EUROCONTROL Guidelines for Minimum Safe Altitude Warning - Part III

Implementation and Optimisation Examples

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EUROPEAN ORGANISATION
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EUROCONTROL Guidelines for Minimum Safe Altitude 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 Minimum Safe Altitude Warning (MSAW).

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

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

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

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EXECUTIVE SUMMARY

These Guidelines specify the minimum requirements and provide comprehensive guidance for the definition, implementation, optimisation and operation of Minimum Safe Altitude Warning (MSAW).

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.

MSAW is a ground-based safety net that warns 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.

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

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

Together with similar Guidelines for Short Term Conflict Alert (STCA), Approach Path Monitor (APM) and Area Proximity Warning (APW) 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

MSAW is 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.

Part I of the EUROCONTROL Guidelines for MSAW 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 MSAW is providing practical technical guidance material on MSAW, 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 MSAW system in technical detail. This chapter allows the reader to understand how MSAW systems work and to compare various options for MSAW. The chapter specifies the inputs to the MSAW system, describes the common algorithms used to detect conflicts and defines the MSAW parameters. Some additional features are described which are present in only some existing MSAW systems.

Chapter 3 provides guidance for the use of digital terrain data.

In chapter 4, guidance is provided in setting appropriate values for the parameters defined in the reference MSAW system. Even without using a full parameter optimisation process, the effect of some of the parameters in MSAW can be foreseen. The risks of using certain “poor” parameter values are highlighted, allowing the user to make a better choice of parameter values.

The principles of parameter optimisation are described in chapter 5 and 6. The optimisation concepts are described in chapter 5 and the optimisation procedure is described in chapter 6.

Chapter 7 describes the data that should be recorded in order to do adequate testing of the MSAW system.

Chapter 8 comprises a description of test scenarios that could be used to test, validate, certify or inspect an MSAW system. Furthermore, these scenarios also serve to demonstrate the variety of types of situation for which MSAW is expected to perform. Some of the test scenario descriptions usefully show the effect of certain parameter values in the context of typical MSAW-related situations.

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.
altitude [Doc 4444]	The vertical distance of a level, a point or an object considered as a point, measured from mean sea level (MSL).
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.
elevation [Doc 4444]	The vertical distance of a point or a level, on or affixed to the surface of the earth, measured from mean sea level.
false alert	Alert which does not correspond to a situation requiring particular attention or action (e.g. caused by split tracks and radar reflections).
flight level [Doc 4444]	A surface of constant atmospheric pressure which is related to a specific pressure datum, 1 013.2 hecto-pascals (hPa), and is separated from other such surfaces by specific pressure intervals. Note 1: A pressure type altimeter calibrated in accordance with the Standard Atmosphere: a. when set to a QNH altimeter setting, will indicate altitude; b. when set QFE altimeter setting, will indicate height above the QFE reference datum; c. when set to a pressure of 1 013.2 hPa, may be used to indicate flight levels. Note 2: The terms "height" and "altitude", used in Note 1 above, indicate altimetric rather than geometric heights and altitude.
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.
height [Doc 4444]	The vertical distance of a level, a point or an object considered as a point, measured from a specified datum.

human performance [Doc 4444]	Human capabilities and limitations which have an impact on the safety and efficiency of aeronautical operations.
level [Doc 4444]	A generic term relating to the vertical position of an aircraft in flight and meaning variously, height, altitude or flight level.
nuisance alert	Alert which is correctly generated according to the rule set but is considered operationally inappropriate.
minimum safe altitude warning [derived from Doc 4444]	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 [derived from Doc 4444]	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
CFIT	Controlled Flight Into Terrain
CFL	Cleared Flight Level
CPU	Central Processing Unit
DTED	Digital Terrain Elevation Data
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
FAT	Factory Acceptance Test
FDPS	Flight Data Processing System
FUA	Flexible Use of Airspace
GAT	General Air Traffic
HMI	Human Machine Interface
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ISA	International Standard Atmosphere
MOCA	Minimum Obstacle Clearance Altitude
MSAW	Minimum Safe Altitude Warning Note: Not to be confused with MSA (Minimum Sector Altitude)
MRVA	Minimum Radar Vectoring Altitude
MSA	Minimum Sector Altitude
MSL	Mean Sea Level
OAT	Operational Air Traffic
PoR	Point of Risk
QFE	Atmospheric pressure at aerodrome elevation *(or at runway threshold)*
QNH	Altimeter sub-scale setting to obtain elevation when on the ground
RVSM	Reduced Vertical Separation Minima
SAT	Site Acceptance Test
SES	Single European Sky
SESAR	Single European Sky ATM Research
SFL	Selected Flight Level
SID	Standard Instrument Departure
SRC	Safety Regulation Commission
SSR	Secondary Surveillance Radar
STAR	Standard Arrival Route
STCA	Short Time Conflict Alert
TOV	Time Of Violation
VFR	Visual Flight Rules

2. The reference MSAW system

2.1 Inputs to MSAW

2.1.1 System tracks

For the reference MSAW 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 3D state vector is the fundamental information used to predict the aircraft's future position. Note that for MSAW the height value used is QNH corrected (i.e. derived from the pressure altitude, tracked and QNH corrected).

Other data, such as system track ages or accuracy estimates, may be present in the system and these data items may be used by MSAW to assess the quality of the tracks. Tracks of insufficient quality may be rejected by MSAW.

Although it is very rare for MSAW to process aircraft tracks without pressure altitude, the feature may be activated in some systems. A variety of ways that MSAW can process aircraft tracks without pressure altitude is described in a later section.

2.1.2 Environment data

Environment data includes terrain and obstacle data, either as a number of polygon volumes, or as a fine mosaic of terrain elevations (sourced from digital data) and additional obstacle definitions. Environment data also comprises MSAW parameters, QNH data and QNH regions.

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.

Some MSAW systems 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 at 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.

2.1.3 Additional flight information

It is assumed that the reference MSAW system is capable of using certain additional flight information. Most essentially, the MSAW system must recognize which tracks belong to aircraft under the responsibility of the ATS unit. If the aircraft is under ATC, then MSAW processing will be performed.

Determination of whether an aircraft is under ATC or not, may be done in a variety of ways. In some MSAW 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 MSAW 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 MSAW systems also allow the controller to exclude individual aircraft from MSAW processing based on either the SSR code or the aircraft call sign.

In some MSAW systems, the CFL and/or the SFL are used by the MSAW 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, prioritization 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 MSAW system it is good practice to draw the controllers' attention, after an appropriate delay, to the fact that CFL and SFL values disagree.

2.2 Minimum surveillance requirements for MSAW

MSAW relies on being provided with accurate and reliable surveillance track information.

High ground and the natural curvature of the earth will lead to many areas of the airspace having no surveillance cover below a certain level. MSAW generally relies upon there being sufficiently low level surveillance coverage in the areas of concern, although some mitigation may be possible by applying overly large MSAW polygons in areas of poor coverage.

2.3 System tracks eligible for MSAW

Most essentially, the MSAW system must recognize which tracks belong to aircraft under responsibility of the ATS unit, and for which tracks MSAW alerts are relevant.

Depending on local requirements, the determination of system track eligibility can be done in a variety of ways. In many MSAW systems, only tracks that are correlated with a flight plan are processed. Alternatively, the SSR code of the track may be used to determine whether the track should be processed.

An MSAW inhibition list is often part of the off-line MSAW parameters. In this respect it is a static list that would be updated when necessary by technical or supervisory staff. On the other hand, some MSAW systems allow the controller to selectively inhibit alerts for VFR aircraft, or selectively inhibit alerts based on call sign or SSR code.

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

- Have a tracked pressure altitude (from surveillance data processing), but see next section
- Be under the responsibility of the ATS unit.
- Have sufficient track quality
- Have a SSR code (Mode A) that is not on an MSAW inhibition list

2.4 Processing system tracks without pressure altitude

Some MSAW systems have the option to process aircraft that have no pressure altitude. If an aircraft has no pressure altitude, and if no assumption is made about the aircraft's height, an MSAW conflict will occur as soon as the aircraft penetrates the horizontal boundary of an MSAW polygon. Processing aircraft without pressure altitude in this way generates a very large number of unwanted alerts.

There are at least two recognized methods for processing aircraft that do not have pressure altitude.

The first method is to allow the controller to manually input a flight level for aircraft without pressure altitude. Tracks with a manually input flight level would be processed by MSAW in the normal way with the assumption made that the aircraft remains at its manually input flight level.

The other approach is that on loss of Mode C, an altitude band is assumed. This band increases with time. Once the Mode C loss reaches a particular age then no MSAW processing is done on this aircraft, since the assumed levels are deemed unreliable.

2.5 MSAW polygons, terrain and obstacles

In many cases MSAW uses polygon volumes to model terrain and obstacles. The polygon volumes may be set several hundred feet below the lowest minimum safe altitudes that could be applicable (Minimum Radar Vectoring Altitude (MRVA), Minimum Obstacle Clearance Altitude (MOCA) or Minimum Sector Altitude (MSA) as appropriate), or if desired may be set to more closely follow the terrain.

The margin of several hundred feet must be allowed for tracker lag and apparent undershoot of safe altitudes. That is, the polygon volumes must be below the lowest minimum safe altitude, otherwise almost every aircraft that levels off at the safe altitude will generate a nuisance alert.

Digital terrain data based on satellite survey information or other sources provides a more precise terrain definition for MSAW. An additional height margin should be added to the terrain elevation to take account of temporary obstacles (e.g. cranes) and vegetation.

MSAW may allow obstacles (e.g. towers, radio masts) to be specified as polygons or as cylinders with a defined altitude limit. This feature of MSAW systems is particularly suited to supplement digital terrain data, since the terrain data itself does not include obstacle information.

The size of each obstacle volume does not necessarily need to match the size of the object. Indeed, it is prudent to add horizontal and vertical safety margins to the obstacle definition. If necessary, one or more polygons or cylinders may be used to represent a cluster of objects, or an object with a complicated shape.

2.6 MSAW configurations with and without digital terrain data

2.6.1 Configuration 1 – use of polygons

Terrain and obstacles are modelled by a mixture of polygon and cylinder-shaped volumes.

Figure 1 shows in profile how the MSAW surface may be designed using polygons to define the minimum safe altitude. The figure shows some high elevation terrain topped by a man-made obstacle:

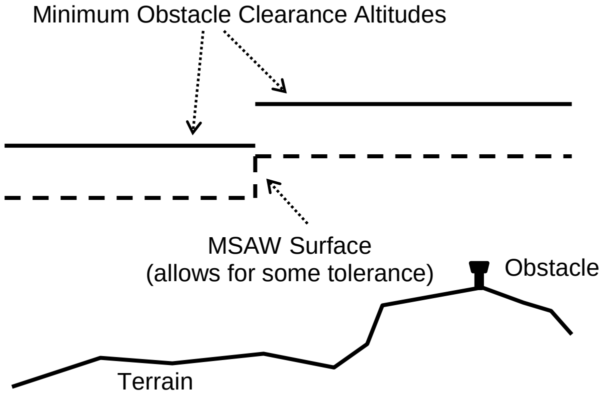

Figure 1: Typical MSAW surface defined using polygons

2.6.2 Configuration 2 – use of digital terrain data

In this configuration, the MSAW surface is defined in MSAW by digital terrain data. This terrain data is supplemented by a set of user-defined polygons and cylinders which represents permanent, static obstacles. In this configuration, MSAW detects predicted and actual conflicts with both terrain and static obstacles.

Figure 2 shows the same terrain defined in MSAW by digital terrain data (sampled at regular intervals) and the obstacle defined as a cylinder or polygon.

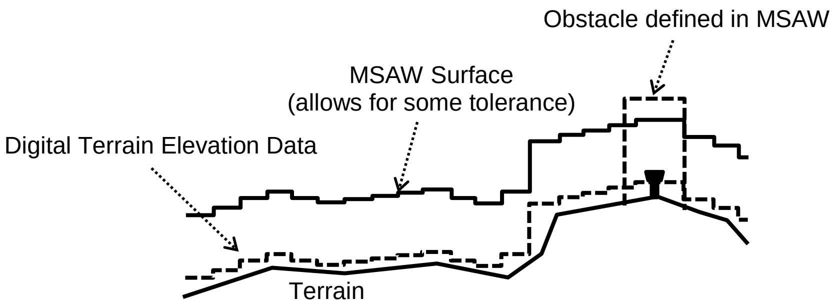

Figure 2: Typical MSAW surface defined using digital terrain data

2.7 MSAW exclusion areas

MSAW exclusion areas may be defined where no MSAW conflict detection will be done.

MSAW is not very suitable for protecting against deviations from the expected final approach path. It is recommended to suppress MSAW functioning in the immediate vicinity of airports and to install an Approach Path Monitor (APM) to cover the final approach.

2.8 The use of grids in MSAW

There are various ways of using grids to store MSAW surfaces, whether the surface is defined using polygons or a digital terrain data base.

The most common use of a grid is to convert and store the input data (polygons or digital data) as a fine cellular matrix of local maximum elevation values. See Figure 3.

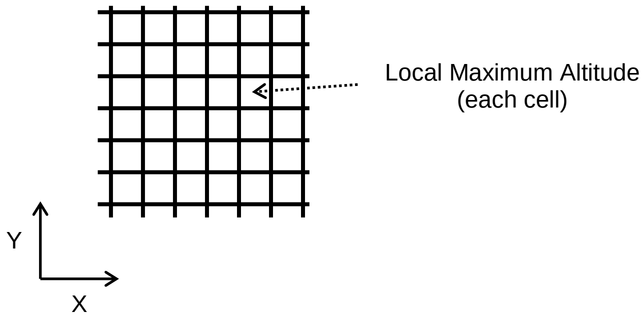

Figure 3: The cellular MSAW grid

When a grid is employed in this way, the size of the cell should be 1 nautical mile or less, in order to ensure that the grid quantization does not degrade MSAW alerting performance. Nevertheless, the appropriate cell size will also depend upon the horizontal precision of the source data. This is the method described in detail for the reference MSAW system in subsequent sections.

However, as an alternative to a fine grid, MSAW may test against the original polygon definitions. For speed, a much coarser grid may be used for fast look up of polygons within a particular cell. The list of polygons that needs to be tested is then only a subset of all those defined by the user. Likewise, obstacles may use a coarse grid structure for fast look up of obstacles within a particular cell.

2.9 MSAW parameters

In the description of the reference MSAW system, the parameters are defined in each section as they occur in the text. They are shown in the test in bold type with no spaces, e.g. **TerrainPredictionTime**.

As a convenient reference, all the parameters in the reference MSAW system are listed Table 1. Note that it is not necessary to memorize all the parameters here, since they will be described in detail in later sections.

Table 1: Typical MSAW parameters

Name	**Description**	**Units**
UseCFL	Flag to use CFL for vertical prediction	Boolean
UseSFL	Flag to use SFL for vertical prediction	Boolean
TerrainPredictionTIme	Prediction time for terrain conflict detection	s
TerrainMinimumClearance	Minimum acceptable clearance from terrain	ft
ObstaclePredictionTIme	Prediction time for obstacle conflict detection	s
TerrainImminentTime	Imminent time for terrain alert confirmation	s
TerrainConflictCount	Conflict count for terrain alert confirmation	integer

Name	Description	Units
TerrainCycleCount	Cycle count for terrain alert confirmation	integer
TerrainWarningTime	Warning time for terrain alert confirmation	s
ObstacleImminentTime	Imminent time for obstacle alert confirmation	s
ObstacleConflictCount	Conflict count for obstacle alert confirmation	integer
ObstacleCycleCount	Cycle count for obstacle alert confirmation	integer
ObstacleWarningTime	Warning time for obstacle alert confirmation	s

2.10 MSAW processing stages

Figure 4 illustrates the MSAW processing stages.

