other areas such as nearby steep terrain or dense air traffic may require the most stringent RNP.

5.1.2 Human factors have been taken into consideration during the development of the processes and procedures associated with this module. Where automation is to be used, the human-machine interface has been considered from both a functional and ergonomic perspective (see Section 6 for examples). The possibility of latent failures however, continues to exist and vigilance is requested during all implementation actions. It is further requested that human factor issues, identified during implementation, are reported to the international community through ICAO as part of any safety reporting initiative.

5.2 Training and qualification requirements

5.2.1 Since required navigation performance authorization required (RNP AR) approaches also require significant training, ANSPs should work closely with airlines to determine where RNP AR approach should be implemented. In all cases PBN implementation needs to be an agreement between the airspace user, the ANSP and the regulatory authorities.

5.2.2 Training in the operational standards and procedures are required for this module and can be found in the links to the documents in Section 8 to this module. Likewise, the qualifications requirements are identified in the regulatory requirements in Section 6 which form an integral part to the implementation of this module.

6. REGULATORY/STANDARDIZATION NEEDS AND APPROVAL PLAN (AIR AND GROUND)

- Regulatory/standardization: use current published requirements that include the material given in Section 8.4.

- Approval plans: must be in accordance with application requirements e.g. airspace design, air traffic operations, PBN requirements for fixed radius transitions, radius-to-fix legs, required time of arrival (RTA), parallel offset, etc.

6.1 Understanding the policy context is important for making the case for local CDO implementation and ensuring high levels of participation. CDO may be a strategic objective at international, State, or local level, and as such, may trigger a review of airspace structure.

6.2 For example, noise contour production may already assume a 3-degree continuous descent final approach. Thus, even if noise performance is improved in some areas around the airport, it may not affect existing noise contours. Similarly, CDO may not affect flight performance within the area of the most significant noise contours, i.e., those depicting noise levels upon which decision-making is based.

6.3 In addition to a safety assessment, a transparent assessment of the impact of CDO on other air traffic operations and the environment should be developed and made available to all interested parties.

6.4 As PBN implementation progresses, standardized international requirements should be set for fixed radius transitions, radius-to-fix legs, required time of arrival (RTA), parallel offset, VNAV, 4D control, ADS-B, data link, etc.

6.5 SMS must be part of any development process, and each one manifests itself differently for each of the PBN processes. For production development, SMS should be addressed through an ISO 9000-compliant production process, workflow, automation improvements, and data management. The production process is monitored for defect control and workflow. For air traffic developed procedures, a safety risk management document (SRMD) may be required for every new or amended procedure. That requirement will extend the time required to implement new procedures, especially PBN-based flight procedures.

6.6 Progress should be measured against the key performance indicators recommended by the working group(s), as approved. PBN does not:

a) add new navigation philosophy, but just is a pragmatic tool to implement navigation procedures for aircraft capability that exists for more than thirty years;

b) require States to completely overhaul navigation infrastructure, but can be implemented step-by-step; and

c) require States to implement the most advanced navigation specifications, it only needs to accommodate the operational needs.

7. IMPLEMENTATION AND DEMONSTRATION ACTIVITIES (AS KNOWN AT TIME OF WRITING)

7.1 Current use

7.1.1 Continuous descent operations

- **United States:** optimized profile descents (OPD) are currently implemented at Los Angeles International Airport (KLAX), Charlotte/Douglas International Airport (KCLT), Minneapolis-St. Paul International Airport (KMSP), Phoenix Sky Harbor International Airport (KPHX), and Las Vegas International Airport (KLAS).

7.1.2 Performance-based navigation

- **United States**: new procedures are currently being developed for Metroplexes in the United States to incorporate performance-based navigation elements such as curved paths into operations. Completion of procedure development for North Texas and Washington DC Metroplex will occur in 2013. Implementation for these two sites will occur in 2014-2015.

7.2 **Planned or ongoing activities**

7.2.1 Continuous descent operations:

- **United States:** New procedures are currently being developed for Denver International Airport (KDEN), Seattle/Seattle-Tacoma International Airport (KSEA), and the Chicago airspace which will incorporate OPDs. Expected completion date of 2014.

7.2.2 Performance-based navigation:

- **United States:** Trials are planned in 2014-2015 to validate the feasibility of RNP established procedures. RNP established will use RNP technology to safely direct aircraft to simultaneous independent and dependent parallel approach paths with no required vertical separation with aircraft on adjacent approaches.

