EUROCONTROL Guidelines for Area Proximity Warning - Part III

Implementation and Optimisation Examples

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EUROPEAN ORGANISATION
FOR THE SAFETY OF AIR NAVIGATION

EUROCONTROL Guidelines for Area Proximity Warning

Part III - Implementation and Optimisation Examples

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Abstract

These Guidelines specify the minimum requirements and provide comprehensive guidance for the definition, implementation, optimisation and operation of Area Proximity Warning (APW).

Part I describes the APW concept of operations as well as the specific requirements on APW.

Part II contains overall guidance for the complete lifecycle of APW.

Part III, **this document**, specifies a generic example of an APW implementation as well as detailed technical guidance for optimisation of APW.

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EXECUTIVE SUMMARY

These Guidelines specify the minimum requirements and provide comprehensive guidance for the definition, implementation, optimisation and operation of Area Proximity Warning (APW).

Ground-based safety nets are functionalities within the ATM system with the sole purpose of monitoring the environment of operations in order to provide timely alerts of an increased risk to flight safety.

APW is a ground-based safety net that warns the controller about unauthorised penetration of an airspace volume by generating, in a timely manner, an alert of a potential or actual infringement of the required spacing to that airspace volume.

The main objective of these Guidelines is to support ANSPs in the definition, implementation, optimisation and operation of APW by means of:

- Part I describing the APW concept of operations as well as the specific requirements on APW
- Part II containing overall guidance for the complete lifecycle of APW
- Part III, **this document**, specifying a generic example of an APW implementation and providing detailed guidance for optimisation and testing of APW

Together with similar Guidelines for Short Term Conflict Alert (STCA), Minimum Safe Altitude Warning (MSAW) and Approach Path Monitor (APM) these Guidelines provide “Level 3” documentation for evolutionary improvement of ground-based safety nets, i.e.:

- “Level 1” – documented in the EUROCONTROL Operational Requirement Document for EATCHIP Phase III ATM Added Functions (Volume 2), published in 1998 with emphasis on automation
- “Level 2” – documented in EUROCONTROL Specifications and Guidance Material for STCA, MSAW, APM and APW, published in 2007-2008 providing a broader context than automation alone, e.g. pointing out the importance of policy, organisational clarity and training
- “Level 3” – documented in EUROCONTROL Guidelines for STCA, MSAW, APM and APW, published in 2017 incorporating the results of SESAR I as well as lessons learned

1. Introduction

1.1 Purpose of this document

APW is a ground-based safety net intended to warn the controller about unauthorised penetration of an airspace volume by generating, in a timely manner, an alert of a potential or actual infringement of the required spacing to that airspace volume.

Part I of the EUROCONTROL Guidelines for APW contains specific requirements, a number of which must be addressed at an organisational or managerial level and others, more system capability related, which need to be addressed with significant input from operational, technical and safety experts.

The purpose of Part III of the EUROCONTROL Guidelines for APW is providing practical technical guidance material on APW, for use by engineers and other technical staff to help them meet the more technical requirements contained in Part I.

1.2 Structure of this document

Chapter 1 describes the purpose and structure of this document.

Chapter 2 describes a reference APW system in technical detail. This chapter allows the reader to understand how APW systems work and to compare various options for APW. The chapter specifies the inputs to the APW system, describes the APW volumes and the method used to detect conflicts.

In chapter 3, guidance is provided to help in adapting the APW volumes and parameters to the local air traffic environment.

The principles of system adaptation are described in chapter 4 and 5. The optimisation concepts are described in chapter 4 and the optimisation procedure is described in chapter 5.

Chapter 6 describes the data that should be recorded in order to do adequate testing of the APW system.

Chapter 7 comprises a description of test scenarios that could be used to test, validate, certify or inspect an APW system. Furthermore, these scenarios also serve to demonstrate the variety of types of situation for which APW may be expected to perform.

1.3 Reference documents

[Doc 4444]	ICAO Doc 4444: Procedures for Air Navigation Services - Air Traffic Management
[SRC-ESARR4]	ESARR 4: Risk Assessment and Mitigation in ATM, Edition 1.0, 05-04-2001
[SRC28.06]	SRC Policy on Ground Based Safety Nets – Action Paper submitted by the Safety Regulation Commission Co-ordination Group (SRC CG) – 15/03/07

1.4 Explanation of terms

This section provides the explanation of terms required for a correct understanding of the present document. Most of the following explanations are drawn from [Doc 4444] and [SRC28.06] as indicated.

alert	Indication of an actual or potential hazardous situation that requires particular attention or action.
approach path monitor	A ground-based safety net intended to warn the controller about increased risk of controlled flight into terrain accidents by generating, in a timely manner, an alert of an unsafe aircraft flight path during final approach.
area proximity warning	A ground-based safety net intended to warn the controller about unauthorised penetration of an airspace volume by generating, in a timely manner, an alert of a potential or actual infringement of the required spacing to that airspace volume.
ATS surveillance service [Doc 4444]	Term used to indicate a service provided directly by means of an ATS surveillance system.
false alert	Alert which does not correspond to a situation requiring particular attention or action (e.g. caused by split tracks and radar reflections).
ground-based safety net [SRC28.06]	A ground-based safety net is functionality within the ATM system that is assigned by the ANSP with the sole purpose of monitoring the environment of operations in order to provide timely alerts of an increased risk to flight safety which may include resolution advice.
human performance [Doc 4444]	Human capabilities and limitations which have an impact on the safety and efficiency of aeronautical operations.
nuisance alert	Alert which is correctly generated according to the rule set but is considered operationally inappropriate.
minimum safe altitude warning	A ground-based safety net intended to warn the controller about increased risk of controlled flight into terrain accidents by generating, in a timely manner, an alert of aircraft proximity to terrain or obstacles.
short term conflict alert	A ground-based safety net intended to assist the controller in preventing collision between aircraft by generating, in a timely manner, an alert of a potential or actual infringement of separation minima.
warning time	The amount of time between the first indication of an alert to the controller and the predicted hazardous situation. Note 1: The achieved warning time depends on the geometry of the situation. Note 2: The maximum warning time may be constrained in order to keep the number of nuisance alerts below an acceptable threshold.

1.5 Abbreviations and acronyms

ADS	Automatic Dependent Surveillance
AGDL	Air-Ground Data Link
ANSP	Air Navigation Service Provider

APM	Approach Path Monitor
APW	Area Proximity Warning
ASM	Airspace Management
ATC	Air Traffic Control
ATCC	Air Traffic Control Centre
ATM	Air Traffic Management
ATS	Air Traffic Service
CFL	Cleared Flight Level
EATCHIP	European ATC Harmonisation and Integration Programme
EATMN	European Air Traffic Management Network
EC	European Commission
ESARR	EUROCONTROL Safety Regulatory Requirement
ESSIP	European Single Sky Implementation
FUA	Flexible Use of Airspace
GAT	General Air Traffic
HMI	Human Machine Interface
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
MSAW	Minimum Safe Altitude Warning
OAT	Operational Air Traffic
PoR	Point of Risk
QNH	Altimeter sub-scale setting to obtain elevation when on the ground
RVSM	Reduced Vertical Separation Minima
SES	Single European Sky
SESAR	Single European Sky ATM Research
SFL	Selected Flight Level
SRC	Safety Regulation Commission
SSR	Secondary Surveillance Radar
STCA	Short Time Conflict Alert
TOV	Time Of Violation
VFR	Visual Flight Rules

2. The reference APW system

2.1 Different types of APW systems

APW systems tend to fall into one of two categories as given below:

1. Those that produce an alert when a unauthorised aircraft is about to enter a restricted area, military aerobatic area or danger area.
2. Those that produce an alert when aircraft not under ATC has entered controlled airspace.

In principle, APW could be adapted to allow both types of functionality (protection of controlled airspace and restricted areas) to be combined in the same system.

However, currently the two types of APW are distinct, and so this document shall where necessary refer to the specific type of system as APW_type1 and APW_type2. APW_type1 protects restricted airspace, APW_type2 protects controlled airspace.

2.2 Inputs to APW

2.2.1 System tracks

For the reference APW system, it is assumed that, at a minimum, the system tracks (of sufficient quality) contain some information to identify the track (e.g. a unique system track number) and an estimate of the current position and velocity of the aircraft. That is, the 3D state vector (X, Y, Z, VX, VY, VZ) measured in the system plane.

The current position of the aircraft is the fundamental data used to detect conflicts. Note that for APW the most appropriate height value to use may depend on the type of APW system and on local requirements. For example, APW_type2 systems could potentially suffer from using the system track altitude if the altitude tracking exhibits excessive lag, leading to aircraft apparently overshooting their flight levels into controlled airspace. On the other hand, raw pressure altitude data may suffer too many erroneous values to be considered valid for APW.

Other data, such as system track ages or accuracy estimates, may be present in the system and these data items may be used by APW to assess the quality of the tracks. Tracks of insufficient quality may be rejected by APW. Processing tracks with aged pressure altitude data may lead to nuisance alerts, particularly in APW_type2 systems.

Depending local requirements, APW may process aircraft without a pressure altitude. For example, it can be appropriate to designate control zones, firing ranges or other specific areas in APW (especially those that exist close to ground level), where aircraft without pressure altitude will provoke an APW alert if the aircraft enters the area. Nevertheless, it is normally essential to discount spurious (short-lived) primary tracks from APW processing.

2.2.2 Environment data

Environment data comprises APW volumes, essential parameters, and where relevant, QNH data and QNH regions, and local air temperature.

The QNH is used in the conversion of the mode C height into a true altitude, for the purpose of detecting APW conflicts against volumes that are defined in terms of true altitude (feet rather than flight levels).

QNH regions are polygons defining the areas to which a particular QNH value applies. There may be several QNH regions covering the area of interest.

APW systems may also use the local outside air temperature to refine the calculation of the true altitude.

The ICAO standard atmosphere has a pressure of 1 013.25 hPa and a mean temperature of 15°C at sea level. In simplistic terms, every 1°C deviation from this temperature will result in a deviation from the true altitude by approximately 0.4%. That is, if the air temperature at sea level were 5°C, an aircraft indicating an altitude of 1 000 ft (after QNH correction), would in reality be at about 960 ft.

In practice, the correction to be applied for temperature only starts to be significant below 0°C, and becomes critical at several thousand feet and very cold temperatures. For example if the air temperature at sea level were -20°C, an aircraft indicating an altitude of 5 000 ft (after QNH correction) would in reality be at about 4 290 ft. The aircraft would in fact be 710 ft lower than indicated.

2.2.3 Additional flight information

It is assumed that the reference APW system is capable of using certain additional flight information. Most essentially, the APW system must recognize which tracks belong to aircraft that are eligible for APW processing.

In some APW systems, the system track is correlated with a flight plan in a flight plan database. Alternatively, the SSR code of the track may be used to look up against a list of “controlled” codes (i.e. those SSR codes normally assigned to aircraft under control of the ATS unit). One potential advantage of a SSR code look-up list is that it makes the APW system more independent of the rest of the ATC system, and therefore able to fully function in some degraded modes. However, the list of “controlled” codes would need to be kept up to date with the operational SSR code allocations.

Some APW systems also allow the controller to exclude individual aircraft from APW processing based on either the SSR code or the aircraft call sign.

In some APW systems, the CFL and/or the SFL are used by the APW system to improve its vertical prediction.

Note 1: The use of CFL and SFL is identical as described below. Use of CFL is only appropriate if air traffic controllers are required to systematically input the CFL. Use of SFL requires appropriate surveillance infrastructure (Mode S or ADS-B).

Note 2: When both CFL and SFL are used, prioritisation rules are needed for situations in which the CFL and SFL values disagree, taking into account that CFL and SFL values are unlikely to change simultaneously.

Note 3: Irrespective of the use of CFL and/or SFL in the APW system it is good practice to draw the controllers’ attention, after an appropriate delay, to the fact that CFL and SFL values disagree.

2.3 APW parameters

Most APW systems use a fairly small number of parameters. In the reference APW system, the parameters are shown in Table 1.

Table 1: Typical APW parameters

Name	**Description**	**Units**
PredictionTime	Prediction time for APW conflict detection	s
HorizontalBuffer[FlightType]	Horizontal buffer dependent on type of flight	NM

Name	Description	Units
VerticalBuffer[FlightType]	Vertical buffer dependent on type of flight	ft
UseCFL	Flag to use CFL for vertical prediction	Boolean
UseSFL	Flag to use CFL for vertical prediction	Boolean
ConflictCount	Conflict count for alert confirmation	integer
WarningTime	Warning time for APW alert confirmation	s

The appropriate values for the parameters will depend very much on the type of APW system, and the local environment. For example, APW_type2 will normally function without any prediction or a buffer (**PredictionTime**, **HorizontalBuffer[FlightType]**, **VerticalBuffer[FlightType]** all zero).

In APW, the flight-type dependency of the parameters **HorizontalBuffer[FlightType]** and **VerticalBuffer[FlightType]** typically relates to IFR and VFR. However, it is conceivable that numerous other flight characteristics could be taken into account (controlled/uncontrolled, civil/military, OAT/GAT etc.) depending on an ATS provider's specific requirements.

2.4 APW volumes

The reference APW system allows an indefinite number of APW volumes to be defined. Each volume is defined as a horizontal shape with a floor and ceiling height. The horizontal shape may be composed by a polygon, a circle or a combination of polygons and circle segments. The floor and ceiling heights may be individually specified in terms of flight levels or altitude for each volume.

