S.37

File With

SECTION 131 FORM

Appeal No

ABP— 314485-22

Defer Re O/H

Having considered the contents of the submission dated/received 14/12/2023 from Sabrina Joyce-Kemper on behalf of Wild Ireland Defence CLG I recommend that section 131 of the Planning and Development Act, 2000 be/not be invoked at this stage for the following reason(s): no new material issues (Inspector to advise).

Section 131 not to be invoked at this stage. ✓

Section 131 to be invoked — allow 2/4 weeks for reply. ☐

Signed: Pat B
EO

Date: 20/12/2023

Signed:
SEO/SAO

Date:

M

Please prepare BP — Section 131 notice enclosing a copy of the attached submission.

To:

Task No:

Allow 2/3/4 weeks: BP

Signed:
EO

Date:

Signed:
AA

Date:

An Bord Pleanála

Planning Appeal Online Observation

Online Reference
NPA-OBS-002986

Online Observation Details

Contact Name
sabrina Joyce-Kemper

Lodgement Date
14/12/2023 14:44:31

Case Number / Description
314485

Payment Details

Payment Method
Online Payment

Cardholder Name
sabrina Joyce

Payment Amount
€50.00

Processing Section

S.131 Consideration Required

☑ Yes — See attached 131 Form

☐ N/A — Invalid

Signed
[signature]
EO

Date
20/12/2023

Fee Refund Requisition

Please Arrange a Refund of Fee of
€

Lodgement No
LDG— 068877-23

Reason for Refund

Documents Returned to Observer
☐ Yes ☐ No

Request Emailed to Senior Executive Officer for Approval
☐ Yes ☐ No

Signed

EO

Date

Finance Section

Payment Reference
ch_3ONG9LB1CW0EN5FC1t4IG6fY

Checked Against Fee Income Online

EO/AA (Accounts Section)

Amount
€

Refund Date

Authorised By (1)

SEO (Finance)

Authorised By (2)

Chief Officer/Director of Corporate Affairs/SAO/Board Member

Date

Date

Planning Observation
ABP-314485
FCC F20A/0668
daa plc
Relevant Action

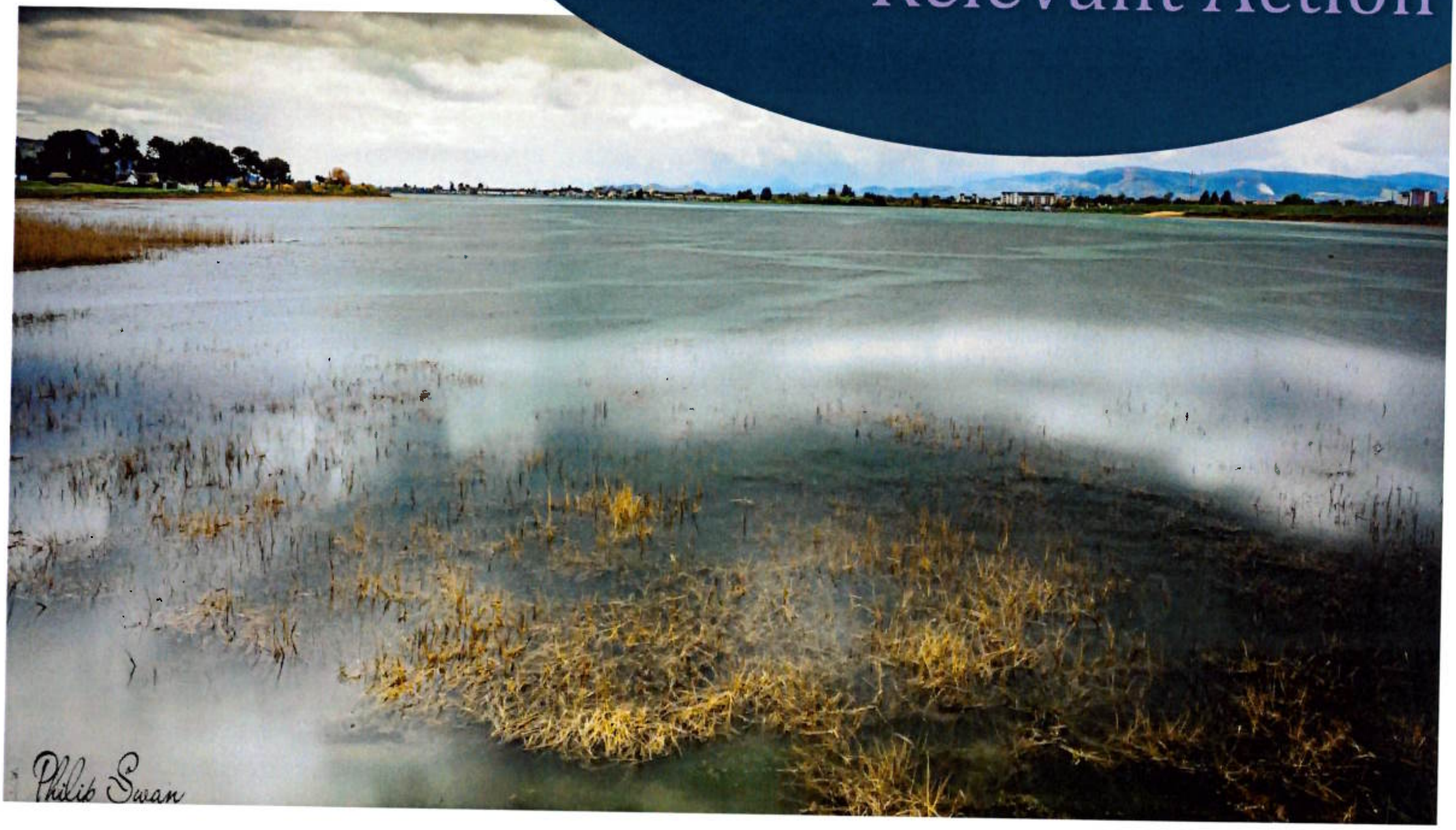

Photo: Baldoyle Bay SAC & SPA by Philip Swan

Submission by:
Sabrina Joyce-Kemper &
Sabrina Joyce-Kemper on behalf of Wild Irish Defence CLG
C/O 23 Portmarnock Crescent
Portmarnock
Co Dublin.

Date of submission: 14th December 2023

Submission

1. Introduction

1.1 Sabrina Joyce-Kemper as an individual and Sabrina Joyce-Kemper as a member of Wild Irish Defence CLG wish to make a submission on additional information in relation to ABP planning appeal 314485. Ms Joyce-Kemper has an advanced diploma in Planning and Environmental law from the Honorable Kings Inn. This submission is in objection to the planning application to amend the conditions imposed by the Bord with decision in case no 217429.

1.2 I provided an appendix to the submission provided by the St. Margaret's and the Ward residents group. I wish to adopt that part of the SMTW submission, but in order to avoid repetition and to facilitate the inspector and the Board with any references to that submission, I have attached the SMTW section as Appendix 1 of this submission. We also adopt all other submission without prejudice to whether they support our arguments or not.

1.3 Due to a number of planning applications and planning appeals live on Dublin airport developments, we have not had time to give this application a full rundown of the issues with this development. We believe we had identified a number of issues in relation to detail of the planning application and some deficiencies in the application report, documentation and Environmental assessments which, need to be updated in order to constitute a complete application (in accordance with the law), which is capable of being properly assessed by ABP. We have raised the procedural/ administration issues and deficiencies in the below submission which we believe should require the application to be deemed invalid and require a new application or without prejudice to that argument require substantial additional information.

1.4 We (SJK and WID) believe that in the first instance the initial F20A/0668 application and subsequent submissions of further information should never have been accepted by the Local Authority once it was pointed out that the lack of AA on the parent permission and extension permission meant that the application should be refused under section 34(12) pf the Planning and development act 2000 o present. ABP have not attempted to have a full AA on the parent permission carried out or included on this application which we believe to be contrary in law. The inspector and Board should refer this file to their internal legal team to risk assess this aspect of the appeal. We believe that the Board should refuse to grant permission and overturn the decision of FCC and ANCA to approve this amendment as it was incorrect in law from the outset. And the entirety of the Parent permission that the instant application seeks to amend constitutes unauthorised development. We refer the board to SJK prevoius detailed arguments to FCC and ANCA in this regard, which to date have remained unaddressed by FCC, ANCA or the applicant.

1.5 We object to the planning application which is described as follows;

The relevant action pursuant to Section 34C (1) (a) is:

- To amend condition no. 3(d) of the North Runway Planning Permission (Fingal County Council Reg. Ref. No. F04A/1755; ABP Ref. No.: PL06F.217429 as amended by Fingal County Council F19A/0023, ABP Ref. No. ABP-305289-19). Condition 3(d) and the exceptions at the end of Condition 3 state the following:

-3(d). Runway 10L-28R shall not be used for take-off or landing between 2300 hours and 0700 hours except in cases of safety, maintenance considerations, exceptional air traffic conditions, adverse weather, technical faults in air traffic control systems or declared emergencies at other airports.' Permission is being sought to amend the above condition so that it reads: 'Runway 10L-28R shall not be used for take-off or landing between 0000 hours and 0559 hours except in cases of safety, maintenance considerations, exceptional air traffic conditions, adverse weather, technical faults in air traffic control systems or declared emergencies at other airports or where Runway 10L-28R length is required for a specific aircraft type.'

- The net effect of the proposed change, if permitted, would change the normal operating hours of the North Runway from the 0700hrs to 2300 hrs to 0600 hrs to 0000 hrs.

The relevant action also is: To replace condition no. 5 of the North Runway Planning Permission (Fingal County Council Reg. Ref. No. F04A/1755; ABP Ref. No.: PL06F.217429 as amended by Fingal County Council F19A/0023, ABP Ref. No. ABP-305289-19) which provides as follows:

5. On completion of construction of the runway hereby permitted, the average number of night time aircraft movements at the airport shall not exceed 65/night (between 2300 hours and 0700 hours) when measured over the 92 day modelling period as set out in the reply to the further information request received by An Bord Pleanála on the 5th day of March, 2007. Reason: To control the frequency of night flights at the airport so as to protect residential amenity having regard to the information submitted concerning future night time use of the existing parallel runway'.

With the following: A noise quota system is proposed for night time noise at the airport. The airport shall be subject to an annual noise quota of 7990 between the hours of 2330hrs and 0600hrs. In addition to the proposed night time noise quota, the relevant action also proposes the following noise mitigation measures:

- A noise insulation grant scheme for eligible dwellings within specific night noise contours;

- A detailed Noise Monitoring Framework to monitor the noise performance with results to be reported annually to the Aircraft Noise Competent Authority (ANCA), in compliance with the Aircraft Noise (Dublin Airport) Regulation Act 2019.

The proposed relevant action does not seek any amendment of conditions of the North Runway Planning Permission governing the general operation of the runway system (i.e., conditions which are not specific to night-time use, namely conditions no. 3 (a), 3(b), 3(c) and 4 of the North Runway Planning Permission) or any amendment of permitted annual passenger capacity of the Terminals at Dublin Airport. Condition no. 3 of the Terminal 2 Planning Permission (Fingal County Council Reg. Ref. No. F04A/1755; ABP Ref. No. PL06F.220670) and condition no. 2 of the Terminal 1 Extension Planning Permission (Fingal County Council Reg. Ref. No. F06A/1843; ABP Ref. No. PL06F.223469) provide that the combined capacity of Terminal 1 and Terminal 2 together shall not exceed 32 million passengers per annum. The planning application will be subject to an assessment by the Aircraft Noise Competent Authority in accordance with the Aircraft Noise (Dublin Airport) Regulations Act 2019 and Regulation (EU) No 598/2014. The planning application is accompanied by information provided for the purposes of such assessment. An Environmental Impact Assessment Report will be submitted with the planning application. The planning application and Environmental Impact Assessment Report may be inspected or purchased at a fee not exceeding the reasonable cost of making a copy, at the offices of the Planning Authority during its public opening hours of 9.30 - 16.30 (Monday – Friday) at Fingal County Council, Fingal County Hall, Main Street, Swords, Fingal, Co. Dublin.

2. Unauthorised Development.

2.1 The applicant breached the 32 mppa condition in 2019 (32.9 mppa) this means that the excess capacity was unauthorised development and no EIA or AA of the 32.9 capacity was ever carried out. Therefore as per required by the Habitats and Birds Directives a remedial EIA and AA must be completed. As this application is quoting the 32mmpa figure and had not referenced the excess unauthorised operational development, this application cannot be in accordance with the law.

2.2 The flight paths on commencement of the parent permission for the North Runway were not in accordance with the permission granted. This application deals with land use planning which is intrinsically link and inseparable from the flight paths that have informed the guidance on the Fingal development plan since 2006. The development plan has based its noise zones and its public safety **(see fig 1.)** zones on the permitted flight paths as assessed in the original EIS. To change the permitted flight paths that have shaped how Fingal has developed since the grant of planning for the North Runway is to materially contravene the current and past Fingal Development plans and maps. Houses and estates were built on the basis of the land planning assessment tied to the original "straight out" flight paths. The IAA may decide that a change is required but any changes they recommend must be put forward for planning consent to inlcude EIA and AA assessment of the changes as they directly influence the sustainable and proper planning on Fingal.

2.3 The originally permitted paths have been breached since Aug 2022 when the permission conditions and permission came into operation. In an attempt to rectify the situation daa tried to bring the as operated flight paths closer to those originally permitted but this does not change the fact that the Airport development has not been in compliance with the plans and application consented in 2006 and 2017. The whole development is unauthorised development due to the use of incorrect flight paths. Remedial EIA and AA must be carried out to identify compensation measures for unauthorised impacts of the development. New flight paths will need a variation of the Fingal development plan and all associated public consultations and assessments (SEA, AA, EIA) As such this application cannot be approved in law.

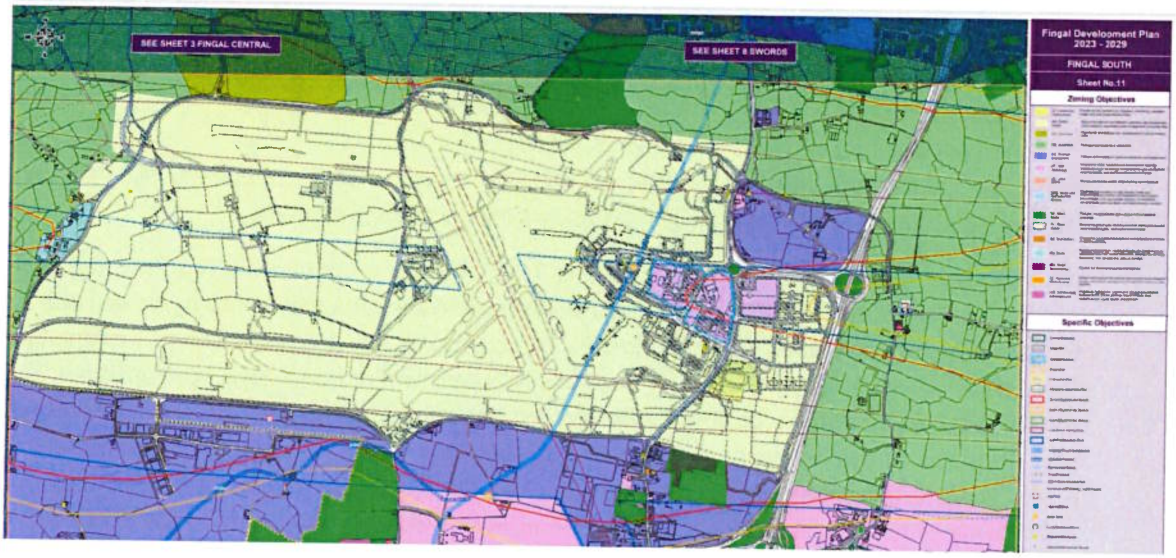

Figure 1: Map 8 for swords Fingal development plan inner PSZ in red and outer PSZ in blue.

2.3 The inner and outer public safety zones (PSZ) which stringently inform the land use planning for Fingal and are included on all development plan maps, are based on the originally permitted flight paths. This zone identifies the risk to the public and infrastructure of potential aviation accidents and provides for lower densities and restricted development in these areas in order to minimize mortality and damage rates in the event of an accident. I have attached the PSZ report for Dublin airports and the PSZ maps based on the permitted flight paths in Appendices 5 and 6 of this report. No changes can happen to permitted flight paths without planning consent and variations to the current Fingal Development plan and SEA for the development plan.

2.4 Figures 2 and 3 on the following pages show the new developments that have been built since the original permission was granted. These developments were restricted by the flight paths land use planning in the development plans. Some would have had density restrictions on estates and no schools or hospitals could be build or were restricted within inner and outer zones. On the other side of the coin if we were to suspend the planninga nd environmental acts for a minute and presume that flight path changes were allowed without consent, the how are we to stop high density building or educational facilities being built in the most dangerous zones under new paths. How do we asses the impact on annex species flight paths and habitats that may not have prevviously been impacted? How do we mitigate for Human impacts (noise and health) that have shifted to communities under the new paths, if we haven't assessed the impacts? The answer is we cant and that is why new flight paths are legally intertwined with land planning and require planning consent and EIA / AA assessment.

2.5 Unfortunately for the applicant the current planning laws do not allow for substitute consent on unauthorised development that would have required EIA and AA screening if it had been applied for planning consent correctly. Therefore in the present legislative landscape at this point in time, these flight paths or indeed the parent permission cannot be regularised in law to bring them into legal compliance. Therefore this planning application must be refused.

2.6 Below are some of the planning policies and objectives from Fingal Development Plan that tie the flight paths and land use planning together in a legally binding manner.

3.5.15.6 Housing within the Airport Noise Zones The development of new housing for those who are not involved in farming will be actively resisted within the area delineated by Noise Zone A for Dublin Airport. However, consideration will be given to the development of new housing for those not involved in farming but who have family homes within Noise Zone A, in locations on suitable sites outside Noise Zone A but within five kilometres from that noise zone. To ensure that the need to live as close as possible to the existing family is met and to avoid undue pressure on certain areas of the Greenbelt, the M1 will provide an east-west boundary, with those living to the east being considered for housing on suitable sites to the east, and those living to the west being considered for housing on suitable sites to the west. Site selection should ensure that the rural character of the area is maintained and that multiple sites on single landholdings are avoided.

Objective SPQHO82 – Rural Settlement Strategy and Airport Noise Zone A Apply the provisions of the Rural Settlement Strategy, only with regard to 'New Housing for Farming Families' as set out within this Chapter, within the Airport Noise Zone A, and subject to the following restrictions: ¨ Under no circumstances shall any dwelling be permitted within the predicted 69dB LAeq 16 hours noise contour. ¨ Comprehensive noise insulation shall be required for any house permitted under this objective. ¨ Any planning application shall be accompanied by a noise assessment report produced by an independent specialist in noise assessment which shall specify all proposed noise mitigation measures together with a declaration of acceptance of the applicant with regard to the result of the noise acceptance report.

Policy DAP4 – Transitioning to a Low Carbon Economy Ensure that all developments comply with the Climate Action Objectives and the Circular Economy and Waste Management Objectives in the Dublin Airport Local Area Plan 2020, or any subsequent LAP or extension of same.

National Policy Objective 65 set out in the Department of Housing Planning and Local Government (DHPLG) National Planning Framework 2040, February 2018, to: "Promote the pro-active management of noise where it is likely to have significant adverse impacts on health and quality of life and support the aims of the Environmental Noise Regulations through national planning guidance and Noise Action Plans."

Policy DAP6 – Health of Residents and Aviation Noise Protect the health of residents affected by aviation noise, particularly night-time noise.

Objective DAO14 – Aircraft Movements and Development Restrict development which would give rise to conflicts with aircraft movements on environmental or safety grounds on lands in the vicinity of the Airport and on the main flight paths serving the Airport, and in particular restrict residential development in areas likely to be affected by levels of noise inappropriate to residential use. Objective DAO15 – Ongoing Review of Operation of Noise Zones Review the operation of the Noise Zones on an ongoing basis in line with the most up to date legislative frameworks in the area, the ongoing programme of noise monitoring in the vicinity of the Airport flight paths, and the availability of improved noise forecasts.

Objective DAO18 – Safety Promote appropriate land use patterns in the vicinity of the flight paths serving the Airport, having regard to the precautionary principle, based on existing and anticipated environmental and safety impacts of aircraft movements. Objective DAO19 – Review of Public Safety Zones Support the review of Public Safety Zones associated with Dublin Airport and implement the policies to be determined by the Government in relation to these Public Safety Zones.

Policy DAP8 – Community Engagement Support the ongoing and continued engagement with neighbouring airport communities to ensure that the environmental impacts associated with the development proposals are carefully managed and mitigated through land use planning and environmental monitoring and review processes. Policy DAP9 – Support for the Local Community Support the local community impacted by the expansion of Dublin Airport in efforts to prevent the fragmentation of their community.

Objective DAO24 – Housing Development and Dublin Airport Noise Zones Restrict housing development in order to minimise the potential for future conflict between Airport operations and the environmental conditions for residents, in accordance with the Dublin Airport Noise Zones 2019.

2.7 We believe that the points 2.2-2.5 above should be read with the conclusion of the original ABP inspector for the parent permission (whom the Board overruled) as we feel it is pertinent to the importance of legal and robust assessments of actual impacts on human and non human communities.

ABP 217429 Inspectors report page 101:

"The matter of noise is particularly problematic and despite the extent of information provided on the subject and the opportunities provided to the applicant to address certain issues I consider that the information before the Board remains materially deficient, namely with regard to the 'significant effects' in terms of night time noise and, in the light of increasing evidence of the correlation of aircraft noise and cognitive skills of children, the ability of schools to be insulated so as to provide the necessary indoor noise levels of 45dBA above which significant effects would occur.

In view of the importance of these issues and their potential material negative impacts on the affected communities and schools, in my opinion it is incumbent on the applicant to provide the necessary information in a format which is easily interpreted without recourse to conjecture or inference so as to allow the Board to make a proper assessment. The repeated failure by the applicant to provide this information has to be considered fatal at this stage and I do not consider it possible that a reasonable expectation in terms of the extent of the impacts in terms of noise can be made on which the Board can realistically make an informed decision.

As I have acknowledged above the proposal accords with national, regional and local policy and its strategic importance is accepted. I would suggest, however, that the advancement of the scheme would effectively require a section of the population to accept the impacts and inconvenience arising for the benefit of the wider community. In the interests of fairness and transparency I would suggest that a positive decision in this instance, should it be predicated on such reasons, should only be countenanced where the full facts as to nature and extent of the potential impacts are available and detailed so that the Board and all persons who are thus affected are cognisant of the potential ramifications. This is not the case in this instance and I do not consider that the material deficiencies which remain could be addressed, in any manner, by way of condition. I therefore recommend that permission for the above described development be refused for the following reasons and consideration

REASONS AND CONSIDERATIONS 1. It is considered that the proposed northern parallel runway, taken in conjunction with the existing southern runway 10R/28L and cross-wind runway 16/34, would result in a material extension in the geographical area and population that would be affected by Dublin Airport in terms of noise and public health and safety risk. These impacts are considered material. The impacts relating to noise would be only partially offset by the proposed mitigation measures in terms of the insulation and buy-out schemes. It is therefore considered that the altered noise environment and increase in aircraft noise both during the day and at night which would arise as a consequence of the proposed development, coupled with the increased risk in terms of public health and safety would, seriously injure the amenities of property and community facilities within the affected areas and would be contrary to the proper planning and sustainable development of the area. 2. Having regard to the correlation between aircraft noise and the development of childrens' cognitive skills the Board is not satisfied on the basis of the submissions made in connection with the planning application and the appeal that the proposed mitigation measures in terms of insulation of schools which would be affected by the proposal would be adequate to ensure a maximum internal classroom noise level of 45dBA LAeq. In the absence of this information it is considered that the proposal would endanger the health and safety of persons attending the said schools and would be contrary to the proper planning and sustainable development of the area. 3. Having regard to the proposed increase in night time flights on the existing southern parallel runway which would be facilitated by the proposed northern parallel runway the Board is not satisfied, on the basis of the submissions made in connection with the planning application and appeal, that either the full nature and extent of the increase in night time noise, the significant effects which may arise from same or the extent of the areas and populations which would be affected by same have been *satisfactorily identified and quantified. It is considered measures proposed reinforced by conditions and monitoring can ensure that a suitable noise environment can be maintained within classrooms and school buildings generally. In coming to the above decision, the Board noted that, in addition to planning controls, Dublin Airport would in the future be subject to the new noise control regime introduced under the EU Environmental Noise Directive 2002/49/EC and the Environmental Noise Regulations, 2006.*

Note: The Board considered both this application and the application for Terminal 2 together and took account of the cumulative impacts of the proposed developments. The Board considered that the EIS and the EIS Addendum supplemented by the further information submitted to the planning authority and the Board, including at the oral hearing, together with the Inspector's report provided for an appropriate Environmental Impact Assessment of the likely significant impacts of the proposed development.

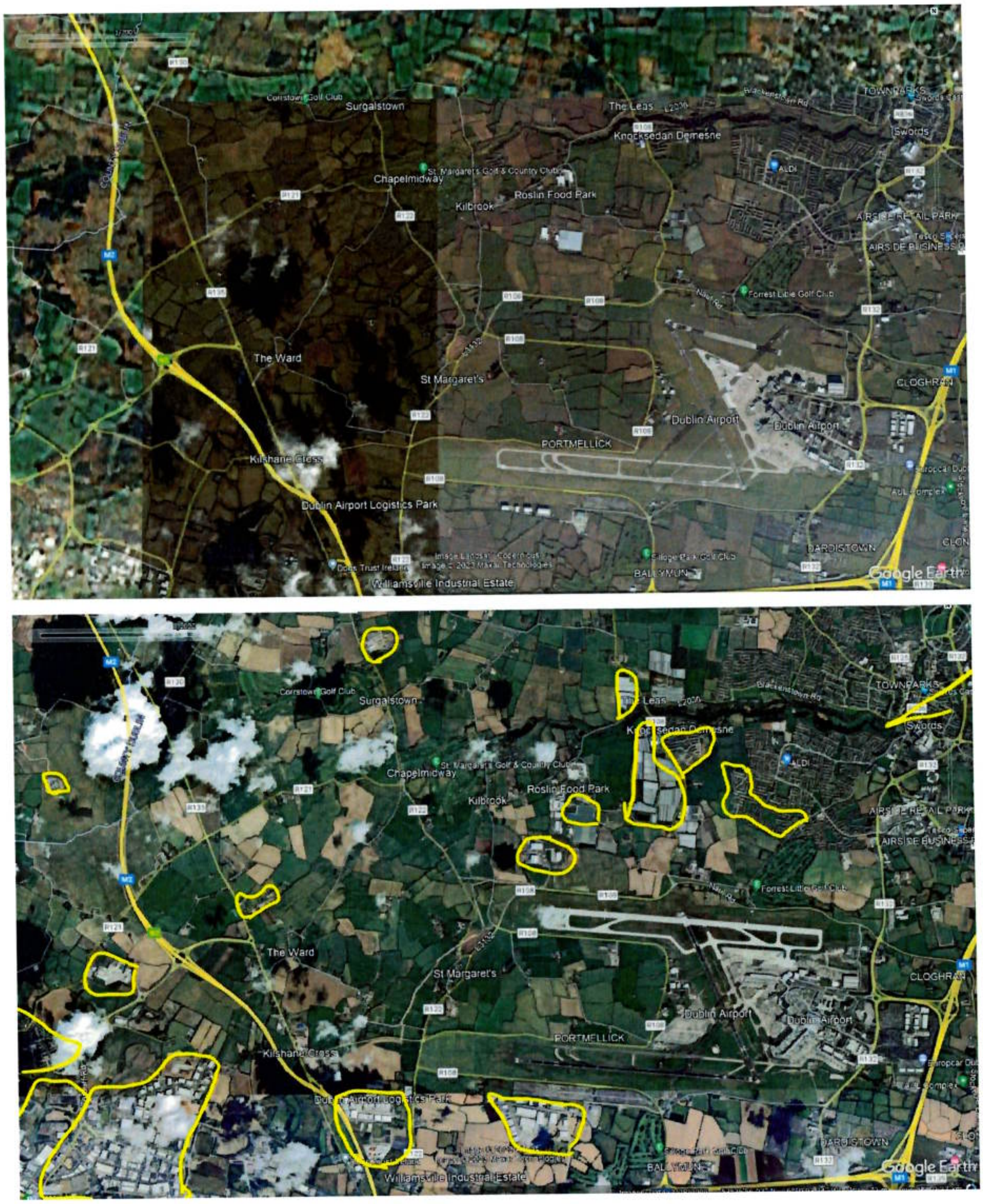

Figure 2 – development before and after comparison west runway lands upper 2006, lower 2023

Fig 3. **development before and after comparison East of runway lands upper 2023, lower 2006**

3. **Appropreate Assesment**

3.1 Aecoms AA screening was not robust. The assessment of impacts generally attempted to tie impacts of aircraft to specific noise levels. Very few scientific papers assess disturbance on specific decibel levels bar the outlier Aecom referred to. Most will asses based on chronic noise both high and low level and on visual stimuli disturbance, vibration etc. so the very basis for excluding other disturbance methods is manifestly wrong.

3.2 although we were happy that the applicants own consultant highlighted the need for AA screening of new flight paths in section 3.9 of the Screening document where They state: *This is in line with a similar AA carried out for Edinburgh Airport in the UK, and reported in HiDef Aerial Surveying Ltd. (2017), where a change in flight paths was proposed, taking aircraft over multiple SPAs in the Firth of Forth. No consideration was given in the test of likely significant effects for this project to the potential impacts of fuel dumping.*

3.3 The screening report concerning states at 3.10 that *"It is impossible to know the location of every area of functionally-linked habitat (i.e. habitat outside of the boundary of a European site but which may be used by QI / SCI species) which may be overflown by aircraft using Dublin Airport. Therefore, for the same reasoning as set out in relation to fuel dumping, it is unreasonable to attempt to assess the potential impacts and effects from the proposed Relevant Action on species when using functionally-linked habitat."* The habitats directive specifically calls for the precautionary principle if there is difficulty producing evidence of no impact and some attempt at fuel dumping along the approach routes and nominated circling roues taken to reduce fuel load before landing should have been made. The reason and considerations produced here were not sufficient.

3.4 In 3.11 Aecom Screenin report states; *The AA Screening Report prepared on behalf of ANCA to inform their own assessment of the Noise Abatement Objective (NAO) states that air emissions from aircraft become negligible, in terms of their ground-level air quality effects, once aircraft are more than approximately 350-650 feet above ground on take-off, or more than approximately 160-350 feet above the ground on landing (Logika Consultants Ltd., 2021). According to the same report, this height will be reached by aircraft using Dublin Airport within 2 km or less of the airport. The nearest European site to North Runway is Malahide Estuary SAC, approximately 4 km north-east, well beyond this distance.*

3.12 Consequently, the only possible impacts from the proposed Relevant Action on the QI / SCI of European sites can be from direct noise and/or visual disturbance caused by over-flying aircraft, or from collision mortality ('bird strike'). Therefore, any SACs which are designated only for habitats, and have no animal species as QI which could be subject to disturbance, are outside of the ZoI of the proposed Relevant Action.