8. **REFERENCE DOCUMENTS**

8.1 **Standards**

8.1.1 For flight plan requirements in Amendment 1, ICAO *Procedures for Air Navigation Services — Air Traffic Management* (PANS-ATM, Doc 4444).

8.2 **Guidance material**

- ICAO Doc 9613, *Performance-based Navigation (PBN) Manual*
- ICAO Doc 9931, *Continuous Descent Operations (CDO) Manual*
- FAA Advisory Circular, AC 90-105, Approval Guidance for RNP operations and barometric vertical navigation in the United States National Airspace System) which provides system and operational approval guidance for operators (only reflects the United States situation)

8.3 **Approval documents**

- ICAO Doc 9931, *Continuous Descent Operations Manual*
- ICAO Doc 9613, *Performance Based Navigation Manual*
- FAA AC120-108, CDFA

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APPENDIX B

MODULE NO. B0-20: IMPROVED FLEXIBILITY AND EFFICIENCY DEPARTURE PROFILES - CONTINUOUS CLIMB OPERATIONS (CCO)

Summary	To implement continuous climb operations in conjunction with performance-based navigation (PBN) to provide opportunities to optimize throughput, improve flexibility, enable fuel-efficient climb profiles and increase capacity at congested terminal areas.	
Main performance impact as per Doc 9854	KPA-04 – Efficiency, KPA-05 – Environment, KPA-10 - Safety	
Operating environment/ Phases of flight	Departure and en-route	
Applicability considerations	Regions, States or individual locations most in need of these improvements. For simplicity and implementation success, complexity can be divided into three tiers: a) least complex: regional/States/locations with some foundational PBN operational experience that could capitalize on near-term enhancements, which include integrating procedures and optimizing performance; b) more complex: regional/States/locations that may or may not possess PBN experience, but would benefit from introducing new or enhanced procedures. However, many of these locations may have environmental and operational challenges that will add to the complexities of procedure development and implementation; and c) most complex: regional/States/locations in this tier will be the most challenging and complex to introduce integrated and optimized PBN operations. Traffic volume and airspace constraints are added complexities that must be confronted. Operational changes to these areas can have a profound effect on the entire State, region or location.	
Global concept component(s) s per Doc 9854	AUO – airspace user operations TS – traffic synchronization AOM – airspace organization and management	
Global plan initiatives (GPI)	GPI 5: Area navigation/required navigation performance (RNAV/RNP) (performance-based navigation) GPI-10: Terminal area design and management GPI-11: RNP and RNAV standard instrument departures (SIDS) and standard instrument arrivals (STARS)	
Main dependencies	Linkage with B0-20	
		Status (ready now or estimated date).
Global readiness checklist	Standards readiness	√
	Avionics availability	√
	Infrastructure availability	√
	Ground automation availability	√
	Procedures available	√
	Operations approvals	√

1. NARRATIVE

1.1 General

1.1.1 This module integrates with other airspace and procedures (PBN, continuous descent operations (CDO), and airspace management) to increase efficiency, safety, access and predictability; and minimize fuel use, emissions, and noise.

1.1.2 As traffic demand increases, the challenges in terminal areas centre on volume, hazardous meteorological conditions (such as severe turbulence and low visibility), adjacent airports and special activity airspace in close proximity whose procedures utilize the same airspace, and policies that limit capacity, throughput, and efficiency.

1.1.3 Traffic flow and loading (across arrival and departure routes) are not always well metered, balanced or predictable. Obstacle and airspace avoidance (in the form of separation minima and criteria), noise abatement procedures and noise sensitive areas, as well as wake encounter risk mitigation, tend to result in operational inefficiencies (e.g. added time or distance flown, thus more fuel).

1.1.4 Inefficient routing can also cause under-use of available airfield and airspace capacity. Finally, challenges are presented to States by serving multiple customers (international and domestic with various capabilities): the intermingling of commercial, business, general aviation and many times military traffic destined to airports within a terminal area that interact and at times inhibit each other’s operations.

1.2 Baseline

1.2.1 Flight operations in many terminal areas precipitate the majority of current airspace delays in many States. Opportunities to optimize throughput, improve flexibility, enable fuel-efficient climb and descent profiles, and increase capacity at the most congested areas should be a high-priority initiative in the near-term.

1.2.2 The baseline for this module may vary from one State, region or location to the next. Noted is the fact that some aspects of the movement to PBN have already been the subject of local improvements in many areas; these areas and users are already realizing benefits.

1.2.3 The lack of ICAO PBN operational approval guidance material and subsequently the emergence of States or regional approval material, which may differ or be even more demanding than intended, is slowing down implementation and is perceived as one of the main roadblocks for harmonization.

