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

Approved by and published under the authority of the Secretary General

INTERNATIONAL CIVIL AVIATION ORGANIZATION

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FOREWORD

The availability of the automatic dependent surveillance — contract (ADS-C) in oceanic airspace allows the application of improved separation procedures which enables aircraft to fly closer to their optimum flight level.

The Separation and Airspace Safety Panel (SASP) developed the ADS-C climb and descend procedure (CDP) that is detailed in the PANS-ATM in response to the demand by airlines to facilitate the assignment of optimal altitudes.

This circular provides guidelines and supporting material for the implementation of the ADS-C CDP intended for use with aircraft equipped with ADS-C, direct controller-pilot communication (using either voice or controller-pilot data link communication) and an air traffic service provider equipped with a ground-based automation system capable of calculating the distance between aircraft by using their near-simultaneous ADS-C position reports.

GLOSSARY

Note.— The terms below are used in the context of this circular and have no official status within ICAO.

Aircraft pair. The manoeuvring aircraft and the blocking aircraft.

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

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.

Manoeuvring 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.

ACRONYMS

ADS-B	Automatic dependent surveillance — broadcast
ADS-C	Automatic dependent surveillance — contract
ANSP	Air navigation service provider
ATC	Air traffic control
ATM	Air traffic management
ATS	Air traffic service
BADA	Base of Aircraft Data (data base)
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
EUROCONTROL	European Organisation for the Safety of Air Navigation
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
ft	Feet
GNSS	Global navigation satellite system
GOLD	Global operational data link document
ITP	In-trail procedure
km	Kilometre
kt	Knot(s)
LDE	Lateral deviation event
m	Metre(s)
MST	Manoeuver start time
NM	Nautical mile(s)
NOPAC	North Pacific (route system)
PANS-ATM	Procedures for Air Navigation Services — Air Traffic Management (Doc 4444)
PBN	Performance-based navigation
RAIM	Receiver autonomous integrity monitoring
SARPs	Standards and Recommended Practices
SASP	Separation and Airspace Safety Panel
TLS	Target level of safety
WP	Working paper

REFERENCES

The following documents are referred to in this circular or may provide additional guidance material.

ICAO DOCUMENTS

Annex 11 — *Air Traffic Services.*

Annex 15 —*Aeronautical Information Services*

Doc 4444 — *Procedures for Air Navigation Services — Air Traffic Management* (PANS-ATM)

Doc 9613 — *Performance-based Navigation (PBN) Manual*

Doc 9734 — *Safety Oversight Manual*

Doc 9859 — *Safety Management Manual (SMM)*

Doc 9869 — *Performance-Based Communication and Surveillance (PBCS) Manual*

Doc 10037 — *Global Operational Data Link Document [GOLD]*

Circular 325 — *In-Trail Procedure (ITP) Using Automatic Dependent Surveillance — Broadcast (ADS-B)*

OTHER DOCUMENTS

EUROCAE ED-76A/RTCA DO-200A — *Standards for Processing Aeronautical Data*

EUROCAE ED-100A/RTCA DO-258A — *Interoperability Requirements for ATS Applications Using ARINC 622 Data Communications* (FANS 1/A Interop Standard)

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Chapter 1

INTRODUCTION

1.1 PURPOSE

1.1.1 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 (using either voice or controller-pilot data link communication(CPDLC)) and an air traffic service provider equipped with a ground-based automation system capable of calculating the distance between aircraft by using their near-simultaneous ADS-C position reports.

1.1.2 The continuing growth of aviation increases demands on airspace capacity 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 the aircraft.

1.1.3 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, thereby increasing both capacity and efficiency. Integral to the ADS-C CDP is the use of advanced communication, navigation, and surveillance (CNS) capabilities (i.e. ADS-C and CPDLC).

1.1.4 The ADS-C CDP is conceptually modelled after existing in-trail distance measuring equipment (DME) rules set forth in the *Procedures for Air Navigation Services — Air Traffic Management* (PANS-ATM, 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.

1.1.5 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 existing separation minima, such as the ADS-C distance-based 55.5 km (30 NM) longitudinal separation minimum, do not allow an aircraft to climb or descend through the altitude of a blocking aircraft.