3.5 ANCA and the applicant forget that increased night flights leads to more emissions from contrails (see appendix 7) which absolutely should be assessed in terms of carbon impacts and warming impacts on non animal SACs for example Baldoyle Bay SAC which has protected Annex

Salt meadows and is a source of eel grass for Brent Geese and SCI of the sister SPA. Increases in sea level due to global warming could eradicate these important species.

3.6 The aecom screening and ANCA NIS failed to assess SCI of Wetlands and waterbirds A999 Baldoyle AC . All bird species listed on the IE Natura2000 annual reports to EU for this SCI must be assessed.

3.7 The screeining report states that at 4.21 *"A total of 252 hours of survey were conducted during the survey period, covering a range of weather conditions, tidal states and times of day. During the VP watches, surveyors recorded all disturbance events, noting the time, source of disturbance, species affected and the number of birds involved. The response of waterbirds was recorded on a scale of 0 – 3: ⑦ 0 – no behavioural change; ⑦ 1 – behavioural change (e.g. vigilance or alarm call) but no flight; ⑦ 2 – flew but soon returned to the site; and, ⑦ 3 – flew and abandoned the site. 4.22 There was an "almost continuous stream of air traffic overhead" during the surveys. AECOM 27 Document Classification: Class 1 - General 4.23 In summary, a total of 184 disturbance events were identified during the surveys, with 89 at Rogerstown Estuary and 95 at Baldoyle Bay. These were caused by a variety of disturbance sources, primarily walkers and/or dogs, but also including aquaculture activities, ground-based transport and predators. A single disturbance event was noted in response to a low-flying Coastguard helicopter. 4.24 During the 21 months of survey, comprising 252 hours of VP watch, no disturbance events caused by aircraft passing overhead on established flight paths to or from Dublin Airport were recorded.* Absolutely no evidence of this was put before the board for the inspector or public to assesss Who were the experts? Where is the raw data? Can it be considered good date post COVID when many species repopulated areas that were less impacted by anytropgenic impacts and disturbance. Not precise or definative.

3.8 The birdstrike data was discussed at 5.16 *"Bird strike incidences at Dublin Airport are recorded by the Applicant. The data recorded between 2010 and 2019, inclusive, are shown in Table 12 (although data are available for 2020, they are not included here because, due to significantly reduced numbers of flights as a result of the Covid-19 pandemic, the bird strike figures are not representative of a typical year). 'External' bird strikes are those which take place outside of the boundary fence of Dublin Airport and can occur anywhere outside of this area. The most important information is therefore the number of 'Confirmed' bird strikes, which occur between birds and aircraft taking-off or landing.* The protected species that may be Ex Situ for foraging, breeding, migrating species must be assessed outside of the boundary fence and also along permitted flight paths and the Natura2000 sites impacted by them This limited assessment is not full definitive or scientific. Full raw data, and wildlife management plans atc should be provided.

3.9 We attach at appendices 2, 3 & 4 scientific reports on aircraft impacts on bird species which identify the limitations of the applicants and Anca screening and AA assessments. In any case ANCA should not have commission their own NIS and been judge in their own cause, so this document may be invalidated and not applicable.

3.10 No impacts of CECs, Nitrogen, PFAS(Deicing/ firefighting foam) pollution runoff into SACs hydro-logically linked to the airport via the Mayne, Sluice, Ward and Cuckoo rivers was assessed. This is a glaring omission and must be rectified, particularly in light of the large amount of PFAS contaminated soil that the airport has removed for remediation, again without development consent or EIA. AA assessment which is another Unauthorised development issue as indication are that the North runway and environ lands were involved and may actually still contain contaminated soil.

4. Other issues:

4.1 The EIA assessment of noise impacts on health only assess under the noise legislation and limited metrics/ parameters that the legislation details. HOWEVER the overarching legislation the EIA Directive and equally the Habitats Directive, which supersede the aircraft and environmental noise legislation, requires that " a WORST CASE SENARIO" must be assessed when it comes to EIA assessment of impacts. This means that the Lmax impacts must also be assessed in actuality and in tandems with the other metrics. The full health impacts at Who recommended levels must also be modeled and assessed in tandem with the noise legislation so that a full worst case scenario can be assessed from the EIA and AA point of view. There is no way around this.

4.2 Last nigh a report from "We Are The Ditch" identified that Ethna Felten the Head of ANCA is also the deputy Chairperson of Fingal County Council. A quick search of Fingal events confirms this. It is an extraordinary breach of article 3(2) and clause 13 of 594/2014 in relation to the functional separation of ANCA and FCC. This in addition the fact that the Chairperson of ANCA receives rent from FCC her employer is a clear and serious conflict of interest which we believe invalidates all of the work undertaken by ANCA in relation to this relevant action. An investigation must be launched immediately. The courts have overturned planning consents for less. ABP must request a response on this issue from both FCC and ANCA.

For the reasons and considerations above, please refuse permission for 314485.

Yours Sincerely

Sabrina Joyce-Kemper, Max Kemper, Lucas Kemper, Amelia Kemper and Ben Kemper.

and

Wild Irish Defence CLG

Appendix 1

Environmental Assessment Chapter

1. Introduction

1.1 This chapter has been prepared by Sabrina Joyce-Kemper as an individual member of the public affected by aircraft noise and on behalf of St. Margaret's and The Ward / FORUM submission. Ms Joyce-Kemper has an advanced diploma in Planning and Environmental law from the Honorable Kings Inn and is local to Portmarnock and involved with environmental matters in her locality.

1.2 We believe that the amendment application does not provide sufficient information for the Board to carry out an Environmental Impact Assessment and Appropriate Assessment that is in accordance with the law. We also believe that the amended application and the most recent additional information, if accepted will constitute an amendment to the original development application outside of the" relevant action" in respect of aircraft noise which would require a dual application for consent under section 34 of the Planning and Development Act of 2000. We also believe that the application materially contravenes the Fingal Development Plan 2023-2029.

1.3 We wish at this stage to adopt all third-party submissions made in relation to F20A/0668 / 314485 without prejudice to the arguments that those submissions make, whether they are in conflict with our own arguments or in support of them. This includes Ms Joyce-Kempers other submission in her personal capacity.

1.4 The instant planning application is described as follows:

A proposed development comprising the taking of a relevant action only within the meaning of Section 34C of the Planning and Development Act 2000, as amended, which relates to the night-time use of the runway system at Dublin Airport

1.5 Below we lay out the reasons and considerations for our objection to this planning application.

2. Administrative / Procedural issues:

2.1 **Incorrect application procedure.** There are aspects of this application that are not governed by Section 34B and 34C of the Planning and Development Act and do not therefore fall under 'operating restrictions' or 'noise mitigation measures', they are in fact changes to the originally granted flight paths that intensify and expand the noise impacts on communities. These changes also impact on land use planning in public safety zones which fall outside of noise mitigation and therefore materially contravenes the Fingal Development plan 2023 -2029.

2.2 These non-relevant action amendments need to be identified and separated from noise mitigation measures and operating restrictions and applied for in a dual planning application under Section 34 of the P&D Act of 2000 to present with associated EIAR and NIS covering all current and historical cumulative impacts.

2.3 **Development in multiple functional areas.** As the Development impacts on more than one local authority functional area and therefore communities in multiple counties and municipalities. As such there should be statutory consultation with Dublin City Council, Meath County Council, and any other council whose functional area may be impacted by the changes in the relevant action elements of the planning application. Despite the airport being removed from the 7th Schedule on relation to Strategic Infrastructural Development (SID), the fact that the flight paths intensify noise and impact on multiple local authorities may have triggered a dual assessment as an SID or at the very least an SID like statutory consultation and engagement with councilors in the public interest.

2.4 We refer the inspector/ board to Section 37E(4) of the Planning and Development (Strategic Infrastructure) Act 2006 which states:

(4) The planning authority for the area (or, as the case may be, each planning authority for the areas) in which the proposed development would be situated shall, within 10 weeks from the making of the application to the Board under this section (or such longer period as may be specified by the Board), prepare and submit to the Board a report setting out the views of the authority on the effects of the proposed development on the environment and the proper planning and sustainable development of the area of the authority, having regard in particular to the matters specified in section 34(2).

2.5 **Invalid NIS and ulta vires decision.** The issue of ANCA producing their own NIS for the relevant action and then being the decision maker on the NIS they commissioned raises issues of irrationality, acting ultra vires of their remit in producing an NIS (rather than the applicant) and being a judge in their own cause. St Margret's and the Ward did attempt to appeal the ANCA decision for this and other reasons, but we were informed by the Board that this was not possible. We again put it to the bord that the NIS prepared by ANCA is inadmissible and its decision invalid in law.

2.6 **Breaches of planning conditions:** It must be noted that the applicant has breached planning conditions in relation to number of night movements in excess of that permitted under condition 5 and in relation to the permitted flight paths/ tracks that were assessed in the original EIS and informed the making of multiple development plans in relation to spatial planning and the identification of public safety zones and policy on public safety zones which are also adopted in the current Fingal Development plan.

2.7 In fact the applicant as voting members of the Dublin Airport slot co-ordination committee have knowingly and willfully and with full knowledge of their legal obligations, decided to potentially breach planning and environmental regulations in relation to the operating conditions included in this application, which are attached to the grant of the parent planning permission for the North Runway. They have done so after full discussions and risk assessments, when deciding co-ordination parameters for Summer 2023/Winter 2023 and Summer 2024 slots some months in advance of the slot periods. The slot decisions are attached at Appendix A, B and C.

These conditions that the slot decisions assessed and decided to contravene are:

1.3 **3(d) of the North Runway Planning Permission** (Fingal County Council Reg. Ref. No. F04A/1755; ABP Ref. No.: PL06F.217429 as amended by Fingal County Council F19A/0023, ABP Ref. No. ABP-305289-19). Condition 3(d) and the exceptions at the end of Condition 3 state the following:

3(d). Runway 10L-28R shall not be used for take-off or landing between 2300 hours and 0700 hours except in cases of safety, maintenance considerations, exceptional air traffic conditions, adverse weather, technical faults in air traffic control systems or declared emergencies at other airports.'

2.8 **Condition no. 5 of the North Runway Planning Permission** (Fingal County Council Reg. Ref. No. F04A/1755; ABP Ref. No.: PL06F.217429 as amended by Fingal County Council F19A/0023, ABP Ref. No. ABP-305289-19) which provides as follows:

On completion of construction of the runway hereby permitted, the average number of night time aircraft movements at the airport shall not exceed 65/night (between 2300 hours and 0700 hours) when measured over the 92-day modelling period as set out in the reply to the further information request received by An Bord Pleanála on the 5th day of March, 2007. Reason: To control the frequency of night flights at the airport so as to protect residential amenity having regard to the information submitted concerning future night time use of the existing parallel runway'

2.8 The net effect of the slots' decisions, is, if and when they were implemented, constituted a potential intentional breach of the planning permission operating conditions. This fact, that the committee including the applicant may have acted with intent to breach Planning conditions, will not sit well with the Courts when the current JR of FCC enforcement, case is at hearing stage. The Courts expect parties to have "clean hands" / not to have partaken in unfair conduct. Actively assessing the risk of adhering to planning conditions 3(b) and 5, when deciding the slot S23 parameters and voting to potentially breach them anyway in favour of economic market concerns, then carrying those decisions through to W23 and this decision S23 raises the legal violation of "the clean hands doctrine". An Bord Pleanála as a quasi-judicial body must also comply with legislation under section 34(12) of the planning act in relation to unauthorised development and whether the breach was carried out in a deliberate manner, which we could be supported by the slot co-ordination decisions.

2.9 We wish to point out to the Inspector that currently active Winter 2023 slots and the future Summer 2024 slot decisions are relevant evidence that must be considered by the inspector to be proof of the committees (including applicant) intention to continue breaching the operating conditions and restrictions of the parent permission some of which make up this application. Section 6.2.2. of the Worldwide Airport Slot Guidelines (WASG)[1] states:

6.2.2 The coordination parameters represent the maximum capacity available for allocation considering the **functional limitations** at the airport such as runway, apron, terminal, airspace, and ***environmental restrictions*** (emphasis added)

In the document the co-ordination parameters are described as follows:

Coordination Parameters: the maximum capacity available for allocation at an airport considering the functional limitations at the airport such as runway, apron, terminal, airspace, and environmental restrictions declared by the airport or ***other competent body.*** *(emphasis in bold added)*

2.9 The industry guidelines therefore state that the parameters considered must be within the constraints to capacity and include limitations and restrictions declared by any other competent body, in this case the local authority and an Bord Pleanála. As the IAA and the slot co-ordination committee have failed to comply with the sustainable planning conditions put in place by ABP in 2007, it falls to the Board to find that the applicant cannot benefit from a breach of planning consent and that the current application should be refused on the basis that no AA was ever carried out on the parent permission in contravention of the Habitats and Birds Directives. In previous submissions we have made detailed case for the invocation of section 34(12) to refuse to accept this planning application as under the current laws it cannot be regularised.

2.10 **Competition Law.** As a member state of the EU, Ireland and its competent authorities required to comply with EU law particularly in relation to the single market. In order to ensure a level playing field, the legislation on State aid (Article 107 and 108 of the Treaty on the Functioning of the European Union (TFEU)) and competition (Articles 101 to 109 TFEU — mergers, alliances, price-fixing, etc.) applies to the air transport sector.

2.11 EU rules ensure that all carriers, European and non-European, are granted the same rights and same opportunities to access air-transport-related services. This may not, however, be the case in some third countries where discriminatory practices and subsidies may give unfair competitive advantages to air carriers from those third countries. Competition law is in place in order to regulate anti-competitive conduct within the single market.

2.12 The applicant as part of the co-ordination slot committee by taking part in a process to potentially breach planning and environmental regulations that apply to all member states equally, the committee and by extension the IAA if they adopt the decision, may be seen to be breaching EU internal market competition law. Other airports in EU member states must comply with regulations and the terms of their planning permission and operating licenses. daa by potentially seeking to dis-apply apply the same rules that other Airports in EU member states must adhere to in relation to EIA, AA and compliance with planning consents, could be gaining an unfair advantage in enticing airlines to use Dublin Airport.

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1 https://www.iata.org/contentassets/4ede2aabfcc14a55919e468054d714fe/wasg-edition-2-english-version.pdf

2.13 To be lawful at the point of application for amendment, the previous operational application of the parent consent that this application seeks to amend must have complied with the planning conditions, as implemented under EU planning and environmental law. If it did not, section 34(12) is a legitimate remedy the Board can utilise to nullify the unlawful consequences of a breach of EU law. Namely habitats directive, EIA directive and competition law.

2.14 **State Aid Issues.** DAA are a semi state company (albeit commercial) but have recently received substantial state aid and subsidies from the state particularly during and after the covid restrictions had an economic impact on the airport. Recent judgments from the European Courts in Luxembourg have confirmed that the construction and operation of an airport may constitute an economic activity, which are subject to the TFEU rules on State aid.

2.15 As a semi-state body if An Bord Pleanála;

a) allow or facilitate the applicant to benefit from amending a planning consent in breach of Planning and Environmental law, and

b) allow them to regularise a potential breach of competition law by making a decision to grant this application

- are they aiding and rewarding the DAA (another semi state body) and the airlines to benefit economically from non-compliance with an EU regulatory regime? Could this be seen as giving state aid to the airport? And is the form of state aid illegal under the TFEU?

2.16 We know that the airport was given tens of millions in State aid under the COVID 19 Temporary framework and may have benefited from state aid via the adoption of co-ordination slots that may have breached planning and environmental law. But there are conditional provisions placed on State aid by the EU. While the focus of State aid control is the protection of the internal market against distortions of competition, as a general matter of coherence within the EU legal order, the Commission must also ensure that State aid is not contrary to other provisions of EU law, including EU environmental law. In a nutshell to receive State aid the DAA must be in compliance with EU legislation/ regulations. The inspector and the Board need to be cognisant of this.

2.17 Insufficient time was given by the Board for members of the public concerned to review highly technical documents. Just the minimum requirement in law of 5 weeks was granted. This was in spite of numerous members of the public contacting the Board and requesting more time due to overlapping planning applications by daa.

2.18 When the applicant first lodged this application the North Runway had not been commissioned. In fact, this is first opportunity for people to give evidence on the failure of the current mitigation measures to prevent awakenings and severe sleep disturbance. Therefore, we ask the board to revisit holding an oral hearing, in the interests of justice.

3. Appropriate Assessment:

3.1 In previous submissions in relation to this application we have gone into great detail on the issue of our National Airport never being subject to an appropriate assessment of the cumulative impacts of the Airport development and infrastructure. This situation of significant and consequential lack of implementation of the Birds and Habitats Directive cannot be allowed to continue. The Board have a statutory duty to ensure that EU law is applied in its fullest iteration, in its decision-making process. On some planning consents the applicant has carried out screening, submitted an NIS but only for piecemeal development and never has it even attempted to carry out a robust EIA and AA of the entire Airport campus.

3.2 This position is no longer tenable and must be corrected. The cumulative impacts of the Dublin Airport Campus on our NATURA2000 Network must be assessed. This can also be applied to a master EIAR. Legal precedent would be case C-392/96 which states:

"The purpose of the EIA Directive cannot be circumvented by the splitting of projects and the failure to take account of the cumulative effect of several projects must not mean in practice that they all escape the obligation to carry out an assessment when, taken together, they are likely to have significant effects on the environment within the meaning of Article 2(1) of the EIA Directive."(C-392/96, Commission v. Ireland, paragraphs, 76, 82; C-142/07, Ecologists en AcciónCODA, paragraph 44 ; C-205/08, Umweltanwalt von Kärnten, paragraph 53; Abraham and Others, paragraph 27; C-275/09, Brussels Hoofdstedelijk Gewest and Others, paragraph 36)

3.3 The problem that is frequently encountered in planning applications is that of carrying out an AA on a development and having a finding of no significant effect. Then incorrectly carrying out a cumulative impact assessment by concluding because each development in isolation had a finding of no significant effect then cumulatively there could be no significant effects. This method is manifestly wrong. All effects identified within each development no matter how significant must be assessed in a cumulative matrix. Below at Figures 1 and 2 we give a visual representation via info-graphic of the correct and incorrect methods of cumulative assessment to be used in AA and EIA assessments.

3.4 Taking the correct methodology into consideration we can safely conclude that as previous AA and EIAR did not apply the correct methodology a robust AA and EIA is now required. Based on an initial examination of airport planning consents it is clear that AA and EIA assessments were not always carried out on new development applications. In order to try and rectify this we have compiled a list of planning applications relating to the Dublin Airport campus in Appendix D, since the implementation of the Habitats Directive in the EU. While some applications are for international modifications there may be capacity, waste and water, traffic components that need to be assessed. DAC certificates and Fire Certificates may or may not require assessments but should still be included in the matrices for cumulative impact.

3.5 The southern runway was built in advance of the implementation of the habitats directive as was the old airport building but their current uses and impact on NATURA2000 sites should be included in cumulative impact assessments.

3.6 In addition to the compliance issues identified earlier, the daa is not in compliance with condition 10 of the parent permission as FCC have deemed their compliance submission unacceptable and not as per the requirements of the condition. This condition directly impacts on the ability of ABP to assess this amendment application in relation to aircraft noise, mitigation and compliance with the NAO.

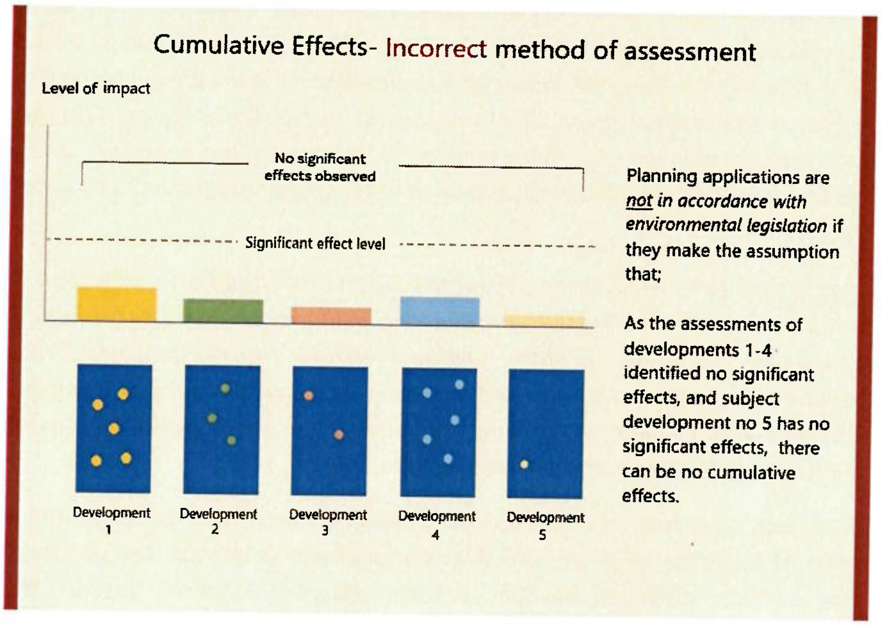

Figure 1: Incorrect method of cumulative assessment.

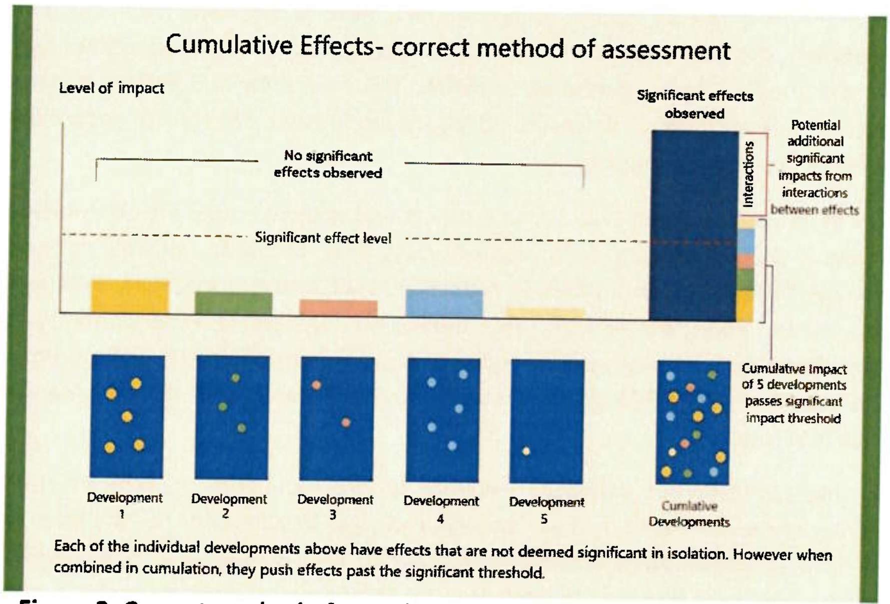

Figure 2. Correct method of cumulative assessment

3.7 Very Recent concerns have been raised about PFAS contamination of soils and water information has come to light of 150 tonnes of contaminated soil that may or may not relate to the North Runway consent being removed and sent to the Netherlands for remediation treatment. The PFAS contamination can come from firefighting foams and de-icing agents used during the historical operations and operations of the North Runway.

3.8 We tried to locate the water (and Air) emissions monitoring data that may contain this information, but it appears that the DAA is also in breach of conditions 21 and 22 of the parent commission in that it is not putting the water and air monitoring raw data online on its website as per the terms of the original grant of permission. It appears that Fingal County Council incorrectly confirmed compliance with these conditions which have not been met, and now are proving a barricade to effective public participation in making this submission. The conditions in question are as follows.

21. A monitoring regime for the monitoring of surface water discharged to streams and the public sewer shall be agreed in writing with the planning authority and shall be fully operational prior to the completion of construction of the runway. Monitoring results shall be submitted to the planning authority on a quarterly basis ***and shall be made available for public inspection on the Dublin Airport Authority's website****. Reason: In the interest of public health and to ensure continuous monitoring of surface water discharges from the site.*

22. The Dublin Airport Authority shall monitor air pollutant concentrations within the environs of Dublin Airport at locations to be agreed with the planning authority. The pollutants to be measured shall include nitrogen dioxide, sulphur dioxide, benzene, carbon monoxide, particulates PM10 and ozone. The measurements shall be undertaken so that concentrations can be compared with compliance of the appropriate National Air Quality Standards. The monitoring network shall include both continuous sampling equipment and passive sampling methods for monitoring the air pollutant parameters. Results obtained from the air quality monitoring network shall be submitted to the planning authority on a quarterly basis, ***and displayed on the Dublin Airport Authority website.*** *The frequency and pollutant parameters shall be reviewed on a yearly basis to ensure adequate monitoring. Reason: To ensure adequate monitoring of emissions and air quality.*

3.9 The impact of PFAS contamination via surface runoff and ground water filtration needs to be assessed as part of this application. All monitoring data must be made available in compliance with the planning conditions. The increase in night flights will mean more planes will need to be de-iced in the colder nocturnal periods. This means an increase in PFAS contamination to surface waters. The Board cannot seek to make a decision without a full assessment via EIA and AA of the impact on SAC/ SPA and the water body catchments that re receiving waters of the Airports surface runoff.

3.10 The applicant has failed to put definitive evidence before the board on bird air strikes and impacts on SPAs. There are no up to date surveys provided in particular for the new Western Irish Sea SPA. The applicants AA screening found no need for a stage two with absolutely no evidence to base this outcome on. In response to frequency of bird strikes the applicants response is vastly different to the information the IAA have in their 2022 safety review report (appendix E) which indicated that bird strikes are a major safety issue for the airport and if it impacts on protected habitats and species needs to be assessed. Th IAA report gives the exact numbers of bird strikes in 2022 and previous years. The applicant's previous response is insufficient, and a detailed and evidential assessment and report must be completed.

3.11 In summary the compliance issues which constitute unauthorised development, and the EIA and AA assessment deficiencies need to be addressed. We hold the position in the first instance that section 34(12) applies and as such the Board should invalidate/ refuse the decision to grant this planning amendment via relevant action.

ENGLISH NATURE

Birds Network
INFORMATION NOTE

Disturbance effects of aircraft on birds

Introduction

The purpose of this note is to examine the evidence of impacts on bird populations resulting from disturbance caused by aircraft. This includes an assessment of the effects of different aircraft types and their proximity, altitude and frequency of flight. Other important factors discussed are differences in sensitivity shown by different species and flock sizes and behavioural responses such as habituation and facilitation. The evidence for harmful disturbance caused by aircraft is then presented under a number of categories of impacts including: increased energy expenditure, reduced foraging rates, reduced breeding success and increased predation. Finally, a number of measures that may reduce disturbance impacts are described, including changes to flight altitudes and the use of no-fly zones.

Before discussing the impact of disturbance caused by aircraft, it is important to define the meaning of disturbance in this context. Disturbance can be defined as 'any situation in which a bird behaves differently from its preferred behaviour' or 'any situation in which human activities cause a bird to behave differently from the behaviour it would exhibit without the presence of that activity'. Here we are concerned mainly with the latter definition, although natural causes of disturbance (weather, predators) will always play an important role and may result in even greater impacts when combined with disturbance caused by human activities.

A gradient or hierarchy of behavioural responses to disturbance shown by birds is described by much of the work presented below. For example, the lowest detectable response is for a bird to briefly look in the direction of the source of disturbance before resuming its previous activity. The other extreme would be for a flock of birds to fly away from an area and to not return for several hours, or even days. Such high levels of disturbance resulting in flushing or escape behaviour are quite likely to have an effect, for example, by increasing the energy expenditure of wintering birds. The more difficult question to answer is at what point along the lower end of the gradient does the disturbance result in an impact on a population. For example, epeated exposure to lower levels of disturbance may result in increased stress which, in turn, may cause lower breeding success.

Useful introductions to bird disturbance and further information on the above issues can be found in Davidson & Rothwell (1993) and Hill *et al* (1997).

Disturbance caused by aircraft

The degree of disturbance caused by aircraft relative to other sources of disturbance varies greatly. For example, Grubb & Bowerman (1997) cite results from research on the human disturbance of Bald Eagles where aircraft caused the lowest frequency of behavioural response of the five disturbance groups evaluated (vehicle, pedestrian, aquatic, noise, aircraft). By contrast, small aircraft and pedestrians were the most important sources of disturbance in a study of waders at a high-tide roost on Terschelling, the Netherlands, summarised by Smit & Visser (1993). Bélanger & Bédard (1989) also concluded that the time spent in flight and the time taken to resume feeding by staging Snow Geese in the Montmagny bird sanctuary, Québec, were greater after disturbance by aircraft than after any other type of disturbance encountered in their study.

Disturbance caused by different types of aircraft

Differences in response to different types of aircraft have also been identified. The work on Bald Eagles by Grubb & Bowerman (1997) established that the eagles in their study showed a much greater response to helicopters (47% of all potential disturbance events) than to jets (31%) and light planes (26%). This is consistent with Platt (1977) who recorded that helicopter flights at 160 m altitude or less disturbed all adult Gyrfalcons being tested. Visser (1986) also compared the effects of jets and helicopters on roosting waders on Terschelling and found that helicopters disturbed birds more frequently and over longer distances than jets, even though the activities from jets were accompanied by weapon testing and high sound levels. Similar results were found in a study of small aircraft flying over wader roosts in the German Wadden Sea (Heinen 1986). In this study helicopters disturbed most often (in 100% of all potentially disturbing situations), followed by jets (84%), small civil aircraft (56%) and motor-gliders (50%). These data confirm the widely accepted view that helicopters are the most disturbing type of aircraft (Watson 1993).

The effects of ultra light aircraft are briefly described by Smit & Visser (1993). Although very little research on the effects of ultra lights has been carried out so far, there is evidence that they can cause significant disturbance, probably because of the low altitude at which they operate and the noise they produce. For example, the numbers of roosting and foraging Bewick's Swans close to an ultra light air strip in the Delta area of the Netherlands dropped from 1,400-4,300 in 1986-88 to only a few birds in 1989, after the strip has been used for one year (Smit & Visser 1989). However, this must be compared with the results of a study on the effects of microlights on wintering Pink-footed Geese near the Ribble Estuary (Evans 1994). Although only based on six observations during January to March, this study concluded that birds rapidly habituated to the presence of microlights landing and taking off from an air-strip only 250 m from their feeding areas.