1.2.4 There is still some work to be done to harmonize PBN nomenclature, especially in charts and States/regional regulations (e.g. most of European regulations still make use of basic area navigation (B-RNAV) and precision area navigation (P-RNAV).

1.2.5 Efficiency of climb profiles may be compromised by level off segments, vectoring, and an additional overload of radio transmissions between pilots and air traffic controllers. Existing procedure design techniques do not cater for current FMS capability to manage the most efficient climb profiles. There is also excessive use of radio transmissions due to the need to vector aircraft in an attempt to accommodate their preferred trajectories.

1.3 **Change brought by the module**

1.3.1 The core capabilities that should be leveraged are RNAV; RNP where possible and needed; continuous climb operations (CCO), increased efficiencies in terminal separation rules; effective airspace design and classification; and air traffic flow. Opportunities to reduce flight block times, fuel/emissions and aircraft noise impacts should also be leveraged where possible.

1.3.2 This module is a first step towards harmonization and a more optimized organization and management of the airspace. Many States will require knowledgeable assistance to achieve implementation. Initial implementation of PBN, RNAV for example, takes advantage of existing ground technology and avionics and allows extended collaboration of air navigation service providers (ANSPs) with partners: military, airspace users, and neighbouring States. Taking small and required steps and only performing what is needed or required allows States to rapidly exploit PBN.

1.4 **Other remarks**

1.4.1 Operating at the optimum flight level is a key driver to improve flight fuel efficiency and minimizing atmospheric emissions. A large proportion of fuel burn occurs in the climb phase and for a given route length, taking into account aircraft mass and the meteorological conditions for the flight, there will be an optimum flight level, which gradually increases as the fuel on-board is used up and aircraft mass therefore reduces. Enabling the aircraft to reach and maintain its optimum flight level without interruption will therefore help to optimize flight fuel efficiency and reduce emissions.

1.4.2 CCO can provide for a reduction in noise, fuel burn and emissions, while increasing flight stability and the predictability of flight path to both controllers and pilots.

1.4.3 CCO is an aircraft operating technique aided by appropriate airspace and procedure design and appropriate air traffic control (ATC) clearances enabling the execution of a flight profile optimized to the operating capability of the aircraft, thereby reducing fuel burn and emissions during the climb portion of flight.

1.4.4 The optimum vertical profile takes the form of a continuously climbing path, with a minimum of level flight segments only as needed to accelerate and configure the aircraft.

1.4.5 The optimum vertical path angle will vary depending on the type of aircraft, its actual weight, the wind, air temperature, atmospheric pressure, icing conditions and other dynamic considerations.

1.4.6 A CCO can be flown with or without the support of a computer-generated vertical flight path (i.e. the vertical navigation (VNAV) function of the flight management system (FMS)) and with or without a fixed lateral path. The maximum benefit for an individual flight is achieved by allowing the aircraft to climb on the most efficient climb profile along the shortest total flight distance possible.

2. **INTENDED PERFORMANCE OPERATIONAL IMPROVEMENT**

Efficiency	Cost savings through reduced fuel burn and efficient aircraft operating profiles. Reduction in the number of required radio transmissions.
Environment	Authorization of operations where noise limitations would otherwise result in

	operations being curtailed or restricted. Environmental benefits through reduced emissions.
Safety	More consistent flight paths. Reduction in the number of required radio transmissions. Lower pilot and air traffic control workload.
Cost Benefit Analysis	It is important to consider that CCO benefits are heavily dependent on each specific ATM environment. Nevertheless, if implemented within the ICAO CCO manual framework, it is envisaged that the benefit/cost ratio (BCR) will be positive.

3. NECESSARY PROCEDURES (AIR AND GROUND)

3.1 The ICAO *Performance-based Navigation (PBN) Manual* (Doc 9613) provides general guidance on PBN implementation.

3.2 This manual identifies the relationship between RNAV and RNP applications and the advantages and limitations of choosing one or the other as the navigation requirement for an airspace concept.

3.3 It also aims at providing practical guidance to States, ANSPs and airspace users on how to implement RNAV and RNP applications, and how to ensure that the performance requirements are appropriate for the planned application.

3.4 The ICAO *Continuous Climb Operations (CCO) Manual* (Doc xxxx – under development) provides guidance on the airspace design, instrument flight procedures, ATC facilitation and flight techniques necessary to enable continuous descent profiles.

3.5 It therefore provides background and implementation guidance for:

a) air navigation service providers;

b) aircraft operators;

c) airport operators; and

d) aviation regulators.