1.2 SCOPE

The material in this circular is related 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.

2.2 This circular addresses the implementation of the ADS-C CDP contained in the PANS-ATM which is reproduced below, Doc 4444, paragraph 5.4.2.8 as follows:

5.4.2.8 LONGITUDINAL SEPARATION MINIMA BASED ON DISTANCE USING ADS-C CLIMB AND DESCEND PROCEDURE (CDP)

5.4.2.8.1 When an aircraft on the same track is cleared to climb or descend through the level of another aircraft, the clearance should be issued provided the following requirements are met:

a) the longitudinal distance between the aircraft is determined by the ground automation system from near-simultaneous demand ADS-C reports which contain position accuracy of 0.25 NM or better (Figure of Merit 6 or higher);

Note.— Refer to 5.4.2.9.5 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 either 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 (2 000 ft);

d) the clearance is issued with a restriction that ensures vertical separation is re-established within 15 minutes of the first demand report request; and

e) direct controller-pilot voice communications or CPDLC is maintained.

5.4.2.8.2 The application of the ADS-C climb and descend procedure (CDP) should be supported by an ongoing monitoring process.

Note.— Supporting information on ongoing monitoring is provided in Circular 342 — Automatic Dependent Surveillance — Contract (ADS-C) Climb and Descend Procedure (CDP).

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 air traffic service (ATS) surveillance service is available. It is similar to the automatic dependent surveillance — broadcast (ADS-B) in-trail procedure (ITP) in that it is a climb- or descend-through procedure (see Circular 325 — *In-Trail Procedure (ITP) Using Automatic Dependent Surveillance — Broadcast (ADS-B)*). Unlike the ITP, however, 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 an ADS-C CDP if they satisfy criteria involving the:

a) intended tracks of the aircraft;

b) position accuracy of the aircraft navigation systems;

c) longitudinal distance between the aircraft;

d) speed difference between the aircraft;

e) altitude difference between the aircraft;

f) duration of the procedure; and

g) available communication services.

These criteria are stated in greater detail in the steps outlined in Table 2-1.

Table 2-1. Application of the ADS-C CDP

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

Note.— Step 1 may be automated.

1.1 The aircraft are on the same track as indicated in the PANS-ATM, paragraph 5.4.2.1.5 as follows:

"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."

See Figure 2-1 for an illustration of aircraft on the same track (Figure 5-7 in the PANS-ATM).

1.2 Check the cleared track. Only same-track scenarios qualify for the ADS-C CDP.

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

b) The ADS-C CDP is a same-track procedure and cannot be conducted with tracks whose difference is 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.

c) 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.

d) Do not issue turns during the ADS-C CDP that would create tracks with an angular difference of 45 degrees or greater (crossing tracks).

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

1.4 Confirm that both aircraft are actively communicating by direct controller-pilot communication (DCPC). DCPC (voice or CPDLC) is required to facilitate the timeliness of the procedure.

Step 2 — Check the altitude difference between the aircraft

Note.— Step 2 may be automated.

Ensure that the altitude difference between the blocking aircraft and the manoeuvring aircraft is not greater than 600 m (2 000 ft) at the start of the ADS-C CDP to minimize the effects of wind gradients. Limiting the altitude difference also facilitates meeting the time requirement.

Step 3 — Check distance, speed and position accuracy

3.1 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.

3.2 ADS-C demand reports are required to ensure the most accurate position information. Use of previous reports could cause the ADS-C CDP to be started with less than the required minimum distance (27.8 km (15 NM) or 46.3 (25 NM)).

3.3 The ADS-C CDP is time-limited and commences with the first demand request.

3.4 From the demand report:

a) *Check distance.* The ground automation system must be programmed to calculate the longitudinal separation (PANS-ATM, paragraph 5.4.2.9.5 refers) between the manoeuvring aircraft and the blocking aircraft.

b) *Check speed.*

1) 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 filed flight plan (FPL).