Effects of proximity and frequency of aircraft flights

The altitude and lateral distance of aircraft have been shown to be important factors affecting bird disturbance. In a model of helicopter disturbance of moulting Black Brant geese it was shown that altitude strongly influenced the results, as measured by the number of birds disturbed and by weight loss. At an altitude of 1220-1830 m (depending on helicopter size) there was no predicted weight loss. However, helicopters at 915-1065 m disturbed most birds along all the flight routes. The greatest weight loss was predicted to occur with helicopters at 305-460 m (Miller 1994). Work carried out by Ward *et al* (1994) also confirms an effect of aircraft altitude for staging Black Brant on the Izembeck Lagoon, Alaska. It was found that large planes flying above 610 m had little effect, causing only brief responses by relatively few birds. Fixed-wing aircraft caused the greatest flight response when passing at less than 610 m and less than 0.8 km lateral distance to the flock. Similarly, Owens (1977) reported that wintering Black Brant showed a greater response to fixed-wing aircraft at less than 500 m altitude and less than 1.5 km lateral distance. Aircraft disturbed Black Brant at greater distance than other disturbance types and affected more geese over a larger area than other stimuli. Again, helicopters caused the greatest response duration of all aircraft types. Jensen (1990) found that helicopters had to fly at over 1070 m to avoid disturbing moulting Black Brant. Mosbech & Glahder (1991) suggest that *distant* helicopters are less disturbing when at low altitudes as they are likely to transmit less noise than helicopters at a higher flying level.

Observations of cliff-nesting seabirds on the coast of Aberdeenshire by Dunnet (1977) showed that helicopters and fixed-wing aircraft flying at 150 m above sea level and 100 m above the cliff top caused no detectable effect on the attendance of breeding Kittiwakes and Guillemots at their nests during egg-laying and hatching. However, it was noted that the cliffs are on the normal route of air traffic and thus the birds may have become habituated. No observations were made of aircraft at less than 100 m above the cliff top. Very different responses by seabirds, presumably not habituated, have been recorded on Ailsa Craig in the Firth of Clyde. During one incident a Hercules transport aircraft made successive flights about 200 m above the summit of the island. This caused an entire gannet colony to scatter for about an hour, leaving eggs and small chicks exposed to predation (Zonfrillo 1992).

Smit & Visser (1993) cite further information on the effects of small civil aircraft on roosting shorebirds at different altitudes:

- Aircraft at an altitude of more than 300 m at various sites in the German Wadden Sea disturbed birds in 8% of all potentially disturbing situations, with those flying at 150-300 m in 66% of the cases and those flying at less than 150 m in 70% (Heinen 1986).

- Disturbance in another study was always registered at 150 m altitude and, at a height of 300 m, there was still disturbance within a radius of 1,000 m (Baptist & Meininger 1984). It has been estimated that an aircraft passing over at 150 m creates a disturbed area of more than 15,000 ha (Meer 1985).

- Disturbance can still be detected when aircraft pass at 1000 m altitude (Werkgroep Waddenzee 1975).

- In addition to altitude, the behaviour of aircraft also influences disturbance levels. Flying high in a straight line leads to smaller effects than flying low or with unpredictable curves (Boer *et al* 1970).

Experimental studies of the effects of microlights on Pink-footed Geese (Evans 1994) indicated that they caused no detectable disturbance of geese, Lapwing, Curlew or Golden Plover when over 1000 ft. Signs of disturbance were first noted at around 500 ft.

Turning to the effect of lateral distance of aircraft, a study of the effects of low level jets on nesting Osprey in Labrador, Canada, could not identify any significant disturbance to birds from over-flights as close as 0.75 nautical miles (Trimper *et al* 1998). However, the Ospreys in this study may have habituated to aircraft during exposures in previous years. Visser (1986) detected the disturbance of roosting waders on Terschelling by jets flying up to 1000 m away. Brent Geese on the Essex coast were put to flight by any aircraft up to 1.5 km away when at altitudes below 500 m (Owens 1977).

Research has also been carried out to assess the effect of the frequency of aircraft flights on birds. For example, a study of staging Snow Geese in the Montmagny bird sanctuary, Québec, found that a rate of greater than two disturbances per hour during a single day could reduce the numbers of geese present on the site the following day (Bélanger & Bédard, 1989). Simulations of the effects of over-flights on moulting Black Brant also showed that increasing flight frequency usually caused greater impact on the birds through increased weight loss (Miller 1994). Similarly, experiments on feeding waders on tidal flats on Terschelling showed that 10 minutes after a single disturbance by a small plane at 360 m altitude bird numbers had returned to the same level as prior to disturbance. However, a plane passing twice, at 450 and 360 m respectively, caused a stronger effect, with only 67% of original number of Oystercatcher and 87% of the Curlew returning after 45 minutes (Glimmerveen & Went 1984).

Effect of noise

There has been little work on the effects of aircraft noise on birds. Busnel (1978) states that some species, such as gulls on airfields, breed close to extremely loud man-made noises without ill effects. Birds are assumed to habituate to the frequent loud noises of landing and departing aircraft, and only unusually loud noises are known to cause a reaction of alarm in these circumstances. Similarly, during the study by Owens (1977), Brent Geese quickly became habituated to most sounds, including extremely loud but regular bangs made during weapon testing. In another study of the effects of pre-recorded aircraft noise on nesting seabirds on Australia's Great Barrier Reef it was found that Crested Terns showed the maximum response of preparing to fly or flying off at exposures of greater than 85 dB(A). However, a scanning behaviour involving head-turning was observed in nearly all birds at all levels of exposure down to 65 dB(A), a level only just above that of the background noise (Brown 1990). It is not known what effect repeated exposure to lower noise levels can have on birds, although Fletcher (1988) found that low level jet and helicopter over-flights can cause physiological changes in domestic animals that may represent symptoms of stress.

Work by Mosbech & Glahder (1991) found that moulting geese in north-eastern Greenland showed signs of disturbance before helicopters were visible and that, typically, the noise stimuli alone disturbed the geese. Trimper *et al* (1998) found that nesting Osprey exhibited a similar response, staring at an approaching aircraft before it was audible to observers. There is also circumstantial evidence associating a near total hatching failure of Sooty Terns nesting on the Dry Tortugas Islands with sonic booms produced by low-flying military jets (reviewed in Bell 1972). However, Schreiber & Schreiber (1980) investigated sonic boom effects on colonial nesting gulls and cormorants and concluded that, compared to a human walking into a colony, a sonic boom had a minimal effect. Further work is needed to examine the combined effects of visual and acoustical stimuli. For example, trial balloon flights during a study by Brown (1990) indicated additional or interactive effects from the visual stimulus. In situations where background noise from natural sources is continually high the visual stimulus may have a greater effect.

Sensitivity of different species and effect of flock size

Significant variations in the sensitivity of different species have been observed during studies of the effects of aircraft on birds. For example, during observations of roosting waders on Terschelling, the Netherlands, it was found that Oystercatchers were rather tolerant of aircraft disturbance and Bar-tailed Godwits and Curlews were less so (Visser 1986). Different responses were also found during a study of coastal waterfowl in the German Wadden Sea. Brent Geese were amongst the most strongly reacting species (being disturbed in 64-92% of all potentially disturbing situations), together with Curlew (42-86%) and Redshank (70%), with Shelduck (42%) and Bar-tailed Godwit (38%) reacting less often (Heinen 1986). However, identifying consistent trends within species is difficult, as shown by another study of waders on Terschelling by Glimmerveen & Went (1984) where the recovery time following disturbance caused by a small air plane was greater for Oystercatcher (30 minutes before feeding resumed) than Curlew (7 minutes).

The relationship between flock size and disturbance was noted by Bélanger & Bédard (1989) when disturbance rates for staging Snow Geese were higher when more birds were present. Similarly, Owen (1977) observed that larger flocks of Black Brant geese took flight at a greater distance than did smaller flocks when approached by people, and Madsen (1985) observed the same reaction in staging Pink-footed Geese in Denmark. Disturbance behaviour of flocks is largely determined by the behaviour of the most nervous members of the group. Take-off of only a few birds may cause the entire flock to take flight, and the larger the flock the more chance of it containing a higher number of especially susceptible individuals. Thus, species that form large flocks may be more vulnerable to disturbance from aircraft.

Habituation and facilitation

The absence of any visible response of some species to aircraft suggests that, under certain circumstances, habituation may take place. The process of 'learning' that a particular stimulus is not associated with risk is probably encouraged by a more or less constant and predictable exposure to that stimulus. This may be the reason for the presence of Lapwings, gulls and Starlings at airfields where the movements and sound levels of planes are very predictable (Burger 1981). Similarly the habituation of nesting Ospreys to human activity has been shown to vary depending on the frequency and type of disturbance (Daele & Daele 1982). Ospreys nesting near humans, highways and the approach corridors for aircraft habituated to those activities, whereas others nesting farther from humans were less tolerant (Mullen 1985).

The importance of 'predictable' stimuli is illustrated in a study of feeding and roosting waders at Texel, the Netherlands, where it was found that a high degree of habituation had occurred to helicopters passing over at a frequency of 2-3 per hour at 100-300 m altitude. However, 'unusual' types of plane, which show up at low frequencies, still had strong effects (Smit & Visser 1993). This study suggests that birds are able to distinguish between types of plane as they do between aerial predators. Koolhaas *et al* (1993) note that habituation is only likely to develop in those individuals that are persistent in using an area throughout the season. Furthermore it is likely that birds never habituate to some types of disturbance. For example, studies of the effects of shooting ranges on roosting waders on Vlieland, the Netherlands, suggest that certain species could not habituate and, as a result, moved to alternative sites (Tanis 1962). Similarly, in a study of wintering Dark-bellied Brent Geese it was noted that, although birds quickly became habituated to most sounds, they never habituated to small, low-flying aircraft (Owens 1977). Jensen (1990) also found that moulting Black Brant geese did not habituate to over-flights.

The opposite to habituation, referred to as facilitation, may also occur when a combination of disturbing stimuli leads to an impact that far exceeds the effect that each activity alone would have had. For example, a study by Smit & Visser (1993) at Texel showed that, following exposure to an unusual aircraft type, otherwise habituated birds became more vulnerable to other forms of disturbance. Thus, an over-flying Grey Heron could cause a panic reaction much greater than would occur under normal conditions. A similar effect was found by Küsters & Raden (1986) on Sylt, Germany, where over-flying jets appeared to have greater effects when wind surfers had previously been in the area. Thus, the effect of facilitation is that birds become much more sensitive to relatively low levels of disturbance.

Impacts of aircraft disturbance on bird populations

As described above, the response of birds to disturbing events depends on a wide range of factors. These include the level of disturbance, reactions of other birds nearby, flock size and knowledge from earlier experiences (habituation and facilitation). Additional factors determine either their willingness to remain in the same place (scarcity of food, adverse weather, physiological condition of individual birds) or their motivation to leave for another place (daily and annual patterns of movement related to time of year and tidal level, or the presence of alternative sites). For this reason it is difficult to accurately predict the response of birds to different sources of disturbance. However there is evidence that, under certain circumstances, disturbance can have serious consequences for bird populations. The evidence of disturbance-related effects on bird populations is presented under the following categories of impacts.

Reduced food intake rates

There is general evidence that disturbance can significantly reduce food intake rates. For example, Beliën & Brummen (1985) found that birds forced out from preferred feeding areas may often simply wait until the source of disturbance has disappeared before resuming feeding. This was shown by the experimental disturbance of a single Oystercatcher. The bird was forced out from its preferred feeding site to another area where, despite the presence of other feeding birds, its intake rate dropped to almost zero. These results are confirmed by Hooijmeijer (1991) during similar work on Oystercatcher at Texel, the Netherlands. This showed that resting and walking during disturbance become the more dominant behaviour than feeding. Also, the food intake rate during the recovery period following disturbance was much higher than normal, presumably a result of birds trying to compensate for the loss of feeding time. Similarly, in response to frequent helicopter disturbance, the amount of time spent grazing by Pink-footed Geese in Northeast Greenland was decreased (Mosbech & Glahder 1991). Instead, the geese spent more time on the water and resting on ice floes. It was concluded that helicopter disturbance had a drastic impact on the time budget of Pink-footed Geese in this area.

Obviously, the impact of reduced intake rates will depend on other factors, including the physiological condition of the disturbed birds and their ability to compensate, for example, by feeding at night. This is illustrated by a simulation of the impact of helicopter flights on staging Black Brant geese which indicated that disturbance could result in significant weight loss (Miller 1994). Taylor (1993) found that Black Brant nearing the completion of wing moult are 'nutritionally emaciated' and that, for birds already in such poor condition, the additional loss of weight resulting from disturbance could result in abnormal or incomplete moult, if not decreased survival. Concerning compensation for reduced intake rates, Jensen (1990) suggested that gut capacity and passage rates and forage digestibility might limit the ability of Black Brant to compensate for lost feeding.

Increased energy expenditure

A potentially serious consequence of the extra flights needed to escape sources of disturbance is that energy expenditure will increase. The energetic costs of man-induced disturbance to staging Snow Geese in the Montmagny bird sanctuary, Québec, have been estimated by Bélanger & Bédard (1989). Human activities here accounted for over 80% of all disturbances recorded, with hunting and over-flying aircraft ranked highest. Two responses of birds to disturbance were considered: birds fly away but promptly resume feeding; and birds interrupt feeding altogether. The average rate of disturbance (1.46/hr) for the first response was estimated to result in a 5.3% increase in hourly energy expenditure combined with a 1.6% reduction of energy intake. The disturbance for the second, more prolonged, response was estimated to result in a 3.4% increase in hourly energy expenditure and a 2.9% reduction of energy intake. A conclusion from this study is that high levels of disturbance may have harmful energetic consequences for Snow Geese in Québec. More than two disturbances per hour may cause an energy deficit that no behavioural compensatory mechanism (such as night feeding) can counterbalance. Davis & Wiseley (1974) carried out similar work and claimed that an average seasonal disturbance rate of one event every two hours would cause a reduction of 20.4% in the energy reserves of staging Snow Geese. White-Robinson (1982) noted that wintering Black Brant geese increased their energy expenditure by 15% because of flights in response to disturbance.

Decreased breeding productivity

Disturbance caused by aircraft can have a range of impacts on breeding birds. Harmful effects include interference with courtship and initial nesting activities, the loss of eggs and chicks as a result of predation or exposure to adverse weather, and greater chick mortality due to starvation or premature fledging. However, the linkage between disturbance and decreased breeding productivity is not always clear and often it is not possible to conclusively show adverse effect. For example, the study by Dunnet (1977) of cliff-nesting seabirds found no evidence that aircraft affected incubating and brooding Kittiwakes, though habituation may have influenced the results. Some of the most dramatic evidence comes from 'catastrophic' incidents of the type described at Ailsa Craig (Zonfrillo 1992) where a low over-flight by a Hercules transport aircraft resulted in the estimated loss of 2000 Gannet eggs or chicks to gull predation. Another incident at the same location caused young auks, mostly Guillemots, to panic and fall from their ledges, resulting in the death of at least 123 birds. A similar panic response has been recorded for species of heron where, because of flimsy nest construction and vulnerable locations, rapid flights from the nest can result in the loss of eggs or young (reviewed in Bell 1972).

More subtle effects were suggested by Burger (1981) in a study of Herring Gulls nesting near Kennedy International Airport. These birds had a lower mean clutch size than expected and it was proposed that this was an indirect result of aircraft disturbance. Significantly more gulls flew up and engaged in more fights when aircraft flew overhead than under normal conditions and it was observed that eggs were broken during these fights. Under normal conditions fights between gulls do not occur because adults return to their nests at different times. However, the aircraft disturbance synchronized the landings of close nesting pairs thus increasing the likelihood of territorial disputes. Chick mortality as a result of aircraft disturbance is also cited by Grubb & Bowerman (1997) where the death of a nestling Bald Eagle was attributed to frequent helicopter flights less than 30 m from the nest which significantly reduced prey deliveries by the adults.

Birds are particularly sensitive to disturbance early in the breeding season. For example, Palmer (1976) and Myerriecks (1960) discuss the sensitivity of Great Blue Herons to startle effects during the early stages of courtship and nesting. Similarly, in a review by Vana-Miller (1987), sporadic activity following the initiation of nesting has been found to have severe effects on Osprey reproduction.

Physiological changes

There has been much experimental work on the effect of noise on the physiology of animals, both wild and domestic (Bell 1972, Fletcher 1988). For example, research on heart-beat rates of breeding Adélie Penguins has shown that rates increase as helicopters fly in the vicinity of their colonies, even when birds remained on their nest and showed no other signs of stress (Culik 1990). This work suggests that unusually loud noises can result in physiological changes that can be equated with increased stress. It has been speculated that continual exposure to disturbance of this nature, although having little visible effect, may reduce reproductive success. A similar effect has been suggested for Black Brant geese in Alaska where stress from aircraft over-flights might inhibit their ability to complete their moult while maintaining or acquiring the body condition necessary for migration (Taylor 1993).

Habitat loss

Frequent and high levels of disturbance can effectively result in habitat loss. This may be in the form of decreased carrying capacity where an area becomes less used by birds or, at its most extreme, it can occur when birds move away from a disturbed site permanently. An example of the latter is cited by Grubb & Bowerman (1997) where aircraft disturbance caused Bald Eagles to depart an area entirely. Consequently, displaced birds may have to feed at higher densities elsewhere, which may effect food intake due to increased competitive interactions between birds.

Mitigation of aircraft disturbance

Any attempt to reduce the effects of aircraft disturbance, for example by setting tolerance distances or disturbance-free zones, is complicated by the large variation in vulnerability to disturbance. This variability occurs across species and within species, across habitat types and between sites, and where exposure to disturbance causes varying amounts of habituation or facilitation. However, there are certain general principles which may help reduce disturbance in most circumstances. Also, a small number of case histories exist that may provide useful examples of effective mitigation measures under certain circumstances.

Timing

The potentially damaging effects of disturbance are greater for birds at particular times of the year. For example, disturbance is most likely to result in greater mortality of wintering birds in conditions of severe weather when food intake rates are reduced and fat and energy reserves are low. As illustrated above, birds are also very vulnerable to disturbance during the breeding season. Thus if aircraft disturbance can be removed or reduced at these critical times then overall impacts may be greatly reduced. Birds are also more vulnerable to 'unusual' disturbance events, for example unfamiliar aircraft types or unpredictable flight behaviour, and these should be avoided at critical times of the year.

Aircraft type

Certain types of aircraft create more disturbance than others. The existing research suggests that the use of helicopters in particular should be avoided in areas of importance for birds. There is also some evidence that ultra-lights are especially disturbing.

Flight distance, altitude and frequency

In some circumstances the use of zones around sensitive bird areas to restrict aircraft movements may be appropriate. Both lateral and altitudinal restrictions may be beneficial, although distances will vary with species and site. For example management plans for Bald Eagles in North America typically include restrictive buffer zones limiting human activity around nest sites and other key habitat areas such as foraging sites. Grubb & Bowerman (1997) suggest that aircraft would best be excluded from within 600 m of nest sites and key habitat areas during the breeding season. Work by Visser (1986) suggests that an exclusion zone of 1000 m may be required to prevent disturbance of roosting waders and Owens (1977) reports disturbance of Brent Geese up to 1.5 km distance. Turning to altitudinal restrictions, the results of the studies of Snow Geese in Québec and Brent Geese in Essex suggested that flights below 500 m over sanctuaries should be prohibited (Bélanger & Bedard 1990, Owens 1977). The work on Black Brant geese by Ward *et al* (1994) indicates that a flying altitude of at least 610 m is necessary to minimise disturbance. The simulation of helicopter disturbance of Black Brant geese by Miller (1994) predicted that the impact of helicopters could be greatly reduced by flying over 1065 m, minimizing flight frequency and by avoiding the use of larger (and thus noisier) helicopter. Similarly, in relation to flight frequency, Bélanger & Bedard (1990) recommended that human disturbance, particularly aircraft over-flights, should be reduced to less than one event per hour.

No-fly zones

There are two mechanisms for identifying such no-fly zones in the UK. The Civil Aviation Authority (CAA) publishes information on 'Bird Sanctuaries' and the MoD identifies national 'Avoidance Areas'. Both rely on map-based information to warn pilots of the location of large numbers of birds in order to reduce the risk of bird strike. The CAA defines a Bird Sanctuary as an *airspace of defined dimensions within which large colonies of birds are known to breed.* The location of these sanctuaries are listed in the UK Aeronautical Information Publication (AIP), an important reference for all civil pilots, giving details of location, avoidance distances (up to 3 nm) and heights (up to 4000 ft). Pilots are requested to avoid the Bird Sanctuaries during a particular period or during the breeding season. They are also advised to avoid flying at less than 1500 ft above surface level over areas where birds are likely to concentrate, such as offshore islands, headlands, cliffs, inland waters and shallow estuaries. The AIP recognizes that, apart from the danger to flying aircraft, the practice of flying close to breeding birds should be avoided for conservation reasons. However, these warning are only advisory for civil pilots.

The MoD can designate permanent and seasonal Low Flying Avoidance Areas to restrict the use of low-flying military aircraft. These are part of the UK Low Flying System (UKFLS) which aims to spread low-flying activity as widely as possible in order to reduce the burden of disturbance in any one area. Military aircraft are deemed to be low-flying when, in the case of fixed wing aircraft, they are less than 2000 ft above the surface, and for propeller-driven light aircraft and helicopters, when they are less than 500 ft. Avoidance areas include civil airspace around airports, airfields and glider sites, industrial sites, major built-up areas, stud farms and hospitals. Some bird reserves and sanctuaries are also included, although the list is far from comprehensive and requires a review.

Reducing other sources of disturbance

Finally, in circumstances where it is not possible to reduce or eliminate aircraft disturbance, it may be beneficial to reduce other sources of disturbance present on the site. This requires an integrated approach to controlling disturbing activities such as wildfowling, sailing and public access through temporal and spatial zoning. For example, the designation of refuges from wildfowling disturbance may help reduce the effects of facilitation and thus lessen the impacts of aircraft activity.

Conclusion

As with all forms of disturbance, it is often difficult to identify the effects of aircraft on birds, especially at the lower levels of potentially disturbing activities. Detecting effects is further complicated by the great variation in response of birds to aircraft, depending on a whole range of factors including aircraft type, proximity and frequency of flights and noise levels. Add to this variation the additional factors of flock size, habituation and facilitation, and it quickly becomes apparent that simple generalisations regarding the effects of aircraft cannot be made. This is especially so when consideration is given to the host of other variables that influence bird populations, including food availability, habitat change, competition, predation and weather. However, from the current information on aircraft disturbance the following general points can be made:

- Low-flying helicopters and ultra-lights cause the greatest level of disturbance.
- Low flight altitudes cause most disturbance; flights over sensitive bird areas should be at least 500 m above surface levels, and preferably over 1000 m (especially for helicopters).
- Unpredictable, curving flight lines are more disturbing than predictable, straight flight lines; birds can often habituate to regular and predictable events.
- The impact of aircraft disturbance may be increased if other sources of disturbance effect the same area.
- Cliff-nesting and other colonial seabirds during the breeding season and flocks of waterfowl during the winter are most vulnerable, especially during severe weather conditions.
- No-fly zones should be sought if serious disturbance is apparent.

Any future studies of the effects of aircraft disturbance, as with all forms of potentially disturbing activity, should take into account a range of factors: the intensity, duration and frequency of disturbance; proximity of source; seasonal variation in sensitivity of affected species; whether birds move away and return after disturbance ceases; whether there are alternative habitats nearby; and whether there are additional forms of disturbance. Ideally work on disturbance effects should include before-and-after studies and experimental controls. However, the flexibility for before-and-after studies rarely exists and often the disturbance is established and on-going. In these circumstances several sites should be studied and as many variables as possible should be measured in order to identify reliable correlations between bird activity and disturbance.

Once an effect has been identified, it is rarely possible to establish an impact on population dynamics and survival without extensive research into the behavioural responses of individual birds. As research of this nature requires significant time and resources it is not always practicable. Where time or resources are constraining it will be necessary to rely on existing research results as presented here to indicate *potential* impacts. Thus, for examples of higher levels of disturbance where an effect has been established, the existing research literature that identifies impacts on populations should be used to reinforce the precautionary approach. However, the evidence for impacts at the lower levels of disturbance is less strong and this requires further research.

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WHAT EFFECT DO AIRPLANES HAVE ON BIRDS? – A SUMMARY

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No one will expect this short question to produce an equally short and simple answer. The diversity of animal species and individual situations results in a wealth of barely classifiable and predictable responses. Outside in wild a lot of individual events can be observed that often appear contradictory. And opinions on the implications of a conflict between protection of birds and air traffic are correspondingly divergent. Representatives of authorities and associations nevertheless frequently expect a decision that is brief and unequivocal as possible. Attempts are often made to quantify and predict the effects of air traffic on birds in expert appraisals. The plethora of local individual situations and the different approaches to studies lead to results that are barely comparable with each other or generally capable of extrapolation.

Against this background, the results widely scattered in publications and the "grey literature" (appraisals, dissertations etc.) have been compiled and their variability and identifiable universally applicable correlations have been presented. In this article, an earlier publication (Kempf & Hüppop 1998) has been partly updated and summarized on the basis of new developments and findings.

Why do birds react at all to flying objects?

Almost all species of bird have to live with the threat of dangerous predators swooping on them out of the sky. The fastest possible escape flight as soon as a predator appears is the only sensible reaction in many cases. In the process, mistakes may also occur, so that birds respond to the sudden approach of animals that are essentially harmless by suddenly flying off.

Airplanes can also prompt birds to take flight, even though the aircraft do not appear as predators. In experiments on birds with different dummies, it was found that escape flight reactions are the natural response to all flying objects. Fear of dummies used many times quickly subsided, but not their attentiveness towards them. Individual features of the flying object, such as shape, size, angular speed etc., are of differing significance as trigger mechanisms. But since wild animals react to enemies according to a complex system, virtually no useful rules can be derived from this for air traffic.

What kinds of reaction occur?

When an airplane appears, all possible levels of excitation are described in birds, from outwardly non-visible physiological reactions to protection, ducking, increased calling activity, restless pacing back and forth, running away, flying off and returning to the same place or a place close by, flying off and leaving the area, right through to panic-like flight reactions.

In addition, during the breeding period, various predatory species of bird repeatedly carry out **pseudo-attacks** and also genuine attacks on gliders, hang-gliders and paragliders. Curlews sometimes launch vicious attacks on model aeroplanes that fly over their breeding grounds, which can also lead to accidents.

Waterfowl which take to the air because of an airplane usually stay in the air for one to three minutes, but sometimes also considerably longer. After this, it takes some time before the birds calm down again and resume their previous activity.

Using modern electronic instruments, it is possible to measure the heart rate of brooding birds. Measurements show that these birds often react to the appearance of airplanes with a marked **increase in heart rate**, in other words they become nervous, even if no outward reaction is visible.

It thus becomes clear that the loss of time immediately associated with taking flight is not the only effect of an airplane on birds which has to be taken into account.

What are the effects of these reactions?

A crucial question that needs to be answered is the extent to which effects can be anticipated on individual life expectancy, reproduction rate and ultimately on population size.

- First of all, any reaction leads to **changes in energy conversion.** In species which fly a lot (e.g. swallows) the energy conversion during flight increases only to three times the base energy conversion, in poor flyers or at high speeds (e.g. in ducks) it sometimes increases to more than 20 times the base figure. In the case of escape and attack flights of e.g. waders of wet meadows, it has to be assumed that the energy consumption corresponds to twelve times the base energy conversion. Even when there is no outwardly visible excitation, the heart rate may show a fifteen-fold increase and energy consumption may at least treble even without physical activity.
- In resting snow geese, it has been found that the **time of food intake during** the day may be reduced by up to 51 % if they are disturbed. Brent geese which are frightened every 30 minutes by aircraft or people must spend 30 % more time feeding compared with birds of the same species in less intensely disturbed areas. When the period of daylight and other resources are limited, it is not always possible to compensate for such loss of time.

Disturbances can thus influence the time and energy budget of birds and hence, for example, the ability to lay down fat reserves for migration and breeding. In many species there is documentary evidence to indicate that breeding success depends on the available energy reserves at the start of the breeding periods. Birds try to make up for the energy deficits that come from constant disturbances by feeding at different times of the day, by feeding at the expense of other activities, e.g. preening, by increased feeding rates or by increased risk taking. Even if it is hardly possible to provide any direct evidence in methodological terms, it becomes clear that individual life expectancy and reproductive capacity may be impaired.

Disturbances can also lead directly to expulsion and thus loss of territory for certain species of bird. In geese, a rate of more than two disturbances an hour can lead to a decrease in the bird population in the area concerned. Breeding birds may for example be driven to the edge of their territory or out of their territory altogether by aircraft, which has obvious consequences for feeding and breeding success. In some cases, breeding areas are abandoned altogether for this reason. Many bird species in Central Europe have been reduced to small scattered populations as the result of a deterioration and decrease in habitat. Thus even the slightest additional damage can lead to further decreases.

Which birds react to airplanes?

- Most reports on disturbances by aircraft concern ducks and waders (plovers). Geese are particularly sensitive to airplanes. Aircraft disturbances are especially striking in those places where the birds gather in **large *swarms***, in our case especially in the area of the Wadden Sea.
- In the literature, negative effects of aircraft **at breeding time** are documented in particular for meadow-breeding waders (including curlews, godwits and lapwings) in relation to model aircraft. Flight reactions of breeding lapwings to powered airplanes have also been documented. In the case of breeding waders (Limicolae), however, air traffic with powered airplanes – in contrast to model aircraft – and low-flying ultralight aircraft (up to 1994, see UL article) – lead more rarely to visible reactions.

The fact that the interests of meadow birds and air sports in particular often come into conflict is explained by their matching "habitat preferences": expansive, open and as far as possible unwooded areas that are remote from residential districts and are or can be extensively used.

Apart from ducks and waders, disturbed reactions to flight activities have been reported for other waterfowl, great bustards, black grouse, various predatory birds and crows. Particular sensitivity to aircraft is shown by breeding colonies, especially those of larger bird species. For colonies of terns, gannets, guillemots and pelicans, almost complete breeding failure has been documented following just a few aircraft fly-overs.

The group of smaller song-birds has hardly been studied. Apart from in two reports on a military jet exercise and an air display, where some small birds reacted with panic-like flight movements, we did not find any reports in the literature about corresponding behavioral impairments. However, the reactions of small birds are difficult to observe. We know from our own observations that starlings at least frequently take flight in response to airplanes. In wine-growing regions, airplanes are used to drive away starlings.

How do birds respond to different types of aircraft?

Most studies on the effects of **model aircraft** are primarily concerned with meadow-breeding waders during the breeding season.

- In an area that has already been used by model aircraft enthusiasts for 17 years, lapwings reacted in two-thirds of fly-overs with protection-seeking behavior (in 50 % of cases as a result of powered airplanes), and sometimes also with escape reactions. A strong reaction was found when several sources of disturbance occurred in combination.
- A newly arrived female lapwing showed substantially greater anxiety than the well-established birds. Even if the meadow birds in this study region appeared to have grown accustomed to the model aircraft to a certain extent, the flying of model aircraft still frequently led to disturbances, especially in combination with people and dogs running

around.

