Safety Case for Wake Vortex Encounter Risk due to the Airbus A380-800

Produced for the A380 Wake Vortex Steering Group

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[1] The Joint Aviation Authorities will continue to exist until June 2009. At that time its responsibilities will be transferred to the European Aviation Safety Agency.

DOCUMENT ENDORSEMENT

ORGANIZATION
EUROCONTROL
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DOCUMENT CHANGE RECORD

The following table records the history of the successive editions of this safety case.

EDITION NUMBER	EDITION DATE	REASON FOR CHANGE
1.0	25 October 2006	First draft for review by endorsing organizations.
2.0	16 November 2006	Final report issued to ICAO and presented at Air Navigation Committee.
3.0	23 May 2008	Revised to include additional LIDAR flight test data collected at Tarbes, France in 2007. Final draft for review by endorsing organizations.
4.0	20 June 2008	Revised to include additional LIDAR flight test data collected at Tarbes, France in 2007. Final report issued to ICAO and presented at Air Navigation Committee.

FOREWORD

This document is Edition 4.0 of the Safety Case for Wake Vortex Encounter Risk due to the Airbus A380-800 (A388). Edition 2.0 of this safety case was originally published in November 2006 before the entry into service of the A388.

Since 2006 additional data have been collected and analysed. As a result some modified wake turbulence separations are now justified. Edition 4.0 of this safety case (this document) describes these modified separation criteria and their basis. This document supersedes the 2006 safety case. The corresponding (proprietary) safety assessment report has been updated and also supersedes the corresponding 2006 safety assessment report.

The A388 entered into commercial service since the publication of the 2006 safety case. It is therefore now convenient to make two new definitions as follows:

Reference Date. This safety case refers to “current separation criteria”, “aircraft in-service today” and similar statements. In such statements the reference date is defined as the day that Edition 2.0 of this safety case was published, 16 November 2006 [A380 SG, 2006b].

Reference Aircraft. The relative safety assessment methodology applied in this report requires comparison to “reference aircraft”. The reference aircraft chosen are defined as the heaviest Heavy aircraft in-service on the reference date. Typical reference aircraft are the Boeing 747-400 (B744), Airbus 340-600 (A346) and the Boeing 777-300 (B773).

These definitions enable this safety case to be revised with the minimum of textural edits.

EXECUTIVE SUMMARY

Objectives and Application

The objectives of this safety case are as follows:

- To define and justify the safety requirements for the A380-800 (A388) wake vortex generator aircraft in all phases of flight, for all categories of potential wake vortex encountering aircraft, and for all operational conditions worldwide. The defined safety requirements are those that are necessary in order to ensure that Wake Vortex Encounter (WVE) risk due to the A388 is acceptably low. The safety requirements are specified as two sets of WVE separation criteria (distance and time based) and two supporting general safety requirements.
- To define and document the basis of the safety requirements.
- To note key assumptions, uncertainties and exceptions.

The overall aim of this safety case is to show, through argument and evidence, that A388 operations will continue to be acceptably safe in principle with respect to WVE risk for all operational conditions (assuming the defined safety requirements are completely implemented), whilst noting any explicit exceptions.

The guiding principle applied in this safety case was to set the minimum separation criteria for the A388 that can be clearly justified by evidence or data, consistent with the requirement of safety regulators that an appropriate level of conservatism is included in system changes during early operations. The starting point for all the safety criteria was Edition 2.0 of this safety case [A380 SG, 2006b], which was based on work performed under the authority of the A380 Wake Vortex Steering Group. Where lower separation criteria could be agreed and justified, these have been specified in this safety case.

It is anticipated that all the safety requirements, and in particular the separation criteria for approach and departure, will be re-evaluated when sufficient operational wake vortex monitoring results, or other data, are available to support further changes to the safety requirements defined in this safety case.

It is emphasised that WVE risk is not the only factor that determines operational aircraft separations. Responsible parties need to assess all other relevant factors (for example, runway occupancy times, etc.) as well as the safety requirements defined in this safety case when determining how to adjust their operational procedures to include the A388.

Scope

The scope of this WVE risk safety case for the A388 is defined as follows:

- Generator aircraft. This safety case applies to passenger and freighter Airbus A380-800 (A388) aircraft with a Maximum certified Take-Off Mass (MTOM, sometimes called maximum take-off weight (MTOW)) of up to 590,000kg and wing-span of 79.8m.
- Phases of flight. This safety case is valid for all phases of flight.
- Encountering aircraft. This safety case is valid for all categories of encountering aircraft.
- All conditions worldwide. This safety case is valid for all weather conditions that may be encountered in any location worldwide.

The strategy for ensuring ATM safety is based on 3 high-level principles:

- Ensuring that airspace design is acceptably safe.
- Ensuring that ATM procedures are acceptably safe.
- Ensuring separation criteria, such as the separation criteria specified in this safety case to ensure WVE risk is acceptable, are acceptably safe.

The scope of this safety case is confined to specifying modifications to a sub-set of the currently defined separations (the third principle above).

This has two important consequences:

- If the current ICAO PANS-ATM WVE separation criteria can be applied in a location without modification then the separation criteria for the A388 specified in this safety case can also be applied without modification.
- Responsible parties must assess if the separation criteria recommended in this report are consistent with their local airspace design and ATM procedures. The A380 Wake Vortex Steering Group cannot, and has not, performed a comprehensive evaluation of if the separation criteria defined in this safety case are consistent with local airspace designs or ATM procedures.

This definition of the scope of this safety case supports the global applicability of the safety requirements derived in this safety case.

Safety Requirements

The safety requirements stated below and developed in this safety case are considered by the A380 Wake Vortex Steering Group to be mandatory in order to ensure that the operation of the A388 will continue to be acceptably safe in practice with respect to WVE risk.

General Safety Requirements

1. WVE reporting, analysis of reports and international dissemination of WVE experience data are required consistent with safety management system principles adopted by ICAO [ICAO Annex 11, 2.26 with guidance contained in the "Safety Management Manual", Doc 9859; ICAO, 2006a]. This safety requirement has 5 component parts:

   a) Responsible parties (normally Air Traffic Service Providers) are required to implement a WVE reporting system for all encountering aircraft, all phases of flight and for all generator aircraft.
   b) Responsible parties are required to review and investigate the WVE reports collected locally.
   c) Responsible parties are required to identify and implement any corrective actions which may be identified as necessary following local review of WVE reports.
   d) Responsible parties are required to send all WVE reports to ICAO so that isolated incidents observed locally may be reviewed to determine if they are indicators of a general safety issue. Responsible parties are required to also notify ICAO of any local corrective actions issued.
   e) ICAO is responsible for ensuring regular review of all WVE reports and local corrective actions and for disseminating any corrective actions that may be identified by that review.

   The overall objective of this safety requirement is to ensure that any unsafe incidents are identified before an accident occurs so that corrective action is applied internationally to prevent the cause(s) of the incident from re-occurring.

   This requirement has been implemented by ICAO and any WVE reports received will be reviewed.

2. Responsible parties must assess if the separation criteria recommended in this report are consistent with their local airspace design and ATM procedures. If they are not consistent then the responsible party must perform an appropriate safety assessment.

Approach Safety Requirements

3. The minimum required radar separations for approach for the A388 are specified in Table 1 together with the ICAO PANS-ATM radar separations for aircraft weight categories at the reference date (shaded).

Table 1 Radar Wake Turbulence Separation Criteria for Approach (Nautical Miles (NM), current ICAO criteria are shown shaded)

	A388 Encounterer	Heavy Encounterer	Medium Encounterer	Light Encounterer
A388 Generator	Not required [a b c]	6NM	7NM	8NM
Heavy Generator	Not required [b c]	4NM	5NM	6NM
Medium Generator	Not required [c]	Not required	Not required	5NM
Light Generator	Not required [c]	Not required	Not required	Not required

Notes:

a Not required = when a wake turbulence restriction is not required then separation reverts to a Minimum Radar Separation as prescribed by the appropriate Air Traffic Services authority.

b Wake turbulence separation minima are not required by this safety case. However 4NM has been specified by ICAO [“Wake turbulence aspects of Airbus A380-800 aircraft”, ICAO 2006b] pending possible amendment to the PANS-ATM.

c When the A388 is the encounterer the requirement is stated as “Not required”. WVE risk has been evaluated down to a minimum distance of 2.0NM and it has been determined that an additional WV separation is not required down to this minimum distance.

The justification of these safety requirements is provided in this safety case.

Cruise Safety Requirements

4. The work that supports this safety case has shown that the WVE risk that results from an A388 generator aircraft in cruise is not noticeably different from those WVE risk levels that result from reference aircraft. Therefore, the currently specified vertical or horizontal separation criteria, as prescribed by the ICAO *Procedures for Air Navigation Services — Air Traffic Management* [PANS-ATM, Doc 4444; ICAO, 2005b], are applicable to the A388.

   Furthermore the work that supports this safety case has shown that the current PANS-ATM vertical separations currently applied to all aircraft can also be applied in relation to the A388 generator aircraft in all phases of flight without modification. This is based on measurements of the A388 performed at cruise speeds (Mach 0.85) and at typical holding/ terminal control area speeds (250knots).

Departure Safety Requirements

ICAO PANS-ATM [ICAO, 2005b] specifies minimum WVE departure separations in terms of time-based and radar separations. The time-based separations are applied on and near the runway(s) in conjunction with take-off and approach as per PANS-ATM 5.8. The radar separations are applied to aircraft in the approach and departure phases of flight as per PANS-ATM 8.7.4.4.

5. The required minimum time-based separations for departure for the A388 are specified in Table 2 together with the ICAO time-based separations for aircraft weight categories at the reference date (shaded).

Table 2 Time-Based WVE Separation Criteria for Departure (seconds, current ICAO criteria are shown shaded)

	A388 Encounterer	Heavy Encounterer	Medium Encounterer	Light Encounterer
A388 Generator	Not required	120s	180s	180s
Heavy Generator	Not required	Not required	120s	120s
Medium Generator	Not required	Not required	Not required	120s
Light Generator	Not required	Not required	Not required	Not required

6. The required minimum radar separations for departure for the A388 are specified in Table 3 together with the ICAO radar separations for aircraft weight categories at the reference date (shaded). Consistent with radar separations specified by ICAO today, Table 3 is identical to Table 1.

Table 3 Radar WVE Separation Criteria for Departure (Nautical Miles (NM), current ICAO criteria are shown shaded)

	A388 Encounterer	Heavy Encounterer	Medium Encounterer	Light Encounterer
A388 Generator	Not required [a b c]	6NM	7NM	8NM
Heavy Generator	Not required [b c]	4NM	5NM	6NM
Medium Generator	Not required [c]	Not required	Not required	5NM
Light Generator	Not required [c]	Not required	Not required	Not required

Notes:

a Not required = when a wake turbulence restriction is not required then separation reverts to a Minimum Radar Separation as prescribed by the appropriate Air Traffic Services authority.

b Wake turbulence separation minima are not required by this safety case. However 4NM has been specified by ICAO ["Wake turbulence aspects of Airbus A380-800 aircraft", ICAO 2006b] pending possible amendment to the PANS-ATM.

c When the A388 is the encounterer the requirement is stated as "Not required". WVE risk has been evaluated down to a minimum distance of 2.0NM and it has been determined that an additional distance is not required.

Safety Recommendations

The above safety requirements specify what is necessary and sufficient to achieve an acceptable level of WVE risk.

However, during the performance of this work, a number of items of best practice to further reduce WVE risk have also been noted. These are recorded in this safety case as general safety recommendations, since no A388-specific safety recommendations were identified. Safety recommendations are not mandatory in this safety case.

An important general recommendation is that the performance of this work has identified some opportunities to improve operations as conducted today. It is strongly recommended that the technical evaluation of WVE risk, begun in this safety case, is continued in order to:

- Develop a scientifically transparent and logically rigorous set of WVE risk acceptance criteria for all aircraft.
- Further review the current (WVE) separation criteria as applied today and to correct any anomalies identified.
- More straightforwardly introduce new aircraft into the commercial fleet.

In particular, there is general agreement within the A380 Wake Vortex Steering Group that the current ICAO Medium wake turbulence category is too broad to provide a good balance between safety and capacity.

More specific safety recommendations are stated in Section 8 of the safety case.

CONTENTS

SECTION 1 - INTRODUCTION

1.1 Background, Justification and Document History

When it was introduced into commercial service the Airbus A380-800 (A388) was one of the world's largest commercial aircraft. Prior to its introduction into commercial service it was demonstrated to aviation regulators that the aircraft was acceptably safe, and that it was predicted to remain acceptably safe, for all reasonably foreseeable operations and circumstances.

The greater size of the A388 resulted in a range of potential safety concerns, one of which was wake vortex encounter risk. All aircraft generate wake vortices along their flight paths. These vortices are transported and decay with time, dependent upon the atmospheric conditions (e.g. wind, turbulence, etc.) that they experience. If an aircraft encounters a strong vortex, then WV-induced motion may result and, in extreme circumstances, the encountering aircraft may lose control or sustain structural damage. Heavier aircraft, like the A388, generate stronger wakes than lighter aircraft and so-called Wake Vortex Encounter (WVE) risk may increase unacceptably unless it is controlled by appropriate safety requirements, including the application of appropriate separation criteria.

Based on new data collected since 2006, this document is Edition 4.0 of the safety case that has been prepared to show that A388 WVE risk is acceptable in principle, and that WVE risk is predicted to remain acceptable in ongoing operational service for all reasonably foreseeable commercial operations worldwide, subject to implementation of all the safety requirements defined herein.

This document is part of a family of related documents. The history and inter-relationships between these documents is summarised below:

- Interim separation guidance for the A380, based on preliminary data and analysis, was issued by ICAO in November 2005 [ICAO, 2005a].
- Edition 2.0 of this safety case was published in November 2006 [A380 SG, 2006a].
- The (proprietary) safety assessment report that provided the detailed evidence for Edition 2.0 of the safety case was completed in 2007 [A380 SG, 2006a].
- Separation guidance for the A380 based on Edition 2.0 of this safety case was issued in October 2006 [ICAO, 2006b].
- This document is Edition 4.0 [A380 SG, 2008b].
- An updated (proprietary) safety assessment report will be prepared to provide the detailed evidence for Edition 4.0 of the safety case [A380 SG, 2008a].
- It is anticipated that ICAO will update their separation guidance for the A380 based on Edition 4.0 of this safety case.

Previous versions of this safety case, the safety assessment report and ICAO guidance are only of historical interest. The updated documents completed in 2008 supersede all previous documents issued under the authority of the A380 SG.

It is emphasised that WVE risk is not the only factor that determines operational aircraft separations. Responsible parties need to assess all other relevant factors (for example, runway occupancy times, etc.) as well as the safety requirements defined in this safety case when determining how to adjust their operational procedures to include the A388.

1.2 Safety Case Context

It is thought that this is the first time that a WVE risk safety case has been developed to support the entry into service of a new aircraft. As this work programme has developed, this has been revealed to be a very significant task involving: the development of methodologies; development of data collection methods; and development of approaches to interpretation of results.

The high-level objective of the safety case has been to develop safety requirements that are both “safe and fair” to the A388. It must be “safe” because safety is of paramount importance to the aviation industry. However, if the safety requirements are also to be “fair” to the A388 they must also not be overly conservative compared to currently operational aircraft. Addressing these two considerations has proved to be a considerable challenge.

It is believed that the output of this process (this safety case, the safety assessment report and supporting documents) adequately (with reasonable conservatism appropriate to a new aircraft) defines the safety requirements needed to safely introduce the A388 into commercial service with respect to WVE risk. This safety case represents the product of a work programme carried out over about 5 years. It includes many man-months of effort and more than 210 hours of flight tests.

1.3 Definitions and Terminology

Some terms used in this safety case have the following specific meanings:

Wake Vortex Encounter (WVE)	a WVE results when an aircraft flies into the flow field of a wake vortex generated by a preceding aircraft. In this safety case the A388 is the generator aircraft of interest.
Wake Vortex Encounter (WVE) consequence	is the result of a wake vortex encounter. This may range from a mild change in aircraft attitude through to impairment, or loss, of control of the encountering aircraft, and/ or structural damage to the encountering aircraft. The severity of the WVE consequence is a complex function of wake vortex strength, structure, encounter geometry and the encountering aircraft’s WV resistance parameters.
Wake Vortex (WV) strength	is termed circulation and is the primary measure of potential WVE consequence, measured in m^2/s.
Wake vortex structure	structure refers to vortex characteristics such as core size and other secondary measures that may affect WVE consequence.
WV resistance	Is a term used to describe the susceptibility of an encountering aircraft to a WVE. Heavy aircraft, with high moments of inertia (for example, aircraft with four wing-mounted engines have higher moments of inertia than other engine configurations) have high passive WV resistance. Aircraft that can exert large rolling moments using their ailerons and roll spoilers thereby have high active WV resistance. (The rudder can also exert large rolling moments but its use is not advised in some circumstances.)
WVE risk	is the combination of the likelihood of a WVE and the consequences of that encounter; it is measured in terms of the expected number of serious incidents, or accidents, due to WVE determined relative to a suitable parameter such as per flight hour or per year.

WVE risk indicator is a parameter that is considered to behave as an approximation to WVE risk (that is, the WVE risk indicator is expected to scale with WVE risk, but not necessarily via a precise mathematical relationship). Risk indicators have been mostly used in this safety case. The difference between WVE risk and WVE risk indicator will not usually be distinguished below in order to aid brevity.

Relative safety assessment aims to compare the risk of a new proposal (e.g. A388 operations) with the risk from a reference operation that has already been agreed to be acceptably safe (e.g. WVE risk from reference aircraft, as defined below).

Fault-free means that the operations are performed as they were intended; for wake vortex criteria, fault-free means complete compliance with specified separation criteria and the other specified safety requirements.

Acceptably safe means that the residual WVE risk that remains after application of the safety requirements, such as WV separation criteria, is sufficiently low as to be acceptable (noting that zero WVE risk is not practicable), and is reduced as far as is reasonably practicable. In a relative safety assessment this means that the risks from the proposed operation (e.g. A388) is less than or equal to the risks for the selected comparator operation (e.g. B744 or other reference aircraft), and is reduced as far as is reasonably practicable.

Safety requirements are those measures this safety case has identified that are necessary to ensure that the proposed operation will be acceptably safe (assuming correct implementation). The wake vortex separation criteria are an important group of safety requirements, but other safety requirements are also necessary and are specified in this safety case.

Safety recommendations are those non-mandatory issues or measures that have been identified as best practice. Their implementation could help to reduce WVE risk as far as reasonably practicable.

Acceptably safe in principle means that the safety case has considered all WVE aspects of A388 operations as far as it is reasonable and feasible to do so, and nothing beyond the safety requirements has been identified that might prevent the A388 being acceptably safe during operation. These safety requirements are the primary output of this safety case, since the safety case authors are not responsible for the operational implementation of the safety requirements specified in this safety case.

Acceptably safe in practice means that the A388 has been shown to be operationally safe by correct implementation of the safety requirements specified in this safety case and by operational in-service safety monitoring.

Responsible parties are those organizations that will implement the safety requirements of this safety case.

Relevant parties are organizations that need to be aware of this safety case. Thus responsible parties are a sub-set of relevant parties.

Phases of flight Approach includes approach with flaps deployed and landing.
Cruise includes high speed "clean" flight configurations.
Hold includes moderate speed "clean" flight configurations.
Departure includes take-off and climb until the aircraft is "clean".
("Clean" is a low-drag configuration (flaps and landing gear up) "Dirty" is the opposite of clean (flaps partly or fully down and landing gear down).)

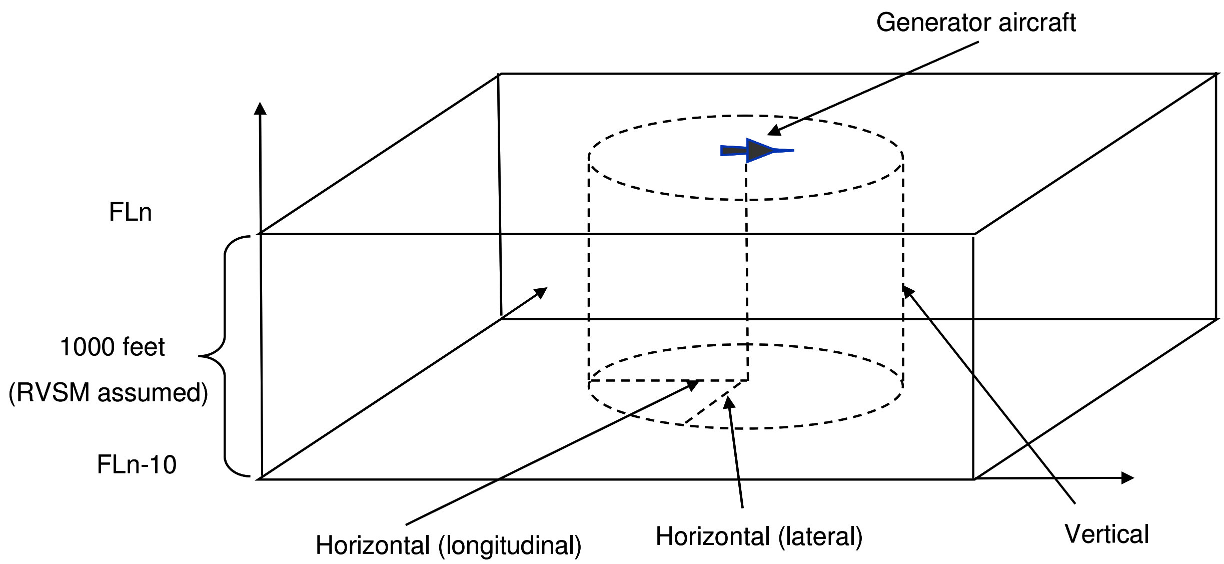
Reference date This safety case refers to "current separation criteria", "aircraft in-service today" and similar statements. In such statements the reference date is defined as the day that Edition 2.0 of this safety case was published, 16 November 2006 [A380 SG, 2006b].

Reference aircraft The relative safety assessment methodology applied in this report requires comparison to "reference aircraft". The reference aircraft chosen are defined as the heaviest Heavy aircraft in-service on the reference date. Typical reference aircraft are the Boeing 747-400 (B744), Airbus 340-600 (A346) and the Boeing 777-300 (B773).

Heavy The term Heavy aircraft has a slightly altered definition in this safety case compared to standard ICAO. When this safety case refers to the Heavy aircraft category it only includes Heavy aircraft in-service at the reference date. At the date of publication of Edition 4.0 of this safety case ICAO considers the A388 to be a Heavy aircraft with aircraft-specific separation standards, pending updates to PANS-ATM.

Figure 1.1 defines the separation descriptions used in this safety case.

Figure 1.1 Definition of Separation Descriptions (RVSM assumed).



1.4 Objectives

The objectives of this safety case are as follows:

- To define and justify the safety requirements for the A380-800 (A388) wake vortex generator aircraft in all phases of flight, for all categories of potentially wake vortex encountering aircraft, and for all operational conditions worldwide. The defined safety requirements are those that are necessary in order to ensure that Wake Vortex Encounter (WVE) risk due to the A388 is acceptably low. The safety requirements are specified as a set of WVE separation criteria and supporting safety requirements.
- To define and document the basis of the safety requirements.
- To note key assumptions, uncertainties and exceptions.

The overall aim of this safety case is to show, through argument and evidence, that A388 operations continues to be acceptably safe in principle with respect to WVE risk for all operational conditions (assuming the defined safety requirements are completely implemented), whilst noting any explicit exceptions.

1.5 Scope

The scope of this WVE risk safety case for the A388 is defined as follows:

- Generator aircraft. This safety case applies to passenger and freighter Airbus A380-800 (A388) aircraft with a Maximum certified Take-Off Mass (MTOM, sometimes called maximum take-off weight (MTOW)) of up to 590,000kg and wing-span of 79.8m.
- Phases of flight. This safety case is valid for all phases of flight.
- Encountering aircraft. This safety case is valid for all categories of encountering aircraft.
- All conditions worldwide. This safety case is valid for all weather conditions that may be encountered in any location worldwide.

The strategy for ensuring ATM safety is based on 3 high-level principles:

- Ensuring that airspace design is acceptably safe.
- Ensuring that ATM procedures are acceptably safe.
- Ensuring separation criteria, such as the separation criteria specified in this safety case to ensure WVE risk is acceptable, are acceptably safe.

The scope of this safety case is confined to specifying modifications to a sub-set of the currently defined separations (the third principle above).

This has two important consequences:

- If the current ICAO WVE separation criteria can be applied in a location without modification then the separation criteria for the A388 specified in this safety case can also be applied without modification.
- Responsible parties must assess if the separation criteria recommended in this report are consistent with their local airspace design and ATM procedures. The A380 Wake Vortex Steering Group cannot, and has not, performed a comprehensive evaluation of if the separation criteria defined in this safety case are consistent with local airspace designs or ATM procedures.

This definition of the scope of this safety case supports the global applicability of the safety requirements derived in this safety case.

1.6 Authorship of this Safety Case and Working Arrangements

Prior to the introduction of the A388, a Steering Group (SG) was set up to examine the WVE risk aspects of A388 operations. The SG consisted of representatives from the following organizations:

- EUROCONTROL (ECTL);
- Joint Aviation Authorities (JAA)[2];
- Federal Aviation Administration (FAA); and
- Airbus SAS.