For example, the floor of an APW volume could be set to 3 000 ft, and the ceiling set to FL150. In this case, QNH is used to convert pressure altitude to true altitude before determining whether the aircraft flies above or below the floor.

An example APW volume is shown in horizontal view in Figure 1. The APW volume itself is shown by the solid line, and an additional margin (**HorizontalBuffer[FlightType]**) is represented by the dashed line.

The volume is also shown in vertical view in Figure 1, with the additional vertical margin (**VerticalBuffer[FlightType]**) represented by the dashed line.

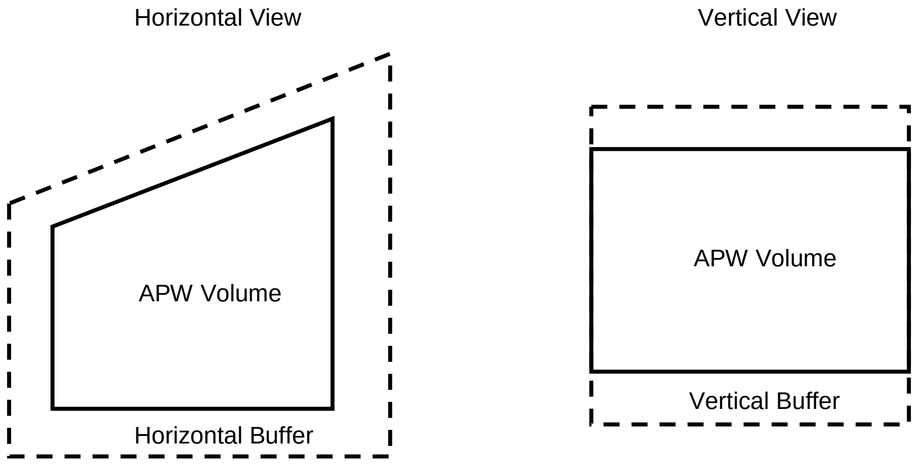

Figure 1: Example APW volume

A typical offline definition of an APW volume may consist of:

- Horizontal shape

- Default vertical span
- Default activation state
- Type (e.g. prohibited airspace, restricted airspace, danger area, TSA, each type having its own set of parameters as listed in Table 1)

2.5 Use of grids in APW

Some APW systems may superimpose the APW volumes onto a grid. However, this would compromise the precision of the original data; it is always preferable to use the original volume definition for computing APW infringements.

Nevertheless it is valid to use a coarse grid to speed up APW processing. A grid can be used for a fast look up of volumes within a particular cell. The list of volumes that needs to be tested is then only a subset of all those defined by the user.

2.6 Activation and deactivation of volumes

Some APW systems allow specific volumes to be activated and deactivated, either manually or automatically. Automatic activation may rely on a schedule of activation periods for each volume, which is defined either on-line or off-line, depending on the ATM system. Alternatively, APW volumes may be activated and deactivated via specific NOTAM messages.

Upon activation of a volume (e.g. a TSA) the default offline-defined vertical span may be changed according to the current civil/military coordination.

2.7 Modification of APW volumes

In some systems, APW volumes can be modified on-line, or new ones can even be created. Typically, modification is allowed to be made to the height limits of some or all of the APW volumes. In some systems new APW volumes can be created on-line by drawing on the appropriate display, using a mouse.

2.8 The APW cycle

The APW processing occurs periodically. This may be a regular cycle time (e.g. 4 seconds), or driven by system track updates. On each APW cycle, the available system tracks are introduced to the APW processing, and any alerts are output to the ATC display system.

2.9 APW processing stages

The essential APW processing stages are shown in Figure 2.

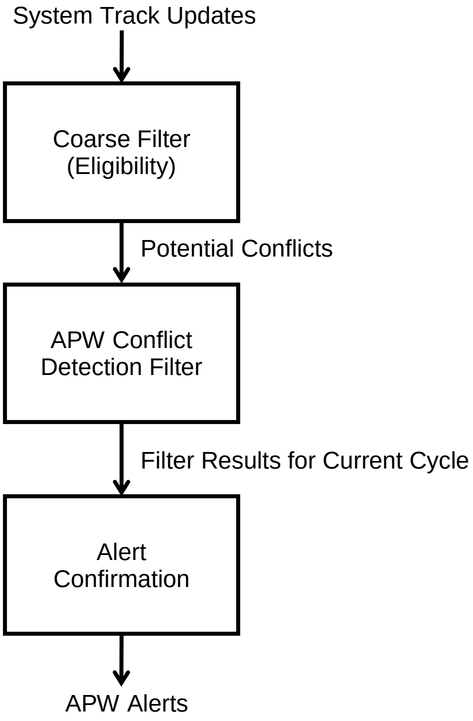
System Track Updates
Coarse Filter (Eligibility)
Potential Conflicts
APW Conflict Detection Filter
Filter Results for Current Cycle
Alert Confirmation
APW Alerts

Figure 2: APW processing stages

2.10 System tracks eligible for APW

Most essentially, the APW system must recognize for which tracks APW alerts are relevant.

Depending on the type of APW (APW_type1 or APW_type2), and upon local requirements, the determination of system track eligibility may be done in a variety of ways.

In APW_type1 systems, it is usual that only tracks that are correlated with a flight plan are processed.

The SSR code of the track may also be taken into account to determine whether the track should be processed. In this case an SSR code inhibition list may be part of the off-line APW parameters.

In APW_type2 systems, the SSR code of the track usually determines whether the track should be processed. For these systems the SSR code list of non-controlled codes is part of the off-line APW parameters.

SSR code lists are generally static lists that would be updated when necessary by technical or supervisory staff. On the other hand, some APW systems allow the controller to selectively inhibit alerts for certain types of flight, or selectively inhibit alerts based on call sign or SSR code.

In the reference APW system, for a track to be eligible for APW processing, the track must:

- Have sufficient track quality
- Have an SSR code that is selected for processing by APW

Whether or not an aircraft must be providing pressure altitude in order to be eligible for processing also depends on the type of APW system and upon local requirements. As explained earlier, it can be appropriate to designate control zones, firing ranges or other specific areas in APW, where aircraft without pressure altitude are capable of provoking an APW alert.

2.11 APW conflict detection

2.11.1 General

For each APW eligible aircraft, the future position of the aircraft is extrapolated forwards from the current track position up to the defined look-ahead time, **PredicitionTime**.

In the horizontal dimension, the prediction is a straight line extrapolation made using the current track position and velocity.

In the vertical, the prediction is a straight-line extrapolation made using the current pressure altitude, and the vertical rate of the track. Correction for QNH may be made for comparison against an APW height threshold defined in terms of altitude. If the flag **UseCFL** and/or **UseSFL** is set, then the CFL and/or SFL is taken into account in the vertical prediction.

A conflict is detected if the aircraft is predicted to simultaneously infringe the horizontal and vertical limits as defined by the volume itself and by the horizontal and vertical buffer parameters (**HorizontalBuffer[FlightType]**, **VerticalBuffer[FlightType]**).

2.11.2 Vertical prediction using the CFL and/or SFL

The CFL and/or SFL of the aircraft may be available and used in APW. The potential advantages and disadvantages of its use are discussed later.

If **UseCFL** and/or **UseSFL** are set, the CFL and/or SFL is taken account of in the calculation of the predicted aircraft altitude as shown in Figure 3.

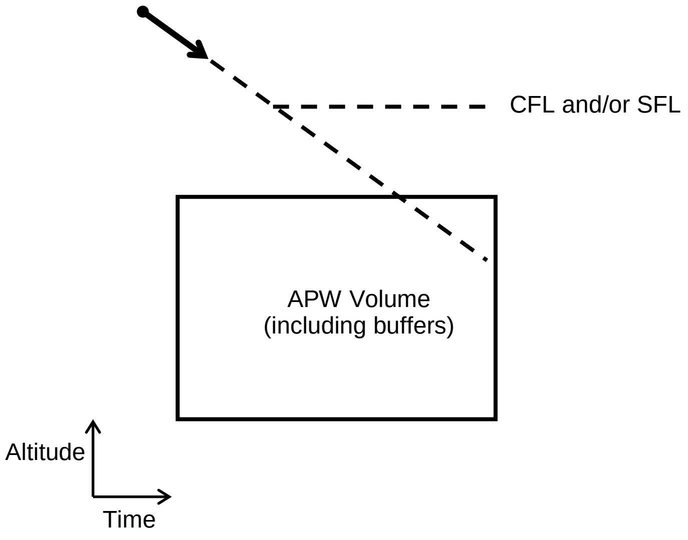

Figure 3: Vertical prediction with the CFL and/or SFL

The diagram shows that, without use of CFL and/or SFL, the aircraft is predicted to penetrate the APW volume (and the vertical buffer). In this example the CFL and/or SFL will prevent a possibly unwanted alert.

2.12 Alert confirmation

2.12.1 General

The alert confirmation stage in APW has a number of objectives:

- To test if an APW volume is currently infringed and an alert is required immediately

- To suppress an alert which might be caused by spurious track data
- To suppress an alert which might be caused by a transitory situation
- To test whether an alert is required on this cycle, or should be delayed, with the hope that the situation will be resolved before an alert is necessary
- To continue an alert when there are temporary perturbations in the track data

Essentially, the alert confirmation stage determines whether to issue an alert based upon the number of conflict "hits" from previous track cycles and the time of violation (i.e. the remaining time until the APW volume is penetrated, adding on any horizontal and vertical buffer).

2.12.2 Conflict results presented to alert confirmation

The conflict result from the APW conflict detection filter is passed to the alert confirmation stage. The conflict result is expressed either as "conflict hit" or a "conflict miss" on the current APW cycle.

A conflict hit result from the filter does not necessarily mean that an alert will be generated. This is determined by the alert confirmation stage. However, if a conflict has been confirmed from either of the individual alert confirmation processes, then the alert is issued to the display.

2.12.3 Alert confirmation logic

The processing logic of the APW alert confirmation stage is shown in Figure 4.

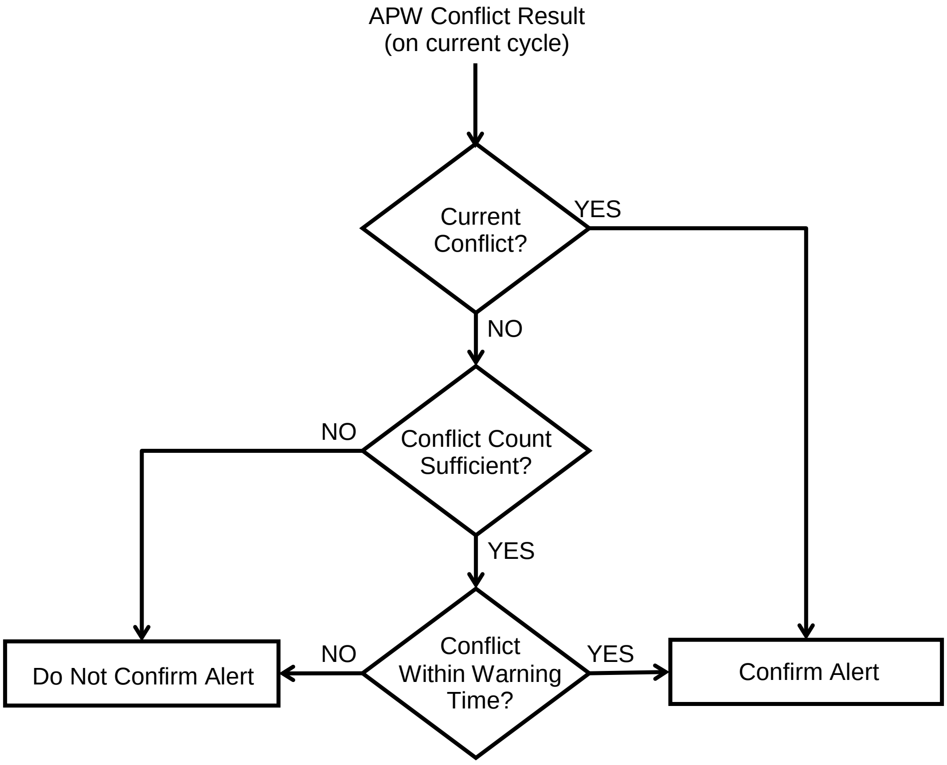

Figure 4: Alert confirmation stage for APW

If the aircraft is currently within an APW volume (plus any horizontal or vertical buffers) then it is appropriate to bypass the other delay mechanisms and provide an alert on the current cycle. Otherwise further tests are done to see if it is safe to delay the alert.

Sometimes tracks can be presented to APW that are very noisy or are in the process of turning or levelling off. See Figure 5 for an example of an aircraft levelling off, taking the aircraft out of conflict with an APW volume.

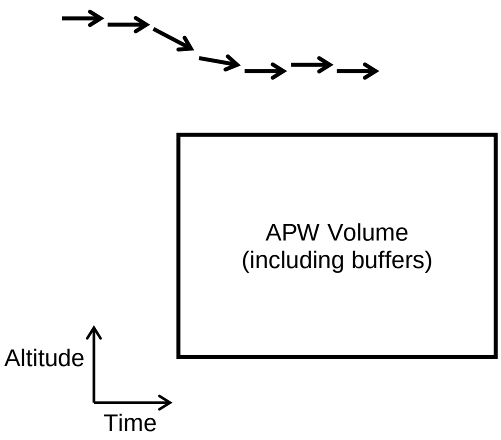

Figure 5: Level off example

To avoid nuisance alerts, the alert confirmation stage employs an algorithm that counts the number of consecutive conflict hits that have been detected for the track. If the number of consecutive hits reaches the parameter threshold, **APWConflictCount**, then the conflict hit count test is passed.

