Attachment A

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Automatic Dependent Surveillance – Contract (ADS-C) Climb and Descend Procedure (CDP)

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Future developments

Comments from States on this circular, particularly with respect to its application and usefulness, would be appreciated. These comments will be taken into account in the preparation of subsequent material and should be addressed to:

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Abbreviations/Acronyms

ADS-B ITP	Automatic dependent surveillance – broadcast in-trail procedure
ADS-C	Automatic dependent surveillance – contract
ANSP	Air navigation service provider
ATC	Air traffic control
ATM	Air traffic management
ATS	Air traffic service
CDP	Climb and descend procedure
CNS	Communications, navigation and surveillance
CPDLC	Controller-pilot data link communication
DCPC	Direct controller pilot communication
DME	Distance measuring equipment
FAA	United States Federal Aviation Administration
FANS 1/A	Future Air Navigation System (1 Boeing, A Airbus)
FDPS	Flight data processing system
FIR	Flight information region
GNSS	Global navigation satellite system
GOLD	Global Operational Data Link Document
KM	Kilometre
KT	Knot
LDE	Lateral Deviation Event
M	Meter
NAVAID	Navigational aid
NM	Nautical mile(s)
NOPAC	North Pacific

PANS-ATM	Procedures for Air Navigation Services – Air Traffic Management (Doc 4444)
PBN	Performance-based navigation
RAIM	Receiver autonomous integrity monitoring
RNP	Required navigation performance
SARPs	Standards and Recommended Practices
SASP	Separation and Airspace Safety Panel
SLOP	Strategic lateral offset procedure
TLS	Target level of safety
WP	Working paper

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GLOSSARY

Explanation of Terms

*Note – The terms contained herein are used in the context of this circular. Except where indicated, they have no official status within ICAO. Where a formally recognized ICAO definition is included herein for convenience, this is noted with an *. Where a term is used differently from a formally recognized ICAO definition, this is noted with an **.*

Aircraft Pair. The manoeuvring aircraft and the blocking aircraft.

Blocking Aircraft. The aircraft that prevents an altitude change under standard separation rules.

Maneuvering Aircraft. The aircraft that is issued the altitude change.

Unsafe Event. A condition or an object with the potential to cause injuries to personnel, damage to equipment or structures, loss of material, or reduction of ability to perform a prescribed function.

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Chapter 1

INTRODUCTION

Purpose

1.1. This Circular provides guidelines and supporting material for the implementation of the Automatic Dependent Surveillance – Contract (ADS-C) Climb and Descend Procedure (CDP) intended for use with aircraft equipped with ADS-C, Direct Controller Pilot Communication (DCPC) using either voice or Controller Pilot Data Link Communication (CPDLC); and an Air Traffic Service (ATS) provider equiped with a ground based automation system capable of calculating the distance between aircraft by using their nearly simultaneous ADS-C position reports.

1.2. The continuing growth of aviation increases demands on airspace capacity therefore emphasizing the need for optimal utilization of available airspace. Improved operational and economic efficiencies are derived from the application of procedures that leverage the use of equipment already on board aircraft.

1.3. The ADS-C CDP utilizes existing ADS-C aircraft equipage and air traffic control (ATC) capabilities to allow more flights to achieve their preferred vertical profiles, and thereby increases both capacity and efficiency. Integral to ADS-C CDP is the use of advanced communication, navigation, and surveillance (CNS) capabilities; i.e., ADS-C and CPDLC.

1.4. The ADS-C CDP is modelled after existing in-trail distance measuring equipment (DME) rules set forth in ICAO Doc 4444, paragraph 5.4.2.3.4. Aircraft pair distance verification is performed by the ground automation system, using simultaneous ADS-C demand contract reports.

1.5. The ADS-C CDP was designed to improve service to appropriately equipped aircraft by providing an air traffic controller with another option for initiating an altitude change when standard separation minima, such as the ADS-C distance-based 30 nautical mile (NM) longitudinal separation minimum, do not allow an aircraft to climb or descend through the altitude of a blocking aircraft.

1.6. The ICAO Separation and Airspace Safety Panel (SASP) developed the procedure detailed in this document in response to the demand by airlines to facilitate the assignment of optimal altitudes.

Scope

1.7. The material in this circular is limited to the application of the ADS-C CDP between aircraft operating on the same track in a procedural control environment.

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Chapter 2

ADS-C CDP

2.1. In situations where standard separation minima would preclude an altitude change, the ADS-C CDP enables a controller to issue an altitude change clearance that allows an aircraft to pass through the altitude of another aircraft. The ADS-C CDP criteria were designed so that two aircraft would not be closer than 19 km (10 NM) horizontally while vertical separation is not applied.

2.2. This Circular addresses the implementation of the ADS-C CDP published in the *Procedures for Air Navigation Services – Air Traffic Management* (PANS-ATM), paragraph 5.4.2.8.

> 5.4.2.8 LONGITUDINAL SEPARATION MINIMA BASED ON DISTANCE USING ADS-C CLIMB/DESCEND PROCEDURE (CDP)
>
> 5.4.2.8.1 Aircraft on the same track may be cleared to climb or descend through the level of another aircraft provided:
>
> a) the longitudinal distance between the aircraft is determined by the ground automation system from simultaneous ADS-C demand reports which contain position accuracy of 0.25 NM or better (Figure of Merit 6 or higher);
>
> *Note: refer to 5.4.2.6.4.1 for distance calculations*
>
> b) the longitudinal distance between the aircraft, as determined in a) above, is not less than:
>
> 1) 27.8 km (15 NM) when the preceding aircraft is at the same speed or faster than the following aircraft; or
>
> 2) 46.3 km (25 NM) when the following aircraft is not more than 18.5 km/h (10 kt) or Mach 0.02 faster than the preceding aircraft;
>
> c) the altitude difference between aircraft is not greater than 600 m (2000 ft);
>
> d) the clearance is issued with a restriction that ensures vertical separation is re-established within 15 minutes from the first demand report request; and
>
> e) direct controller-pilot communications (either voice or controller pilot data link communications) is maintained.
>
> 5.4.2.8.2 Application of the ADS-C CDP requires *ongoing monitoring as described in the Monitoring the Application of Performance-Based Horizontal Separation Minima Manual and the ADS-C CDP Circular XXX.*

2.3. The proposed implementation of the ADS-C CDP is primarily intended to facilitate access to optimum flight levels for aircraft operating in airspace where no ATS surveillance service is available. The ADS-C CDP is similar to the automatic dependent surveillance – broadcast (ADS-B) in-trail procedure (ITP) (see ICAO Circular 325) in that it is a climb or descend through procedure. Unlike the ITP, the pilots involved in an ADS-C CDP may not be aware of which separation minima a controller is utilizing.