4. NECESSARY SYSTEM CAPABILITY

4.1 Avionics

4.1.1 CCO does not require a specific air or ground technology. It is an aircraft operating technique aided by appropriate airspace and procedure design, and appropriate ATC clearances enabling the execution of a flight profile optimized to the operating capability of the aircraft, in which the aircraft can attain cruise altitude flying at optimum air speed with climb engine thrust settings set throughout the climb, thereby reducing total fuel burn and emissions during the whole flight. Reaching cruise flight levels sooner where higher ground speeds are attained can also reduce total flight block times. This may allow a reduced initial fuel upload with further fuel, noise and emissions reduction benefits.

4.1.2 The optimum vertical profile takes the form of a continuously climbing path. Any level or non-optimal reduced climb rate segments during the climb to meet aircraft separation requirements should be avoided. Achieving this whilst also enabling CDO is critically dependent upon the airspace design and the height windows applied in the instrument flight procedure. Such designs need an understanding of the optimum profiles for aircraft operating at the airport to ensure that the height windows avoid, to greatest extent possible, the need to resolve potential conflicts between the arriving and departing traffic flows through ATC height or speed constraints.

4.2 Ground systems

4.2.1 Controllers would benefit from some automation support to display aircraft capabilities in order to know which aircraft can do what.

5. HUMAN PERFORMANCE

5.1 Human factors considerations

5.1.1 Human factors have been taken into consideration during the development of the processes and procedures associated with this module. Where automation is to be used, the human-machine interface has been considered from both a functional and ergonomic perspective (see Section 6 for examples). The possibility of latent failures however, continues to exist and vigilance is requested during all implementation actions. It is further requested that human factor issues, identified during implementation, be reported to the international community through ICAO as part of any safety reporting initiative.

5.2 Training and qualification requirements

5.3 Training in the operational standards and procedures are required for this module and can be found in the links to the documents in Section 8 to this module. Likewise, the qualifications requirements are identified in the regulatory requirements in Section 6 which form an integral part to the implementation of this module**.**

6. REGULATORY/STANDARDIZATION NEEDS AND APPROVAL PLAN (AIR AND GROUND)

- Regulatory/standardization: use current published requirements that include the material given in Section 8.4.

- Approval plans: must be in accordance with application requirements.

6.1 Understanding the policy context is important for making the case for local CCO implementation and ensuring high levels of participation. CCO may be a strategic objective at international, State, or local level, and as such, may trigger a review of airspace structure when combined with CDO.

6.2 For example, noise contour production may be based on a specific departure procedure (noise abatement departure procedure 1 (NADP1) or NADP2-type). Noise performance can be improved in some areas around the airport, but it may affect existing noise contours elsewhere. Similarly CCO can enable several specific strategic objectives to be met and should therefore be considered for inclusion within any airspace concept or redesign. Guidance on airspace concepts and strategic objectives is contained in the *Performance-based Navigation (PBN) Manual* (Doc 9613). Objectives are usually collaboratively identified by airspace users, ANSPs, airport operators as well as by government policy. Where a change could have an impact on the environment, the development of an airspace concept may involve local communities, planning authorities and local government, and may require formal impact assessment under regulations. Such involvement may also be the case in the setting of the strategic objectives for airspace. It is the function of the airspace concept and the concept of operations to respond to these requirements in a balanced, forward-looking manner, addressing the needs of all stakeholders and not of one of the stakeholders only (e.g. the environment). Doc 9613, Part B, Implementation Guidance, details the need for effective collaboration among these entities.

6.3 In the case of a CCO, the choice of a departure procedure (NADP1 or NADP2-type), requires a decision of the dispersion of the noise. In addition to a safety assessment, a transparent assessment of the impact of CCO on other air traffic operations and the environment should be developed and made available to all interested parties.

7. IMPLEMENTATION AND DEMONSTRATION ACTIVITIES (AS KNOWN AT TIME OF WRITING)

7.1 Current use

- **United States:** procedures are currently being developed to incorporate optimized climb profiles as part of procedure and airspace development.

7.2 Planned or ongoing activities

- **United States:** none at this time.