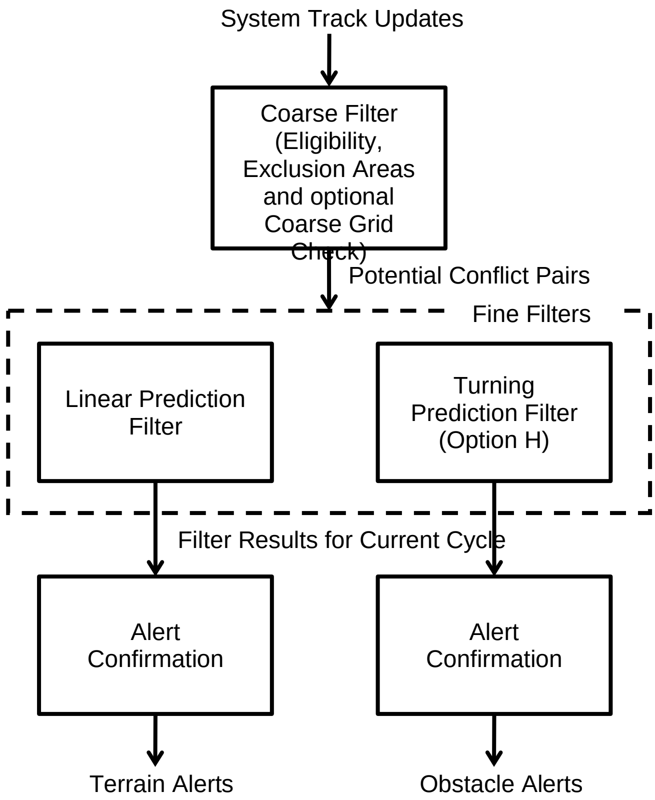

Figure 4: MSAW processing stages

2.11 The MSAW cycle

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

2.12 MSAW exclusion area test

Each aircraft track is tested to see if it lies in an MSAW exclusion area. If this is the case, the aircraft track will not be processed any further by MSAW.

2.13 The coarse filter grid

Some MSAW systems use a coarse filter grid in order to reduce the amount of CPU load. For modern computer systems, CPU load is less of an issue, and in recent years a coarse filter has become a less essential feature of MSAW.

2.14 Terrain conflict filter

2.14.1 Objective

The purpose of the terrain conflict filter is to detect potential conflicts with the terrain.

2.14.2 Overview of processing

The future position of each eligible aircraft is extrapolated forwards from its current track position for a time given by the parameter **TerrainPredictionTime**.

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 altitude (with barometric correction), and the vertical rate of the track. If the CFL is used then this is taken into account, as described in a later section.

If a terrain infringement is current or predicted, then a terrain conflict hit is registered on this cycle. Otherwise a terrain conflict miss is registered.

2.14.3 Horizontal prediction

The predicted horizontal path of the aircraft is used to determine which of the MSAW terrain grid cells the aircraft will pass through. See the example in Figure 5.

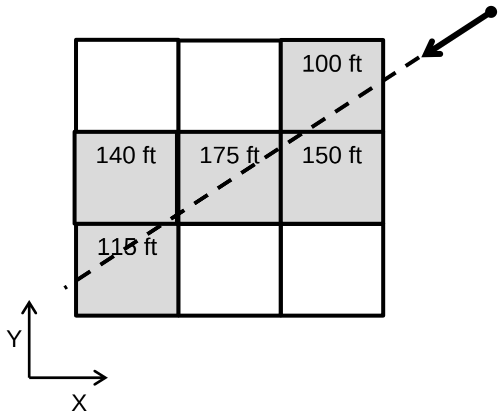

Figure 5: Predicted horizontal path through the MSAW terrain grid

In the figure, the aircraft is predicted to pass through the shaded cells of the MSAW terrain grid.

2.14.4 Vertical prediction

Starting at the aircraft's current position, the predicted aircraft altitude is computed at the points that the aircraft is predicted to cross over these shaded cell boundaries. The prediction continues through to the prediction time limit, **TerrainPredictionTime**.

The predicted aircraft altitude should be computed at the appropriate edge of each cell, depending on whether the aircraft is climbing or descending. For a climbing aircraft, the predicted altitude is computed at the near edge of the cell, and for descending aircraft the predicted altitude is computed at the far edge of the cell. This predicted altitude is then compared against the altitude value for the cell.

Additional clearance is defined by the parameter **TerrainMinimumClearance**.

If, at a cell boundary, the predicted altitude provides insufficient clearance from the ground, i.e.:

Predicted Altitude < Cell Elevation + **TerrainMinimumClearance**

Then a terrain conflict hit is registered on the current cycle, and the time of violation (TOV) is set to the point in time at which the altitude violation occurs. Otherwise, if there is no predicted violation with the terrain within the prediction time, a terrain conflict miss is registered for this filter.

Note that some MSAW systems allow for different terrain clearance depending on whether the aircraft is IFR or VFR traffic.

2.14.5 Vertical prediction with use of the CFL and/or SFL

In some MSAW systems, the CFL and/or SFL is available and used by the terrain conflict filter. The potential advantages and disadvantages of its use are discussed later in a later section.

When **UseCFL** and/or **UseSFL** is set, the CFL and/or SFL is used. It is taken account of in the calculation of the predicted aircraft altitude at each cell boundary, as shown in Figure 6.

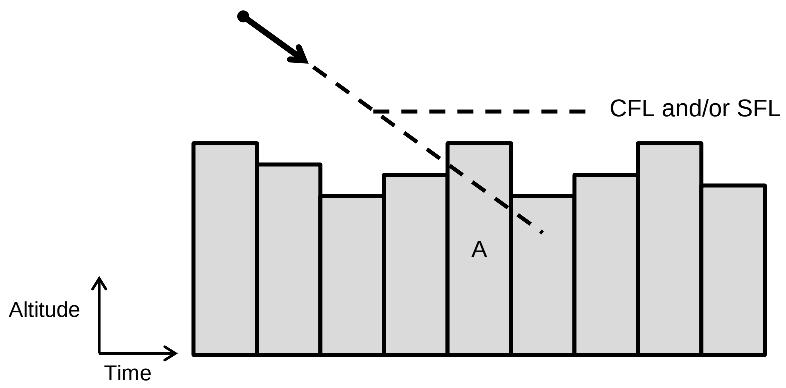

Figure 6: Vertical prediction with the CFL and/or SFL

The figure shows that, without use of CFL and/or SFL, a conflict is predicted to occur with the terrain. In this particular example, the CFL and/or SFL will prevent a possibly unwanted alert. However, the CFL and/or SFL will not necessarily suppress all alerts. For example, if cell A (in the figure) were higher, the CFL and/or SFL would not prevent a wanted alert. However, the CFL and/or SFL may serve to delay the start of an alert.

2.14.6 Optional vertical prediction assumptions

The vertical prediction that is described above is simply a linear extrapolation from the current altitude (at the current altitude rate). However, some MSAW systems have more complex vertical prediction assumptions.

For most MSAW systems, which use linear prediction, earlier MSAW alerts could be achieved simply by increasing the warning and prediction time parameters. However, extrapolating the linear prediction too much will lead to an intolerable nuisance alert rate, as an enormous number of descending aircraft will be predicted to hit the ground. An alternative is to assume a level-off manoeuvre. This does not lead to an excessive nuisance alert rate, yet allows an extended prediction capable of detecting conflicts with terrain, as shown in the example shown below.

Under this option, the MSAW models a descent for a parameterized amount of time followed by a level-off manoeuvre. See Figure 7.

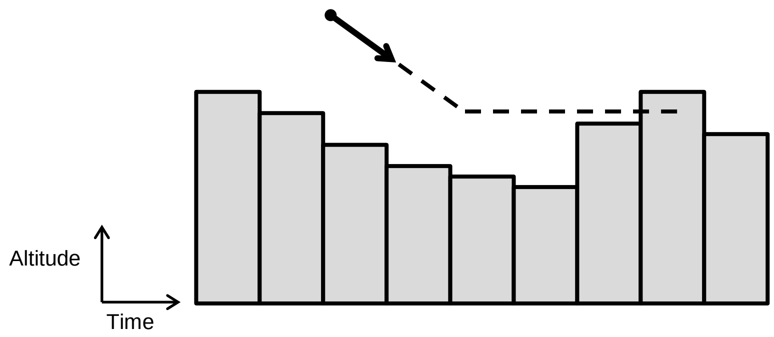

Figure 7: Vertical prediction with a level off assumption

Furthermore, some MSAW systems model a descent, a level off manoeuvre and then a standard climb. The reason for this is because an aircraft must be able to climb out of conflict with local terrain. See Figure 8.

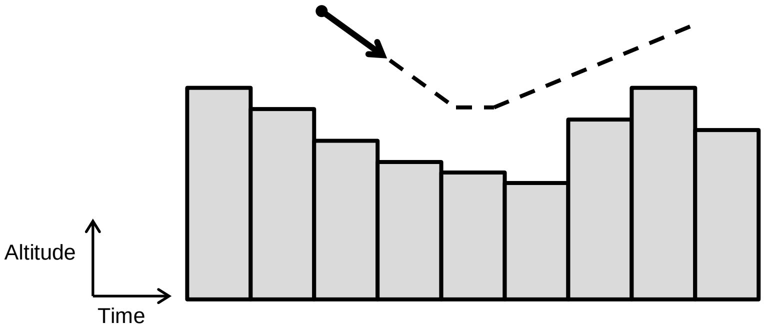

Figure 8: Vertical prediction with a level off and slow climb assumption

2.14.7 MSAW systems that use the original polygons rather than a grid

In MSAW systems that use the original polygons for conflict detection, the principles of horizontal and vertical violation are much the same as with in the Obstacle Conflict Filter, described below. The horizontal violation period is computed first, followed by the vertical violation period. A conflict hit is declared if the horizontal and vertical violations overlap.

2.14.8 MSAW systems that use step-wise predictions

One option in MSAW is to use a step-wise prediction, rather than the arithmetic one described here. Using a step-wise prediction has a slight disadvantage in that a balance has to be struck between having a sufficiently small time step (to reduce the number of missed conflicts) and the CPU load. With modern computers, the problems of CPU load are diminishing, and short (1 second) step times are often feasible.

2.15 Obstacle conflict filter

2.15.1 Objective

The purpose of the obstacle conflict filter is to detect potential conflicts with obstacles stored in the obstacle database.

2.15.2 Overview of processing

The future position of each aircraft is extrapolated forwards from its current track position for a time given by the parameter **ObstaclePredictionTime**.

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

In the vertical dimension, the prediction is a straight-line extrapolation made using the current altitude (with barometric correction), and the vertical rate of the track.

The predicted course of the aircraft is compared with the positions of the obstacles in the obstacle database.

If an obstacle infringement is current or is predicted, then an obstacle conflict hit is registered. Otherwise a conflict miss is registered.

2.15.3 Horizontal prediction

Firstly, the predicted horizontal course (as a straight-line extrapolation) is tested against each obstacle. The horizontal situation is shown in Figure 9.

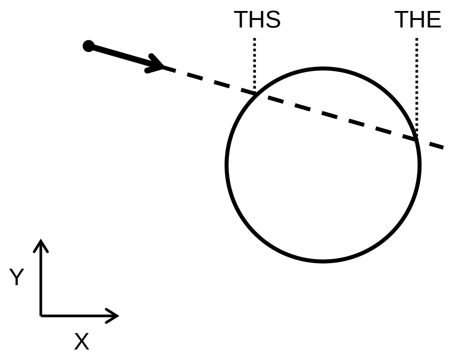

Figure 9: Predicted horizontal violation of an obstacle

If the aircraft is predicted to infringe the horizontal dimensions of an obstacle, the time of horizontal violation start (THS) and the time of the horizontal violation end (THE) are calculated.

The horizontal prediction may indicate that several obstacles will be infringed. Therefore, the filter must calculate and store the horizontal violation times for each infringement, and also consider the vertical violation with each obstacle.

2.15.4 Vertical prediction

The vertical prediction is a straight-line extrapolation from the current position at the current altitude rate. The time of vertical violation start (TVS) and the time of vertical violation end (TVE) are calculated based upon the straight course assumption. See the vertical situation in Figure 10.

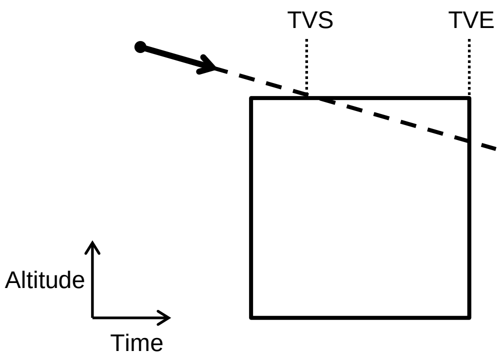

Figure 10: Predicted vertical violation of an obstacle

2.15.5 Vertical prediction with use of CFL and/or SFL

In some MSAW systems, the CFL and/or SFL is available to and used by the obstacle conflict detection in the MSAW system.

The potential advantages and disadvantages to its use are discussed later in a later section.

When **UseCFL** and/or **UseSFL** are set, the CFL and/or SFL is used and is taken account of in the calculation of the vertical violation. Figure 11 shows what happens in a typical situation to the vertical prediction when a CFL and/or SFL is introduced. In such cases, the CFL and/or SFL can be very effective at suppressing nuisance alerts.

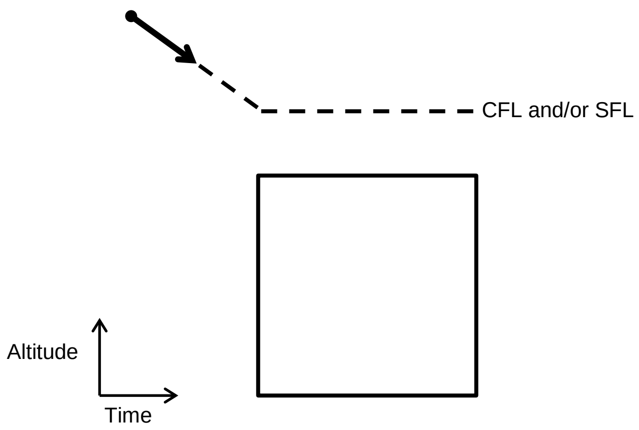

Figure 11: Vertical prediction with the CFL and/or SFL

2.15.6 Horizontal and vertical violation overlap

Having calculated the horizontal and vertical violation intervals (THS, THE, TVS and TVE), for each infringed obstacle, further calculations are done to see if the two intervals overlap (again, for each obstacle). If the two intervals overlap then the time of violation (TOV) of the obstacle is calculated. The time of violation of the obstacle is the time of the start of the overlap. See Figure 12.

In the example above, TOV is set to the start of the vertical violation interval, TVS. However, if the vertical violation occurred first, TOV would be set to THS. Of course, it is also possible that there may be no overlap at all.

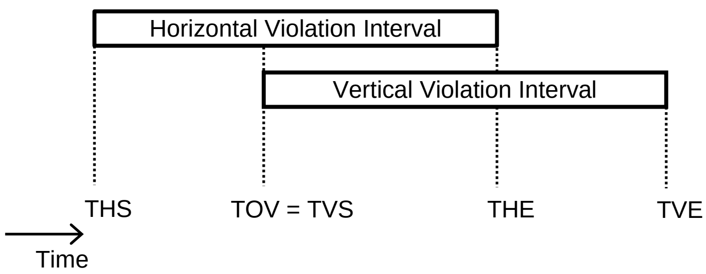

Figure 12: Calculation of violation overlap and TOV

In the case of no violation interval overlap with an obstacle, the obstacle conflict filter registers a “conflict miss” result. If there is a violation overlap, the TOV is calculated as indicated and an obstacle “conflict hit” is declared for the current cycle.

Note that after this processing there may be a conflict with more than one obstacle. However, the TOV for the obstacle conflict filter is set to the earliest TOV for all the obstacles.

2.16 Alert confirmation

2.16.1 Objectives

The final stage of processing in MSAW, called the alert confirmation stage has a number of objectives:

- To test if a conflict is imminent and an alert is required immediately
- To suppress an alert that might be caused by spurious track data

- To suppress an alert that 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

2.16.2 Conflict results presented to alert confirmation

The conflict results from the terrain conflict filter and the obstacle conflict filter are passed to the corresponding alert confirmation stage. The conflict result is expressed either as a “conflict hit” or a “conflict miss” on the current MSAW cycle.

A conflict hit result from a 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 corresponding alert is issued to the display.