2.4. A pair of aircraft may qualify for a CDP if its members satisfy criteria involving:

a) the intended tracks of the aircraft;

b) the position Accuracy of the aircraft navigation systems;

c) the longitudinal distance between the aircraft;

d) the speed difference between the aircraft;

e) the altitude difference between the aircraft;

f) the duration of the procedure; and

g) the available communication services.

The criteria are stated in greater detail in paragraph 2.6 (below).

2.5. The ANSP ground automation system must be programed to calculate the longitudinal distance between the aircraft. (See paragraph 2.6, Step 3) In addition, it is highly recommended that as many as possible of the criteria checks specified in paragraph 2.6 be automated.

2.6. A detailed description of the application of the ADS-C CDP follows:

Step 1: Determine whether a pair of aircraft is a possible candidate for an ADS-C CDP.

a. The aircraft are on the same track per PANS-ATM, para 5.4.2.1.5.a

> 5.4.2.1.5 For the purpose of application of longitudinal separation, the terms *same track*, *reciprocal tracks* and *crossing tracks* shall have the following meanings:
>
> a) Same track (see Figure 5-6):
>
> Same direction tracks and intersecting tracks or portions thereof, the angular difference of which is less than 45 degrees or more than 315 degrees, and whose protected airspaces overlap.

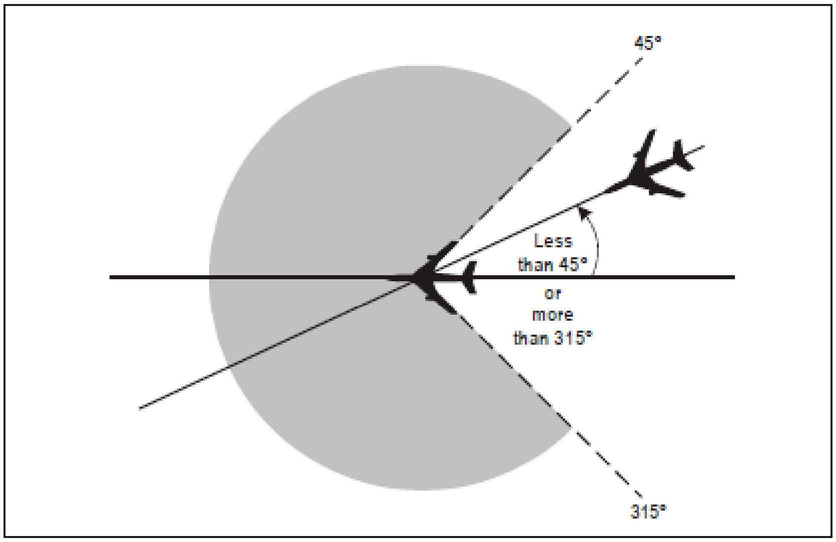

Figure 5-6. Aircraft on same track (see 5.4.2.1.5 a))

b. Check the cleared track. Only same track scenarios qualify for the procedure.

  1) An automated check for turns in the route would mitigate the possibility of the controller's failure to notice a turn.

  2) This procedure is a same track procedure and cannot be conducted with tracks whose difference is different by 45 degrees or greater. Not only does there need to be a check for same track compliance prior to commencing the procedure, but there also needs to be a check for a turn in the route during the procedure to ensure the turn does not exceed the parameters of same track. These checks can be automated.

  3) Additional situations to be aware of are aircraft routing and ATC routing that do not match, aircraft deviating for weather or contingency procedures without notifying ATC, and aircraft equipment failure. Most of those eventualities can be detected by establishing an ADS-C lateral deviation contract with the aircraft concerned.

  4) Do not issue turns during the procedure that would create tracks with an angular difference of 45 degrees or greater (crossing tracks)

c. Confirm that both aircraft have an active ADS-C connection.

d. Confirm that both aircraft are actively communicating by DCPC. DCPC (voice or CPDLC) is required to facilitate the timeliness of the procedure.

Note: Step 1 could be automated.

Step 2: Check the altitude difference between the aircraft.

Ensure that the altitude difference between the blocking aircraft and the maneuvering aircraft is not greater than 2000 feet at the start of the procedure to minimize the effects of wind gradients. Limiting the altitude difference also facilitates meeting the time requirement.

Note: Step 2 could be automated.

Step 3: Check distance, speed, and position accuracy

a. Request ADS-C demand reports from both aircraft, as near to simultaneously as possible. Simultaneous reports are likely to give the best information for the automation system's distance calculations. The farther apart the reports, the more the system is required to extrapolate, and the less accurate its distance calculations are likely to be.

b. New ADS-C demand reports are required to ensure the most accurate position information. Previous reports could cause the procedure to be started with less than the required distance minimum (15 NM or 25 NM).

c. The procedure is time-limited and commences with the first demand request.

d. From the demand report:

1. Check Distance

The ground automation system must be programed to calculate the longitudinal separation as per PANS ATM para 5.4.2.6.4.1 between the manoeuvring aircraft and the blocking aircraft.

5.4.2.6.4.1 Separation based on the use of ADS-C shall be applied so that the distance between the calculated positions of the aircraft is never less than the prescribed minimum. This distance shall be obtained by one of the following methods:

a) when the aircraft are on the same identical track, the distance may be measured between the calculated positions of the aircraft or may be calculated by measuring the distances to a common point on the track (see Figures 5-28);

Note. — Same identical tracks are a special case of same track defined in 5.4.2.1.5 a) where the angular difference is zero degrees or reciprocal tracks defined in 5.4.2.1.5 b) where the angular difference is 180 degrees.

b) when the aircraft are on same or reciprocal non-parallel tracks other than in a) above, the distance shall be calculated by measuring the distances to the common point of intersection of the tracks or projected track (see Figures 5-30 to 5-32); and

c) when the aircraft are on parallel tracks whose protection areas overlap, the distance shall be measured along the track of one of the aircraft as in a) above using its calculated position and the point abeam the calculated position of the other aircraft (see Figure 5-33).

