International Civil Aviation Organization

WORKING PAPER

TWELFTH AIR NAVIGATION CONFERENCE

Agenda Item 5: Efficient flight paths – through trajectory-based operations
5.3: Increased flexibility and efficiency in descent and departure profiles

IMPLEMENTING AND INTEGRATING CONTINUOUS CLIMB OPERATIONS (CCO) AND CONTINUOUS DESCENT OPERATIONS (CDO) IN A PBN SYSTEM

(Presented by the Secretariat)

EXECUTIVE SUMMARY

Continuous descent operations (CDO) offer the promise of fuel savings, emission reduction, and reduced workload, whilst increasing safety and capacity. CDO must be properly designed and implemented to allow accurate sequencing well in advance of airport arrival to achieve these goals. The current 3D description of aircraft position is not sufficient to fully enable efficient advance sequencing. Some movement has begun towards development of a 4D system whereby time over a waypoint is specified. This holds the potential to balance arrival traffic loads and thus enable full time CDO. Counterbalancing this is the way different aircraft operators manage their aircraft by means of a cost index in the flight management system (FMS). Different cost index values cause a variation in aircraft performance. Varying cost index values cause significant differences in velocity among different aircraft operators even within the same aircraft type. A complete air traffic management (ATM) sequencing system must include the desired aircraft velocity over a waypoint in order to fully control all factors affecting system optimization. Such a system can be thought of as a 4D plus velocity system and is more effective when aircraft are programmed via a speed schedule as opposed to a cost index. Continuous climb operations (CCO) also offer significant safety and efficiency benefits. The predictable trajectories and reduced lateral separation distances offered by performance-based navigation (PBN) help integrate CCO with CDO and can thus enable higher initial CCO climb altitudes.

1. BACKGROUND

1.1 Developing performance-based navigation (PBN) procedures and routes in an airspace can make air transportation both safer and more efficient. Continuous descent operations (CDO) and continuous climb operations (CCO) offer the promise of fuel savings, emission reduction, and reduced workload, whilst increasing safety and capacity. There are challenges to deploying full time CDO and CCO procedures in all areas. PBN, due to the flexibility in lay-out of the airspace design and relative higher accuracy, is a perfect enabler for CDO and CCO. To picture an ideal flight system, imagine that one is the pilot of the only airplane in the world, there is no terrain to obstruct flight, and there are no airspace boundaries. The ideal flight profile consists of an aircraft taking off on the active runway and executing an immediate turn direct to the destination airport, with an uninterrupted CCO to the most efficient altitude. En route navigation should be via the most direct route and selected altitudes that take into account winds and weather and aircraft flight characteristics to obtain maximum efficiency. The aircraft would begin a CDO from cruise flight level at the destination and join an instrument approach in a continuous flight idle descent to touchdown. This flight path would be preloaded into the aircraft via computer data link so that the pilots would have ample time to review the route prior to departure, workload in flight would be small, and chances for mistakes on data entry would be minimal. En route modifications to respond to changes in weather would be communicated via data link, with the flight crew only needing to acknowledge the change. This system can be thought of as an end state ideal. Flight management systems (FMS) already included as standard equipment aboard most commercial aircraft today can readily calculate this ideal route automatically with the push of a few buttons. So the question becomes, why are aircraft not flying the ideal route and what steps can be taken to move us towards more fully optimized flight paths? Movement towards a fully optimized system can continuously evolve over time starting with the implementation of CDO and CCO at all airports, and progressing to user-preferred trajectories between destinations.

2. CONTINUOUS DESCENT OPERATIONS IN PBN

2.1 Some of the issues that complicate enabling an ideal flight path are other aircraft, national boundaries, restricted airspace, terrain, and weather. One of the primary issues limiting efficiency is the other aircraft in the system that need to be both separated from and sequenced with. Managing the sequencing of aircraft to congested airfields has become a significant limiting factor in system efficiency.