A staff member of the Secretariat of the International Civil Aviation Organization (ICAO) has participated in some of the meetings of the SG as an observer and advisor on matters of ICAO protocol.

WVE risk was recognised as an important safety issue for the A388 and a specialist Work Group (WG), reporting to the SG, was set up to address it. The results generated by the WG [A380 SG, 2008a] are the basis of this safety case for presentation to the SG, subsequent dissemination through ICAO and eventual amendment of ICAO PANS-ATM wake turbulence criteria through the normal rule-making process of the organization.

1.7 ICAO WVE Separation Criteria

This section summarises the WVE separation criteria defined by ICAO. Criteria are shown as defined both before and after the reference date (that is, before and after the issue of Edition 2.0 of this safety case [A380 SG, 2006b], but prior to the issue of Edition 4.0 of this safety case) to provide reference points for the consideration of the A388 separation criteria defined in Edition 4.0 of this safety case. It should be noted that a number of States have modified the separation criteria specified by ICAO for national use.

To assist the definition of separation criteria, aircraft are classified in terms of their size (Maximum certified Take-Off Mass (MTOM)). Typical commercial aircraft in each WV category are as follows:

- Heavy category with MTOM 136 000 kg or more. Example Heavy aircraft include: B747, A340, B777, etc.
- Medium category with MTOM less than 136 000 kg but more than 7 000 kg. Example Medium aircraft include: A320, A319, B737, ERJ, CRJ, etc.
- Light category with MTOM 7 000 kg or less. Example Light aircraft include: Beech 55 Baron, Piper PA-28, etc.

National State variations of aircraft size categories also exist.

ICAO WVE separation criteria for approach and departure are specified for generating (preceding) and encountering (succeeding) aircraft in terms of 3 aircraft size categories (Heavy, Medium and Light) as shown in Table 1.1 for before the reference date and in Table 1.2 for after the reference date.

[2] The Joint Aviation Authorities will continue to exist until June 2009. At that time its responsibilities will be transferred to the European Aviation Safety Agency.

Table 1.1 ICAO WVE Radar Separation Criteria applied before the Reference Date for Approach and Departure in Nautical Miles (NM)

	Heavy Encounterer	Medium Encounterer	Light Encounterer
Heavy Generator	4NM	5NM	6NM
Medium Generator	MRS	MRS	5NM
Light Generator	MRS	MRS	MRS

Note:
MRS = Minimum Radar Separation (as prescribed by the appropriate Air Traffic Services authority).

Table 1.2 ICAO WVE Radar Separation Criteria applied after the Reference Date for Approach and Departure in Nautical Miles (NM)

	A388 Encounterer	Heavy Encounterer	Medium Encounterer	Light Encounterer
A388 Generator	4NM	6NM	8NM	10NM
Heavy Generator	4NM	4NM	5NM	6NM
Medium Generator	MRS	MRS	MRS	5NM
Light Generator	MRS	MRS	MRS	MRS

Note:
MRS = Minimum Radar Separation (as prescribed by the appropriate Air Traffic Services authority).
ICAO considers the A388 to be a Heavy aircraft with aircraft-specific separation criteria pending possible amendment to the PANS-ATM

Generally, radar separation as prescribed by ICAO PANS-ATM 8.7.4.1 is 5NM. This minimum may be reduced, if so prescribed by the appropriate ATS authority, but not below 3NM when radar capabilities at a given location so permit; 2.5NM may be applied between succeeding aircraft which are established on the same final approach track within 10NM of the runway end, provided that a number of strict criteria listed in PANS-ATM 8.7.4.2 are met. Examples of radar separation criteria established within this framework by national authorities are:

- Below FL 245 only 3NM separation is required in designated areas, for example in the Terminal Control Area (TMA).
- 5NM apply to multiple radar sources environment and within the range of 80NM from a single radar source.
- 10NM in a single radar source area beyond the range of 80NM (this is a very rare situation).

For cruise, some controllers apply a horizontal spacing of 5NM behind Medium and Light and 8 to 10NM behind Heavy aircraft.

Currently cruise separation is achieved if either the above horizontal separations are maintained or a vertical separation of 1000 feet (2000 feet in non-Reduced Vertical

Separation Minimum (RVSM) airspace) is maintained. Horizontal separations are required between aircraft at the same level, as well as when aircraft are climbing or descending with less than the vertical separation requirement (1000 or 2000 feet) in relation to other traffic.

These cruise separations are applied both before and after the reference date.

At airports, time-based WVE separation criteria for departure are provided in Table 1.3 for before the reference date and in Table 1.4 for after the reference date. Although it is not explicitly stated in the PANS-ATM, it is assumed that all departure time separations are applied between succeeding aircraft starting their take-off roll.

Table 1.3 ICAO Non-Radar Departure WVE Separation Criteria before the Reference Date in seconds (measured at the point where the aircraft start their take-off roll)

	Heavy Encounterer	Medium Encounterer	Light Encounterer
Heavy Generator	Not Specified	120s	120s
Medium Generator	Not Specified	Not Specified	120s
Light Generator	Not Specified	Not Specified	Not Specified

Table 1.4 ICAO Non-Radar Departure WVE Separation Criteria after the Reference Date in seconds (measured at the point where the aircraft start their take-off roll)

	A388 Encounterer	Heavy Encounterer	Medium Encounterer	Light Encounterer
A388 Generator	Not Specified	120s	180s	180s
Heavy Generator	Not Specified	Not Specified	120s	120s
Medium Generator	Not Specified	Not Specified	Not Specified	120s
Light Generator	Not Specified	Not Specified	Not Specified	Not Specified

Note:

ICAO considers the A388 to be a Heavy aircraft with aircraft-specific separation criteria pending possible amendment to the PANS-ATM

ICAO PANS-ATM requires that 3 minute WVE separation be applied if a Heavy aircraft precedes a non-Heavy aircraft which takes off from an intermediate part of the same runway ("intersection take-off").

1.8 Use of this Safety Case and Related Documentation

This safety case specifies what needs to be done (the safety requirements) in order that A388 operations will be acceptably safe in principle after the implementation of the revised separation standards defined in this safety case. It also specifies generically who is responsible for safety. Some best practice safety recommendations are also identified.

It is anticipated that this safety case will be used mainly by the following organizations or types of organization:

- ICAO;
- Regional and national aviation regulators;
- Regional authorities that may be responsible for co-ordinating upper-airspace cruise operations (e.g. EUROCONTROL); and
- Air Navigation Service Providers (ANSP), either national or local airport based services, that may be responsible for approach, departure, TMA and cruise operations.
- Airport and airline planners.

A guidance document has been prepared to support this safety case document; it is appended to this safety case as Appendix B. The guidance document provides assistance to each of the above types of organizations regarding how they can use this safety case and how they can ensure that acceptably safe A388 operations are achieved in practice.

1.9 Structure of this Safety Case

This document is structured as follows:

- Section 1 (this section) defines the scope and objectives of this safety case, defines the key terms used and presents other introductory material necessary for the proper interpretation of this safety case.
- Section 2 explains the overall strategy to show that A388 operations will continue to be acceptably safe with respect to WVEs and introduces the tools and techniques used to support the safety assessment.
- Section 3 presents the first main safety argument (safety requirements specified such that A388 WV encounters are acceptably safe in principle).
- Section 4 presents the second main safety argument (sufficient guidance exists and has been communicated to enable complete and correct implementation of the safety requirements by all parties).
- Section 5 presents the third main safety argument (implementation of WV safety requirements is complete and correct).
- Section 6 presents the fourth main safety argument (on-going operation of A388 will be shown to be acceptably safe regarding WVE risk).
- Section 7 summarises the safety requirements for the A388.
- Section 8 states the key assumptions, exceptions and open issues of this safety case. It also states the safety recommendations identified during the work programme.
- Section 9 provides references, acronyms and abbreviations used by this safety case.

Appendix A contains the entire safety argument presented in Goal Structuring Notation (GSN).

Appendix B contains guidance material to assist the correct implementation of the safety requirements defined in this safety case.

SECTION 2 - OVERVIEW OF SAFETY ARGUMENT STRUCTURE AND SAFETY ASSESSMENT TOOLS

2.1 General Strategy to Satisfy the Safety Argument

The safety argument is the set of statements which is used to assert that the A388 is acceptably safe in principle and is likely to be acceptably safe in practice for the specified reasonably foreseeable operations with respect to, in this safety case, WVE risk.

The top level of the safety argument for this safety case is shown in the form of Goal Structuring Notation (GSN) in Figure 2.1; the full safety argument is presented in the same form in Appendix A. The shading in the GSN (Figure 2.1 and Appendix A) indicates where the main responsibility for safety is located (that is, with those responsible for specifying the safety requirements of this safety case (the A380 Wake Vortex Steering Group) or with those responsible for implementing these safety requirements (the responsible parties)).

As summarised in Figure 2.1, the safety argument starts with a top-level claim (that WVE due to the A388 will continue to be acceptably safe in practice if the specified safety requirements are correctly implemented). This is developed into 4 sub-arguments and supported by 4 other GSN statements (Justification, Context, Assumption and Criteria). The rationale for the overall safety argument structure is explained by the overall safety strategy (Strategy 0 under Argument 0 in Figure 2.1 and Appendix A). This strategy is to show that the selected safety criteria are satisfied in each of the key lifecycle phases of “Concept”, “Implementation” and “Ongoing Operation”, for all phases of flight and in all reasonably foreseeable operational conditions worldwide.

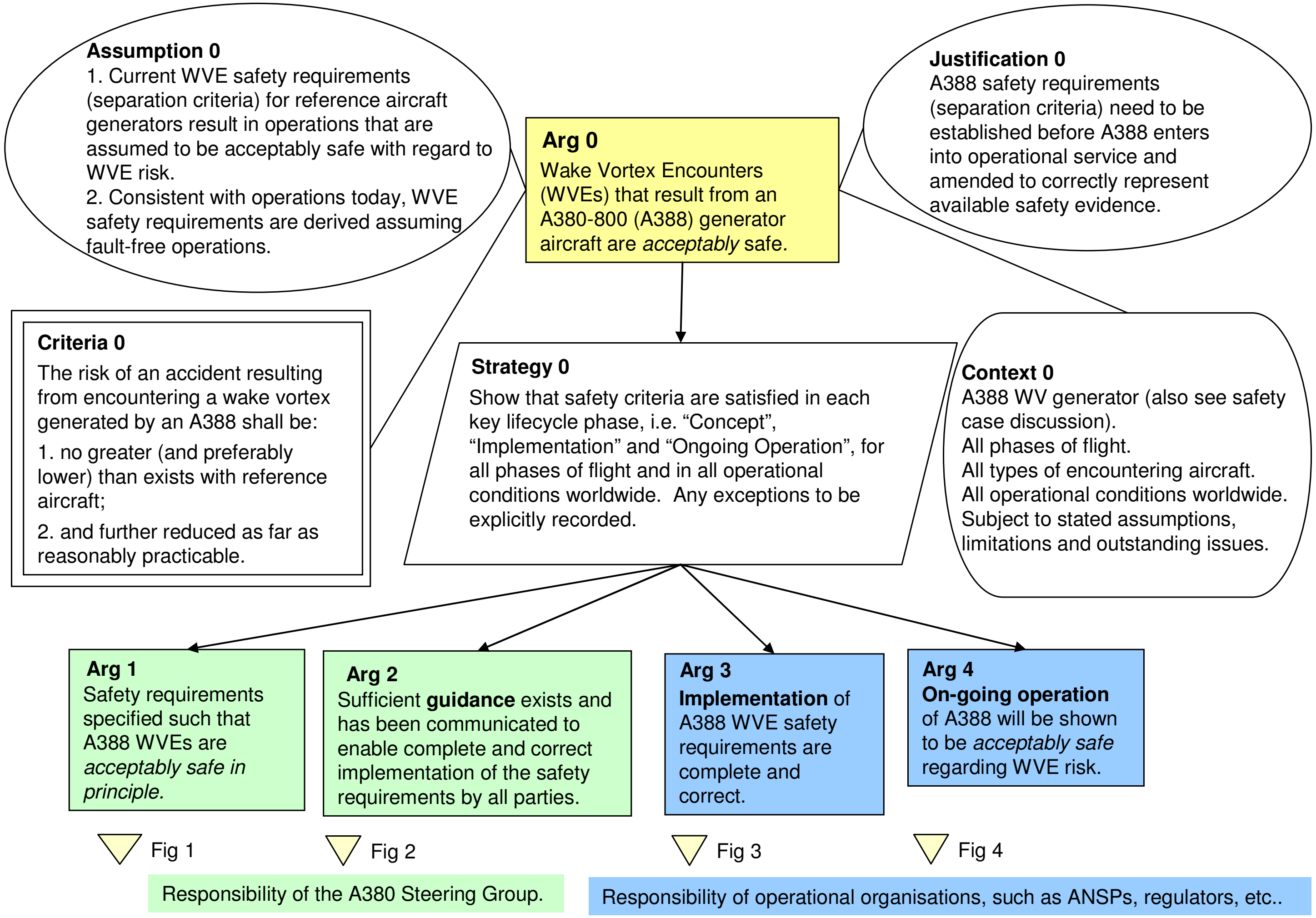
The top-level claim in Figure 2.1 is supported by:

- Justification 0: This safety case has been produced as a means of showing that A388 operations will continue to be acceptably safe in operational service.
- The context of the safety case (Context 0), which corresponds to the safety case scope presented in Section 1.5 above.
- Two input assumptions into the safety case.
    - It is assumed that current WVE safety requirements for reference aircraft are acceptably safe. This assumption allows the adoption of the relative risk assessment approach as reflected in Criteria 0.
    - It is assumed, consistent with today’s WV separation criteria described in Section 1.7, that fault-free conditions apply when deriving the WVE safety requirements for the A388. That is, the risk from WVEs that results if Air Traffic Controllers (ATCOs) or pilots do not maintain the defined minimum separation criteria has not been assessed.
- The safety assessment criteria (Criteria 0) that have been selected for this safety case. These state that the WVE risk from A388 generator aircraft will be no greater than that that exists due to reference aircraft, and that WVE risks will be reduced as far as reasonably practicable, taking account of technical and economic factors.

This relative formulation of the safety assessment criteria is possible because of Assumption 0. It enables the use of the relative risk assessment strategy (see Section 1.3 and Section 3) for A388 WVE risk. Briefly, the relative safety assessment approach calculates a WVE risk indicator for an accepted operation, such as a reference aircraft on approach followed by a Heavy aircraft 4NM behind. It then calculates the equivalent WVE risk indicator, on the same basis, for the proposed operation (in this case, an A388 on approach followed by a Heavy aircraft at various separation distances). The appropriate separation criterion is selected in the form of the A388 separation distance that allows the WVE risk indicator results for the A388 case to be always less than or equal to those from the reference aircraft operation.

Figure 2.1 Overview of A388 WVE Relative Safety Argument

Figure 0 Overall Relative Argument Structure



The 4 supporting arguments of the overall safety argument are described below.

Argument 1 asserts that the safety requirements (including the WVE separation criteria) for the A388 will result in A388 operations that are acceptably safe in principle. The evidence to support this argument is based on the flight test measurements obtained from pulsed LIDAR, including intentional WV encounters flown by a typical Medium category aircraft in cruise, and on the WV risk assessment that has been performed by the WG, see Section 3 and reference [A380 SG, 2008a].

Argument 2 asserts that sufficient information and guidance has been prepared and communicated to enable responsible parties to understand and implement the specified safety requirements completely and correctly. The evidence to support this argument has been provided by the WG, see Section 4.

Argument 3 asserts that the responsible parties have reviewed the safety case and its safety requirements and that they have implemented all the requirements effectively. Responsible parties are required to provide the evidence to show this argument is satisfied, see Section 5.

Argument 4 asserts that A388 operations, and in particular early operations, will be subject to safety monitoring. The results of the safety monitoring programmes will be reviewed and lessons learned will be disseminated internationally. Implicit in Argument 4 is the WG understanding that WVE risk assessment techniques and the results they generate are subject to uncertainty. A critical part of the safety argument, to show that ongoing A388 operations will continue to be acceptably safe in practice, is based on the use of proactive in-service safety-performance monitoring (that is, looking for safety issues and either correcting problems or confirming that none exist). Responsible parties are required to provide the evidence to show this argument is satisfied, see Section 6.

The detailed evidence and further decomposition of the argument structure for Arguments 1 to 4 are presented in Sections 3 to 6 respectively below.

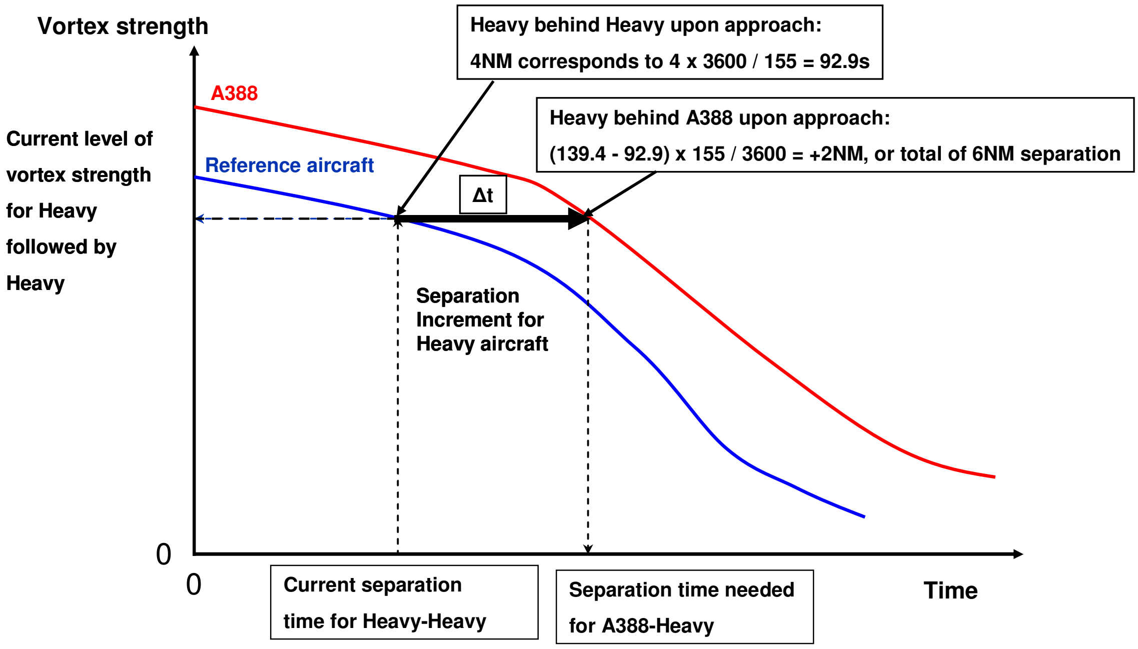
2.2 Assessment Tools and Methods

A key part of this safety case is the safety assessment performed by the WG [A380 SG, 2008a]. The WG has used and developed WVE safety assessment tools to perform this safety assessment. The main tools used are described briefly below.

2.2.1 Overview of Assessment Strategy

Figure 2.2 shows an example graph of the measured decay of WV strength with time. Figure 2.2 also illustrates the central principle of the relative safety assessment strategy adopted in this work. This uses current criteria, such as 4NM horizontal separation distance during approach for a Heavy aircraft in-service at the reference date behind a reference aircraft, to infer a currently accepted WV circulation strength. The extra time required for the A388 WV to decay to this WV strength is read across from the graph. This Δt is combined with the encountering aircraft's speed to calculate the required distance-based separation behind the A388.

Figure 2.2 Example Graph of Wake Vortex Strength versus Time and Derivation of Increased Separation on Approach (assumed encounterer speed 155knots)



This calculation method is the basis used to derive most of the numerical safety requirements presented in Section 3.

2.2.2 Pulsed LIDAR Measurements and Flight Tests

LIDAR (LIght Detection And Ranging) is a technique that uses a pulsed laser to determine distance to an object, from the delay time from pulse transmission to detection of back scattered laser light, and the relative speed of the object, from the Doppler shift of the back scattered laser light.

LIDAR can be used to determine the position and strength of an aircraft's wake vortex by detecting the scattered laser light from particulate objects (such as soot and water droplets) entrained in the wake vortex. The LIDAR beam scans across the aircraft's wake about once every 5 seconds. Analysis software is used to convert the raw signals obtained into wake vortex transport and decay curves. The spatial resolution of LIDAR is sufficient to track both the port and starboard vortex transport and decay signatures separately.

LIDAR measurements of wake vortices from aircraft in flight are the only practical approach to measurements of wake vortices from real aircraft. They are the best scientific evaluation of a real aircraft's wake. However, LIDAR measurements are relatively resource-intensive to collect. Thus, it is not practical to obtain datasets of LIDAR data for all meteorological conditions and all phases of flight that are statistically completely robust.

Several types of flight tests have been performed to support this safety case as follows:

- Single aircraft tests. As implied, one aircraft is in the air during a flight test measurement campaign.

- Back-to-back tests. Typically two aircraft (of different types) fly in a circuit past the LIDAR station. The LIDAR measures the WV behaviour first from one aircraft type and then from the other aircraft type. The short time separation between these measurements (typically 5 minutes) should minimise the effect of systematic variation in atmospheric and other test conditions, and so provide a clearer relative comparison of the WV behaviour of the two aircraft types.
- Cruise tests. WV measurements under cruise conditions (for example, Mach 0.85 and above 30,000 feet altitude) using LIDAR were performed. These tests were made using two generator aircraft flying parallel tracks. An airborne LIDAR mounted in a Falcon measured the WVs. A fourth aircraft (an A318) also flew through the WVs at variable distances to provide some data on WV encounter severity as a function of wake age. Data from about 130 deliberate encounters have been analysed. It should be noted that the cruise measurements are also back-to-back measurements, even though the aircraft fly side-by-side, because the aircraft fly in closely matched atmospheric conditions.

The details of the flight test data and the LIDAR WV measurements are provided elsewhere [A380 SG, 2008a]. Sections 3 to 6 below summarise how this flight test derived evidence supports the safety argument and the derived safety requirements and safety recommendations.

2.2.3 Analysis of WVE Response Data

Part of the flight test programme included flying an A318 into the wakes of an A388 and other reference aircraft to compare the response of the A318 to the WVEs. All these encounter flight tests were performed at cruise altitude. Some of these flight tests were observed by an FAA certification pilot. Both the subjective judgements of the pilots and the analysis of the flight recorder data were used to determine the relative severity of the WVE.

Wake vortex encounters were flown to investigate:

- Wake descent.
- Start of wake disintegration (Crow instability). This was obtained from video recordings from the A318 encountering aircraft.
- Wake effects in terms of aircraft parameters, such as bank angle, roll rate, lateral and vertical acceleration, etc.
- Influence of the flight control system of the encountering aircraft.

The recorded encounter data were used to identify the wake characteristics in addition to the airborne LIDAR data that have been recorded from a Dassault Falcon 20 aircraft.

2.2.4 Analysis of WVE Consequence Severity

Estimates of WVE consequence severity were obtained by use of relatively simple computer models that apply basic principles of flight physics. The calculation method involves:

- Estimating the average and 95th percentile WV strength at the encounter from LIDAR measurements and the estimated time separation between generator and encounterer aircraft.
- Calculating the wake velocity distribution according to the Burnham-Hallock model (Burnham and Hallock, 1982a) and an assumed core radius of 2.5% of the generator wing span.
- Summation of the encounterer's rolling moment using the strip method of wake-induced lift over the wing span using an elliptic weighting and assuming the encounter is parallel to, and centred on, one vortex.

- Calculating the roll acceleration from the rolling moment and the moment of inertia of the encountering aircraft. This is a measure of the "passive resistance" of the encountering aircraft.
- Calculating the roll control ratio. This is the ratio of the WV induced rolling moment compared to the rolling moment that can be applied by use of the encountering aircraft ailerons and roll spoilers (not the rudder). This is a measure of the "active resistance" of the encountering aircraft.

The results of these calculations were assessed using the relative argument. Calculations of situations that are accepted today, such as lightest-Heavy aircraft encounterers and heaviest-Heavy generators, were compared to proposed operations, such as A388 encounterer and A388 generator.

SECTION 3 - SAFETY REQUIREMENTS SPECIFIED SUCH THAT A388 WV ENCOUNTERS ARE ACCEPTABLY SAFE IN PRINCIPLE (ARGUMENT 1)

3.1 Strategy to Show Satisfaction of Safety Argument 1

The WG experts have performed a relative safety assessment in order to determine the safety requirements that are necessary to ensure A388 operations will continue to satisfy the specified safety criteria (will be acceptably safe in principle). The strategy (Strategy 1 under Argument 1 in Appendix A) for each phase of flight has been:

1. To show that the safety requirements satisfy Criteria 0 items 1 and 2 for specific scenarios (Argument 1.1).
2. To show that the specific scenario results are valid in general (Argument 1.2).
3. To show the analysis is trustworthy (Argument 1.3).

The sub-argument structure and evidence that supports this strategy is presented in Section 3.2.

3.2 Sub-Argument Structure and Supporting Evidence for Argument 1

3.2.1 Safety criteria are satisfied by the Safety Requirements derived by consideration of specific scenarios (Argument 1.1)

See Appendix A, Figure 1.1 for the GSN representation of Argument 1.1.