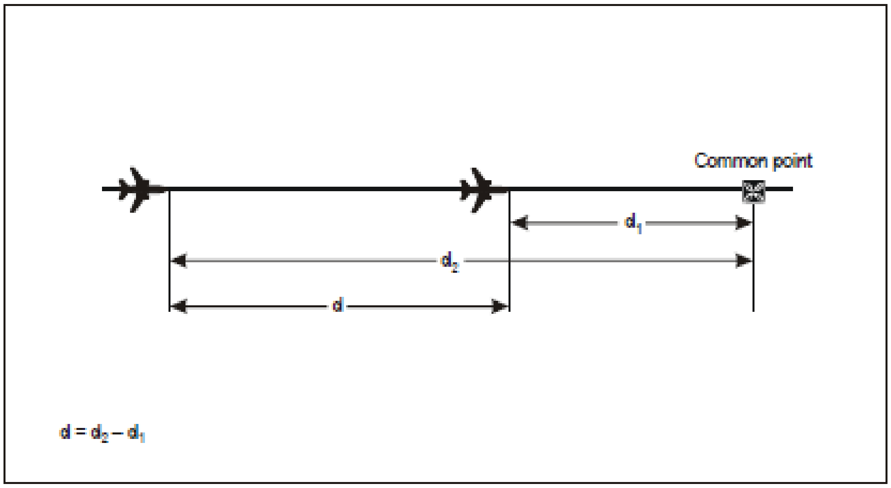

Figure 5-28. Calculation of longitudinal distance between aircraft — identical track, same direction (see 5.4.2.6.4.1 a))

Note. — In all cases presented in Figures 5-28 and 5-30 to 5-32, "d" is calculated by subtracting the distance of the closer aircraft from the common point from the distance of the more distant aircraft from the common point, except in Figure 5-32 where the two distances are added and the order of the aircraft is not important in the calculation.

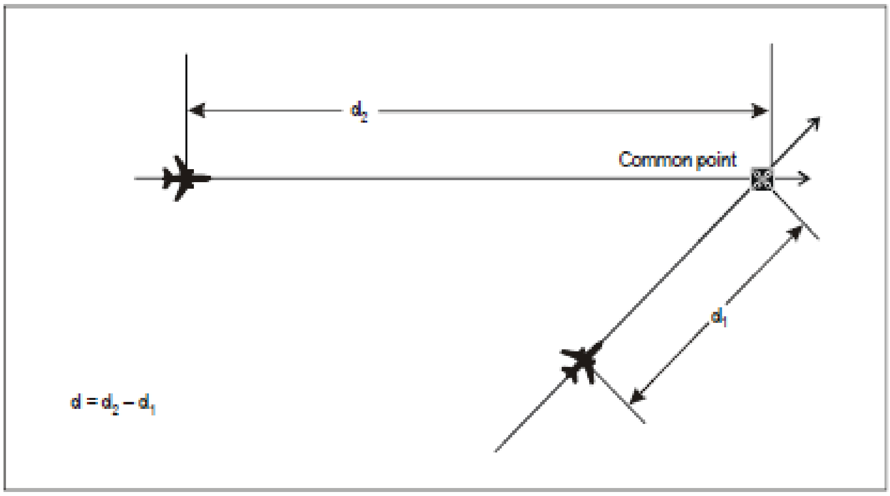

Figure 5-30. Calculation of longitudinal distance between aircraft — same track, but not identical (see 5.4.2.6.4.1 b))

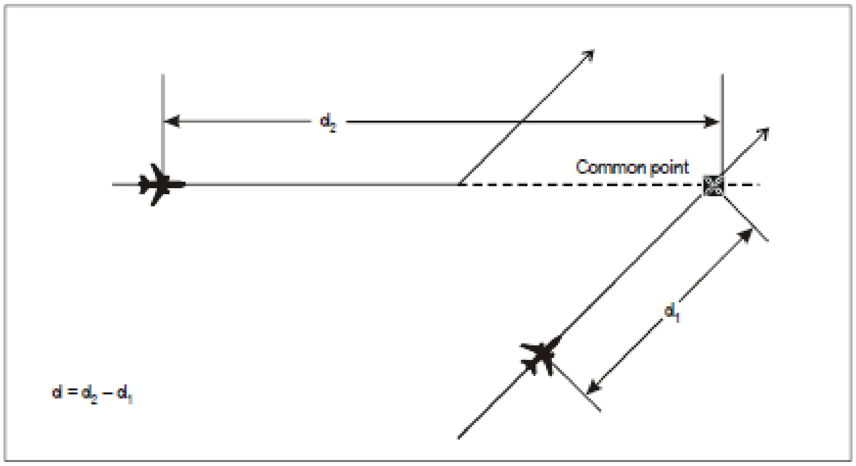

Figure 5-31. Calculation of longitudinal distance between aircraft — same track projected, but not identical (see 5.4.2.6.4.1 b))

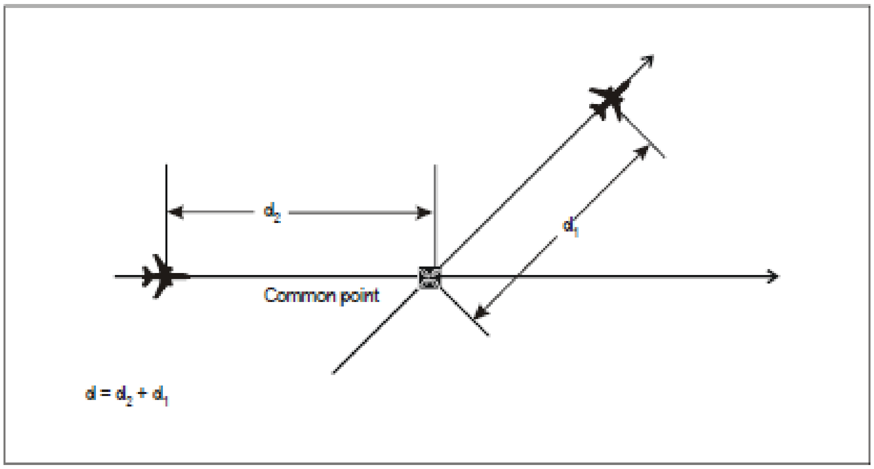

Figure 5-32. Calculation of longitudinal distance between aircraft — opposite sides of the common point (see 5.4.2.6.4.1 b))

2. Check Speed

   a) The ADS-C demand report will contain speed information when requested. If the aircraft have not been assigned a fixed Mach speed, the ADS-C reported speed should be used instead of the speed filed in the FPL.