2.16.3 Terrain conflict alert confirmation

2.16.3.1 Overview

The processing logic of the terrain conflict alert confirmation stage is shown Figure 13.

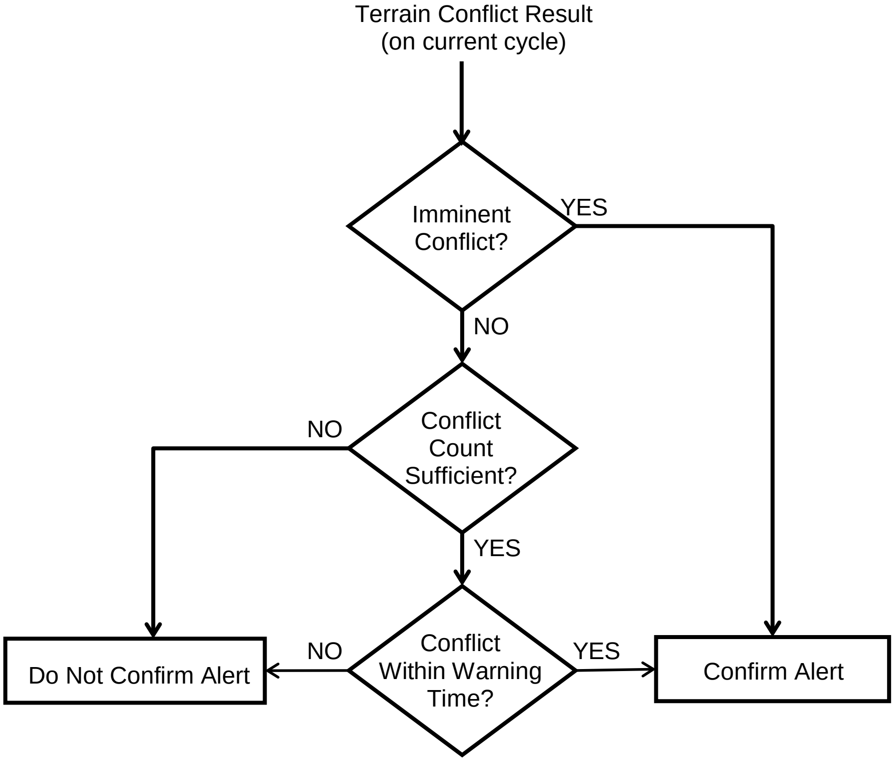

Figure 13: Alert confirmation stage for the terrain conflict filter

2.16.3.2 Test for imminent conflict

If a conflict situation is imminent then it is appropriate to bypass the other delay mechanisms and provide an alert on the current cycle. For example, an imminent conflict may be caused by a sudden descent from a safe flight level, or a situation may become imminent as the aircraft gets closer to the terrain.

The test for an imminent conflict is simply based on the time of violation (TOV) calculated earlier in terrain conflict detection.

If TOV is less than a parameter **TerrainImminentTime**, then a terrain alert is declared immediately. Otherwise further tests are done to see if it is safe to delay the alert.

2.16.3.3 The conflict hit count mechanism (M out of N)

Sometimes tracks can be presented to MSAW that are very noisy or are in the process of levelling off. See Figure 14 for an example of an aircraft levelling off, taking the aircraft out of conflict with the terrain.

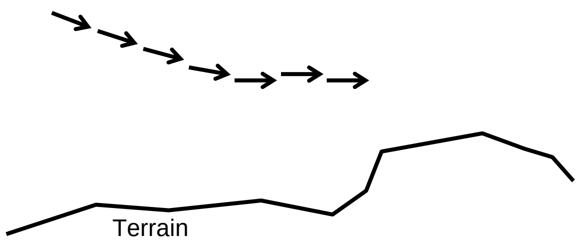

Figure 14: A level off manoeuvre taking the aircraft out of terrain conflict

To avoid nuisance alerts, the alert confirmation stage employs an algorithm that counts the number of conflict hits that have been detected for the track over the last few cycles. Furthermore, the mechanism allows continuity of the alert if there is an occasional miss in the sequence of conflict hits from the filter.

It is assumed that the algorithm is implemented using a sliding window to store the last few conflict results. The algorithm considers the conflict results over the last N cycles. If the number of conflict hits in the last N cycles reaches a threshold, M, then the conflict count test is passed. (It is sometimes referred to as an M out of N test).

In the terrain conflict alert confirmation stage the thresholds M and N, for declaring an alert are specified by **TerrainConflictCount** and **TerrainCycleCount**, respectively. If the conflict count is sufficient then a terrain alert is declared on this cycle.

2.16.3.4 Warning time test

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) calculated earlier in the terrain conflict detection.

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

2.16.4 Obstacle conflict alert confirmation

2.16.4.1 Overview

The obstacle conflict alert confirmation stage is essentially identical to that used for terrain conflicts. However, the parameters are different for the two alert confirmation stages.

The processing logic of the obstacle conflict alert confirmation stage is shown in Figure 15.

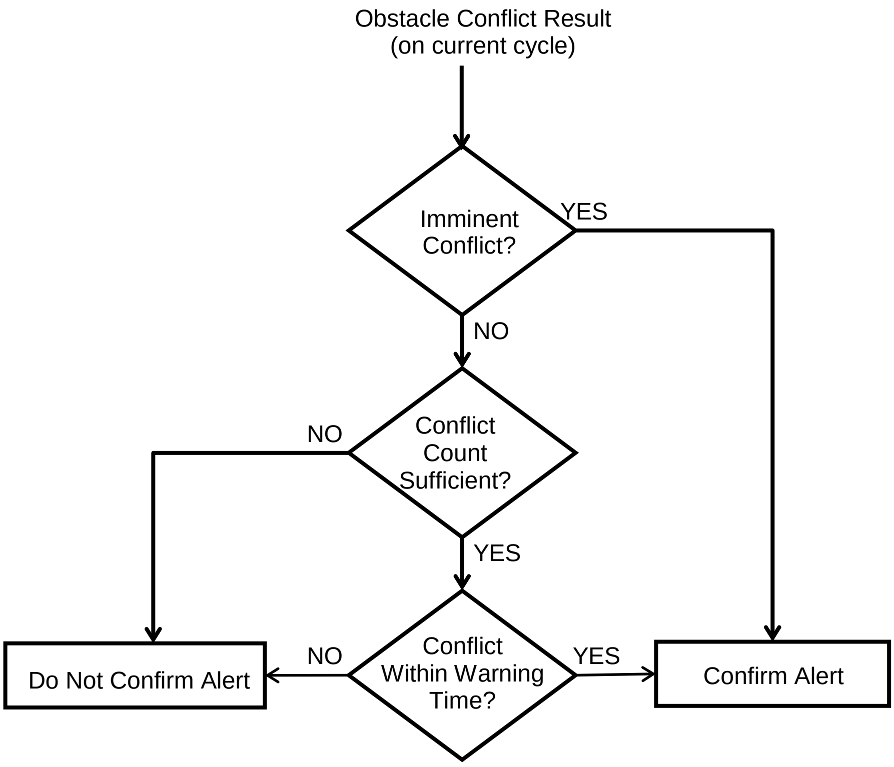

Figure 15: Alert confirmation stage for the obstacle conflict filter

2.16.4.2 Test for imminent conflict

If a conflict situation is imminent then it is appropriate to bypass the other delay mechanisms and provide an alert on the current cycle.

The test for an imminent conflict is simply based on the time of violation (TOV) calculated earlier in obstacle conflict detection.

If TOV is less than a parameter **ObstacleImminentTime**, then an obstacle alert is declared immediately. Otherwise further tests are done to see if it is safe to delay the alert.

2.16.4.3 Counting conflict hits to confirm alerts

The alert confirmation stage employs the same conflict hit counting mechanism as is used in the terrain conflict alert confirmation stage.

In the obstacle conflict alert confirmation stage, the thresholds M and N, for declaring an alert are specified by **ObstacleConflictCount** and **ObstacleCycleCount**, respectively.

If the number of conflict hits is less than **ObstacleConflictCount**, then the alert is rejected on this cycle. Otherwise further consideration is given in the alert confirmation stage.

2.16.4.4 Warning time test

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) calculated earlier in the obstacle conflict detection.

If FOV is less than a parameter **ObstacleWarningTime**, then an alert is declared on this cycle.

3. Guidance for the use of Digital Terrain Elevation Data (DTED)

3.1 General

It is necessary to ensure that the terrain data used by MSAW is safe and fit for purpose.

Where problems with the DTED exist, these result from either gaps in the DTED data or errors (vertical or horizontal) in individual measurements. This section provides a brief overview as to how to identify and correct errors in DTED. Particularly significant are those errors that would have the greatest negative impact on MSAW performance.

The precise characteristics of DTED will depend on the particular data source, the technology used to take measurements, error corrections applied during and after measurements are taken, and any other post-processing of the data.

In general, the distribution of the elevation errors are Gaussian-like (although not truly Gaussian), consisting of a bell like curve with some errors in the tails of the distribution. The methods proposed for reducing the potential effect include:

- Plotting the DTED data for a visual verification
- Sampling additional DTED data around points of interest
- Comparing multiple DTED sources
- Mitigations within MSAW itself

3.2 Plotting DTED data

Converting the DTED data into a colour coded bit-map in which elevation values are graded in a red green blue scale (for example, black at zero and red at point of highest elevation) will provide an immediate representation of the digital terrain data. Bodies of water such as the sea and lakes will be immediately identifiable and should correspond closely to such features seen on any accurate map. Gaps in missing data could similarly be identified through a dark colour. Under the suggested colour coding, seas and lakes will be surrounded by low-lying land represented by green pixels.

Gaps in DTED most often appear in the shadow of mountain peaks, and so are easily discernible from water as they appear scattered amongst the reddish hues of the higher terrain.

Some attempts have already been made to fill in gaps in the SRTM (Shuttle Radar Topography Mission) DTED, either by simple interpolation between the existing elevation measurement, or better by filling the gaps with elevation data from an alternative source.

3.3 Sampling DTED data around local peaks

In principle, an MSAW terrain grid is more likely to be adversely affected by errors around local peaks. Therefore, one simple test of DTED is to take a number of elevation samples at known and identifiable peaks for comparison. For example, Mont Blanc should be identifiable on the DTED grid with a measured elevation at or close to 15 775 ft. Perhaps more important are those mountains and hill peaks that are close to airports, TMAs and air routes.

Although the number of peaks that can be located and sampled manually is limited, if a large proportion of the sampled DTED elevations were significantly in error then this could justify a low confidence in the entire terrain data source.

3.4 Comparing two or more DTED sources

Two or more DTED sources can be compared by producing and displaying color-coded bit-maps. The method is similar to that described in section 3.2. In this case, gaps in either data source are converted to a distinct colour (e.g. black). Other data points are converted into a colour related to the difference in elevation between the two data sources.

When displayed, the largest discrepancies between the data sources can immediately be seen. In addition, some patterns may be seen suggesting that one or more data sources are in error in particular areas (e.g. in forests, in mountainous areas, etc.).

One difficulty with this technique is identifying which data source is in fact in error in various parts of the terrain (or even if one is more in error than the other). A third or fourth data source may help to determine which source is more accurate. However, a “majority vote” method to determine the best data source is often unreliable.

3.5 Mitigations in MSAW

3.5.1 General

Many of the MSAW algorithms designed to reduce the impact of errors on alerting performance rely on the application of horizontal or vertical buffers.

3.5.2 Using an appropriate MSAW terrain grid

The method used by MSAW systems of sampling the source terrain data and using the highest elevation for the MSAW grid has a mostly positive effect; it increases the likelihood that the MSAW grid that is used is above the actual terrain, rather than below it. This in itself helps to mitigate many of the potential DTED errors.

The cell size chosen for the grid should be appropriate. A very large cell size (say 4 NM or more) would result in too coarse a grid, oversized compared to the actual terrain and is likely to lead to nuisance MSAW alerts. On the other hand, a very fine grid (say 1/16 NM or less) would model the terrain closely. The only down side to this is that errors in the digital terrain data are more likely to be preserved in the MSAW terrain grid and where the DTED is below the real terrain, this may also be true of the grid.

The appropriate cell size depends to an extent on the post-spacing of the original data. As a guide, an intermediate cell size (in the region of 1/2 to 1 NM) usually offers the advantage of reducing the likelihood of preserving unwanted terrain errors (the grid elevation is more likely to be above the terrain, rather than below it) whilst also building a horizontal buffer of a more-or-less appropriate magnitude, even though the buffer is not of a guaranteed size.

3.5.3 Inclusion of a horizontal buffer in the MSAW terrain grid

In the future, MSAW systems could easily mitigate some of the horizontal errors by applying a horizontal buffer around the terrain. The most efficient way to do this is, when constructing the MSAW grid, to take contributions from data samples outside the horizontal boundary of each cell, say up to 1/2 NM. This solution neatly builds a natural 1/2 NM buffer into the MSAW terrain grid, and requires no extra processing power when MSAW is executing. Note that a 1/2 NM horizontal buffer could still be applied even if the cell size was reduced below 1/2 NM.

4. Guidance to appropriate MSAW parameter values

4.1 Introduction

The purpose of this section is to provide guidance as to which parameter values are likely to give better performance than others. The effect of some parameter values can be understood, even without recourse to performance measurement of an MSAW system.

The purpose of each of the parameters (defined in chapter 2) is identified. In addition, the most appropriate parameters to modify in a number of different situations are identified and the risks associated with certain “poor” parameter choices are highlighted.

4.2 Performance issues concerning terrain and obstacle definitions

The performance of an MSAW system depends very much on environment data such as the terrain and obstacle definitions, and exclusion areas. It is essential therefore that this data be correctly defined before major effort is expended on tuning the MSAW parameters themselves.

As has previously been discussed, MSAW can be used either with or without digital terrain data. The use of digital terrain data, rather than polygons to define MSAW areas is likely to have a profound effect on MSAW performance and the choice of MSAW parameter values.

In many cases MSAW uses polygon volumes to model terrain and obstacles. The polygon volumes may be set several hundred feet below the lowest minimum safe altitudes that could be applicable (Minimum Radar Vectoring Altitude (MRVA), Minimum Obstacle Clearance Altitude (MOCA) or Minimum Sector Altitude (MSA) as appropriate), or if desired may be set to more closely follow the terrain.

It is quite common to have circumstances like the example below where an aircraft appears to be heading towards an obstacle. The alert rate against obstacles increases with the horizontal margin that is added to an obstacle. If the aircraft is turning slowly away from the obstacle, the reality can turn out very different from the prediction. See Figure 16.

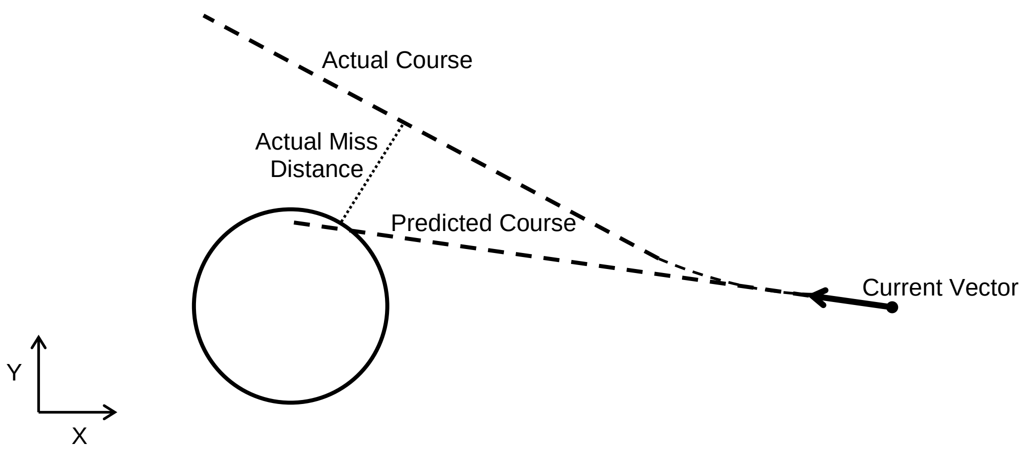

Figure 16: Situation showing the potential inaccuracy of linear prediction in presence of subtle turns

The same inaccuracies in the linear prediction assumption also apply in the terrain prediction filter.