Argument 1.1.1 WV characteristics and hence types of WV hazards from the A388 are confirmed to be the same as for other Heavy aircraft

The relative safety argument is most straightforward to apply if the qualitative characteristics of the WV are the same for the new (A388) and for the reference (e.g. B744) operation that are to be compared. The word "characteristics" is used here to represent the *qualitative* behaviour exhibited by the A388 WV pair. The *quantitative* parameters that represent the A388 WV are clearly different from those that represent other aircraft; quantitative differences are addressed under Argument 1.1.2 below.

The WG has performed the following assessment tasks:

1. Performing and witnessing LIDAR measurements, examination of "quick-look" LIDAR outputs, data reduction of LIDAR results and analysis of those results. Independent groups in both Europe and the US have performed these tasks using similar, but not identical, methods and have obtained similar results [A380 WG, 2008a].
2. Flying into the wakes of reference aircraft and the A388 in cruise conditions and analysing the encounter severity both subjectively and analytically [A380 SG, 2008a].

The results of these activities enable the Work Group to confirm that they have found no evidence to suggest that WV characteristics from the A388 are different from the WV characteristics from reference aircraft, other than in vortex strength and lifetime terms.

It is concluded that the relative safety argument is valid and that the WV hazards (conditions the safety requirements are designed to avoid) applicable to this safety case are the same as those that result from currently operational aircraft, that is:

- Loss of control of the encountering aircraft due to WVE.
- Structural failure of the encountering aircraft due to WVE.

These hazards are consistent with historical incident and accident data, and with WG expert judgement.

Argument 1.1.2 WVE Risks are no higher than current levels

Approach Safety Requirements

The safety requirements for approach are presented and justified below.

The safety requirements for approach were deduced and justified by consideration of the following factors:

- A quantitative estimate of the amount of extra separation required for the A388 in order to expose the encountering aircraft to the same WV strength as it would encounter behind a reference aircraft (see Figure 2.2). These estimates are based upon back-to-back flight test results of aircraft in approach configurations both In Ground Effect (IGE) and Out of Ground Effect (OGE) using LIDAR.
- A qualitative estimate of the relative frequency of WVEs for the new (A388) and reference aircraft operations.

An overall qualitative evaluation of these factors is used to show that the safety criteria are met.

Distance-Based Separation: Heavy Encounterer Landing Behind A388 Generator

The safety requirement is 4NM + 2NM = 6NM separation for a Heavy encounterer landing behind an A388 generator in a radar controlled environment.

Please note, the equation above, and in subsequent sections, corresponds to:

(current criterion) + (additional separation required by A388) =
(Total separation required by A388).

The evidence upon which this safety requirement is based is described in detail in the safety assessment report [A380 SG 2008a] and is summarised in Figure 3.1.

Figure 3.1 Evidence Summary for Approach Radar Environment: Heavy Encounterer Landing behind A388 Generator

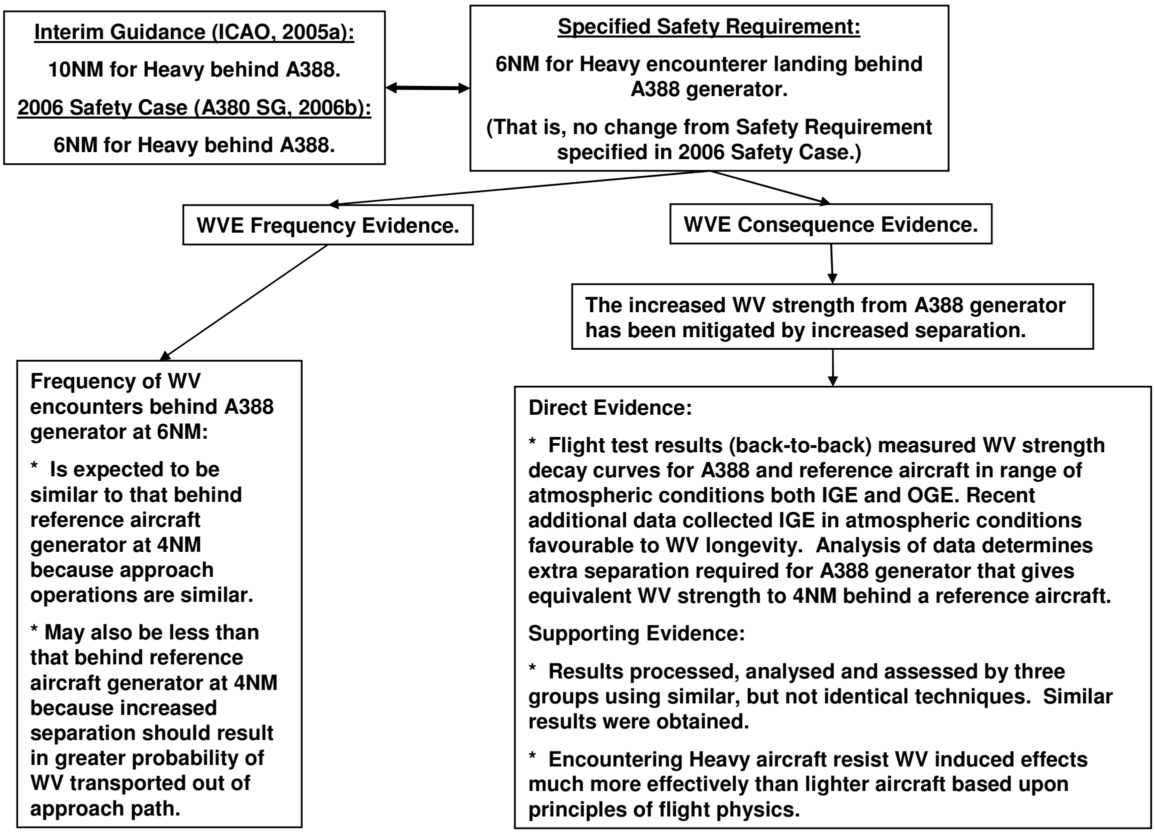


Figure 3.1 indicates that:

- The frequency of WVE for Heavy aircraft landing 6NM behind an A388 will be similar to, or less than, the frequency of WVE for Heavy aircraft landing 4NM behind a reference aircraft.
- The consequence of WVE due to a WV from the A388 at 6NM is similar to that from a WV from a reference aircraft at 4NM because the extra separation defined for the A388 results in an equivalent WV strength at the specified separation of 6NM.
- Encountering Heavy aircraft effectively resist the WV induced effects. This qualitatively assessed effect provides an appropriate degree of conservatism in the derived safety requirement for Heavy aircraft landing behind A388.

It is concluded that criterion 1 is satisfied. For Heavy encounterers the WVE risk for the A388 generator is predicted to be equal to, or less than, that for reference aircraft generators.

Distance-Based Separation: Medium Encounterer Landing Behind A388 Generator

The safety requirement is 5NM + 2NM = 7NM separation for a Medium encounterer landing behind an A388 generator in a radar controlled environment.

The evidence upon which this safety requirement is based is described in detail in the safety assessment report [A380 SG, 2008a] and is summarised in Figure 3.2.

Figure 3.2 Evidence Summary for Approach Radar Environment: Medium Encounterer Landing behind A388 Generator

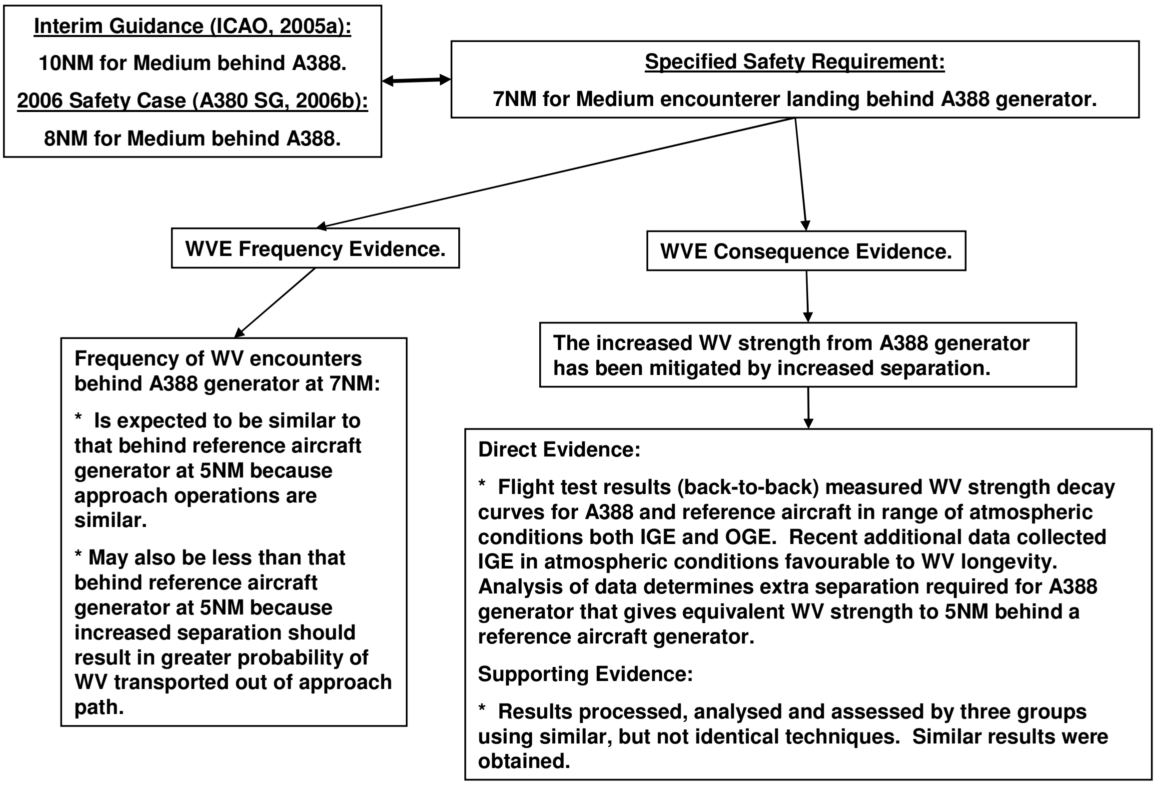


Figure 3.2 indicates that:

- The frequency of WVE for Medium aircraft landing 7NM behind an A388 will be similar to, or less than, the frequency of WVE for Medium aircraft landing 5NM behind a reference aircraft.
- The consequence of WVE due to a WV from the A388 at 7NM is similar to that from a WV from a reference aircraft at 5NM because the extra separation defined for the A388 results in an equivalent WV strength at the specified separation of 7NM.

It is concluded that criterion 1 is satisfied. For Medium encounterers the WVE risk for the A388 generator is predicted to be equal to, or less than, that for reference aircraft generators.

Distance-Based Separation: Light Encounterer Landing Behind A388 Generator

The safety requirement is 6NM + 2NM = 8NM separation for a Light encounterer landing behind an A388 generator in a radar controlled environment.

The evidence upon which this safety requirement is based is described in detail in the safety assessment report [A380 SG, 2008a] and is summarised in Figure 3.3.

Figure 3.3 Evidence Summary for Approach Radar Environment: Light Encounterer Landing behind A388 Generator

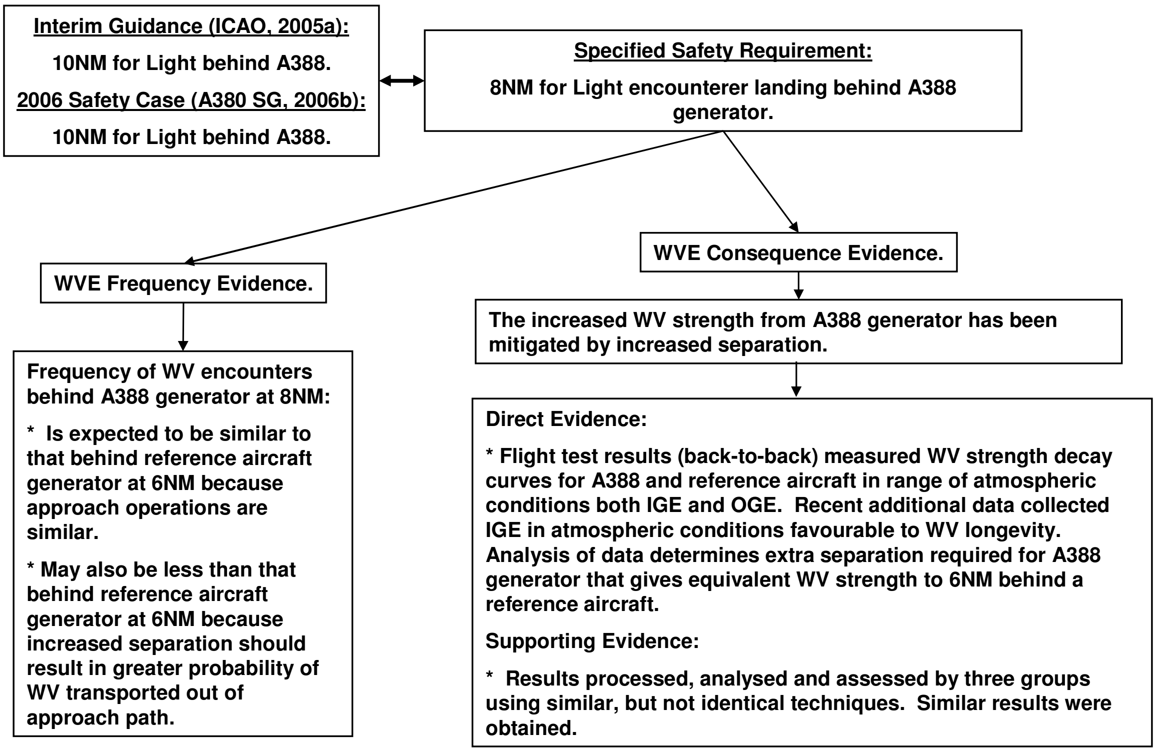


Figure 3.3 indicates that:

- The frequency of WVE for Light aircraft landing 8NM behind an A388 will be similar to, or less than, the frequency of WVE for Light aircraft landing 6NM behind a reference aircraft.
- The consequence of WVE due to a WV from the A388 at 8NM is similar to that from a WV from a reference aircraft at 6NM because the extra separation defined for the A388 results in an equivalent WV strength at the specified separation of 8NM.

It is concluded that criterion 1 is satisfied. For Light encounterers the WVE risk for the A388 generator is predicted to be equal to, or less than, that for reference aircraft generators

Distance-Based Separation: A388 Encounterer Landing Behind A388 Generator

A wake turbulence restriction is not required for an A388 encounterer landing behind an A388 generator in a radar controlled environment. In this case the separation applied reverts to the Minimum Radar Separation (MRS). WVE risk has been evaluated down to a minimum separation of 2.0NM and it has been determined that an additional WV separation is not required down to this minimum separation. “MRS” is used below as an abbreviation to state that no wake turbulence restriction is required down to 2NM.

The evidence upon which this safety requirement is based is described in detail in the safety assessment report [A380 SG, 2008a] and is summarised in Figure 3.4.

Figure 3.4 Evidence Summary for Approach Radar Environment: A388 Encounterer Landing behind A388 Generator

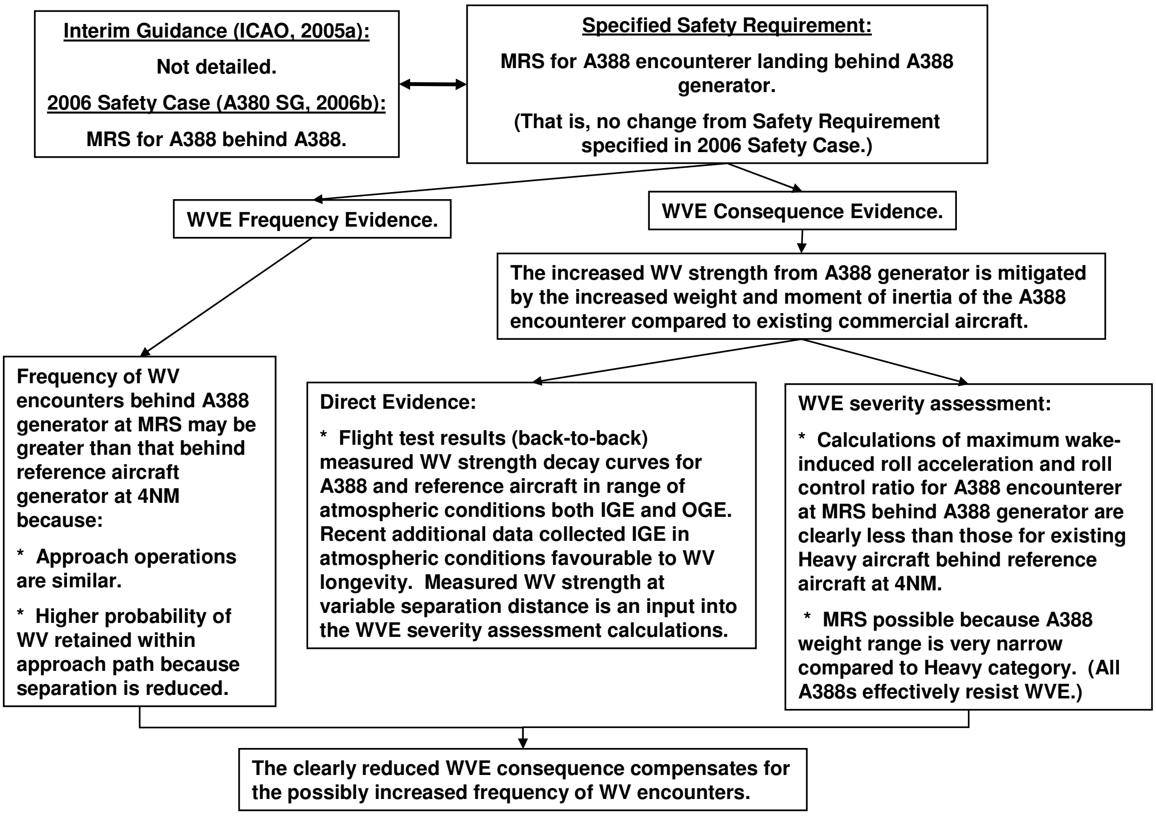


Figure 3.4 indicates that:

- The frequency of WVE for A388 aircraft landing at MRS behind an A388 will be similar to, or greater than, the frequency of WVE for Heavy aircraft landing 4NM behind a reference aircraft.
- The WV strength encountered at MRS behind an A388 will be greater than the WV strength encountered at 4NM behind a reference aircraft.
- Quantitative estimates clearly show that the increased mass, moment of inertia and control characteristics of the A388 encountering aircraft results in lower wake-induced effects for the A388 encounterer compared to currently accepted reference values for lighter Heavy aircraft behind a reference aircraft.
- It should be noted that MRS is not judged to be acceptable today for Heavy aircraft landing behind Heavy aircraft because there is an appreciable variation of mass within the Heavy category at the reference date (4NM is necessary to protect the lighter Heavy aircraft landing behind the heavier Heavy aircraft). For the A388 “category” the mass range is very narrow and thus a separation of MRS can be justified.

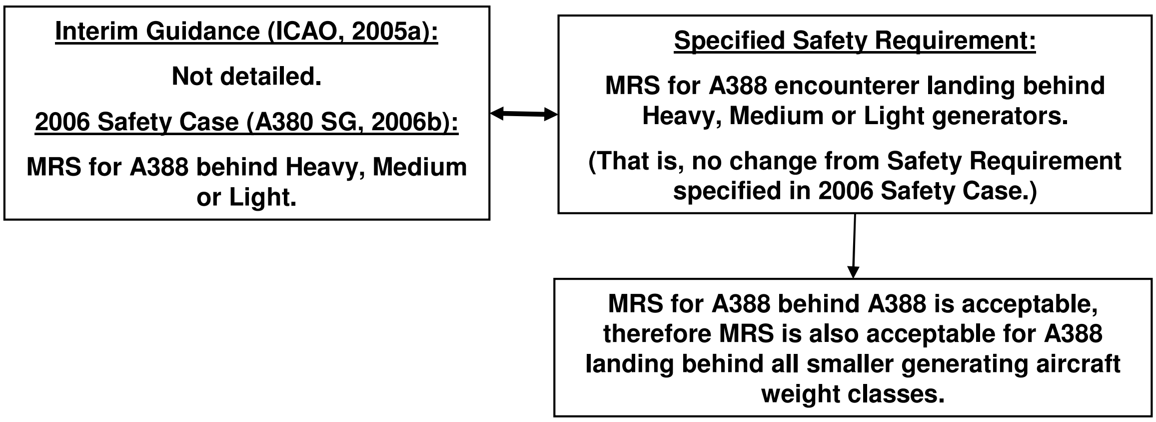
It is concluded that criterion 1 is satisfied because the clearly reduced WVE consequence severity, due to the passive and active resistance of the A388, is more significant than the increased WVE frequency and strength. For A388 encounterers the WVE risk for the A388 generator is predicted to be equal to, or less than, that for reference aircraft generators.

Distance-Based Separation: A388 Encounterer Landing Behind Heavy, Medium or Light Generators

A wake turbulence restriction is not required for an A388 encounterer landing behind Heavy, Medium or Light generators in a radar controlled environment. In this case the separation applied reverts to the Minimum Radar Separation (MRS). WVE risk has been evaluated down to a minimum separation of 2.0NM and it has been determined that an additional WV separation is not required down to this minimum separation. “MRS” is used below as an abbreviation to state that no wake turbulence restriction is required down to 2NM.

The evidence upon which this safety requirement is based is described in detail in the safety assessment report [A380 SG, 2008a] and is summarised in Figure 3.5.

Figure 3.5 Evidence Summary for Approach Radar Environment: A388 Encounterer Landing behind Heavy, Medium or Light Generators



If MRS for A388 landing behind an A388 is acceptable then MRS is also predicted to be acceptable for A388 landing behind Heavy, Medium or Light generator aircraft.

Cruise Safety Requirements

No additional safety requirements specific for cruise have been identified as necessary for the A388 compared to reference aircraft.

The evidence upon which this conclusion is based is described in detail in the safety assessment report [A380 SG, 2008a] and is summarised in Figure 3.6.

Figure 3.6 Evidence Summary for Cruise, Holding and TMA Separations

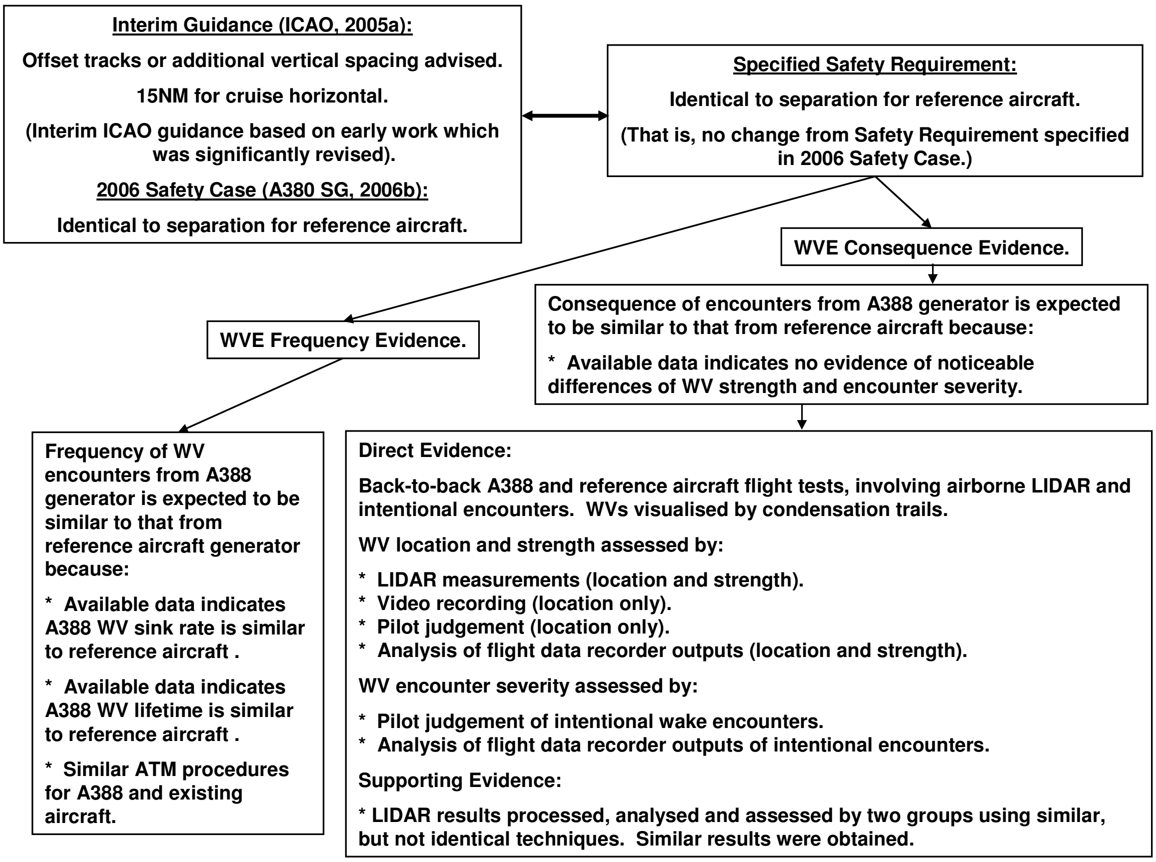


Figure 3.6 indicates that the evidence shows that WVE risk from the A388 is not larger than that from reference aircraft.