2) The ADS-C CDP 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 27.8 km (15 NM). Scenario 2 has the faster aircraft behind, and not faster by more than 19 km/h (10 kt) or 0.02 Mach, with an initial distance between aircraft of not less than 46.3 km (25 NM). Errors are likely to occur if these scenarios are misapplied.

3) Assess speeds to determine if 27.8 km (15 NM) or 46.3 km (25 NM) is required. The distance at the start of the ADS-C CDP is critical and takes into account distance reduction due to speed differences.

4) Automation systems can and should be programmed to perform speed checks.

5) The ADS-C CDP does not require speeds to be assigned due to the short duration of the procedure. This does not preclude a controller from assigning speeds.

c) *Check position accuracy.*

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

2) Loss of navigation performance could produce inaccurate positions which could cause the ADS-C CDP to be conducted with less than the required minimum distance (27.8 km (15 NM) or 46.3 km (25 NM)).

3) The position accuracy check may be automated.

Step 4 — Construct the clearance

4.1 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

4.2 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).

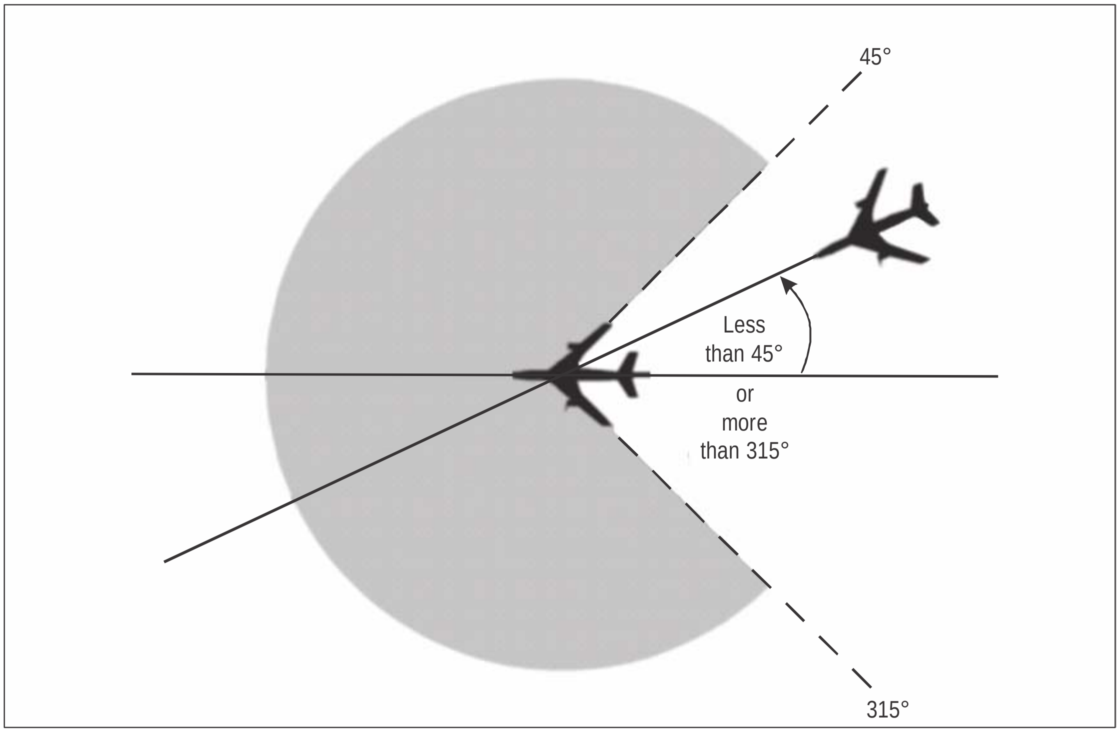

Figure 2-1. Aircraft on same track

2.5 The air navigation services provider (ANSP) ground automation system must be programmed to calculate the longitudinal distance between the aircraft (see Table 2-1, Step 3). In addition, it is highly recommended that as many as possible of the criteria checks specified in Steps 1 to 3 of Table 2-1 be automated.

2.6 Once the ADS-C CDP is commenced, it is not recommended 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. In order to avoid human error the checks associated required for the ADS-C CDP should be automated to the maximum extent possible.