Simplistic diagrams showing MSAW alerts occurring for aircraft on perfectly straight courses are misrepresentative of typical traffic. In reality, aircraft may be turning or even have small fluctuations in the heading that will have a significant effect on the calculated conflict (with either terrain or obstacles). The same is true in the vertical dimension, where a situation can appear dangerous when in reality the aircraft is in the process of levelling off. Pictures of actual vertical climbs and descents show that the aircraft vertical rate often fluctuates during the course of the climb or descent.

In actual fact, the error in the predicted future position of the aircraft has two sources:

- The error in the assumed linear motion of the aircraft (because aircraft may turn or change their vertical rates in the future)
- The error in the current 3D state vector from imperfect tracking

From these simple facts, we can conclude two things:

- A conflict predicted by MSAW may not be accurate
- Improving the accuracy of the system tracks will have a positive effect on MSAW performance but the benefit will be somewhat limited

Bearing these facts in mind, it is clear that although some additional safety margin may be added to obstacles, there is a limit to how much may be added before an intolerable alert rate is reached. Furthermore, it is essential that the obstacle is not enlarged so much that it causes aircraft on normal arrival or departure routes to habitually generate nuisance alerts.

Because of the inaccuracies in the linear prediction assumption, the length of prediction time used in MSAW will also need to be limited in order to minimize the number of nuisance alerts.

4.3 Exclusion of particular aircraft

It will often be necessary to exclude particular SSR codes from the MSAW processing either because they are not under ATC, are flying VFR, or otherwise they are assigned to aircraft that engage in regular operations close to the ground (e.g. airport helicopters, aircraft taking part in special events).

4.4 Guidelines to using the recommended values

Although using these guidelines alone will not yield a fully optimized data set for a particular MSAW system, it is likely that a reasonably optimal data set can be achieved and many of the common pitfalls will be avoided. When a full parameter optimization method is employed, the guidelines may also help identify which parameters are worth modifying for each iteration of the process.

For some parameters, a range of values is suggested. In these cases, the values appropriate for less busy airspace are indicated by being underlined. These values will tend to provide more warning time, but may give too high a nuisance alert rate in busier airspace or where significant terrain or obstacles are located close to standard arrival routes. When testing MSAW performance, it may be appropriate to start with the “less busy” parameter values, and to progress towards the “more busy” values if the nuisance alert rate is considered too high.

It is not necessary to be restricted to the quoted parameter ranges, especially if the parameter optimization process indicates that other values give a better MSAW performance. The ATS provider should be free to choose wider parameters in order to achieve more warning time, whilst accepting the alert rate penalty. Furthermore, wider parameter values may be appropriate if the air traffic environment allows.

The use of CFL and/or SFL may reduce the alert rate. Therefore, if CFL and/or SFL are used in MSAW, then this may also allow the parameters to be extended slightly beyond the quoted ranges.

4.5 The use of CFL and/or SFL

UseCFL
UseSFL

In some MSAW systems the CFL and/or SFL is used. In the reference MSAW system, it is used to enhance the vertical prediction in both the terrain conflict filter and the obstacle conflict filter.

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 reduces the nuisance alert rate, especially in situations where the aircraft is about to safely level off
- MSAW will often provide more warning time if a climbing aircraft is cleared to an altitude that is insufficient to clear a hazard (terrain or obstacle)
- The 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, potentially having an adverse effect on MSAW performance

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

- In the event of a level bust, MSAW may alert before the level bust occurs
- The controller would 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 will be necessary to restrict the MSAW parameters (particularly the horizontal, vertical and 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 because it will overcome much many of 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 CFL is used, it is recommended that:

- For consistent behaviour, the CFL is applied in all MSAW airspace
- The controller is familiar with the MSAW vertical prediction mechanism

- The MSAW system is configured to alert as soon as a level bust occurs

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

4.6 Terrain conflict filter parameters

TerrainPredictionTime
TerrainMinimumClearance

The optimal values for these parameters will depend greatly on how the terrain has been defined by the user. MSAW systems with terrain defined by digital terrain data can generally tolerate a longer prediction time than one that has been defined by polygons. If polygons have been used and their ceilings are set just below the lowest minimum safe altitude then almost no prediction time or minimum clearance will be tolerated without having an excessive nuisance alert rate.

If the required clearance from the terrain is defined by the polygons, the **TerrainMinimumClearance** parameter is effectively unnecessary in MSAW. In this case, it may be set to zero. If terrain is defined by digital terrain data, **TerrainMinimumClearance** may be set to a value between 300 ft and 1 000 ft. It is recommended to start with a high value and to only reduce it, if necessary, to limit the nuisance alert rate.

Furthermore, if the terrain is defined by digital terrain data, it is normal that longer prediction and warning times can be set before the alert rate becomes excessive.

It should be noted, however, that in a fully tuned MSAW system, the value of **TerrainPredictionTime** is not critical, since the timing of the alert (and alert rate) will be determined by **TerrainImminentTime** and **TerrainWarningTime** in the alert confirmation stage.

TerrainPredictionTime simply needs to be high enough to allow sufficient conflict hits to have built up by the time the alert could pass the alert confirmation stage. (Perhaps 20 to 30 s greater than the longest time limit parameter in the alert confirmation stage). With this in mind, the recommended values for **TerrainPredictionTime** are:

WHEN digital terrain data is used, 40 - 60 s
OTHERWISE 0 - 50 s

If level offs are modelled in the vertical prediction or a climb out of conflict is modelled, there should be parameters that allow the descent, level flight and climb segments to be set by the user. The values of these parameters should be based upon an assessment of controller and pilot reaction times, as well as expected aircraft performance.

For example, the initial descent time should cover time for the controller to react, to give a resolving instruction to the pilot, and for the pilot to start the manoeuvre. This time may be in the region of 30 - 40 s.

When level-offs are modelled, extra time should be added to predict further, during the level flight phase (after the level off manoeuvre). This extra time could be anything between 20 and 60 s.

If a climb out of conflict is included, the climb phase of the prediction could in principle extend to several minutes. This would ensure that the aircraft is capable of climbing clear of any surrounding terrain. The feature is especially applicable in high-sided valleys or close to cliff edges.

4.7 Terrain conflict alert confirmation parameters

TerrainImminentTime
TerrainConflictCount
TerrainCycleCount
TerrainWarningTime

The terrain conflict alert confirmation parameters are used to provide MSAW terrain alerts at the appropriate time. If there is plenty of time until violation, then the alert may be delayed to see how the situation develops. Many potential terrain conflict situations resolve themselves without the need for controller intervention. However, if the infringement of safe altitude is imminent then the alert should be provided immediately.

The value of **TerrainWarningTime** has a profound effect on the alert rate. Figure 17 shows how the alert rate typically increases with the value of **TerrainWarningTime** for terrain defined with digital data.

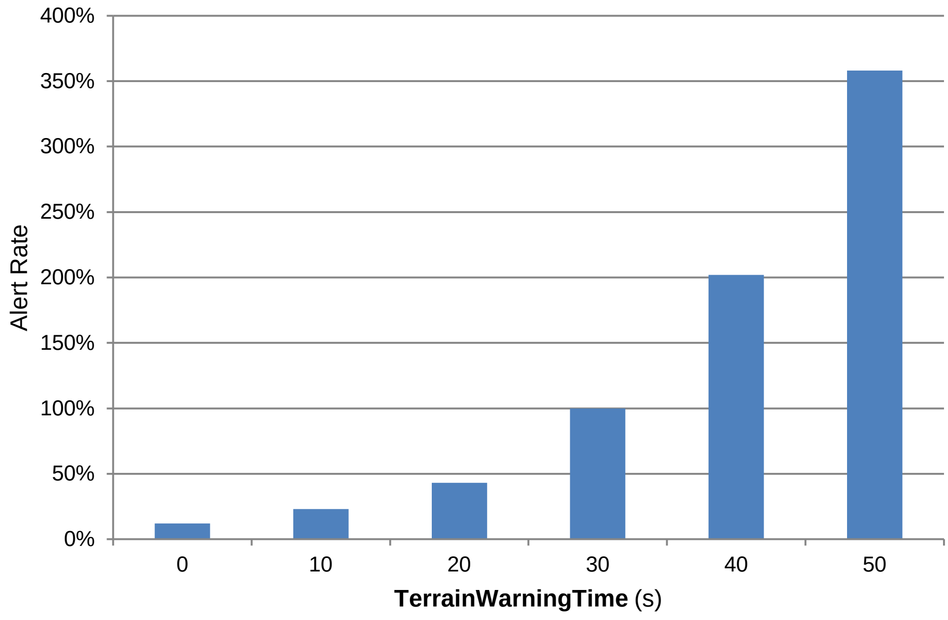

Figure 17: Increase in alert rate with TerrainWarningTime

The graph is indicative of the expected increase in the alert rate. In any particular system, the alert rate will increase faster or slower depending on the amount of traffic and the nature of the terrain.

From the graph, it is apparent that a balance must be struck between providing sufficient warning time and keeping the number of alerts to a tolerable level. Therefore, when digital terrain data is used, the recommended value for **TerrainWarningTime** is in the range 30 – 50 s. Any less than this and there will be insufficient time for the controller and pilot to react to the alert. Any more than this and the nuisance alert rate is likely to become excessive.

Without digital terrain data, the recommended values for **TerrainWarningTime** are in the range 0 – 30 s.

The recommended values for **TerrainImminentTime** are in the range 20 – 30 s when digital terrain data is used and 0 – 20 s otherwise.

The purpose of the terrain conflict count mechanism is to suppress MSAW alerts in transitory situations or where the track data is noisy or jumpy. See Figure 18.

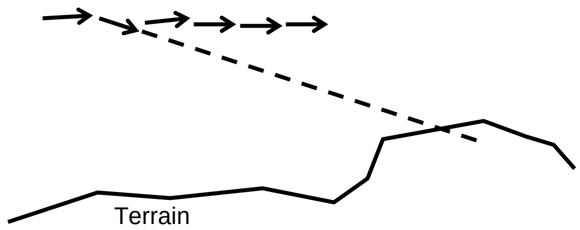

Figure 18: Noisy tracks giving rise to an MSAW terrain alert

The figure shows an aircraft with noisy track data giving rise to an MSAW alert. The conflict hit count mechanism acts to suppress such nuisance alerts by requiring a conflict to be detected on more than one cycle before confirming the alert.

Typically the conflict count parameters should take the following values:

TerrainConflictCount = 2 or 3

TerrainCycleCount = 4 or 5

Using higher values of **TerrainConflictCount** and **TerrainCycleCount** (maybe in an attempt to reduce the nuisance alert rate) is not appropriate because this will lead to excessive delays in the generation of alerts.

Consider what happens if an aircraft departs from level flight towards terrain or an obstacle immediately below. See Figure 19.

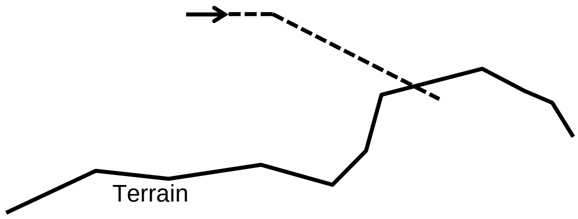

Figure 19: A departure from flight level situation

Here, an apparently safe situation can rapidly develop into a serious conflict situation with terrain or with an obstacle. A similar situation could be imagined in the horizontal with turning aircraft. It is imperative that MSAW produces an alert quickly for this type of situation. A high conflict count value (say 4 or 5) will delay the alert unnecessarily; depending on the conflict cycle period, it could delay the alert considerably.

4.8 Obstacle conflict filter parameters

ObstaclePredictionTime

In a fully tuned MSAW system, the value of **ObstaclePredictionTime** is not critical, since the timing of the alert and the obstacle conflict alert rate will be determined by **ObstacleImminentTime** and **ObstacleWarningTime**, in the alert confirmation stage.

ObstaclePredictionTime simply needs to be high enough to allow sufficient conflict hits to have built up by the time the alert could pass the alert confirmation stage. (Perhaps 20 to 30 s greater than the longest time limit parameter in the alert confirmation stage). With this in mind, the recommended values for **ObstaclePredictionTime** are in the range 50 to 60 s.

4.9 Obstacle conflict alert confirmation parameters

ObstacleImminentTime
ObstacleConflictCount
ObstacleCycleCount
ObstacleWarningTime

The obstacle conflict alert confirmation parameters are used to provide MSAW obstacle alerts at the appropriate time. If there is plenty of time until violation, then the alert may be delayed to see how the situation develops. Many potential obstacle conflict situations resolve themselves without the need for controller intervention. However, if the conflict with the obstacle is imminent then the alert should be provided immediately.

The value of **ObstacleWarningTime** has a profound effect on the alert rate. Figure 20 shows how the alert rate typically increases with the value of **ObstacleWarningTime**.

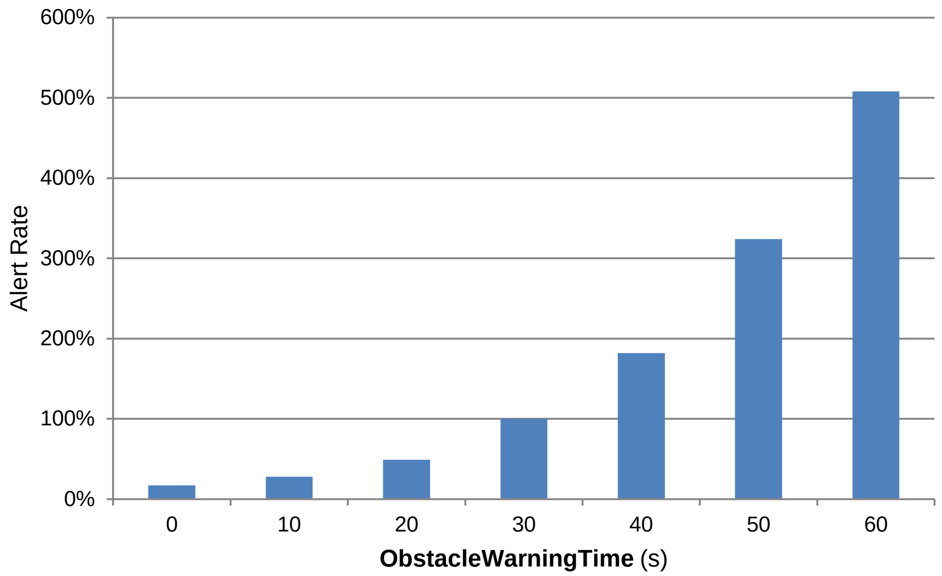

Figure 20: Increase in alert rate with ObstacleWarningTime

The graph is indicative of the expected increase in the alert rate. In any particular system, the alert rate will increase faster or slower depending on the number and size of the defined obstacles.

From the graph, it is apparent that a balance must be struck between providing sufficient warning time and keeping the number of alerts to a tolerable level. Therefore, the recommended value for **ObstacleWarningTime** is in the range 30 - 40 s. Any less than this and there will be insufficient time for the controller and pilot to react to the alert. Any more than this and the nuisance alert rate is likely to become excessive.

The recommended values for **ObstacleImminentTime** are in the range 20 – 30 s.

The purpose of the obstacle conflict count mechanism is to suppress MSAW alerts caused by an occasional noisy track update, whilst allowing some continuity of the alert in the event of a conflict

The following conflict count parameters values are recommended:

ObstacleConflictCount = 2 or 3

ObstacleCycleCount = 4 or 5

Using higher values of **ObstacleConflictCount** and **ObstacleCycleCount** (maybe in an attempt to reduce the nuisance alert rate) is not appropriate because this will lead to excessive delays in the generation of alerts.

If aircraft on final approach generate excessive nuisance alerts then effort should be spent refining the exclusion areas in the vicinity of the airport, and the obstacle definitions, before considering modifying the parameters in the alert confirmation stage.

5. Optimisation concepts

5.1 Introduction

MSAW 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.

5.2 Analysis team composition

It is vital that the analysis and optimisation of MSAW 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.