If the count of conflict hits is sufficient then the situation is examined further to see if an alert is required.

The test to see if an alert is required is simply based on the time of violation (TOV).

If TOV is less than the parameter **APWWarningTime**, then an alert is declared on this cycle.

3. Guidance to appropriate APW parameter values

3.1 Introduction

The purpose of this section is to provide guidance for tuning APW.

Successful tuning of APW is generally a matter of carefully defining the volumes and setting appropriate values for certain key parameters. The general scheme will be to set up the volumes, and then to tune the parameters. Depending on the complexity of the airspace, it may be necessary to redesign the volumes before satisfactory performance can be achieved.

The parameter values that should be used are likely to depend hugely on the local environment, and it is therefore recommended that the local context be considered above all else.

3.2 General guidelines

3.2.1 APW_type1

APW_type1 systems are designed to produce an alert when an unauthorised aircraft is about to enter a restricted area, military aerobatic area, danger area or other such type of airspace.

Often the APW volumes can be made to match the published airspace exactly. If the APW supports polygons only, but the airspace is defined using curved sections, then the curve will need to be modelled in the volume definition using a significant number of polygon points.

The appropriate values of the parameters will depend on the proximity of civil traffic on normal routes to the protected airspace.

If the civil air traffic routes and the protected airspace are well separated then it should be expected that the look-ahead time parameter, **PredictionTime** can extend to more than 60 s with a negligible nuisance alert rate penalty.

On the other hand, if a piece of protected airspace lies adjacent to a civil air traffic route, then **PredicitionTime** and **WarningTime** may have to be reduced to keep the number of nuisance alerts to a tolerable level. There is also likely to be a severe restriction on **HorizontalBuffer[FlightType]** and **VerticalBuffer[FlightType]**. Furthermore, if civil air traffic is frequently heading towards the protected airspace (due to the airspace design, or the type of traffic), **PredictionTime** and **WarningTime** should take small values in order to reduce the number of nuisance alerts.

3.2.2 APW_type2

APW_type2 systems are designed to produce an alert when aircraft not under ATC has entered controlled airspace.

These types of systems are usually somewhat harder to tune because of the proximity of General Aviation traffic close to controlled airspace. A lot of uncontrolled activity may occur below controlled areas (CTAs), and small deviations in the aircrafts’ vertical positions and rates could lead to an intolerable number of nuisance alerts. Therefore, very careful tuning and volume design is required.

The nature of the surveillance and the traffic close to the ground tends to exacerbate the situation:

- Uncontrolled flights tend not to be straight and predictable, but are capable of high turn rates
- Uncontrolled flights do not generally maintain strict flight levels, resulting in an erratic vertical track, and nuisance alerts particularly for traffic below the CTAs

- General aviation aerodromes are sometimes in very close proximity to controlled airspace
- Surveillance cover may be patchy close to the ground, sometimes resulting in wobbly tracks
- Multiple aircraft with the same VFR Mode A code may lead to plot to track association problems in the tracker, and consequent false alerts

Setting the APW volumes to the published controlled airspace is a good starting point. However, it may well be necessary to trim the airspace regions if the nuisance alert rate is too high.

PredictionTime and **WarningTime** will almost certainly have to be set to zero. This means that a warning will only be provided by APW after the aircraft has infringed the airspace. Unfortunately, any prediction applied to uncontrolled tracks is likely to lead to an intolerable nuisance alert rate.

It is strongly recommended to set both **HorizontalBuffer[FlightType]** and **VerticalBuffer[FligthtType]** to zero.

3.3 Prediction and warning time parameters

In most APW systems there is no point in having a prediction time parameter (**PredicitionTime**) far in excess of the warning time (**WarningTime**), since the APW will be using CPU for no reason. On the other hand, if the prediction time is less than the warning time, then the warning time parameter serves no useful function (because the APW will always alert as soon as the required number of conflict hits have been registered).

It is recommended to determine the value of the warning time parameter first, and then set a prediction time sufficient to allow the required number of hits to have built up before the alert will need to be issued.

As a rough guide, **PredicitionTime** can be set as follows:

PredictionTime = **WarningTime** + (**ConflictCount** x APW processing period)

3.4 Conflict count parameter

The appropriate value of the conflict count parameter, **ConflictCount**, will depend on the type of APW system, the precise logic in the alert confirmation stage, and on the local environment.

If the APW volumes are generally well separated from the traffic, the number of nuisance alerts is small and **WarningTime** has a reasonably large value, then **ConflictCount** should be set to a low value (2 or 3) in order that genuine alerts are not unnecessarily delayed. This is more likely to be the case for APW_type1 systems, than for APW_type2.

It is strongly recommended that the **ConflictCount** should not be set so high that it prevents alerts being generated with sufficient warning time.

In APW_type2 systems, the characteristics of the traffic as well as the surveillance and tracking characteristics should be taken into account. Manoeuvring aircraft may appear to be heading momentarily towards an APW volume, and in the coverage of just one or two radars such problems are often exaggerated by track coasting (extrapolation of the track without a surveillance update). Track coasting will occur in the horizontal and vertical dimension, and it may be common for uncontrolled flights underneath controlled airspace to appear to breach this airspace due to mode C errors, unstable tracks, tracker lag and especially track coasting.

In order to find the correct value of conflict count, it is advisable to be guided by the answers to a number of questions:

- What is the worst case radar cover, and will this lead to track coasting? (i.e. if the track updates more frequently than the radar)
- How long (typically) does a track coast for before the tracker detects a blunder and resets itself to the correct position (in horizontal and vertical)?
- Does the damping effect of the vertical tracker lead to overshoot of the intended flight level, and will this affect APW?
-

3.5 Surveillance data quality and APW performance

The performance of APW is sensitive to the quality of the surveillance data and the tracker. This is especially true for APW_type2 systems where the quality of surveillance data generally deteriorates the lower one goes.

Aircraft close to the ground may be in the cover of just one or two radars, and this can lead to frequent coasting of the track (i.e. the track extrapolates in the absence of a radar plot). The result is that slight horizontal or vertical deviations will be exaggerated, producing nuisance APW alerts.

Because uncontrolled flights often fly below controlled airspace, vertical tracking problems could exacerbate problems with the nuisance alert rate.

If surveillance and track quality are proving to be an overriding issue for the APW system performance, the following courses of action could be considered:

- Improve the surveillance infrastructure close to the airports of interest
- In APW, avoid using tracks that are too old (i.e. they have coasted for too long)
- Seek to enhance or optimise the tracker (horizontal and/or vertical)
- If problems persist in the vertical tracking, consider using the last valid pressure altitude measurement (radar plot) instead. (These data must be checked for credibility before use)

3.6 The use of CFL and/or SFL

In some APW systems the CFL and/or SFL is used. In the reference APW system, it is used to improve the vertical prediction that is applied for conflict detection.

The use of the CFL can be quite a contentious issue, since there are clear advantages and disadvantages to using it. The advantages are:

- It considerably reduces the nuisance alert rate, especially the frequently occurring level-off type of situations
- APW may provide more warning time if an aircraft is cleared into an APW volume.
- A reduction in the nuisance alert rate may allow the user to set wider parameters, further increasing the achievable warning time

The disadvantages are:

- There may be very little warning time if the controller inputs a CFL, but the aircraft busts through the level
- The CFL may be input inaccurately or may not be updated by the controller

Not using the CFL also has certain advantages and disadvantages. The advantages are:

- In the event of a level bust, it will be possible for APW to alert before the level bust occurs

- The controller will be aware of a potentially hazardous situation arising, if the aircraft were not to adhere to the cleared level

The disadvantages are:

- The alert rate is likely to be higher
- It may be necessary to restrict the APW parameters (particularly the prediction time parameters) in order to achieve an acceptable alert rate

Because of these advantages and disadvantages, it is not possible to recommend either use, or non-use of CFL.

If the SFL is available down-linked from the aircraft, then this may be favourable for use instead because it will overcome the inherent disadvantage of using a controller input CFL. Furthermore, it is possible in the ATM system to check the input CFL against the down-linked SFL and indicate any inconsistency to the controller.

In the event that the CFL is used, it is recommended that:

- For consistent behaviour, the CFL is applied in all APW airspace.
- The controller is familiar with the APW vertical prediction mechanism.
- The APW system is configured to alert as soon as a level bust occurs.

Ultimately, the use of the CFL in the APW system must be decided by the ATS provider. The effects of the use of CFL in APW should be fully considered in the safety case. The inherent advantages must be weighed against the disadvantages.

3.7 QNH data quality

The performance of APW may also be sensitive to the quality of the QNH data. Depending on the error, incorrect QNH values may lead to nuisance alerts or insufficient warning time. It may be appropriate to automatically disable APW when no up-to-date QNH data is available.

4. Optimisation concepts

4.1 Introduction

APW optimisation aims to maximise the number of conflicts which are alerted with adequate warning time and minimise the number of nuisance alerts. These objectives are, to some extent, incompatible with each other and therefore need to be prioritised. The priority is based on the perceived importance of the objective in contributing to the overall aim of improving safety. It is considered that minimising nuisance alerts is less important than alerting all conflicts with adequate warning time. However, a balance must be struck so that, for example, large warning times are not provided at the expense of an excessive nuisance alert rate.

In APW this balance between warning time and nuisance alert rate may be difficult to achieve particularly if traffic routinely operates close to the airspace that is to be protected.

For APW systems where the **WarningTime** parameter is zero out of necessity, the concept of warning time may have little meaning unless it is suitably modified.

4.2 Analysis team composition

It is vital that the analysis and optimisation of APW performance is undertaken by a team that includes all the appropriate skills and experience. Function technical experts and data analysts must be accompanied by experienced ATC staff from the ATS Unit for which the function is being optimised. Without the ATC input, the scenarios may not be categorised in a suitable manner.

4.3 Scenario categorisation

4.3.1 Introduction

APW performance is measured by the numbers of genuine and nuisance alerts which are displayed to controllers, together with the amount of warning time provided for genuine alerts. Before these items can be measured, the APW analysts need to know which scenarios should have been alerted and which should not. In order to determine this, scenarios are divided into a number of categories.

Scenarios can be considered to range from “alert definitely required” to “alert definitely not required”, with a number of levels in between. The formal categories must be agreed between the analysis staff and ATC management before optimisation can proceed.

The scenario category is determined from recordings of the surveillance track data for the entire scenario. The category will depend on the actual and/or predicted deviations from the nominal approach path with respect to the appropriate criteria for the scenario. A series of suggested categories are described later in this section. They may be summarised as follows:

- Category 1 necessary alert
- Category 2 desirable alert
- Category 3 unnecessary alert
- Category 4 undesirable alert
- Category 5 void scenario

Using these categories, the theoretical aim of APW design and optimisation should be to alert all Category 1 and 2 scenarios and no Category 3, 4 or 5 scenarios. However, in practice the aim is to alert all Category 1 scenarios, virtually all Category 2 scenarios, very few Category 3 scenarios and virtually no Category 4 scenarios. Category 5 scenarios may or may not produce alerts and must normally be dealt with by improvements to the appropriate part of the ATM system. It may well prove impracticable to prevent APW occasionally alerting Category 5 scenarios, either by system adaptation or algorithm design.

4.3.2 Category 1

Category 1 scenarios are those where it is considered necessary that the controller's attention was drawn to the situation.

Category 1 scenarios include actual penetration of the protected airspace, and situations where an infringement was only avoided by means of a late manoeuvre.

Late manoeuvres are usually fairly easy to identify since they generally involve a sudden (and rapid) change in an aircraft's path to avoid, or minimise the consequences of, the potential hazard.

4.3.3 Category 2

Category 2 scenarios are those where it is considered desirable that the controller's attention was drawn to the situation.

Category 2 scenarios are those scenarios which, although involving some risk, can be dealt with by means of normal ATC instructions, and are likely to be resolved without resort to emergency manoeuvres.

These scenarios may include situations where not infringement of the protected airspace occurred, as well as those where the airspace was volume was clipped.

4.3.4 Category 3

Category 3 scenarios are those where it is considered unnecessary that the controller's attention was drawn to the situation. However, an alert was "predictable" or "understandable" in the circumstances and so would not cause a major distraction.

Category 3 scenarios are generally situations similar to those discussed under category 2 without any element of risk. Negligible infringements of the airspace or the safety margins may be considered to be Category 3.

4.3.5 Category 4

Category 4 scenarios are those where it is considered undesirable that the controller's attention was drawn to the situation.

Category 4 scenarios would typically be aircraft carrying out standard operations where, for a short period of time the aircraft's predicted path(s) results in a predicted hazard within the specified look-ahead time but would not be of any concern from the controller's point of view.

There may also be scenarios where the analysis does not suggest how a conflict could be predicted. These scenarios should also be considered as Category 4 since it is unlikely that the controller could tell the reason for the alert, and thus would be distracted by it, if it is not clear with the full aircraft path available for detailed examination.

4.3.6 Category 5

Category 5 scenarios are those where errors elsewhere in the ATM system produced an apparent situation which did not in fact exist. These scenarios can therefore be considered as void but it may prove difficult to prevent them being alerted in some cases.