   b) This procedure considers the two speed scenarios that impact the separation using different distances. Scenario 1 has aircraft of the same speed, or has the faster aircraft in front, with an initial distance between aircraft of not less than 15 NM. Scenario 2 has the faster aircraft behind, and not faster by more than 10 knots or 0.02 Mach, with an initial distance between aircraft of not less than 25 NM. Errors are likely to occur if these scenarios are misapplied.

c) Assess speeds to determine if 15 NM or 25 NM is required. The distance at the start of the procedure is critical and takes into account distance reduction due to speed differences.

d) Automation systems can and should be programed to perform speed checks.

e) This procedure does not require speeds to be assigned due to the short duration of the procedure. This does not preclude a controller or an ATS provider from assigning speeds or requiring that speeds be assigned in accordance with the PANS-ATM, paragraph 5.4.2.6.4.2. When aircraft are at, or are expected to reduce to, the minimum separation applicable, speed control techniques, including assigning Mach number, shall be applied to ensure that the minimum distance exists throughout the period of application of the minimum.

3. Check Position Accuracy

   a) The position accuracy is required to be 0.25 NM or better (Figure of Merit 6 or higher for each aircraft of the pair);

   b) Loss of navigation performance could produce inaccurate positions which could cause the procedure to be conducted with less than the required distance minimum (15 NM or 25 NM).

   c) The position accuracy check can be automated.

Step 4: Construct the clearance

a. The clearance must contain a restriction to re-establish vertical separation before the 15 minute time limit, to minimize the effects of compression between the aircraft in the pair. (The timer begins when the first demand report is requested, and not when the clearance is issued). An example of such a clearance using FANS 1/A CPDLC is:

UM26: CLIMB TO REACH F340 BY 1237

UM28: DESCEND TO REACH F300 BY 0214

b. The CPDLC clearance elements can be automatically populated with the altitude (derived from the request) and the time (derived 15 minutes after the first demand report request).

2.7. Once the procedure is commenced, it is not recommended to try to stop the altitude change unless the destination altitude is determined to be unsafe. This is a complex procedure that requires ground automation to determine the distance between the aircraft. As much of the procedure as possible should be automated, as suggested above, to avoid human error.

2.8. To ensure safe application of the ADS-C CDP, continuous monitoring of the application is required in accordance with the following criteria:

1. the minimal longitudinal separation distances (D) between aircraft when at the same flight level;
2. the number of events where longitudinal distance falls below 10 NM during the ADS-C CDP.
3. the probability of P(D<10NM) < 3.0·10−5 must be demonstrated (number of events with less than 10 NM/total number of times the procedure has been applied)
4. If the probability is exceeded, safety mitigations must be established to reduce likelihood of reoccurrence.

2.9. The application of the SASP process demonstrated that the procedure developed and detailed in this document has been determined as being safe provided that it can be demonstrated that the required criteria listed in 2.8 is satisfied. SASP also identified a number of hazards together with appropriate mitigations and controls listed in Appendix A.

2.10. Notwithstanding the above, there is a requirement for a Region or State to undertake an implementation safety assessment. In principle, this comprises two parts, namely a safety assessment for navigation performance and a hazard assessment. In practice, only a hazard assessment needs to be performed for any local implementation since the safety assessment for the navigation performance under the various navigation specifications is valid for any implementation. The hazard analysis is to identify hazards and related mitigation measures that are specific to the local situation.

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Chapter 3

SAFETY ASSESSMENT

3.1. Beginning in 2009, the ICAO Separation and Airspace Safety Panel (SASP) discussed several quantitative safety studies related to the ADS-C CDP. Two versions of a mathematical model of collision risk relied on major similarities between the ADS-C CDP and a similar procedure, called the “In-Trail Procedure” (also a climb and descent procedure). The papers that are a basis of the ADS-C CDP development are listed in Chapter 5.

3.2. The models described in references 10 and 11 follow the well-known Reich-model approach in which a collision between same-direction airplanes is seen as occurring in exactly one of three ways: nose-to-tail, top-to-bottom, or side-to-side. Since a maneuvering airplane passes through the flight level of a non-maneuvering airplane while executing an ADS-C CDP, and the two airplanes are assumed to be assigned to the same track, their only planned separation is in the longitudinal dimension. On the other hand, even if a longitudinal overlap does occur, it does not necessarily lead to a collision, which is a simultaneous overlap in all three dimensions. The mathematical models used a parameter value for the maneuvering airplane’s rate of climb or descent – a value that could be changed as needed or desired – and assumed reasonable distributions for two significant random variables: (1) U, the signed longitudinal separation between the airplanes when the maneuvering airplane begins its climb or descent, and (2) V, the signed speed difference between the airplanes during the climb or descent. These random variables were assumed to be independent. A later amendment to the procedure makes the speed difference dependent on the initial longitudinal separation, for any pair of airplanes that has been correctly approved for an ADS-C CDP; but the amended procedure is more conservative than the original one, and the modeling was seen by the SASP as demonstrating that the original procedure would be safe if the rate of blunder errors were kept reasonably small. A blunder, in this sense, was taken to be an ADS-C CDP execution in which $|U|$, the longitudinal separation when the climb or descent begins, is grossly inadequate.

3.3. During the SASP’s discussions of reference 10, some participants expressed the view that the probability density function used to describe the random variable U, was overly conservative. Reference 11 used a less conservative probability density function; and the change in density functions caused several changes in the details of the formulas derived to estimate the probability of a collision during the execution of an ADS-C CDP. However, the overall modeling approach was the same in both working papers, and the principal result – a formula estimating the probability of a collision during a typical execution of an ADS-C CDP – differed in only one respect. The formula derived in the first paper includes a factor representing the minimum permitted longitudinal separation. In the formula derived in the second paper, that factor is replaced by a factor representing the minimum non-blunder longitudinal separation.

3.4. In any particular execution of the ADS-C CDP, the values assumed by the random variables U and V, together with the assumed rate of climb or descent, determine whether a simultaneous longitudinal and vertical overlap occurs. Such an overlap occurs if and only if the interval of longitudinal overlap – if there is one – and the interval of vertical overlap, have a non-empty intersection (i.e., if there is a period of time common to both). The work showed that there are 12 distinct ways in which this can occur, and derived formulas for their probabilities. Adding the probabilities of four of these 12 events gives the probability of an entry into longitudinal overlap during a period in which the airplanes are already in vertical overlap. Adding the probabilities of the other eight events gives the probability of an entry into vertical overlap during a period in which the airplanes are already in longitudinal overlap.