5.3 Scenario categorisation

5.3.1 Introduction

MSAW 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 MSAW 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

Figure 21 illustrates some sample categories.

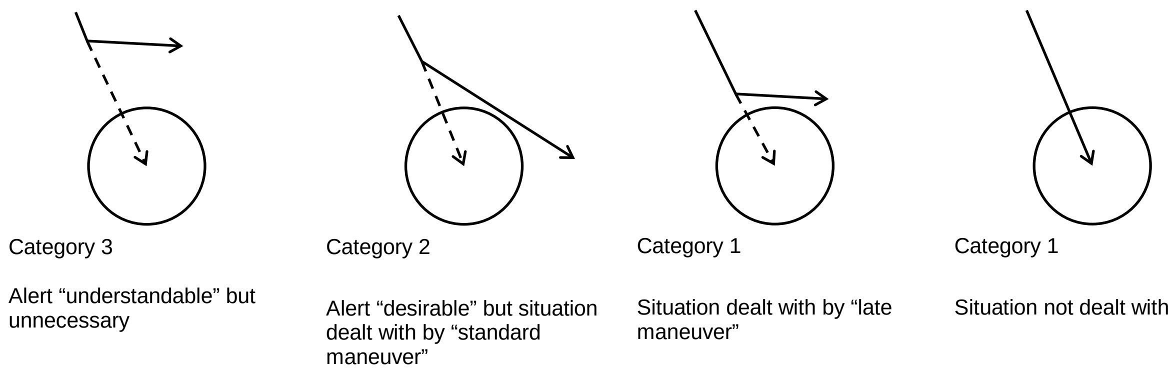

Figure 21: Sample MSAW categories

Using these categories, the theoretical aim of MSAW 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 MSAW occasionally alerting Category 5 scenarios, either by system adaptation or algorithm design.

5.3.2 Lowest minimum safe altitudes

The lowest minimum safe altitude (MRVA, MOCA or MSA) may be used to determine the category for a scenario, since this indicates the minimum official permitted altitude. For example, infringing the minimum safe altitude by 400 ft would be considered more severe than an infringement of 200 ft.

5.3.3 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 collisions and serious proximity to terrain or an obstacle or a serious infringement of the minimum safe altitude, plus those scenarios where such a situation 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.

The precise definition assigned to “serious proximity to terrain” and “serious infringement of minimum safe altitude” (and hence the appropriate parameter settings) is dependent on the individual circumstances surrounding each implementation. A quantified definition should be precisely established at a local level, taking into account the specific implementation of MSAW and local operational constraints.

5.3.4 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 a standard manoeuvre. It is therefore not necessary for the minimum safe altitude to be breached for a scenario to be Category 2.

A situation likely to cause a Category 2 scenario is where a descending aircraft is about to level off at a safe altitude, but no CFL information is available. The predicted path during the descent may indicate a potential terrain or obstacle hazard, and thus generate an alert, even though the aircraft's intended route is perfectly acceptable. Category 2 scenarios include those where the aircraft overshoots the minimum safe altitude by a defined vertical margin, taking account of normal overshoot due to tracker lag.

5.3.5 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 the element of risk. Negligible losses of separation may, in certain situations, be considered to be Category 3.

5.3.6 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 display 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(s) available for detailed examination.

5.3.7 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.

5.4 Performance indicators overview

The precise nature of the performance indicators used to assess MSAW meet their 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.

5.5 Warning time

5.5.1 Introduction

MSAW will provide an amount of time in which the situation may be dealt with ("warning time"). The warning time is measured as the time between the MSAW alert and the Point of Risk (PoR). Flexibility in the calculation of warning times, depending on the rationale behind a MSAW implementation, is provided by appropriately defining how the PoR is determined.

For non-predictive functions, the warning time is entirely produced by the size of the protective "buffer zone". The size of the buffer zone must therefore be optimised for the nature of the traffic in that region.

5.5.2 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 and the "adequate" warning time may vary between different types of airspace. 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 MSAW 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 horizontal avoidance manoeuvres.

5.5.3 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 MSAW. 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 descent
- Changes from climb to level flight or descent

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^o).

5.5.4 Objective warning time

It is not considered appropriate to provide MSAW 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 22 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.

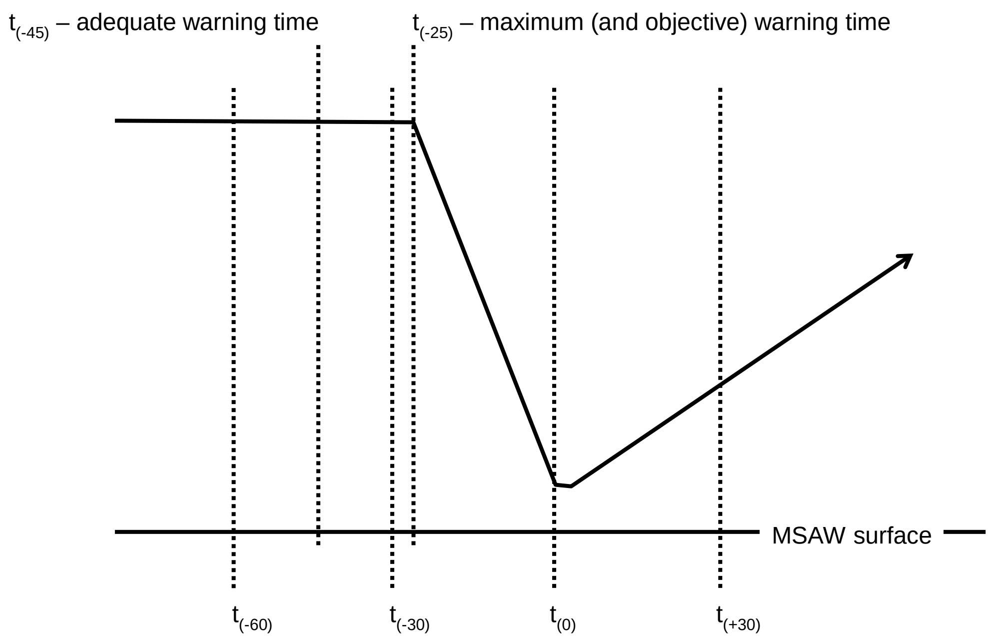

Figure 22: Example of maximum warning time less than adequate

5.5.5 Achieved warning time

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

Where a predicted PoR is used to assess the performance of an MSAW with a mixture of MSAW surface definitions (minimum safe altitudes, terrain and obstacles) the method of calculating the PoR (and thus the achieved warning time) must be appropriate to the reference feature which caused the alert. For example, the PoR appropriate to an MSAW function that defines the MSAW surface relative to minimum safe altitudes may well be very different to one that uses terrain or obstacles as the reference for conflict detection.

5.6 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 function and implementation.

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

For predictive MSAW functions, the PoR could be defined as the Closest Vertical Distance (CVD) to terrain or an obstacle or the breach of some specified separation criteria (such as lowest minimum safe altitude). It should be noted that longer warning times are required when CVD is used as the PoR as opposed to breach of minimum safe altitude, in order to provide the same level of safety. Figure 23 illustrates some types of PoR which could be used for MSAW.

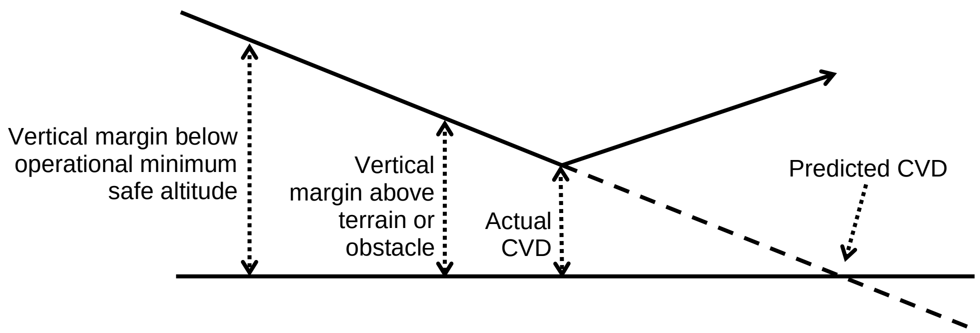

Figure 23: Example Points of Risk for MSAW

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.

5.7 Analysis tools

5.7.1 Introduction

MSAW 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.

5.7.2 Off-line models

It is vital that MSAW 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) MSAW. 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 MSAW 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 MSAW 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 MSAW 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 MSAW it is used to test, even if the actual programming source code is different. Different versions of a MSAW 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. For optimisation purposes, each data set will need to be re-run many times against the model, with varying parameter sets.

5.7.3 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. One convenient way of displaying scenarios is via printed diagrams showing plan and elevation views of the scenario, although alternative methods may prove to be equally satisfactory. 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 MSAW polygons and exclusion areas have been located correctly and subsequently for identifying any part of the airspace with an unexpectedly high alert rate (i.e. alert hotspots). The facility to display actual tracks and/or modelled alerts on a map may prove useful when defining MSAW surfaces in the first place.

5.7.4 Categoriser

MSAW 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 a “categoriser”, is totally independent from the simulation function of the MSAW model. The categoriser classifies scenarios according to categories as outlined in section 4.3 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 vertical position of the aircraft in relation to an appropriate Point of Risk (usually the minimum safe altitude, the terrain or an obstacle).

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 MSAW and should be tuned to overestimate the seriousness of scenarios rather than underestimate. Using the categories given in Section 4.3, 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 MSAW can highlight problems in other parts of the data processing chain. As optimal MSAW 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 MSAW 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 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.

5.7.5 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. This should be done using different algorithms from those contained in the actual MSAW since the “actual” elapsed time is available for measurement, rather than a predicted version.

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.

5.7.6 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 MSAW in a realistic manner. However, it may be considered necessary to use simulated scenarios for formal test purposes.

6. Optimisation Procedure

6.1 Overview

The objective of MSAW optimisation is tuning the MSAW volumes and parameters to meet the requirements laid out in the EUROCONTROL Guidelines for MSAW Part I:

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

Figure 24 shows the main tasks involved in the first optimisation of MSAW. Some of the initial tasks may not need to be undertaken when the system is re-optimised at a later date. Once Parameter Sensitivity Analysis has been performed for MSAW, it should not need to be redone for subsequent implementations of that MSAW at other ATS units.

Figure 25 and Figure 26 each provide a more detailed indication of the steps involved in a particular task shown in Figure 24.

Figure 25 shows the steps taken in the actual iterative process of determining the optimal parameters.

Figure 26 shows the steps involved in the operational trial of MSAW 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.