It is concluded that criterion 1 is satisfied by the application of cruise horizontal or vertical separation criteria as applied today.

<u>TMA Safety Requirements (Horizontal separations for approach and departure are derived elsewhere)</u>

Other than approach and departure horizontal separations, no additional safety requirements specific for TMA operations have been identified as necessary for the A388 compared to reference aircraft.

The evidence upon which this conclusion is based is described in detail in the safety assessment report [A380 SG, 2008a]. It is very similar to the evidence summarised in Figure 3.6, except that the flight test data was collected in “clean” A388 configuration at 250knots.

It is concluded that criterion 1 is satisfied by the application of TMA vertical separation criteria as applied today, or by the horizontal distance separations defined for approach and departure (that is, “not required” or MRS, 6NM, 7NM and 8NM for A388, Heavy, Medium and Light encounterers respectively).

Holding Safety Requirements

No additional safety requirements specific for holding operations have been identified as necessary for the A388 compared to reference aircraft.

The evidence upon which this conclusion is based is described in detail in the safety assessment report [A380 SG, 2008a]. It is very similar to the evidence summarised in Figure 3.6, except that the flight test data was collected in "clean" A388 configuration at 250knots.

It is concluded that criterion 1 is satisfied by the application of holding vertical separation criteria as applied today.

Departure Safety Requirements

The safety requirements for departure are presented and justified below. ICAO specifies both time-based and distance-based departure separations. These are discussed separately.

The safety requirements for departure were deduced and justified by consideration of the following factors:

- A quantitative estimate of the amount of extra separation required for the A388 in order to expose the encountering aircraft to the same WV strength as it would encounter behind a reference aircraft (see Figure 2.2). These estimates are based upon back-to-back flight test results of aircraft in take-off configuration using LIDAR.
- A qualitative estimate of the relative frequency of WVEs for the new and reference operation.
- A qualitative or quantitative estimate of the WVE consequence severity. Consideration of basic principles of flight physics confirms that heavier aircraft much more strongly resist WV induced rolling moments than lighter aircraft.
- A quantitative estimate of the consistency of time-based and distance-based departure separations using documented aircraft performance data.

Qualitative evaluation of these factors is used to show that the safety criteria are met.

Time-Based Separation: Heavy Encounterer Departing Behind A388 Generator

The safety requirement is 120 seconds time delay for a Heavy encounterer departing behind an A388 generator in a non-radar controlled environment.

The evidence upon which this safety requirement is based is described in detail in the safety assessment report [A380 SG, 2008a] and is summarised in Figure 3.7.

Figure 3.7 Evidence Summary for Departure in Non-Radar Environment: Heavy Encounterer Departing behind A388 Generator

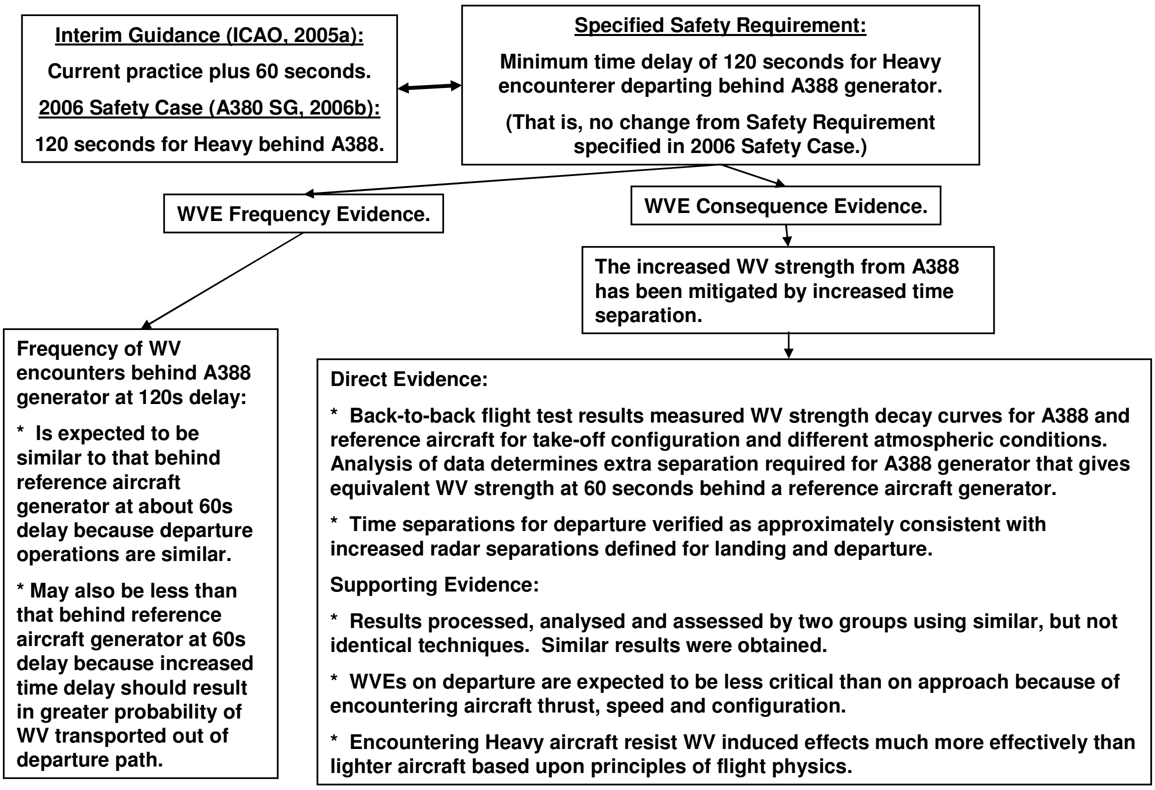


Figure 3.7 indicates that:

- The frequency of WVE for Heavy aircraft departing 120s behind an A388 will be similar to, or less than, the frequency of WVE for Heavy aircraft departing 60s behind a reference aircraft.
- The consequence of WVE due to a WV from the A388 at 120s delay is similar to that from a WV from a reference aircraft at 60s delay because the extra time delay defined for the A388 results in an equivalent WV strength to that for the assumed Heavy behind reference aircraft delay of 60 seconds.

It is concluded that criterion 1 is satisfied. For Heavy encounterers the WVE risk for the A388 generator is predicted to be equal to, or less than, that for reference aircraft generators.

Time-Based Separation: Medium Encounterer Departing Behind A388 Generator

The safety requirement is 120s + 60s = 180s time delay for a Medium encounterer departing behind an A388 generator in a non-radar controlled environment.

The evidence upon which this safety requirement is based is described in detail in the safety assessment report [A380 SG, 2008a] and is summarised in Figure 3.8.

Figure 3.8 Evidence Summary for Departure in Non-Radar Environment: Medium Encounterer Departing behind A388 Generator

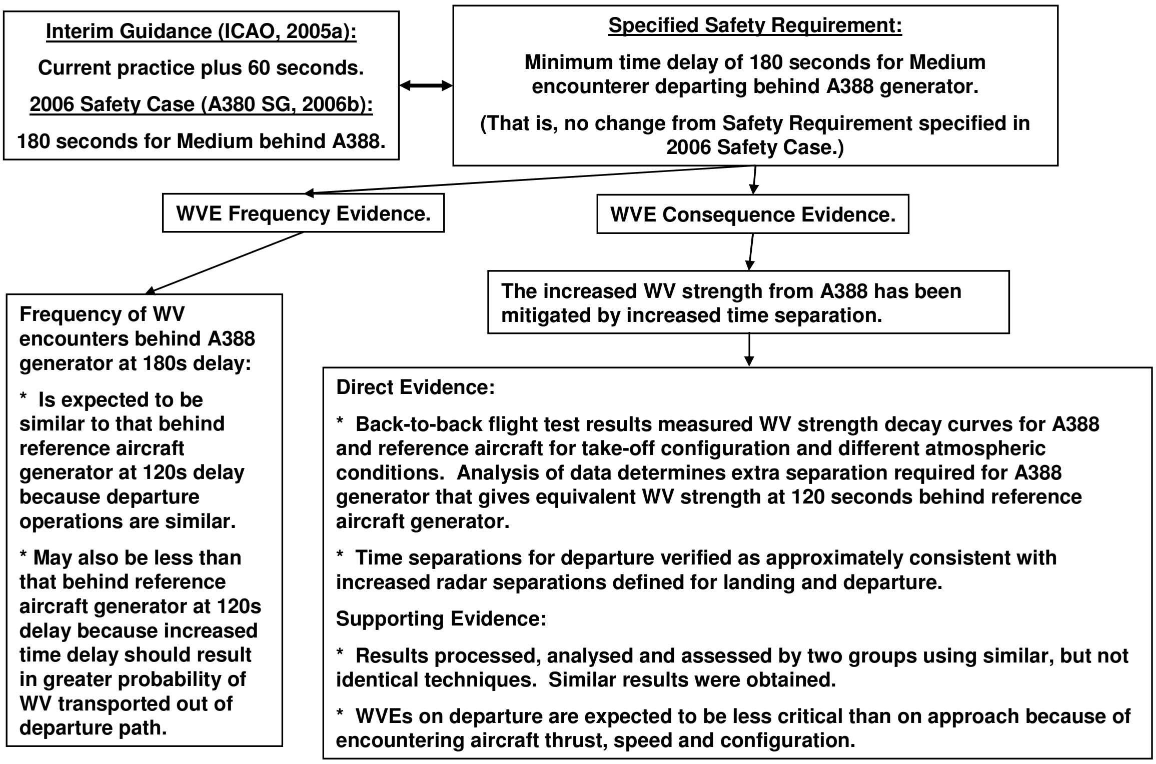


Figure 3.8 indicates that:

- The frequency of WVE for Medium aircraft departing 180s behind an A388 will be similar to, or less than, the frequency of WVE for Medium aircraft departing 120s behind a reference aircraft.
- The consequence of WVE due to a WV from the A388 at 180s delay is similar to that from a WV from a reference aircraft at 120s delay because the extra time delay defined for the A388 results in an equivalent WV strength to that for the Medium behind reference aircraft delay of 120 seconds.

It is concluded that criterion 1 is satisfied. For Medium encounterers the WVE risk for the A388 generator is predicted to be equal to, or less than, that for reference aircraft generators.

Time-Based Separation: Light Encounterer Departing Behind A388 Generator

The safety requirement is 120s + 60s = 180s time delay for a Light encounterer departing behind an A388 generator in a non-radar controlled environment.

The evidence upon which this safety requirement is based is described in detail in the safety assessment report [A380 SG, 2008a] and is summarised in Figure 3.9.

Figure 3.9 Evidence Summary for Departure in Non-Radar Environment: Light Encounterer Departing behind A388 Generator

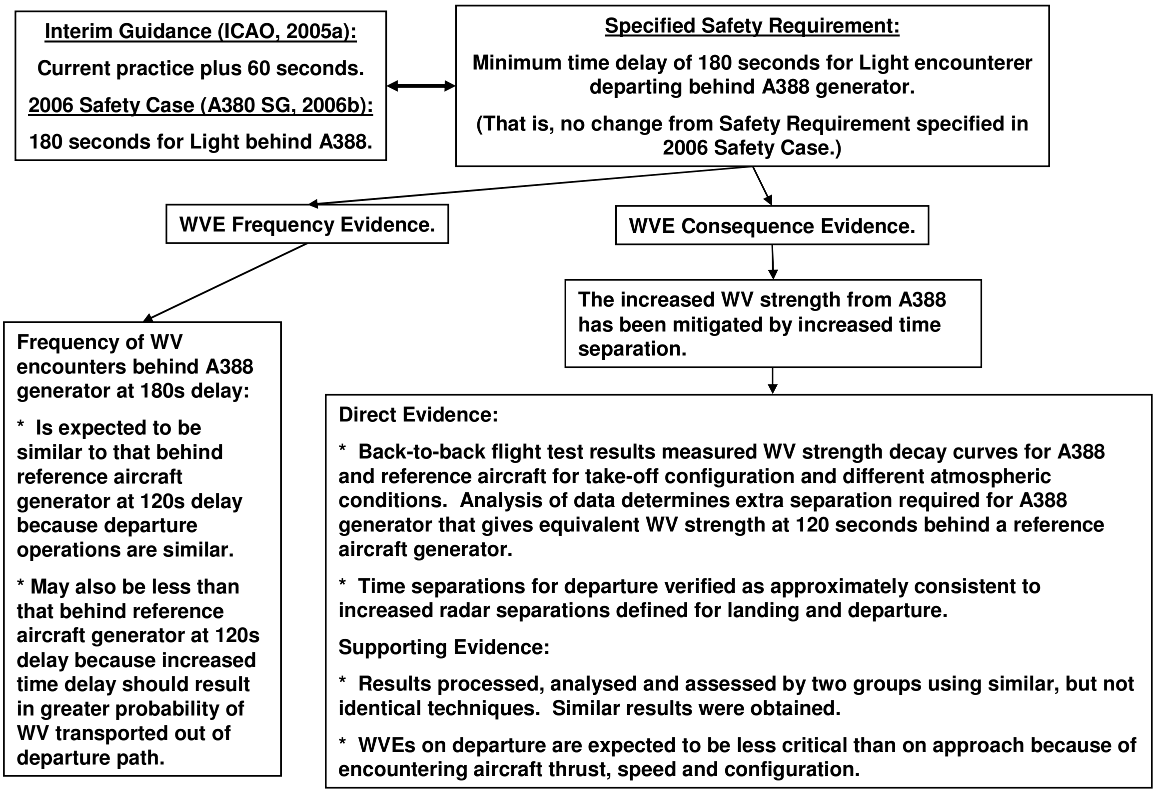


Figure 3.9 indicates that:

- The frequency of WVE for Light aircraft departing 180s behind an A388 will be similar to, or less than, the frequency of WVE for Light aircraft departing 120s behind a reference aircraft.
- The consequence of WVE due to a WV from the A388 at 180s delay is similar to that from a WV from a reference aircraft at 120s delay because the extra time delay defined for the A388 results in an equivalent WV strength to that for the Light behind reference aircraft delay of 120 seconds.

It is concluded that criterion 1 is satisfied. For Light encounterers the WVE risk for the A388 generator is predicted to be equal to, or less than, that for reference aircraft generators.

Time-Based Separation: A388 Encounterer Departing Behind A388 Generator

A WV separation does not need to be specified for an A388 encounterer departing behind an A388 generator in a non-radar controlled environment.

The evidence upon which this conclusion is based is described in detail in the safety assessment report [A380 SG, 2008a] and is summarised in Figure 3.10.

Figure 3.10 Evidence Summary for Departure in Non-Radar Environment: A388 Encounterer Departing behind A388 Generator

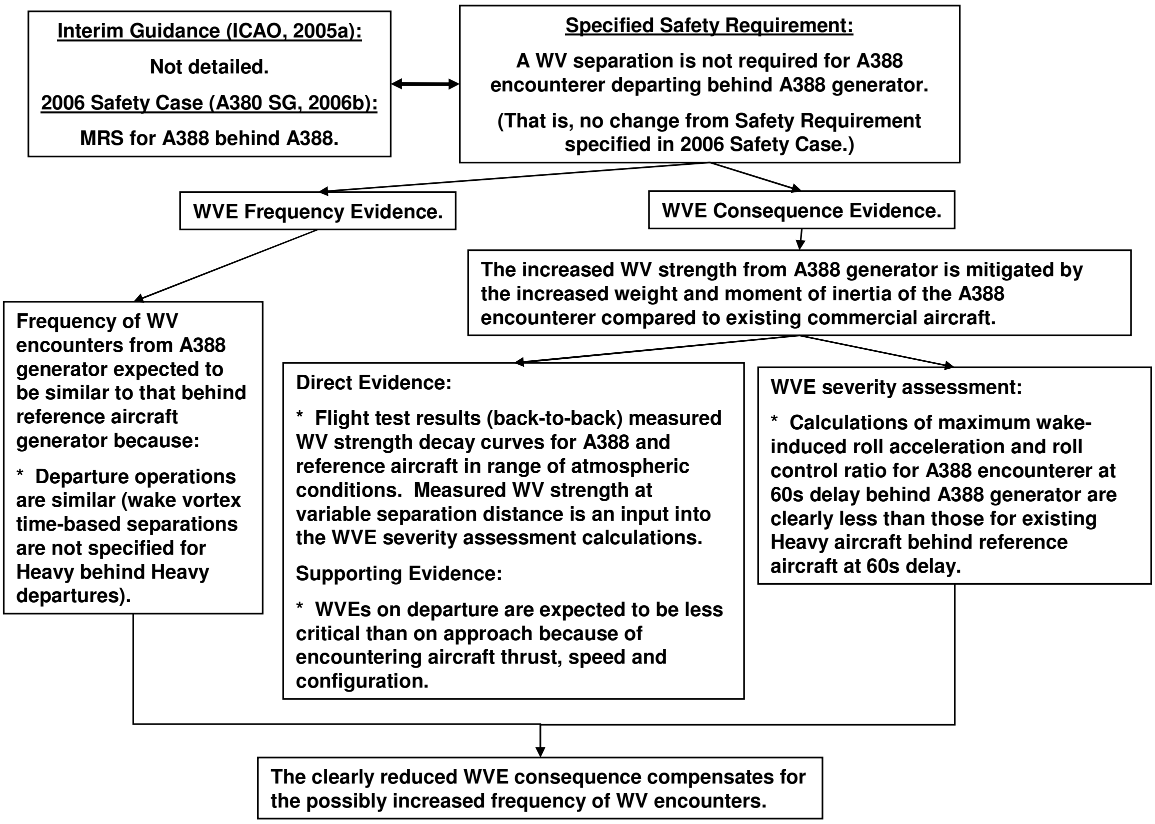


Figure 3.10 indicates that:

- The frequency of WVE for A388 aircraft departing at an assumed time delay of 60s behind an A388 will be similar to the frequency of WVE for Heavy aircraft departing at an assumed time delay of 60s behind a reference aircraft.
- The WV strength encountered at an assumed time delay of 60s behind an A388 will be similar to, or greater than, the WV strength encountered at an assumed time delay of 60s behind a reference aircraft.
- Quantitative estimates clearly show that the increased mass, moment of inertia and control characteristics of the A388 encountering aircraft results in lower wake-induced effects for the A388 encounterer compared to currently accepted reference values for lighter Heavy aircraft behind reference aircraft for an assumed time delay of 60s.

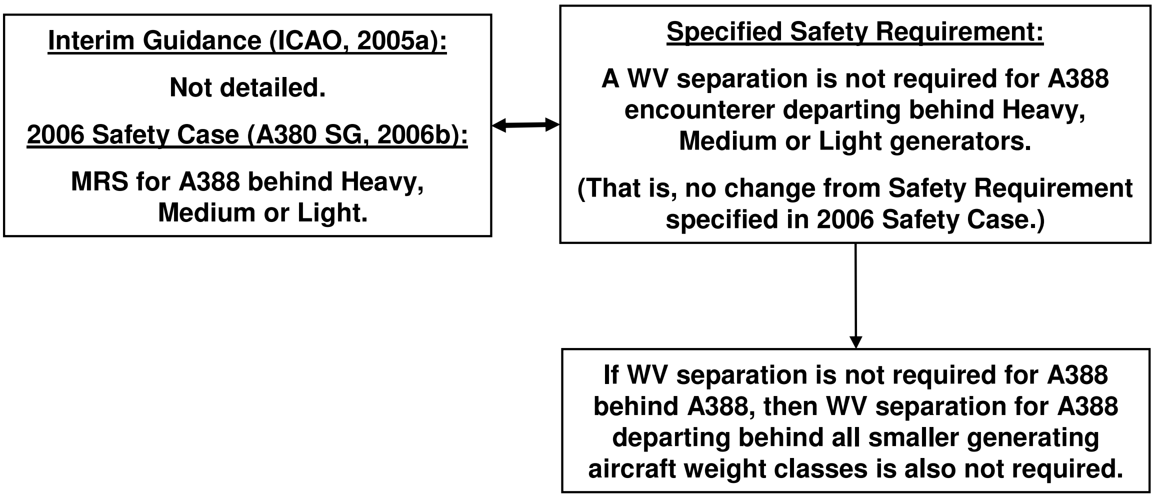
It is concluded that criterion 1 is satisfied because the clearly reduced WVE consequence severity, due to the passive and active resistance of the A388, is more significant than the increased WVE strength. For A388 encounterers the WVE risk for the A388 generator is predicted to be equal to, or less than, that for reference aircraft generators.

Time-Based Separation: A388 Encounterer Departing Behind Heavy, Medium or Light Generators

A WV separation does not need to be specified for an A388 encounterer departing behind a Heavy, Medium or Light generators in a non-radar controlled environment.

The evidence upon which this conclusion is based is described in detail in the safety assessment report [A380 SG, 2008a] and is summarised in Figure 3.11.

Figure 3.11 Evidence Summary for Departure in Non-Radar Environment: A388 Encounterer Departing behind Heavy, Medium or Light Generators



If a WV time-based separation is not required for an A388 departing behind an A388, then a WV time-based separation is also predicted to be not required for an A388 departing behind Heavy, Medium or Light generator aircraft.

Distance-Based Separation: Heavy Encounterer Departing Behind A388 Generator

The safety requirement is 6NM separation for a Heavy encounterer departing behind an A388 generator in a radar controlled environment. This safety requirement is identical to that specified for approach, consistent with procedures currently specified by ICAO.

The evidence upon which this safety requirement is based is described in detail in the safety assessment report [A380 SG, 2008a] and is summarised in Figure 3.12.

Figure 3.12 Evidence Summary for Departure in Radar Environment: Heavy Encounterer Departing behind A388 Generator

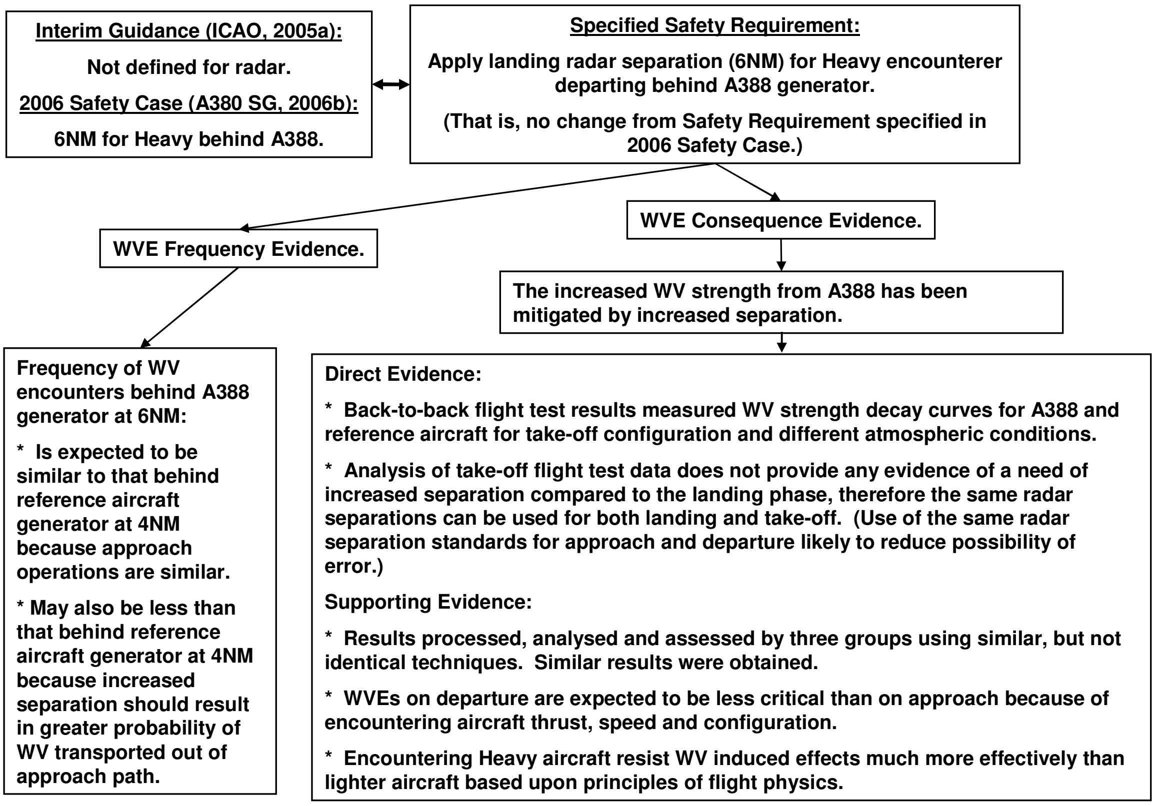


Figure 3.12 indicates that:

- The frequency of WVE for Heavy aircraft departing 6NM behind an A388 will be similar to, or less than, the frequency of WVE for Heavy aircraft departing 4NM behind a reference aircraft.
- The consequence of WVE due to a WV from the A388 at 6NM is similar to that from a WV from a reference aircraft at 4NM because the extra separation defined for the A388 results in an equivalent WV strength at the specified separation of 6NM.
- Encountering Heavy aircraft effectively resist the WV induced effects.

It is concluded that criterion 1 is satisfied. For Heavy encounterers the WVE risk for the A388 generator is predicted to be equal to, or less than, that for reference aircraft generators.

Distance-Based Separation: Medium Encounterer Departing Behind A388 Generator

The safety requirement is 7NM separation for a Medium encounterer departing behind an A388 generator in a radar controlled environment. This safety requirement is identical to that specified for approach, consistent with procedures currently specified by ICAO.