- One author measured escape distances from model aircraft of 150 - 250 m for meadow-breeding waders in the breeding area, and 300 - 450 m for resting birds. On three occasions he observed that breeding lapwings were driven from their nests by model aircraft. The escape distances were in the range 130-200 m. As long as the aircraft flying continued, the birds did not return to their nests.
- In studies on curlews in Southern Germany, losses of egg clutches were detected on several occasions as a result of flying model aircraft. The birds evacuated the areas completely or partly during model aircraft flying and often did not return for the whole day. Young curlews hatched more frequently in areas with no aircraft flying activity than in those where model aircraft were flown.
- After a model aircraft site was set up, the curlew population in Isarmoos fell from a maximum of 15 to 3 - 4 pairs of birds. The short-eared owl, Montagu's harrier, snipe and corncrake all migrated away from the area. Since the habitat was progressively worsening at the same time, however, it is not possible to identify the factor that was ultimately responsible for this migration.
- In almost every large curlew breeding area in the southern region of the Upper Rhine there is at least one site used for flying model aircraft. The illustrates the potentially grave consequences of this type of aerial sports.
- One author studied the propensity of model aircraft for perpetually frightening off birds. Remote-controlled model aircraft resulted in a marked frightening effect on almost all groups of birds. Geese reacted most strongly. It was observed that the main advantage of this frightening technique was that no acclimatization effects occurred. Other authors also assume that acclimatization to model aircraft is hardly possible.

It is worth noting that **hang-gliders and paragliders** can induce greater anxiety in chamois goats and ibexes than other aircraft, including helicopters. In some cases, these animals respond with panic-like flight reactions and no longer appear in the same area again for the rest of the day. A corresponding effect in birds has only once been documented, and this was in black grouse. In the aerial sports regions of Oberallgäu, no decline was observed in any members of the grouse family. In the few direct encounters that were observed, black grouse did not flee.

Larger predatory birds may feel disturbed in their area by hang-gliders and paragliders , and pilots even have to expect attacks. The abandonment of breeding grounds or breeding losses appear to be occurring from time to time by golden eagles as a result of disturbances by aerial sports enthusiasts, although it is difficult to provide any direct evidence of a link.

Reports on the marked negative effects of **ultralight aircraft** are essentially attributable to the low-flying practices (at a maximum height of 150 m) that were required by law until 1994.

- There is evidence to show that, on the landing area of Reichelsheim, Hessen, a small brood of black-tailed godwits (over half the population in Hessen) and curlews died out in the 80s as a result of ultralight aircraft activities. On active flying weekends, the district hunting system of the birds broke up. The many years of air traffic with other aircraft apparently had no negative impact.
- The numbers of resting and foraging Bewick's swans in an area of the Dutch delta region declined from 1400 - 4300 in the period from 1986 to 88 to a few individual

birds in 1989 after a take-off and landing strip for ultralight aircraft was installed nearby and had been in operation for a year.

With the flying laws that have also been in place for ultralight aircraft since 1994 (e.g. minimum flying altitude of 600 m above the ground on cross country flights) and in view of the type of construction of modern ultralight aircraft, their effect on wild birds today can probably be regarded as similar to that of powered airplanes.

With normal **glider** operations, disturbing effects on birds are hardly to be expected: Except at take-off and landing, the thermal-dependent gliders mostly fly at a great height. In the literature there are few specific data on the reactions of birds to gliders/motor gliders.

- The flight pattern of gliders with large wing-spans and a slowly gliding flight movement at what is usually a great height does however seem to fit the generalized pattern of an airborne enemy. In a study on breeding and resting birds in the Wadden Sea, the disturbing effect of motor gliders was considerably greater than that of powered airplanes.
- The scarcity of gliders would also seem to play a role here: the only registered motor glider on the Wangeraage during the period of the study triggered the strongest and longest-lasting reaction of all. As soon as the motor glider came into view, all the birds resting on the salt flats – even the usually unruffled gulls and oyster catchers – took to the air, making calling sounds as they circled the area for a long time.
- In the case of black grouse in an aviary used to reintroduce birds into the wild, panic-like flight reactions were observed with the direct approach flight and fly-over of gliders and motor gliders – much more often than in the case of fly-overs by fighter jets.
- Flight reactions of goats to gliders have been reported from the Alps.

The effects of **powered airplanes** on birds have been reported in particular from the Wadden Sea.

- On various East Frisian islands, resting birds showed a reaction to direct aircraft fly-overs in 50 – 90 % of cases. Resting birds reacted more by taking to the air (57 % of reactions) than breeding birds (22 %) (see "What other parameters influence the reaction?"). While there no marked differences were seen in the effects of aircraft flying at low and medium altitude, there was overall a discernible tendency for higher-flying aircraft to cause less of a disturbance than lower-flying aircraft. In a study on the impact of human disturbance on Brent geese, aircraft or helicopters were the cause of geese taking to the air in 26 % of all cases. While helicopters had the greatest impact, the reactions to airplanes were only slightly weaker. No clear difference was discernible between the impact of aircraft fly-overs at altitudes above or below 150 m.
- In a study on the factors disturbing birds at a high-tide sanctuary in the Dutch Wadden Sea, airplanes and walkers were found to be by far the most importance causes of reactions.
- According to a literature review on the disturbing effects on waders in the Dutch Wadden Sea, airplanes were among the most disruptive factors in the Wadden Sea. The authors presented a model which can be used to calculate the area affected by a disruptive object. This model is based on data relating to escape flight distance, the distance within which birds interrupt their search for food, and the time it takes for the

various disturbing effects to disappear again. In the case of oyster catchers, the affected area for a mud-flats hiker walking at a speed of 3.6 km/h is 20 ha and for an airplane flying at an altitude of 150 m over the mud-flats 15,000 ha. This large area is produced with a 1000 m breadth of impact to the right and left, a speed of 150 km/h and a duration of 30 minutes.

- A group of authors observed the flight of breeding meadow birds from powered airplanes in many cases – both at low altitudes (50 - 100 m) and also at very high altitudes (in some cases then very long protection-seeking behaviour). Powered airplanes induced protection-seeking behaviour in half of cases, and model aircraft in about two-thirds of cases.

In terms of the intensity of the impact which they have on birds, powered airplanes lie between helicopters and jet fighters which are used comparatively little, if at all, in air sports. The disturbing effect of military jet fighters on birds is often less than one would expect in view of their rather unpleasant effects for humans. By contrast, almost all authors come to the conclusion that, of all aircraft, helicopters most frequently lead to reactions in birds and at the same time to the strongest disturbance reactions.

Systematic studies on the effect of **free balloons** on animals do not appear to have been carried out to date. In 1996, the Society of Wildlife Biology in Munich (*Wildbiologische Gesellschaft München*) carried out an extensive survey of experiences on this subject among balloonists, hunters, farmers, nature lovers, biologists and others. In many respects, the evaluation suggests a situation similar to that with other flying devices: most balloon rides are carried out without any discernibly negative consequences for animals. To some degree, many different species of bird and mammal show reactions of fear towards free balloons (flying at low altitude). Through a combination with the burner, which may ignite precisely when the animal is already in a state of nervous tension, panic flight reactions are possible with dramatic consequences for the individuals concerned. However, the effects of silent gas balloons is no less marked.

The latest example of an unfortunate incident: a pair of sea eagles which had nested in the Segeberg district for the first time in 2000 suffered enormous disturbance from a landing hot-air balloon, whereupon they abandoned their brood.

What other parameters influence the reaction?

Since the visual faculties of birds tend to be essentially far better developed than their auditory faculties, they respond less to noise than is generally assumed. Silent flying objects can induce reactions similar in intensity to those induced by noisy aircraft. However, visually comparable loud airplanes on average induce more and stronger reactions in birds than quiet ones.

- In breeding bald-headed eagles in North America, the parameter of noise (in contrast to distance or duration of visibility) played no role in disturbances caused by aircraft.
- In a study on a colony of terns, it was not until jet noise reached 90 and 95 dB (A) that two and four percent, respectively, of the birds took to the air, and a further four percent showed a fright reaction.
- With motorized model aeroplanes, it is above all the irregular changes of volume and frequency that play an important part in the disturbance effect.

There are more conclusive findings on the influence of **flight altitude** than there are on the influence of noise volume, but these findings are rarely based on measured altitude data.

- In one expert appraisal on military air traffic, the altitude of helicopters was calculated from distance with reference to land markings and from the angle. The frequency of bird reactions was clearly dependent on the altitude of the helicopters (at 50 – 80 m there was a reaction in 83 % of cases, at 120 - 150 m in 56 % and at 200 - 300 m in 27 %). But strong reactions were still induced even at greater altitudes. This is confirmed by various other authors.
- Brent geese in Alaska reacted in 68 % of cases to airplanes flying at altitudes lower than 610 m and in 33 % to higher flying aircraft (altitude calculation via land markings, experimental fly-overs and listing into radio communications).
- In two literature reviews for the Wadden Sea, it is concluded in the summary that effects on birds are very marked at altitudes below 500 m (1700 ft) and decrease substantially above this altitude.

The disruptive effect of an airplane depends on the **lateral distance** of the fly-over.

- In various studies, the frequency and intensity of the reaction decreased in inverse proportion to the lateral distance. From 700 to 1000 m upwards, no birds took to the air.
- Geese, however, flew off up to a lateral distance of 1.5 km. The first unrest at the approach of an aircraft occurred on average at a distance of 2.6 km.

In general, it can be said that an airplane travelling at high speed in a straight trajectory has less impact on birds than a slow airplane flying in a curved trajectory.

A stronger reaction is often observed in combination with several sources of disturbance **(stimulus summation)**. Such a situation frequently occurs precisely in those places where air sports attract spectators: flying model aircraft, flying sites for hang-gliders and paragliders and also in areas around airfields, day-tripping activities, people walking and dogs off the leash can cause additional disturbances. The stress caused by people seeking relaxation produces stronger and longer-lasting reactions to airplanes in birds than are seen at times when there are no such leisure activities. Conversely, air traffic, even if it does not cause birds to take to the air, can lead to a substantial increase in the distance of the animals' escape flight from humans.

Some **stimulus-independent factors** also affect the reaction of a bird. For example, breeding birds are inhibited from leaving the nest and for this reason alone react differently to disturbances. The willingness of parent birds to take risks may increase in the course of the day or with advancing incubation and rearing of chicks. Weather and season can also play a role. During the wing moulting period, when they are incapable of flight, ducks show substantially greater sensitivity in their reactions to airplanes than at other times. Birds in relatively large swarms tend more towards escape flight reactions than groups of a few individuals. In mixed groups, species may influence each other in their reactions. In the Wadden Sea, the birds are substantially more sensitive before high tide than after high tide.

Do birds become accustomed to air traffic?

Almost all authors report on habituation effects. It would seem that the frequency and above all the regularity with which an airplane flies past have a decisive influence on the reactions of birds. This is especially striking during military exercises or in the vicinity of airfields, where bird species that are regarded as sensitive can also be found.

- The same bird species which developed a certain tolerance to air traffic on Wadden Sea islands that have an airfield showed considerable flight reactions to comparable fly-overs on Mellum, where there is no airfield in the vicinity.
- Rare types of aircraft in a certain area also produce conspicuously strong reactions.

These correlations provide an explanation for the different results, e.g. with regard to critical flight altitudes, in the various studies or for unusual observations that contradict the results of most other studies.

But there are limits to the capacity for habituation. The uneven and unpredictable movements of model airplanes and to a certain degree also of gliders, hang gliders and low-flying trikes do not generally allow any habituation. In sensitive species (e.g. resting curlews or Brent geese) even regular air traffic does not lead to a greater degree of tolerance. At least some bird species or individuals react to heavy air traffic by leaving the area, and no habituation takes place. If only insensitive birds are then observed, there is a tendency for this to be confused with habituation.

Demands of nature conservation

- Many authors recommend **maximum possible flight altitudes** for airplanes to avoid disturbances of birds or mammals. The minimum altitude figures here range between 150 and 750 m. Most experts recommend a flight altitude of at least 500 m.
- In various projects, there was also seen to be a need for an **adequate lateral distance.** Depending on the sensitivity of the animals studied, this minimum distance ranges from one to eight kilometres (for helicopters).
- In several studies, authors demand that air traffic keep to routes and certain areas. A separation into **areas with regular traffic and areas free of air traffic** on the one hand facilitate habituation and on the other effective protect the rest of the landscape.
- In addition to this proposal not to fly over areas with especially sensitive and threatened species, **seasonal or day-time restrictions of air traffic** are recommended where there are specific or local problems. Examples of this are to set flight shows on a date in late summer or not to fly over ice-free places of refuge for waterfowl during periods of frost.

The original article Kempf, N. & O. Hüppop (1998): "Wie wirken Flugzeuge auf Vögel? - Eine bewertende Übersicht" in *Naturschutz und Landschaftsplanung* 30, (l), pp.17 - 28, is based on a review of 161 publications and expert reports. These also list the citations of these studies, which are not given in this short summary.

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Long-term effects of noise pollution on the avian dawn chorus: a natural experiment facilitated by the closure of an international airport

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The impacts of noise pollution on birdsong have been extensively investigated but potential long-term effects are neglected. Near airports, where noise levels are particularly high, birds start singing earlier in the morning, probably to gain more time of uninterrupted singing before air traffic sets in. In a previous study, we documented this phenomenon in the vicinity of Berlin Tegel airport. In 2020, Tegel airport closed down, giving us the opportunity to investigate potential long-term effects after noise removal and to gain insight into the mechanisms underlying the advancement of dawn singing. We found that several species at the airport shifted their song onset back after the closure and now had similar schedules to their conspecifics at a control site. Some species, however, still sang earlier near the closed airport. While the first suggests plastic adaptation, the latter suggests selection for early singing males in areas with long-lasting noise pollution. Our findings indicate that a uniform behavioural response to anthropogenic change in a community can be based on diverging evolutionary mechanisms. Overall, we show that noise pollution can have long-lasting effects on animal behaviour and noise removal may not lead to immediate recovery in some species.

1. Introduction

Anthropogenic noise is arguably one of the most pervasive and least controlled pollutants, with vehicle and aircraft noise being particularly widespread [1]. In the European Union, for instance, more than 100 million people are affected by hazardous traffic noise levels [2]. These hazards include sleep deprivation, hypertension and cardiovascular disease, metabolic dysregulation, psychological disorders, and reduced cognitive performance [3]. For these reasons, the World Health Organization classified traffic noise as a major threat to public health [1]. Noise is not only detrimental to humans, it also affects many non-human animals, including arthropods, fish, amphibians, birds and mammals [4]. Typically, noise impacts animals on different biological system levels, from physiology to behaviour and ecological processes [5,6]. Hence, it is of major importance to understand how noise pollution affects wildlife [7,8].

Generally, noise can have two types of effect on animals: auditory effects (i.e. impairments of hearing and masking of acoustic signals or cues, and non-auditory effects, such as stress, noise-induced diseases, and changes in predator or prey abundance). Anthropogenic noise has auditory effects in animals that use sound to communicate or to find their prey [9]. For instance, noise from traffic and industry infrastructure interferes with the detection of alarm calls by birds [10,11], which is likely to increase the predation risk in noise-polluted areas. Traffic noise also disrupts the detection of acoustic cues used by greater mouse-eared bats (*Myotis myotis*) to find their insect prey, which leads to a reduced hunting efficiency close to motorways [12]. As for non-auditory effects of anthropogenic noise, a growing body of evidence from different taxa has identified effects on stress physiology and the immune system [13,14], as well as on behaviour, including acoustic signalling [15,16], space use [17,18] and learning [19,20]. Other non-auditory effects include reduced pairing and breeding success [21,22]. Ultimately, noise pollution can affect whole communities [23–26] and alter ecological services [27]. Two recent studies found that the abundance of different bird species and their reproductive success varies with noise pollution levels across a continental scale [28,29].

In the context of noise pollution, studying animal behaviour is of special interest for two reasons. First, behaviour is the interface between the physiological changes in an animal and the environment; second, behaviour can be markedly plastic, allowing rapid adaptations to changing environments. One particular behaviour that has been widely studied in relation to anthropogenic noise is bird song [30,31]. Noise effects on bird song have strong implications for the evolution of signals as well as for conservation [32], and for almost 20 years, researchers have been investigating whether and how birds adjust their songs to anthropogenic noise. It emerges that the most basic mechanism is the regulation of vocal amplitude (the Lombard effect), which is probably present in all birds [33]. In addition, some species also adjust the timing and frequency of their songs in response to anthropogenic noise [30]. Counteracting acoustic masking is crucial for birds because their songs carry vital information. Specifically, birds use their songs in territory defence and mate attraction [34]. Therefore, differences in the efficiency of signal transmission due to noise likely have major fitness consequences.

A particularly severe case of noise pollution is that from aircraft [1]. Noise measurements in bird territories close to airport runways have registered peak levels as high as 87–118 dB(A) SPL [35,36], which is above the limit that birds can compensate through the Lombard effect [37]. Shifts in song frequency are of no help either, as aircraft noise is typically very broadband, covering the entire frequency range of bird songs [38]. On top of this, major airports often operate almost continuously throughout the day, with airplane take-offs every one to two minutes [39]. The resulting extreme noise pollution poses an unusual challenge to birds, most likely surpassing all natural noise sources they have encountered in their evolutionary past. Therefore, noise pollution from airports is not only a special concern for conservation but also an eminent case for research into the mechanisms of song adaptation.

It appears that birds in the vicinity of airports adjust their song timing in relation to the airplane noise. For instance, chaffinches (*Fringilla coelebs*) fell silent during fly-overs from starting airplanes when the noise exceeded 78 dB(A) SPL [35]. In addition to such short-term plasticity in response to single noise events, many bird species in noise-polluted areas begin singing earlier in the morning [35,40,41]. This phenomenon leads to an advancement of the so-called 'dawn chorus' (i.e. the marked peak of singing activity around dawn in the breeding season) by 4–45 min, depending on the species and the airport location [35,40,42]. The dawn chorus in Europe usually starts before airports begin their daily operations, and it is thought that birds at airports advance their dawn song onsets to gain more time of unimpaired singing before the onset of air traffic [35]. This shift seems crucial since singing around dawn is optimal to attract mates and defend territories [43]. It remains unknown, however, how the advancement in song onset in noise-polluted areas arises. Two hypotheses have been put forward to explain the emergence of this phenomenon: (i) population-wide, microevolutionary changes (e.g. through selection for earlier chronotypes), and (ii) behavioural plasticity (i.e. individual short-term changes in song onset in response to changes in the environment) [35,40].

The closure of the Berlin Tegel international airport in November 2020 afforded us the opportunity to test these hypotheses in a natural experiment. Tegel airport opened in 1948 as a military airport and civil aviation with regular flights started operating in 1960 [44]. Thus, the forest bordering the airport was exposed to frequent high-level noise pollution for at least 60 years, which might have led, over the course of many generations, to microevolutionary changes in the local bird populations. In a previous study, while the airport was still operating, we recorded the onset of the dawn song for all species of the bird community in a forest close to the airport and at control sites together with the environmental noise levels, and we then quantified the noise-related shift in the dawn chorus [35]. Now we intend gaining insight into the mechanisms underlying the noise-related advancement of dawn singing. To this end, we repeated the previous study during the first breeding season after the airport closure in the same areas as in the previous study. The selection hypothesis (H1) predicts that birds near the airport still sing earlier than in the control areas. The behavioural-plasticity hypothesis (H2), in contrast, predicts that birds shift back to normal dawn song schedules so that no difference in song onsets times between airport and control locations can be detected.

2. Methods

(a) Field recordings

We recorded the bird dawn chorus at two forested sites, referred to as 'airport' and 'control', on 2, 3 and 4 May 2021. These sites were the same as in a previous study by Dominoni *et al.* [35]. The control forest was chosen because it was close to the airport site (the sites were roughly 4 km apart; electronic supplementary material, figure S1), and it had a similar age and vegetation structure (mixed deciduous and pine forests with little undergrowth). Within each site, recordings were made at 21 locations. To this end, we used 14 AudioMoth audio recorders (v. 1.2.0) [45], seven of which were deployed at each site at the same time, and then swapped between locations the next day. The audio recorders were packed in resealable plastic bags to protect them from humidity and then attached to trees. The locations were chosen so that the surface area of both sites was well covered but the recorded areas did not overlap (based on previous tests, we estimated the recording distance of each unit to be around 100 m). Each recording (sample rate 32 kHz, gain 'medium') started at 03.40 and lasted until 06.30, resulting in 170 files with a duration of 55 s, separated by a 5 s pause (we chose to split up the recording into short files because they are easier to handle, the 5 s pause was necessary to allow the system to save the data on the SD card without overloading the memory).

All recordings were analysed with Avisoft-SASLab Pro software (v. 5.2.08, Avisoft Bioacoustics, Berlin, Germany) by the same observer (LdF). For every recording session (one recording unit, 1 day), the spectrograms (FFT window 256, gain 30) were visually screened until the first bird vocalization was detected and then all following files were listened to. Species songs (or drumming in case of the great spotted woodpecker) were identified and the onset time (minute at which the first bird of each species was heard) was noted. This scoring was done blindly (i.e. the observer was not informed about the site of the recording when identifying the species). To verify that the scoring in the present study was comparable with that of Dominoni *et al.* [35], one recording session was also analysed by one of the observers involved in the previous study (HB). Both observers detected the same 21 species, for 18 of which they had an inter-observer reliability for the dawn chorus onset of 100%, for two species the detected onset time differed by 1 min, and for one species it differed by 2 min.

In addition to the onset of the dawn chorus, we also used the Audiomoth recordings to measure the ambient noise levels. For this purpose, one 55 s file per location was chosen between 06.15 and 06.30. We selected this time period because it is the noise levels after 06.00 that were crucial for the advancement of the dawn chorus at Tegel airport [35]. For the noise level measurements, we selected recordings with no wind and no birds singing close to the recorder. We bandpass filtered the recordings in the range of bird hearing (0.1–10.0 kHz), then corrected them for the frequency response of the microphone and finally applied an A weighting (see 'Recorder calibration' below). Similarly to Dominoni *et al.* [35], we define ambient levels as the sound level (dB(A) RMS re 20 µPa) of the 100 ms window with the highest value in the selected 55 s file.

(b) Recorder calibration

To obtain accurate sound level measurements, it is necessary to correct the recordings for the frequency response of the recording system because microphones do not record all frequencies with the same amplitude. Therefore, we measured the frequency response and the sensitivity of each recorder in the range of bird hearing. All sound generation and analyses for the calibration were performed in R (v. 4.0.4, R Foundation for Statistical Computing) with the package *seewave* (v. 2.1.6) [46]. The calibration was done separately for each audio recorder.

We generated a pulse train (100 Hz–10 kHz in 100 Hz steps, pulse duration 0.2 s including a 0.05 s linear fade-in and 0.05 s linear fade-out) and a 10 s 1 kHz tone. This playback was broadcasted through a Pioneer A-109 amplifier and a JBP Pro III loudspeaker and then recorded with an AudioMoth recorder and at the same time with a Behringer ECM 8000 measuring microphone (connected to a Marantz PMD 660 recorder). The source level of the 1 kHz tone was measured with a Casella CEL-240 SPL meter. The AudioMoth recorder, the measuring microphone, and the SPL meter were mounted 1 m in front of the loudspeaker in an anechoic room, the floor and walls of which were covered with sound-absorbing foam. The frequency response of the loudspeaker was first calculated using the recordings made with the measuring microphone. The central section of each pulse (0.08 s excluding the fade-in and the fade-out) was extracted from the recordings and then bandpass filtered ±200 Hz around the pulse frequency. Thereafter, we calculated the amplitude of each pulse (dB RMS FS). In a next step, we subtracted the amplitude of the 1 kHz pulse from the amplitude values obtained for all other frequencies, such that the amplitude of all pulses is expressed in dB relative to the amplitude of the 1 kHz signal. This procedure was applied to each audio recorder used in this study. We then subtracted the frequency profile of the loudspeaker (measured with the measuring microphone) from the frequency profile obtained for the audio recorders, to obtain the frequency response of each individual recorder. We padded zeros before 100 Hz and after 10 kHz and performed a linear interpolation on the frequency response to obtain 256 values, equally spaced between 0 and 16 kHz, and added the A-weighting factor to the frequency response. We used A-weighting because it is a good proxy for the frequency-dependant sensitivity of bird hearing [47]. The frequency response was then used as an impulse-response filter. The received level of the 1 kHz tone (dB RMS FS) was used to determine the sensitivity of each recording unit. Based on the sensitivity and frequency response curves, we could then obtain the true ambient sound levels from the recordings.

(c) Statistical analysis

Statistical analyses were conducted in R (v. 4.0.4), using the package *lme4* (v. 1.1-26) and *arm* (v. 1.11-2). In line with our previous study [35], we included in the analysis all species that were detected at least at ten different locations at each site. To compare the effect of the site (airport or control) on the onset of dawn chorus before the airport closure [35] with the situation after the closure (present study), we performed a similar analysis as described in [35]. We fitted a multiple linear regression with the onset time (in minutes after civil twilight) as the response variable for all species together (global model). The peak ambient level measured from the recordings, and the site (airport versus control) were included as fixed predictors. The date (3 May, 4 May and 5 May) was also included as a fixed predictor to account for potential day-to-day variability in singing activity independent of noise levels and site (due, e.g. to differences in the weather). The species was included as a random factor to account for species-specific variability in the singing behaviour. The recorder ID was used as a random factor to account for potential differences in recording quality. We checked model fit by visual inspection of the diagnostic plots [48] (i.e. we made sure that residuals and random effects were normally distributed, residuals plotted against fitted values did not show any signs of heteroscedasticity or any obvious trend, and that there were no autocorrelations in the residuals). Credible intervals of estimates were obtained by simulating the posterior distribution of the model 1000 times and calculating the 2.5% and 97.5% percentiles of the simulated estimates [49]. In addition to the global model, we also analysed the effect of the site for each species separately because previous studies have found species-specific effects of the ambient noise on dawn chorus onset times [35,40,50]. For this purpose, we fitted 15 sub-models (one per species) with the date, ambient noise level and the site as predictors of the onset of dawn chorus, and with the recorder ID as a random effect. We used the same procedure as described for the global model to check model fit and to calculate credible intervals for each of the 15 species-specific models. Altogether, we constructed 16 different models that investigated the long-term effect of noise pollution on the onset of the avian dawn chorus: one global model, across all species, and 15 species-specific models. Because our aim was to compare the onset of the dawn chorus before and after the closure of the airport, we refitted the species-specific models with the data from [35] to obtain the respective estimates and credible intervals.

3. Results

After the closure of the airport, the median peak level of environmental noise at the airport site was 46.2 dB(A), which is a drop by more than 28 dB(A) compared to the noise levels when the airport was operating (two sample t-test: 95% confidence interval = −33.69, −28.34; $p < 0.001$). Still, the airport locations were on average somewhat noisier than the control locations (two sample t-test: 95% confidence

Table 1. Estimates, credible intervals and s.e. of the general linear mixed model explaining the dawn chorus onset time across all species (global model). The intercept represents the average onset time on 2 May at the control site. The 'site' variable shows the effect of the airport site relative to the control site. Statistically significant variables are shown in italics.

	estimate (95% CRI)	s.e.	*t*-value
(intercept)	26.62 (13.51, 39.01)	6.53	4.11
site	*−3.83 (−6.71, −0.96)*	*1.46*	*−2.66*
peak ambient level	−0.11 (−0.36, 0.14)	0.12	−0.85
date 3 May	−0.75 (−3.87, 2.24)	1.58	−0.49
date 4 May	1.28 (−2.01, 4.31)	1.65	0.76

interval = 1.41, 9.02; $p = 0.008$), but this difference was as little as 3.9 dB(A) (electronic supplementary material, figure S2).

In total, we recorded 46 species in the dawn chorus recordings, 45 at the airport site and 33 at the control site (electronic supplementary material, table S1). Of these, 15 species were detected more than 10 times at both sites, including all of the 10 species analysed in the previous study when the airport was still operating. The order in which the different species started singing around dawn was similar across all recording locations (electronic supplementary material, figure S3).

The global model indicated that birds near the airport started the dawn chorus on average 3.83 min earlier compared to birds in the control forest (table 1). However, unlike in the previous study, the onset of the dawn chorus did not vary with ambient noise levels (table 1). The day of the recordings had also no significant effect on chorus onset times (table 1).

While the global model points to a persisting effect of the airport site on the onset of the dawn chorus after the airport was closed (table 1), our species-specific analyses show that the birds' reactions to the closure of the airport differed between species. The bird species that we considered in our analyses fall into three categories: the species that started the dawn chorus significantly earlier at the airport site when the airport was operating (seven species, figure 1*a*), the species that did not sing significantly earlier at the airport when it was operating (three species; figure 1*b*), and the species that were not analysed in the previous study because they occurred at less than ten locations per site but have now passed this threshold after the closure of the airport (five species; figure 1*c*).

Of the seven species in the first category that commenced the dawn chorus earlier at the airport site while it was operating (figure 1*a*), five shifted the chorus onset to later times after the airport was closed down, namely robins, great tits, blue tits, chaffinches and great spotted woodpeckers. The effect sizes in the two tit species were larger (greater than 2 min) than in the other three species (less than 2 min, credible intervals centred on zero) and they fell in-between zero and the values measured while the airport was operating. Blackbirds and nuthatches still sang considerably earlier at the airport site compared to the control site (effect size greater than 5 min, credible interval not overlapping with 0), just as they did when the airport was in operation (figure 1*a*, table 2*a*).

The species in the second category (those that did not sing significantly earlier in the presence of noise) shifted their dawn song onsets in different directions after the noise removal (figure 1*b*): song thrushes and woodpigeons started singing considerably earlier at the airport (on average 4.6 and 21.1 min, respectively; table 2*b*), whereas wrens started singing later at the airport compared to the control area (on average 7.7 min).

Finally, in the third category (figure 1*c*), four of the five species that were not included in the previous study [35] tended to sing earlier at the airport compared to the control site although the noise pollution had been removed for almost six months (mean effect size between 4 and 12 min; table 2*c*). It is important to note that the sample sizes in this group of species was smaller than in the other two categories (electronic supplementary material, table S1) and probably because of this the variation in the data resulted in wide credible intervals (that overlapped zero in the short-toed treecreeper, the wood warbler and the willow warbler), calling for a careful interpretation of the results.

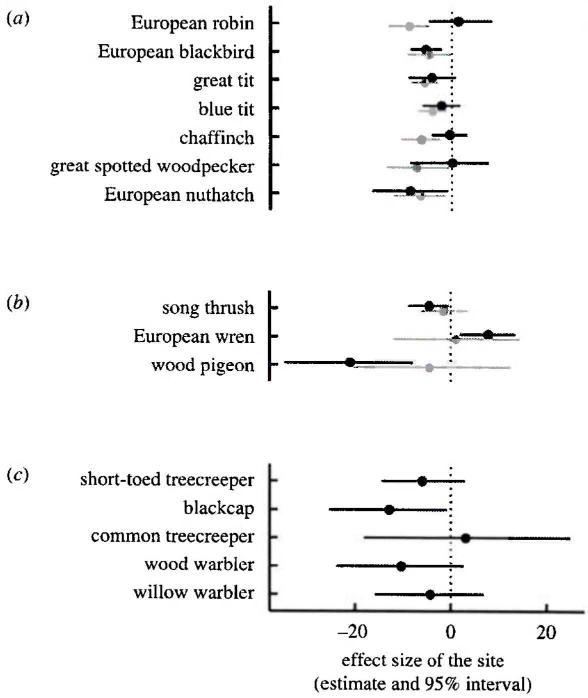

Figure 1. Effect sizes (average and 95% credible interval) of the difference in the onset of dawn song between the airport site and the control site. The dotted line indicates no effect of the site, i.e. birds start singing at the same time in both forests. Negative values indicate earlier song onsets at the airport than in the control forest and positive values indicate later song onsets at the airport than in the control forest. Grey: airport operating (spring 2013 and 2014); black: airport closed (spring 2021). Species are organized in three categories based on their behaviour when the airport was operating [35]: (*a*) bird species that sang significantly earlier at the airport, (*b*) bird species that did not sing significantly earlier at the airport and (*c*) bird species that were not investigated when the airport was operating.