3.5. If the airplanes enter into longitudinal overlap during a period in which they are already in vertical and lateral overlap, they collide nose-to-tail. If they enter into vertical overlap during a period in which they are already in longitudinal and lateral overlap, they collide top-to-bottom. If they enter into lateral overlap during a period in which they are already in longitudinal and vertical overlap, they collide side-to-side. The models assumed that airplanes assigned to the same track have a constant probability of lateral overlap – which can be derived from an empirically estimated distribution of a typical aircraft's lateral deviations from its route's center line. Multiplying the lateral overlap probability by the probability of entry into longitudinal overlap during a period of vertical overlap, gives the probability of a nose-to-tail collision. Likewise, multiplying the lateral overlap probability by the probability of entry into vertical overlap during a period of longitudinal overlap, gives the probability of a top-to-bottom collision.

3.6. From the lateral overlap probability and an empirical estimate of the lateral passing speed of airplanes assigned to the same track, the papers derived the airplanes' frequency of entry into lateral overlap. The average duration of a simultaneous longitudinal and vertical overlap was conservatively estimated (i.e., over-estimated) by the duration of vertical overlap (for the assumed speed of climb or descent). Multiplying together the probability of occurrence of a simultaneous longitudinal and vertical overlap, the average duration of such an overlap, and the rate of entry into lateral overlap, yields an estimate of the probability of a side-to-side collision.

3.7. The probability that a collision occurs during the execution of an ADS-C CDP was taken to be the sum of the probabilities of a nose-to-tail collision, a top-to-bottom collision, and a side-to-side collision.

3.8. Having found an estimate for P(C), the probability of a collision during a typical execution of an ADS-C CDP, the papers showed how to convert this probability to an accident rate. The number of ADS-C CDP executions in a given airspace, during a (long) period of H hours, was called n; and thus n/H was the airspace's average hourly rate of ADS-C CDPs. The airspace's average number of flights (its average instantaneous airborne count) was called f; and it was shown that the airspace's rate of fatal accidents due to ADS-C CDPs would be $2 \cdot (n/H) \cdot [P(C)/f\,]$.

3.9. This rate of accidents could then be used by an air navigation service provider (ANSP) to determine whether it could safely implement ADS-C CDPs in its airspace. Since the only prescribed separation during an ADS-C CDP is in the longitudinal dimension, the ANSP would first need to estimate its prevailing level of longitudinal risk – i.e., its rate of accidents due to the loss of planned longitudinal separation, prior to the implementation of ADS-C CDPs – and subtract that rate of accidents from the ICAO-endorsed target level of safety (TLS) of $5 \cdot 10^{-9}$ fatal accidents per flight-hour. The difference would be the maximum tolerable rate of accidents due to the use of ADS-C CDPs. If the maximum tolerable rate exceeded $2 \cdot (n/H) \cdot [P(C)/f\,]$ (which is the estimated rate of accidents due to ADS-C CDPs) the ANSP could reasonably expect that even after implementing ADS-C CDPs, it would be able to keep its total longitudinal risk less than the TLS.

3.10. Reference 12, presented to the SASP in the fall of 2010, used the basic approach summarized in the last paragraph in order to develop guidance for an operational trial of the ADS-C CDP. The operational trial, which was being planned by the United States Federal Aviation Administration (FAA), was to take place in the Oakland flight information region (FIR).

Using the result of a risk estimate developed in 2005, according to which the prevailing longitudinal risk in the Oakland FIR was approximately $2.7 \cdot 10^{-9}$ accidents per flight-hour, reference 12 assigned the remaining “budget” of $2.3 \cdot 10^{-9}$ accidents per flight-hour to the ADS-C CDP. This upper bound on the rate of collisions due to ADS-C CDPs allowed the maximum tolerable value of P(C) to be expressed as a function of n/(Hf), the flight-hourly rate of ADS-C CDPs. The average instantaneous airborne count, f, and the hourly rate of execution of ADS-C CDPs, n/H, were both unknown; but reference 12 assumed a value for n/(Hf),), so that it could illustrate the use of a statistical test for determining whether the ADS-C CDP actually does meet the TLS. The value assumed for n/(Hf) was 0.01, and the corresponding maximum tolerable value of P(C) was $1.15 \cdot 10^{-7}$.

3.11. One of the approximations derived in reference 11 shows P(C) as a function of several basic parameters of the ADS-C CDP. One of those parameters, called b, is the probability that the climb or descent begins with grossly inadequate longitudinal separation between the airplanes. It is easy to invert the formula showing P(C) as a function of b; and thus it is also easy to find the maximum tolerable value of b as a function of the maximum tolerable value of P(C). The maximum tolerable value of b was called b_M. Using the illustrative value of P(C) (= $1.15 \cdot 10^{-7}$), along with reasonable values for the other basic parameters, a corresponding value of b_M was computed to be equal to $3.625 \cdot 10^{-5}$. This was equivalent to one gross error per $1/(3.625 \cdot 10^{-5})$ executions of the procedure, i.e., one gross error per 27,586 executions. A grossly inadequate separation at the beginning of the climb or descent was understood to be any distance less than a parameter whose value (for the illustrative example) was taken to be 12 NM.

3.12. Reference 12 then summarized the theory behind sequential probability ratio tests, and showed how a sequential sampling test could be applied to the operational trial that was then being planned by the FAA. The purpose of the test was to determine whether the actual rate of executions with grossly inadequate longitudinal separation, was less than or greater than the maximum tolerable rate, b_M. If the actual rate turned out to be less than b_M, the procedure could be considered safe. If it turned out to be greater than b_M, the procedure would be seen to have exceeded its maximum tolerable collision probability.

3.13. For each execution of the ADS-C CDP, the Oakland Oceanic Control Center would estimate the longitudinal separation between the airplanes at the time the climb or descent began. If the estimated separation happened to be greater than the required minimum (or even slightly less than the minimum), the Center would simply add one to a count of ADS-C CDP executions. If the estimated separation happened to be grossly inadequate, the Center would add one to its count of ADS-C CDP executions, and also add one to a count of ADS-C CDPs executed with grossly inadequate separation.