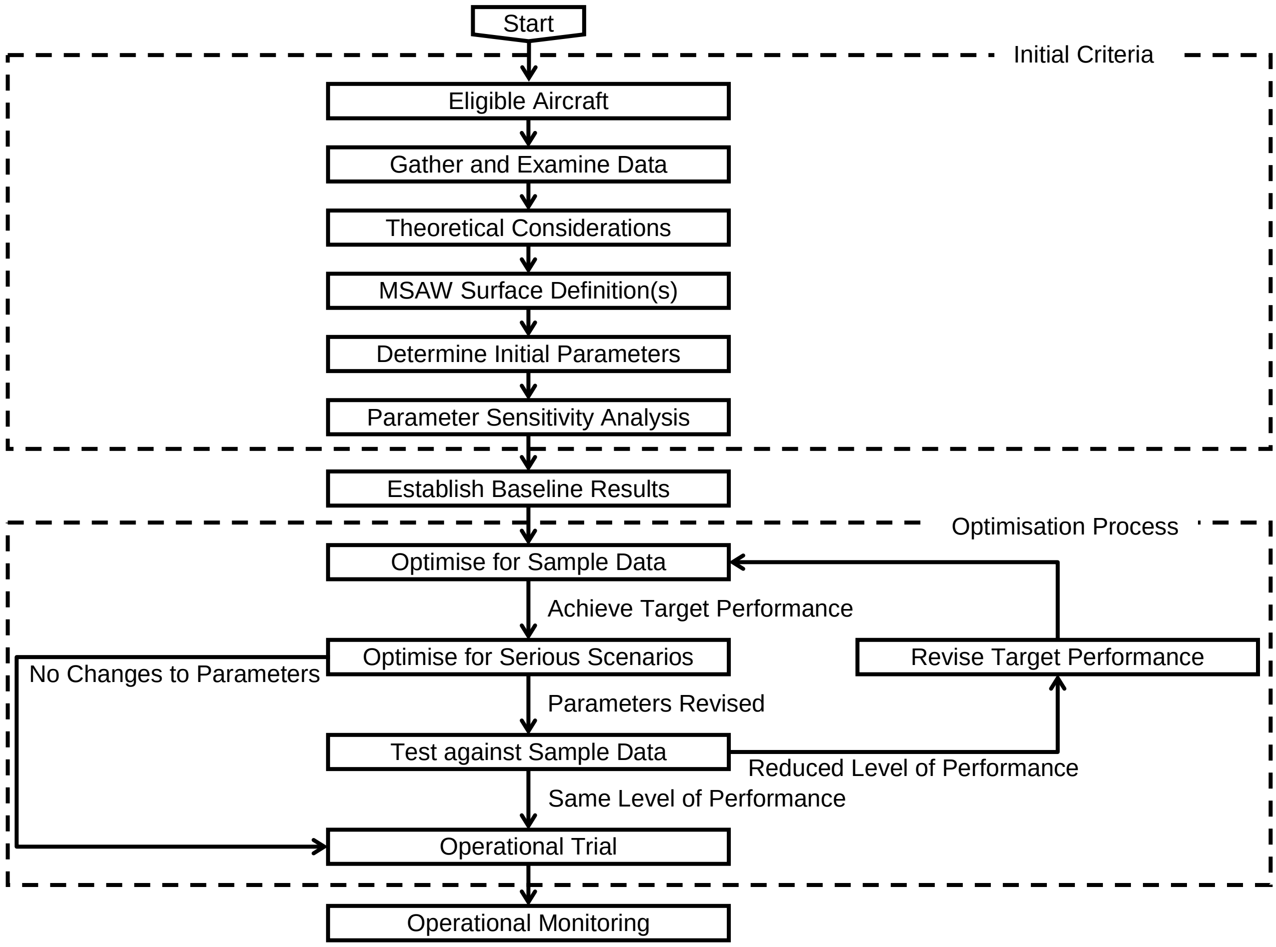

Figure 24: System adaptation tasks

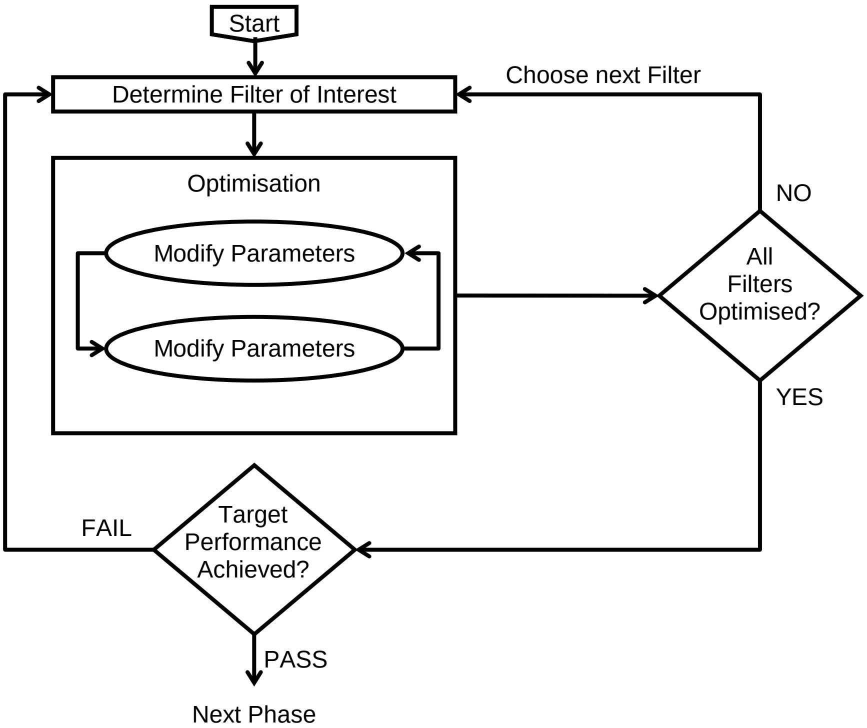

Figure 25: Iterative optimisation

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

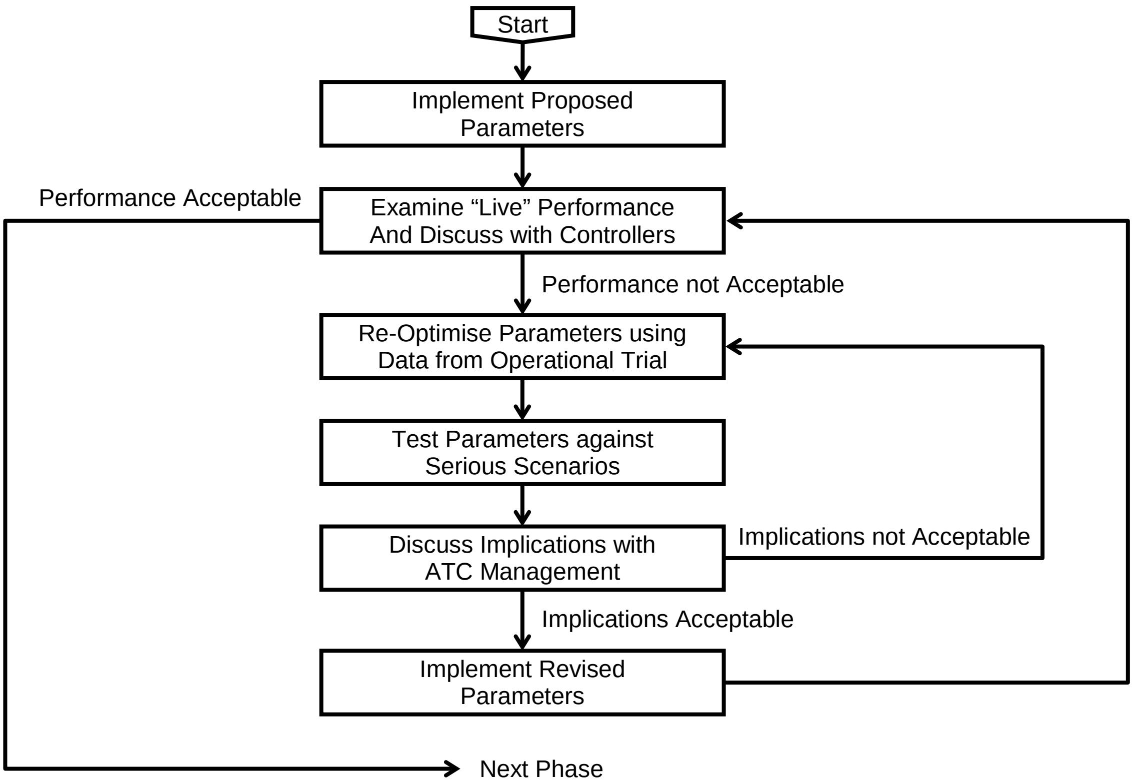

Figure 26: Operational trial

6.2 Initial Criteria

6.2.1 Eligible aircraft

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

It is therefore vital that off-line MSAW 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 MSAW 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 MSAW parameters to take account of SSR code changes.

MSAW which uses 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.

6.2.2 Data

6.2.2.1 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 areas 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.

6.2.2.2 “Serious” scenarios

The purpose of MSAW is to alert controllers to situations which have gone seriously wrong. Such situations are not an everyday occurrence but it is important that MSAW 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 a SID or STAR has been changed some previously recorded incidents may need to be discarded.

6.2.2.3 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.

6.2.3 MSAW surface definition

An initial MSAW surface has to be determined before the optimisation process may start.

As previously discussed, in many MSAW systems the MSAW surface is defined as a number of polygons. Alternatively, the MSAW surface may be defined by digital terrain data, supplemented by an obstacle data base.

Determining the appropriate MSAW surface will normally involve discussions with controllers and examination of the traffic patterns evident from surveillance recordings, examination of terrain maps and aeronautical charts.

Within the area of responsibility there will be volumes of airspace where it is not appropriate for MSAW to be active. These exclusion zones will normally be defined around airports and airfields, on final approach paths and potentially in some areas where low flying is routine.

6.2.4 Theoretical considerations

6.2.4.1 Summary

Theoretical issues which need to be considered when determining MSAW parameters include:

- The MSAW surface definition
- Typical aircraft performance capabilities
- Typical local traffic manoeuvres
- Desired warning times
- Desired look ahead times
- Surveillance tracking performance
- ATC operational procedures

These issues will provide practical limits to the potential ranges for the values of a number of MSAW parameters.

6.2.4.2 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.

6.2.4.3 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, the standard arrival route for a particular runway may routinely bring aircraft into the vicinity of terrain, which may impose limits to the amount of prediction that can be done in MSAW before provoking an excessive nuisance alert rate.

6.2.4.4 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 constrains parameters related to reaction times. Local variations in aircraft types and operations may result in corresponding variations to the minimum desired warning time.

6.2.4.5 Desired look ahead times

The minimum look-ahead time is that which provides for the minimum warning time plus the MSAW processing time. The desired look-ahead time must therefore be at least the desired warning time plus the processing time. However, the alert rate may be sensitive to the look-ahead time and this must also be considered when setting such parameters to avoid producing an excessive number of nuisance alerts.

6.2.4.6 Surveillance tracking performance

The behaviour of the vertical tracker should be considered when setting parameters and vertical tolerances in MSAW.

For example, it should be considered that tracker lag and (on occasion) vertical coasting can cause the aircraft to appear to overshoot the flight level by one or two hundred feet. Therefore, many aircraft in the process of levelling off at a safe altitude will appear to overshoot, and it is important that vertical tolerances allow for some overshoot 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.

To a more limited extent, general surveillance tracking performance may also be considered when determining the ranges for parameters. Two theoretical approaches can be adopted. The first approach is to set the parameters to large enough values to ensure that all predicted conflicts will be detected, even when poor tracking means that there are large errors in the aircraft heading values. The second approach is to set the parameters to smaller values to reduce the number of spurious alerts caused by poor tracking or small fluctuations in aircraft trajectories.

6.2.5 Initial parameter set

The initial optimisation process will not have an existing parameter set to use as a baseline. 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 baseline.

6.2.6 Parameter sensitivity analysis

6.2.6.1 Introduction

The initial optimisation process will not have an existing parameter set to use as a baseline. 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 baseline.

6.2.6.2 Method

The first step in parameter sensitivity analysis is to pass appropriate surveillance data through the MSAW 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.

6.2.6.3 Aspects of graphs for consideration

6.2.6.3.1 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.

6.2.6.3.2 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 MSAW. 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.

6.2.6.3.3 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.

6.2.6.3.4 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.

6.2.6.4 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 MSAW algorithms themselves.

6.2.6.5 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 minimises the risk that inconsistent or redundant parameter values will be set

6.3 Baseline results

Once theoretical values have been determined for each parameter, the parameter set should be run against the sample test data. This produces a set of results to be used as the baseline for the parameter optimisation process.

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

6.4 Optimisation process

6.4.1 Procedure

The parameter optimisation 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 function. The efficient and effective optimisation of MSAW 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 parameter sensitivity analysis results combined with the expertise of the analysis team are crucial in determining which combinations should be examined and which may be ignored.

The iterative optimisation process should be performed for all filters.

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

6.4.2 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).

6.4.3 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.

6.4.4 Test against sample data

In theory, the parameter set which 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.

6.4.5 Operational trial

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

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 MSAW. 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.

6.5 Operational monitoring

Traffic patterns, airspace design, SSR allocations and ATC practice all change with time. These factors have a bearing on the “optimum” parameter set for MSAW. Parameter optimisation 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.

7. Guidelines for recording MSAW data

7.1 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 MSAW systems.

7.2 Routine data recording

In most ATC systems, data such as surveillance plots, system tracks, alerts 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 MSAW data that is recorded routinely generally includes the alert messages and may also include MSAW status (or alive, or heartbeat) messages. Other information related to MSAW may also be routinely recorded, such a flight plan data and QNH.

7.3 Occasional data recording

7.3.1 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 MSAW data must contain sufficient information and must be precise enough to allow the correct functioning of MSAW to be verified.

If a test MSAW system is used for parameter optimisation then at the very least, the MSAW 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 MSAW functioning, whilst desirable items of data may provide analysts with further valuable details.

Recorded data may be grouped as follows:

- Environment data (desirable, but may be obtainable from elsewhere)
- All system tracks available to MSAW (desirable, but bulky)
- System tracks that are relevant for MSAW (required)
- Values calculated for the track before or during the fine filters (required)
- Flags and results of conflict detection processes (required)
- Alert messages (required)

- Additional information such as QNH (required) or temperature (if relevant)

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 (e.g. using a system track reference number), so that the inputs to MSAW and the MSAW 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.

7.3.2 Environment data

It is convenient to include all relevant environment data at the start of the data recording. This data should include all MSAW parameters, MSAW surfaces, terrain definitions, and obstacle definitions, as well as any other items related to MSAW 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.

7.4 System tracks

Despite its inevitable size, it is sometimes desirable to record all the system tracks that are presented to MSAW. This would allow the correct functioning of the eligibility criteria and coarse filter grid (if used) to be tested.

7.5 System tracks that are relevant to MSAW

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

Since many MSAW systems do not include a coarse filter, some criteria need to be set to exclude the majority of tracks that are far from terrain. It is suggested that tracks should be recorded if they are eligible for MSAW processing and they are below a predefined altitude.

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

The information required for each track is listed below:

- System track number
- System track eligibility information
- 3D state vector (X, Y, Z, VX, VY, VZ) and true altitude
- Track age and quality information used by MSAW
- Data from the flight plan such as the cleared flight level, if used

7.6 Values calculated before or during the fine filters

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

- The track number for the track of concern
- The current aircraft altitude

- The CFL (if any) that was used in the terrain conflict prediction
- The terrain conflict filter time of violation, TOV
- The altitude of the aircraft at TOV
- The height of the terrain at TOV
- An indication of which obstacles are predicted for lateral infringement
- The start and end times of lateral violation, TLS and TLE, for each infringed obstacle
- The CFL (if any) that was used in the obstacle conflict prediction
- The start and end times of vertical violation, TVS and TVE, for each infringed obstacle
- The start and end times of the lateral violation, TLS and TLE (if calculated)
- The time of violation, OTOV for each infringed obstacle
- The final time of violation, FTOV, for the obstacle conflict filter

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.

7.7 Flags and fine filter results

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

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

Flags before the Fine Filters:

- Track is in an MSAW exclusion area
- Track is eligible for MSAW processing (or reasons for non-eligibility)
- Coarse filter passed

Terrain Conflict Filter Flags:

- Terrain conflict filter called
- Terrain conflict result (hit or miss) on this cycle

Obstacle Conflict Filter Flags:

- Obstacle conflict filter called
- For each obstacle of concern, a lateral violation is predicted
- For each obstacle of concern, a vertical violation is predicted
- For each obstacle of concern, there is an overlap of lateral and vertical violation
- Obstacle conflict result (hit or miss) on this cycle

Terrain Conflict Alert Confirmation Flags:

- Terrain conflict is imminent - time of violation, TOV, is within **TerrainImminentTime**
- Count of conflict hits is sufficient (>= **TerrainConflictCount**)
- Time of violation, TOV, is within **TerrainWarningTime**
- Terrain conflict alert is confirmed

Obstacle Conflict Alert Confirmation Flags:

- Obstacle conflict is imminent - time of violation, FTOV, is within **ObstacleImminentTime**
- Count of conflict hits is sufficient (>= **ObstacleConflictCount**)
- Time of violation, FTOV, is within **ObstacleWarningTime**
- Obstacle conflict alert confirmed

7.8 Alert messages

An MSAW 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
- The nature of the alert, e.g. terrain alert, obstacle alert.
- Any other information relevant to the alert

7.9 Additional information

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

- Changes to the QNH and/or the transition level
- Changes in the local temperature

8. Test scenarios for MSAW

8.1 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 MSAW system
- To demonstrate the variety of types of situation for which MSAW is expected to perform

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

The test scenarios are useful to demonstrate the variety of mid-air situations that can occur between aircraft. It is not desirable to improve the alerting performance for one type of situation at the expense of the performance in other situations. Therefore, as part of the parameter optimisation process, the different types of situation must be properly considered.

8.2 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 MSAW system under test is optimised.

8.3 Derivation of the performance targets

The performance targets were derived by using the appropriate equations of uniform motion that would be employed in an MSAW system. The expected time of the alert was then calculated using the parameter values at the narrowest end of the recommended range, and taking full account of the delay that might be added by the alert confirmation stage, including conflict counts.

Where the aircraft are in vertical transition, the flight level at the target time has been given. This may be a convenient way of checking the timing of the alert on an ATC display.

8.4 List of test scenarios

The test scenarios are:

- Aircraft descends on terrain
- Aircraft descends on an obstacle
- Aircraft flying level in conflict with terrain

- Aircraft flying level in conflict with an obstacle
- Departure from level flight towards terrain
- Departure from level flight towards an obstacle
- Climbing aircraft levels off at an unsafe (due to terrain) altitude (optional use of CFL and/or SFL)
- Climbing aircraft levels off at an unsafe (due to an obstacle) altitude (optional use of CFL and/or SFL)
- Aircraft proceeds out of an MSAW exclusion region into imminent conflict with terrain
- Aircraft proceeds out of an MSAW exclusion region into imminent conflict with an obstacle

8.5 Aircraft descends on terrain

8.5.1 Objective

The objective of this scenario is to test MSAW performance in the very simple case of an aircraft descending to infringe a terrain protection threshold.

8.5.2 Aircraft geometry

The simulated aircraft is arranged to infringe a terrain protection threshold with an elevation of 1 000 ft, at time t = 120 s after the start of the scenario. The aircraft is fully eligible for MSAW processing. The aircraft descends from 4 000 ft at a vertical rate of 1 500 ft/min. The scenario is depicted in Figure 27.

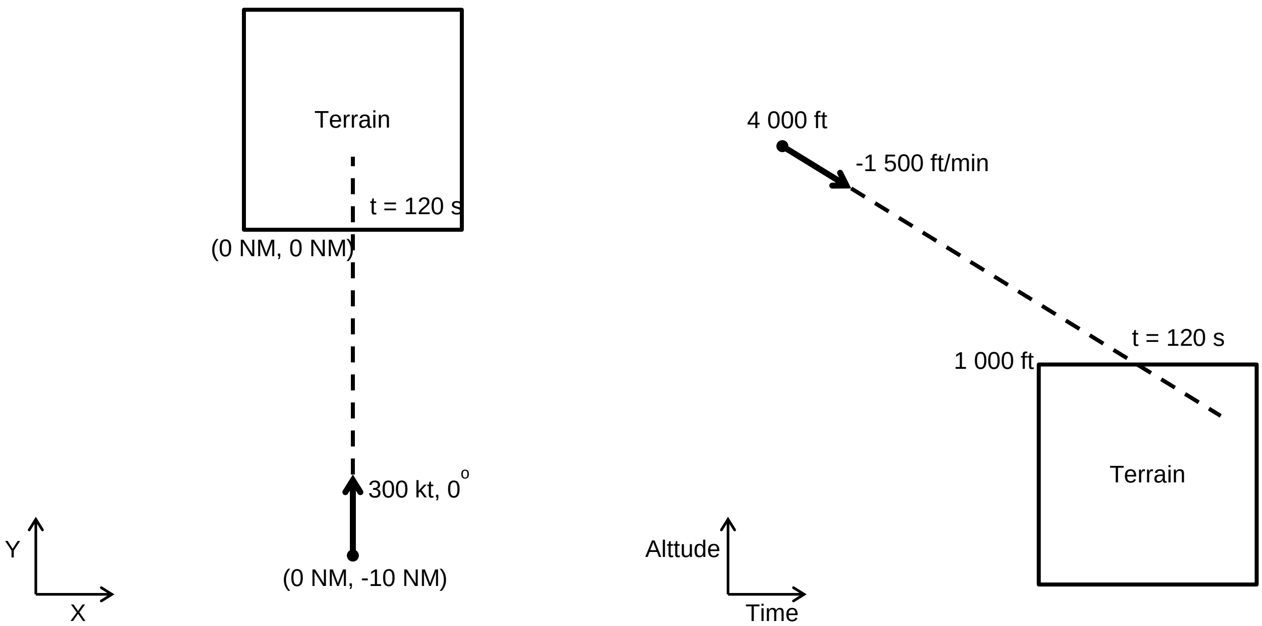

Figure 27: Aircraft descends on terrain test scenario

8.5.3 Target result

The MSAW alert should be displayed at least 10 s before the infringement time, t. That is, at the very latest when the track label shows the aircraft at 1 300 ft.