4. Discussion

Evidence for the impact of anthropogenic noise on animals is growing [6,28,51] but only few studies have examined potential long-term effects. Birds advance the onset of their diel singing activity in areas that are heavily noise polluted during the day [40–42], and we hypothesized that this is

Table 2. Estimates, credible intervals and s.e. of the species-specific linear mixed models explaining the dawn chorus onset time as a function of the site. The intercept represents the average onset time on 2 May at the control site. The 'site' variable shows the effect of the airport relative to the control. Species are organized in three categories based on their behaviour when the airport was operating [35]: (*a*) bird species that sang significantly earlier at the airport, (*b*) bird species that did not sing significantly earlier at the airport and (*c*) bird species that were not investigated when the airport was operating. Statistically significant variables are shown in italics.

species		estimate (95% CRI)	s.e.	*t*-value
(*a*) species that sang earlier at the airport while it was operating				
European robin	(intercept)	−28.26 (−35.01; −21.87)	3.71	−7.59
	site	1.37 (−4.8; 8.3)	3.82	0.4
	date 3 May	*16.97 (9.56; 24.46)*	*4.5*	*3.71*
	date 4 May	12.37 (4.24; 20.61)	4.8	2.57
European blackbird	(Intercept)	−0.47 (−3.9; 2.78)	2	−0.19
	site	*−5.44 (−8.68; −2.1)*	*1.97*	*−2.77*
	date 3 May	0.69 (−3.21; 4.59)	2.36	0.25
	date 4 May	0.47 (−3.73; 4.85)	2.45	0.12
great tit	(intercept)	11.24 (6.48; 16.05)	2.89	3.94
	site	−4.17 (−9.05; 0.78)	2.93	−1.43
	date 3 May	−1.52 (−7.13; 4.24)	3.47	−0.49
	date 4 May	1.89 (−4.25; 7.9)	3.68	0.43
blue tit	(intercept)	17.7 (13.99; 21.44)	2.27	7.76
	site	−2.18 (−6.16; 1.75)	2.34	−0.87
	date 3 May	2.29 (−2.23; 7.18)	2.8	0.81
	date 4 May	−3.09 (−8.08; 2)	2.87	−1.07
chaffinch	(intercept)	21.61 (17.89; 25.22)	2.08	10.4
	site	−0.43 (−4.17; 3.12)	2.13	−0.21
	date 3 May	*−4.47 (−8.73; −0.41)*	*2.53*	*−1.78*
	date 4 May	−0.29 (−4.74; 3.95)	2.64	−0.15
great spotted woodpecker	(intercept)	38.67 (31.02; 46.59)	4.61	8.37
	site	0.1 (−8.74; 7.6)	4.75	0.09
	date 3 May	4.76 (−4.7; 14.07)	5.67	0.82
	date 4 May	0.54 (−9.04; 9.98)	5.81	0.07
European nuthatch	(intercept)	53.95 (45.65; 62.22)	4.8	11.19
	site	*−8.69 (−16.5; −0.8)*	*4.65*	*−1.87*
	date 3 May	2.29 (−6.84; 12.27)	5.65	0.49
	date 4 May	−10.08 (−19.48; −0.62)	5.77	−1.75
(*b*) species that did not sing earlier at the airport while it was operating				
song thrush	(intercept)	−5.78 (−10.11; −1.24)	2.49	−2.37
	site	*−4.58 (−8.96; −0.36)*	*2.54*	*−1.8*
	date 3 May	−4.34 (−9.41; 0.62)	3.04	−1.4
	date 4 May	0.48 (−4.98; 5.61)	3.18	0.23
European wren	(intercept)	6.3 (0.41; 12.39)	3.32	1.86
	site	*7.72 (1.92; 13.28)*	*3.4*	*2.3*
	date 3 May	−5.88 (−12.95; 1.22)	4.15	−1.41
	date 4 May	−0.67 (−7.55; 6.36)	4.05	−0.16
wood pigeon	(intercept)	49.5 (36.46; 61.88)	7.41	6.67
	site	*−21.03 (−34.71; −7.99)*	*7.69*	*−2.71*
	date 3 May	8.48 (−5.75; 22.17)	8.71	0.98
	date 4 May	*18.72 (2.15; 35.84)*	*9.96*	*1.9*
(*c*) new species that were not analysed while the airport was operating				
short-toed treecreeper	(intercept)	25.99 (17.59; 34.72)	5.18	5.01
	site	−6.01 (−14.42; 2.92)	5.34	−1.17
	date 3 May	2.16 (−8.55; 13.06)	6.42	0.39
	date 4 May	−4.81 (−15.87; 6.22)	6.45	−0.72

(*Continued.*)

Table 2. (*Continued.*)

species		estimate (95% CRI)	s.e.	*t*-value
blackcap	(intercept)	42.37 (28.27; 56.18)	8.19	5.22
	site	*−12.88 (−25.38; −0.71)*	*7.65*	*−1.71*
	date 3 May	−7.05 (−21.68; 8.44)	9.03	−0.8
	date 4 May	1.51 (−15.73; 18.42)	9.86	0.15
common treecreeper	(intercept)	41.26 (21.75; 60.92)	11.32	3.64
	site	3.11 (−18.07; 24.93)	12.05	0.28
	date 3 May	−8.53 (−34.61; 18.45)	15.79	−0.57
	date 4 May	−0.3 (−22.34; 24.06)	13.56	0
wood warbler	(intercept)	72.49 (59.67; 85.52)	7.71	9.36
	site	−10.38 (−23.79; 2.65)	7.88	−1.28
	date 3 May	*−17.47 (−34.67; −0.45)*	*9.87*	*−1.79*
	date 4 May	−4.81 (−21.56; 12.26)	9.51	−0.47
willow warbler	(intercept)	69.22 (59.18 79)	5.95	11.66
	site	−4.34 (−15.71; 6.83)	6.36	−0.72
	date 3 May	−8.47 (−21.58; 3.18)	7.25	−1.18
	date 4 May	1.69 (−11.8; 16.18)	8.35	0.18

either the result of behavioural plasticity or the outcome of selection for earlier chronotypes [35]. Here, we used the opportunity of the closure of an international airport to test these hypotheses. We found that most species at the airport shifted their song onsets back after the closure and had now similar dawn song schedules as their conspecifics in a control forest. However, some species still started singing earlier in the vicinity of the airport and a general trend of earlier dawn song onsets at the airport could still be detected across the entire bird community (table 1).

Thus, we found support for both the selection (H1) and the behavioural-plasticity hypothesis (H2). In line with H1, blackbirds, nuthatches, song thrushes, wood pigeons and blackcaps still sang earlier at the airport after the closure (figure 1). There is ample evidence that environmental selection through noise may shape acoustic signals, resulting in population-wide changes in signal characteristics in many taxa (reviewed in [52–54]). For instance, grasshoppers from noisy road-side habitats produce mating songs with elevated frequencies that are less masked by the vehicle noise and this increased song frequency persist when the insects are transferred to a silent room [55]. Moreover, there is a cross-generational effect of the noise, as the offspring from road-side grasshoppers also produce higher-pitched songs, even when they are reared with no noise exposure [16]. Our study suggests that not only the signal itself but also when it is produced can be subjected to more permanent shifts in chronically noisy environments. Such a long-term shift may be based on selection for certain chronotypes [35]. Several studies have shown that the timing of song onset and other behaviours can be under sexual selection [56–58]. Likewise, the timing of dawn song could be under environmental selection, with the massive noise pollution from aircraft leading to the selection of males with earlier song onsets. Such a scenario would explain the patterns we observed in the species that still sang earlier at the airport although noise pollution had stopped (e.g. song thrush, blackbird and nuthatch; figure 1). If the observed persistence of the advanced song timing indeed reflects selection for earlier chronotypes, then we would expect that these species will return only slowly to later song onsets at the silent airport site, probably over the course of several generations.

By contrast, robins, great tits, blue tits and chaffinches had shifted back their song onsets at the airport (figure 1), suggesting noise-dependant plasticity of dawn song timing in these species. Likewise, great spotted woodpeckers started drumming later in the morning at the airport after it had been closed, resulting in similar daily routines as their conspecifics in the control forest. Thus, the onset of drumming in woodpeckers appears to be as plastic as the dawn song in some songbird species and, just as well, modulated by the level of noise masking later in the day. Noise-dependant song plasticity is well documented in birds (reviewed in [30]). Presumably all extant birds exhibit the Lombard effect (i.e. they increase their vocal amplitude when background noise levels rise) [33]. In addition, some species may also adjust song pitch [59] or song rate [60] in response to anthropogenic noise. Spotless starlings (*Sturnus unicolor*) and house sparrows (*Passer domesticus*) shifted their dawn chorus onset on a daily basis when they were experimentally exposed to traffic noise [61], which is in line with the behavioural-plasticity hypothesis. Similarly, most species in our study shifted the onset of their dawn chorus to later schedules after the noise pollution from the airport ceased, corroborating the notion of noise-related song plasticity. Sierro *et al.* [42] suggested that the advanced blackbird dawn chorus at airports is also a plastic adjustment, as the observed birds shifted song onsets only early in the season, when the dawn chorus overlapped with aircraft noise at their study site in Spain. However, the two studies conducted at Tegel airport indicate that the dawn chorus in blackbirds was affected by long-term effects of noise pollution. Blackbirds near the operating airport began the dawn chorus significantly earlier even though the song onset did not overlap with aircraft noise (which set in about 70 min later) [35], and they still sang earlier six months after the closure of the airport (present study). Taken together, these findings support the selection hypothesis rather than the behavioural-plasticity hypothesis for this species. Conflicting results from different locations may be accounted for by latitudinal differences in the onset of the dawn chorus and, related to this, in the resulting response to noise pollution, as suggested by Gil *et al.* [40]. Indeed, no consistent dawn chorus shift could be found in bird communities around tropical airports [50]. These differences between tropical and temperate birds suggest that biogeography can have substantial effects on how animals respond to anthropogenic change [41].

Although the exact mechanism underlying the observed behavioural plasticity in our study is not known, the results indicate that some bird species are able to anticipate the onset of noise masking later in the day and to flexibly adjust their song onset accordingly. In a classic experiment, Gwinner [62] demonstrated that social sound cues can function as zeitgeber for circadian rhythms in songbirds, in particular, he found that Eurasian siskins (*Spinus spinus*) and European serins (*Serinus serinus*) synchronize their daily activity patterns to the periodic broadcast of conspecific song. Our findings suggest that other periodic sound cues, such as anthropogenic noise, can have similar effects on the chronobiology of at least some bird species.

In addition to noise-induced microevolutionary shifts and song plasticity, the onset of dawn song may also be affected indirectly by the massive noise pollution, such as through changes in the predatory landscape. It is known that Passerines sing more and earlier when the perceived predation pressure is low [63]. Moreover, anthropogenic noise can disrupt both the distribution [23] and the hunting success [64] of predators. Therefore, heavy noise pollution might lead to reduced predation pressure on birds and, in turn, result in advanced song onset. On the other hand, anthropogenic noise can also mask the alarm calls of songbirds [10] which then increases predation risk. Without empirical data, however, it is impossible to tell what the outcome of these opposing factors is, and it remains to be shown whether the potential noise-induced changes in predation indeed affect the onset of the dawn chorus.

While there is increasing interest in the impacts of anthropogenic noise on wildlife [65], potential long-term effects have been neglected. One notable exception comes from the work by Clinton Francis and colleagues on the ecological impacts of noise from gas well compressors in New Mexico. These compressors emit continuous noise at high amplitudes, which has strong effects on the behaviour of birds and mammals, leading to large-scale modifications in plant communities through altered seed dispersal and pollination [27]. In some areas, the compressors had been switched off (after running for a decade or so) but the plant community did not recover within the first four years after the noise removal [66]. This long-term disruption is the outcome of cascading ecological effects, in which the negative impact of noise pollution may persist for longer periods than in our study that addressed behavioural responses of individual animals. However, our results indicate that noise pollution can also have long-lasting effects on individual behaviours in some species.

After Tegel airport was shut down, the noise levels in the adjacent forest dropped massively as expected. It must be noted, though, that even after the closure the ambient noise was slightly higher at the airport site than the control forest. However, the average ambient noise level at the airport locations was 46 dB(A) SPL, which is within the range of natural noise levels in a temperate forest [30,67]. Moreover, the mean difference in noise levels between the airport and the control site was lower than 4 dB, which is unlikely to affect the song timing. In previous studies, shifts in the dawn chorus were related to much larger noise differences, namely 8–30 dB [61], 20–25 dB [40] and 30 dB [35]. Indeed, our global model indicated no effect of the noise level on the onset of dawn chorus. Therefore, we are confident that the observed advances in dawn singing near the airport in our study were due to carry-over effects of the noise pollution from previous years rather than the current differences in ambient noise levels.

In conclusion, our study suggests that intense anthropogenic noise pollution can have long-term consequences for animal behaviour, even after noise emissions have ceased. Specifically, we still observed advanced dawn singing six months after an international airport stopped operating, which means that birds did not shift their behavioural routines back to normal times after the massive noise pollution from aircraft was removed. On the other hand, some species quickly shifted their song onset back to the typical schedule of undisturbed conditions, illustrating the complexity of noise pollution impacts on wildlife. Our study indicates that both phenotypic plasticity and population-wide long-term changes may lead to a noise-induced advance of dawn chorus onsets in different species. A better understanding of the long-term consequences of pollution on organisms and ecosystems is of major importance for conservation so that mitigation and avoidance measures can be implemented to minimize not only immediate but also long-term impacts.

Data accessibility. The data used in this study are available from the Open Research Data Repository of the Max Planck Society (https://doi.org/10.17617/3.EGLBLP) [68] and in the electronic supplementary material [69].

Authors' contributions. L.F.: data curation, formal analysis, investigation, methodology, writing—original draft and writing—review and editing; H.B.: conceptualization, funding acquisition, investigation, methodology, writing—original draft and writing—review and editing.

All authors gave final approval for publication and agreed to be held accountable for the work performed therein.

Conflict of interest declaration. We declare we have no competing interests.

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CONTENTS

1 INTRODUCTION

This report is a detailed account of an investigation into Public Safety Zones (PSZs) at Ireland's three principal airports; Cork, Dublin and Shannon.

The investigation was performed by ERM Environmental Resources Management Ireland Ltd on behalf of the Department of Transport (DT) and the Department of Environment, Heritage and Local Government (DoEHLG) between December 2000 and June 2003 (1) (2).

A technical report was issued for public comment on 23rd June 2003, and three 'public information' days were held in July 2003 at Cork, Dublin and Shannon airports.

Over 130 people attended the information days, and a total of 42 written submissions were received up until 28th August 2003.

In response to the public comments this revised technical report was issued on 30th September 2003.

1.1 STRUCTURE OF THIS REPORT

This report is set out as follows:

- this section, *Section 1*, provides a synopsis of the project team who performed the work and undertook the public consultation, and it also provides background to Public Safety Zones (PSZs);
- *Section 2* outlines the processes undertaken in defining and calculating the PSZs proposed for Cork, Dublin and Shannon airports;
- *Sections 3, 4* and *5* illustrate the calculated PSZs for Cork Airport, Dublin Airport and Shannon Airport, respectively;
- *Section 6* provides ERM's recommendations and conclusions for PSZs at Cork, Dublin and Shannon airports;
- *Annex A* provides a detailed and mathematical explanation of the calculation method;

(1) Environmental Resources Management. Contact: 22 Earlsfort Terrace, Dublin 2.

(2) Department of Transport (formerly the Department of Public Enterprise) and Department of the Environment and Local Government (2000). Terms of Reference for the preparation of Recommendations for Public Safety Zones in the Vicinity of Dublin Airport. Letter of 29th November 2000, from Martina Walsh, Secretary to the Public Safety Zones Working Group, Aviation Regulations & International Relations Branch.

- *Annex B* provides an overview of risk and land-use planning, expert opinions, and the development of criteria and policy for Cork, Dublin and Shannon airports;

- *Annexes C, D* and *E* detail the assumed aircraft movement data and provide an example risk calculation for Cork Airport, Dublin Airport and Shannon Airport, respectively;

- *Annex F* details ERM's response to the public comments received following issue of the technical report on 23rd June 2003 and the information days held in July 2003 at Cork, Dublin and Shannon airports.

1.2 *PROJECT TEAM*

Davies, Paul. Dr Paul Davies is a Partner of ERM. He has an honours degree in Mechanical Engineering, a doctorate in Quantitative Risk Assessment, and over 15 years experience in the field. This experience has covered fire, explosion, toxic, and crash hazards in process operations, storage facilities, road, rail, air and pipeline transport, quarrying, offshore platforms, ports and power generation.

With regards to airports and aircraft, Paul has been the project director, manager and/or principal analyst for numerous studies. These include: the investigation of risks to persons 'on-the-ground' from potential aircraft crashes at Manchester Airport (this work was presented as evidence for Queens Council at the Public Inquiry into the Proposed Second Runway at Manchester Airport); a peer review of the assessment of risk to major hazard installations due to runway re-alignment at Liverpool Airport; the assessment of risks presented to aircraft from the blasting of rock during the development of Hong Kong's Chek Lap Kok Airport; methodology development for the investigation of third party risk (land-use planning issues) for the proposed location of a second Sydney Airport; and an assessment of the risks to persons 'on-the-ground' in the vicinity of Farnborough Aerodrome.

O'Riordáin, Seán. Sean is the Managing Director of ERM's Dublin office. He joined ERM from the Institute of Public Administration, Dublin (IPA) in 2000. He continues to contribute to the planning and regional development elements of the IPAs MA Local Government programme. He is also a visiting lecturer in Planning at the University of Dublin, Trinity College.

Sean has widespread experience in liaising with public agencies, including the EU, and has been involved with research into public management issues in Ireland and the European Union generally. This includes undertaking evaluation and assessment of regional policy initiatives in Ireland and elsewhere in the European Union and Central and Eastern Europe. Since joining ERM he has been involved in work addressing the National Spatial Strategy and local and regional planning.

Quinn, Daniel. Daniel is a Senior Consultant with ERM. His principal areas of work include hazard identification, scenario quantification, risk evaluation and mathematical modelling of fire, gas and crash impacts. Projects include the risk assessment of gas compression stations, power stations, underground gas storage facilities, sulphur trioxide/oleum transport, petroleum transport, management factors in the prevention and cause of accidents associated with the transport of hazardous materials by road, rail and inland waterway; and risks profiling of flammable gas storage and delivery systems.

With regards to airports and aircraft, Daniel was the principal analyst for the assessment of risks to persons 'on-the-ground' from potential aircraft crashes in the vicinity of Farnborough Aerodrome.

Williams, Kirsten. Kirsten is a Social Scientist/Social Planner with considerable experience in environmental impact assessment, social impact assessment and strategic planning components of large multi-disciplinary infrastructure projects. Ms Williams also designs, manages and conducts consultation and evaluation processes, is experienced in strategy and policy development, and is a highly experienced Project Manager.

Projects undertaken have covered a wide range of industries including transportation (roads, rail, ports and airports), construction, mining, housing, education, tourism, recreation, public utilities, water resources, forestry, agriculture, pipelines, and foreign aid. In addition to her extensive European and Australian experience, Ms Williams has been responsible for undertaking social and environmental resource assignments in China and Indonesia for a major international donor agency, and more recently for BP in Turkey. Areas of focus have included environmental and social impact assessment, poverty alleviation, community and stakeholder consultation, natural resource management, infrastructure development and institutional strengthening. More recently, Kirsten has been involved in the development Ireland's National Spatial Strategy, revision of Irelands Nuclear Emergency Plan, and a Strategic review of Ireland's rail network.

1.3 BACKGROUND

The risks to persons 'on the ground' from aircraft crashes have been appreciated for some time. As such, Ireland, as do many other countries, operates 'protection zones' at the end of runways where the risk is greatest.

In Ireland, these zones are currently referred to as 'red zones' and serve to aid safe navigation of aircraft and to protect the public on the ground (1). This is done by limiting the type and allowable height of buildings and structures within the zones.

(1) In Ireland, a number of terms have been used when referring to the 'red zones', for example safety zones, and even public safety zones. The reason for this, most probably, relates to the (existing) dual purpose of the 'red zones' (i.e. to aid safe navigation of aircraft, by providing an obstacle clearance surface, and to protect persons on the ground by controlling land-use (within the zones)). In this report, the existing zones are referred to as 'red zones' and those zones proposed to protect people 'on the ground' as public safety zones or PSZs.

Advances in modelling techniques have made it possible to quantify the risks to the public (on the ground) from aircraft crashes. These techniques have shown that the risk pattern 'on the ground' bears little relation to the extent and shape of the red zones. Therefore, a set of protection zones, termed Public Safety Zones (PSZs), have been recommended for Cork, Dublin and Shannon airports. If adopted, these PSZs will help protect the public, whilst the red zones will continue to aid safe navigation of aircraft.

Two 'individual risk values' have been assessed in determining appropriate PSZs at Cork, Dublin and Shannon airports. They are 1 in 100,000 per year and 1 in one million per year (1). An inner and an outer PSZ, corresponding to these risk values, have been set for each runway.

These 'individual risk values' were selected because they are established in the setting of protection zones at airports, for example in the Netherlands and the UK (as discussed in *Section 1.3.1*); and because they are comparable with those used in setting protection zones around chemical installations in Ireland and internationally. Further details are provided in *Annex B*.

Furthermore, in calculating and setting the PSZs for Cork, Dublin and Shannon airports it was recognised that they may impact upon existing and proposed land-use in the vicinity of the airports. As such, the study scope was broadened to investigate the potential land-use implications of the proposed PSZs. It was found that there would be no changes to existing land-use around Cork, Dublin and Shannon airports, and only minor alterations to proposed development plans (i.e. either a reduction in housing density or a variation to a proposed location). Further details are provided in *Annex B*.

In summary, this study has led ERM to propose a two-zone PSZ system for Cork, Dublin and Shannon airports, i.e. an inner and an outer PSZ. The calculation and setting of these zones, and the proposed criteria/policy to apply in operating these zones are outlined in the following sections.

1.3.1 *The Experience of Setting PSZs in the Netherlands and the United Kingdom*

Studies performed in the Netherlands and the UK have drawn similar conclusions to the investigation of PSZs in Ireland. This has resulted in the setting of new/revised PSZs at the end of runways at Schiphol Airport and at all major UK airports (2) (3).

The extent of the Dutch and UK PSZs has been based on the individual risk of fatality. The Dutch government has adopted both an inner and outer PSZ set at an individual risk of 1 in 100,000 per year and 1 in one million per year,

(1) Individual risk of 1 in 100,000 per year; i.e. 10^{-5} or a 0.00001 chance of death per year for an individual exposed 24 hours per day, 365 days per year. Individual risk of 1 in one million per year; i.e. 10^{-6} or a 0.000001 chance of death per year for an individual exposed 24 hours per day, 365 days per year.

(2) Ale, B.J.M. and Piers, M. (2000). The Assessment and Management of Third Party Risk Around a Major Airport. Journal of Hazardous Materials, 71, 1-3, pp 1-16.

(3) UK Department of the Environment, Transport and the Regions (DETR). (1997). Third Party Risk Near Airports and Public Safety Zone Policy. R&D Report 9636. National Air Traffic Services, London.

respectively (1). By comparison, the UK government has adopted only a single PSZ set at 1 in 100,000 per year.

Within the PSZs that are set at an individual risk of 1 in 100,000 per year, both the Dutch and UK governments prevent any further building. In addition, the Dutch government plan to remove all existing housing within this zone. This compares with the UK government's decision to allow all existing developments to remain within this zone.

In addition, within the Dutch government's outer PSZ (i.e. set at a risk of 1 in one million per year), no future development of housing, hospitals and/or schools is permitted. However, all existing development is permitted to remain. This compares with the UK's approach of allowing unrestricted development outside the 1 in 100,000 PSZ (in respect of the risk from aircraft).

Annex B provides further details on the zones, criteria and policy adopted in the Netherlands and the UK.

(1) Individual risk of 1 in 100,000 per year; i.e. 10^{-5} or a 0.00001 chance of death per year for an individual exposed 24 hours per day, 365 days per year. Individual risk of 1 in one million per year; i.e. 10^{-6} or a 0.000001 chance of death per year for an individual exposed 24 hours per day, 365 days per year.

2.1 *IDENTIFYING AN APPROPRIATE METHODOLOGY*

In determining the most appropriate method to use in calculating Public Safety Zones (PSZs) for Cork, Dublin and Shannon airports, a review was undertaken of the methodologies used by the Dutch and UK governments in setting PSZs at their airports (1) (2).

Both governments' methods have been translated into computer models, with the results used to develop policy and set the size, shape and extent of PSZs in these countries (3) (4). The approaches used have drawn upon the work of others during this period, and an overview of some of these methods is given in the UK government's report on third party risk around airports and in a recent paper on the approach adopted in the Netherlands (5) (6).

The principal difference between the two approaches is the adoption of different crash location models. In the Netherlands, the probability of crash location is related to individual flight paths (known as a curve-linear approach). By comparison, the UK method relates potential crash location to a runway's extended centreline.

Intuitively, a potential crash location is related to an aircraft's flight path, and so the Dutch approach appears to offer improved modelling accuracy. However, in many accident reports no details of an aircraft's intended route are given and hence, compared with the UK approach, fewer accidents are available to form the basis of the Dutch model. Considering the already 'small' set of accidents upon which the UK model is based, it can be argued that the Dutch approach has less statistical basis.

Further support for the UK approach is given by the fact that landing aircraft (half of all movements) tend to align with the extended runway centreline at considerable distances from the runway (e.g. 10 km or more) and that the crash rate for landings is approximately 2½ times that of departures. Hence, landing crashes (which are likely to be distributed about the extended runway centreline) have a greater influence on the overall distribution of crash locations.

With regards to accident consequences, both approaches use the extent of potential crash area to estimate fatal injuries, and relate this area to Maximum

(1) Ale, B.J.M. and Piers, M. (2000). The Assessment and Management of Third Party Risk Around a Major Airport. Journal of Hazardous Materials, 71, 1-3, pp 1-16.

(2) Cowell, P.G., et al. (2000). A Methodology for Calculating Individual Risk Due to Aircraft Accidents Near Airports. R&D Report 0007. National Air Traffic Services, London.

(3) Ministerie van Verkeer en Waterstaat, Den Haag. (19-Dec-99). The Future of the National Airport [Schiphol].

(4) UK Department for Transport. (10-Jul-02). Control of Development in Airport Public Safety Zones. Circular 1/2002.

(5) UK Department of the Environment, Transport and the Regions (DETR). (1997). Third Party Risk Near Airports and Public Safety Zone Policy. R&D Report 9636. National Air Traffic Services, London.

(6) Refer to footnote 1, page 6.

Aircraft Weights (MAW) (1). Similarly, crash rates are based on established accident databases, and modified to reflect so called 'first-world' operations (i.e. eliminating accidents specific to countries where aircraft types and aircraft/airport operations are not comparable to Western Europe and the United States).

With the above in-mind, the model used to calculate PSZs for Cork, Dublin and Shannon airports is based upon the method employed on behalf of the UK government. The method is detailed in *Annex A*.

2.2 *IDENTIFYING APPROPRIATE GUIDANCE (RISK CRITERIA AND POLICY)*

As stated in *Section 1.3* a two-zone Public Safety Zone (PSZ) system is proposed for Cork, Dublin and Shannon airports; an inner PSZ representing an individual risk of 1 in 100,000 per year, and an outer PSZ representing 1 in one million per year (2).

Within the PSZs the following land-use policy is proposed:

- prevent further development within inner PSZs, but allow existing developments to remain; and
- allow existing developments to remain within outer PSZs, but prevent high density housing development, and the building of schools, hospitals and facilities attracting large numbers of people (for further detail refer to *Section 6*).

These 'individual risk values' (i.e. criteria) and the associated policy on land-use within the PSZs are based upon:

- a review of the established risk criteria used to protect the public from industrial hazards both in Ireland and internationally;
- a comparison of these 'industrial' criteria with those recently implemented at airports in the Netherlands and the UK; and
- a consideration of expert opinions.

The review, comparison and expert opinions are detailed in *Annex B*.

(1) The Dutch and UK approaches refer to Maximum Take-off Weight (MTOW) and Maximum Take-off Weight Authorised (MTWA), respectively. These terms are synonymous with the term used here, Maximum Aircraft Weight (i.e. the maximum weight allowed, to include full load and fuel).

(2) Individual risk of 1 in 100,000 per year; i.e. 10^{-5} or a 0.00001 chance of death per year for an individual exposed 24 hours per day, 365 days per year. Individual risk of 1 in one million per year; i.e. 10^{-6} or a 0.000001 chance of death per year for an individual exposed 24 hours per day, 365 days per year.

2.3 *CALCULATING RISKS*

The calculation of risks upon which to determine Public Safety Zones (PSZs) in Ireland involved the following stages:

1. identifying the number of annual movements (i.e. landings and take-offs) with respects to aircraft types/classes (1);

2. calculating an 'all classes' movement-weighted average crash rate (crashes per million movements). This is done by using crash rates for each aircraft class (crashes per million movements) and multiplying it by the proportion of movements for that class, and summing the individual products;

3. calculating average crash areas (within which persons 'on the ground' are assumed to be fatally injured) for 'large' aircraft and 'light' aircraft. These are calculated by determining the average Maximum Aircraft Weight (MAW) for each class, multiplying the average crash area by the proportion of annual crashes for that class, and summing the individual products;

4. calculating the probability that crashing aircraft impact a specified location. For 'large' aircraft, this is performed by integrating probability density functions over the calculated average crash area. A similar calculation is performed for 'light' aircraft;

5. calculating the annual frequency that crashing aircraft impact a specified location (i.e. the individual risk). This is performed by multiplying the annual probability of a crash for the specified location by the appropriate average crash rate and associated number of movements (landings and take-offs) for each runway end;

6. using the individual risk results to determine 'best fit' zones representing specified annual individual risks (e.g. 1 in 100,000 per year and 1 in one million per year for the proposed inner and outer PSZs). The shape of each contour (extending away from the runway end) is very similar to that of a triangle. Therefore, to provide a simple geometric area that can be readily defined and easily reproduced on maps and plans, the risk contours are represented by zones alongside and parallel to the runway and triangular zones extending away from the runway ends.