8. REFERENCE DOCUMENTS

8.1 Procedures

- *ICAO Doc 8168, Procedures for Air Navigation Services — Aircraft Operations*
- ICAO Doc 4444, *Procedures for Air Navigation Services — Air Traffic Management Guidance Material*
- ICAO Doc 9613, *Performance-based Navigation (PBN) Manual*
- ICAO Doc xxxx, *Continuous Climb Operations (CCO) Manual* (under development)

8.2 Approval documents

- ICAO Doc xxxx, *Continuous Climb Operations (CCO)Manual* (under development)
- ICAO Doc 9613, *Performance Based Navigation Manual*
- ICAO Doc 4444, *Procedures for Air Navigation Services — Air Traffic Management*

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APPENDIX C

MODULE NO. B1-05: IMPROVED FLEXIBILITY AND EFFICIENCY IN DESCENT PROFILES (CDOS) USING VNAV

Summary	To enhance vertical flight path precision during descent, arrival, and enables aircraft to fly an arrival procedure not reliant on ground based equipment for vertical guidance. The main benefit is higher utilisation of airports, improved fuel efficiency, increased safety through improved flight predictability and reduced radio transmissions, and better utilization of airspace.	
Main performance impact as per Doc 9854	KPA-02 – Capacity, KPA-04 – Efficiency, KPA-06 – Predictability, KPA-10 – Safety	
Operating environment/ Phases of flight	Descent, arrival, flight in terminal area	
Applicability considerations		
Global concept component(s) as per Doc 9854	AO – aerodrome operations AOM – airspace organization and management AUO – airspace user operations CM – conflict management DCB – demand and capacity balancing TS – traffic synchronization	
Global plan initiatives (GPI)	GPI-2: Reduced vertical separation minima GPI-5: Area navigation (RNAV) and required navigation performance (RNP) (performance-based navigation) GPI-9: Situational awareness GPI-10: Terminal area design and management GPI-11: RNP and RNAV standard instrument departures (SIDS) and standard terminal arrivals (STARS)	
Main dependencies	B0-05	
Global readiness checklist		Status (ready now or estimated date).
	Standards readiness	2018
	Avionics availability	√
	Ground system availability	2018
	Procedures available	√
	Operations approvals	2018

1. NARRATIVE

1.1 General

1.1.1 PBN with vertical navigation (VNAV) is an altimetry-based capability which enables an equipped aircraft to precisely descend on a vertical path, as computed by the flight management computer (FMC), within a tolerance set in feet, while providing the flight crew with navigation performance information though avionics monitoring and alerting. The system defaults to an initial tolerance set by the individual operator, but a crew may select a new tolerance (e.g. 75 ft in the terminal area).

1.2 Baseline

1.2.1 The baseline for this block is improved flight descent profile enabled by Block B0-5. This block is a component of trajectory-based operations (TBO).

1.3 Change brought by the module

1.3.1 VNAV contributes to terminal airspace design and efficiency due to an aircraft's ability to maintain a vertical path during descent thus enabling vertical corridors for ingressing and egressing traffic. Other benefits include reduced aircraft level-offs, enhanced vertical precision in the terminal airspace, de-confliction of arrival and departure procedures and adjacent airport traffic flows, and the ability of an aircraft to fly an approach procedure not reliant upon ground based equipment for vertical navigation. This ultimately leads to higher utilization of airports.

2. INTENDED PERFORMANCE OPERATIONAL IMPROVEMENT

2.1 Metrics to determine the success of the module are proposed in the *Manual on Global Performance of the Air Navigation System* (Doc 9883).

Capacity	PBN with VNAV allows for added accuracy in a continuous descent operation (CDO). This capability allows for the potential to expand the applications of standard terminal arrival and departure procedures for improved capacity and throughput, and improve the implementation of precision approaches.
Efficiency	Enabling an aircraft to maintain a vertical path during descent allows for development of vertical corridors for arriving and departing traffic thus increasing the efficiency of the airspace. Additionally, VNAV promotes the efficient use of airspace through the ability for aircraft to fly a more precisely constrained descent profile allowing the potential for further reduced separation and increased capacity.
Predictability	VNAV allows for enhanced predictability of flight paths which leads to better planning of flights and flows.
Safety	Precise altitude tracking along a vertical descent path leads to improvements in overall system safety.
Cost Benefit Analysis	Safety enhancement: flying more precise vertical profiles. Efficiency: VNAV contributes to terminal airspace efficiency by enabling an aircraft to maintain a vertical path during descent. This allows for vertical corridors for arriving and departing traffic which makes the airspace more efficient. Vertical RNP will also lay the foundation for expanded use of optimized and continuous descent profiles. Economic: VNAV allows for reduced aircraft level-offs, resulting in fuel and time savings.

3. NECESSARY PROCEDURES (AIR AND GROUND)

3.1 Flight crews require training in the proper use of the VNAV functions of the FMC. Standard procedures guide the flight crews on which altitude tolerances may be selected for a particular phase of flight.