2.7 The ADS-C CDP criteria were designed so that aircraft would not be closer than 22.3 km (12 NM) horizontally when vertical separation is not applied. A gross error (blunder) as applied to the ADS-C CDP is, therefore, an event where the longitudinal distance falls below 22.3 km (12 NM). The rate of gross errors must be kept sufficiently small to ensure the safety of the ADS-C CDP. Details on these calculations are contained in Chapter 3 of this circular.

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

a) the minimal longitudinal separation distances (*D*) between aircraft when at the same flight level;

b) the number of events where longitudinal distance falls below 22.3 km (12 NM) during the ADS-C CDP;

c) the probability (*P*) of $P(D<12\text{ NM}) < 3.0E^{-5}$ must be demonstrated (number of events (*E*) with less than 12 NM/total number of times the ADS-C CDP has been applied); and

d) if the probability is exceeded, safety mitigations must be established to reduce likelihood of reoccurrence.

2.9 It is supposed that any event where the longitudinal distance falls below 12 NM should be investigated and mitigated. The procedure was designed with many safeguards (starting distance, speed, position accuracy, etc.) to prevent longitudinal deterioration to the level of a gross error.

2.10 The application of the SASP safety assessment process (see Chapter 3) demonstrated that the ADS-C CDP has been determined as being safe provided that it can be confirmed that the required criteria detailed in 2.7 above have been satisfied. The SASP also identified a number of hazards together with appropriate mitigations and controls as listed in the appendix to this circular.

2.11 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, for local implementation only the hazard assessment need be performed since the safety assessment for 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.

Chapter 3

SASP SAFETY ASSESSMENT

3.1 Early in 2009, the 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 known as a "climb and descent procedure").

3.2 The models used by the SASP during working group meetings in January 2009 and April 2010 follow the well-known Reich-model approach in which a collision between same-direction aircraft is seen as occurring in one of three ways: nose to tail, top to bottom or side to side. Since a manoeuvring aircraft passes through the flight level of a non-manoeuvring aircraft while executing an ADS-C CDP, and the two aircraft 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 manoeuvring aircraft'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:

U — the assigned longitudinal separation between the aircraft when the manoeuvring aircraft begins its climb or descent; and

V — the assigned speed difference between the aircraft during the climb or descent.

These random variables were assumed to be independent.

3.3 The ADS-C CDP was later amended to make the speed difference dependent on the initial longitudinal separation for any pair of aircraft approved for the procedure; but the amended procedure was more conservative than the original one, and the modelling was seen by the SASP as demonstrating that the original procedure would be safer if the rate of blunders was kept reasonably small. A blunder, in this sense, was taken to be an ADS-C CDP execution in which the longitudinal separation when the climb or descent begins (*U*) is grossly inadequate.

3.4 The view was expressed during the SASP working group meeting in January 2009 that the probability density function used to describe the random variable *U* was overly conservative. Subsequently, the SASP working group meeting in April 2010 investigated a less conservative probability density function, and the change in density function 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 modelling approach was consistent at both meetings, 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 at the January 2009 meeting included a factor representing the minimum permitted longitudinal separation. In the formula derived at the April 2010 meeting, that factor was replaced by a factor representing the minimum non-blunder longitudinal separation.

3.5 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 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 SASP work showed that there are twelve distinct ways in which a simultaneous longitudinal and vertical overlap can occur and derived formulas for their probabilities. Adding the probabilities of four of these twelve events gives the probability of an entry into longitudinal overlap during a period in which the aircraft 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 aircraft are already in longitudinal overlap.

3.6 If the aircraft 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 aircraft 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 centre 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.

3.7 From the lateral overlap probability and an empirical estimate of the lateral passing speed of aircraft assigned to the same track, each aircraft's frequency of entry into lateral overlap was derived. The average duration of a simultaneous longitudinal and vertical overlap was conservatively estimated (i.e. overestimated) 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.

3.8 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.