The principal purpose of the outer PSZ is to minimise the possibility of a multiple fatality accident. For example, to limit the possibility of an aircraft crashing into a school, hospital or other development where large numbers of people can be expected. In relation to the 'size', 'speed' and weight of aircraft,

(1) The extent of PSZs is related to the number of aircraft movements and aircraft types. To minimise the need to periodically revise zone extents the Steering Group agreed that the number of aircraft movements for each runway should be set as either (a) the runway's movement capacity, or (b) the expected maximum number of movements. Similarly, aircraft types have been categorised as either 'large' or 'light', and the proportion of both set to provide a good representation of the expected split.

it is judged that 'light' aircraft have a far lower likelihood of causing a multiple fatality accident than 'large' aircraft (1). Therefore, the extent of the outer PSZs is based upon large aircraft crashes only.

A detailed explanation of the calculation procedure and input data is given in *Annex A*, *Annex C* (Cork Airport), *Annex D* (Dublin Airport) and *Annex E* (Shannon Airport).

(1) Light aircraft <4 tonnes MTWA, compared with a movement weighted average MTWA of 33 tonnes, 95 tonnes and 54 tonnes for Cork, Dublin and Shannon Airports, respectively. Maximum Take-off Weight Authorised (MTWA).

The dimensions of the Public Safety Zones (PSZs) proposed for the two runways at Cork Airport are described below and illustrated in *Figures 3.1* to *3.5*. The inner and outer PSZs relate to an individual risk of fatality of 1 in 100,000 per year and 1 in one million per year, respectively. Where calculated, the individual risk of fatality of 1 in 10,000 per year is also shown.

3.1 MAIN RUNWAY 17/35

3.1.1 Towards the North - End 17

Inner PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 3065 m, and a maximum width at the end of the runway of 260 m.

Outer PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 11290 m, and a maximum width at the end of the runway of 962 m.

3.1.2 Towards the South - End 35

Inner PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 3055 m, and a maximum width at the end of the runway of 278 m.

Outer PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 11015 m, and a maximum width at the end of the runway of 1056 m.

3.2 CROSS-RUNWAY 7/25

3.2.1 Towards the West - End 7

Inner PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 625 m, and a maximum width at the end of the runway of 96 m.

Outer PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 2615 m, and a maximum width at the end of the runway of 224 m.

CONTENTS

Maps of proposed Public Safety Zones at Dublin Airport

The following maps can be viewed below.

Figure 2 Dublin Airport - Proposed Public Safety Zones, Existing Runways

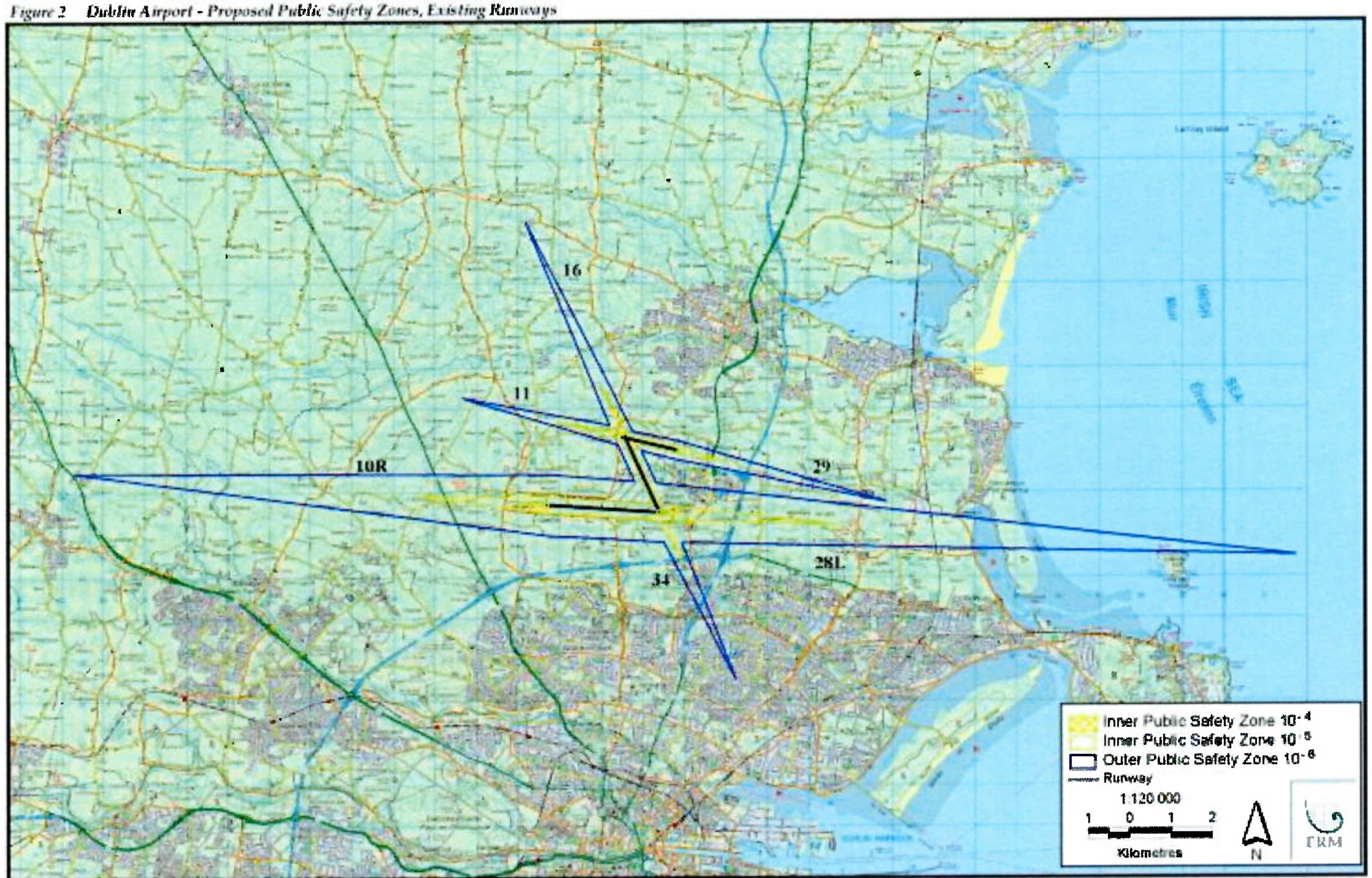
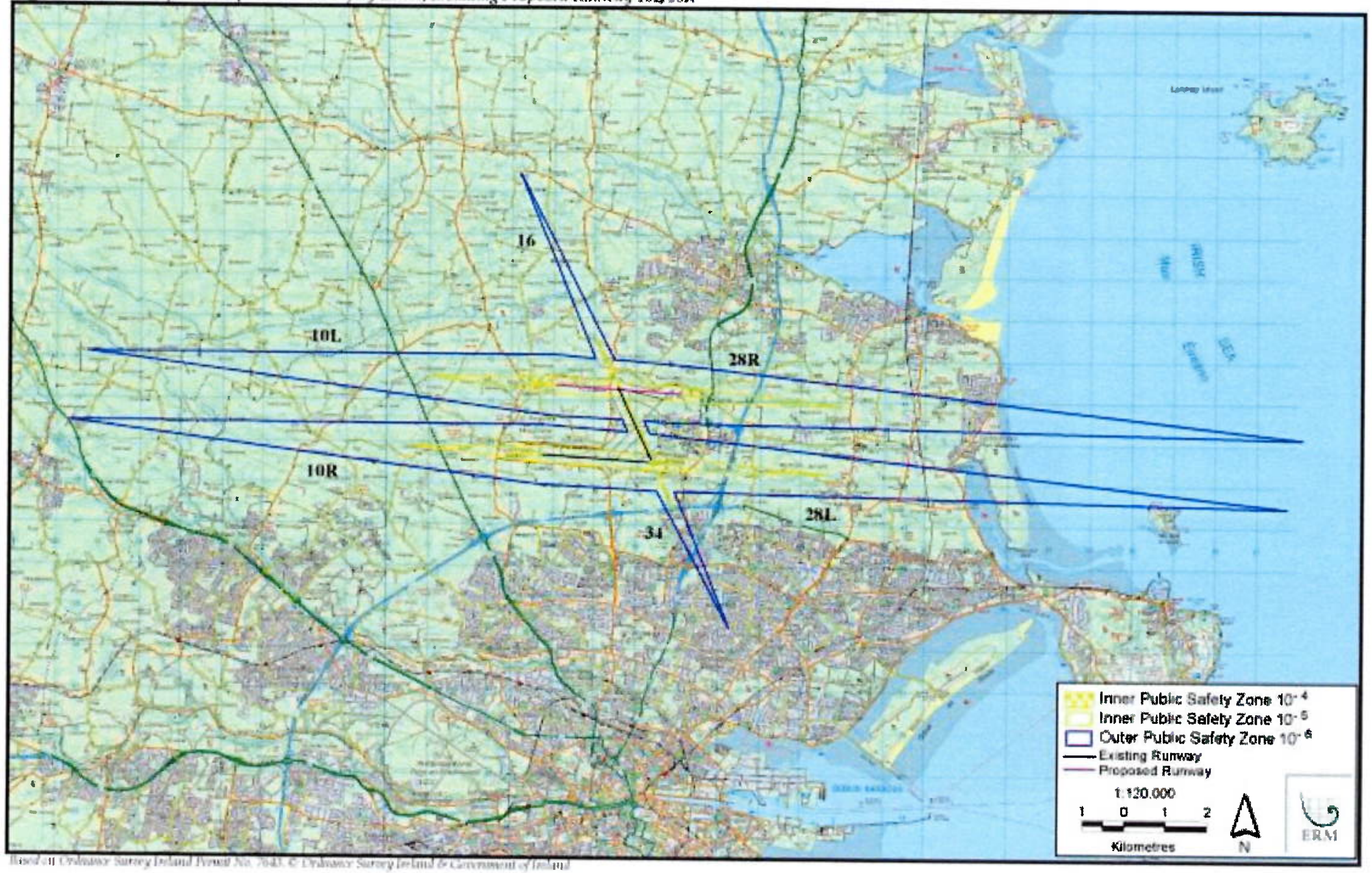
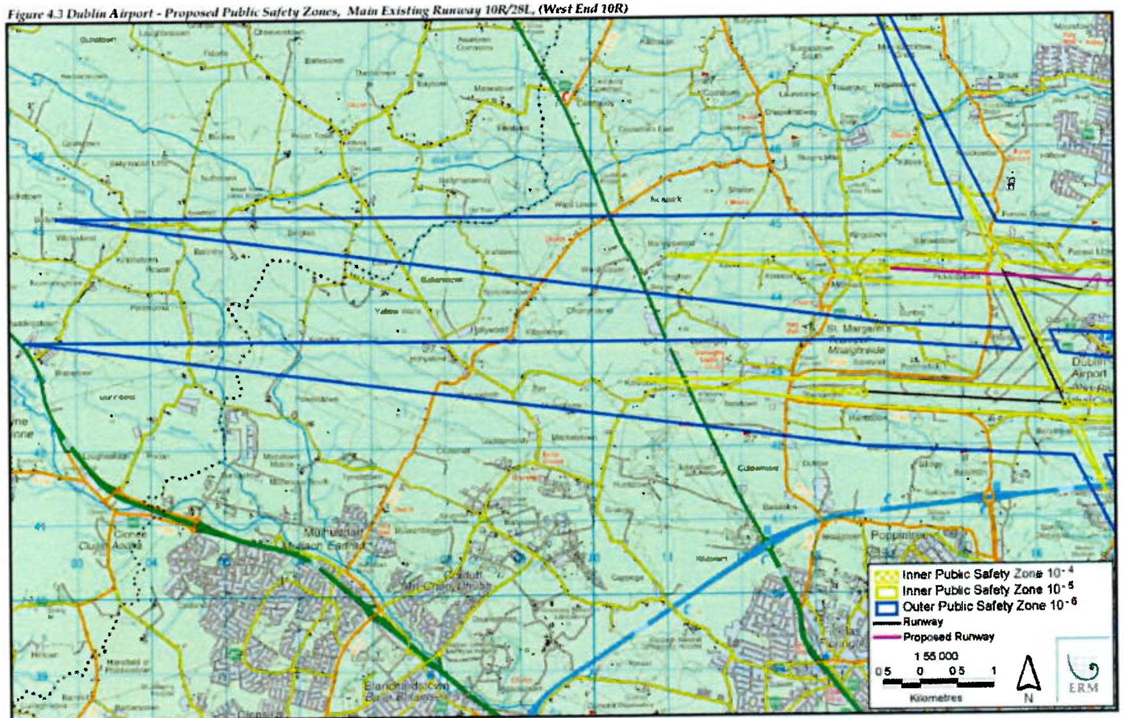


Figure 3 **Dublin Airport - Proposed Public Safety Zones, Including Proposed Runway 10L/28R**



Based on Ordnance Survey Ireland Permit No. 7643. © Ordnance Survey Ireland & Government of Ireland

Figure 4.3 Dublin Airport - Proposed Public Safety Zones, Main Existing Runway 10R/28L, (West End 10R)



Based on Ordnance Survey Ireland Permit No. 7643. © Ordnance Survey Ireland & Government of Ireland

3.2.2 *Towards the East - End 25*

Inner PSZ

An area with a maximum extent from the end of the runway, along the extended runway centreline, of 625 m, and a maximum width at the end of the runway of 96 m.

Outer PSZ

An area with a maximum extent from the end of the runway, along the extended runway centreline, of 2300 m, and a maximum width at the end of the runway of 170 m.

Figure 3.1 *Cork Airport – Proposed Public Safety Zones*

Figure 3.2 *Cork Airport – Proposed Public Safety Zones, Main Runway 17/35 (North End 17)*

Figure 3.3 *Cork Airport – Proposed Public Safety Zones, Main Runway 17/35 (South End 35)*

Figure 3.4 *Cork Airport – Proposed Public Safety Zones, Cross Runway 7/25 (West End 7)*

Figure 3.5 *Cork Airport – Proposed Public Safety Zones, Cross Runway 7/25 (East End 25)*

4 *PUBLIC SAFETY ZONES: DUBLIN AIRPORT*

The dimensions of the Public Safety Zones (PSZs) proposed for the three existing runways and the additional proposed runway at Dublin Airport are described below and illustrated in *Figures 4.1* to *4.11*. The inner and outer PSZs relate to an individual risk of fatality of 1 in 100,000 per year and 1 in one million per year, respectively. Where calculated, the individual risk of fatality of 1 in 10,000 per year is also shown.

4.1 *MAIN (EXISTING) RUNWAY 10R/28L*

4.1.1 *Towards the West - End 10R*

Inner PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 3155 m, and a maximum width at the end of the runway of 370 m.

Outer PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 11455 m, and a maximum width at the end of the runway of 1448 m.

4.1.2 *Towards the East - End 28L*

Inner PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 4375 m, and a maximum width at the end of the runway of 352 m.

Outer PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 15430 m, and a maximum width at the end of the runway of 1394 m.

4.2 *PROPOSED RUNWAY 10L/28R*

4.2.1 *Towards the West - End 10L*

Inner PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 3050 m, and a maximum width at the end of the runway of 378 m.

Outer PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 11330 m, and a maximum width at the end of the runway of 1462 m.

4.2.2 *Towards the East - End 28R*

Inner PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 3970 m, and a maximum width at the end of the runway of 344 m.

Outer PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 15010 m, and a maximum width at the end of the runway of 1383 m.

4.3 CROSS-RUNWAY 16/34

4.3.1 *Towards the North-west - End 16*

Inner PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 1240 m, and a maximum width at the end of the runway of 138 m.

Outer PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 5645 m, and a maximum width at the end of the runway of 462 m.

4.3.2 *Towards the South-east - End 34*

Inner PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 1290 m, and a maximum width at the end of the runway of 146 m.

Outer PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 4370 m, and a maximum width at the end of the runway of 454 m.

4.4 RUNWAY 11/29

4.4.1 *Towards the West - End 11*

Inner PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 1655 m, and a maximum width at the end of the runway of 144 m.

Outer PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 3970 m, and a maximum width at the end of the runway of 438 m.

4.4.2 *Towards the East - End 29*

Inner PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 1230 m, and a maximum width at the end of the runway of 118 m.

Outer PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 5215 m, and a maximum width at the end of the runway of 432 m.

Figure 4.1 ***Dublin Airport - Public Safety Zones, Existing Runways***

Figure 4.2 ***Dublin Airport - Public Safety Zones, Including Proposed Runway 10L/28R***

Figure 4.3 ***Dublin Airport - Public Safety Zones, Main Existing Runway 10R/28L (West End 10R)***

Figure 4.4 ***Dublin Airport - Public Safety Zones, Main Existing Runway 10R/28L (East End 28L)***

Figure 4.5 ***Dublin Airport - Public Safety Zones, Proposed Runway 10L/28R (West End 10L)***

Figure 4.6 ***Dublin Airport - Public Safety Zones, Proposed Runway 10L/28R (East End 28R)***

Figure 4.7 *Dublin Airport - Public Safety Zones, Cross-Runway 16/34 (North-west End 16)*

Figure 4.8 *Dublin Airport - Public Safety Zones, Cross-Runway 16/34 (South-east End 34)*

Figure 4.9 *Dublin Airport - Public Safety Zones, Runway 11/29 (West End 11)*

Figure 4.10 Dublin Airport - Public Safety Zones, Runway 11/29 (East End 29)

5 PUBLIC SAFETY ZONES: SHANNON AIRPORT

The dimensions of the Public Safety Zones (PSZs) proposed for the two runways at Shannon Airport are described below and illustrated in *Figures 5.1* to *5.5*. The inner and outer PSZs relate to an individual risk of fatality of 1 in 100,000 per year and 1 in one million per year, respectively. Where calculated, the individual risk of fatality of 1 in 10,000 per year is also shown.

5.1 MAIN RUNWAY 6/24

5.1.1 Towards the West -End 6

Inner PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 2505 m, and a maximum width at the end of the runway of 307 m.

Outer PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 9805 m, and a maximum width at the end of the runway of 1161 m.

5.1.2 Towards the East - End 24

Inner PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 3770 m, and a maximum width at the end of the runway of 295 m.

Outer PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 13970 m, and a maximum width at the end of the runway of 1,149 m.

5.2 CROSS-RUNWAY 13/31

5.2.1 Towards the North-west - End 13

Inner PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 600 m, and a maximum width at the end of the runway of 72 m.

Outer PSZ
An area with a maximum extent from the end of the runway, along the extended runway centreline, of 2315 m, and a maximum width at the end of the runway of 225 m.

5.2.2 *Towards the South-east - End 31*

Inner PSZ

An area with a maximum extent from the end of the runway, along the extended runway centreline, of 665 m, and a maximum width at the end of the runway of 91 m.

Outer PSZ

An area with a maximum extent from the end of the runway, along the extended runway centreline, of 2285 m, and a maximum width at the end of the runway of 199 m.

Figure 5.1 *Shannon Airport - Public Safety Zones*

Figure 5.2 *Shannon Airport - Public Safety Zones, Main Runway 6/24 (West End 6)*

Figure 5.3 *Shannon Airport - Public Safety Zones, Main Runway 6/24 (East End 24)*

Figure 5.4 *Shannon Airport - Public Safety Zones, Cross Runway 13/31 (North-west End 13)*

Figure 5.5 ***Shannon Airport - Public Safety Zones, Cross Runway 13/31 (South-east End 31)***

6 RECOMMENDATIONS AND CONCLUSIONS

6.1 RECOMMENDATIONS FOR PUBLIC SAFETY ZONES

ERM Environmental Resources Management Ireland Ltd, proposes the following Public Safety Zones (PSZs) for Cork, Dublin and Shannon airports:

- *Inner PSZ (extent set at an individual risk of 1 in 100,000 per year)*
  - prevent further development within inner PSZs, but allow existing developments to remain; and

- *Outer PSZ (extent set at an individual risk of 1 in one million per year)*
  - allow existing developments to remain within the outer PSZs, but prevent high density housing development, and the building of schools, hospitals and facilities attracting large numbers of people.

The permitted developments proposed for these zones are detailed in *Table 6.1* and summarised in *Table 6.2* and *Table 6.3*. Further guidance is given in *Section 6.2* and *Annex B*.

It is important to note that the guidance given in *Table 6.1* is not recommended for retrospective use. This is because the risks to existing developments (within the PSZs) are not so high as to be judged intolerable. The sole purpose of the guidance is to ensure that the risks do not become intolerable/unacceptable by controlling future land-use within the PSZs.

The size, shape and extent of the PSZs for each airport and runway are detailed in *Sections 3, 4* and *5*.

6.2 GUIDANCE ON PERMITTED DEVELOPMENTS WITHIN THE PROPOSED PUBLIC SAFETY ZONES (TABLE 6.1)

Table 6.1 is for guidance, and only applicable to 'safety risks' from aircraft. It should be used in conjunction with appropriate legislative and regulatory controls and guidance, and other guidance, official development plans and objectives.

In some cases, permitted developments are restricted to a maximum density of persons. This density is expressed as the number of persons per half hectare. A half hectare was chosen as this approximates the average maximum aircraft crash area. The maximum density should be applied to any single half hectare within which the proposed development is located.

The guidance for the inner PSZ and outer PSZ applies only to those parts of a development located within the respective zone. The guidance does not apply to parts of a development outside the PSZs.

6.2.1 *What Types of Developments Need to be Assessed Against the Guidance?*

It is not practical to list all development types that may or may not be permitted in the PSZs. However, in general terms, a development should be assessed where people can be expected to be present for all or part of the day.

It follows that developments that need not be considered are those where persons are not normally expected to be present (e.g. normally unoccupied buildings, such as a tool store) (1).

6.2.2 *Exceptions to Permitted Developments in the Inner PSZ*

The only exceptions for permitted developments in the inner PSZ are:

- developments where persons are not expected to be present;
- long stay car parks (i.e. greater than 24 hours), provided that persons are normally expected to park their car and then immediately leave the car park development. Buildings associated with car parks are subjected to the guidance given in *Table 6.1*; and
- roads and railways where vehicles and passenger trains/trams are not expected to be stationary. For example, road vehicles can be expected to be stationary at major road intersections, junctions and traffic lights. Therefore, major road intersections, junctions, traffic lights and similar should not be permitted in the inner PSZ.

6.2.3 *Exceptions to Permitted Developments in the Outer PSZ*

In most cases, the guidance given in *Table 6.1* will be sufficient to identify whether a proposed development should be permitted in the outer PSZ. However, there may be cases, in exceptional circumstances, where it is judged that a development's socio-economic benefits (etc.) outweigh the 'safety risk', and that it is impractical for such a development to be located elsewhere. An Airport Terminal, as described below, is a good example of such a development.

Airport Terminals

To ensure risks to people are as low as reasonably practicable, it is desirable to locate airport terminals outside PSZs. However, this may not be practicable and there are precedents to accept a greater, but tolerable risk, where persons gain a direct benefit from the activity presenting the risk.

In the case of an airport terminal, all those working and using the terminal would be receiving a direct benefit (i.e. related to employment or travel) and

(1) For chemical sites, it is understood that the UK Health & Safety Executive has judged a building to be unoccupied where the presence of people does not amount to more than 2 hours in one day. Gakhar, S.J. (2000). Assessing Risks to Occupants of Existing Buildings on Chemical Plants due to Hazards of Fire and Explosion. Hazards XV, The Process, its Safety, and the Environment, Getting it Right, pp 433-449. Manchester, 4-6 April.

therefore an annual individual risk greater than 1 in one million (i.e. corresponding to the extent of the outer PSZ) but less than 1 in 100,000 (i.e. corresponding to the extent of the inner PSZ) is considered tolerable. Hence, location of an airport terminal in the outer PSZ is judged tolerable.

Extensions to Existing Developments

Extensions to existing developments are permitted. This is provided the development is of a permitted development type, and the proposed extended development (i.e. original development plus extension) does not result in the density figures listed in *Table 6.1* being exceeded (i.e. the number of persons per half hectare should not be exceeded).

For example, a proposed extension to a house which would increase the occupancy to five would be appropriate, provided no half hectare (i.e. 5,000 m^2 or approximately 1.24 acres) encompassing the extended development exceeded 60 persons.

Roads and Railways

Roads and railways are permitted in the outer PSZs, including major road and rail intersections, junctions and traffic lights.

Bus and Rail Terminals

Bus and rail terminals are permitted in the outer PSZs provided the density does not exceed 110 persons per half hectare.

Car Parks

Car parks are permitted in the outer PSZs. This is provided that persons are normally expected to park their car and then leave the car park development. Buildings associated with car parks are subjected to the guidance given in *Table 6.1*.

Table 6.1 *Permitted Developments (applicable to new applications for development)*

Permitted Developments	Public Safety Zone (PSZ)	
	Inner PSZ	**Outer PSZ**
All developments	No further development (existing developments remain)	see below (existing developments remain)

	Outer PSZ
1. Housing	≤ 60 persons/half hectare
2. Holiday Accommodation	≤ 100 beds per development
3. Retail/Leisure Facilities	≤ 85 persons/half hectare
4. Working Premises	≤ 110 persons/half hectare
5. Institutional Accommodation	No further development
6. Sports Stadia	No further development
7. Limited Use	≤ 220 persons/half hectare

No restrictions on development beyond Outer PSZ

Notes

1. Housing – i.e. residential accommodation, persons at home.
2. Holiday Accommodation – i.e. hotels, caravan parks.
3. Retail/Leisure Facilities – i.e. shopping centres, sports halls, sports grounds, swimming pools, bowling alleys, golf clubs.
4. Working Premises – i.e. factories, offices and facilities where persons are expected to congregate, such as railway stations.
5. Institutional Accommodation – i.e. hospitals, schools, nurseries, care homes, prisons.
6. Sports Stadia – i.e. football/rugby stadia.
7. Limited Use – use not exceeding (approximately) a maximum of 12 hours in one week. i.e. Sunday markets, car boot sales, day fairs.

Table 6.2 *Proposed Developments – Summary of Permitted Developments (applicable to new applications for development)*

	Inner PSZ			Outer PSZ[1]		
	Industry[2]	Housing	Vulnerable[3]	Industry[2]	Housing	Vulnerable[3]
Ireland	NO	NO	NO	YES	YES	NO
Netherlands	NO	NO	NO	YES	NO	NO
UK	NO	NO	NO	YES	YES	YES

NO – development not permitted YES – development permitted

1. For the UK, the Outer PSZ refers to land beyond the single PSZ.
2. Industry – includes offices.
3. Vulnerable – hospitals, schools and sports stadia, etc.

Table 6.3 *Existing Developments – Summary of Permitted Developments (applicable to existing development)*

	Inner PSZ			Outer PSZ[1]		
	Industry[2]	Housing	Vulnerable[3]	Industry[2]	Housing	Vulnerable[3]
Ireland	Remain	Remain	Remain	Remain	Remain	Remain
Netherlands	Remain	Remove	Remove	Remain	Remain	Remain
UK	Remain	Remain	Remain	Remain	Remain	Remain

Remove – developments to be removed Remain – developments to remain and current use can continue

1. For the UK, the Outer PSZ refers to land beyond the single PSZ.
2. Industry – includes offices.
3. Vulnerable – hospitals, schools and sports stadia, etc.

6.3 *CONCLUSIONS*

It is the Consultant's view that the proposed inner and outer PSZs provide appropriate consistency with established risk criteria and zoning practice around airports, and around chemical installations in Ireland (set by the Health and Safety Authority), whilst recognising the differences between hazards presented by chemical installations and aircraft approaching and departing airports.

Acknowledging that the proposed PSZs might impact upon existing and proposed land-use, the implications of the zones calculated for Cork, Dublin and Shannon airports have been investigated. It is concluded that adoption of the PSZs would not require any changes to existing land-use around the airports, and would only require minimal changes to proposed development plans.