8.5.4 Significant parameters

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

- **TerrainMinimumClearance**
- **TerrainWarningTime**
- **TerrainConflictCount**
- **TerrainImminentTime**

8.6 Aircraft descends on an obstacle

8.6.1 Objective

The objective of this scenario is to test MSAW performance in the very simple case of an aircraft descending on an obstacle.

8.6.2 Aircraft geometry

The simulated aircraft is arranged to infringe an obstacle with an elevation of 500 ft, at time t = 120 s after the start of the scenario. The aircraft is fully eligible for MSAW processing. The aircraft descends from 2 500 ft at a vertical rate of 1 000 ft/min. The scenario is depicted in Figure 28.

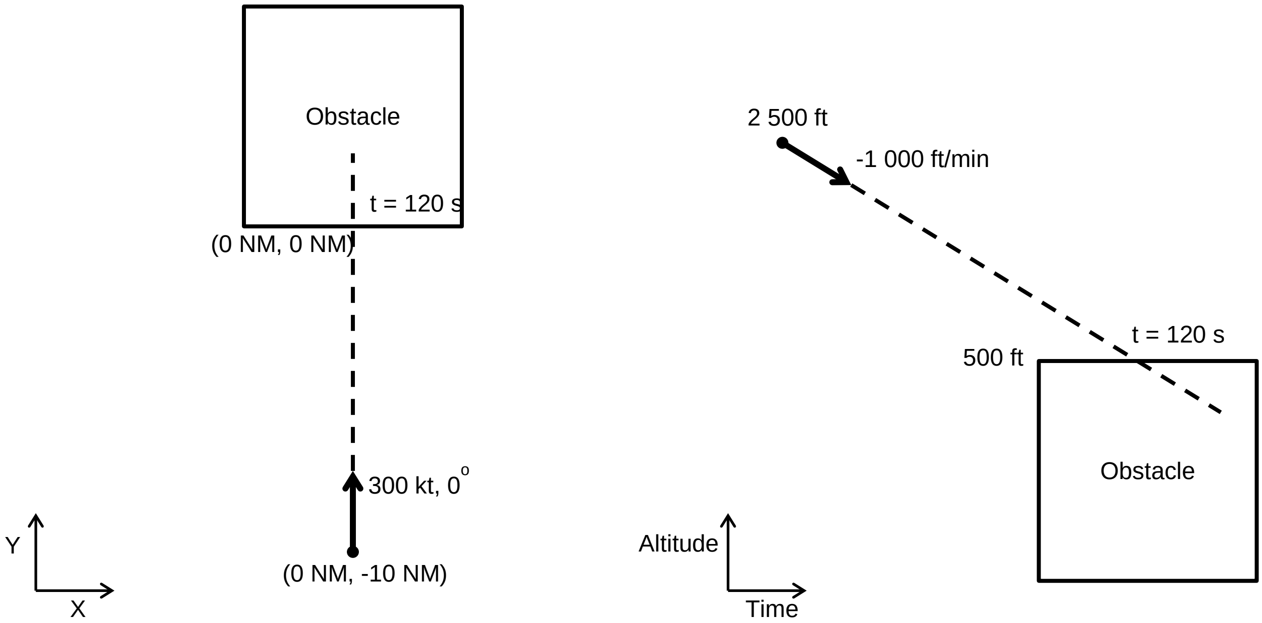

Figure 28: Aircraft descends on an obstacle test scenario

8.6.3 Target result

The MSAW alert should be displayed at least 20 s before the infringement time, t. That is, before the track label shows the aircraft at 800 ft.

8.6.4 Significant parameters

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

- **ObstacleWarningTime**
- **ObstacleConflictCount**
- **ObstacleImminentTime**

8.7 Aircraft flying level in conflict with terrain

8.7.1 Objective

The objective of this scenario is to test MSAW performance in the case of an aircraft flying level into conflict with a terrain protection threshold.

8.7.2 Aircraft geometry

The simulated aircraft is arranged to infringe a terrain protection threshold with an elevation of 2 200 ft, at time t = 120 s after the start of the scenario at coordinate (0 NM; 0 NM). The aircraft is fully eligible for MSAW processing. The aircraft is level at 2 000 ft. The scenario is depicted in Figure 29.

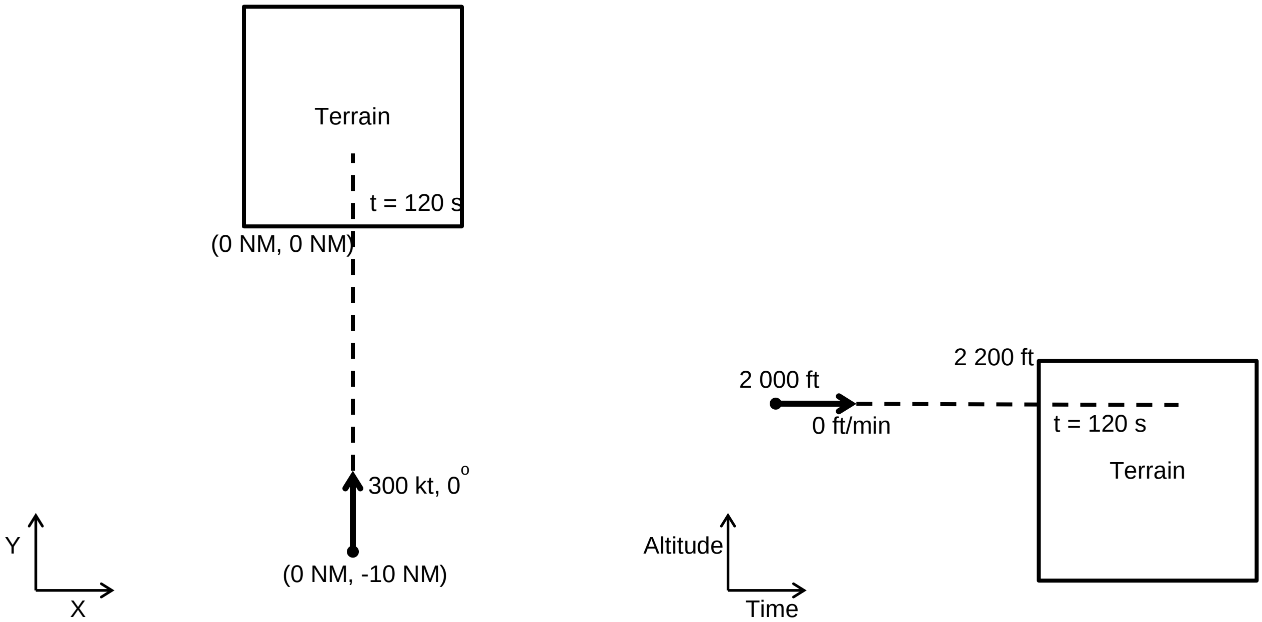

Figure 29: Aircraft flying level in conflict with terrain test scenario

8.7.3 Target result

The MSAW alert should be displayed at least 10 s before the infringement time, t.

8.7.4 Significant parameters

The following parameters are significant to MSAW performance in this scenario:

- **TerrainWarningTime**
- **TerrainConflictCount**
- **TerrainImminentTime**

8.8 Aircraft flying level in conflict with an obstacle

8.8.1 Objective

The objective of this scenario is to test MSAW performance in the case of an aircraft flying level into conflict with an obstacle.

8.8.2 Aircraft geometry

The simulated aircraft is arranged to infringe an obstacle with an elevation of 700 ft, at time t = 120 s after the start of the scenario at coordinate (0 NM, 0 NM). The aircraft is fully eligible for MSAW processing. The aircraft is level at 500 ft. The scenario is depicted in Figure 30.

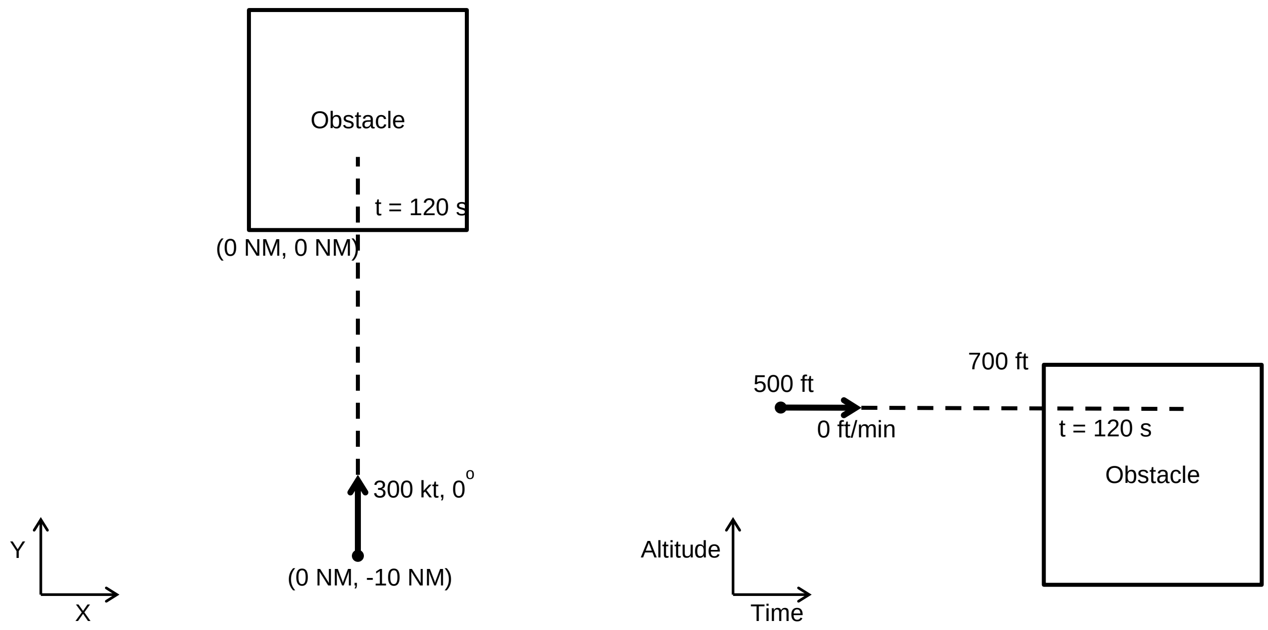

Figure 30: Aircraft flying level in conflict with an obstacle test scenario

8.8.3 Target result

The MSAW alert should be displayed at least 20 s before the infringement time, t.

8.8.4 Significant parameters

The following parameters are significant to MSAW performance in this scenario:

- **ObstacleWarningTime**
- **ObstacleConflictCount**
- **ObstacleImminentTime**

8.9 Departure from level flight towards terrain

8.9.1 Objective

The objective of this scenario is to test MSAW performance in the case of an aircraft descending suddenly towards a terrain polygon.

8.9.2 Aircraft geometry

The simulated aircraft starts in level flight at 2 000 ft. Then, the aircraft descends suddenly at 1 500 ft/min towards a terrain polygon with an elevation of 1 500 ft. The aircraft is fully eligible for MSAW processing. The scenario is depicted in Figure 31.

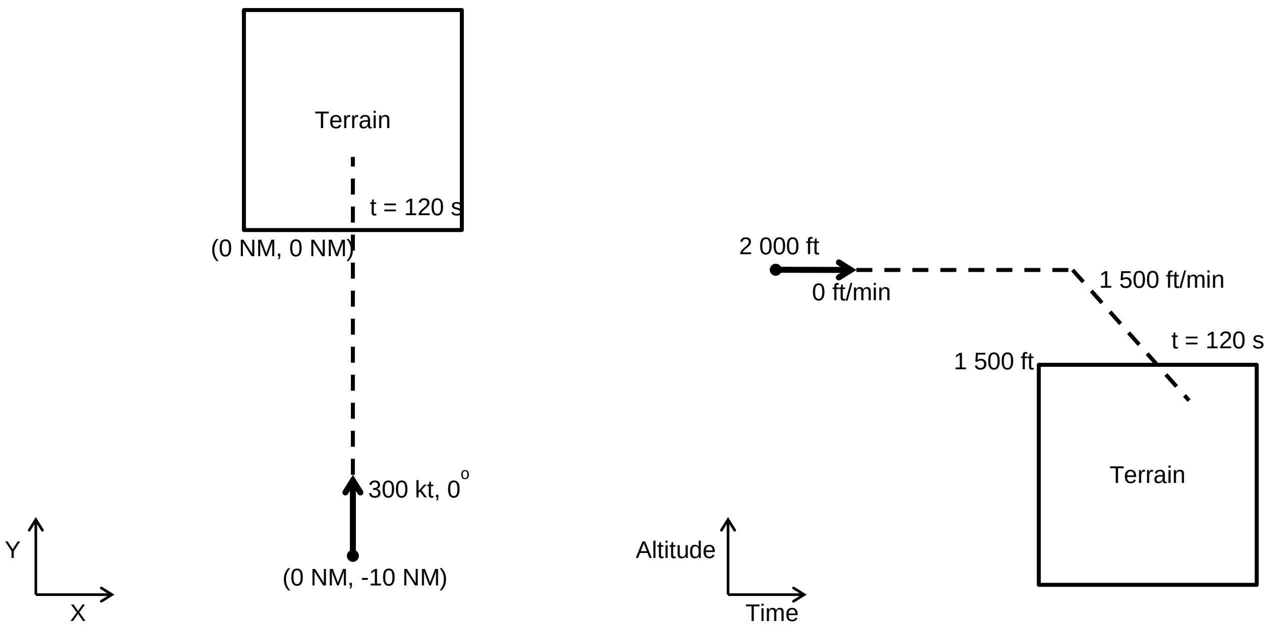

Figure 31: Departure from level flight towards terrain test scenario

8.9.3 Target result

The MSAW alert should be displayed at least 10 s before the infringement time, t. That is, before the track label shows the aircraft at 1 700 ft.

8.9.4 Significant parameters

The following parameters are significant to this scenario:

- **TerrainMinimumClearance**
- **TerrainWarningTime**
- **TerrainConflictCount**
- **TerrainImminentTime**

8.10 Departure from level flight towards an obstacle

8.10.1 Objective

The objective of this scenario is to test MSAW performance in the case of an aircraft descending suddenly towards an obstacle

8.10.2 Aircraft geometry

The simulated aircraft starts in level flight at 1 000 ft. Then, the aircraft descends suddenly at 1 500 ft/min towards an obstacle with an elevation of 500 ft. The aircraft is fully eligible for MSAW processing. The scenario is depicted in Figure 32.