The nature of Category 5 scenarios will differ between systems. They cannot, therefore, definitively be described in this document. Some Category 5 scenarios will be immediately obvious as data errors whereas some may require thorough investigation to determine that the aircraft did not in fact fly the path as indicated by the tracker output.

4.4 Performance indicators overview

The precise nature of the performance indicators used to assess whether APW meets its design objectives may well vary between systems. However, the following indicators may be adopted as a general guide:

- Percentage of scenarios alerted for each scenario category
- Percentage of alerted scenarios which were considered to be nuisance alerts
- Percentage of scenarios worthy of an alert which did not give adequate warning time, although adequate warning time was available
- Mean achieved warning time for scenarios worthy of an alert where adequate warning time was available
- Mean achieved warning time for scenarios worthy of an alert where adequate warning time was not available
- Overall mean achieved warning time for scenarios worthy of an alert

Further information on performance indicators is contained in the following sections.

4.5 Warning time

4.5.1 Achieved warning time

APW will provide an amount of time in which the situation may be resolved (“warning time”). The warning time is measured as the time between the APW alert and the Point of Risk (PoR). Flexibility in the calculation of warning times, depending on the rationale behind the APW implementation, is provided by defining an appropriate PoR.

4.5.2 Adequate warning time

An “adequate” warning time is one which allows sufficient time for controller reaction, communications, pilot reaction and aircraft response.

The amount of time needed for each of these four phases is dependent on a number of factors. External assessment, including the consideration of human factors issues, is necessary to determine the appropriate time for each phase.

Warning times are usually based on the time required for individual operations during normal circumstances. In some situations, such as when there are R/T difficulties, the “adequate” warning time may not be sufficient. However, it is impracticable to attempt to set warning times to cover all cases. In some situations, an aircraft may manoeuvre in such a way that it is not possible for APW to give an “adequate” warning time.

In theory, controller-alerting functions should alert before pilot-alerting functions. The adequate warning time should therefore be defined as being sufficiently large that the controller is alerted before the pilot.

It may be possible for an aircraft to perform an avoidance manoeuvre in the vertical plane in a shorter time than it would take to perform a manoeuvre in the lateral plane. For some implementations, it may therefore be desirable to distinguish between those scenarios which can be resolved vertically and those which cannot. For these implementations it will be necessary to specify separate adequate warning times for vertical and lateral avoidance manoeuvres.

4.5.3 Maximum warning time

The maximum warning time is the time between the earliest possible point at which an alert could be given and the PoR. The earliest possible point of alert is determined by finding the point in the surveillance track data prior to the conflict where a manoeuvre occurred that could not have been foreseen by APW. The track states are inspected, working back from the actual alert until one of the following is found:

- A vertical state change
- A horizontal state change
- The start of the track

Vertical state changes, particularly where aircraft change from level flight to climb or descend towards the potential hazard, are often responsible for limitations in the maximum amount of warning time available. In general, substantial changes in vertical rate cannot be anticipated by tolerances in vertical prediction. A vertical state change occurs when an aircraft:

- Changes from level flight to climb or descent
- Changes from climb or descent to level flight
- Changes vertical direction (climb to descent or vice versa)

Horizontal state changes are not as easily defined (or determined) as vertical state changes. In many cases lateral tracks exhibit slow turns or meanders for which the starting points are very indistinct. It is suggested that the track states prior to the conflict are inspected until a point is reached in the trajectory where the aircraft has turned through a parameterised amount (e.g. 20°).

4.5.4 Objective warning time

It is not considered appropriate to provide APW alerts in excess of the adequate warning time before the PoR actually occurs. This is to avoid unnecessary controller distraction by an increased number of unwanted alerts. However, in some situations, the maximum warning time is smaller than the adequate warning time. In these situations it is not possible to achieve the adequate warning time and effort should therefore be concentrated on achieving the maximum warning time.

The aim is therefore to provide an alert at the lesser of the adequate warning time and the maximum warning time. This is the objective warning time, and is the optimum time for the alert.

Figure 6 shows a situation where the maximum warning time is less than the defined adequate warning time. The maximum warning time is therefore taken as the objective warning time for this particular scenario.

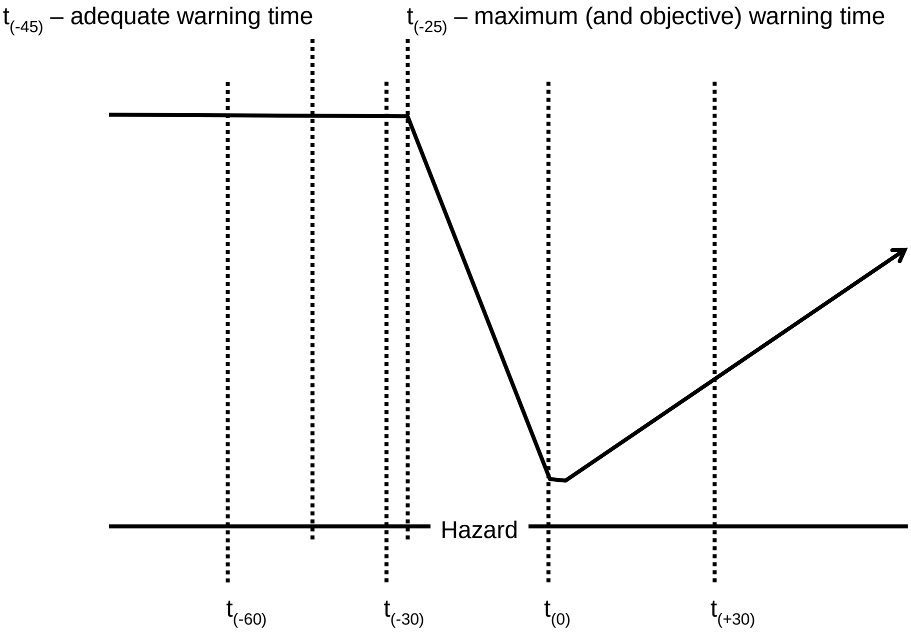
t(-45) – adequate warning time
t(-25) – maximum (and objective) warning time
Hazard
t(-60)
t(-30)
t(0)
t(+30)

Figure 6: Example of maximum warning time less than adequate

4.5.5 Achieved warning time

The achieved warning time is the actual time between the APW alert and the conflict.

4.6 Point of risk

The concept of the PoR is used in this document to provide a single term to represent the point from which warning times are retrospectively measured. The nature of the PoR will vary between implementations, depending on the underlying rationale behind the specific implementation. The PoR can be considered as a point on either the actual or predicted aircraft path and may deal with distances in time, space or a combination of the two, as appropriate to the implementation.

The PoR may or may not be the same as the point which triggers the APW alert. This again depends on the approach taken by the designers and analysts.

For predictive APW, the PoR could be defined as the breach of the protected airspace. Figure 7 illustrates some types of PoR which could be used for APW.

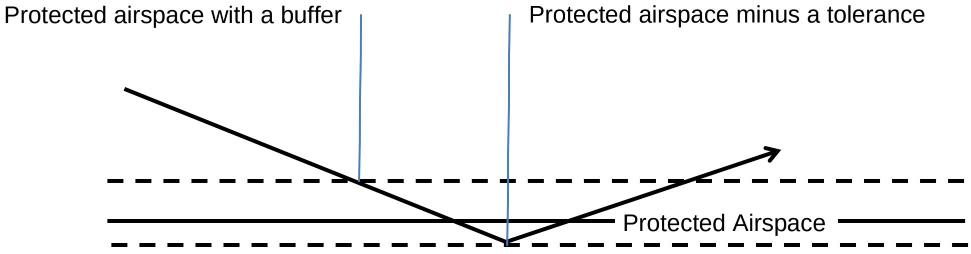
Protected airspace with a buffer
Protected airspace minus a tolerance
Protected Airspace

Figure 7: Example Points of Risk for APW

It may be appropriate to use smoothed track data to determine the PoR, rather than the system tracks, from which alerts are generated. This is because the true PoR lies on the actual path flown by the aircraft and this is best represented by smoothed data.

4.7 Analysis tools

4.7.1 Introduction

APW implementations can require a considerable amount of optimisation and analysis. It is therefore important that such optimisation and analysis can be performed routinely and easily. This is most simply achieved via a series of automated software tools, as outlined below.

4.7.2 Off-line models

It is vital that APW performance can be optimised and monitored without affecting the operational ATC system. The most efficient way of doing this is probably via a series of off-line computer models which accurately replicate the algorithms of the (proposed) APW. It is preferable that the models are not contained within the main ATC simulation/test facility since they will be used intensively during optimisation phases and are therefore best used under the exclusive control of the APW analysts. The models should make detailed information available on the internal processes related to each scenario contained in each test so that it may be clearly understood why an alert was or was not given. The models should also produce the Performance Indicator information.

If the operational APW can be run in an off-line environment and generate adequate analysis information, it is not necessary to use off-line models. However, using the operational APW for optimisation purposes must not have an impact on the functioning of the on-line ATM system.

A model should use exactly the same algorithms as the APW it is used to test, even if the actual programming source code is different. Different versions of an APW will, therefore require different versions of the model; otherwise the results of the optimisation may be invalid.

The models should be able to run in fast time (e.g. process one day’s surveillance track data in a few minutes). To assist this, recording of surveillance track data can be reduced to just those tracks which are of concern, taking care not to filter out tracks that could produce an alert. For optimisation purposes, each data set will need to be re-run many times against the model, with varying parameter sets.

4.7.3 Analysis display function

A means of displaying scenarios off-line is needed so that they can be examined manually, including an indication of when an alert would have been displayed. Scenarios may be displayed in 3D or otherwise in both plan and elevation view. A facility to print out the display for detailed analysis is often an advantage. In some circumstances, a pseudo-radar display may prove to be useful, particularly so that controllers can assess the situation in a familiar context.

A means of displaying the locations of scenarios on a map of the relevant airspace may also prove useful, initially for checking that APW volumes have been located correctly and subsequently for identifying any part of the airspace with an unexpectedly high alert rate. The facility to display actual tracks on a map may prove useful when defining APW volumes in the first place.

4.7.4 Categoriser

APW optimisations can potentially involve the examination of tens of thousands of scenarios, the vast majority of which should not result in an alert. It is therefore extremely useful to have an automated process to identify which scenarios require manual inspection and which may be discarded.

This tool, known as the “categoriser”, is totally independent from the simulation function of the APW model. The categoriser classifies scenarios into categories and will work retrospectively over the entire scenario.

The entire aircraft trajectories during the scenario are available for examination by the categoriser. The seriousness of the scenario is determined by considering the position of the aircraft in relation to the protected airspace or an appropriate point of risk.

Since the purpose of the categoriser is to reduce the number of scenarios which need to be inspected manually, the analysis staff should be able to have complete confidence that no serious scenarios will be discarded. The categoriser must therefore use different algorithms from those contained in APW and should be tuned to overestimate the seriousness of scenarios rather than underestimate. Any questionable scenarios should be classified as categories 1 or 2, rather than 3, 4 or 5. Only scenarios classified as categories 1 and 2 then need to be examined manually and possibly re-classified.

Determining whether scenarios are the result of data processing errors may require additional tools and expertise. For example, it may be worth checking the performance of the tracking system. Testing APW can highlight problems in other parts of the data processing chain. As optimal APW performance may only be achievable when such problems have been resolved, scenarios containing erroneous track information (category 5) may need to be identified and removed from the optimisation data set. This will allow APW to be optimised correctly for real situations but any performance figures derived from such a reduced data set must indicate the removal of category 5 scenarios.

It may also be of benefit to produce an “ideal” track by retrospectively smoothing the data. The “ideal” track will indicate more accurately the actual path(s) of the aircraft concerned and can be used to distinguish scenarios which are genuinely severe from those which appear to be severe because of substantial errors in the recorded surveillance track.

4.7.5 Warning time calculator

Calculating the actual and available warning times for each scenario should be automated since it is a large and repetitive task with considerable scope for human error.

The warning time is calculated as the time between the alert and the PoR.

Since a predicted PoR may be of more use than the actual PoR if avoiding action was taken, the warning time should be calculated for all forms of PoR used in the optimisation.

4.7.6 Scenario editor / generator

Even when surveillance data is recorded for several days, it may be necessary to increase the number and diversity of the serious (Category 1 and 2) scenarios comprising the test sample.

This may be done by generating such situations artificially or by manipulating the track data of recorded tracks. This is often useful for checking the performance of algorithms for situations not yet encountered in real data. However, more appropriate indications of the function’s operation are given by collecting serious scenarios from the live ATM system.

It is possible to create totally artificial scenarios but this is likely to take a great deal of effort if the scenarios are to test APW in a realistic manner. However, it may be considered necessary to use simulated scenarios for formal test purposes.

5. Optimisation procedure

5.1 Overview

The following diagrams are intended to provide a guide to the various stages likely to be involved in the optimisation of APW. They will not, necessarily, match the exact pattern of stages involved in specific optimisations.

Figure 8 shows the main tasks involved in the first optimisation of APW. Some of the initial tasks may not need to be undertaken when the system is re-optimised at a later date.

Figure 9 and Figure 10 each provide a more detailed indication of the steps involved in a particular task shown in Figure 8.

Figure 9 shows the steps taken in the actual iterative process of determining the optimal parameters.

Figure 10 shows the steps involved in the operational trial of APW and its parameters.

These diagrams assume that the algorithms themselves are correct. If errors are detected in the algorithms, or other parts of the software, then the process may be aborted at any point.

The tasks are explained in more detail in the rest of this section.