2.2 PBN has the potential to change much of the current established route structure and procedures to enable more efficiency. More accurate placement of aircraft with respect to other airspace and other aircraft enable this efficiency. The positioning capability defined by latitude and longitude in the area navigation (RNAV) specification enables accurate position placement.

2.3 Altitude has been used as the primary means to separate aircraft since IFR flight first began over sixty years ago, and is still used as a primary means of separation today. Altimeter accuracy enables aircraft to fly as close as 1 000 ft (300 m) from each other. Considering the state of initial aircraft equipage sixty years ago, the ability to routinely place aircraft one-sixth of a mile (1 000 ft) vertically from each other is truly remarkable. The most recent expansion of altitude separation, reduced vertical separation minima (RVSM), has doubled the number of high altitude routes available by reducing required vertical separation from 2 000 ft to 1 000 ft at high altitudes. Contrast this with required horizontal separation which has often been as much as 100 miles, shrinking in some areas of radar coverage to as little as three miles, which is still significantly more than the one-sixth of a mile used for vertical separation.

2.4 The reason for this relatively small required vertical separation is positional accuracy and positive rate of closure control. Altimeters are very accurate devices easily able to display altitudes within 100 ft of the desired vertical level; and aircraft vertical rate of change has proven to be very manageable. This combination enables accurate position assurance and manageable closure rates, thus providing a safe margin of aircraft separation. To put this into perspective, contrast vertical separation with horizontal separation. VHF omnidirectional radio range (VOR) navigation allows aircraft to be several miles from the ideal flight path with potential closure rates of over 1 000 miles per hour. PBN and global navigation satellite system (GNSS) enable a system where horizontal accuracy can be measured in hundreds of feet as opposed to miles. PBN systems enable accurate position calculation, position communication, and closure rate management. The positional accuracy of a PBN system provides the potential for air traffic management (ATM) system computers to calculate aircraft interaction and accomplish advance sequencing with a high degree of accuracy.

2.5 A 3-dimensional cartesian coordinate system consisting of an X, Y, and Z axis is used to describe any position in space (see Figure 1).

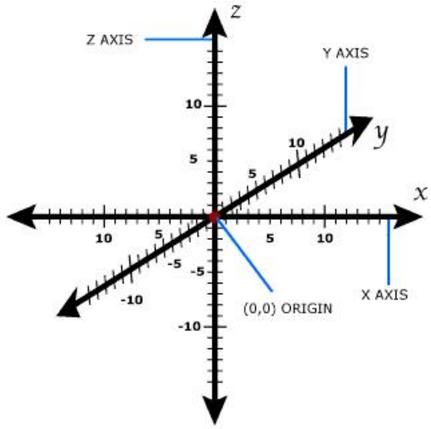

Figure 1

2.6 This is often referred to as a 3D system, and in PBN is enabled using latitude, longitude, and altitude as shown below (see Figure 2); with defined cross track tolerances (XTT) and along track tolerances (ATT).