The evidence upon which this safety requirement is based is described in detail in the safety assessment report [A380 SG, 2008a] and is summarised in Figure 3.13.

Figure 3.13 Evidence Summary for Departure in Radar Environment: Medium Encounterer Departing behind A388 Generator

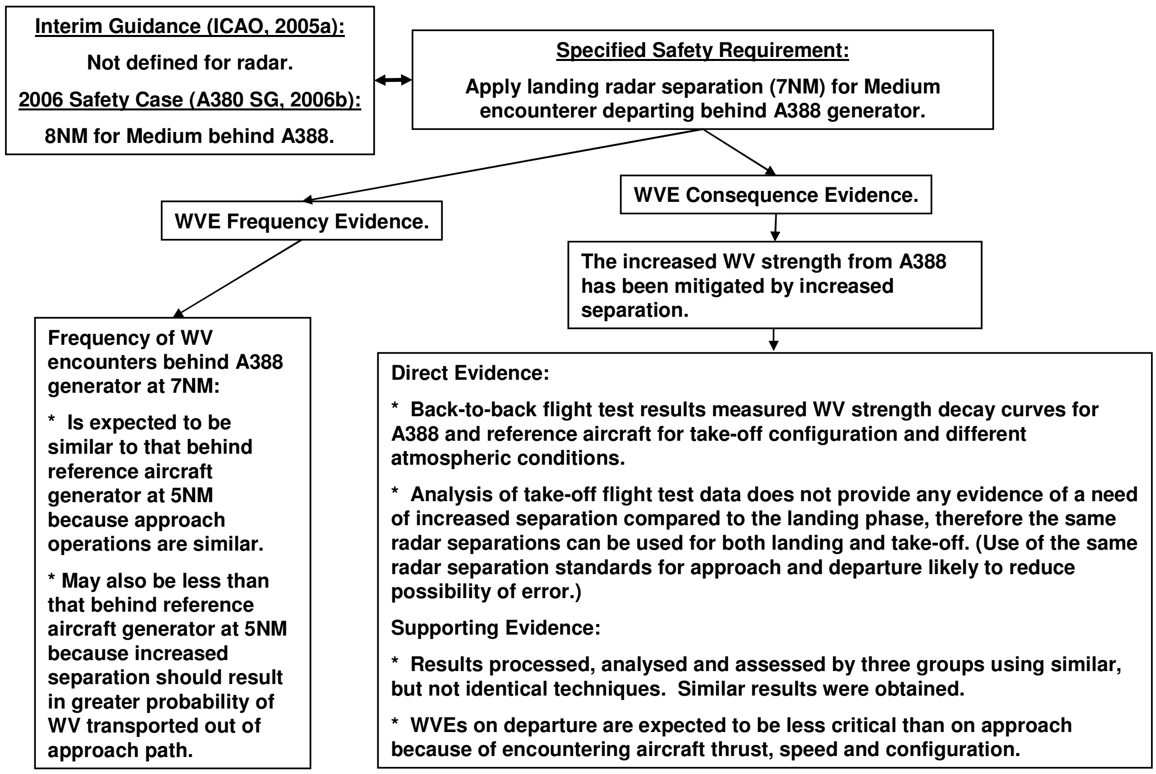


Figure 3.13 indicates that:

- The frequency of WVE for Medium aircraft departing 7NM behind an A388 will be similar to, or less than, the frequency of WVE for Medium aircraft departing 5NM behind a reference aircraft.
- The consequence of WVE due to a WV from the A388 at 7NM is similar to that from a WV from a reference aircraft at 5NM because the extra separation defined for the A388 results in an equivalent WV strength at the specified separation of 7NM.

It is concluded that criterion 1 is satisfied. For Medium encounterers the WVE risk for the A388 generator is predicted to be equal to, or less than, that for reference aircraft generators.

Distance-Based Separation: Light Encounterer Departing Behind A388 Generator

The safety requirement is 8NM separation for a Light encounterer departing behind an A388 generator in a radar controlled environment. This safety requirement is identical to that specified for approach, consistent with procedures currently specified by ICAO.

The evidence upon which this safety requirement is based is described in detail in the safety assessment report [A380 SG, 2008a] and is summarised in Figure 3.14.

Figure 3.14 Evidence Summary for Departure in Radar Environment: Light Encounterer Departing behind A388 Generator

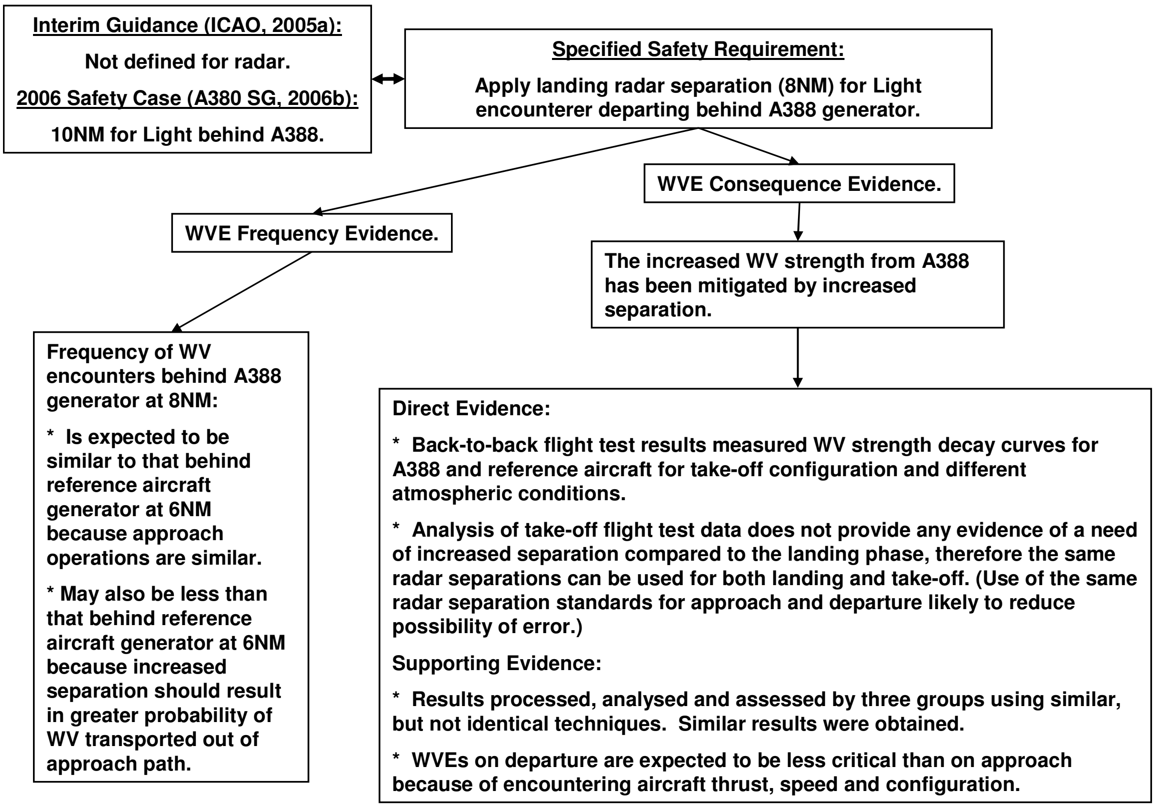


Figure 3.14 indicates that:

- The frequency of WVE for Light aircraft departing 8NM behind an A388 will be similar to, or less than, the frequency of WVE for Light aircraft departing 6NM behind a reference aircraft.
- The consequence of WVE due to a WV from the A388 at 8NM is similar to that from a WV from a reference aircraft at 6NM because the extra separation defined for the A388 results in an equivalent WV strength at the specified separation of 8NM.

It is concluded that criterion 1 is satisfied. For Light encounterers the WVE risk for the A388 generator is predicted to be equal to, or less than, that for reference aircraft generators.

Distance-Based Separation: A388 Encounterer Departing Behind A388 Generator

A wake turbulence restriction is not required for an A388 encounterer departing behind an A388 generator in a radar controlled environment. In this case the separation applied reverts to the Minimum Radar Separation (MRS) applied at the take-off location. WVE risk has been evaluated down to a minimum separation of 2.0NM and it has been determined that an additional WV separation is not required down to this minimum separation. “MRS” is used below as an abbreviation to state that no wake turbulence restriction is required down to 2NM on departure.

The safety requirement is MRS for an A388 encounterer departing behind an A388 generator in a radar controlled environment. This safety requirement is identical to that specified for approach, consistent with procedures currently specified by ICAO.

The evidence upon which this safety requirement is based is described in detail in the safety assessment report [A380 SG, 2008a] and is summarised in Figure 3.15.

Figure 3.15 Evidence Summary for Departure in Radar Environment: A388 Encounterer Departing behind A388 Generator

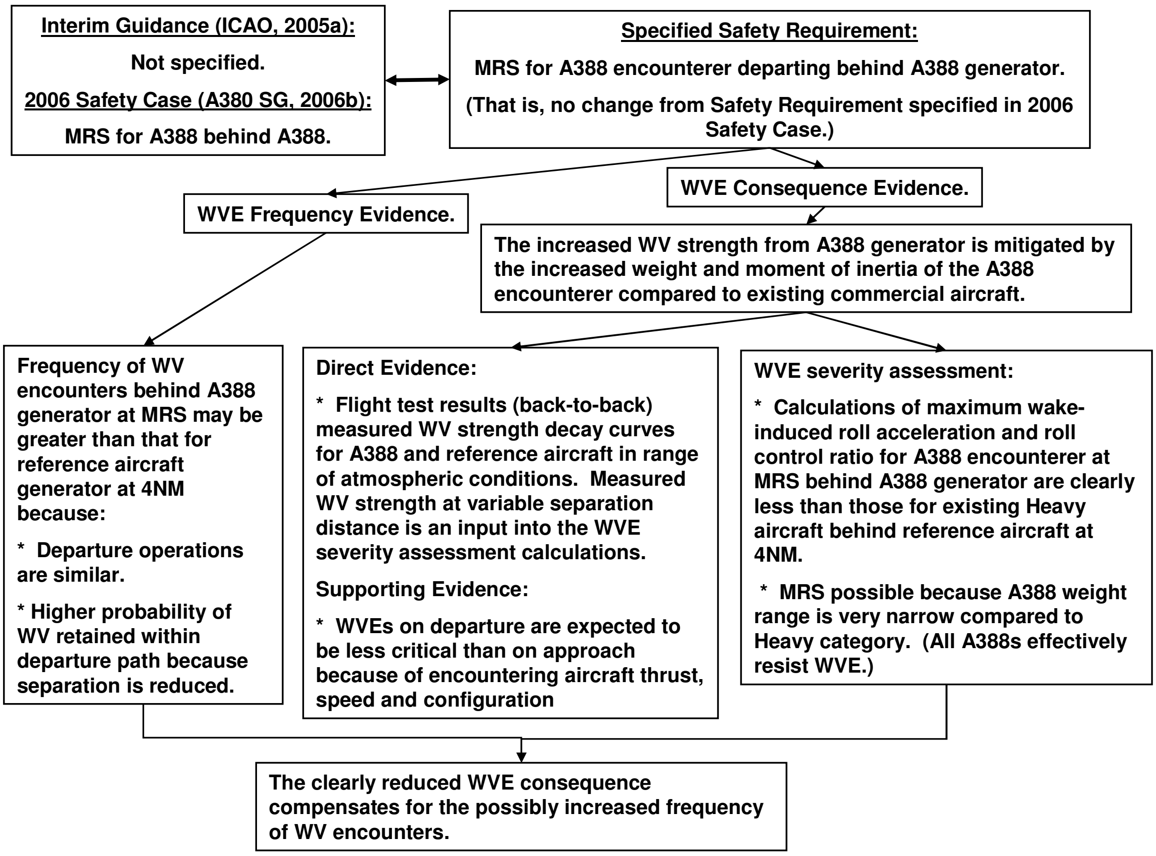


Figure 3.15 indicates that:

- The frequency of WVE for A388 aircraft departing at MRS behind an A388 will be similar to, or greater than, the frequency of WVE for Heavy aircraft departing 4NM behind a reference aircraft.
- The WV strength encountered at MRS behind an A388 will be greater than the WV strength encountered at 4NM behind a reference aircraft.
- Quantitative estimates clearly show that the increased mass, moment of inertia and control characteristics of the A388 encountering aircraft result in lower wake-induced effects for the A388 encounterer compared to currently accepted reference values for lighter Heavy aircraft behind reference aircraft.
- It should be noted that MRS is not judged to be accepted today for Heavy aircraft departing behind Heavy aircraft because there is an appreciable variation of mass within the Heavy category at the reference date (4NM is necessary to protect the lighter Heavy aircraft departing behind the heavier Heavy aircraft). For the A388 "category" the mass range is very narrow and thus a separation of MRS can be justified.

It is concluded that criterion 1 is satisfied because the clearly reduced WVE consequence severity, due to the passive and active resistance of the A388, is more significant than the increased WVE frequency and strength. For A388 encounterers the WVE risk for the A388 generator is predicted to be equal to, or less than, that for reference aircraft generators.

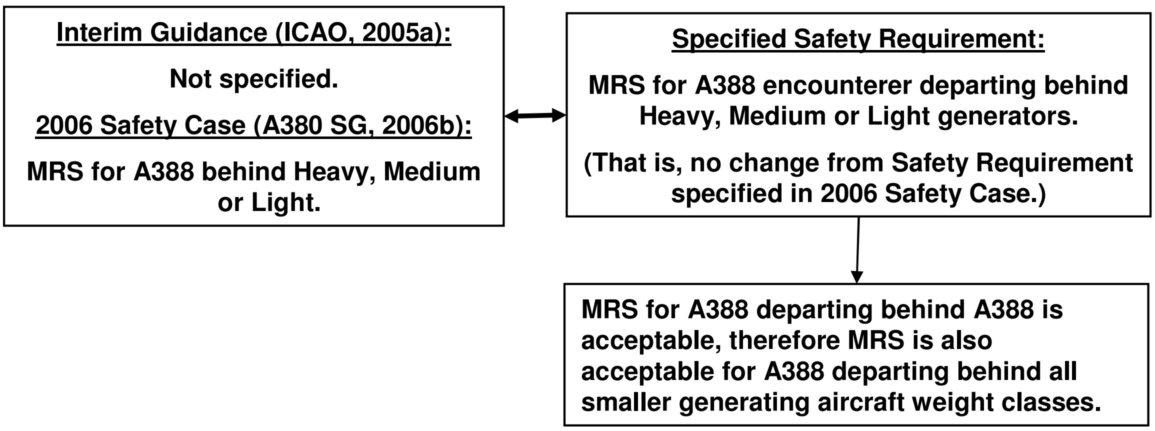
<u>Distance-Based Separation: A388 Encounterer Departing Behind Heavy, Medium or Light Generators</u>

A wake turbulence restriction is not required for an A388 encounterer departing behind Heavy, Medium or Light generators in a radar controlled environment. In this case the separation applied reverts to the Minimum Radar Separation (MRS). WVE risk has been evaluated down to a minimum separation of 2.0NM and it has been determined that an additional WV separation is not required down to this minimum separation. “MRS” is used below as an abbreviation to state that no wake turbulence restriction is required down to 2NM.

The safety requirement is MRS for an A388 encounterer departing behind Heavy, Medium or Light generators in a radar-controlled environment. This safety requirement is identical to that specified for approach, consistent with procedures currently specified by ICAO.

The evidence upon which this safety requirement is based is described in detail in the safety assessment report [A380 SG, 2008a] and is summarised in Figure 3.16.

Figure 3.16 Evidence Summary for Departure in Radar Environment:
A388 Encounterer Departing behind Heavy, Medium or Light Generators



If MRS for A388 departing behind an A388 is acceptable then MRS is also predicted to be acceptable for A388 departing behind Heavy, Medium or Light generator aircraft.

Argument 1.1.3 WVE Risk has been reduced as far as reasonably practicable (taking account of technical and economic factors)

During the work programme the alternative ways to reduce WVE risk as far as reasonably practicable have been considered as part of the general objective of being “safe and fair” to the A388. It is considered that both WVE monitoring and the general safety recommendations help to ensure that WVE risk is reduced as far as reasonably practicable. No other practicable and reasonable means were identified.

It is concluded that WVE risk for the A388 has been reduced as far as reasonably practicable (taking account of technical and economic factors).

Argument 1.1.4 Safety Requirements are realistic

The safety requirements defined in this section are numerical amendments of existing separation criteria. It is considered that it is realistic to apply these numerical amendments.

These proposals have been reviewed by experts with pilot, controller and regulatory experience from within the Work Group. The conclusion is that the safety requirements are realistic.

3.2.2 Safety criteria are satisfied in general by the specific scenario Safety Requirements plus any further identified Safety Requirements (Argument 1.2)

See Appendix A, Figure 1.2 for the GSN representation of Argument 1.2.

Argument 1.2.1 Generalisation issues have been considered and all reasonably foreseeable generalisation issues have been identified

The safety requirements defined in Section 3.2.1 above are based upon flight test measurements performed under specific test conditions. The objective of this safety case is to define safety requirements that can be applied worldwide. The Work Group has identified the following main factors that could influence the general applicability of the safety requirements:

- Effect of variation in generator aircraft configuration (mass, speed, etc.).
- Effect of variation of atmospheric conditions (turbulence, wind, etc.).
- Effect of variation of encountering aircraft type.

The Work Group's expert judgement is that the above are the only significant generalisation issues that need to be considered in this safety case (see also Assumption 3 in Section 8.1.1).

It is concluded that all generalisation issues have been considered and all reasonably foreseeable generalisation issues have been identified.

Argument 1.2.2 All identified generalisation issues have been evaluated

The effect of the generalisation issues identified under Argument 1.2.1 is considered in turn below.

Effect of variation in generator aircraft characteristics (mass, speed, etc).

The WV strength and decay characteristics of a generator aircraft can be affected by a number of parameters which might vary during flight test or operational conditions. The Work Group has identified the following parameters as the main influences:

- Generator mass and centre of gravity.
- Generator speed.
- Generator configuration (flaps, spoilers, etc.).

These issues were considered before the performance of the flight tests and representative or conservative parameters were used in the flight tests in order to not under-estimate the potential WVE risk due to the A388 generator. Each parameter is discussed in turn.

Generator mass and centre of gravity. Maximum certified landing mass, maximum certified take-off mass and estimated maximum mass in the cruise were used for the A388 flight tests. Flight physics indicates that initial WV strength is proportional to generator mass thus the use of maximum values is conservative compared to the variation of mass likely to be observed operationally.

The location of the centre of gravity of the generator aircraft can affect how the WVs from the main wing and the tail-plane interact, which may affect WV decay rates. Variations in centre of gravity of the A388 were investigated and the effect of realistic variations in centre of gravity on the WV strength is concluded to be acceptably small.

Generator speed. The lowest appropriate generator speeds characteristic of each phase of flight and aircraft weight were used for the flight tests [A380 SG, 2008a] in order to produce the largest initial WV strength.

Generator configuration (flaps, spoilers, etc.). All appropriate aircraft configurations as specified by the aircraft flight manuals were tested [A380 SG, 2008a].

It is concluded that the effect of variation in generator aircraft characteristics has been considered, the defined safety requirements have been derived using reasonably conservative values and therefore the defined safety requirements can be applied worldwide.

Effect of variation of atmospheric conditions (turbulence, winds, etc.).

Atmospheric conditions such as turbulence and wind speed can affect WV transport and decay rates. The aim was to perform all flight tests in calm and near-neutral atmospheric conditions, since these conditions minimise WV decay and maximise the WV lifetime. The actual atmospheric conditions encountered during flight tests were recorded and examined in detail as part of the analysis of the results. Safety criteria were estimated from all tests averaged together, from groups of tests performed in similar atmospheric conditions and from individual back-to-back flight tests.

Ambient air temperature and pressure can affect aircraft performance. The Work Group considers that variation of ambient air conditions will not significantly affect the defined safety requirements because current ICAO separation criteria applied today operate safely in a wide variety of ambient conditions worldwide. Flight physics indicates that this will also apply for the separation criteria specified for the A388.

It is concluded that the effect of variation in atmospheric conditions has been considered, the defined safety requirements have been derived using reasonably conservative atmospheric conditions and therefore the defined safety requirements can be applied worldwide.

Effect of variation of encountering aircraft type (e.g. B737, A320).

The specified safety requirements are mostly estimated without reference to the characteristics of the encountering aircraft type, by using the process illustrated in Figure 2.2. This process is based on deducing an extra separation that provides an equivalent WV strength and is thus independent of encountering aircraft type. Therefore variation of encountering aircraft type does not affect the safety requirements defined in this safety case.

The safety requirements for the A388 as an encountering aircraft have taken account of the encountering aircraft characteristics. This is supported by explicit calculations as described in the safety assessment report [A380 SG, 2008a] and summarised in this safety case.

It is concluded that the effect of variation of encountering aircraft has been considered and that the defined safety requirements can be applied worldwide.

Argument 1.2.3 Exceptions and additional Safety Requirements necessary because of generalisation have been identified

Factors that may affect the general application of the defined safety requirements have been identified and assessed. It is concluded that the safety requirements as defined can be applied generally worldwide without the need for additional safety requirements *directly* as a result of the introduction of the A388 (either upon entry into service or upon introduction to new locations).

However it should be noted that the strategy for ensuring ATM safety is based on 3 high-level principles:

- Ensuring that airspace design (e.g. locations and widths of airways, layout of runways, etc.) is acceptably safe.
- Ensuring that ATM procedures are acceptably safe.
- Ensuring separation criteria, such as the separation criteria specified in this safety case to ensure WVE risk is acceptable, are acceptably safe.

This safety case only modifies a sub-set of the third principle above.

This has four main consequences:

- If the current ICAO WVE separation criteria can be applied in a location without modification then the separation criteria for the A388 specified in this safety case can also be applied without modification. This is a logical extension of the relative safety argument.
- Conversely, if the current ICAO WVE separation criteria require modification in a location, then the separation criteria for the A388 specified in this safety case may also need modification. The assessment of the appropriate modification must be performed by the responsible party.
- Responsible parties must assess if the separation criteria recommended in this report are consistent with their local airspace design and ATM procedures.
- Responsible parties may amend any or all of the 3 high-level principles to best meet their operational objectives. However if a responsible party does not apply the WVE separation criteria specified in this safety case then they must provide the safety assessment evidence to show that their operations, including the separations criteria they apply, are acceptably safe.

This assumption supports the global applicability of the safety requirements derived in this safety case. However the following safety requirement must be specified:

Responsible parties must assess if the separation criteria defined in this report are consistent with their local airspace design and ATM procedures. If they are not consistent then the responsible party must perform an appropriate safety assessment.

3.2.3 Safety Requirements evidence is trustworthy (Argument 1.3)

See Appendix A, Figure 1.3 for the GSN representation of Argument 1.3.

The strategy for demonstrating that the safety requirements evidence is trustworthy is based on showing that the evidence was derived by the application of a sound and appropriate process, using suitably competent personnel. This is reflected in the decomposition of Argument 1.3 as described below.

Argument 1.3.1 Safety Assessment processes were adequate

The safety assessment processes are considered to be adequate for the 3 reasons stated in Arguments 1.3.1.1, 1.3.1.2 and 1.3.1.3 below.

Argument 1.3.1.1 Techniques and methods used to support Argument 1.1.2 are validated and results are consistent with expert judgement

Analysis work has been performed by at least two, and sometimes three, groups using similar, but not identical, data reduction and data analysis methods. Similar results have been obtained. This consistency is considered to provide very robust validation of the analysis results that form the basis of this safety case.

Argument 1.3.1.2 Safety Assessment processes comply with qualitative requirements of ESARR 4

EUROCONTROL Safety Regulatory Requirement 4 (ESARR 4) specifies the following qualitative requirements that are applicable to this safety case:

Hazard identification and risk assessment have addressed life cycle issues. Hazard identification is addressed under Arguments 1.1.1 and 1.2.1. Life cycle risk assessment issues (A388 will be safe upon introduction and during continued operations) have been addressed mainly by Arguments 1 and 4.

Hazard identification, risk assessment and mitigation processes have included consideration of scope boundaries and interfaces of the proposed change. The broad scope of this safety case limits the importance of this requirement. It is considered that this safety case is compliant with this requirement of ESARR 4.

A risk mitigation strategy has been derived that specifies the safety requirements and has verified that these are feasible and effective. The risk mitigation strategy is defined by the safety requirements (separation criteria have been increased to compensate for the increased WV strength of the A388 and on-going WVE monitoring and reporting is required). Verification and feasibility evidence has been provided under Arguments 1.1.4 and 1.3.

Verification that safety requirements have been met prior to implementation, during implementation and during ongoing operations. This requirement can only be achieved by the responsible parties who are required to implement the safety requirements defined in this safety case.

Complete and correct safety requirements have been derived that are traceable to safety assessment processes and evidence. This is achieved by the complete safety case supported by the safety assessment report [A380 SG, 2008a].

It is concluded that the qualitative requirements of ESARR 4 are satisfied by this safety case.

Argument 1.3.1.3 Evaluation of A388 operations is consistent with expert judgement. Any unresolved issues to be noted.

Assessment of the safety requirements to control WVE risk for the A388 is a complex technical problem that requires many skills and experiences. A crucial cross-check on the validity of the results obtained is that they should be consistent with the judgement and experience of expert reviewers.