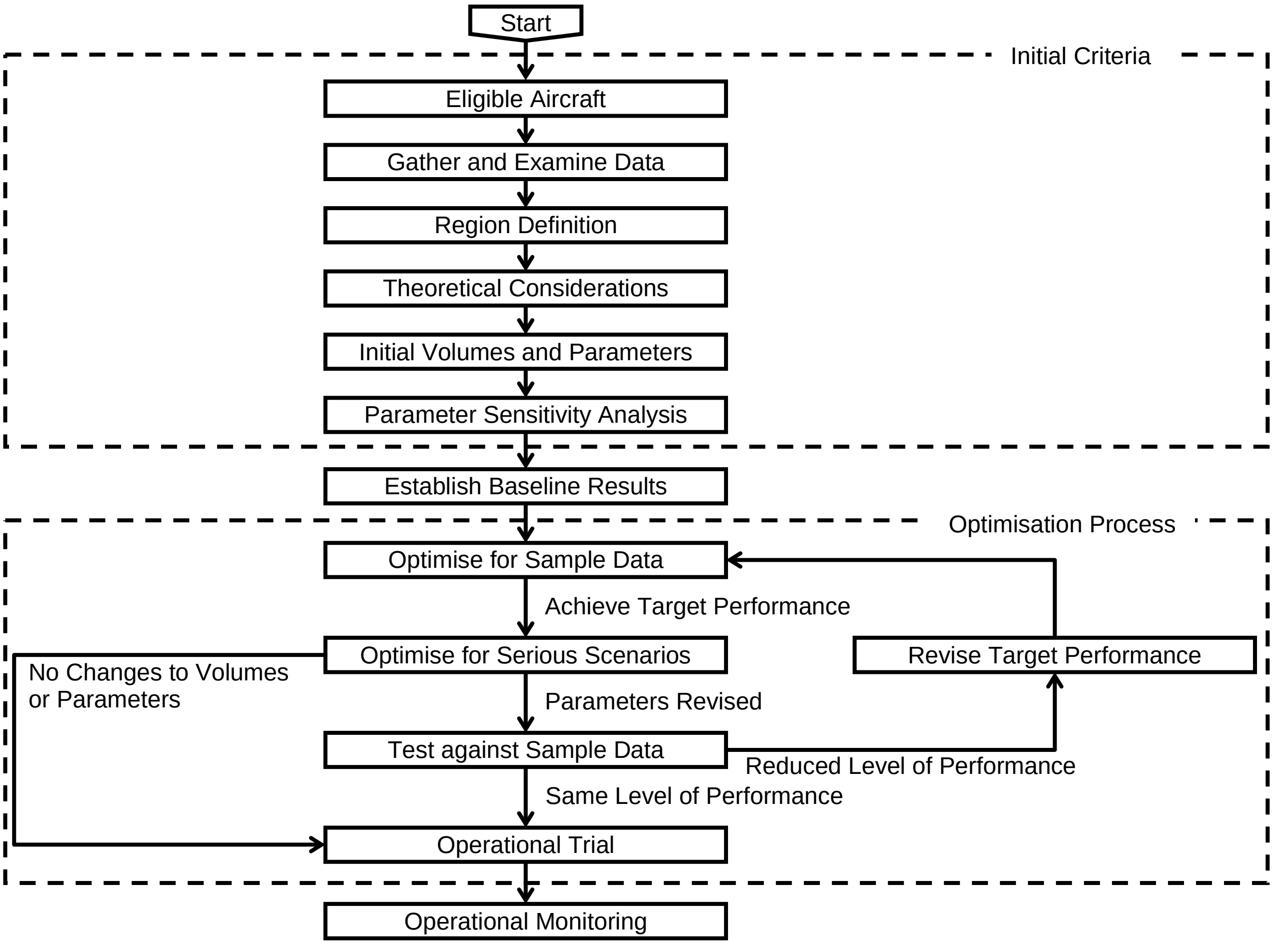
Start
Initial Criteria
Eligible Aircraft
Gather and Examine Data
Region Definition
Theoretical Considerations
Initial Volumes and Parameters
Parameter Sensitivity Analysis
Establish Baseline Results
Optimisation Process
Optimise for Sample Data
Achieve Target Performance
Optimise for Serious Scenarios
Revise Target Performance
No Changes to Volumes or Parameters
Parameters Revised
Test against Sample Data
Reduced Level of Performance
Same Level of Performance
Operational Trial
Operational Monitoring

Figure 8: System adaptation tasks

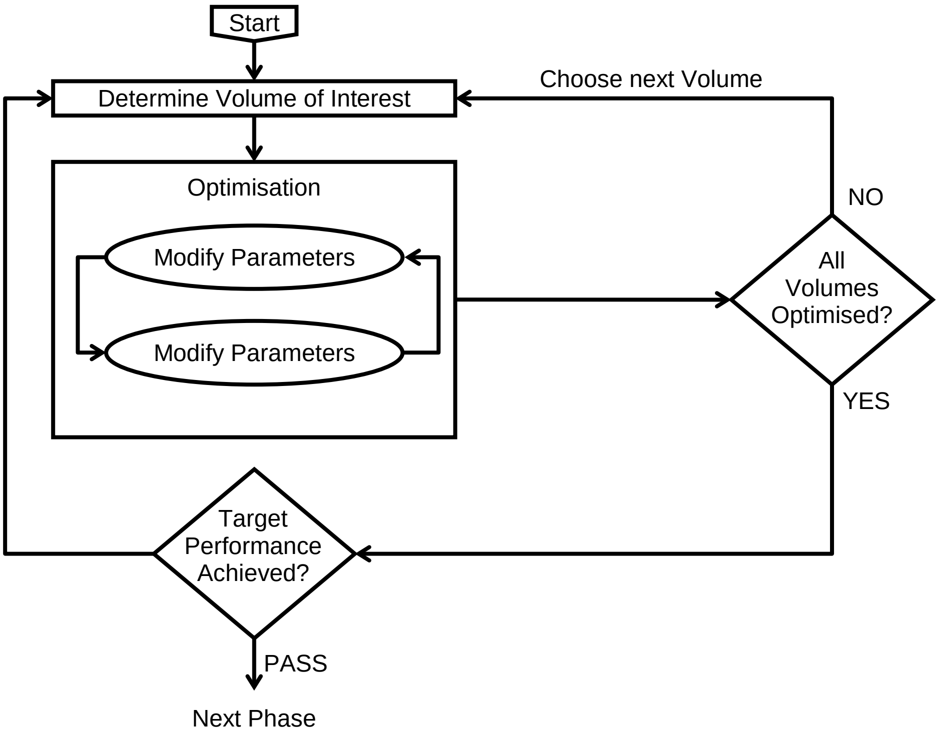

Figure 9: Iterative optimisation

Note: This iterative optimisation process applies to both sample and serious scenario data.

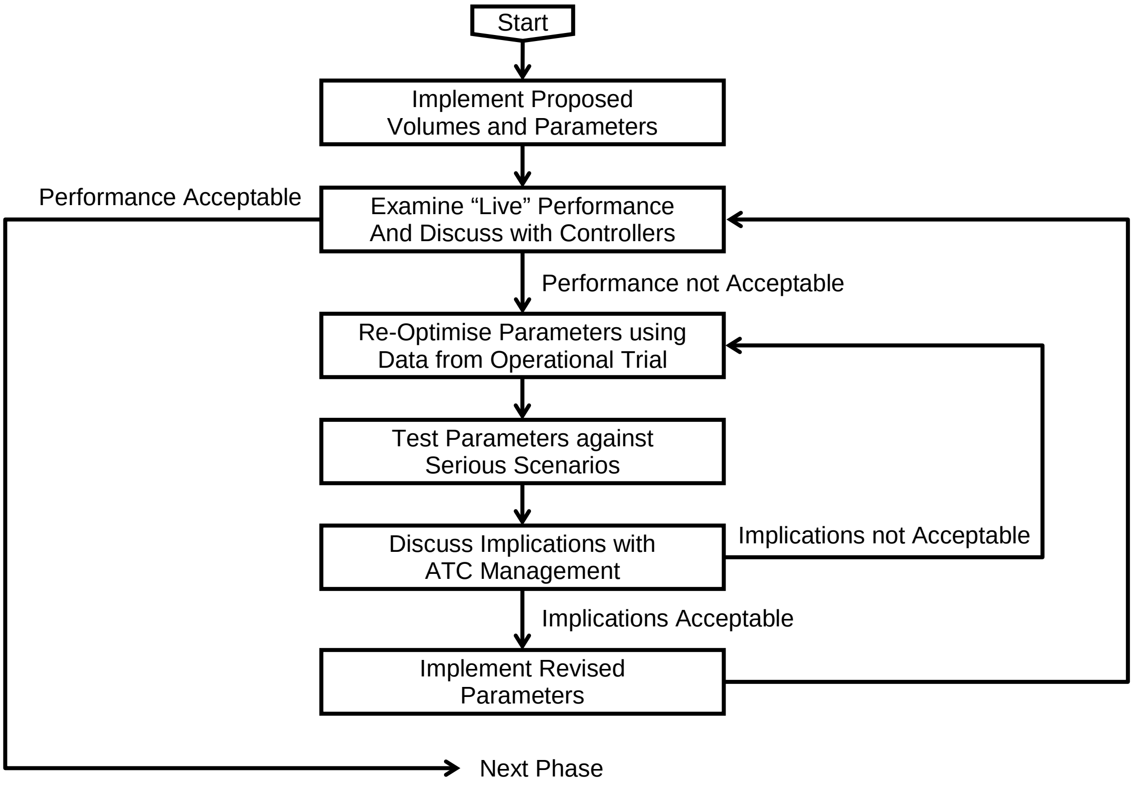
Start
Implement Proposed Volumes and Parameters
Performance Acceptable
Examine “Live” Performance And Discuss with Controllers
Performance not Acceptable
Re-Optimise Parameters using Data from Operational Trial
Test Parameters against Serious Scenarios
Discuss Implications with ATC Management
Implications not Acceptable
Implications Acceptable
Implement Revised Parameters
Next Phase

Figure 10: Operational trial

5.2 Initial criteria

5.2.1 Eligible aircraft

APW will normally use certain information about an aircraft in order to determine its eligibility for processing.

It is therefore vital that off-line APW simulations have correct information available as to the (in)eligibility of the aircraft in the data sets.

Where a list of SSR codes is used to determine eligibility, this may well prove to be the part of APW which is most frequently changed. Test data sets which include “historic” data may need to be reviewed to take account of changes in SSR code allocation. It should not be necessary to re-optimise APW parameters to take account of SSR code changes.

APW systems that use a link to Flight Data Processing to indicate eligibility may not require SSR code lists. However, off-line simulations may need some other mechanism to indicate those aircraft which are eligible since there will not necessarily be a link to a Flight Data Processing simulator.

5.2.2 Data

5.2.2.1 Sample data

It is important that sufficient data is used in the optimisations. In general, one month’s data from a busy period should provide a sufficient base sample. However, certain geometries or volumes of airspace may be under-represented and it may be necessary to modify existing data to create additional scenarios. The base sample should contain data for all typical traffic patterns.

It is possible to produce entirely artificial scenarios for test purposes. However, producing a sufficient number of realistic scenarios which conform to the appropriate traffic patterns may prove to be an excessively time-consuming task.

Ideally some data should also be collected at various times of the year and in different weather conditions since these are likely to affect the traffic patterns.

Furthermore, the collected data should include information about APW area activation/deactivation to be able to identify expected, unexpected and missing alerts.

5.2.2.2 “Serious” scenarios

The purpose of APW is to alert controllers to situations which have gone wrong. Such situations are not necessarily an everyday occurrence but it is important that APW is adequately tested against precisely these scenarios. It is therefore important that the appropriate data is obtained for “serious” scenarios over as long a period as possible. These serious scenarios can then be used to check that a parameter set optimised for sample data still provides satisfactory performance for real problem situations.

Care should be taken to ensure that serious scenarios, collected over a long period of time, are still representative of what could happen in the current airspace environment. For example, if changes to airspace, routes or procedures have been made some previously recorded incidents may need to be discarded.

5.2.2.3 Scenario categorisation

All scenarios should be categorised before they are used in the optimisation process. To do this, all scenarios should be run through the automatic categoriser and those described as worthy of an alert should then also be analysed manually. Where the automatic and manual categories differ, the manual categories should be used when measuring the performance of the system.

Scenario categorisation should take place every time new data is acquired for test or optimisation purposes.

5.2.3 APW volumes

Initial APW volumes have to be determined before the optimisation process may start.

Determining the appropriate APW volumes will normally involve discussions with controllers and examination of the traffic patterns evident from radar recordings and examination of aeronautical charts.

5.2.4 Theoretical considerations

5.2.4.1 Summary

Theoretical issues which need to be considered when determining APW volumes and parameters include:

- Typical aircraft performance capabilities
- Typical local traffic manoeuvres
- The definition of the airspace to be protected
- Desired warning times
- Surveillance data and tracking performance
- ATC operational procedures

These issues will provide practical limits to the APW adaptation parameters.

5.2.4.2 Typical aircraft performance capabilities

Aircraft performance should be considered, particularly in relation to maximum descent rates, and vertical accelerations. Under normal ATC operations, typical rates of vertical acceleration are in the region of 250 ft/min/s. However, in an emergency, many aircraft would easily be able to exceed this. APW should be able to deal with a representative mix of military/civil traffic on restricted areas boundaries.