3.14. Reference 12 showed two linear relationships that determine whether the ADS-C CDP meets the TLS or fails to meet the TLS. The relationships are illustrated by two parallel lines drawn on a graph, one called the “pass” line, the other called the “fail” line. The lines slope from the lower left corner of the graph toward the upper right corner, and the “fail” line lies above the “pass” line. Each time a gross error is detected (i.e., each time an ADS-C CDP is found to have been executed with grossly inadequate separation), a point is plotted on the graph. Its abscissa (“x-coordinate”) is the current count of ADS-C CDP executions; its ordinate (“y-coordinate”) is the number of ADS-C CDP executions with grossly inadequate separation. If the point falls above the “fail” line, the procedure is judged to have failed the test, in that it has exhibited an error rate that is too large for it to meet the TLS. If, on the other hand, the point falls below the “pass” line, the ADS-C CDP is judged to have passed the test, in that the exhibited error rate is small enough for the procedure to meet the TLS. If the point falls between the two lines, the test has not reached a conclusion, and should be continued. If the operational trial continues for a sufficiently large number of ADS-C CDP executions without the occurrence of any gross errors, then a point plotted on the graph, with abscissa equal to the number of executions, and ordinate equal to 0, will fall below the "pass" line. That is, such a point will fall on the horizontal axis, to the right of the point at which the "pass" line crosses that axis.

3.15. Reference 12 suggested ways in which the sequential sampling test could be made relatively conservative or relatively liberal. In a "neutral" test, 27,725 CDP executions without any gross errors would suffice to show the procedure to be safe. However, as is the case for any statistical test, there is a non-zero probability that the test yields the wrong answer. Indeed, that probability is used in designing the test. The probability of a correct result – i.e., the level of confidence that could be placed in the outcome of the test suggested by reference 12 – was taken to be 80%.

3.16. As was noted above, the numbers used to develop the statistical tests were simply illustrative values, as n/(Hf), the flight-hourly rate of ADS-C CDPs in the operational trial, was not known.

3.17. The ADS-C CDP tested in the operational trial was a procedure in which air traffic controllers were required to manually determine the eligibility of pairs of aircraft. The detailed procedure that controllers were obliged to follow turned out to be relatively cumbersome; and so the ADS-C CDP was rarely used. Only a handful of executions were recorded, not even remotely approaching the number that would have been needed for the test to reach a conclusion, even if no gross errors had been observed. The FAA eventually made plans to automate much of the procedure, hoping thereby to encourage its use.

3.18. While planning an automated procedure, the FAA undertook a fast-time simulation of the ADS-C CDP. The simulation was described in Reference 13, presented to the SASP in May 2014.

3.19. Reference 13 explained that the simulation used traffic data from two days of operations in the North Pacific (NOPAC) route system, one from the summer of 2012, the other from the winter of 2013. The traffic data showed aircraft origins and destinations, as well as position reports. Weather data from the same two days were applied to the flights, and data on communication delays were also incorporated into the simulated behavior of the fleet and the air traffic control system. Aircraft performance characteristics were drawn from the Base of Aircraft Data (BADA) data base maintained by Eurocontrol. Roughly 90% of the NOPAC flights were equipped for the ADS-C CDP in the simulation.

3.20. The simulation program used estimates of fuel burn to decide when airplanes would be candidates for a change in altitude. It also used position data to determine which climbs could only be accomplished through the use of an ADS-C CDP.

3.21. The simulation model includes a manoeuver start time (MST) interval. The MST interval begins with the ADS-C demand request for position reports and ends when the pilot begins to climb/descend the aircraft

3.22. Fifteen scenarios were examined by the simulation. Eight of them used data from the summer traffic sample, seven used data from the winter sample. A variety of conditions were considered in the scenarios, including the use of wind data, aircraft speed variation data, and various levels of increased traffic volume. As expected, the scenarios with increased traffic volume yielded larger numbers of ADS-C CDP applications. The scenarios reported in reference 13 allowed for altitude changes of either 2000 ft or 3000 ft, and gave rise to 159 applications of the ADS-C CDP. The largest observed decrease in the longitudinal spacing was 4.84 NM. This particular decrease occurred with a 3000 ft climb. There were 29 ADS-C CDP applications observed with a slower aircraft operating in front of a faster aircraft. Of these 29 applications, the largest speed differences in magnitude were observed to be 8.8 and 8.6 knots, resulting in longitudinal spacing changes of 2.09 NM and -1.6 NM respectively.

3.23. The maximum time needed to complete a simulated CDP was 15.84 minutes. This time included the MST interval, which begins with the controller initiating an ADS-C demand uplink message to obtain aircraft positions. The MST interval was derived from both empirical data distributions (to account for components for which data were available) and time allotments (to account for components for which data were not available).). The simulated time for the MST is independent of the number of flight levels through which the maneuvering aircraft travels.

3.24. There were five ADS-C CDP aircraft pairs whose CDP execution time (including MST interval) was greater than or equal to 15 minutes. In all of these cases, the maneuvering aircraft climbed 3000 ft during the procedure. It should be noted that the simulation did not apply the required time restriction to reestablish vertical separation within 15 minutes, nor did it account for the ability of the pilot to reject the clearance for lack of sufficient time to complete the procedure.

3.25. To assist regions and States with their implementation safety assessment, a State Implementation plan is provided in the next chapter. This plan will be seen to rely upon the various outputs from the application of the SASP safety assessment.

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Chapter 4

IMPLEMENTATION CONSIDERATIONS

Introduction

4.1. The successful implementation of the proposed procedure is not possible at the regional, State or local level without undertaking a safety assessment prior to implementation (See Chapter 3). When undertaking this activity, reference should be made to the requirements detailed in Annex 11 — Air Traffic Services (Chapter 2, Section 2.27), PANS-ATM (Chapter 2, Section 2.6), and the guidance material contained in the Safety Management Manual (ICAO Doc 9859) including the development of hazard identification, risk management and mitigation procedures tables.

4.2. This chapter provides an overview of the minimum steps that are considered necessary for a region, State or local ANSP to undertake a safety assessment.

Safety Assessment Process

4.3. When undertaking a regional, State or local safety assessment, the following process is provided as guidance:

Step 1 Undertake widespread regional consultation with all possible stakeholders and other interested parties.

Step 2 Develop an airspace design concept or ensure that the proposed separation minima being implemented will fit the current airspace system and regional or state airspace planning strategy.

Step 3 Review this circular noting specific assumptions, constraints, enablers and system performance requirements (see paragraphs 2.3 through 2.9)

Step 4 Compare assumptions, enablers, and system performance requirements in this circular with the regional or State's operational environment, infrastructure and capability.