Figure 4.4 Dublin Airport - Proposed Public Safety Zones, Main Existing Runway 10R/28L, (East End 28L)

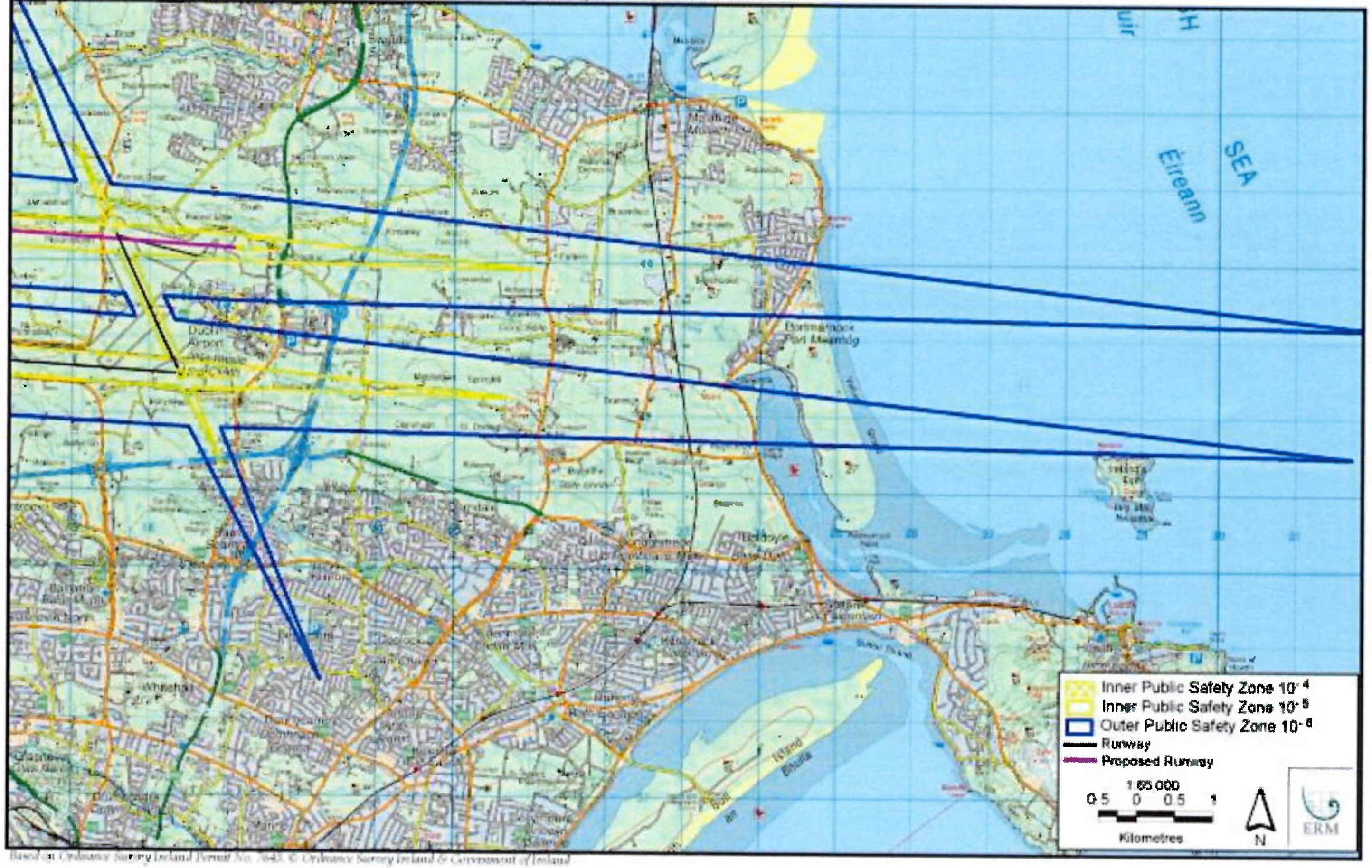


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Figure 4.5 Dublin Airport - Proposed Public Safety Zones, Proposed Runway 10L/28R, (West End 10L)

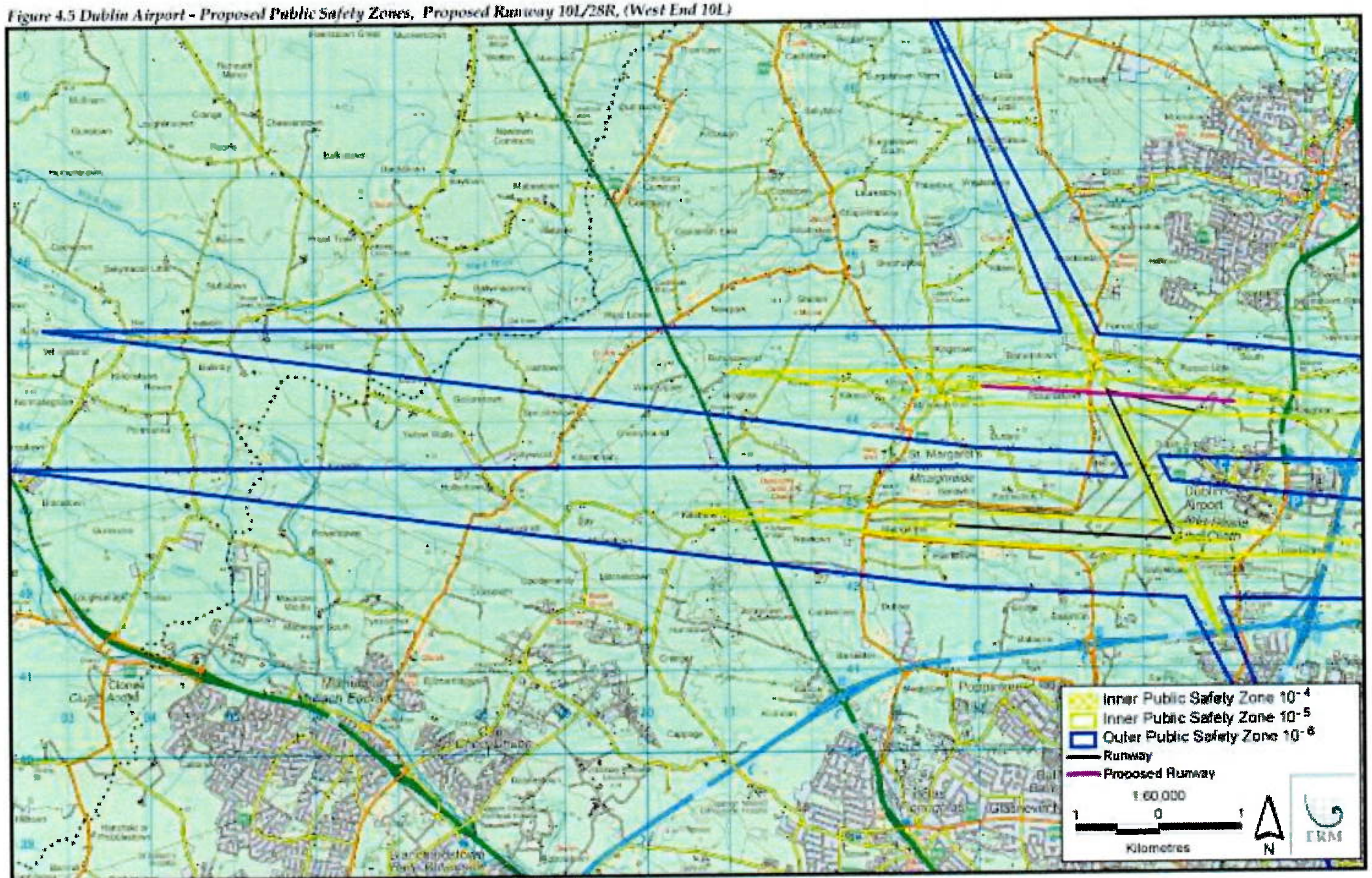

*Figure 4.6 Dublin Airport - Proposed Public Safety Zones, Proposed Runway 10L/28R, (**East End 28R**)*

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Figure 4.7 Dublin Airport - Proposed Public Safety Zones, Cross Runway 16/34, (North-West End 16)

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Figure 4.8 Dublin Airport - Proposed Public Safety Zones, Cross Runway 16/34, (South-East End 34)

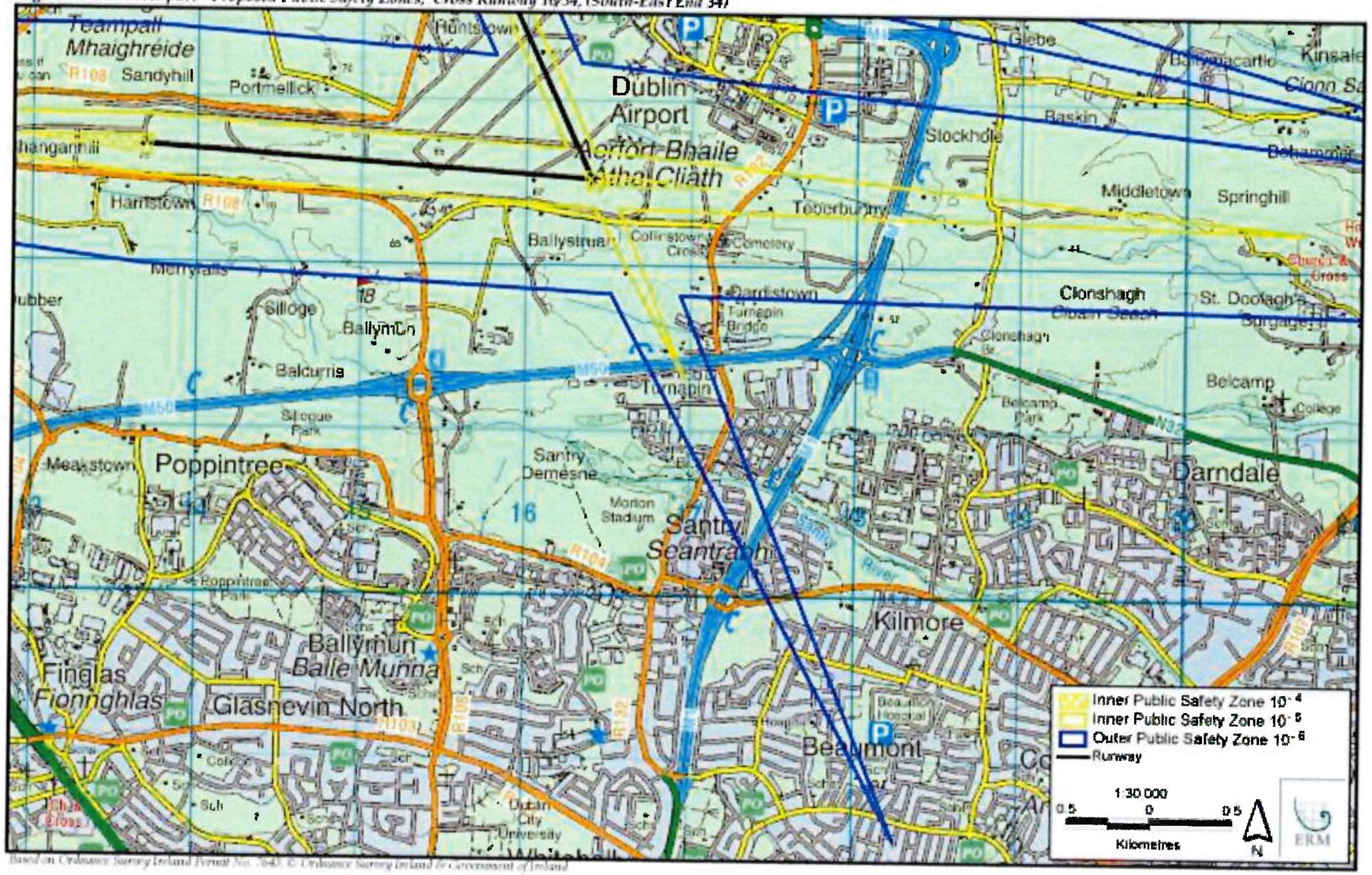

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Figure 4.9 Dublin Airport - Proposed Public Safety Zones, Runway 11/29, (West End 11)

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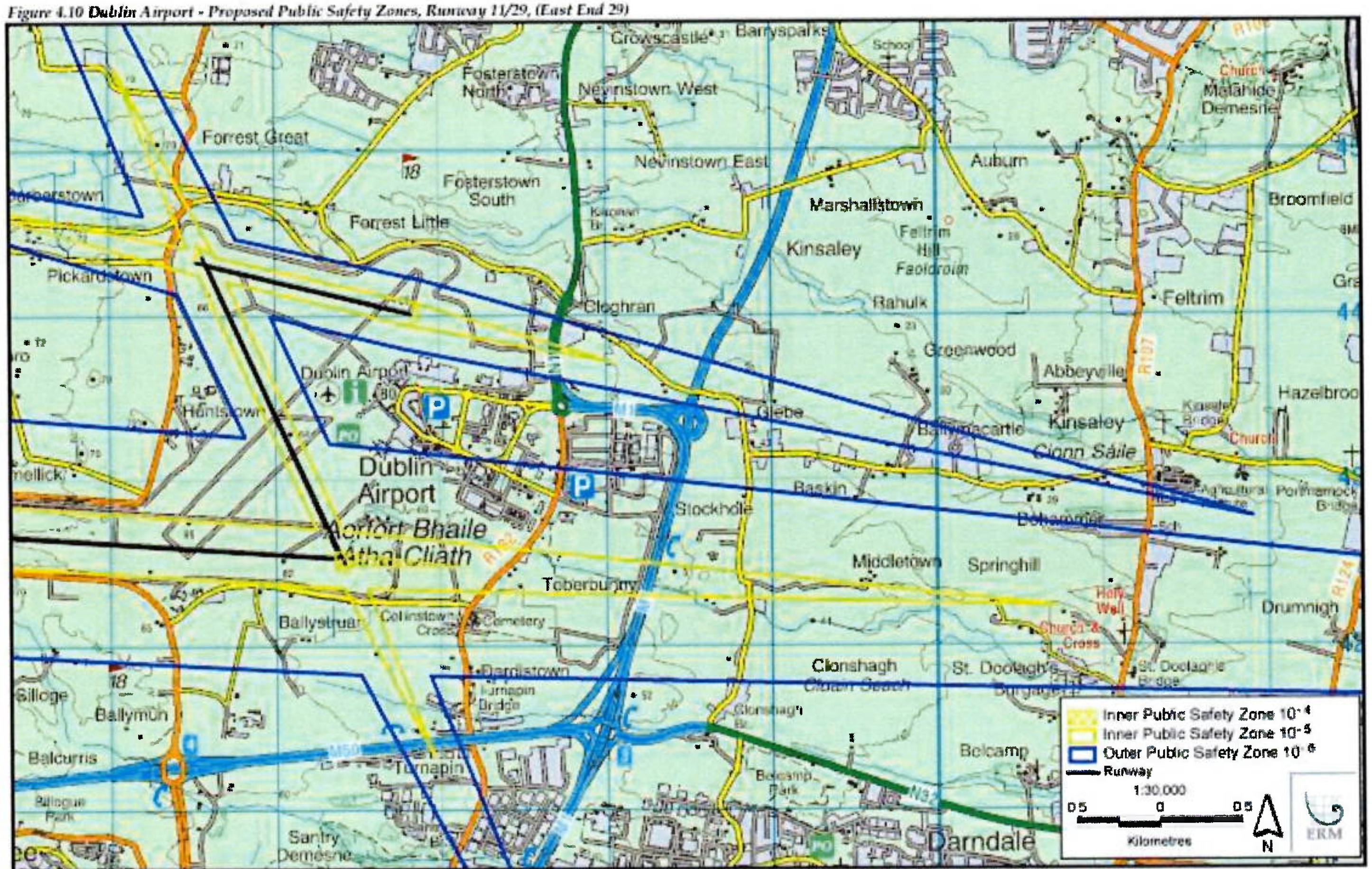
Figure 4.10 Dublin Airport - Proposed Public Safety Zones, Runway 11/29, (East End 29)



APPENDIX 7

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Contrail minimization through altitude diversions: A feasibility study leveraging global data

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ABSTRACT

As global flight volume rises, the aviation industry is facing increasing climate challenges. One major factor is the impact of contrails, which trap outgoing terrestrial radiation and counteract emission reduction benefits from emission-optimized flight routes. Our study quantifies contrail-forming flights globally and assesses altitude adjustments necessary to avoid these regions. Using the Integrated Global Radiosonde Archive and global flight data from 2021-2022, we highlight several contrail-prone regions with high air traffic volumes and high potential for contrail-formation. We propose an operational strategy in altitude diversion, which can halve the amount of persistent contrails. Further, we analyse the additional carbon emissions caused by the altitude diversions and safety risks in terms of potential new conflicts. Our findings provide actionable strategies for policymakers to balance climate mitigation and operational challenges in aviation.

1. Introduction

Global aviation currently accounts for approximately 5% of net anthropogenic climate forcing (Lee, 2021), and this contribution is expected to increase as air traffic continues to rise worldwide. As a result, sustainability has become one of the most pressing challenges facing the aerospace industry. While alternative fuels and aerodynamic aircraft hold promise for reducing emissions, their implementation on a commercially relevant scale is still years away.

In addition to carbon dioxide, aircraft emissions also include nitrogen oxides, water vapour, sulphur oxides, and aerosols (Lee et al., 2010). However, the most significant individual contributor to aviation's total radiative forcing at shorter timescale is the formation of contrail cirrus, albeit with some uncertainties (Grewe et al., 2017). While carbon dioxide emitted today impacts global warming within 20–40 years, the warming effect of contrails is immediate (Avila et al., 2019).

This emphasizes the importance of minimizing contrails as a way to limit aviation's climate impact immediately as well as into the future. To address this challenge, the novel application of multidisciplinary fields beyond aviation, such as combining global aircraft surveillance data, atmospheric science, and satellite remote sensing, can help create a climate-optimized trajectory generator.

This paper aims to quantify the global extent of contrail-forming flights, their geographical location, as well as the typical altitude deviation necessary to avoid contrail-forming regions. Research done in Teoh et al. (2022), utilizes ERA5 reanalysis from ECMWF and an air traffic dataset from NATS (UK air navigation). Investigating the feasibility of incremental step-wise altitude diversion has been researched in Avila et al. (2019) in accordance with Domestic Reduced Vertical Separation Minimum (DRVSM) rules, using a year's worth of NOAA's Rapid Refresh Products (RAP) and a repeatedly using a single day of ADS-B data of mainland USA (24,095 flights).

This paper uses weather balloon data from the open-source Integrated Global Radiosonde Archive, as in Agarwal et al. (2022), where the radiosondes were used to validate reanalyses data like ECMWF and MERRA-2 to determine the estimation accuracy of contrail formation.

Additionally, the potential climate gain of these deviated flights will be computed in terms of radiative forcing (RF), applying the same net radiative forcing model as in Avila et al. (2019). Similar to the approach used in Rosenow and Fricke (2019), where the radiative forcing of individual condensation trails was calculated. Regarding the additional emissions caused by altitude changes, in previous research this was calculated using BADA, a database of Aircraft from EUROCONTROL (Teoh et al., 2022). This combination provides a sense of the overall true climate impact of altitude deviations to prevent contrails.

Furthermore, the potential safety impacts of contrail-mitigation are investigated. Through work has been done on this topic in Simorgh et al. (2023), which utilizes scenarios with around 1,000 flights during a 4-hour time frame in the Spanish and Portuguese airspace. Similarly, in Sausen et al. (2023), 212 aircraft were deviated vertically in MUAC airspace in order to avoid contrail formation.

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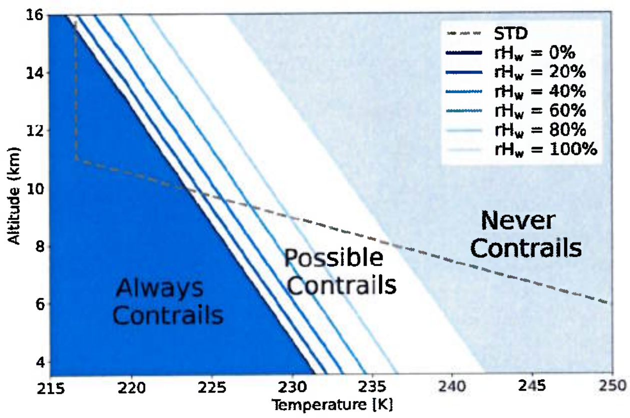


Fig. 1. A Schmidt-Appleman Diagram where the solid lines indicate the threshold temperatures at 0, 20, 40, 60, 80 and 100% relative humidity respectively, for kerosene fuel and an overall propulsion efficiency of 0.4. The international standard atmosphere temperature profile (STD) is plotted as well.

Our paper utilizes over 5.7 million flights, 2 years of real world data with global coverage, focusing on altitude changes rather than changing latitudinal or longitudinal positions. The assumption is that the flights are already horizontally and vertically separated according to safety protocols. We also solely consider the feasibility of altitude changes at the tactical short-term decisions, not possible strategical or pre-tactical decisions. Recent work regarding this has been done by Baneshi et al. (2023) and Simorgh et al. (2022).

By utilizing new data sets, this paper provides an alternate geographic coverage, as well as utilizing the high vertical resolution for the altitude deviation.

2. Contrails

2.1. Theories for contrail formation

Contrails, resembling clouds, can emerge in the wake of aircraft. To initiate contrail formation, certain atmospheric conditions must be met: the air temperature should be below −40 °C (233.15 K), and there should be a high relative humidity (Schumann, 1996). The formation of contrails is determined by the Schmidt–Appleman criterion (SAC) (Schumann et al., 2011), a thermodynamic theory developed by Schmidt and Appleman, which was later revised by Schumann (1996). The SAC states that the formation of contrails from condensing exhaust water depends on ambient pressure, humidity, and the ratio of water and heat released into the exhaust plume. When an aircraft flies through atmospheric conditions that satisfy the SAC, saturation with respect to liquid water occurs, resulting in contrail formation.

Fig. 1 shows the Schmidt-Appleman Diagram, which can be divided into three sections: always contrails, possible contrails, and never contrails. If the ambient temperature exceeds the line of relative humidity with respect to water (RH_w) at 100%, contrails are not expected to form (Service, 1981; Schumann, 2005). In conditions where the ambient temperature falls below the relative humidity line of 0%, contrails should always form. When the point lies between these two lines, in the *possible contrail* section of the graph, the formation of contrails depends on the relative humidity at that point, determining whether it falls on the left (always contrail) or right (never contrail) side of the corresponding RH_w line.

2.2. Climate impact contrails

While many contrails disappear quickly, persistent contrails have lifetimes of more than five minutes, occurring when the condensing exhaust water does not evaporate in that given time frame (Ferris, 2007). Persistent contrails contribute to global warming by trapping outgoing terrestrial radiation (Schumann, 1996). This creates an imbalance between the incoming solar radiation and radiation from the Earth's atmosphere and surface, causing radiative forcing (RF) which leads to an alteration of temperature in the lower atmosphere (Karcher, 2018).

Whether a contrail is persistent is indicated by the presence of an ice-supersaturation region (ISSR), which forms when the ambient air is supersaturated with respect to ice (Schumann, 1996). Therefore, for persistent contrail formation, the aircraft must fly through a part of the atmosphere that satisfies both the SAC (indicating contrails can theoretically form) and is an ISSR (indicating their persistence).

Although contrails have a warming impact on global climate by trapping outgoing radiation, the impact of daytime contrails can be counteracted by their cooling impact, making their overall effect uncertain (Schumann et al., 2011). Nighttime contrails, however, always have a warming impact. Analysis from Stuber et al. (2006) showed that while night flights account for only 25 percent of air traffic, they account for 60 to 80 percent of the contrail climate forcing. Similarly, while winter flights are 22 percent of annual air traffic, they contribute to half of the annual mean forcing (Stuber et al., 2006). This paper includes a day and nighttime analysis, as well as seasonal variations, to more specifically understand the contribution of contrails to global climate change.

2.3. Contrail detection and avoidance

In practice, avoiding persistent contrail-forming atmospheric regions often involves either flying around the perimeter or changing altitude (Avila et al., 2019). The expansiveness of these regions typically makes re-routing less environmentally effective than varying altitude (Gao and Hansman, 2013; Sridhar et al., 2014). This implies that contrail avoidance would need to be incorporated into the flight planning process.

The deviations need to be in accordance with Domestic Reduced Vertical Separation Minimum (DRVSM) rules (Avila et al., 2019). Before such climate-optimized routing can be implemented, contrail formation needs to be adequately predicted, for re-routing but also for developing metrics to enforce compliance from airlines and industry.

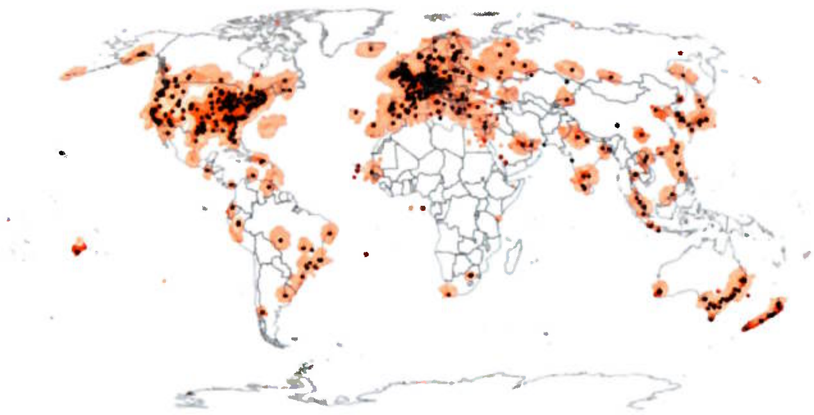
3. Data

The assessment of the number of flights that fall within a persistent contrail-forming atmospheric region and the required altitude change to leave the region, are based on remote sensing and flight data. This section explains these data sources and the steps taken before further processing.

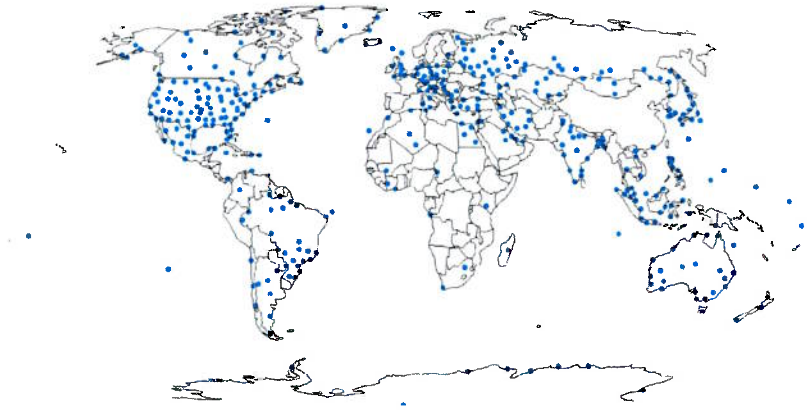
3.1. Integrated global radiosonde archive

The Integrated Global Radiosonde Archive (IGRA) consists of radiosonde observations collected and maintained by the US National Centers for Environmental Information (NCEI) of the US National Oceanic and Atmospheric Administration (NOAA) (Durre et al., 2018). Radiosondes are launched once or twice daily, usually at 0000 and 1200 UTC. During the 1 to 2-hour ascent, the radiosonde instruments collect measurements that are transmitted to ground stations (Durre et al., 2021).

At the ground station, the data is processed into pressure, geopotential height, temperature, and derived wind direction and speed based on the latitude and longitude of the balloon. In some cases, relative humidity with respect to water (RH_w) is also measured. For assessing persistent contrail formation, relative humidity with respect to ice is a crucial parameter, as any value of RH_w exceeding 100% indicates the presence of an ISSR. While $RH_w > 100\%$ does not occur in the Earth's



(a) OpenSky receiver locations and coverage in 2022 (sourced from: Sun et al. (2022)).



(b) IGRA station locations used in this research

Fig. 2. Research Area: the OpenSky receiver locations and the IGRA stations that have an OpenSky receiver nearby.

atmosphere, relative humidity with respect to ice, RH_i, exceeding 100% is one of the criteria for persistent contrails and is common (Sonntag, 1994).

There are several ways of determining the RH_i based on the RH_w. In this study, we use the formulas (Eqs. (1) and (2)) developed by Sonntag (1994). The equilibrium vapour pressure of water molecules (e_w) or ice (e_i) is temperature-dependent and can be used to determine the relative humidity with respect to water and ice (Buehler and Courcoux, 2003).

$$RH_w = \frac{e}{e_w} \tag{1}$$

$$RH_i = \frac{e}{e_i} \tag{2}$$

Previous research (Soden and Lanzante, 1996; Moradi et al., 2010) shows good agreement between IGRA relative humidity measurements and satellite data, with mean differences of 1 to 3%. The IGRA sensors (such as the Vaisala RS92) themselves have been shown to have an accuracy within ±1 K for temperature (Dirksen et al., 2014) and 10% for the relative humidity (Miloshevich et al., 2009).

3.2. Flight data: OpenSky and Spire

To ensure global coverage, two flight data sources were used in this research: OpenSky and Spire. The OpenSky Network, which has been collecting global air traffic surveillance data since 2013, provides unfiltered and raw data based on ADS-B, Mode S, TCAS, and FLARM messages that are open for use (Strohmeier et al., 2021). The spatial coverage is visualized in Fig. 2.a, with black dots representing station locations and red shading indicating the coverage of each station. The coverage is highest over Europe and North America, whereas due to the nature of terrestrial ADS-B, coverage over the oceans is minimal.

On the other hand, Spire uses satellite in addition to ground receivers, enabling ocean coverage. Since July 2018, a constellation of hundreds has been collecting ADS-B data globally. While OpenSky provides year-round temporal coverage, Spire data is available to us only for the month of April.

4. Method

In this section, we outline the methodology used to quantify the number of flights that fall within persistent contrail-forming atmospheric regions and the necessary altitude change required to leave these regions.

4.1. Contrail quantification

Unfortunately, only 304 of the 695 station locations measure the parameter of relative humidity over water vapour, which is necessary to determine the relative humidity over ice.

To identify flights that fall within ISSRs, we draw a 100 × 100 km^2 square around each IGRA station location. This area is deemed to be a representative area of influence for a single IGRA measurement, considering the lateral expansive nature of ISSR (Avila et al., 2019). We then overlay the locations of OpenSky receivers with these polygons.

If an OpenSky receiver is located within an IGRA polygon, we use the corresponding IGRA measurement location and OpenSky receiver data in our research. For cases where there is no OpenSky receiver

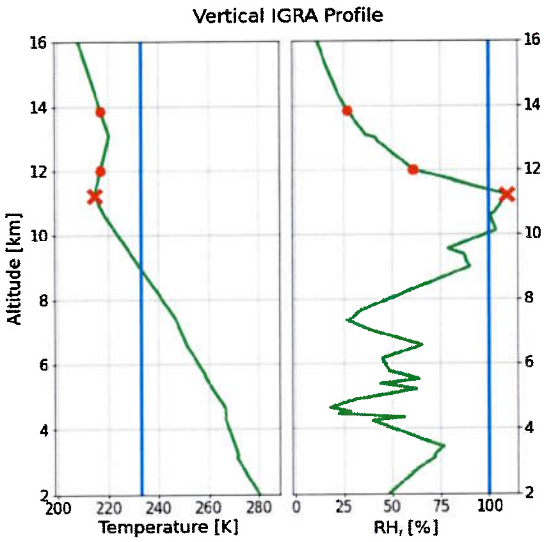


Fig. 3. An example of a vertical profile of temperature (left) and relative humidity (right) w.r.t. ice at the Camborne, a U.K. station on December 12, 2022 only. One of the aircraft is indicated in both plots by a cross (here at an altitude of 11.2 km) satisfies both SAC and the ISSR criterion, thus produces persistent contrails. The two aircraft at higher altitudes (indicated by dots) satisfy SAC but not the ISSR criterion, thus should produce non-persistent contrails.

within the IGRA polygon, we use Spire flight data. This data intersection results in coverage of 72 countries, the locations of the stations are shown as black dots in Fig. 10.

Only aircraft at cruise are considered, and the flight altitude closest to the weather balloon station (at the centre of each polygon) is used. Using this flight data, we then calculate the number of flights that pass through each polygon and identify those that fall within persistent contrail-forming atmospheric regions.

4.2. Flight level change

In Fig. 3, we present an example of a vertical profile of temperature and relative humidity with respect to ice for the Camborne station (UK) on December 12, 2022. The temperature profile on the left shows the vertical blue line indicating the −40 °C (233.15 K) SAC condition for contrail formation. On the right, the 100% RH_i is shown as a blue line, representing the ice-supersaturation condition.

Moreover, the figure also includes the representation of aircraft at their respective flight levels along with the vertical relative humidity profile. A cross in both plots indicates one of the aircraft located at an altitude of 11.2 km satisfying both the SAC and ISSR criteria, thereby producing persistent contrails.

In Fig. 3, it is also demonstrated that a small increase in altitude, only a few hundred feet, could cause the aircraft indicated by a cross to descend below the 100% RH_i line, thereby ceasing to satisfy the ISSR condition and stop producing persistent contrails.

Flight level changes that would exceed FL400 are not included in this analysis.

4.3. Net radiative forcing

As explained in Section 1, the foremost climate impact of contrails is through their trapped radiative forcing. Radiative forcing (RF) is a measure of the contribution of a greenhouse gas to the radiative energy budget of the climate system on Earth, which can disrupt the balance of incoming and outgoing energy in the atmosphere and alter the equilibrium state of the climate system (Ramaswamy et al., 2001). Measuring this impact can be done through net radiative forcing, which is the sum of incoming solar shortwave radiation (RF_{SW}) and outgoing longwave radiation (RF_{LW}).