5.2.4.3 Typical local traffic manoeuvres

In addition to the absolute limits on aircraft performance there will normally be additional limits imposed by different types of airspace and these also need to be considered. For example, normal routings may frequently bring aircraft into the vicinity of protected airspace, which may impose limits on the amount of prediction that can do made in APW before provoking an excessive nuisance alert rate.

5.2.4.4 Desired warning times

The minimum desired warning time is the time below which it may not be possible for a controller to issue an instruction and for the aircraft to have performed the necessary manoeuvre. This may constrain parameters related to warning time. Local variations in aircraft types and operations may result in corresponding variations in to the minimum desired warning time.

5.2.4.5 Surveillance tracking performance

The behaviour of the vertical tracker should be considered when setting the APW parameters and designing the volumes.

For example, it should be considered that tracker lag and (on occasion) vertical coasting can cause the aircraft to appear to overshoot a flight level by one or two hundred feet. Therefore, it is important that some vertical tolerance be added in order to avoid an excessive number of nuisance alerts.

Vertical rates, particularly at lower levels, can be inaccurate. This is especially true if the tracker is misled by one or more false mode C plots. Therefore, a conflict count mechanism may be used to reduce the number of nuisance alerts due to spurious tracks.

5.2.5 Initial parameter set

The initial optimisation process will not have an existing parameter set to use as a base-line. The initial parameter set is therefore determined from the theoretical criteria above, plus any other appropriate information. Future modifications to existing systems should normally use the operational parameter set as the base-line.

5.2.6 Parameter sensitivity analysis

5.2.6.1 Introduction

Before attempting to optimise the parameters it is important to know which ones have the most effect on the alert rate and how related parameters depend on each other. This allows effort to be directed appropriately during optimisation and helps to ensure that inconsistent or redundant parameter values are not used.

Parameter sensitivity analysis usually only needs to be performed once for a system since the sensitivity will not normally change. It may therefore not be necessary for an analysis to be performed before the optimisation of systems which have already been implemented at other ATS units.

5.2.6.2 Method

The first step in parameter sensitivity analysis is to pass appropriate radar data through the APW computer model, using the agreed base-line parameter set. The alert rates produced by this parameter set provide a reference level against which all future results may be compared.

Parameters may then be varied in turn to determine their effect on the alert rate. Parameters should normally only be varied within ranges which are consistent with the theoretical considerations discussed above.

The size of the increments over which each parameter is altered will initially be rather arbitrary, although the following factors may be taken into account:

- The time available for the task; it is better to try large increments first in order to discover where the greatest areas of alert change are. These areas of change may then be “filled in” by using smaller increments.
- Small increments are only needed around the area in which the optimum is believed to exist.

As well as changing the values of each parameter in turn, it is also necessary to examine the effect of varying combinations of related parameters. Appropriate groups of parameters should be determined from the specification for each individual system.

When the model has been used with all the proposed parameter sets the resulting alert rates need to be examined and compared. Graphs of alert rates for varying parameters may prove to be as, or more, useful than tables of results. It may be helpful if the graphs for groups of related parameters are superimposed.

5.2.6.3 Aspects of graphs for consideration

5.2.6.3.1 Graph shape

The alert rate may increase or decrease as the parameter value is increased. Alternatively the rate may be unaffected by changes in a particular parameter. This could indicate that the parameter under consideration is redundant given the other parameter values chosen or that the data sample does not test the relevant algorithm properly.

5.2.6.3.2 Gradient

The gradient of the graph indicates the sensitivity of the alert rate to changes of the parameter.

Measuring the gradient is easy for graphs with a constant slope. Where the slope is constantly changing, the gradient should be measured at significant points only, such as when the slope is at its maximum value or after a gradient change. Reasons for the changes in gradient should be sought. This information may, by itself, be sufficient to derive potentially optimal parameter values; however, any such values should, of course, be thoroughly checked during the optimisation process.

Parameter variations which produce a graph that changes its slope (especially those which change direction) must be investigated thoroughly. A change of slope could indicate that the parameter has a dual action or that it is used in different parts of APW. A change of slope could also indicate that the alert output includes possible errors - for example, a single continuous alert might be divided into two short alerts. Investigating such slope changes may require considerable effort and a detailed inspection of system debug information.

5.2.6.3.3 Superimposed graphs for different parameters

In some circumstances it may be useful to superimpose graphs to check for parameter interdependence. If the graphs of alert rate against a parameter value have different shapes for different values of a second parameter this could indicate that the parameters are interdependent. This would normally mean that the total alert rate change arising from the combined parameter change is different from the sum of the alert rate changes arising from the individual parameter changes.

It may be the case that one parameter will not affect the alert rate until a certain threshold value of the other related parameter has been reached.

Superimposed graphs may also show variations in the sensitivity of the alert rate to a parameter. A large difference in alert rate between similarly shaped graphs indicates that the alert rate is particularly sensitive to the parameter being varied to produce the different graphs.

5.2.6.3.4 Comparison of graphs

The parameter sensitivity data obtained from the graphs provides a means of prioritising the parameters for the main optimisation. However, since different parameters have different units it is not always possible to compare like with like when comparing graphs. This is particularly true when comparing vertical parameters with lateral ones. It is therefore more useful to consider parameter sensitivities in terms of the proportion of the change in alert rate that is produced by varying each parameter over the total viable range of values for that parameter.

The shape of the graphs is likely to be a useful guide to the relative importance of different parameters. Parameters which produce exponential graphs tend to be of more importance (for optimisation purposes) than those which produce linear graphs.

5.2.6.4 Parameter interdependencies

Parameter sensitivity analysis is also intended to indicate those parameters which are interdependent.

Parameter interdependencies can be used to supplement the external constraints in determining the viable ranges over which individual parameters should be optimised. Examination of the parameter interdependencies may also indicate inconsistencies in the APW algorithms themselves.

5.2.6.5 Results

When the parameter sensitivity analysis has been completed the following information should be available:

- A list of the most important parameters in terms of their effect on the alert rate (this gives a priority order for examining the parameters during optimisation)
- Hypotheses on optimal values for certain parameters (these may result in changes to the initial parameter set prior to the optimisation)

- Ranges for all the parameter values which ensure that external constraints and parameter interdependencies have been taken into account; in practice this means determining upper and lower bounds for each parameter, either in absolute terms or in terms of other parameter values; this minimizes the risk that inconsistent or redundant parameter values will be set
-

5.3 Baseline results

Once the initial volumes and other parameters have been set up, the adaptation should be run against the sample test data. This produces a set of results to be used as the baseline for the system adaptation process.

When optimisations are being performed on APW systems that are already in operation, the operational parameter set should normally be used to produce the baseline results.

5.4 Optimisation process

5.4.1 Procedure

The system adaptation process is undertaken at least twice - first with the sample data and then with the specially selected serious scenarios.

Precise instructions cannot be given for this process since its size and complexity will vary considerably between different systems, or even different optimisations of the same system. The efficient and effective optimisation of APW is dependent on the analysis team’s skill and knowledge of the system under examination.

The way in which the results from individual filter/parameter set combinations are scored will be largely dependent on the specific implementation under examination. However, the basic purpose of a scoring system is to assess the relative performance of each parameter set against targets.

It will not normally be possible to examine all the possible combinations of parameter values, or even all the viable combinations. The expertise of the analysis team is crucial in determining which combinations should be examined and which may be ignored.

The iterative optimisation process should be performed for all volumes. Note that in many APW systems, the parameters are globally applied to all volumes, so parameter values optimal for one volume may not be optimal for other volumes, and where such inconsistencies are found ANSPs may wish to make changes to the volumes in preference to the parameters. If parameters have been changed, it will be necessary to re-optimise for previously examined volumes.

When all the iterations have been performed, the values for the Performance Indicators should be determined for the parameter set / data set combination.

5.4.2 Optimise for sample data

The system is initially optimised for the sample test data set. This should produce a parameter set which provides acceptable system performance in normal circumstances (according to the target performance requirements).

5.4.3 Optimise for serious scenarios

The optimised system should then be tested against a set of serious incidents, to ensure that all such scenarios lead to an alert and that, where possible, the warning times provided are adequate.

If the parameter set does not need to be re-optimised for the serious scenarios, it is suitable for use in an operational trial. However, if the parameter set does need to be re-optimised for the serious scenarios it must then be re-tested against the sample data.

5.4.4 Test against sample data

In theory, the parameter set that has been optimised for the serious scenarios should give the same or a lower level of performance when tested against the sample data than the parameter set which was optimised for the sample data. (If it gives improved performance, the original optimisation for the sample data was incorrect.)

If the revised parameter set gives the same level of performance, it can be adopted for use in the operational trial. If it gives a lower level of performance then further re-optimisation may be necessary. It may be that no one parameter set can give optimal results for both data sets. In this case some degree of compromise is necessary. The serious incidents should all be alerted but it may be that some degree of flexibility must be given to the warning times in some cases. Nuisance alert rates for the sample data may have to be allowed to increase above the minimum achievable values in order to alert all the serious scenarios.

5.4.5 Operational trial

When APW has been optimised and tested off-line it should be subjected to an operational trial in the “live” ATC environment before being declared fully operational. This is because of the risk that an off-line optimisation could miss “real world” problems.

An operational trial also gives controllers the opportunity to make comments which can be incorporated into the “final” system and should, therefore, help to develop confidence in the system. The operational trial presents a suitable opportunity for the system objectives to be explained to the controllers. If controllers are not aware of the objectives, and limitations, of the system then their participation in the trial will be of limited value.

An operational trial would normally perform the following functions:

- Ensure APW functions correctly in the operational environment
- Test APW under a variety of conditions, such as traffic levels and weather
- Provide information on APW to controllers
- Enable feedback from controllers on APW

An operational trial will also provide information on the controllers’ perception of the nuisance alert rate. This is vital since an excessive number of nuisance alerts will lessen the impact of genuine alerts and thus reduce the potential effectiveness of APW. An acceptable nuisance alert rate can only truly be determined by operational experience.

The operational trial may highlight problems requiring further revision of the parameter set. This will involve the repetition of some tasks for the previous phases of the optimisation. If possible, the data from the operational trial period should be available so that proposed solutions can be tested on the scenarios which revealed the problems. Revised parameter sets should again be run against the serious scenarios data set.

5.5 Operational monitoring

Traffic patterns, airport equipage, SSR allocations and ATC practice all change with time. These factors have a bearing on the “optimum” parameter set for APW. System adaptation should, therefore, be regarded as a continuing process which does not necessarily cease once the system goes operational. The performance of the system should be kept under review and the optimal parameter set checked from time to time. It is also important to establish operational monitoring procedures so that technical problems may be detected as early as possible.

6. Guidelines for recording APW data

6.1 Introduction

When discussing data recording, it is essential to distinguish between data that is be recorded routinely, such as for system monitoring or legal replay, and data that is recorded only on occasion, such as for system verification.

The quantity of data that is required for full system verification is often very much bigger than is recorded during normal ATC operation. If a large quantity of data were recorded routinely the data recording media would fill very rapidly.

This section should be viewed as guidance only. The material is intended to give an indication as to the type and detail of data that is required for full system verification. Clearly, certain data items will not be relevant to all APW systems.

6.2 Routine data recording

In most ATC systems, data such as radar plots, system tracks, alert messages, flight plan data and controller inputs on the display are continuously recorded to allow a legal replay, if required at a later date.

The APW data that is recorded routinely generally includes the alert messages and may also include APW status (or alive, or heartbeat) messages. Other information related to APW may also be routinely recorded, such a flight plan data, volume activations/deactivations and QNH.

6.3 Occasional data recording

6.3.1 General

Data that is recorded for system verification should include not only the alert messages but also the data values and flags throughout the complete logical chain. In this case, the recorded APW data must contain sufficient information and must be precise enough to allow the correct functioning of APW to be verified.

If a test APW system is used for system adaptation then at the very least, the APW alerts must be recorded. However, it is often valuable to be able to analyse individual alerts in detail, in which case the full internal data values and flags can prove very informative.

In this section, an item of recorded data is defined either as required or as desirable. Required items are essential to allow a basic analysis of APW functioning, whilst desirable items of data may provide further valuable details.

Recorded data may be grouped as follows:

- Environment data (desirable, but may be obtained from elsewhere)
- All system tracks available to APW (desirable on occasion, but bulky)
- System tracks that are subject to APW processing (required)
- Values calculated for the track during APW processing (required)
- Flags and results of conflict detection processes (required)
- Alert messages (required)

- Additional information such as QNH (required) or temperature (if relevant), as well as APW volume activations/deactivations including possible changes of vertical span at activation time

To conserve space, the data is best recorded in a binary format. The data will almost inevitably be recorded in time order. However, the format must allow information to be extracted on the basis of aircraft track trajectories (using a system track reference number), so that the inputs to APW and the APW functioning and output can be analysed on a track by track basis.

It is also useful to be able to select which data items will be recorded. For example, recording all the system tracks will take up a large amount of file space and may not be required on a regular basis.

6.3.2 Environment data

It is convenient to include all relevant environment data at the start of the data recording. This data should include all APW parameters, volumes, as well as any other items related to APW processing such as QNH regions.

Without this information in the file, it may be difficult to establish the environment data in use at the time of the recording.

6.4 System tracks

Despite its inevitable size, it is sometimes desirable to record all the system tracks that are presented to APW. This would allow the correct functioning of the eligibility criteria and any pre-filtering to be tested.

Note that this same system track data may also be common to other system functions (e.g. other safety nets).