Step 5 If a region or State or ANSP has determined that the change proposal for that region or State is equal to or better than the reference requirements and system performance in this circular, then the region or State must undertake safety management activities including:

a) formal hazard and consequence(s) identification, and safety risk analysis activities including identification of controls and mitigators;

b) implementation plan;

c) techniques for hazard identification/safety risk assessment which may include:

    1) the use of data or experience with similar services/ changes;
    2) quantitative modeling based on sufficient data, a validated model of the change, and analyzed assumptions;
    3) the application and documentation of expert knowledge, experience and objective judgment by specialist staff; and
    4) a formal analysis in accordance with appropriate safety risk management techniques as set out in the Doc 9859;

d) identification and analysis of human factors issues identified with the implementation including those associated with Human Machine Interface matters;

e) simulation where appropriate;

f) operational training; and

g) regulatory approvals

Step 6 Develop suitable safety assessment documentation including a safety plan and associated safety cases.

Step 7 Implementation activities should include:

a) trial under appropriate conditions;

b) expert panel to undertake scrutiny of proposals and development of identified improvements to the implementation plan;

c) develop an appropriate backup plan to enable reversion if necessary; and

d) continuous reporting and monitoring results of incidents, events, observations.

Step 8 Develop a suitable post-implementation monitoring and review processes.

Chapter 5

REFERENCES

ICAO DOCUMENTS

1. Annex 11 *Air Traffic Services*
2. Circular 325 *In-Trail Procedure (ITP) Using Automatic Dependent Surveillance – Broadcast (ADS-B)*
3. Doc 4444 *Procedures for Air Navigation Services — Air Traffic Management* (PANS-ATM)
4. Doc 9613 *Performance-based Navigation (PBN) Manual*
5. Doc 9734 *Safety Oversight Manual*
6. Doc [GOLD] Global Operational Data Link Document
7. Doc 9869 *Performance-Based Communication and Surveillance (PBCS) Manual*
8. Doc 9859 *Safety Management Manua*l

OTHER DOCUMENTS

9. EUROCAE ED-100A/RTCA DO258A Interoperability Requirements for ATS Applications Using ARINC 622 Data Communications (FANS 1/A Interop Standard)
10. B. Flax, SASP Working Group of the Whole (WG/WHL)/16-Working Paper (WP)/2: *A Model for Estimating the Probability of Collision During the Execution of an In-Trail Procedure*, 22 January, 2009
11. B. Flax, SASP-WG/WHL/17-WP/6: *A Revised Model for Estimating the Probability of Collision During the Execution of an In-Trail Procedure*, 19 April 2010
12. B. Flax, SASP-WG/WHL/18-WP/17: *Use of a Sequential Sampling Test for Determining Whether the Climb and Descent Procedure (CDP) Satisfies its Target Level of Safety*, 29 October, 2010
13. C.Falk and D. Baart, SASP-WG/WHL/24-WP24: Fast-Time Simulation of the Automatic Dependent Surveillance-Contract (ADS-C) Climb/Descend Procedure (CDP), 5 May, 2014

APPENDIX A

IMPLEMENTATION HAZARD LOG

This section lists some hazards that were considered by the SASP when developing the ADS-C CDP. The pertinent ATS authority must, in its implementation safety assessment, review these hazards and reflect how they may affect its local implementation and additionally identify if there are other regional, state or local hazards that need to be considered.

Definitions:

Hazard: An unsafe event defined as a condition or an object with the potential to cause injuries to personnel, damage to equipment or structures, loss of material, or reduction of ability to perform a prescribed function.

Subject 1 – Application of Separation

Hazard

Loss of separation

Unsafe Event (cause)

A failure of the ground based automation system to correctly calculate the longitudinal distance between the aircraft.

Analysis

The distances specified in PANS-ATM paragraph 5.4.2.8.1 b) are minimum separation values. A ground automation system is required to determine the longitudinal distance between aircraft pairs derived from ADS-C position reports. Simultaneous demand reports are required to ensure the most up-to-date information is used.

It is imperative that distances are determined as depicted in Figures 5-28, and 5-30 thru 5-33 of the PANS ATM.

SASP Global controls and/or mitigators

PANS-ATM paragraph 5.4.2.6.4.1 describes the methods for determining the longitudinal distance between aircraft for the application of longitudinal distance-based separation using ADS-C.

Regional and local controls and/or mitigators required

The ground automation system must be validated to ensure correct distance calculations are carried out (per PANS-ATM 5.4.2.6.4.1, rather than by using aircraft-to-aircraft distance).

Subject 2 – Application of Separation

Hazard

Loss of separation

Unsafe Event (cause)

The controller incorrectly applies the ADS-C Climb and Descend Procedure (CDP).

Analysis

Controllers apply the seven elements of ADS-C CDP:

1. Track – aircraft pair must be same track to avoid significantly different winds
2. Position Accuracy – if reported performance is too low, position may be inaccurate.
3. Longitudinal distance between aircraft pair – if aircraft to aircraft distance is used rather than longitudinal distance, aircraft may be closer together than the procedure requires.
4. Speed difference between aircraft pair – if incorrect speeds are used, an unsafe decrease in longitudinal separation may occur.
5. Altitude difference between aircraft pair – if the aircraft are farther apart vertically than specified in the procedure, then wind differences may become significant, and the duration of the procedure may lead to an unsafe reduction in separation.
6. Procedure duration – Extending the duration of the procedure can cause an unsafe loss of

longitudinal separation to occur.

7. Communication – DCPC (voice or CPDLC) is required to facilitate timely exchange of messages to comply with the procedure duration requirement.

SASP Global controls and/or mitigators

Prior to and during the application of the ADS-C CDP, the controller must consider the adequacy of the available communications, considering the time required to receive replies from aircraft, and the overall workload/traffic volume associated with the application of the procedure (per PANS ATM 5.4.2.6.2.2.1).

ATS authority applying the ADS-C CDP must monitor performance per the requirement

Regional and local controls and/or mitigators required

1) All instances of loss of separation related to this procedure must be reported and investigated.
2) ATS authority intending to apply this procedure should automate as much of the procedure as possible. The flight data processing system (FDPS) must automatically determine distance between aircraft. In addition the automation could be programed to do the rest of the eligibility checks (i.e.: same course, accuracy and altitude difference)
3) The ATS authority intending to apply this procedure must ensure that the amount of traffic is not more than can be safely handled by this type of procedure.
4) The ATS authority intending to apply this procedure must ensure that appropriate training concerning the application of this procedure is provided to controllers.