3.2 New arrival procedures and instructions used by the ground are required for a maximum use of this capability.

4. NECESSARY SYSTEM CAPABILITY

4.1 Avionics

4.1.1 Barometric vertical navigation (Baro-VNAV) capability is contained within the flight management computer.

4.2 Ground systems

4.2.1 Controllers would benefit from some automation support to display aircraft capabilities in order to know which aircraft can support CDOs.

5. HUMAN PERFORMANCE

5.1 Human factors considerations

5.1.1 The identification of human factors considerations is an important enabler in identifying processes and procedures for this module. In particular, the human-machine interface for the automation aspects of this performance improvement will need to be considered and where necessary accompanied by mitigation risk mitigation strategies such as training, education and redundancy.

5.2 Training and qualification requirements

5.2.1 Training in the operational standards and procedures will be identified along with the Standards and Recommended Practices necessary for this module to be implemented. Likewise the qualifications requirements will be identified and included in the regulatory readiness aspects of this module when they become available**.**

6. REGULATORY/STANDARDIZATION NEEDS AND APPROVAL PLAN (AIR AND GROUND)

- Regulatory/standardization: use current published criteria that include the material given in Section 8.4.

- Approval plans: must be in accordance with application requirements e.g. operations and procedures that necessitate vertical performance and guidance.

- Discussion: vertical RNP availability is better than 99.9 per cent/hour for a single FMC installation. From an equipment certification standpoint, the loss of function is probable. Redundant equipment installation supports improbable loss of function, where required.

7. IMPLEMENTATION AND DEMONSTRATION ACTIVITIES (AS KNOWN AT TIME OF WRITING)

7.1 Current use

7.1.1 Continuous descent operations

United States – optimized profile descents (OPD) are currently implemented at Angeles International Airport (KLAX), Charlotte/Douglas International Airport (KCLT), Minneapolis-St. Paul International Airport (KMSP), Phoenix Sky Harbor International Airport (KPHX), and Las Vegas International Airport (KLAS).

7.1.2 Performance-based navigation

United States – new procedures are currently being developed for Metroplexes in the United States to incorporate PBN elements such as curved paths into operations. Completion of procedure development for North Texas and Washington DC Metroplex will occur in 2013. Implementation for these two sites will occur in 2014-2015.

7.2 Planned or ongoing activities

- **United States** – VNAV was demonstrated as part of 4D FMS trials in 2011.
- **SESAR**: trials on advance CDOs and integration of initial 4D with continuous descend approach procedures and arrival management in 2012-2013 timeframe.

8. REFERENCE DOCUMENTS

8.1 Standards

- EUROCAE ED-75B, MASPS Required Navigation Performance for Area Navigation
- RTCA DO-236B, Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation
- Boeing Document D6-39067-3, RNP Capability of FMC Equipped 737, Generation 3
- Boeing Document D243W018-13 Rev D, 777 RNP Navigation Capabilities, Generation 1

8.2 Guidance material

ICAO Doc 9931, *Continuous Descent Operations (CDO) Manual*

8.3 Approval documents

- FAA AC20-138
- EASA AMC20-27

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APPENDIX D

MODULE NO. B2-05: IMPROVED FLEXIBILITY AND EFFICIENCY IN DESCENT PROFILES (CDOS) USING VNAV, REQUIRED SPEED AND TIME AT ARRIVAL

Summary	A key emphasis is on the use of arrival procedures that allow the aircraft to apply little or no throttle in areas where traffic levels would otherwise prohibit this operation. This block will consider airspace complexity, air traffic workload, and procedure design to enable optimized arrivals in dense airspace.	
Main performance impact as per Doc 9854	KPA-02 – Capacity, KPA-04 – Efficiency, KPA-05 – Environment; KPA-06 – Flexibility, KPA-10 – Safety	
Operating environment/ Phases of flight	En-route, terminal area, descent	
Applicability considerations	Global, high density airspace (based on the United States FAA procedures)	
Global concept component(s) as per Doc 9854	AOM – airspace organization and management AUO – airspace user operations TS – traffic synchronization	
Global plan initiatives (GPI)	GPI-5: Area navigation (RNAV) and required navigation performance (RNP) (performance-based navigation) GPI-9: Situational awareness GPI-11: RNP and RNAV standard instrument departures (SIDS) and standard terminal arrivals (STARS)	
Main dependencies	B1-05, B0-20, B1-40	
Global readiness checklist		**Status** (ready now or estimated date)
	Standards readiness	√
	Avionics availability	2023
	Ground systems availability	2023
	Procedures available	2023
	Operations approvals	2023