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

3.10 This accident rate could then be used by an ANSP to determine whether it could safely implement the ADS-C CDP 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 the ADS-C CDP) and subtract that rate of accidents from the ICAO-endorsed target level of safety (TLS) of $5\text{x}10^{-9}$ fatal accidents per flight hour. The difference would be the maximum tolerable accident rate due to the use of the ADS-C CDP. If the maximum tolerable rate exceeded $2\cdot(n/H)\cdot[P(C)/f\,]$, the ANSP could reasonably expect that even after implementing the ADS-C CDP, it would be able to keep its total longitudinal risk less than the TLS.

3.11 The basic approach summarized in 3.10 above was used to develop guidance for an operational trial of the ADS-C CDP. The operational trial, which was being planned by the Federal Aviation Administration (FAA), was to take place in the Oakland flight information region (FIR).

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

3.13 One of the approximations derived by SASP showed *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 aircraft. It is easy to invert the formula showing *P(C)* as a function of *b*; 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 *bM*. Using the illustrative value of *P(C)* = 1.15×10^{-7}, along with reasonable values for the other basic parameters, a corresponding value of *bM* was computed to be equal to 3.625×10^{-5}. This was equivalent to one gross error per $1/3.625 \times 10^{-5}$ executions of the ADS-C CDP, i.e. one gross error per 27 586 executions. A grossly inadequate longitudinal 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 22.3 km (12 NM).

3.14 The SASP working group meeting in October 2010 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 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, *bM*. If the actual rate turned out to be less than *bM*, the procedure could be considered safe. If it turned out to be greater than *bM*, the procedure would be seen to have exceeded its maximum tolerable collision probability.

3.15 For each execution of the ADS-C CDP, the Oakland Oceanic Control Center would estimate the longitudinal separation between the aircraft 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 longitudinal 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 longitudinal separation.

3.16 The SASP working group meeting in October 2010 then 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 of which is called the “pass line”, the other of which is 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 longitudinal 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 longitudinal 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, 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.

3.17 The SASP working group meeting in October 2010 suggested ways in which the sequential sampling test could be made relatively conservative or relatively liberal. In a neutral test, 27 725 ADS-C 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) was taken to be 80 per cent.

3.18 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 CDP executions in the operational trial, was not known.

3.19 The ADS-C CDP tested in the operational trial was a procedure in which 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; 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 process for applying the ADS-C CDP, thereby hoping to encourage its use.

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

3.21 The simulation used traffic data from two days of operations in the North Pacific (NOPAC) route system, one from the summer of 2012 and 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 behaviour of the fleet and the ATC system. Aircraft performance characteristics were drawn from the Base of Aircraft Data (BADA) database maintained by European Organisation for the Safety of Air Navigation (EUROCONTROL). Roughly 90 per cent of the NOPAC flights were equipped for the ADS-C CDP in the simulation.

3.22 The simulation programme used estimates of fuel burn to decide when aircraft 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.

3.23 The simulation model includes a manoeuver start time (MST) interval. The MST interval begins with the controller initiating an ADS-C demand report request and ends when the pilot begins to climb/descend the aircraft.

3.24 Fifteen scenarios were examined by the simulation. Eight of them used data from the summer traffic sample and 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 executions. The scenarios reported allowed for altitude changes of either 600 m (2 000 ft) or 900 m (3 000 ft) and gave rise to 159 executions of the ADS-C CDP. The largest observed decrease in the longitudinal spacing was 4.84 NM. This particular decrease occurred with a 3 000-ft climb. There were twenty-nine ADS-C CDP applications observed with a slower aircraft operating in front of a faster aircraft. Of these twenty-nine applications, the largest speed differences were observed to be 8.8 kt and 8.6 kt, resulting in changes to longitudinal spacing of 2.09 NM and -1.6 NM, respectively.

3.25 The maximum time needed to complete a simulated ADS-C CDP was 15.84 minutes. This time included the MST interval which 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 interval is independent of the number of flight levels through which the manoeuvring aircraft travels.

3.26 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 manoeuvring aircraft climbed 900 m (3 000 ft) during the procedure. It should be noted that the simulation did not apply the required time restriction to re-establish 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.

3.27 To assist regions and States with their implementation safety assessment, a safety assessment process is provided in Chapter 4 of this circular. This process relies on the various outputs from the application of the SASP safety assessment.