Subject 3 – An aircraft fails to meet a restriction

Hazard

Loss of separation

Unsafe Event (cause)

A pilot does not comply with the time restriction component of the ATC clearance

Analysis

There are many possible situations which might cause the maneuver to exceed the time parameter, A few are as follows:

1) Aircraft performance
2) Turbulence
3) Emergency or contingency
4) Weather
5) ACAS resolution advisory
6) Pilot fails to initiate the procedure in a timely manner
7) Communications failure

SASP Global controls and/or mitigators

ICAO Global Operational Data Link Document (GOLD)

Regional and local controls and/or mitigators required

The appropriate ATS authority should make controllers aware of the potential mistakes made by pilots in controller training programs.

Briefings to the pilot community to advise of the new procedure with focus on an increased use of clearances with time restrictions.

Subject 4 – Unexpected speed changes

Hazard

Loss of separation

Unsafe Event (cause)

Unexpected speed change during the maneuver.

Analysis

This event pertains to speed changes outside the range of the model (see chapter 3 and reference papers) when the leading aircraft reduces its speed or the trailing aircraft increases its speed enough to cause a significant loss of separation.

There are many possible situations which might cause unexpected speed variation during the maneuver. A few are:

1) Turbulence
2) Weather
3) Aircraft performance
4) Equipment failure
5) Blocking/maneuvering aircraft pilot effects speed change without advising ATC

SASP Global controls and/or mitigators

Speed variations were accounted for in the SASP collision risk assessment

Regional and local controls and/or mitigators required

none

Subject 5 – Database integrity and incorrect waypoint entry

Hazard

Loss of separation

Unsafe Event (cause)

Loss of integrity in a database resulting in incorrect waypoint information in the aircraft and ATM system navigation database.

Analysis

This specifically refers to databases that do not have the latest update. The worst case scenario would be when the aircraft and the ANSP are using different versions of a database. A problematic situation arises when the location of a waypoint changes and the associated name does not change.

Database integrity issues are common to all aspects of area navigation and to the application of all separation minima that employ area navigation. This issue is therefore not specific to the application of the ADS-C CDP.

With the implementation of area navigation procedures, the handling of navigation data is a significant aspect of safe operations. Its importance increases as operations move away from traditional procedures and routes based on flying "to and from" ground-based navigational aids (NAVAIDs). Data base integrity relies on minimizing errors throughout the entire data chain, commencing with surveying, through procedure design, data processing and publication, data selection, coding, packing processes and up to the replacement of onboard data. The latter occurs as often as every 28 day AIRAC cycle, and in the future may become a near real-time activity.

Modern ATM systems also employ navigation databases. Data base errors may result in incorrect results from conflict probes and could therefore lead to loss of separation.

International efforts are currently in progress to ensure database integrity by the introduction of new database quality control procedures. Refer to the following documents for further information about this issue:

List of documents: Annex 15, EUROCAE ED76A/RTCA document DO-200A.

Navigation systems allow pilots to create waypoints manually in the enroute mode. This presents the possibility that pilots may enter waypoint co-ordinates incorrectly.

CPDLC enables ATC to uplink route information into the area navigation system. This presents the possibility that ATC may uplink an incorrect waypoint.

Pilots and ATC sometimes have to create ad hoc latitude/longitude waypoints in the absence of predefined waypoints or air routes. The risk of entering such waypoints incorrectly into the ATC- or navigation system increases as the number of digits defining the waypoint increases. The risk of manually entering very complex waypoints such as 6521.9N 01312.6W may be too high in the context of applying this procedure. There may be a high risk of misunderstanding when communicating such waypoints between controller and pilot.

SASP Global controls and/or mitigators

None

Regional and local controls and/or mitigators required

ATS authority must ensure that ADS-C intent data is used to check route

The appropriate ATS authority must ensure that appropriate quality control procedures are followed at all levels to ensure database integrity in aircraft and ATM systems.

Subject 6 – GNSS outage

Hazard

Loss of separation

Unsafe Event (cause)

GNSS failure affecting multiple aircraft or a failure of individual GNSS receivers.

Analysis

A Global Navigation Satellite System (GNSS) failure could affect the accuracy reported in the ADS-C message (see also subject 2b).

The effect of a failure of an individual GNSS receiver or a failure affecting multiple aircraft will have different impacts on the ATM system

GNSS outages are detected by receiver autonomous integrity monitoring (RAIM) equipment. If an individual GNSS receiver fails, the pilot shall advise ATC if the failure results in the aircraft no longer being able to navigate using the GNSS signal or no longer being able to satisfy an applicable navigation specification. Controllers will then apply other forms of separation that are not reliant on GNSS. This is no different from a traditional avionics equipment failure

Local GNSS outages are possible, for example during periods of GNSS signal interference. Pilots cannot distinguish interference from loss of GNSS integrity, so again they would simply advise ATC that they are receiving a RAIM warning, and ATC would again apply a different form of separation. Following further RAIM warning reports from other pilots in the area, controllers should suspect that interference may be occurring, and shall not use GNSS for separation.

SASP Global controls and/or mitigators

1) Navigation specifications in the Performance-based Navigation (PBN) Manual (ICAO Doc 9613) detail that the pilot shall inform ATC when the aircraft can no longer satisfy the navigation requirements applicable to the navigation specification being employed in the airspace.
2) RAIM warning
3) The following paragraph is contained in PANS-ATM:

   5.4.1.1.3 When information is received indicating navigation equipment failure or deterioration below the navigation performance requirements, ATC shall then, as required, apply alternative separation methods or minima.

Regional and local controls and/or mitigators required

The appropriate ATS authority must consider the effect of GNSS outages in their contingency plans.

The appropriate ATS authority must conduct conformance monitoring of position information (LDE and time estimates)

Issues considered and deemed to not be a hazard:

1) An assigned lateral offset is likely to improve the safety of a longitudinal procedure involving airplanes assigned to identical tracks. When aircraft are using lateral offsets, the relevant ATC system must measure longitudinal distance rather than aircraft-to-aircraft distance.

2) Turns – any turn must be small enough to maintain the same-track requirement. The use of lateral offsets by aircraft assigned to the identical track is likely to increase the safety of the procedure.

— END —