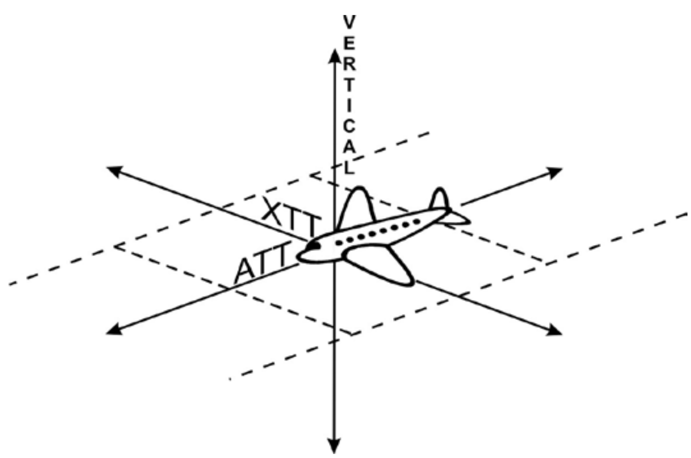

Figure 2

2.7 To manage and sequence multiple aircraft, radar vectoring or time over fix is used to ensure adequate distance is maintained between aircraft arriving over any one point. Historically, initial non-radar time separation was developed consisting of aircraft reporting a time over a fix. Many tens of minutes between aircraft are used to guarantee separation for aircraft at the same altitude. Radar vectoring was a significant improvement over reporting the time over fix and has been used for many years as a way to gain maximum airspace utilization. Vectoring is workload intensive and at busy airports the workload required to issue and track multiple aircraft on vectors may limit capacity. Radar vectoring also introduces many chances for pilot/controller miscommunication, limits advance planning, and is not fuel efficient; thus entailing significant system costs. Radar vectors also prevent aircraft from calculating the most efficient descent to an airport because the precise distances to the runway are unknown. Thus efficient CDO is not possible when radar vectors are used. Time over fix/waypoint is being developed for PBN as a way to minimize the need for radar vectoring to sequence aircraft. This is often referred to as 4D navigation (3D plus time). Having aircraft arrive over a defined waypoint at specific precise time intervals can ensure an even flow of aircraft to the airport thus allowing aircraft to remain on an optimal, predefined CDO route. This is referred to as required time of arrival (RTA) (see Figure 3).

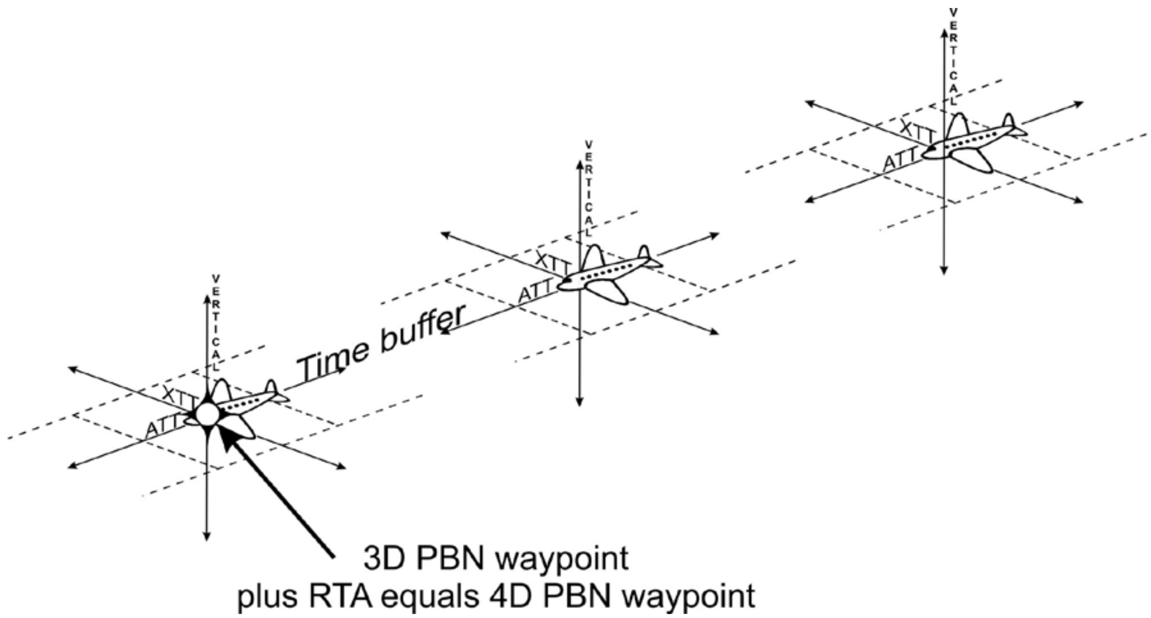

Figure 3

2.8 Computer programs are currently being developed and refined in several air traffic control (ATC) systems to allow implementation of an optimum 4D system. The time of arrival must be issued to the aircraft with enough lead time to enable compliance with the RTA. Implementing a RTA scheme that allows for maximum advance aircraft notification enables the aircraft to calculate an optimum descent point and complete a CDO with maximum efficiency. Each aircraft FMS is programmed to calculate the most efficient path according to a cost index. A cost index is a calculated value that takes into account such things as fuel costs, operational costs, crew costs, etc. When the cost of fuel rises, an operator may adjust the cost index that is programmed into each aircrafts FMS, and often this translates into a slower programmed flight speed as the price of fuel goes up. However, all operators do not use the same cost index and this difference is one reason for observed performance differences between the same aircraft type among different operators.