The WG concludes that the safety assessment results are consistent with their experience and expert judgement. This provides additional validation of the defined safety requirements.

Argument 1.3.2 Safety Assessment processes were executed by competent staff

The WG consists of the following experts:

Lead Investigators

- Stephen Barnes (FAA) represented the FAA's Aviation Safety (AVS) Organization. He has over 30 years of aviation experience including research, development, engineering, operations, and piloting. He manages the Flight Systems Laboratory where they perform risk analyses of aviation operations, conduct fast time simulations, develop operational safety standards, and explore new analyses methodology. He became more actively involved with the A380 WG from August 2007.
- Jean-Michel Govaere (Airbus) is responsible for the Certification of the A380. He provided expertise and guidance in methodology and processes based on his 18 years experience in Airbus Certification activities with various worldwide Authorities.
- George Greene (FAA) was the US Federal Aviation Administration's Chief Scientific & Technical Advisor for Wake Turbulence until he retired in December 2006. Since his retirement he has continued to support the A388 wake assessment activity through the FAA.
- Gordon Höhne (Airbus) provided expertise in flight dynamics to the WG. He has 11 years of experience in the field of flight dynamics, handling qualities and simulation. About 6 years have been devoted particularly to the investigation of wake vortex encounters, to wake vortex encounter severity assessment and to wake encounter flight test evaluations.
- Steven Lang (FAA) represented the FAA's Air Traffic Organization (ATO). He has 30 years experience in the field of Air Traffic Control, at multiple levels of the organization.
- Florent Laporte (Airbus) provided expertise to the WG in the field of wake vortex physics, modelling, measurements and analysis. He has a Ph.D thesis grade on the subject and has led the Airbus aerodynamics activities on A388 wake vortex from the end of 2002 to 2008.
- Claude Lelaie (Airbus) is an experimental test pilot and was Head of Flight Test from 1994 to September 2007. Now Senior Vice President of Product Safety and co-ordinator for all wake vortex activities for Airbus. He has been actively involved in the WG since 2006.
- Terry Lutz (Airbus) joined the WG in late 2006 as an experimental test pilot, and was assigned as a pilot for the LIDAR campaign at Tarbes. He has experience in many different airplane types, both military and civilian, and was previously a Captain at Northwest Airlines.

- Jean-Pierre Nicolaon (EUROCONTROL) provided wake and ATM expertise to the WG until February 2007. He has 25 years experience in French ATM operations and 15 years in Research & Development activities at the EUROCONTROL Experimental Center.
- Frank Ogilvie (Airbus) led the A380 Aerodynamics Programme from 1996 to 2007. He has 44 years of experience in the design and development of civil transport aircraft.
- Geza Schrauf (Airbus) provided expertise on aerodynamic wake vortex modelling. He has more than twenty years experience in aerodynamics and has served the last three years as the leader of the wake vortex group at Airbus in Bremen.
- Vincent Treve (EUROCONTROL) provided expertise in the analysis and modelling of wake vortex LIDAR data to the WG since March 2008. In coordination with the Direction des Services de la Navigation Aérienne (DSNA - French ANSP), he has run the wake dependence study (WIDAO) at Charles de Gaulle airport, Paris. Before joining EUROCONTROL he worked in wake research teams at Université Catholique de Louvain and Airbus.
- Hugues van der Stichel (Airbus) is an experimental test pilot with 15 years experience flying more than 60 aircraft type, from the lightest propeller aircraft to the heaviest jets. He has provided pilot experience to the WG between March 2006 and February 2007 and he ran the early flight test campaigns.

Supporting Investigators

- Donald Delisi (NWRA/FAA) provided data analysis expertise to the FAA in support of the Work Group. He has over 25 years of experience analyzing wake vortex data from field experiments, laboratory simulations, and numerical models.
- Tim Fowler (DNV) provided safety assessment expertise to the WG. He has over 15 years experience providing specialist safety management consultancy services to a range of clients including 8 years of aviation industry experience.
- Richard Greenhaw (FAA) is a senior statistician and risk analysis expert with the FAA who has over 30 years experience in applying statistical methods to risk analysis. He has developed analyses for multiple parallel approach safety, RNAV/RNP en route separation standards, wake strength safety, and obstacle clearance among other areas of interest.
- James Hallock (Volpe/FAA) provided analytical support. He has over 35 years experience studying wake vortex behaviour and in the application of wake vortex data to derive safe separation standards.
- David Lankford (FAA) was a former lead investigator and assumed a supporting role in August 2007. He has over 30 years of experience in developing operational safety standards and has established computer based modelling techniques that quantify levels of safety.
- Fred Proctor (NASA/FAA) provided expertise in meteorology and wake vortex behaviour to the FAA in support of the Work Group until November 2007. He has over 23 years experience studying aviation weather hazards for NASA and has been a contributing researcher in NASA wake vortex programs during the past 12 years.
- James Yates (ISI/FAA) provided mathematical/ statistical support to the FAA representatives. He has over 30 years experience in the application of mathematical/ statistical techniques to risk analysis of aviation operations.

The WG met about 40 times over about 5 years. Over this period a highly effective working process evolved which entailed healthy and vigorous debate before drawing conclusions. This process coupled with the collective education, experience and dedication of the WG members provide re-assurance that the safety case is fit for its intended purpose.

3.3 General Assumptions, Exceptions and Open Issues for Argument 1

This safety case has been developed on the assumption of full compliance with the defined separation criteria (fault-free operations). However during operations today, *full* compliance with today's separation criteria is unlikely to be achieved. Thus the following two questions are relevant to this relative safety assessment:

- Will the frequency of non-compliant incidents increase after the definition of 4 sets of separation criteria?
- Will the consequences of non-compliant incidents increase for the A388 compared to reference aircraft?

The WG consider that the main non-compliant incident of concern is mis-identification of aircraft class and the resulting application of an incorrect separation criterion.

The WG has not obtained any data to answer the first question. However, the increased complexity of the separation criteria (4 sets of separation criteria instead of 3) that arises due to the introduction of the A388 (and other "heavy-Heavy" aircraft in the future) raises the possibility that the frequency of non-compliant incidents may increase. Conversely, the novelty of, and interest in, the A388 (and other new heavy aircraft) may result in air traffic controllers paying particular attention to the these new aircraft which could reduce the frequency of non-compliant incidents. The answer to this question is, therefore, unclear.

The WG has also not obtained all necessary data to answer the second question because in-service experience will be required. As a result the WG make the following general safety recommendation:

Good situational awareness of pilots and controllers may be enhanced by amending operational procedures to stipulate that initial communication (telephone and radio) concerning heavy aircraft (other Heavy and the A388) should use either the word "HEAVY" (for Heavy aircraft in-service at the reference date) or the word "SUPER" (for the A388); this recommendation is identical to the revised ICAO interim guidance [ICAO, 2006b].

In addition, responsible parties should also monitor their operational performance ("error rates") so that failure to apply the correct WV separation criteria occurs at an acceptably low frequency to ensure adequate safety levels are maintained for all operations. It should be noted that this is a restatement of current ATSP objectives and is not a requirement that results from the introduction of the A388.

It is noted that the requirements stated under Argument 4 (in-service WVE monitoring) also help responsible parties to minimise the frequency of non-compliant incidents.

3.4 Future Work

The members of the A380 SG and WG intend to continue to meet and collaborate to perform work in the following areas:

- To review in-service operational data and other data as available and to use this as a basis to revise the separation standards for the A388 defined in this safety case when this is justified.
- To review the ICAO wake vortex encounter reports particularly in relation to:
    - The WV performance of the A388 and other Heavy aircraft yet to enter service.

- The magnitude of WVE risk in the cruise when aircraft are separated vertically by 1000 feet.
- The magnitude of WVE risk during climb and descend.
- The relative magnitude of WVE risk for all aircraft in the commercial fleet.

This WG recommendation is further elaborated in Section 8.2.

SECTION 4 - SUFFICIENT GUIDANCE EXISTS AND HAS BEEN COMMUNICATED TO ENABLE COMPLETE AND CORRECT IMPLEMENTATION OF THE SAFETY REQUIREMENTS BY ALL PARTIES (ARGUMENT 2)

4.1 Strategy to Show Satisfaction of Safety Argument 2

The WV Steering Group experts have provided guidance regarding who should implement the safety requirements specified in this safety case and how they should be implemented. The strategy (Strategy 2 under Argument 2 in Appendix A) is to ensure that the safety requirements specified in this safety case are correctly implemented by:

1. Preparing guidance, including responsibilities for safety and early operations.
2. Communicating guidance to all relevant parties to ensure consistent application worldwide.

The sub-argument structure and evidence that supports this strategy is presented in Section 4.2.

4.2 Sub-Argument Structure and Supporting Evidence for Argument 2

Argument 2.1 This safety case and its supporting guidance document has been prepared and communicated to all relevant parties.

This safety case and its supporting guidance document (Appendix B) have been prepared [A380 SG, 2008b; A380 SG, 2008a]. Both safety case documents have been delivered to ICAO. Furthermore the SG has informally briefed the Air Navigation Commission (ANC) of ICAO on an as-required basis. The SG assumes that the safety case will be effectively distributed to all relevant parties via the normal ICAO communication channels.

Argument 2.2 Safety responsibilities of all parties have been clearly, correctly and completely specified

The SG consider that guidance on safety responsibilities has been provided, as far as it is possible to do so, in the safety case (see Section 5.2, Argument 3.1) and the guidance document (see Appendix B, Sections B.3.2 and B.3.3).

Argument 2.3 All parties have been provided with sufficient guidance on implementation

When providing guidance to support the implementation of a safety case it is important to achieve the correct balance between sufficient guidance to ensure correct implementation and overly prescriptive guidance which might cause responsible parties to apply the guidance mechanistically.

The SG consider that the level of guidance provided (see Appendix B) is sufficient without being overly prescriptive.

Argument 2.4 All parties have been provided with sufficient guidance on early operations and especially on when and how to monitor WVEs and when to report them

The SG consider this guidance has been provided in the safety case (see Section 6) and the guidance document (see Appendix B, Section B.3.4). The SG note that a worldwide WVE reporting system is now operational (see Section 6).

Argument 2.5 Guidance on safety processes provides basis for consistent safety-regulatory approval.

The SG consider this safety case and its supporting guidance document (see Appendix B) provide this.

4.3 Assumptions, Exceptions and Open Issues for Argument 2

It is assumed that:

- Normal mechanisms for the promulgation of information to all relevant parties will be adequate.
- All relevant parties will perform their assigned tasks responsibly, professionally and without undue delay.
- Relevant parties will clearly assign safety responsibilities using the guidance provided.

SECTION 5 - IMPLEMENTATION OF WV SAFETY REQUIREMENTS ARE COMPLETE AND CORRECT (ARGUMENT 3)

5.1 Strategy to Show Satisfaction of Safety Argument 3

The responsible parties are responsible for communicating, reviewing and implementing the safety requirements of this safety case. Responsible parties may do this in any acceptable way, but the recommended strategy (Strategy 3 under Argument 3 in Appendix A) is:

1. All parties that are responsible for WVE safety in each location for each phase of flight (approach, cruise and departure) need to demonstrate that the contents of this safety case have been applied correctly before A388 operations commence locally. Key issues are technical review, update of ATC procedures and tools, communication and training.

It is emphasised that WVE risk is not the only factor that determines aircraft separations. Responsible Parties need to assess all other relevant factors (for example, runway occupancy times, performance of surveillance systems, etc.) as well as the safety requirements defined in this safety case when determining how to adjust their operational procedures for the A388.

The evidence that supports this, or an alternative, strategy needs to be provided by the implementing responsible parties. Examples of the type of information required is provided in Section 5.2.

5.2 Sub-Argument Structure and Supporting Evidence for Argument 3

Argument 3.1 Responsibilities for WVE safety have been cascaded through the implementing organization.

Top level responsibilities for safety within this safety case are indicated in Figure 2.1. To summarise:

- The A380 Wake Vortex Steering Group is responsible for preparing this safety case, for the WVE safety assessment (Argument 1) and for the accompanying guidance document (Argument 2).
- The responsible parties are responsible for implementing the safety requirements defined in this safety case (Argument 3), including the very important safety requirement of implementing WVE in-service monitoring (Argument 4).

Responsible parties are to provide evidence of the latter (see also Appendix B – Guidance).

It is not feasible to specify responsibilities for safety more completely in this safety case than as given above. Nevertheless, an implicit assumption of this safety case is that responsibilities for ensuring safety are effectively cascaded down to national organizations through named individuals or defined organizational positions. Correct allocation of responsibilities throughout the implementation chain is an important contributor to ensuring that A388 operations will be acceptably safe in practice. Example evidence that could be provided by responsible parties is the assignment of safety responsibilities to individual(s) or organizational position(s) within an implementation plan.

Argument 3.2 Implementation of WV safety requirements is complete and correct.

Responsible parties should provide evidence of the satisfaction of safety requirements (see also Appendix B – Guidance).

Evidence could be provided responsible parties have implemented the safety requirements correctly by consideration of how the safety requirements affect their own operational procedures, amending procedures as required, training staff in the use of the new procedures and communicating the change throughout the organization.

Argument 3.3 Safety case exceptions, assumptions and other issues have been reviewed by competent staff.

Responsible parties should review the safety case contents, and especially the safety case exceptions, assumptions and open issues, to ensure that:

- Either the safety case is applicable within the locality without modification, or
- Additional safety requirements are identified and implemented

in order to ensure that A388 operations will be acceptably safe upon commencement of commercial services locally.

Example evidence that could be provided by responsible parties is the review report and/ or a resulting actions list which could form part of an A388 implementation plan.

Argument 3.4 Safety case exceptions have been included in local implementation plan.

Responsible parties have implemented all the identified safety requirements (safety case and any local requirements) through the definition and execution of a local implementation plan.

Example evidence that could be provided by responsible parties is the local implementation plan that details how the identified exceptions have been addressed.

5.3 Assumptions, Exceptions and Open Issues for Argument 3

This item should be addressed by the responsible parties.

SECTION 6 - ON-GOING OPERATION OF A388 WILL BE SHOWN TO BE ACCEPTABLY SAFE REGARDING WVES (ARGUMENT 4)

6.1 Strategy to Show Satisfaction of Safety Argument 4

Demonstration that the on-going operation of the A388 will be acceptably safe regarding WVE risk will be done via a robust incident recording, analysis and corrective-action process.

The strategy (Strategy 4 under Argument 4 in Appendix A) is to show that the process is capable of indicating WVE trends, of identifying potentially unsafe operations, and removing the causes of incidents to prevent recurrence. Such effective safety monitoring is a key feature of a safety management system as required by ICAO [ICAO, 2006a].

WVE safety monitoring will be performed for all phases of flight, for the A388 generator *and for all in-service generator aircraft*. WVE monitoring from all current (reference) aircraft, especially in-service non-A388 Heavy aircraft, provides the reference, or benchmark, that is necessary to effectively interpret WVE reports from the A388 aircraft. It will also support the re-categorisation process described in Section 3.4 on Future Work. Evidence for the function of the WV monitoring of on-going A388 operations will be provided both by responsible parties at the operational level in States (nationally) and by responsible parties reviewing reports at the international level (ICAO).

This strategy is reflected in the decomposition of Argument 4 as shown in Section 6.2.

International co-ordination of A388 WVE incidents will be performed by ICAO. Reporting will be to:

International Civil Aviation Organization
Air Navigation Bureau
999 University Street
Montreal, Quebec
Canada H3C 5H7

Additional guidance regarding why monitoring is required (for A388 and other Heavy aircraft in all phases of flight), what should be monitored and how to perform monitoring is provided in Appendix B, Section B.3.4.

Since Edition 2.0 of this safety case was published in 2006, ICAO has implemented a worldwide WVE reporting system for all aircraft in all phases of flight. These reports are being assessed to determine if any trends can be identified.

6.2 Sub-Argument Structure and Supporting Evidence for Argument 4

Argument 4.1 Local WVE-incident and operational data recording process

Evidence that an adequate local WVE-incident and operational data recording process exists should be provided by responsible parties. The data that is reported should be sufficient to determine: the severity of the incident; the position (and hence the type) of the likely WV generator aircraft; the incident rate (e.g. number of incidents per approach); and the possible cause(s) of the incident (e.g. were the separation criteria specified in this safety case applied correctly or not). Further guidance on these issues is given in Appendix B, Section B.3.4.

Example evidence could be:
- WVE reporting procedure;
- WVE record form;
- Completed WVE incident reports (possibly non-attributed).

Argument 4.2 Local WVE-incident review and investigation process

Evidence that an adequate local WVE-incident review and investigation process exists should be provided by responsible parties.

Example evidence could be:
- WVE review procedure (to include assessment of incident severity and assessment of incident occurrence rates (e.g. incidents per operation));
- WVE report review records;
- WVE corrective action records (if applicable).

Argument 4.3 Local corrective-action process

Evidence that an adequate local corrective-action process exists should be provided, if applicable, by responsible parties.

Example evidence, if applicable, could be:
- Revised operational procedure;
- Local corrective action;
- Report to ICAO describing the safety problem and the corrective action adopted.

Argument 4.4 Process for reporting of operational experience and incident data to ICAO

Evidence that an adequate process exists for reporting of operational experience and incident data to ICAO should be provided by responsible parties. Two reporting frequencies are necessary: all corrective actions issued locally and any serious WVE incidents (those that involve a significant loss of control) should be reported to ICAO as soon as possible; and periodic reporting of *all* WVE incidents should be performed at least once per year, or possibly more frequently depending on the number of incidents reported.

Example evidence, if applicable, could be:
- Example evidence could be a report to ICAO.

Argument 4.5 Process for international review of incident data and dissemination of WVE lessons learned to validate a priori the safety assessment

ICAO will be responsible for the periodic analysis and review of WVE reports received and for recommending and disseminating any corrective actions identified as a result of these periodic reviews. ICAO should disseminate all locally implemented corrective actions and all reported serious WVE incidents to all ICAO member States as soon as possible. ICAO should also annually review *all* WVE incident data received and disseminate the report that describes the result of this review.

If hazardous or potentially hazardous WVE incident *rates* (e.g. incidents per operation) for the A388 are very low, then this will be identified by this review and could be used as evidence for the revision of separation criteria to less conservative values. The number of WVE reports is not yet sufficient to provide evidence either way.

Evidence that an adequate process exists for international review of incident data and dissemination of WVE lessons learned to validate *a priori* the safety assessment should be provided by the responsible parties.

Example evidence could be:
• An ICAO report describing the review process and its conclusions. • A corrective action issued by ICAO.

6.3 Assumptions, Exceptions and Open Issues for Argument 4

The safety requirements in this safety case are provided to ensure that A388 operations will continue to be acceptably safe in practice. A critical assumption of this safety case is that effective and sufficient wake vortex encounter monitoring (at least equivalent to that recommended in the guidance material to this safety case, see Appendix B) of early A388 operations will be performed and any lessons learned will be effectively and promptly disseminated worldwide.

Other matters should be addressed here by the responsible parties, as required.

SECTION 7
- WAKE VORTEX SAFETY REQUIREMENTS FOR A388

The safety requirements re-stated below are considered by the A380 Wake Vortex Steering Group to be mandatory in order to ensure that the operation of the A388 will be acceptably safe in practice with respect to WVE risk.

7.1 General Safety Requirements

1. WVE reporting, analysis of reports and international dissemination of WVE experience data are required consistent with safety management system principles adopted by ICAO [ICAO Annex 11, 2.26 with guidance contained in the "Safety Management Manual", Doc 9859; ICAO, 2006a]. This safety requirement has 5 component parts:

   a) Responsible parties (normally Air Traffic Service Providers) are required to implement a WVE reporting system for all encountering aircraft, all phases of flight and for all generator aircraft.
   b) Responsible parties are required to review and investigate the WVE reports collected locally.
   c) Responsible parties are required to identify and implement any corrective actions which may be identified as necessary following local review of WVE reports.
   d) Responsible parties are required to send all WVE reports to ICAO so that isolated incidents observed locally may be reviewed to determine if they are indicators of a general safety issue. Responsible parties are required to also notify ICAO of any local corrective actions issued.
   e) ICAO is responsible for ensuring regular review of all WVE reports and local corrective actions and for disseminating any corrective actions that may be identified by that review.

   The overall objective of this safety requirement is to ensure that any unsafe incidents are identified before an accident occurs so that corrective action is applied internationally to prevent the cause(s) of the incident from re-occurring. It is essential that this requirement should be implemented without delay.

   This requirement has been implemented by ICAO and any WVE reports received will be reviewed.

2. Responsible parties must assess if the separation criteria recommended in this report are consistent with their local airspace design and ATM procedures. If they are not consistent then the responsible party must perform an appropriate safety assessment.

7.2 Approach Safety Requirements

3. The minimum required radar separations for approach for the A388 are specified in Table 7.1 together with the current ICAO PANS-ATM radar separations for existing aircraft categories (shaded).

Table 7.1 Radar Wake Turbulence Separation Criteria for Approach (Nautical Miles (NM), current ICAO criteria are shown shaded)

	A388 Encounterer	Heavy Encounterer	Medium Encounterer	Light Encounterer
A388 Generator	Not required [a b c]	6NM	7NM	8NM
Heavy Generator	Not required [b c]	4NM	5NM	6NM
Medium Generator	Not required [c]	Not required	Not required	5NM
Light Generator	Not required [c]	Not required	Not required	Not required

Notes:

a Not required = when a wake turbulence restriction is not required then separation reverts to Minimum Radar Separation as prescribed by the appropriate Air Traffic Services authority.

b Wake turbulence separation minima are not required by this safety case. However 4NM has been specified by ICAO ["Wake turbulence aspects of Airbus A380-800 aircraft", ICAO 2006b] pending possible amendment to the PANS-ATM.

c When the A388 is the encounterer the requirement is stated as "Not required". WVE risk has been evaluated down to a minimum distance of 2.0NM and it has been determined that an additional WV separation is not required down to this minimum distance.

The justification of these safety requirements is provided in this safety case. The detailed technical work that forms the basis of this safety case is documented in the safety assessment report ["A380 Wake Vortex Safety Assessment Report", A380 SG, 2008a].

7.3 Cruise Safety Requirements

4. The work that supports this safety case ["A380 Wake Vortex Safety Assessment Report", A380 SG, 2008a] has shown that the WVE risk that results from an A388 generator aircraft in cruise is not noticeably different from those WVE risk levels that result from reference aircraft. Therefore, the currently specified vertical or horizontal separation criteria, as prescribed by the ICAO *Procedures for Air Navigation Services — Air Traffic Management* [PANS-ATM, Doc 4444; ICAO, 2005b], are applicable to the A388.

   Furthermore the work that supports this safety case ["A380 Wake Vortex Safety Assessment Report", A380 SG, 2008a] has shown that the current PANS-ATM vertical separations currently applied to all aircraft can also be applied in relation to the A388 generator aircraft in all phases of flight without modification. This is based on measurements of the A388 performed at cruise speeds (Mach 0.85) and at typical holding/ terminal control area speeds (250knots).

7.4 Departure Safety Requirements

ICAO PANS-ATM [ICAO, 2005b] specifies minimum WVE departure separations in terms of time-based and radar separations. The time-based separations are applied on and near the runway(s) in conjunction with take-off and approach as per PANS-ATM 5.8. The radar separations are applied to aircraft in the approach and departure phases of flight as per PANS-ATM 8.7.4.4.

5. The required minimum time-based separations for departure for the A388 are specified in Table 7.2 together with the current ICAO time-based separations for existing aircraft categories (shaded).

Table 7.2 Time-Based WVE Separation Criteria for Departure (seconds, current ICAO criteria are shown shaded)

	A388 Encounterer	Heavy Encounterer	Medium Encounterer	Light Encounterer
A388 Generator	Not required	120s	180s	180s
Heavy Generator	Not required	Not required	120s	120s
Medium Generator	Not required	Not required	Not required	120s
Light Generator	Not required	Not required	Not required	Not required

6. The required minimum radar separations for departure for the A388 are specified in Table 7.3 together with the current ICAO radar separations for existing aircraft categories (shaded). Consistent with radar separations specified by ICAO today, Table 7.3 is identical to Table 7.1.

Table 7.3 Radar WVE Separation Criteria for Departure (Nautical Miles (NM), current ICAO criteria are shown shaded)

	A388 Encounterer	Heavy Encounterer	Medium Encounterer	Light Encounterer
A388 Generator	Not required [a b c]	6NM	7NM	8NM
Heavy Generator	Not required [b c]	4NM	5NM	6NM
Medium Generator	Not required [c]	Not required	Not required	5NM
Light Generator	Not required [c]	Not required	Not required	Not required

Notes:

a Not required = when a wake turbulence restriction is not required then separation reverts to Minimum Radar Separation as prescribed by the appropriate Air Traffic Services authority.

b Wake turbulence separation minima are not required by this safety case. However 4NM has been specified by ICAO ["Wake turbulence aspects of Airbus A380-800 aircraft", ICAO 2006b] pending possible amendment to the PANS-ATM..

c When the A388 is the encounterer the requirement is stated as "Not required". WVE risk has been evaluated down to a minimum separation of 2.0NM and it has been determined that an additional separation is not required.

SECTION 8
- KEY ASSUMPTIONS AND SAFETY RECOMMENDATIONS

8.1 Key Assumptions, Exceptions and Open Items

8.1.1 Key Assumptions

Assumption 1: Current wake vortex criteria are acceptably safe

Current wake vortex and other separation criteria have been applied for many years. The very small WVE-related accident and incident rates have been used to infer that current separation criteria are acceptably safe.