3.28 As indicated above, the SASP concluded that the ADS-C CDP could be safely applied as long as the rate of gross errors does not exceed 3.625×10^{-5} and the total longitudinal risk, including risk from ADS-C CDP and all other applications of longitudinal separation, does not exceed 5.0×10^{-9} fatal accidents per flight hour. Guidance for monitoring of the rate of gross errors is provided in paragraph 2.8 of this circular.

Chapter 4

IMPLEMENTATION CONSIDERATIONS

4.1 Successful implementation of the ADS-C CDP is not possible at the regional, State or local level without first undertaking a safety assessment (see Chapter 3 of this circular). When undertaking this safety assessment reference should be made to the requirements detailed in Annex 11 — *Air Traffic Services* (Chapter 2, section 2.27 refers) and the PANS-ATM (Chapter 2, section 2.6 refers) and guidance material contained in the *Safety Management Manual (SMM)* (Doc 9859), including the development of hazard identification, risk management and mitigation procedures tables.

4.2 Table 4-1 provides an overview of the minimum steps that are considered necessary for a region, State or local ANSP to undertake a safety assessment.

Table 4-1 Safety assessment process

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 Chapter 2, paragraphs 2.3 through 2.8).
Step 4	Compare assumptions, enablers and system performance requirements in this circular with the regional or State 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, the region or State must undertake safety management activities including: a) an implementation plan; b) formal hazard and consequence identification, and safety risk analysis activities including identification of controls and mitigators; c) techniques for hazard identification/safety risk assessment which may include: 1) the use of data or experience with similar services/changes; 2) quantitative modelling based on sufficient data, a validated model of the change and analysed 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 Doc 9859 — *Safety Management Manual (SMM)*;

d) identification and analysis of human factors issues associated 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) an expert panel to undertake scrutiny of proposals and development of identified improvements to the implementation plan;

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

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

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

Appendix

IMPLEMENTATION HAZARD LOG

This section lists 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 identify whether there are other regional, State or local hazards that need to be considered.

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. Near-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 5-29 through 5-34 of the PANS-ATM.
SASP global controls and/or mitigators PANS-ATM paragraph 5.4.2.9.5 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 paragraph 5.4.2.9.5, 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 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, 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 paragraph 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) The 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 system could be programmed to do the rest of the eligibility checks (i.e.: same track, 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 the ADS-C CDP 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 manoeuvre to exceed the time parameter, some of which are: 1) aircraft performance; 2) turbulence; 3) emergency or contingency; 4) weather; 5) ACAS resolution advisory; 6) failure of the pilot to initiate the procedure in a timely manner; and 7) communications failure.
SASP global controls and/or mitigators The *Global Operational Data Link Document (GOLD)* (Doc 10037) provides guidance material concerning data link operations and the *Performance-Based Communication and Surveillance (PBCS) Manual* (Doc 9868) provides guidance material concerning performance-based communication and surveillance operations.
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. The appropriate ATS authority should provide 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 manoeuvre.
Analysis This event pertains to speed changes outside the range of the model 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 manoeuvre, some of which are: 1) turbulence; 2) weather; 3) aircraft performance; 4) equipment failure; and 5) blocking/manoeuvring 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 (see Chapter 3 of this circular).
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 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. Database 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. Database 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. Further information about this issue may be found in Annex 15 — *Aeronautical Information Services* and EUROCAE ED-76A/RTCA DO-200A — *Standards for Processing Aeronautical Data*. Navigation systems allow pilots to create waypoints manually in the en-route mode. This presents the possibility that pilots may enter waypoint coordinates 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 ATM 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 the ADS-C CDP. 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 The appropriate ATS authority must ensure that ADS-C intent data is used to check routes. The appropriate ATS authority must ensure that appropriate quality control procedures are followed throughout the entire data chain to ensure database integrity in aircraft and ATM systems.

Subject 6 — Global navigation satellite system (GNSS) outage

Hazard

Loss of separation

Unsafe event (cause)

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

Analysis

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

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* (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 provision is contained in the 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 (lateral deviation event (LDE) and time estimates).

— END —

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