1. NARRATIVE

1.1 General

1.1.1 Optimized arrivals in dense airspace integrates capabilities that will provide improved use continuously descending arrivals in highest congested airspace. Key aspects of optimized profiles in dense airspace are:

a) arrival procedures which allow the aircraft to fly an efficient vertical path from en-route airspace to final approach;

b) limited or no throttle is applied throughout the descent, with momentary level-offs being used to slow an aircraft as required by airspace restrictions;

c) flow management automation that allows air traffic control to manage aircraft flying optimized arrivals with crossing, departing, and other arriving traffic;

d) cockpit automation that allows aircraft to freely choose top-of-descent and descent profile based on aircraft state and meteorological conditions;

e) en-route and terminal controllers rely on automation to identify conflicts and eventually propose resolutions;

f) RNAV operations remove the requirement for routes to be defined by the location of navigational aids, enabling the flexibility of point-to-point aircraft operations;

g) RNP operations introduce the requirement for onboard performance monitoring and altering. A critical characteristic of RNP operations is the ability of the aircraft navigation system to monitor its achieved navigation performance for a specific operation, and inform the air crew if the operational requirement is being met;

h) the basis for the operation is an accurate three-dimensional trajectory that is shared among aviation system users. This provides accurate latitude, longitude, and altitude information to airspace users; and

i) consistent and up-to-date information describing flights and air traffic flows are available system-wide, supporting both user and service provider operations.

1.2 **Baseline**

1.2.1 The baseline for this module is improved flight descent profile and complexity management enabled by modules B1-05, B1-35 and B1-10. Optimized arrivals are a component of trajectory-based operations (TBO) initiatives. Decision support capabilities are available that are integrated to assist aircraft crew and air traffic separation providers in making better decisions and optimizing the arrival profile. Consistent 3D trajectory information is available to users to inform air traffic management (ATM) decision making.

1.3 **Change brought by the module**

1.3.1 This module provides extensions to the baseline, with emphasis on economic descents in airspace with dense traffic levels. Benefits of these trajectory-based operations include fuel savings and noise and emission reduction by keeping aircraft at a higher altitude and at lower thrust levels than traditional step-down approaches. Simplifying routes using optimized arrivals may also reduce radio transmissions between aircraft crew and controllers.

1.3.2 Benefits of these operations in dense airspace include achieving target traffic and throughput levels while also enabling fuel savings and noise reduction. A traditional assumption is that the use of optimized arrivals will reduce throughput in dense airspace, or may not be achievable at all due to complexities created in sequencing optimized arrivals with non-optimized arrivals, departures, and crossing traffic.

1.3.3 The aircraft's ability to accurately fly an optimized arrival, coupled with the state and intent information sent from the aircraft to ATC automation, will increase accuracy of trajectory modelling and problem prediction.

1.4 Other

1.4.1 This module continues the evolution in RNAV and RNP procedure design in dense airspace, and the evolution of automation used to aid in decision support for both air crews and air traffic control.

1.5 Element 1: Accurate trajectory modelling

1.5.1 This element is focused on obtaining the most accurate trajectory model for use by all automation systems. This includes accurate position information, clearance information, and the use of automated resolutions that reduce controller workload.

1.6 Element 2: Advanced aircraft capabilities

1.6.1 This element will focus on cockpit capabilities that enable optimal trajectory selection and the ability to fly point-to-point RNAV and RNP procedures. This element will also examine cockpit automation that enables the aircraft to self-separate and avoid potential conflicts. This element will focus on globally-harmonized standards development for trajectory data exchange between the ground and aircraft avionics systems such as the frequency management system (FMS).

1.7 Element 3: Traffic flow management and time-based metering

1.7.1 This element will harmonize the traffic flow management automation which continuously predicts the demand and capacity of all system resources, and will identify when the congestion risk for any resource (airport or airspace) is predicted to exceed an acceptable risk. Traffic management will take action in the form of just in time reroutes and metering times to congested resources. The problem resolution element will create a solution that meets all system constraints.

2. INTENDED PERFORMANCE OPERATIONAL IMPROVEMENT

2.1 Metrics to determine the success of the module are proposed in *Manual on Global Performance of the Air Navigation System* (Doc 9883).