Assumption 2: This Safety Case only considers fault-free operations

Safety assessments can consider both fault-free operations (are the risks acceptable if the system is operated as intended) and faulted operations (are the risks acceptable if the system is not operated as intended). It is noted that this safety case only considers fault-free operations. Clearly if separation criteria imposed in practice are less than those required, then risks will increase and, at some unknown point, will become unacceptable. Responsible parties should ensure that faulted-operations occur at an acceptably low frequency to maintain adequate safety levels.

Assumption 3: ATM safety strategy and scope of this safety case

The strategy for ensuring ATM safety is based on 3 high-level principles:

- Ensuring that airspace design is acceptably safe.
- Ensuring that ATM procedures are acceptably safe.
- Ensuring separation criteria, such as the separation criteria specified in this safety case to ensure WVE risk is acceptable, are acceptably safe.

This safety case only modifies a sub-set of the third principle above.

This has four main consequences:

- If the current ICAO WVE separation criteria can be applied in a location without modification then the separation criteria for the A388 specified in this safety case can also be applied without modification. This is a logical extension of the relative safety argument.
- Conversely, if the current ICAO WVE separation criteria require modification in a location, then the separation criteria for the A388 specified in this safety case may also need modification. The assessment of the appropriate modification must be performed by the responsible party.
- Responsible parties must assess if the separation criteria recommended in this report are consistent with their local airspace design and ATM procedures. If they are not consistent then the responsible party must perform an appropriate safety assessment.
- Responsible parties may amend any or all of the 3 high-level principles to best meet their operational objectives. However if a responsible party does not apply the WVE separation criteria specified in this safety case then they must provide the safety assessment evidence to show that their operations, including the separations criteria they apply, are acceptably safe.

This assumption supports the global applicability of the safety requirements derived in this safety case.

Assumption 4: Characteristics of the reference operation

In order to apply the relative safety assessment methodology used in this safety case to derive wake vortex separation criteria for the A388, it has been helpful to make some working assumptions regarding how today's criteria could have been derived on the basis of the data now available. These assumptions, which are associated with the reference operation, are defined below:

- The WV generator for a mass category should be the heaviest aircraft operating at the reference date at its maximum certified mass for each phase of flight. This is a conservative assumption because lighter generators will generate weaker WVs.
- The WV encounterer for a mass category should be the most susceptible aircraft to WVE consequence in the mass category. Susceptibility depends on the encountering aircraft's characteristics (such as mass, moment of inertia, control characteristics, etc.).
- The atmospheric conditions are assumed to be "reasonable low turbulence" conditions. This is a conservative assumption because WVs decay more slowly under low-turbulence conditions; it is not an "absolute worst case", since lower turbulence conditions may occur, but is conservative relative to higher turbulence conditions that may apply for the majority of the time.

Thus these 3 assumptions for the reference operation are conservative for each of the 3 main factors that determine WVE risk.

Assumption 5: Typical speeds used for converting distance and time

The safety assessment methodology summarised in Figure 2.2 involves establishing a relationship between distance and time. This is performed via the aircraft speed. The typical speeds used were 155knots for Heavy, 135knots for Medium and 125knots for Light aircraft.

8.1.2 Exceptions and Open Items

Parallel Runways on Approach and Departure

A limited amount of A388 data relevant to parallel runway operations was acquired during this work. This limited data indicates that parallel runways separated by 760m or more can be utilised independent of wake vortex considerations. For runways separated by less than 760m, the single runway separation criteria specified herein for the A388 apply.

Other Multiple Runway Configurations

This situation has not been explicitly considered by this safety case. As stated under Argument 1.2.2, responsible parties are required to consider the contents of this safety case (if any) on their operational procedures for multiple runway configurations.

8.2 General Safety Recommendations

The above safety requirements specify what is necessary and sufficient to achieve an acceptable level of WVE risk.

However, during the performance of this work, a number of items of best practice to further reduce WVE risk have also been noted. These are recorded in this safety case as general safety recommendations, since no A388-specific safety recommendations were identified.

An important general recommendation is that the performance of this work has identified some opportunities to improve operations as conducted today. It is strongly recommended that the technical evaluation of WVE risk, begun in this safety case, is continued in order to:

- Develop a scientifically transparent and logically rigorous set of WVE risk acceptance criteria for all aircraft.
- Further review the current (WVE) separation criteria as applied today and to correct any anomalies identified.
- More straightforwardly introduce new aircraft into the commercial fleet.

In particular, there is general agreement within the A380 Wake Vortex Steering Group that the current ICAO Medium wake turbulence category is too broad to provide a good balance between safety and capacity.

General Safety Recommendations

1. Educational material that describes general WV behaviours should be updated and distributed by ICAO. This should reflect the current understanding of wake vortex behaviour and should include reference to issues such as: WV descent distance; variable approach speeds; and visual approaches.

Cruise Safety Recommendations

The distances, descents and times stated below in recommendation 2 are all approximate.

2. Measurements of WV descent indicate that during the cruise WVs from B744, A346 and A388 aircraft may descend more than 1000 feet; other Heavy aircraft are expected to have similar WV characteristics. WVE frequency is probably highest, but still low in absolute terms, for aircraft flying counter-flow parallel tracks vertically separated by 1000 feet, compared to all other encounter geometries. At cruise speeds measurements indicate that the vortex trajectory crosses the flight level 1000 feet below the generator aircraft at about 10 to 20NM behind the generator aircraft in calm atmospheric conditions. Lighter aircraft should be aware of possible encounters for up to about 20NM behind (horizontal longitudinal) and 1000 feet below a Heavy or A388 generator aircraft, especially when the aircraft are flying close to parallel tracks (see also Recommendation 3). Based on current separation criteria, WVE risk is considered to be acceptable at this time; however it is recommended that this issue be investigated further.

   The results from the worldwide WVE reporting system described in Section 6 will be used to help identify any further actions required to address this recommendation.

Cruise, Climb and Descent Safety Recommendations

3. There are some WVE incident reports that indicate that current operational aircraft can generate moderate to severe WVEs for an encountering aircraft during climb or descent. Such encounters have *very low probabilities*, but controllers and pilots should be aware that *if* they occur then the encountering aircraft may experience significant accelerations. These reports are consistent with the limited cruise flight test measurements involving A388, B744 and A346 generator aircraft, and with the intentional encounters that were flown with an A318.

   Though this is not an A388 specific issue, and it is beyond the scope of this group, the Work Group *strongly recommends* review, as a matter of urgency, of spacing for non-

Heavy encounterers that climb or descend behind all Heavy aircraft generators (including the A388).

The results from the worldwide WVE reporting system described in Section 6 will be used to help identify any further actions required to address this recommendation.

SECTION 9 - REFERENCES, ACRONYMS AND ABBREVIATIONS

9.1 References

A380 SG, 2006a	A380 Wake Vortex Safety Assessment Report, A380 Wake Vortex Safety Assessment Steering Group, expected 31 December 2006.
A380 SG, 2006b	Safety Case for Wake Vortex Encounter Risk due to the Airbus A380-800, 16 November 2006.
A380 SG, 2008a	A380 Wake Vortex Safety Assessment Report, A380 Wake Vortex Safety Assessment Steering Group, expected 31 December 2008.
A380 SG, 2008b	Safety Case for Wake Vortex Encounter Risk due to the Airbus A380-800, expected 20 June 2008 (this document).
Burnham and Hallock, 1992a	Chicago Monostatic Acoustic Vortex Sensing System: Vol. IV: Wake Vortex Decay, D. Burnham and J. Hallock, Report FAA-RD-79-103.IV, July 1982.
EUROCONTROL, 2005a:	Safety Case Development Manual, Edition 2.0, 28 Sep 2005.
ICAO, 2005a	Wake Vortex aspects of Airbus A380 aircraft, ICAO Interim Guidance, 10 November 2005, T13/3-05-0661.SLG, issued from all ICAO Regional Offices.
ICAO, 2005b	Procedures for Air Navigation Services - Air Traffic Management (PANS-ATM), Doc 4444 ATM/501, Fourteenth Edition - 2001, applicable as per 24 November 2005 (Amendment No. 4).
ICAO, 2006a	Safety Management Manual (SMM) – Doc 9859 AN/460, First Edition 2006.
ICAO, 2006b	Wake turbulence aspects of Airbus A380-800 aircraft, revised ICAO interim guidance, 9 October 2006, ES AN 4/44 – 0750, issued from all ICAO Regional Offices.

9.2 Acronyms and Abbreviations

A318	Airbus A318
A346	Airbus A340-600
A388	Airbus A380-800
ANC	Air Navigation Commission (ICAO)
ANSP	Air Navigation Service Provider
ATCO	Air Traffic Controller
ATM	Air Traffic Management
ATS	Air Traffic Services
ATSP	Air Traffic Service Provider
B744	Boeing 747-400
B773	Boeing 777-300ER
DNV	Det Norske Veritas
EASA	European Aviation Safety Agency

ECAC	European Civil Aviation Conference
ECTL	EUROCONTROL
ESARR	EUROCONTROL Safety Regulatory Requirement
FAA	Federal Aviation Administration
FL	Flight Level
GSN	Goal Structuring Notation
HAZID	Hazard Identification
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IGE	In Ground Effect
ISI	Innovative Solutions International Inc.
JAA	Joint Aviation Authorities
LIDAR	Light Detection and Ranging
MRS	Minimum Radar Separation
MLM	Maximum Landing Mass (sometimes called Maximum Landing Weight (MLW))
MTOM	Maximum Take Off Mass (sometimes called Maximum Take-Off Weight (MTOW))
NASA	National Aeronautics and Space Administration
NWRA	NorthWest Research Associates
OGE	Out of Ground Effect
PANS-ATM	Procedures for Air Navigation Services - Air Traffic Management. See reference [ICAO, 2005b]
NM	Nautical Mile
RVSM	Reduced Vertical Separation Minimum
SG	Steering Group
TMA	Terminal Control Area (sometimes called terminal manoeuvring area)
VFR	Visual Flight Rules
WG	Work Group
WV	Wake Vortex
WVE	Wake Vortex Encounter

Appendix A

Safety Argument represented using Goal Structuring Notation

The full safety argument in GSN format is presented in this appendix.