2.9 4D is often assumed to be the end state of a fully optimized PBN arrival system, but 4D alone can produce unintended effects. Most notably a 4D system, while producing separation and proper sequencing at the waypoint, does not guarantee separation beyond the waypoint. The reason for this is that each aircraft will calculate the best speed at which to reach the waypoint according to its individually programmed cost index. Thus while two aircraft may be separated at the moment the lead aircraft is over the waypoint, if the lead aircraft has calculated a slower speed to reach the waypoint at the desired time than the trailing aircraft, the trailing aircraft may overcome the lead aircraft immediately after passing the waypoint (see Figure 4).

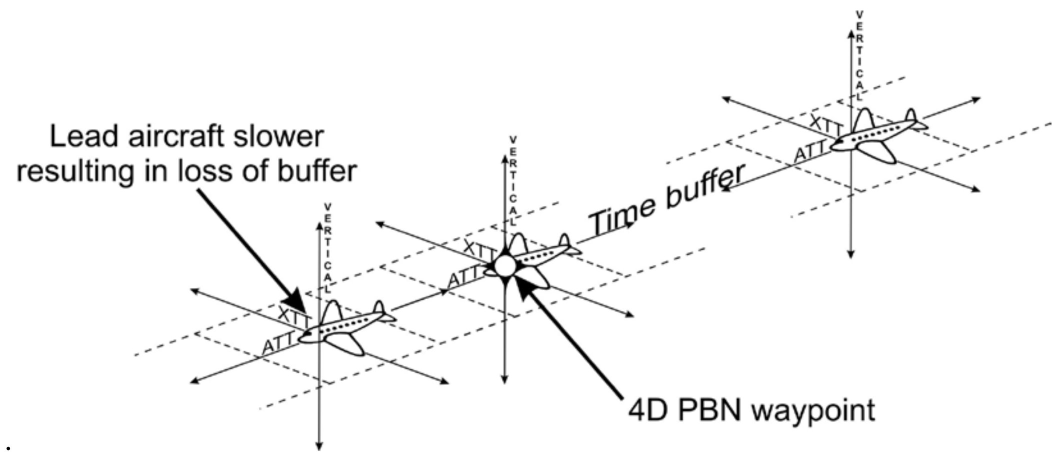

Figure 4

2.10 A proven way to manage this interaction is to issue a required aircraft speed at the waypoint. Thus a given set of aircraft can be assigned like speeds and so remain separated after passing the waypoint. This is best described as 4D plus velocity (see Figure 5).

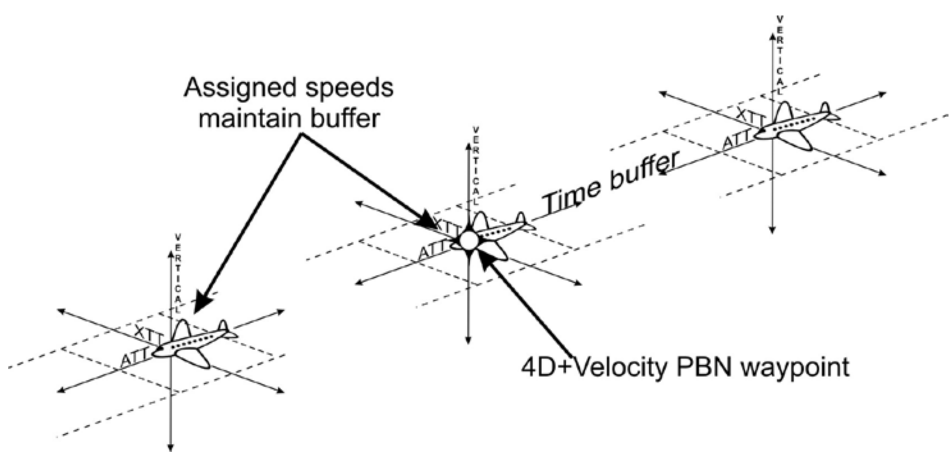

Figure 5

2.11 The importance of speed assignment is often overlooked when developing a CDO system but is a critical component in maintaining system capacity and safety. A fully optimized CDO system can thus be thought of to include:

Horizontal accuracy	2D	PBN RNAV specification
Vertical accuracy	3D	Altitude window
Required time at waypoint	4D	RTA – plus or minus specified
Required speed at waypoint	4D+V	Speed – plus or minus specified

2.12 This 4D+Velocity system can only be assured when aircraft are programmed to descend using a speed schedule. A speed schedule is a way of programming the FMS to calculate the most efficient path using required speeds. Aircraft velocity and closure rates between aircraft can thus be more easily managed by using a speed schedule.

2.13 An accurate mathematical description of any moving object in space consists of X, Y, and Z axis points (latitude, longitude and altitude), as well as velocity and time. A fully optimized ATM system requires all five descriptors. A speed schedule is used, as opposed to a cost index, to guarantee that the FMS is programmed to comply with all five parameters. Using all five elements in a 4D+V system enables full time CDO to achieve maximum efficiency and throughput, minimizes pilot and controller workload, whilst maintaining the highest level of safety.

3. CONTINUOUS CLIMB OPERATIONS IN PBN

3.1 CCO offer significant safety and efficiency benefits. The challenge is to integrate CCO with CDO and enable higher initial climb altitudes. Limits to CCO are based on past practices, inbound traffic flows, and other traffic. The ATC system has historically been very proactive in climbing departures as soon as possible. There is a natural incentive to climb the aircraft rapidly because the sooner an aircraft climbs the sooner the aircraft leaves a particular air traffic controllers' airspace. However, the initial altitude assigned by the ATC tower in some areas can be less than 3 000 ft above aerodrome level (AAL). This is done to provide 1 000 ft of separation from aircraft arrivals inbound to an extended downwind that may be a factor for the departure aircraft or in some cases as a historical carryover. Even though the departure is usually assigned a higher altitude prior to reaching 3 000 ft AAL, modern aircraft climb at a faster rate than those of thirty years ago. A higher climb rate combined with FMS navigation and profile control means that aircraft may begin the inefficient process of levelling off long before reaching 3 000 ft AAL. Airspace design that allows for a higher initial assigned altitude is to be encouraged. A smooth implementation transition might be achieved by initially assigning all departures an altitude at least 5 000 ft AAL, followed by a goal of assigning all departures an altitude of at least 10 000 ft AAL, and eventually assigning all departures their requested cruise flight level.

3.2 Reducing the lateral distance required from arrival aircraft is a means of improving departure separation. Reduced lateral separation can allow for an uninterrupted climb for all departures due to the fact that lateral separation can be maintained from arrival aircraft at all times. Curved flight paths also hold the potential of early departure flight path crossing with arrival aircraft and thus allow for an early departure climb. Implementing required navigation performance (RNP) standard instrument RNP 1 departure procedures for standard instrument departures has the potential to reduce arrival and departure aircraft interaction and thus improve both capacity and safety.

4. CONCLUSION

4.1 4D trajectories are envisioned as a means to improve sequencing, equalize terminal arrival traffic flows, and enable CDO in congested airspace by specifying aircraft arrival times over waypoints. 4D alone will not be successful due to the potential of rapid overtakes and loss of separation that speed variations will allow. 4D plus an assigned velocity (4D+V) specified at a waypoint are required in order to provide for stable, uniform separation of traffic.

4.2 RNP 1 standard instrument departures (SIDs) may improve the chances of CCO issuance to higher initial altitudes. RNP 1 provides for stable flight trajectories, reduces required separation, and makes possible early flight departure/arrival trajectory crossing.

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