6.5 System tracks that are relevant to APW

All the tracks that are relevant to APW are required in the recorded data file.

Since APW systems do not usually include a coarse filter, some criteria may need to be set to exclude the majority of tracks that are far from the airspace of interest. It is suggested that tracks should be recorded if they are eligible for APW processing and they are within a defined distance of one or more specific points of interest.

The track data must include all the track information relevant to APW in sufficient precision to allow a full analysis of each situation.

The information required for each track is listed below:

- System track number
- SSR code
- System track time
- System track eligibility information
- 3D state vector (X, Y, Z, VX, VY, VZ) and true altitude
- Track age and quality information used by APW
- Data such as the type of flight, call sign, CFL, SFL (if used)

6.6 Values calculated before or during the conflict detection filters

The values calculated before or during the conflict detection filters should be sufficient to allow the APW functioning to be adequately examined. The information should include:

- The track number for the track of concern
- The current aircraft altitude
- The CFL and/or SFL (if any) that was used in the prediction
- An identifier for the volume with which the aircraft is in conflict
- The time of violation of an APW volume TOV (if infringed)
- The 3D position of the aircraft at TOV

All the values must be recorded with sufficient precision to allow a proper analysis to be done. Precision of at least 0.01 NM, 1 ft, 1 kt, 0.1 ft/s and 0.1 s is recommended.

6.7 Flags and fine filter results

Flags are the true or false results of essential tests in the APW system. They allow the user to follow the logic of the APW processing and to see the reason why there was or was not a conflict for a particular track.

Depending on the features of the APW system, the flags required in the data file may include:

Flags before the Conflict Detection Filters:

- Track is eligible for APW processing (or reasons for non-eligibility)

APW Conflict Filter Flags:

- APW conflict filter called
- APW conflict result (hit or miss) in this cycle

APW Conflict Alert Confirmation Flags:

- Conflict is current (i.e. aircraft is in an APW volume)
- Count of conflict hits is sufficient (>= **ConflictCount**)
- Time of violation, TOV, is within **WarningTime**
- APW alert is confirmed

6.8 Alert messages

An APW alert message must be included in the recorded data for each cycle that an alert is in progress. The information required is:

- The system track number
- APW volume identifier
- Any other information relevant to the alert

6.9 Additional information

This data will depend on the particular APW system, but may contain

- Changes to the QNH
- Changes in the local temperature
- APW volume activations/deactivations

7. Test scenarios for APW

7.1 Purpose of these scenarios

The purpose of this section is twofold:

- To provide a description of simulated scenarios that could be used to test the alerting performance of an APW system
- To demonstrate the variety of types of situation for which APW is expected to perform

Each test scenario indicates a target result, assuming that the reference APW system is used with given parameter values. However, in practice, the result of each scenario will depend upon the chosen APW parameter values and the capabilities of the particular APW system. Therefore, only some of the scenarios presented here might be valid for the APW system under test. In practice, some may require minor modification or extra scenarios may be required to test specific elements of the APW system.

The test scenarios are useful to demonstrate the variety of conflict situations that can occur between aircraft. It is not desirable to improve the alerting performance for one type of situation at the expense of alerting in other situations. Therefore, as part of the system adaptation process, the full variety of situations must be considered.

Since APW performance depends so heavily on local factors (airspace, traffic etc.), only a few of the scenarios have a target result indicated.

7.2 The test scenario situation pictures

Each test scenario includes a situation picture. This picture comprises a horizontal situation picture, a vertical situation picture and a brief description of the encounter. The horizontal situation picture presents a plan view of the situation. The vertical situation picture presents a vertical profile of the situation, with the flight level plotted on the y-axis against time on the x-axis. The times at which significant events occur may also be shown on the pictures.

All (x, y) coordinates are relative coordinates. The coordinates and flight levels should be relocated to appropriate values in the environment for which the APW system under test is optimised.

7.3 List of test scenarios

The test scenarios are:

- Aircraft descends into protected airspace
- Aircraft climbs into protected airspace
- Aircraft flying level into protected airspace
- Departure from level flight towards protected airspace
- Climbing aircraft levels off at an unsafe altitude
- Aircraft track starts in immediate conflict with an APW volume
- Aircraft track starts within an APW volume

7.4 Aircraft descends into protected airspace

7.4.1 Objective

The objective of this scenario is to test APW performance in the simple case of an aircraft descending to infringe an APW volume.

7.4.2 Aircraft geometry

The simulated aircraft is arranged to infringe an APW volume with a ceiling at FL150 at time t = 120 s after the start of the scenario. The aircraft descends from FL170 at a vertical rate of 1 000 ft/min. The aircraft is fully eligible for APW processing. The scenario is depicted in Figure 11.

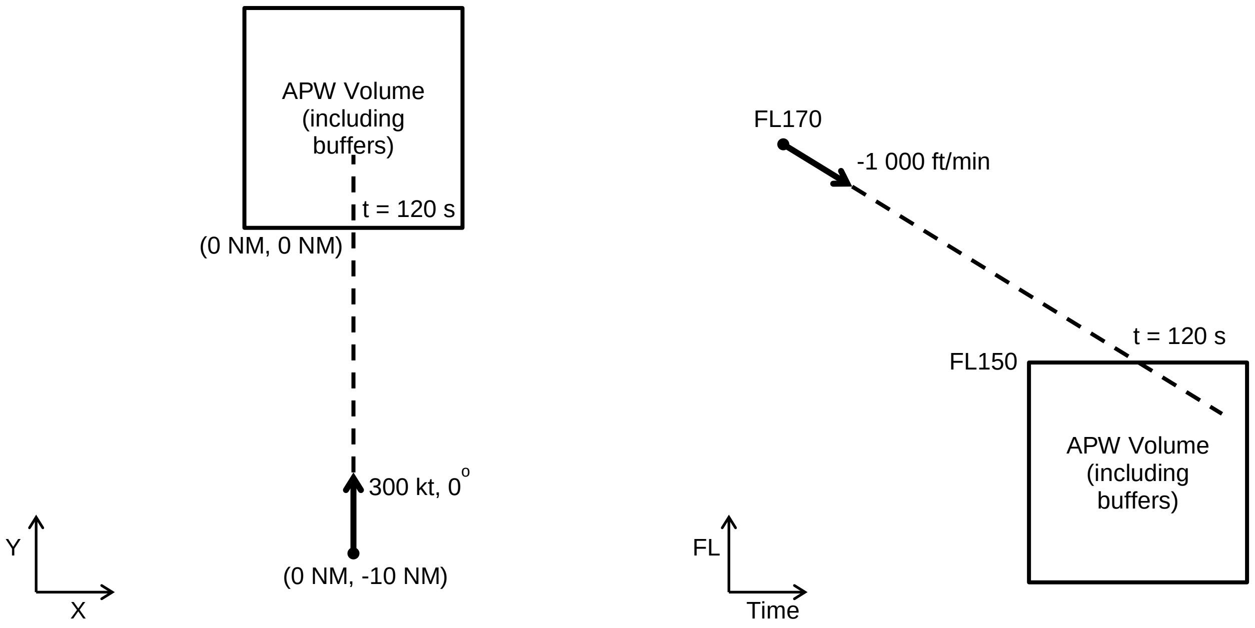

Figure 11: Aircraft descends into protected airspace test scenario

7.4.3 Significant parameters

The exact timing of any APW alert will depend on the following parameters:

- **WarningTime**
- **ConflictCount**

7.5 Aircraft climbs into protected airspace

7.5.1 Objective

The objective of this scenario is to test APW performance in the simple case of an aircraft climbing to infringe an APW volume.

7.5.2 Aircraft geometry

The simulated aircraft is arranged to infringe an APW volume with a floor at altitude 3 000 ft at time t = 120 s after the start of the scenario. The aircraft climbs from an altitude of 1 000 ft at a vertical rate of 1 000 ft/min. The aircraft is fully eligible for APW processing. The scenario is depicted in Figure 12.

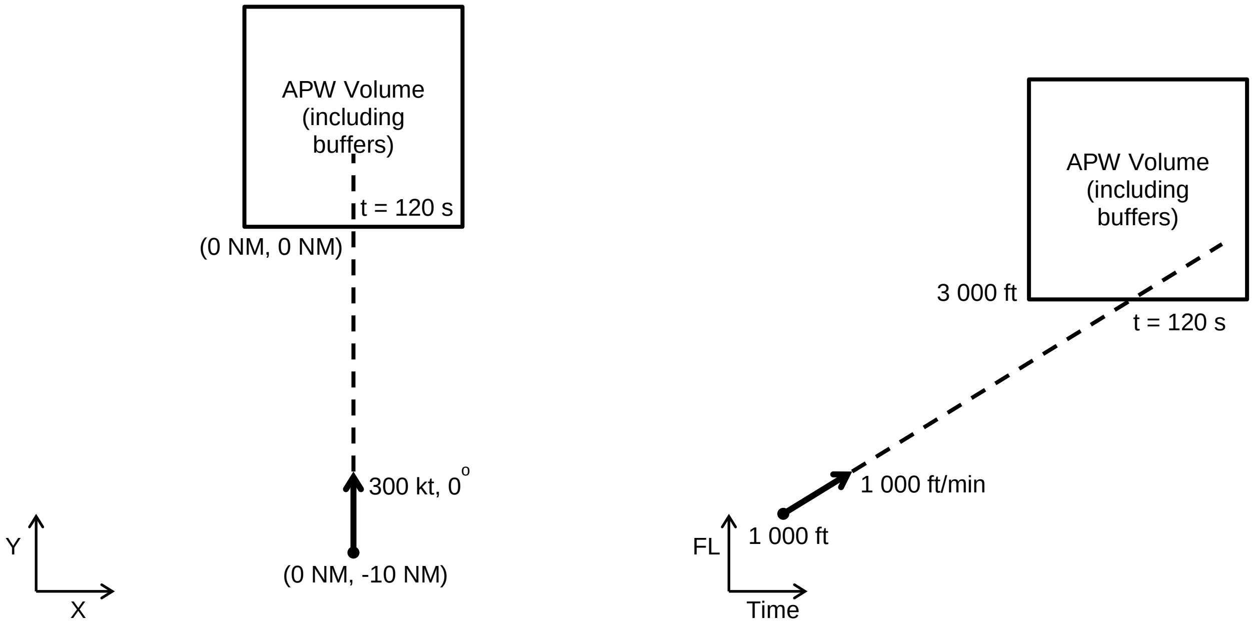

Figure 12: Aircraft climbs into protected airspace test scenario

7.5.3 Significant parameters

The exact timing of any APW alert will depend on the following parameters:

- **WarningTime**
- **ConflictCount**

7.6 Aircraft flying level into protected airspace

7.6.1 Objective

The objective of this scenario is to test APW performance in the case of an aircraft flying level into an APW volume.

7.6.2 Aircraft geometry

The simulated aircraft is arranged to infringe an APW volume at time t = 120 s after the start of the scenario at coordinate (0 NM, 0 NM). The aircraft is level at FL130. The aircraft is fully eligible for APW processing. The scenario is depicted in Figure 13.

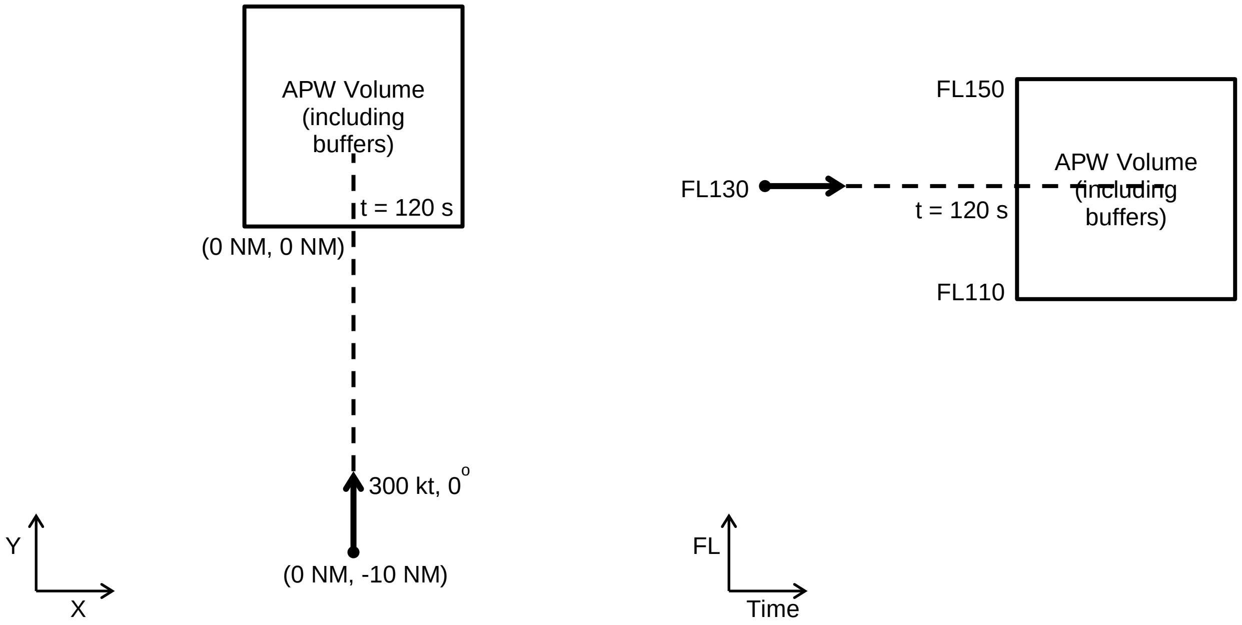

Figure 13: Aircraft flying level into protected airspace test scenario

7.6.3 Significant parameters

The exact timing of any APW alert will depend on the following parameters:

- **WarningTime**
- **ConflictCount**

7.7 Departure from level flight towards protected airspace

7.7.1 Objective

The objective of this scenario is to test APW performance in the case of an aircraft descending suddenly towards an APW volume.