Figure 0 Overall Relative Argument Structure

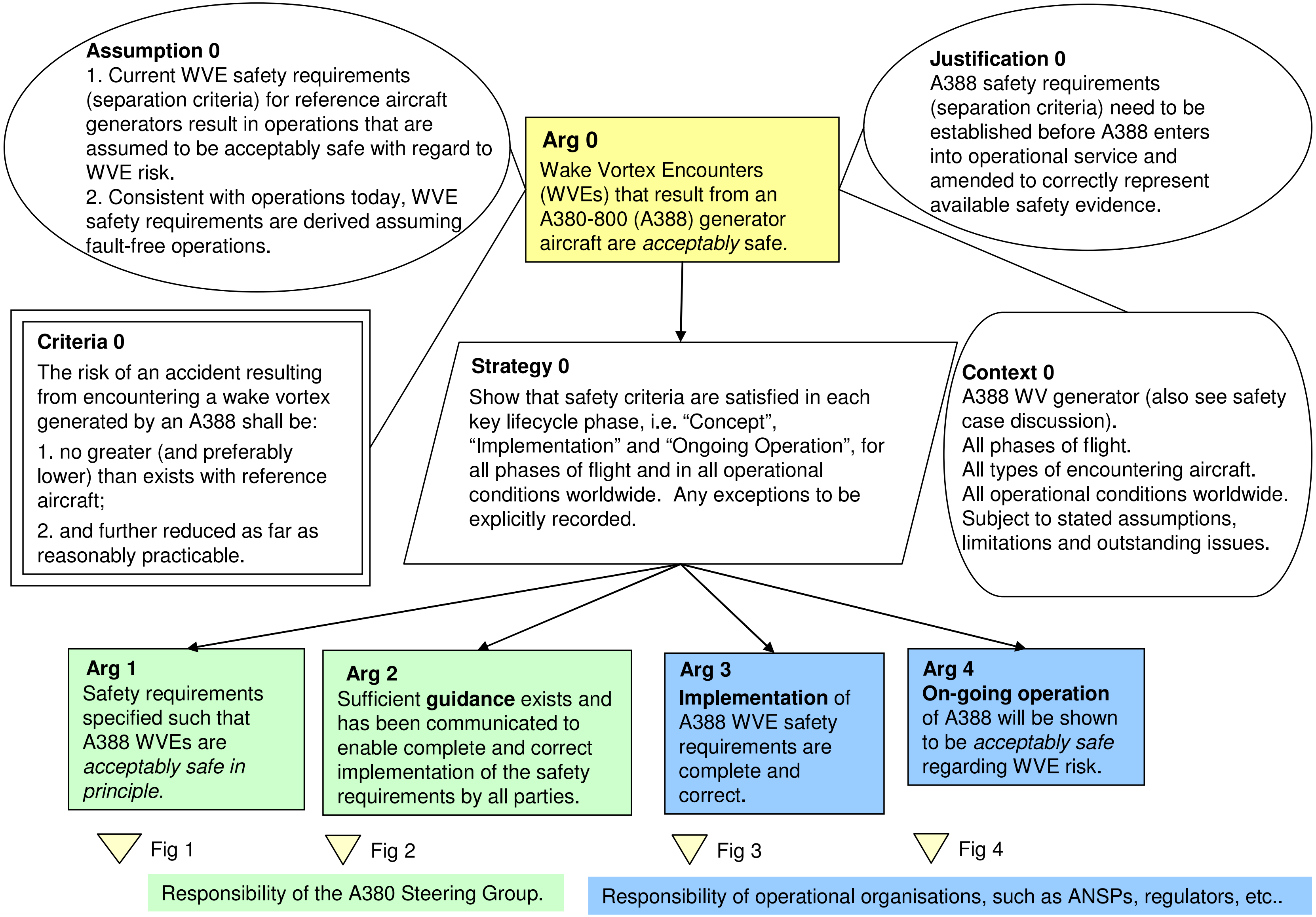


Figure 1 Concept - Overall

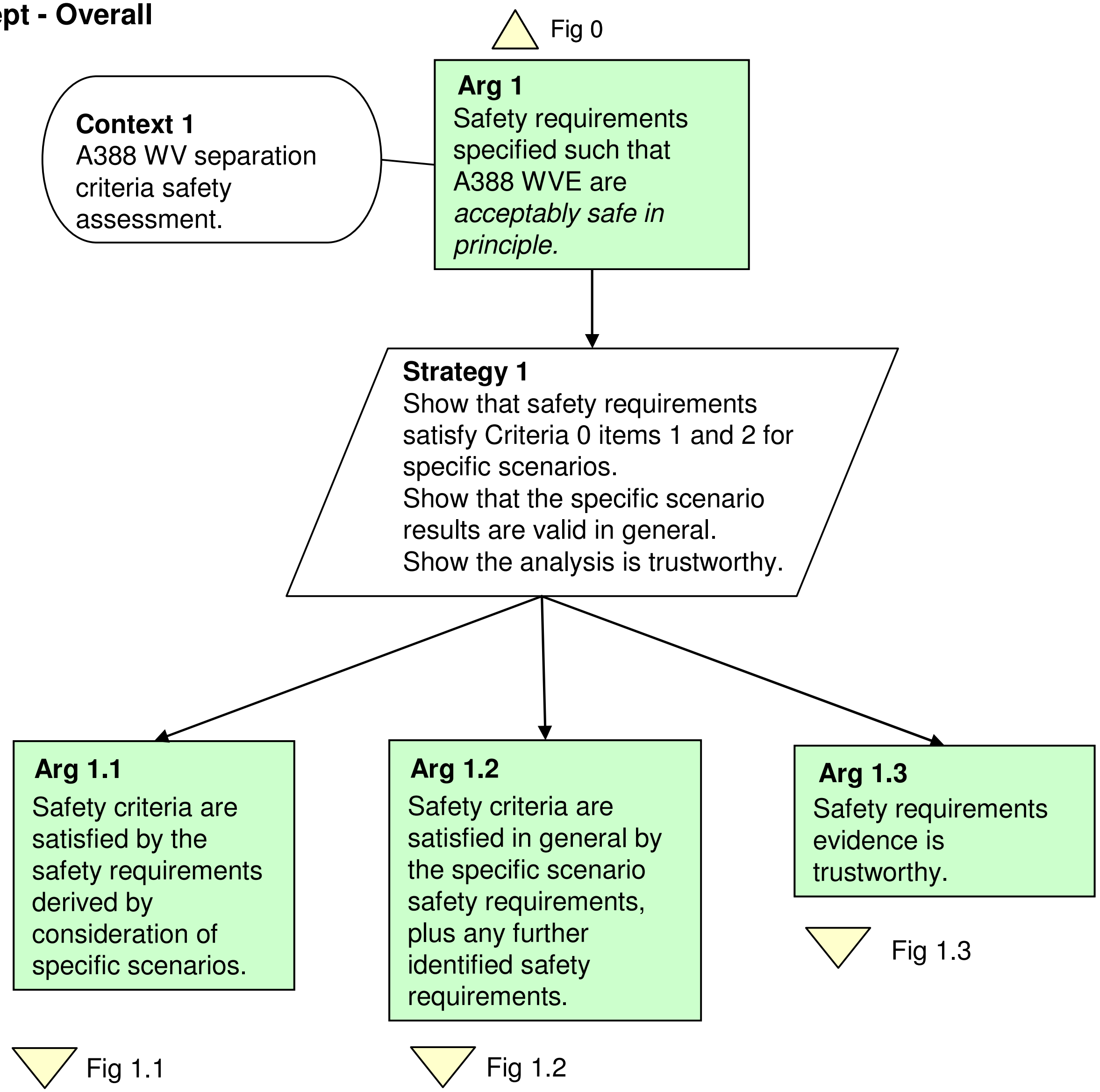


Figure 1.1 Safety Requirements Satisfaction

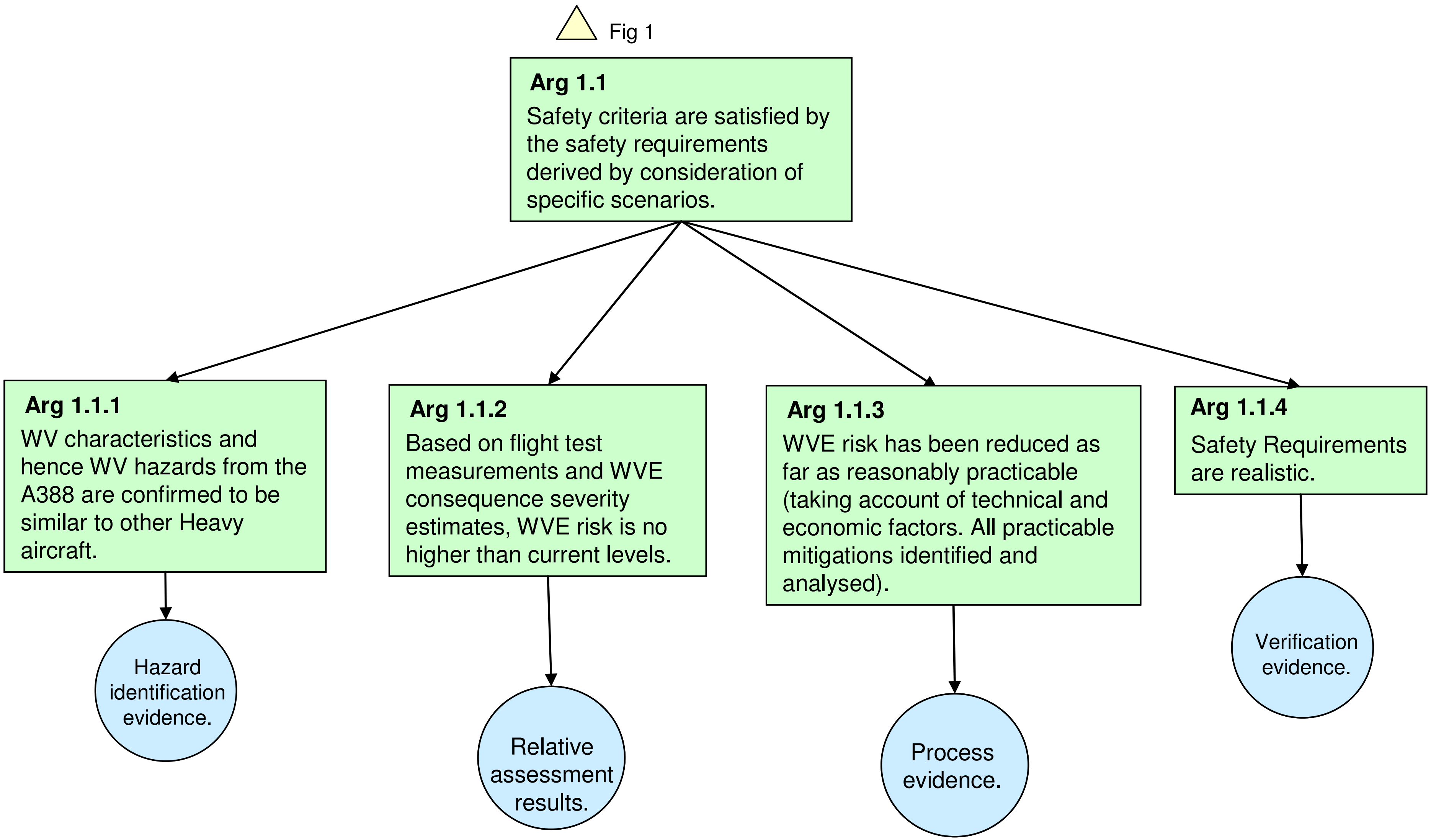


Figure 1.2 Approach to Generalisation

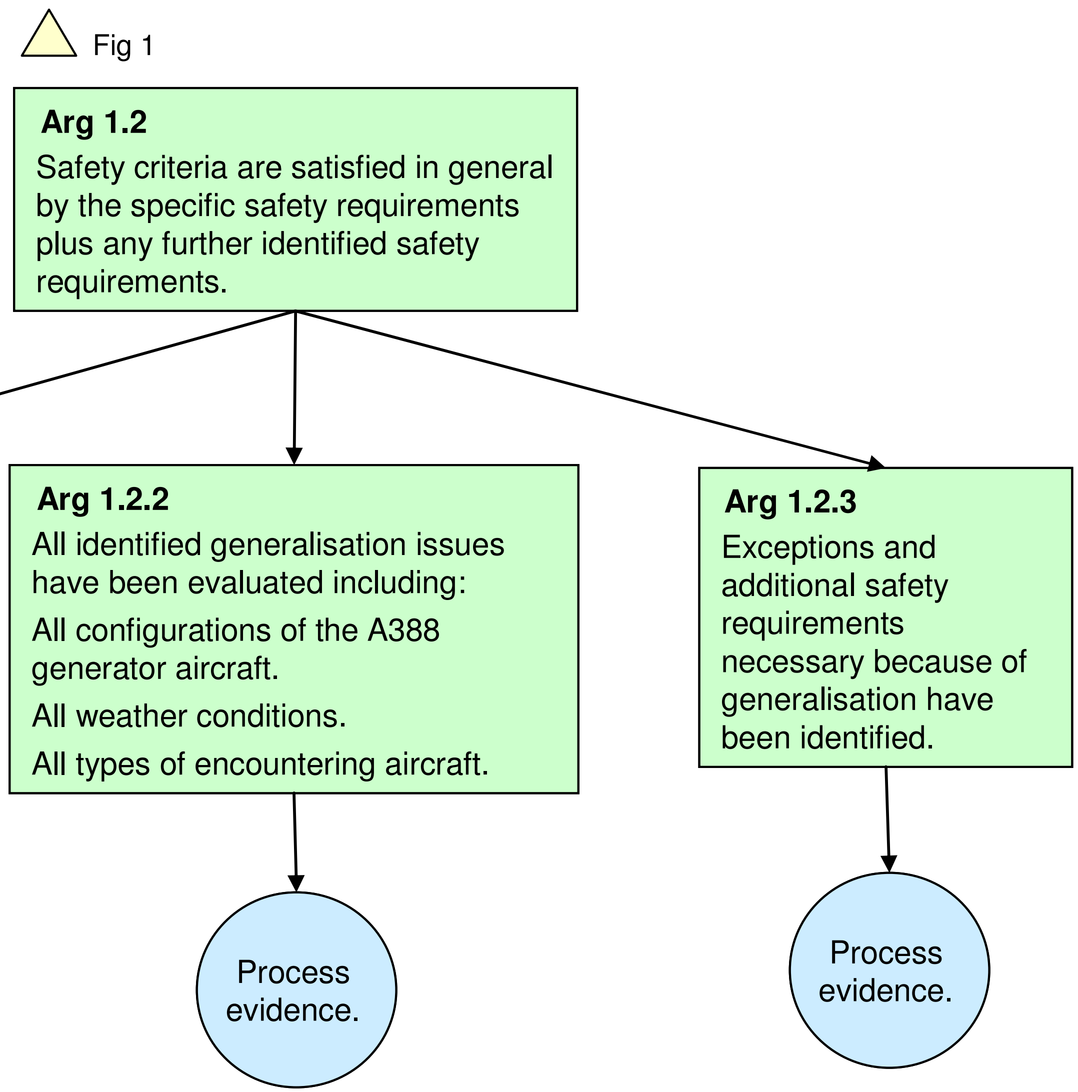


Figure 1.3 Backing

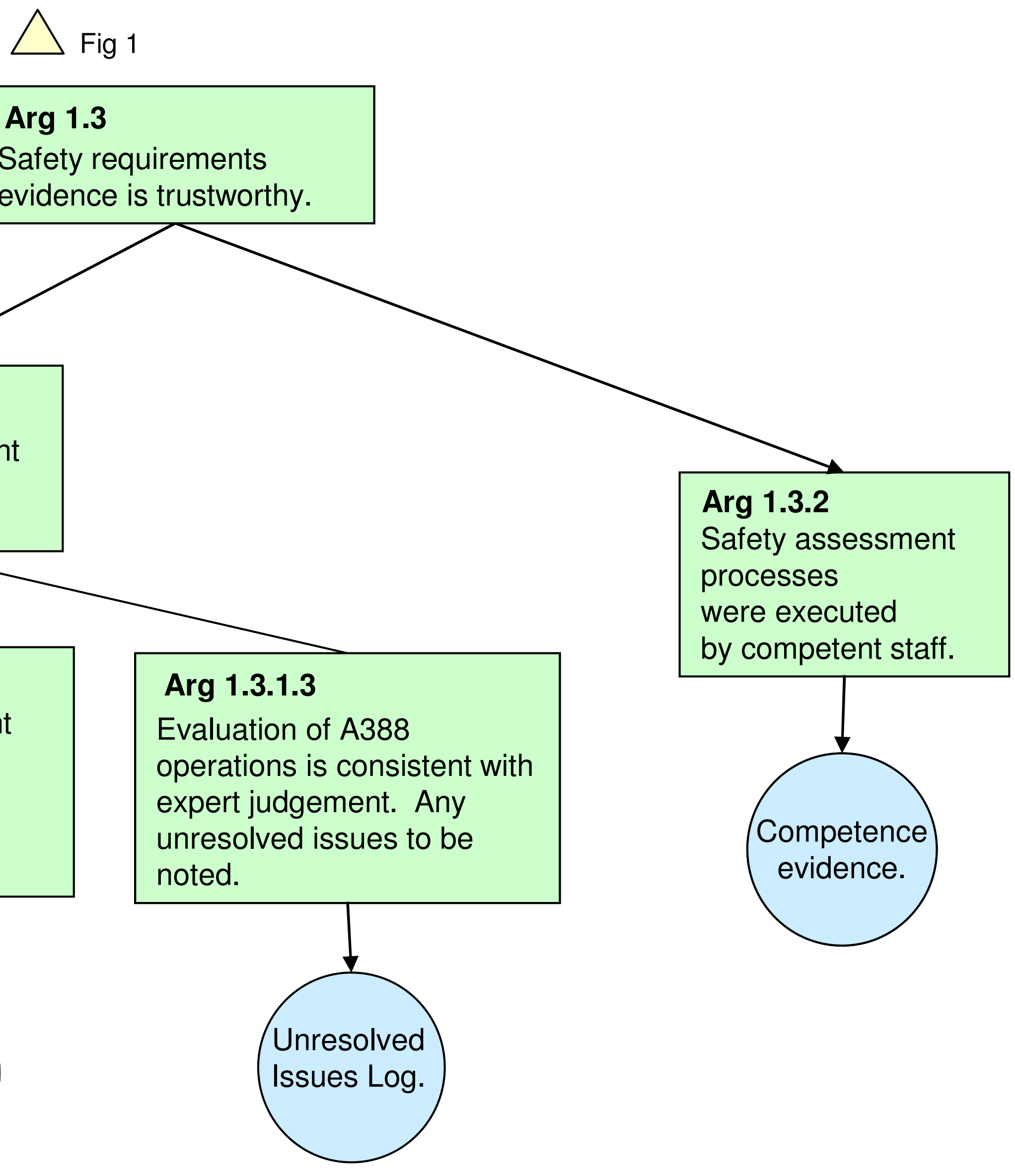


Figure 2 Guidance

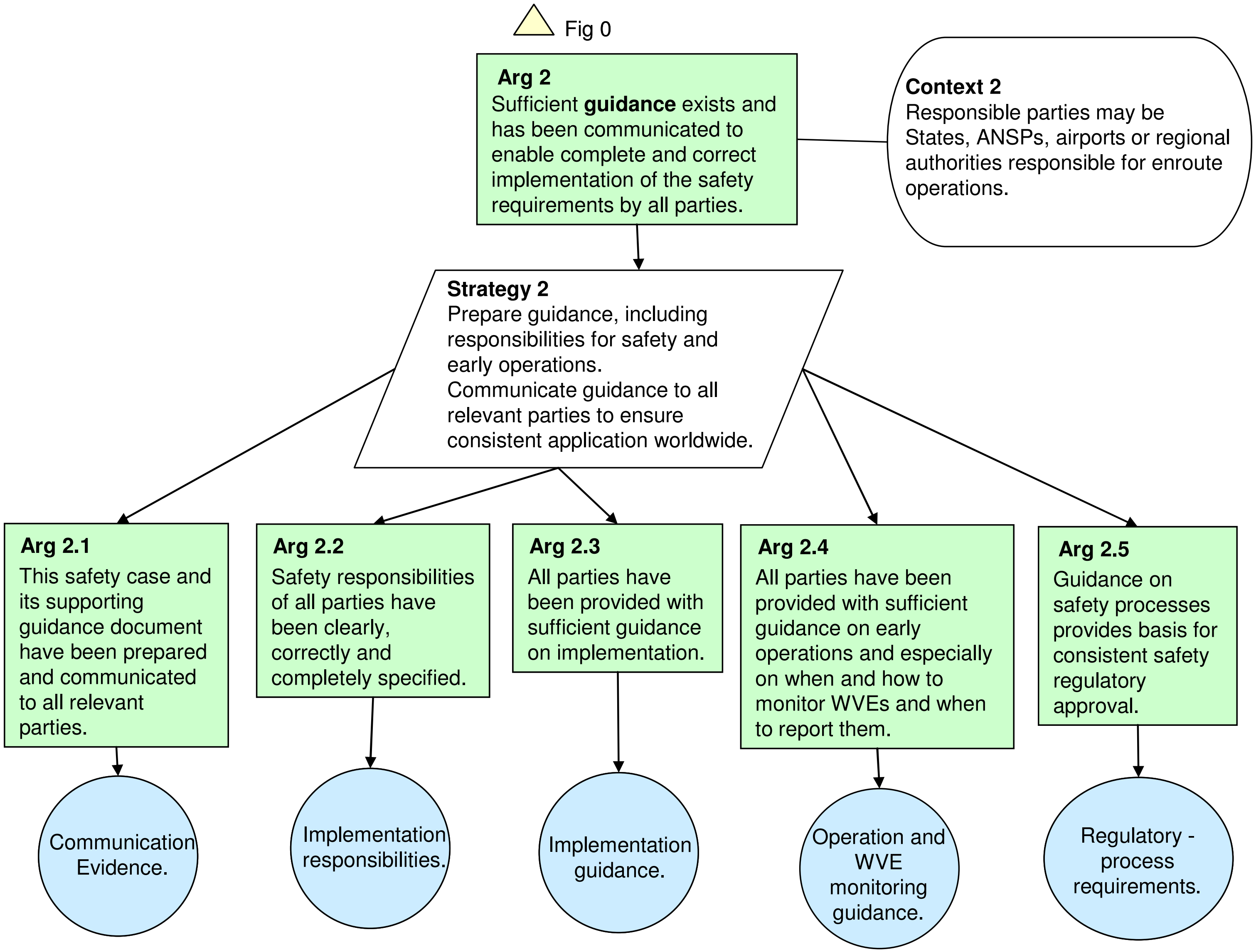


Figure 3 Implementation

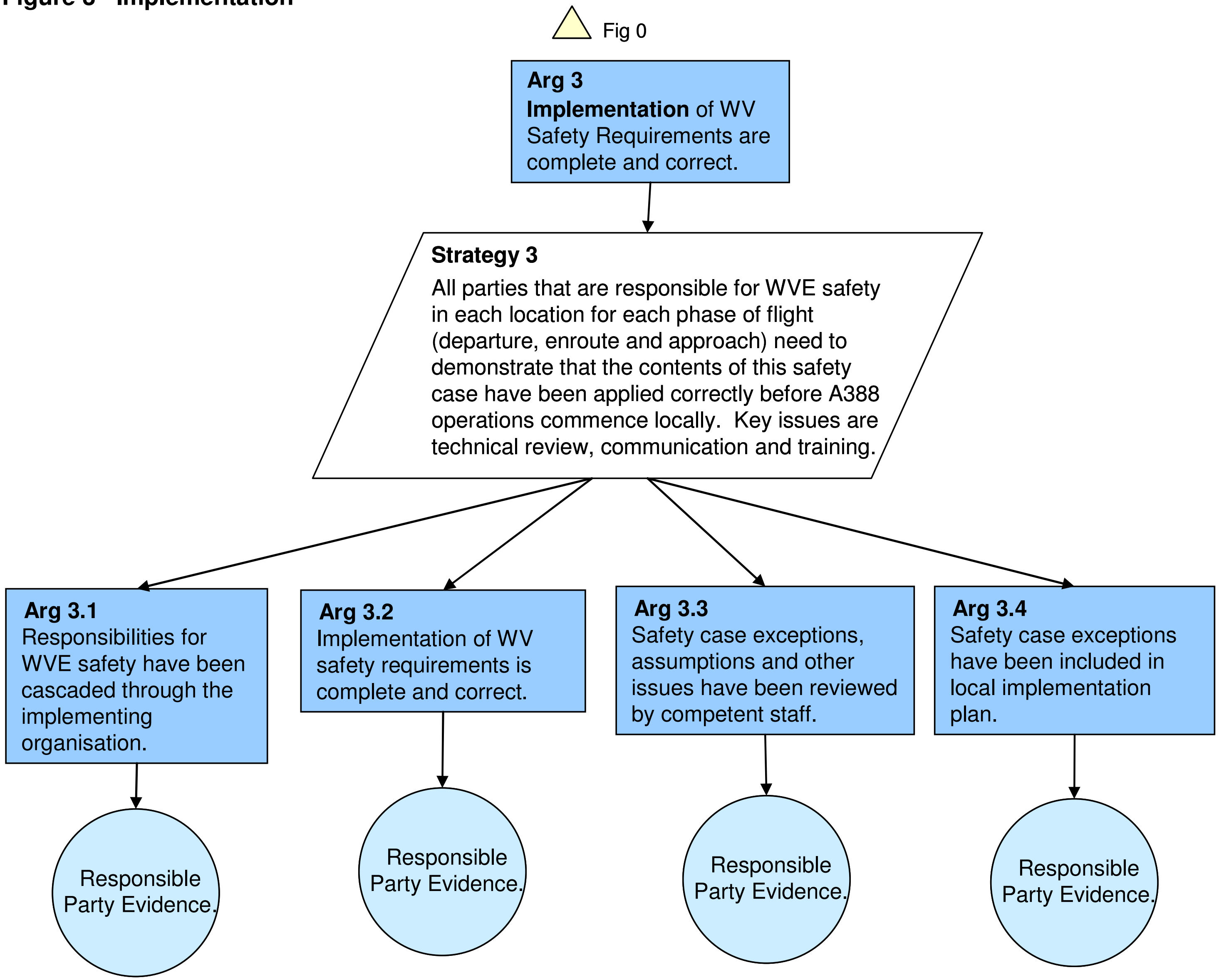
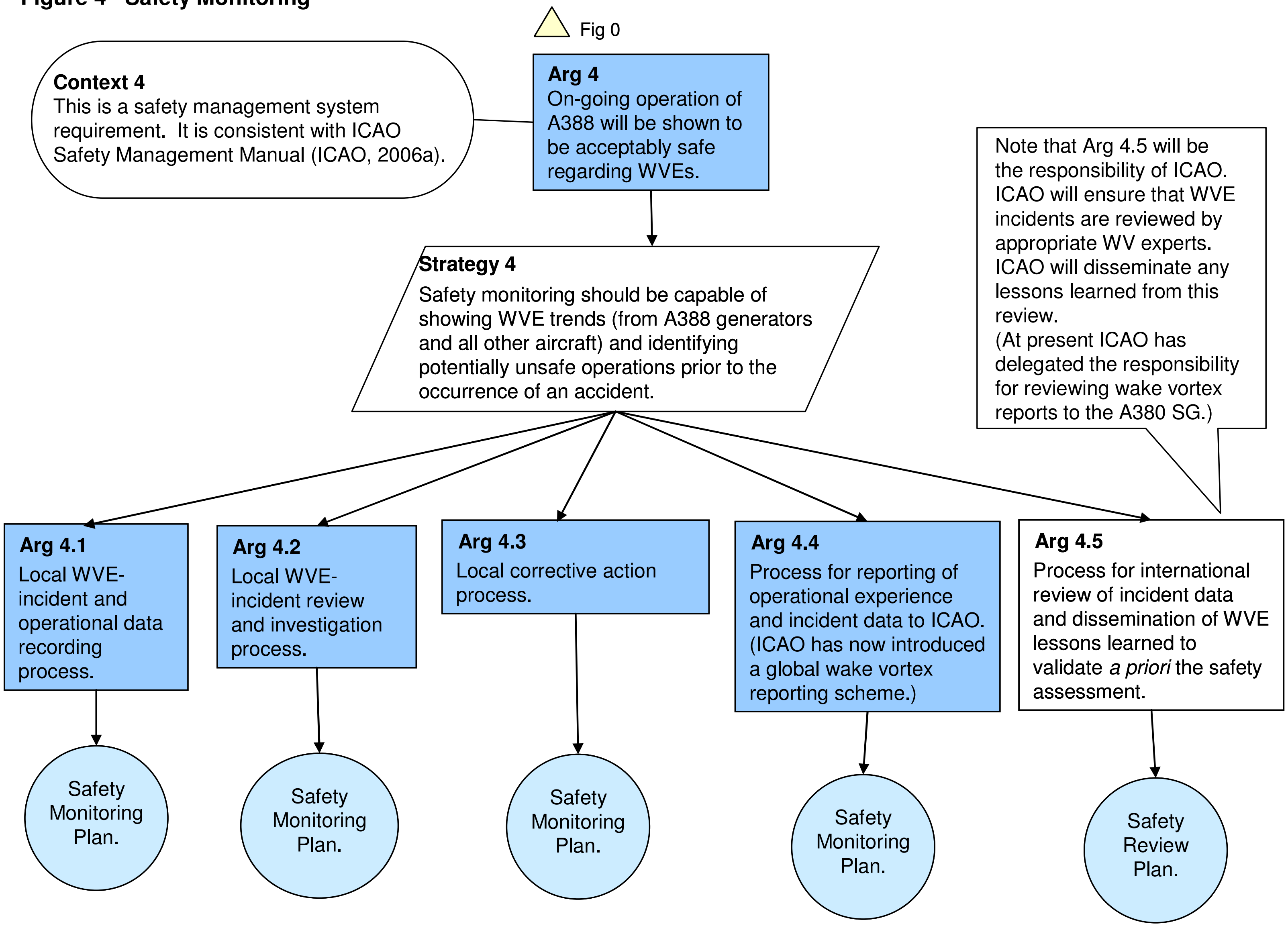


Figure 4 Safety Monitoring



Appendix B

Safety Case Guidance

B.1 INTRODUCTION

This appendix contains additional guidance to support organizations that need to take account of the Airbus A388 wake vortex safety case.

It is anticipated that this safety case, and this guidance document, will be used mainly by the following types of organizations (these organizations are the “responsible parties”):

- Air Navigation Service Providers (ANSP) that may be responsible for approach, departure, TMA and cruise operations;
- National aviation regulators;
- Regional authorities that may be responsible for upper airspace cruise operations (e.g. EUROCONTROL);
- Regional and international regulators.

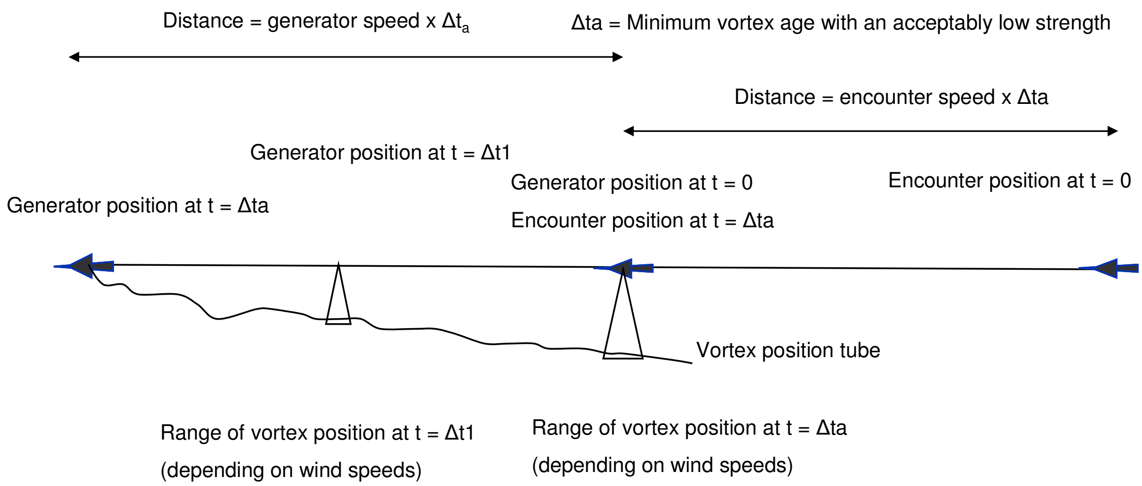
This guidance has been prepared to support the implementation of the safety requirements specified in the safety case by the above responsible parties.

B.2 DESCRIPTION OF WV CHARACTERISTICS

The safety requirements presented in this safety case are derived from detailed observations and calculations of wake vortex transport and decay behaviour. This section aims to present mostly non-scientific generalisations of wake vortex transport and decay characteristics, that apply to all Heavy aircraft including the A388 and other heavy aircraft not yet in-service. This may assist controllers and pilots to minimise their exposure to WVE risk.

When vortex transport and decay characteristics are not influenced by the ground (Out of Ground Effect (OGE)) then its generic behaviour is shown in Figure B.1.

Figure B.1 Schematic Illustration of Vortex Transport and Decay



> It should be noted that if the generator aircraft is climbing or descending significantly (e.g. at greater than about 1000 feet per minute) then strong WVs (WVs that have decayed for less than about 2 minutes) can exist on more than 1 flight level, and above the generator aircraft for descending generators. See also general safety recommendation 5 in Section 8.2.

As shown in Figure B.1, a notional vortex pair is generated at time equals zero. The vortex pair then sinks to lower heights because of its downwards momentum (to generate lift the aircraft exerts a downwards force on the atmosphere) and is transported laterally and vertically due to atmospheric conditions (lateral and vertical winds). When all vortices are considered, then a “vortex position tube” is generated as shown in Figure B.1.

Wake vortex pairs decay with time. In general, decay rates are increased by increased atmospheric turbulence. Both lateral and vertical wind speeds will increase vortex decay rates compared to stable air conditions.

When vortex transport and decay characteristics are influenced by the ground (usually on approach) then the vortex is said to be In Ground Effect (IGE). When a vortex is IGE the sink rate may be reduced or, in some circumstances, may be reversed leading to the vortex “stalled” in the final approach path of the generator or even rising above the final approach path of the generator. WVs that are IGE generally decay faster than those that are OGE.

The most critical parameter which determines the maximum potential severity of a WVE is the age of the WV at encounter. Any wake vortex from heavy aircraft (Heavy aircraft at the reference date and all heavy aircraft that may enter service after the reference date) that is less than about 60 to 120 seconds old may result in a very severe wake encounter if the encounter is “just wrong” (it is a low probability event to encounter a vortex in such a way as to cause the maximum impact that the vortex could deliver to the encountering aircraft). In cruise airspace 60 seconds corresponds to over 8NM.

The WVE risk can be minimised by minimising the frequency of encounters by:

- Defining separation criteria such that encountering aircraft cannot encounter WVs younger than (stronger than) an acceptable limit.
- Managing the relative position of the WV generator and encounterer such that a WVE is unlikely to occur.

In this safety case the safety requirements are derived by consideration of the first bullet.

B.3 GUIDANCE ON SAFETY ARGUMENTS 1 TO 4

B.3.1 Guidance on Safety Argument 1

The parties responsible for implementing the safety requirements of this safety case are not mainly responsible for providing the evidence to support Argument 1. Nevertheless the relative safety assessment approach should be reviewed to ensure it is relevant to the specific operations under consideration. In particular, the assumptions, exceptions and open issues should be considered to determine if there might be location specific factors that might invalidate the safety requirements deduced by the safety case. Alternatively local circumstances might indicate the need for additional safety requirements.

B.3.2 Guidance on Safety Argument 2

The parties responsible for implementing the safety requirements of this safety case are not mainly responsible for providing the evidence to support Argument 2. Nevertheless the guidance (this appendix) should be reviewed and the following issues should be addressed:

- The safety case and this supporting guidance must be communicated to all relevant parties to support Argument 2.1.
- Responsibilities for safety must be assigned and accepted by named individuals or functions clearly, correctly and completely, to support Argument 2.2.

- Local implementation plans should be developed and communicated to all responsible parties to support Argument 2.3.
- All responsible parties should be informed of the importance of WVE reporting, especially during early operations, to support Argument 2.4.

B.3.3 Guidance on Safety Argument 3

Responsible parties are responsible for:

- The complete and correct implementation of the safety case safety requirements to support Argument 3.1.
- Review of the exceptions, assumptions and other issues to ensure that these do not modify the safety requirements necessary to ensure A388 operations are acceptably safe to support Argument 3.2.
- The drafting, dissemination and implementation of a local implementation plan to support Argument 3.3.

B.3.4 Guidance on Safety Argument 4

An important safety requirement specified in this safety case is the need for on-going WVE safety monitoring of A388 *and all other aircraft generators*, for all phases of flight and for all encountering aircraft. This requirement is consistent with ICAO [ICAO, 2006a]. WVE safety monitoring is required for the A388 *and* for other aircraft in order to provide a reference against which the A388 reports can be assessed. All phases of flight should be monitored because the flight tests performed as part of this safety assessment have shown that WVs from reference aircraft and from the A388 in the cruise and in hold can descend more than 1000 feet.

WVE monitoring could be performed in any of 4 ways, or by a combination of 1 or more of these 4 ways:

- By pilots reporting incidents (for example, "I encountered an unexpected roll of x degrees at this location. I judged its severity to be non-serious/ serious/ dangerous").
- By interrogating aircraft flight data recorders to identify possible wake encounters.
- Correlation of pilot reports and/ or flight data recorder-derived encounters to ATC radar tracks.
- Any other technique that provides as much of the following data as possible:
    - The ATC situation to enable the identification of the generator aircraft type, its position, speed and track.
    - The type of the encountering aircraft, its position, speed and track.
    - An assessment of the severity of the WVE (e.g. pilot subjective assessment or flight recorder data).
    - Other supporting information if available.

The data that is reported should be sufficient to determine: the severity of the incident; the position (and hence the type) of the likely WV generator aircraft; the incident rate (e.g. number of incidents per approach); and the possible cause(s) of the incident (e.g. were the separation criteria specified in this safety case applied correctly or not).

Existing examples of WVE incident reporting forms can be found at the worldwide web address: http://asrs.arc.nasa.gov/main_nf.htm. WVEs that occur during the cruise or in the hold may also be reported using the RVSM monitoring system, such as that in use in ECAC airspace today.

In order to fully understand WVE monitoring reports it is necessary to also record exposure data, such as estimates of the number of approaches or departures made or the number of cruise flight hours that correspond to an incident period. This type of information supports the generation of more meaningful parameters such as WVE incident rates.

The WVE reporting system requires the reporting of all significant WVE incidents by pilots to the responsible party. The existence of such reports is the evidence that supports Argument 4.1.

Responsible parties are required to review WVE incident reports and to investigate incidents they classify as serious (or dangerous) promptly. The existence of periodic reviews of incidents ("we had 30 non-serious incidents in the last 3 months compared to 45 similar incidents in the previous 3 month period") and promptly prepared serious incident reports are the evidence that supports Argument 4.2.

Incidents assessed as serious (or dangerous) by the responsible party may generate local corrective actions designed to further control WVE risk. These modified safety requirements are the evidence that supports Argument 4.3.

All serious WVE incidents and all corrective actions implemented locally should be reported to ICAO as soon as possible so that ICAO can disseminate this information internationally with the minimum of delay. This may prevent occurrence of similar serious WVEs in other States.

All local incident data (serious and non-serious) and exposure data should be reported to ICAO to allow regular review of all data at an international level. This may allow safety trends to be identified which might go un-detected at the local level. Local corrective actions should also be reported to ICAO. These reports are the evidence that supports Argument 4.4.

Review of aggregated WVE incident data and exposure data at the international level, and the dissemination of any necessary international corrective actions by ICAO is the evidence that supports Argument 4.5.

Ideally WVE monitoring based at least on pilot reporting schemes should function at all the high traffic density airports that will take the A388, for several months prior to the introduction of A388 operations, but definitely at the outset of A388 operations.

B.4 SUMMARY

This appendix provides guidance to assist responsible parties to apply professionally and consistently the safety requirements disseminated in the A388 WV safety case.