Shortwave radiation from the sun is scattered or reflected by clouds and aerosols, or absorbed in the atmosphere (Trenberth et al., 2009; Sanz-Morère I. Eastham et al., 2021). On the other hand, longwave or terrestrial radiation refers to the infrared radiation emitted by the Earth, which is absorbed by clouds before being re-emitted. Contrails, similar to natural cirrus clouds, reflect incoming solar radiation during the daytime, resulting in a negative shortwave radiation effect. However, they also absorb terrestrial radiation and re-emit it at a higher altitude, leading to a positive longwave radiation effect during both day and night (Sanz-Morère I. Eastham et al., 2021).

To quantify the radiative effects of contrails, we will use the cloud radiative-transfer model (Corti and Peter, 2009). This model calculates the contrail-induced radiative imbalance in net warming of the Earth (Sanz-Morère I. Eastham et al., 2020). A positive RF_{Net} would indicate an increase in the net energy of the Earth-atmosphere system.

4.4. Additional fuel burn

The additional fuel burn required for the altitude manoeuvres was determined using OpenAP (Sun et al., 2020), which is an open-source aircraft performance model capable of estimating fuel consumption and emissions based on flight data.

Based on the necessary altitude change, the additional fuel burn is determined, based on the aircraft type, altitude, vertical rate, and speed. A sensitivity analysis is performed on the initial mass parameter (0.70, 0.85, and 0.90% of the maximum take-off weight). The type code and engine parameters are based on the ICAO 24-bit transponder code, an aircraft identifier gathered from the ADS-B data. From this fuel flow analysis, the additional CO_2 emissions can be derived.

4.5. Risks to separation from altitude changes

Uncoordinated flight changes cannot always be safely performed. In Figs. 4, two scenarios illustrate the potential risks to separation caused by altitude changes to avoid contrail-forming areas. The sole criterion for an altitude diversion is that it is the shortest vertical way out, and the absolute change is less than 2000 ft.

Even though a loss of separation does not always imply an impending collision, it does signify aircraft being closer than safety regulations. A loss of separation occurs when aircraft within distance less than 5 nautical miles (9.26 km) and less than 1000 ft (300 m) altitude difference. A conflict is a predicted loss of separation, and uses the protected aircraft zone (Organization, 2016).

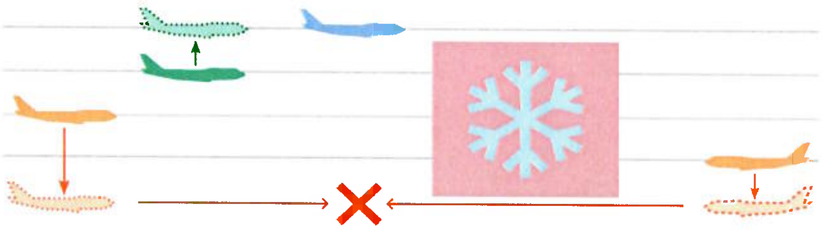
In this study, we determine nearby aircraft using a kd-tree algorithm. The *cKDTree* library from the *scipy* Python package is used as an efficient way to perform such calculations. We first search for 10 nearest aircraft for each individual aircraft, then the ones with distances below 5 nm are selected. Subsequently, these are also filtered with a maximum vertical distance of 1000 ft.

The loss of separation detection is first performed with the ADS-B data from OpenSky with the original altitude and then with the data including altitude diversions. This allows for the identification of intrusions similar to those sketched in Fig. 4.b.

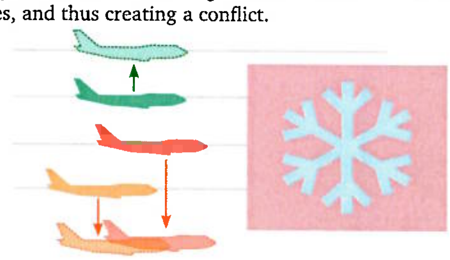
Besides this intermediate loss of separation, Fig. 4.a shows a future conflict. Based on the track and ground speed from the ADS-B data, an extrapolation was made for the trajectories for a look-ahead time of 10 min. It was investigated whether the extrapolated trajectories of the five nearest neighbours intersected. If so, this intersection was treated as a conflict.

5. Results

In this section, we evaluate the results and discussion, subdividing our analysis into several parts:

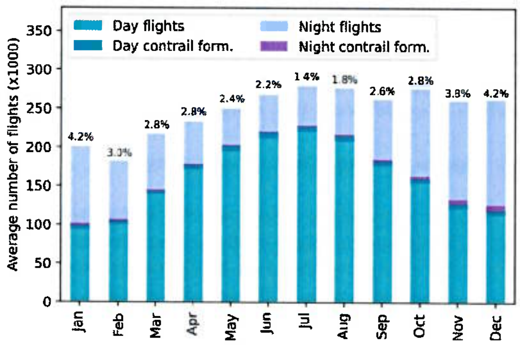


(a) Example of a conflict. The red box with a snowflake indicates a contrail-forming region that should be avoided. The blue aircraft does not have to change its altitude, and the green aircraft needs to increase its altitude. The orange aircraft both need to decrease their altitudes, and thus creating a conflict.

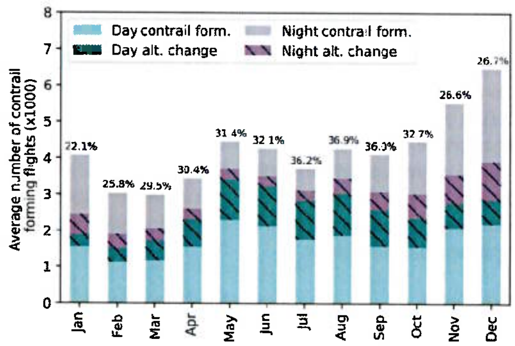


(b) Example of a potential loss of separation. The green aircraft increases its altitude to avoid the contrail-forming area without difficulties. The two orange aircraft are initially vertically separated, but because they both decrease their altitude, a loss of separation occurs.

Fig. 4. Two scenarios illustrating the potential risks to separation caused by altitude changes to avoid contrail-forming areas.



(a) Average number of flights per month in 2021 and 2022 in our dataset, with colours indicating day or nighttime flights, and whether they create contrails (indicated by the percentage above the bars).



(b) Average number of contrail-forming flights in 2021 and 2022 in our dataset and the subset of flights that are suitable for an altitude change of less than 2000 ft, indicated by hatching (indicated by the percentage above the bars).

Fig. 5. Temporal effects of contrail formation.

5.1. Quantifying contrails

Following the method described in Section 4, we analysed a total of 5,722,588 flights. Of these, 202,240 (3.5%) were identified as satisfying both the SAC and ISSR conditions, indicating the production of persistent contrails.

5.2. Temporal effects

As described in Section 1, seasonality has a large impact on contrail formation. In addition, the time of day when contrails form influences the climate impact. We consider these two temporal effects in this subsection.

In Fig. 5.a, we show the total number of flights per month, with colours indicating day and nighttime flights, as well as the percentage of total flights that create contrails (percentage above the bars). These values represent the monthly averages from 2021 and 2022. While air traffic peaks in the (Northern Hemisphere's) summer months, there is a higher occurrence of persistent contrails during winter, according to Avila et al. (2019). In Fig. 5.a, we observe a similar result. Although the total number of flights is lowest during the winter months, the number of days with persistent contrail-forming atmospheric conditions and the percentage of contrail-producing flights per month peak during the winter months. Since the IGRA sounding data is global, with 87% of the stations located in the Northern Hemisphere (as seen in Fig. 2), we apply the Northern Hemisphere seasonal cycle to our analysis.

Fig. 5.b shows the number of contrail-forming flights, with colours indicating day or night, and hatching indicating the portion where an altitude change of less than 2000 ft would stop contrail formation.

5.3. Geographical effects

In addition to the temporal effects discussed in the previous section, contrail formation is also expected to vary based on geographical location. By utilizing the global nature of the OpenSky, Spire, and IGRA data, we examine the geographical effects in this subsection.

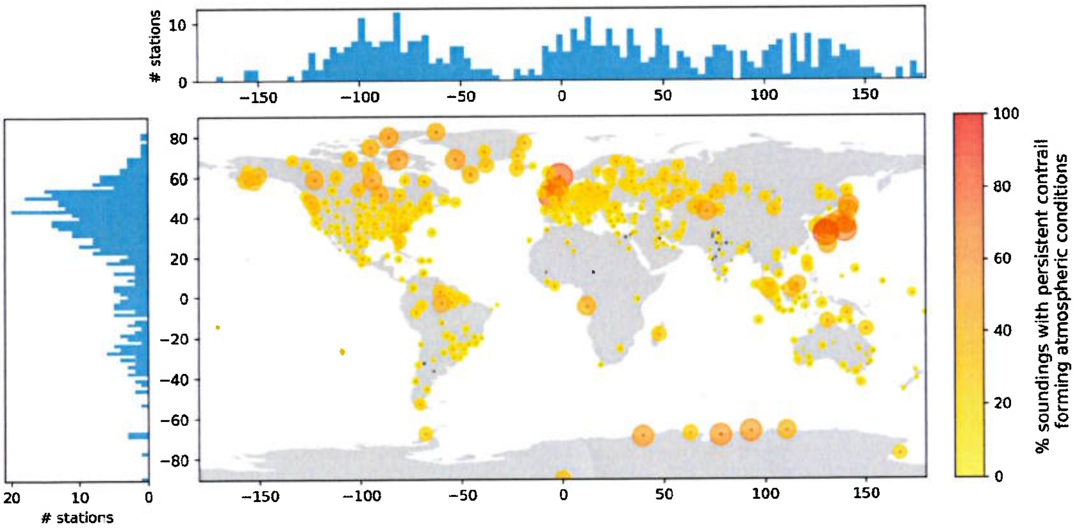


Fig. 6. Global distribution of persistent contrail-forming atmospheric conditions, with black dots indicating station locations, and shaded circles indicating the percent of soundings with atmospheric conditions satisfying persistent contrail formation. The vertical and horizontal histograms indicate the latitudinal and longitudinal distribution of IGRA stations.

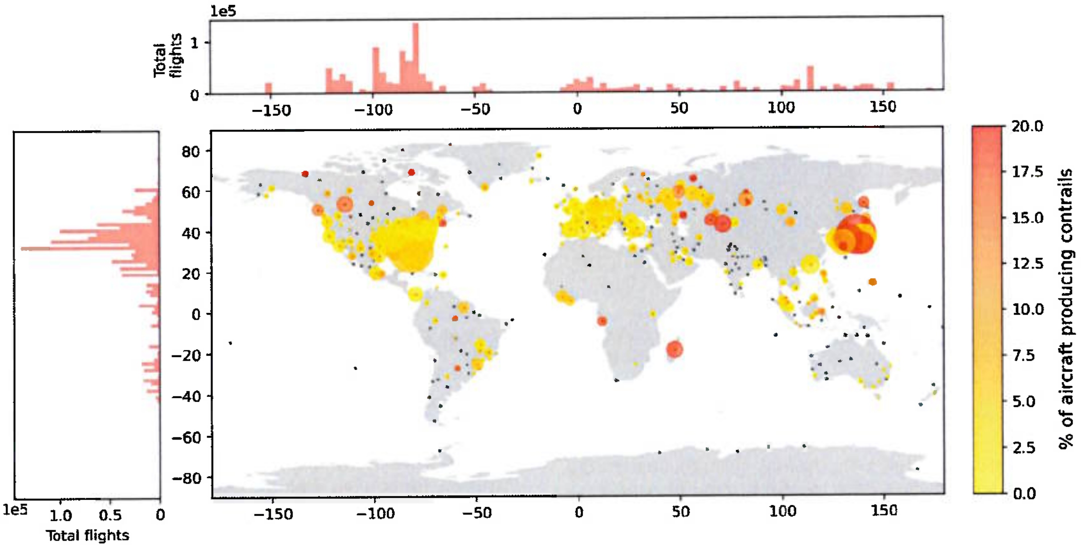


Fig. 7. Global distribution of aircraft producing persistent contrails, with black dots indicating station locations, and shaded circles indicating the percent of total aircraft and the size of the circle indicating the absolute number of aircraft. The vertical and horizontal histograms indicate the latitudinal and longitudinal distribution of total flights.

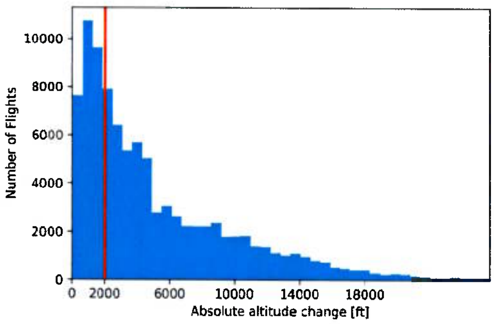
Fig. 6 shows a global yearly overview of the percent of weather balloon soundings that include persistent contrail-forming atmospheric conditions, namely instances of RH_i exceeding 100% and temperature falling below −40° (233.15 K). The black dots indicate the locations of the stations, and the shade and size of the circles indicate the percentage of soundings when atmospheric conditions allow for the formation of persistent contrails. The vertical and horizontal histograms indicate the latitudinal and longitudinal distribution of IGRA stations.

Fig. 7 shows a similar graph, however here the colouring of the circles indicates the percentage of aircraft that fly through these atmospheric conditions that allow for persistent contrail formation. The sizes of the circles indicate the number of flights in absolute terms. The vertical and horizontal histograms display the latitudinal and longitudinal distribution of the total number of flights. Large and darker red circles mean that not only the percentage of contrail-forming flights is high, but also the absolute number of contrail-forming flights is high, as well.

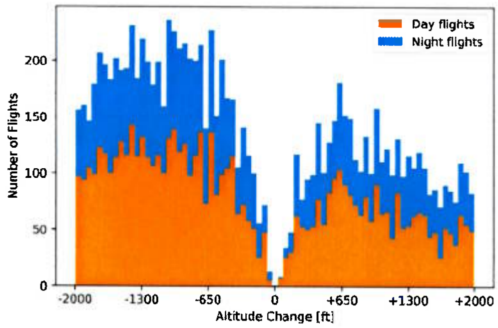
5.4. *Flight level change*

We previously illustrated the opportunity to change the flight level to stop contrail formation in Fig. 3. In Fig. 8.a, we show a histogram of the absolute nearest distance for a flight to *exit* a persistent contrail-forming atmospheric layer. From literature (Avila et al., 2019), we know that altitude changes of less than 2000 ft are feasible, and the histogram in Fig. 8.b shows that this accounts for a significant portion (31%) of the flights.

Filtering the histogram for deviations of less than 2000 ft, we show the absolute deviations in Fig. 8.b, with negative values indicating a decrease and positive values indicating an increase in the required altitude. A majority of 61% of the flights required an altitude decrease (an average of 1071 ft (326.44 m)), while the remaining 39% required an increase to exit the ISSR (an average of 996 ft (303.58 m)). We also indicate a distinction between day and night flights using colour in the histogram.



(a) Histogram of all flight level changes (absolute values), with the vertical red line at 2000 ft.



(b) Histogram of flight level changes, less than 2000 ft, with negative values indicating a decrease and positive values indicating an increase in altitude to avoid ISSRs.

Fig. 8. Flight level changes required to stop producing contrails.

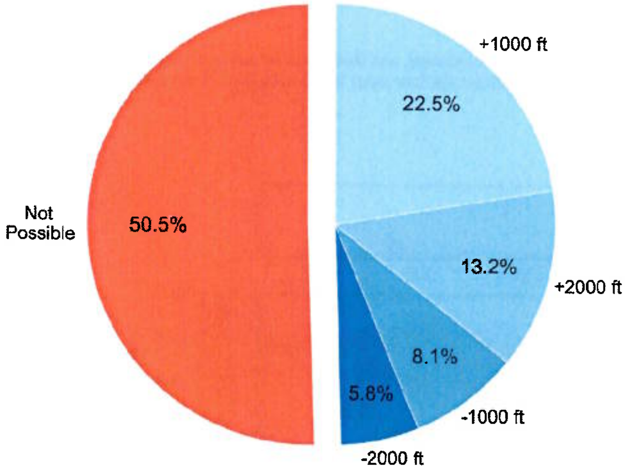


Fig. 9. Pie chart of flight level changes, where only discrete altitude options are available, among range the four steps of 1000 ft. If no alternative altitude can be found, the flight was categorized as *not possible*. A total of 64,288 were considered.

In the current airspace configuration, custom altitude changes (as shown in Fig. 8.b) are not always possible. Typically, only discrete steps are available when requesting an altitude change. These alternative altitudes are shown in Fig. 9. For each contrail-forming flight, we first checked whether an altitude change of +1000 ft would prevent persistent contrail formation. If it is insufficient, we then considered a higher increase of +2000 ft. Conversely, we also examined the possibility of reducing the altitude by −1000 ft and −2000 ft as alternatives. This order was chosen as altitude decreases are unfavourable when minimizing climate impact since they decrease fuel efficiency (Avila et al., 2019; Schumann et al., 2011). If none of these alternative altitudes are possible, we categorized it as *not possible* in Fig. 9, which occurs in 50.5% of cases.

In Fig. 10, we show the global distribution of the occurrences requiring a flight level change of less than 2000 ft to stop contrail production. The shading of the circles indicates the percentage of total flights that are suitable for such an altitude change, and the size of the circle indicates the number of these flights.

5.5. *Additional CO_2 emissions*

Since flight emission estimations can be heavily influenced by the aircraft mass, we performed a sensitivity analysis by varying the initial mass between 75% and 100% of the maximum take-off weight to study the additional CO_2 emissions caused by the altitude change. In Fig. 11, each line represents the additional emissions (in percent) in a month with different aircraft mass assumptions.

5.6. *Climate impact*

In this subsection, we demonstrate the true climate gains feasible through the altitude deviations described in Section 5.4. In Fig. 12, we show the top 25 stations where the largest climate gains can be made, with the smallest percentage of flights changing altitude. We limited the stations to those with a minimum of 10,000 yearly flights. Following the method described in Section 4.3, we determined the radiative forcing for all contrail-forming flights and then the radiative forcing for flights suitable for an altitude change of less than 2000 ft. The ratio between these two values, referred to as the percent of radiative forcing that can be prevented, is shown in Fig. 12.

5.7. *Safety*

We analyse the potential loss of separation and conflicts due to the change of flight altitude without any air traffic control coordination. Table 1 shows the change in the number of actions required for intrusion prevention and for conflict solving, because of the change in altitude required to avoid contrail creation. The column *'change in number of intrusions'* refers to the scenario illustrated in Fig. 4.b, and *'change in number of conflicts'* refers to the one in Fig. 4.a. The total number of flights and the number of flights with a changed altitude (and their percentage of the total) are also shown.

It is important to highlight that within controlled airspace, addressing these additional conflicts requires only a minimal additional effort for air traffic controllers. Therefore, the safety risks associated with flight altitude changes to prevent contrail formations are nearly negligible.

Table 1 shows that there is only a slight increase in the number of intrusions or conflicts when changing altitudes for contrail prevention. This result is somewhat expected based on the small percentage of flights that required an altitude change for contrail prevention, and the relative emptiness of the airspace in general, even considering the large number of flights analysed for the year 2021 (2.6 million).

6. Discussion

In this section, we adhere to the general structure of the results section for discussion.

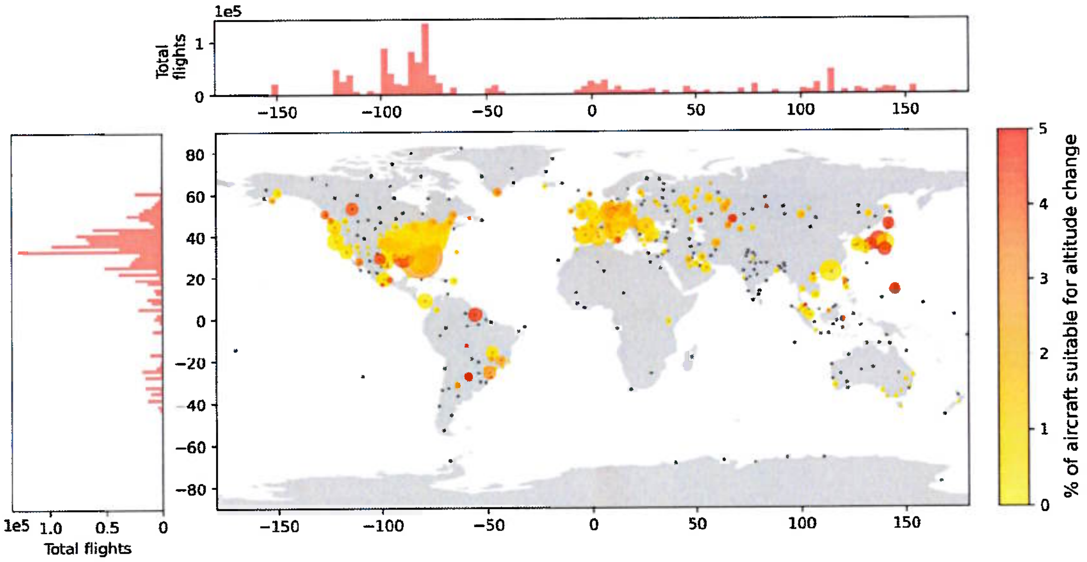


Fig. 10. Global distribution of the percent of aircraft where an altitude change of less than 2000 ft would prevent them from producing contrails. The size of the circles indicates the number of suitable flights. The vertical and horizontal histograms indicate the latitudinal and longitudinal distribution of all flights.

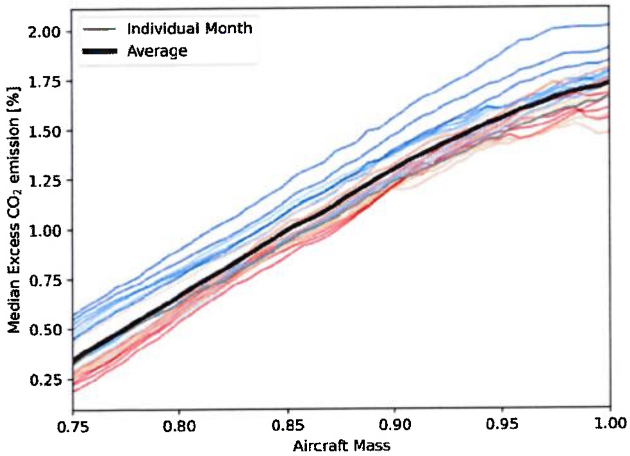


Fig. 11. Sensitivity analysis for additional CO_2 emissions, with varying initial mass. Each line represents a single month, and the black line shows the average of all 24 months. Seasonal dependency is also illustrated here, with colder winter months in blue colours and warmer summer months in red.

Table 1
Monthly actions for intrusion prevention and actions for conflict solving. The total number of flights and the number of flights with a changed altitude (and their percentage of the total) are also shown.

	Actions for intrusion prevention	Actions for conflict solving	Total flights	Flights with changed altitude
January	0	+1	166,651	1154 (0.93%)
February	0	0	149,998	1168 (0.78%)
March	0	0	191,979	1338 (0.70%)
April	+1	0	200,296	1452 (0.72%)
May	0	0	208,731	1604 (0.77%)
June	0	+1	220,712	1580 (0.71%)
July	0	0	243,836	1492 (0.61%)
August	+1	+2	238,265	1862 (0.78%)
September	0	0	227,643	2,340 (1.02%)
October	0	0	238,664	2,372 (0.99%)
November	+1	0	232,122	2,254 (0.97%)
December	+1	0	239,523	2,974 (1.24%)

6.1. Quantifying contrails

Based on atmospheric data from the same source as (Roosenbrand et al., 2022; Avila et al., 2019) estimates that 15% of flights generate contrails in the United States, while our results show 4.6%. Avila and Sherry (2019) indicates a maximum of 34% of flights generate contrails on a given day, with the daily average percentage of flights at 15.1% with a median of 13.8%. However, these results encompass the mid-Atlantic, where ISSRs are very prevalent and has a high air traffic volume.

OpenSky and IGRA both have limitations regarding coverage over oceans, and so could not be included in this research. The limited data coverage over oceans likely contributes to the differences in overall contrail percentages. Further extensive analysis using satellite networks (Cappaert, 2020) for cross-Atlantic flights should confirm this hypothesis.

6.2. Temporal effects

Teoh et al. (2022) reveals that while air traffic peaks in summer, persistent contrails are more common in winter. Fig. 5 supports this finding.

Notably, Avila et al. (2019) indicates that summer flights exhibit roughly three times higher Net Radiative Forcing than other months. Therefore, though fewer flights produce contrails in summer, their climate impact per flight is higher, especially given the greater number of flights in that season.

Fig. 5.b displays a reduction in aircraft suitable for altitude changes during winter, likely due to increased ISSR vertical extent (Hoinka et al., 1993).

The dominance of Northern Hemisphere seasonal cycle in the IGRA data influences the estimate of night flights, with an increase during winter and a decrease in summer. Weather balloon data skewed to the Northern Hemisphere shows a higher proportion of night flights compared to earlier studies (Stuber et al., 2006) (33.2% compared to literature 25%). However, night flights contribute disproportionately to contrail forcing (Stuber et al., 2006), suggesting the potential of flight rescheduling for climate impact mitigation.

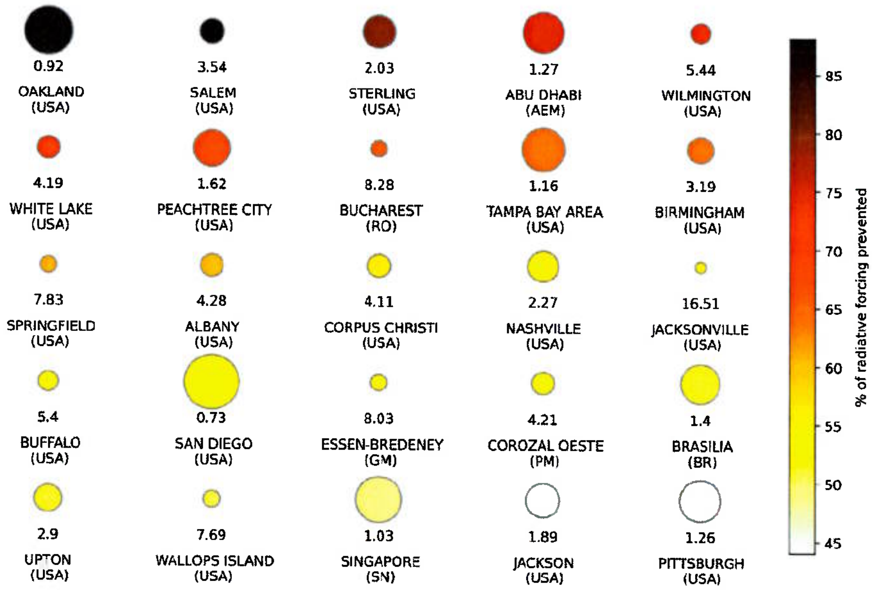


Fig. 12. Top 25 stations for minimizing contrail radiative forcing, with more than 10,000 yearly flights. The circle colour indicates the percent of contrails, which are prevented, and the size of the circle is correlated to the number of flights that need to be diverted (specifically the inverse). This percentage of flights is also shown below the circles. Thus, large circles in dark red indicate that with a few altitude diversions, a large percentage of contrails can be prevented.

6.3. Geographical effects

Avila et al. (2019) focuses on contrail generation in the contiguous United States and notes greater prevalence in the southeastern states. Our results (Fig. 7) align with this observation, but underestimate contrail formation in the Pacific region of the U.S.A. (Roosenbrand et al., 2022). These discrepancies may stem from contrail-forming regions mainly over the ocean, not covered by IGRA ground stations. Linking IGRA to ECMWF data in these oceanic regions may offer a solution.

Meyer et al. (2007) notes contrail prevalence in Southern and Eastern Asia, corroborated by our analysis (Fig. 6). With the region's increasing air traffic, contrail mitigation becomes increasingly relevant.

In Europe, a high volume of flights, rather than a high percentage of contrail-producing flights, drives contrail prevalence. However, atmospheric conditions allowing contrail formation are relatively frequent (Fig. 6). Further research is needed to understand altitude adjustments' impact on contrail formation.

6.4. Flight level change and its policy implications

Due to the discrete points used for the measurements and not using interpolation, the required altitude change could be overestimated, and might be even less in reality.

In our analysis, the aircraft has the option to either increase or decrease the altitude to *exit* the atmospheric layer. In Fig. 8, we see that in a majority (63%) of these flight alterations, the nearest option is reached by decreasing the altitude. Altitude decreases are generally unfavourable for minimizing climate impact due to decreased fuel efficiency (Avila et al., 2019; Schumann et al., 2011). Additional research on the trade-off between contrail climate effects and fuel burn is necessary.

A crucial result of this paper can be seen in Fig. 9: nearly 50% of contrail-forming flights can be mitigated through discrete altitude changes within the range of −2000 ft, −1000 ft, +1000 ft, and +2000 ft, already common in air traffic management.

Fig. 10 highlights regions where contrails could be minimized within current aircraft operations: mid-Western Europe, southeastern United States, and Southeast Asia.

6.5. Additional CO_2 emissions

Altitude diversions result in 0.25% to 2.0% additional carbon emissions, depending on aircraft mass assumptions. This range aligns with existing literature (<1% additional fuel burn - (Avila et al., 2019); 2.24% fuel - (Sridhar et al., 2010)).

The vertical extent of ISSRs in winter requires larger altitude deviations (Hoinka et al., 1993), resulting in higher CO_2 emissions, as depicted in Fig. 11 (bluish hues for winter and red for summer). Avila et al. (2019) points out that in the Summer months, more flights require an altitude *increase* to avoid ISSR's, which would also explain the lower fuel burn required we see.

With comparable results (Avila et al., 2019), concludes that the additional fuel burn caused by the altitude change from the original to the new flight level is *not* statistically significant. Mainly because the additional fuel burn was compensated by the advantage of cruising at higher altitudes with lower drag.

7. Conclusion

Global contrail formation was assessed using OpenSky, Spire, and weather balloon data from the years 2021 and 2022. Furthermore, the magnitude of altitude changes necessary to minimize contrail formation was quantified. The analysis of these persistent contrail flights shows that there are strong geographical and seasonal influences for identifying contrail-forming flights.

The key aspects examined in this study, namely safety, discrete altitude steps, and additional CO_2 emissions, are often cited as reasons that make altitude deviations for contrail prevention impractical. However, through a thorough analysis conducted within the scope of our research, we have effectively addressed and refuted these arguments. Of the required altitude changes to avoid contrails, 50.5% are possible within the discrete altitude step and a maximum of 2000 ft.

By carefully dissecting these concerns, we have demonstrated that the perceived obstacles surrounding safety, discrete altitude steps, and additional CO_2 emissions can be overcome. This research has successfully disarmed these commonly presented arguments against the feasibility of altitude deviations as a practical approach for contrail formation prevention, as well as illustrating the substantial climate gains possible through this approach.

CRediT authorship contribution statement

Esther Roosenbrand: Conceptualization, Methodology, Writing – original draft, Data curation, Writing – review & editing, Visualization, Software. **Junzi Sun:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Visualization, Software. **Jacco Hoekstra:** Conceptualization, Methodology, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Open and public data are used for this paper.

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