Capacity	Better use of terminal airspace. High levels of traffic can be accommodated while still allowing the use of best economy descents that save fuel, emissions, and noise. Capacity will be enhanced by improved ability to plan for flows in and out of the airport.
Efficiency	Time in flight may be reduced to automation that enhances decision making and selection of a preferred trajectory.
Environment	Users will fly more fuel and noise efficient arrivals and descent profiles.
Flexibility	Users will be able to select arrival trajectory that best accommodates aircraft according to traffic conditions, meteorological conditions, and aircraft state.
Safety	Economical descents used without sacrificing safety due to enhanced airspace management and automation to aid in aircraft separation.
Cost Benefit Analysis	The major qualitative business case elements of this module are as follows: a) capacity: additional flights can be accommodated in terminal airspace because of reduced controller workload and better trajectory

	modelling/planning; b) efficiency: users will fly more fuel and noise efficient arrival descent profiles; c) safety: economic descents flown without sacrificing safety; and d) flexibility: users will have greater flexibility in selecting the flight trajectory that best meets their needs.

3. NECESSARY PROCEDURES (AIR AND GROUND)

3.1 For strategic actions, the necessary procedures basically exist for air navigation service providers (ANSPs) and users to collaborate on flight path decisions. Extensions to those procedures will need to be developed to reflect the use of increased decision support automation capabilities, including automation-to-automation negotiation. The use of automatic dependence surveillance – broadcast/cockpit display of traffic information (ADS-B/CDTI) and other cockpit capabilities to support aircraft avoidance is still a research topic and will necessitate procedure development, including the roles of ANSPs. International standards for information exchange between systems to support these operations need to be developed. This includes development of global standards for the exchange of trajectory information, including required time of arrival and required speed of arrival, between ground and air to support deployment envisioned in Module No B3-05.

4. NECESSARY SYSTEM CAPABILITY

4.1 Avionics

4.1.1 The continued development of automation for both the cockpit and ANSPs is needed to aid in trajectory modelling and required separation decision making. Aircraft-based capabilities, such as ADS-B/CDTI exist, but applications are still being developed to support the objectives of this module.

4.2 Ground systems

4.2.1 The continued development of automation for both the cockpit and ANSPs is needed to aid in trajectory modelling and required separation decision making. In addition, development of technology that provides mitigation strategies for conflicts or potential conflicts will also aid in enabling optimized profiles in dense airspace.

5. HUMAN PERFORMANCE

5.1 Human factors considerations

5.1.1 This module is still in the research and development phase so the human factors considerations are still in the process of being identified through modelling and beta testing. Future iterations of this document will become more specific about the processes and procedures necessary to take the human factors considerations into account. There will be a particular emphasis on identifying the human-machine interface issue if there are any and providing the high risk mitigation strategies to account for them.

5.2 **Training and qualification requirements**

5.2.1 This module will eventually contain and number of personnel training requirements. As and when they are developed, they will be included in the documentation supporting this module and their importance signified. Likewise, any qualifications requirements that are recommended will become part of the regulatory needs prior to implementation of this performance improvement**.**

6. REGULATORY/STANDARDIZATION NEEDS AND APPROVAL PLAN (AIR AND GROUND)

- Regulatory/standardization: new or updated criteria and standards are needed that include:

  - Global standards for trajectory information exchange
  - ICAO Doc 8168, *Aircraft Operations*
  - ICAO Doc 4444, *Procedures for Air Navigation Services — Air* Via" clearance when utilizing an optimized arrival

- Approval plans: to be determined

7. IMPLEMENTATION AND DEMONSTRATION ACTIVITIES (AS KNOWN AT TIME OF WRITING)

7.1 **Current use**

7.1.1 Optimized arrivals are currently being used at the following United States airports in dense airspaces:

a) Los Angeles International Airport (KLAX);

b) Phoenix Sky Harbor International Airport (KPHX);

c) Atlanta Hartsfield International Airport (KATL); and

d) Las Vegas International Airport (KLAS).

7.2 **Planned or ongoing trials**

- **United States/Europe:** current work is being completed to validate trajectory performance required to support advanced TBO.
- **United States:** completing simulation and modelling to validate trajectory modelling accuracy.
- **United States:** FIXM/Data link work that is being completed with SESAR to standardize trajectory data elements.
- **United States:** airborne reroute currently in development which will provide just in time congestion resolution to the aircraft during congested events.

8. REFERENCE DOCUMENTS

8.1 Guidance material

- ICAO Doc 9931, *Continuous Descent Operations (CDO) Manual.*

8.2 Approval documents

- Global standards for trajectory information exchange. (Update required);
- ICAO Doc 8168, *Aircraft Operations.* (Updated required); and
- ICAO Doc 4444, *Procedures for Air Navigation Services — Air Traffic Management*; ATC/pilot phraseology.

— END —