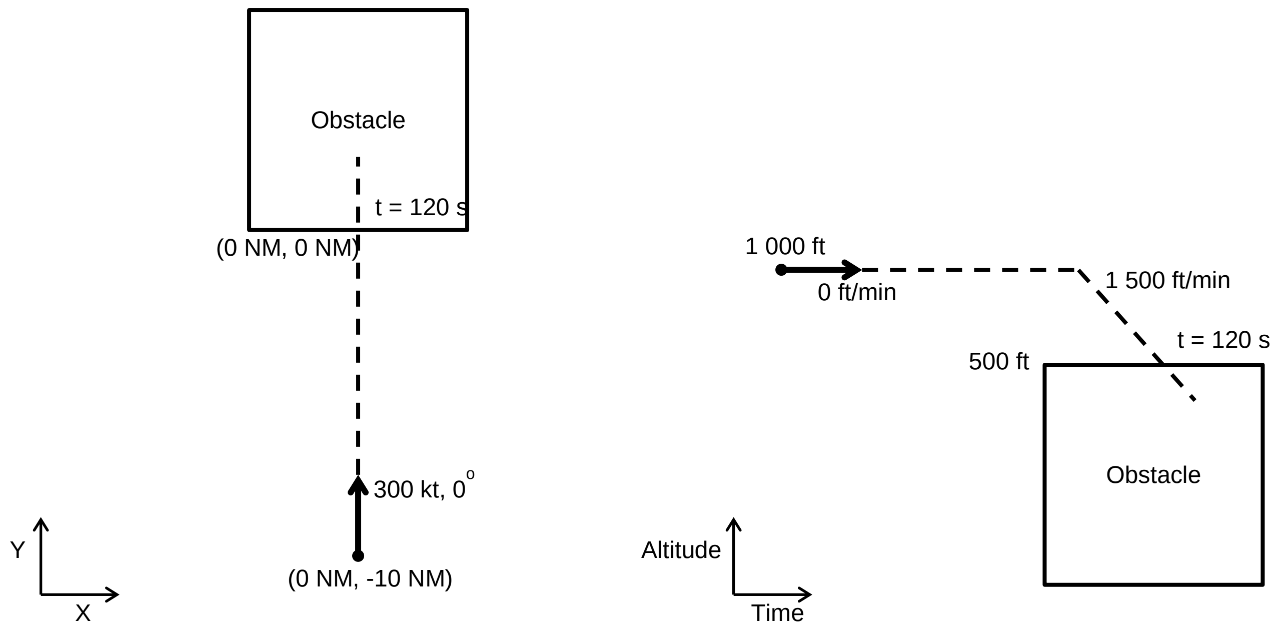

Figure 32: Departure from level flight towards an obstacle test scenario

8.10.3 Target result

The MSAW alert should be displayed as soon as the aircraft departs from level flight. That is, when the track label shows the aircraft at 900 ft.

8.10.4 Significant parameters

The following parameters are significant to this scenario:

- **ObstacleWarningTime**
- **ObstacleConflictCount**
- **ObstacleImminentTime**

8.11 Climbing aircraft levels off at an unsafe (due to terrain) altitude (optional use of CFL and/or SFL)

8.11.1 Objective

The objective of this scenario is to test MSAW performance in the case of an aircraft climbing, but then levelling off before reaching a safe altitude.

Without CFL and/or SFL, MSAW alerts soon after the aircraft has levelled off.

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

8.11.2 Aircraft geometry

The simulated aircraft is initially at FL70 and climbing at 2 000 ft/min. The climb rate is just sufficient to clear the terrain before the aircraft is within horizontal conflict. However, the aircraft levels off 60 s from the start of the scenario, at FL90 below a terrain polygon with an elevation of 10 000 ft (this represents a high mountain). The aircraft is fully eligible for MSAW processing. The scenario is depicted in Figure 33.

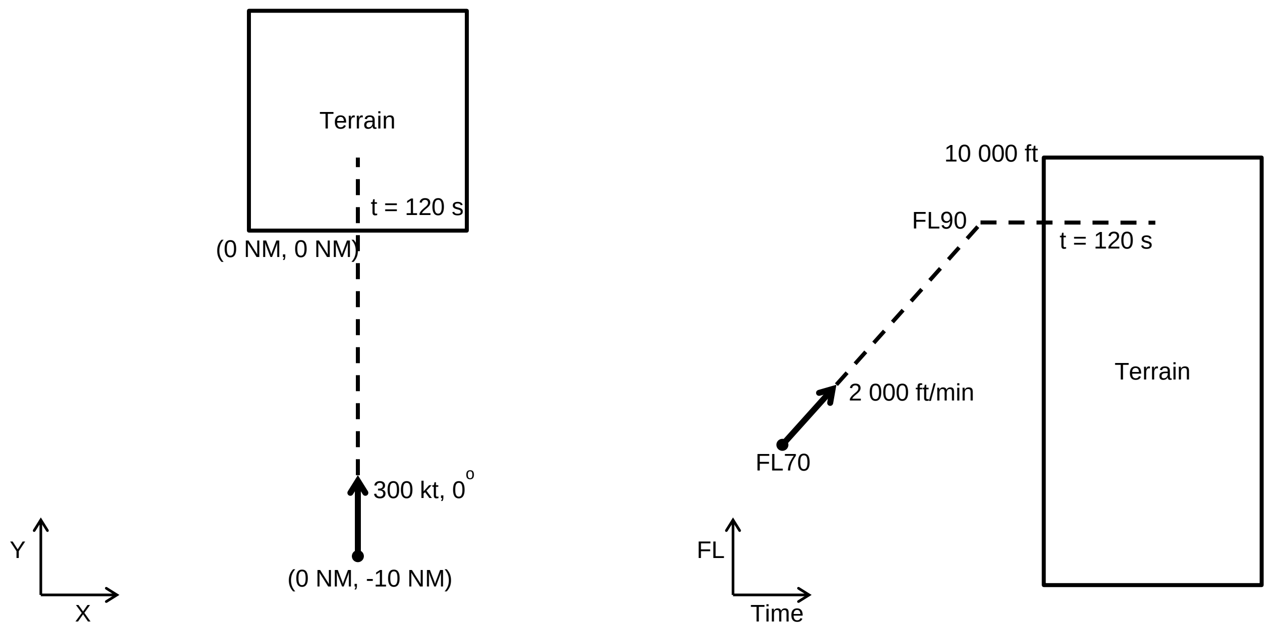

Figure 33: Climbing aircraft levels off at an unsafe (due to terrain) altitude (optional use of CFL and/or SFL) test scenario

8.11.3 Target result

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

With CFL and/or SFL used by the MSAW system and with a CFL and/or SFL of FL90 input for the aircraft, it should be possible for MSAW to alert before the aircraft levels off.

8.11.4 Significant parameters

The following parameters are significant to this scenario:

- **UseCFL**
- **UseSFL**

- **TerrainMinimumClearance**
- **TerrainWarningTime**
- **TerrainConflictCount**
- **TerrainImminentTime**

8.12 Climbing aircraft levels off at an unsafe (due to an obstacle) altitude (optional use of CFL and/or SFL)

8.12.1 Objective

The objective of this scenario is to test MSAW performance in the case of an aircraft climbing, but then levelling off before reaching a safe altitude.

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

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

8.12.2 Aircraft geometry

The simulated aircraft is initially at FL70 and climbing at 2 000 ft/min. The climb rate is just sufficient to clear an obstacle before the aircraft is within horizontal conflict. However, the aircraft levels off 60 s from the start of the scenario, at FL90 below the obstacle with an elevation of 10 000 ft (this represents an obstacle on top of a high mountain). The aircraft is fully eligible for MSAW processing. The scenario is depicted in Figure 34.

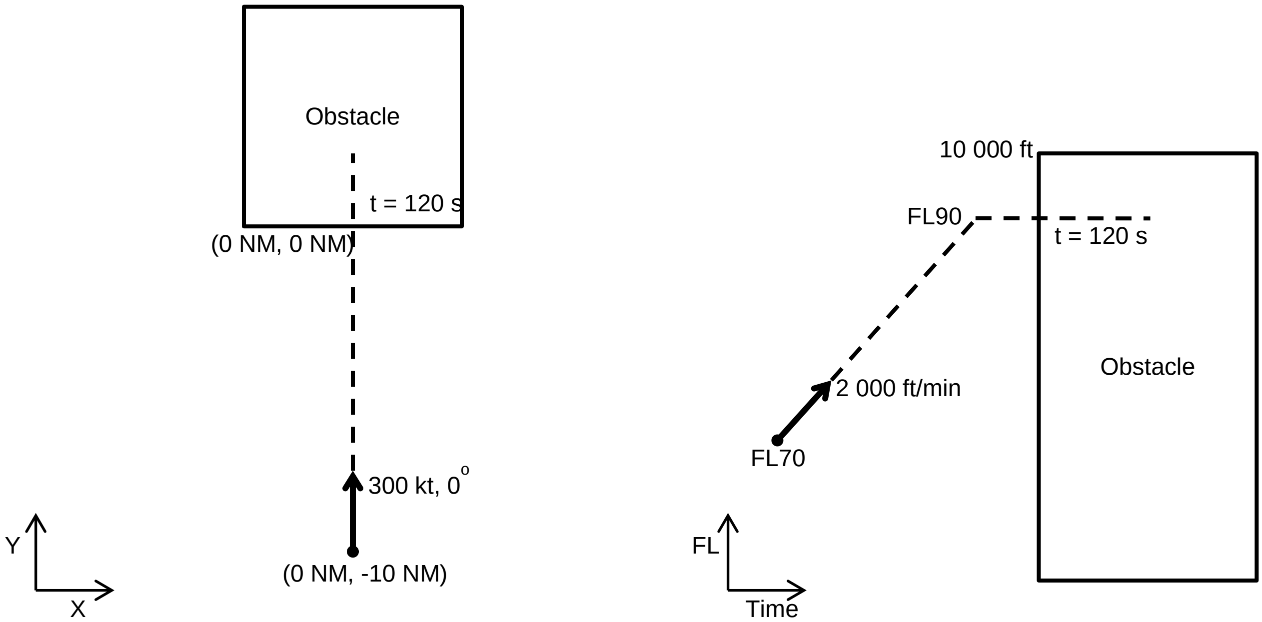

Figure 34: Climbing aircraft levels off at an unsafe (due to an obstacle) altitude (optional use of CFL and/or SFL) test scenario

8.12.3 Target result

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

With CFL and/or SFL used by the MSAW system and with a CFL and/or SFL of FL90 input for the aircraft, it should be possible for MSAW to alert before the aircraft levels off.

8.12.4 Significant parameters

The following parameters are significant to this scenario:

- **UseCFL**
- **UseSFL**
- **ObstacleWarningTime**

- **ObstacleConflictCount**
- **ObstacleImminentTime**

8.13 Aircraft proceeds out of an MSAW exclusion region into imminent conflict with terrain

8.13.1 Objective

The objective of this scenario is to test whether MSAW generates an alert as soon as an aircraft emerges from an exclusion region into imminent conflict with terrain.

8.13.2 Aircraft geometry

The aircraft starts in an MSAW exclusion region, but then proceeds out of the exclusion region into imminent conflict with terrain at 4 000 ft. The aircraft is flying level at 3 000 ft throughout the scenario. The simulated aircraft is arranged to collide into the terrain at time t = 120 s after the start of the scenario at coordinate (0 NM, 0 NM). The aircraft is fully eligible for MSAW processing.

The aircraft emerges from the exclusion region t = 110 s into the scenario (10 s to potential collision). At this time, the separation between the aircraft and terrain has reduced to 1.0 NM and the aircraft is at coordinate (1.0 NM, 0 NM). The scenario is depicted in Figure 35.

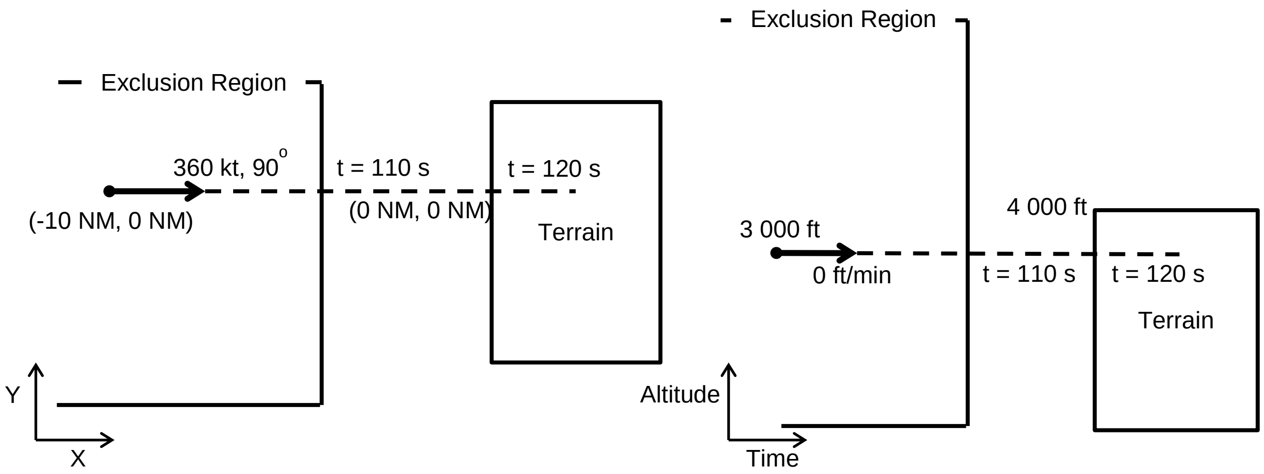

Figure 35: Aircraft proceeds out of an MSAW exclusion region into imminent conflict with terrain test scenario

8.13.3 Target result

The MSAW terrain alert must occur on the first cycle that the aircraft emerges from the exclusion region.

8.13.4 Significant parameters

The following parameters are significant:

- **TerrainImminentTime**

8.14 Aircraft proceeds out of an MSAW exclusion region into imminent conflict with an obstacle

8.14.1 Objective

The objective of this scenario is to test whether MSAW generates an alert as soon as an aircraft emerges from an exclusion region into imminent conflict with an obstacle.

8.14.2 Aircraft geometry

The aircraft starts in an MSAW exclusion region, but then proceeds out of the exclusion region into imminent conflict with an obstacle at 1 200 ft. The aircraft is flying level at 1 000 ft throughout the scenario. The simulated aircraft is arranged to collide into the terrain at time t = 120 s after the start of the scenario at coordinate (0 NM, 0 NM). The aircraft is fully eligible for MSAW processing.

The aircraft emerges from the exclusion region 100 s into the scenario (20 s to potential collision). At this time, the separation between the aircraft and the obstacle has reduced to 2.0 NM and the aircraft is at coordinate (-2.0 NM, 0 NM). The scenario is depicted in Figure 36.

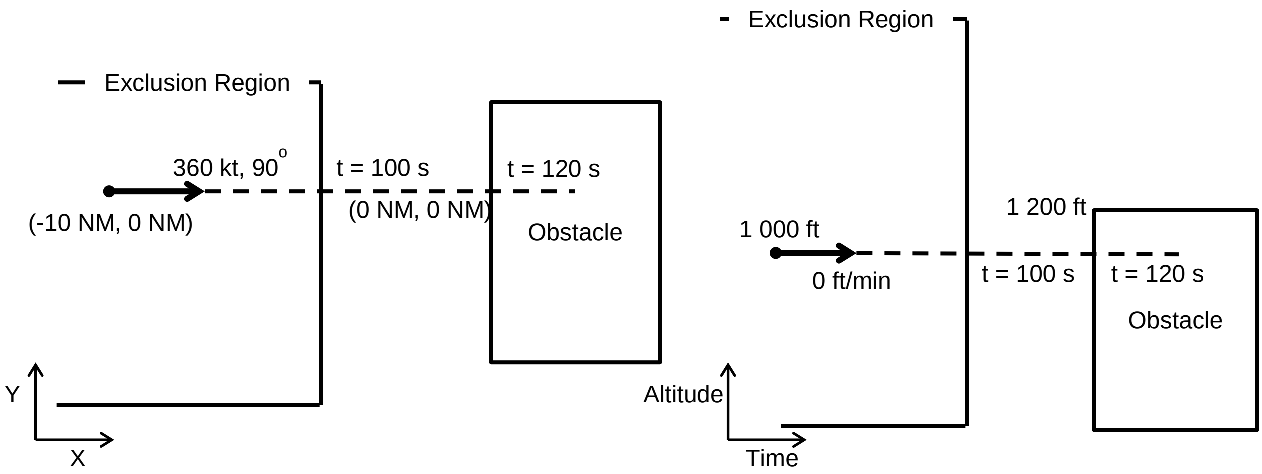

Figure 36: Aircraft proceeds out of an MSAW exclusion region into imminent conflict with an obstacle test scenario

8.14.3 Target result

The MSAW obstacle alert must occur on the first cycle that the aircraft emerges from the exclusion region.

8.14.4 Significant parameters

The following parameters are significant:

- **ObstacleImminentTime**

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