7.7.2 Aircraft geometry

The simulated aircraft starts in level flight at 3 500 ft. Then, the aircraft descends suddenly at 1 500 ft/min towards an APW volume with a ceiling of 3 000 ft. The aircraft is fully eligible for APW processing. The scenario is depicted in Figure 14.

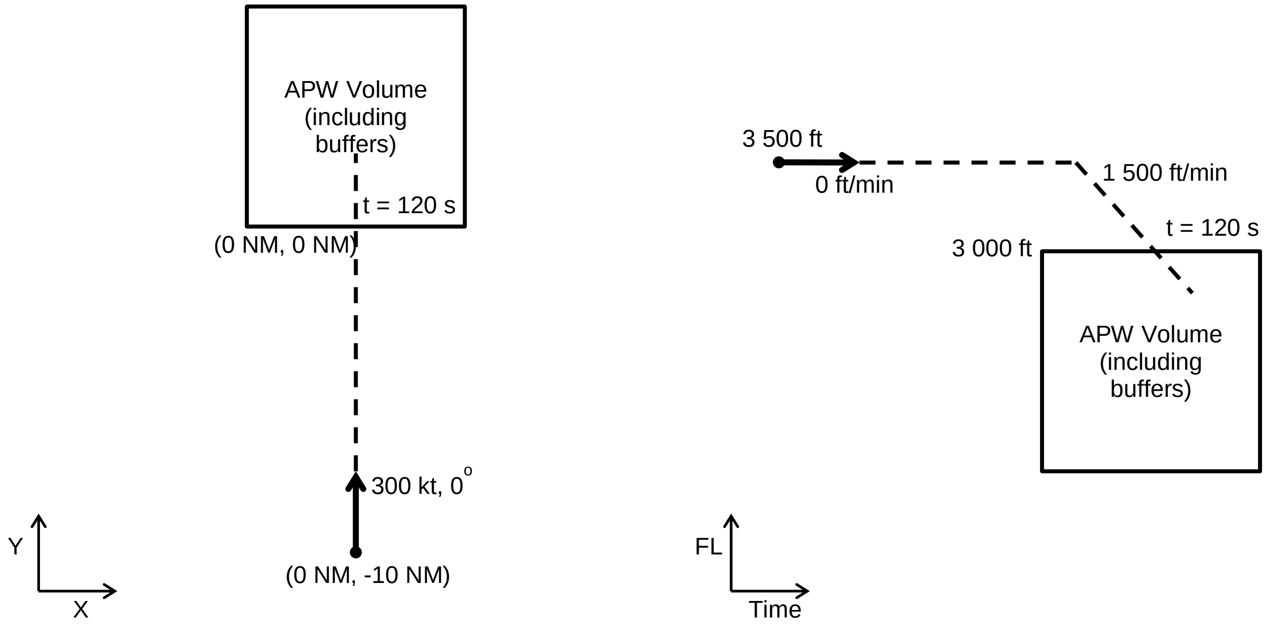

Figure 14: Departure from level flight towards protected airspace test scenario

7.7.3 Significant parameters

The exact timing of any APW alert will depend on the following parameters:

- **WarningTime**
- **ConflictCount**

7.8 Climbing aircraft levels off at an unsafe altitude

7.8.1 Objective

The objective of this scenario is to test APW performance in the case of an aircraft climbing, but then levelling off before clearing the ceiling of an APW volume.

Without use of CFL and/or SFL, APW can alert soon after the aircraft has levelled off.

With use of CFL and/or SFL, the CFL and/or SFL is correctly used for the calculation of the vertical violation in the APW conflict detection filter and leads to an alert well before the level off.

7.8.2 Aircraft geometry

The simulated aircraft is initially at FL110 and climbing at 2 000 ft/min. The climb rate is just sufficient to clear an APW volume, which has a ceiling at FL140. However, the aircraft levels off 60 s from the start of the scenario, at FL130 below the APW volume. The aircraft is fully eligible for APW processing. The scenario is depicted in Figure 15.

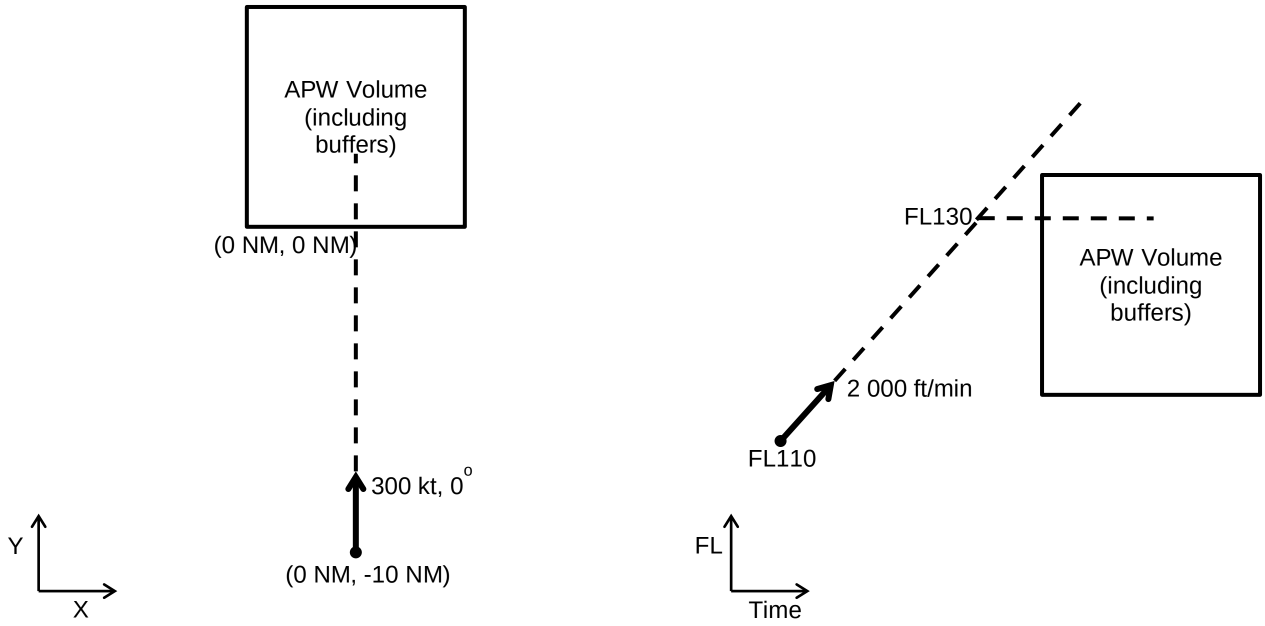

Figure 15: Climbing aircraft levels off at an unsafe altitude test scenario

7.8.3 Target result

Without CFL and/or SFL, the APW system should alert within 3 cycles of the aircraft levelling off.

With CFL and/or SFL used by the APW system and with a CFL and/or SFL of FL130 input for the aircraft, it should be possible for APW to alert before the aircraft levels off.

7.8.4 Significant parameters

The following parameters are significant to this scenario:

- **UseCFL**
- **UseSFL**
- **WarningTime**
- **ConflictCount**

7.9 Aircraft track starts in immediate conflict with an APW volume

7.9.1 Objective

The objective of this scenario is to test APW performance in the case that an aircraft track initiates, or become eligible for processing close to an APW volume.

7.9.2 Aircraft geometry

The simulated aircraft is arranged to infringe an APW volume at time t = 12 s after the start of the scenario at coordinate (0 NM, 0 NM). The aircraft is level at FL130. The aircraft is fully eligible for APW processing. The scenario is depicted in Figure 16.

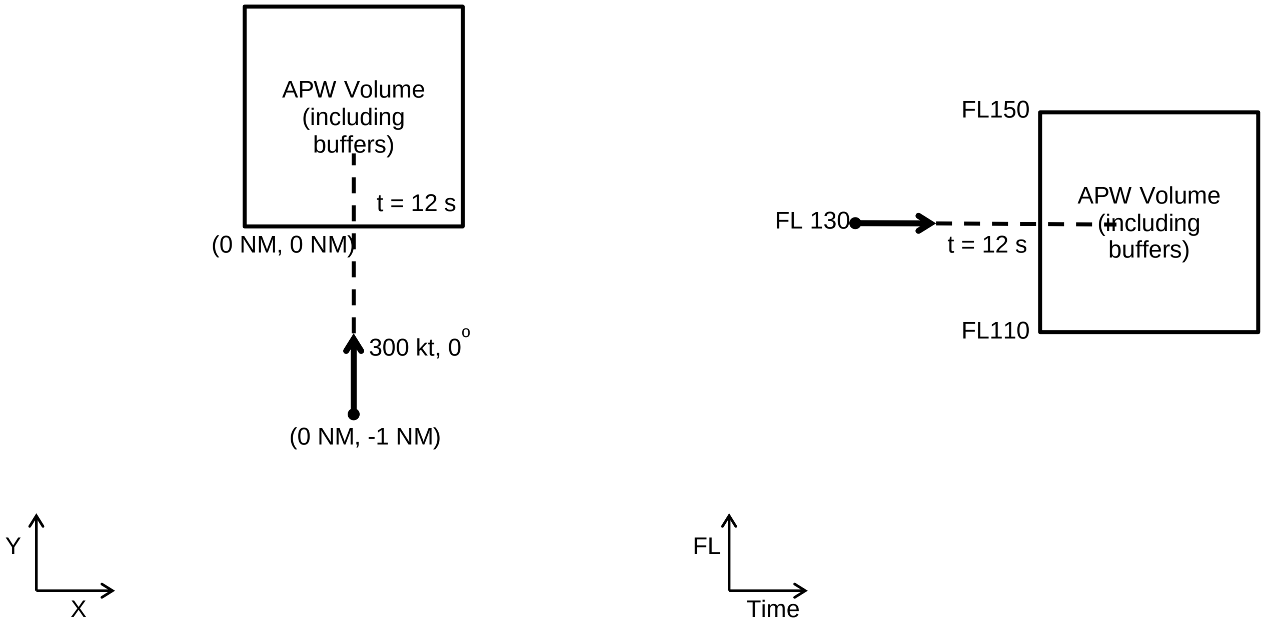

Figure 16: Aircraft track starts in immediate conflict with an APW volume test scenario

7.9.3 Significant parameters

The exact timing of any APW alert may depend on the following parameters:

- **WarningTime**
- **ConflictCount**

7.10 Aircraft track starts within an APW volume

7.10.1 Objective

The objective of this scenario is to test APW performance in the case that an aircraft track initiates, or become eligible for processing inside an APW volume.

7.10.2 Aircraft geometry

The aircraft geometry is not significant to this scenario. The simulated aircraft is arranged to start within an APW volume. The aircraft is fully eligible for APW processing. The scenario is depicted in Figure 17.

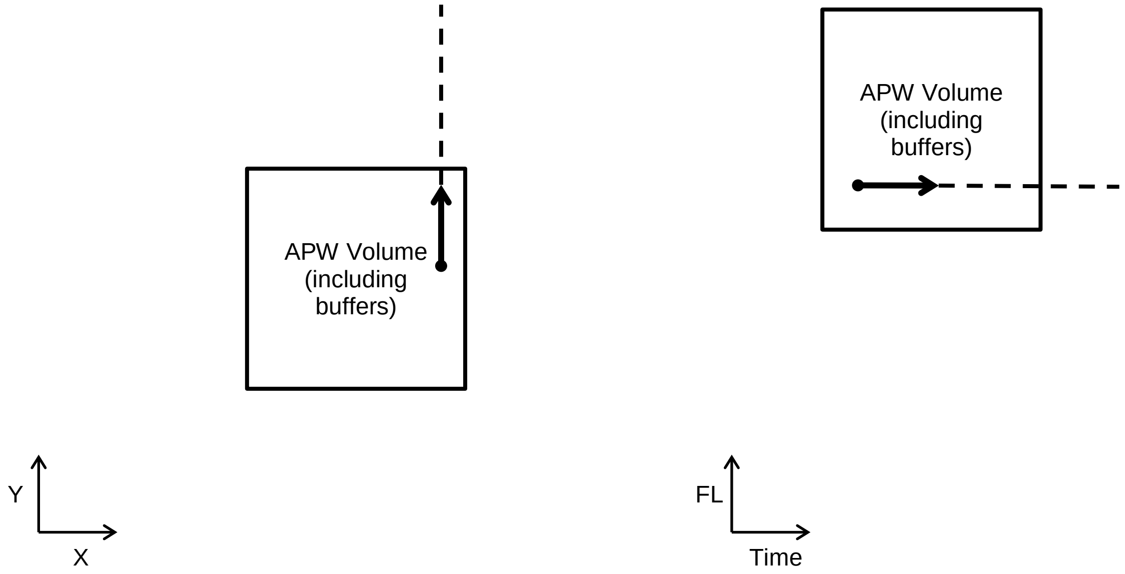

Figure 17: Aircraft track starts within an APW volume test scenario

7.10.3 Significant parameters

The exact timing of any APW alert may depend on the following parameter:

- **ConflictCount**

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