Civil Aviation Authority

RATIONALE FOR THE REMOVAL OF THE CURRENT VOLCANIC ASH BUFFER ZONE

Background

This paper brings together work conducted in the UK Civil Aviation Authority on the Buffer Zone (BZ) and provides an evidence-based case for its removal.

The BZ is a 60NM region around areas predicted to have an ash density greater than that determined to be tolerable by the aircraft and engine manufacturers (2 milligrams of ash per cubic metre of air ($2e^{-3}g/m^3$)). The BZ forms part of the currently promulgated No-Fly Zone (NFZ) which is, in turn, positioned within the published Enhanced Procedures Zone (EPZ) as indicated in the Figure 1. The dimensions of the BZ were proposed by Eurocontrol, and agreed by the Eurocontrol Member States at relatively short notice, to take some account of the assumed limitations of the ash concentration forecasting model and weather uncertainties.

The value of 60NM is arbitrary and derived, it is believed, not from data describing these uncertainties, but from interpretations of ICAO documents for the management of volcanic ash contingencies: In these documents[1] the value of 60NM is given as a downwind offset for the centre of a temporary danger zone to be put in place immediately after an eruption. No other reference has been found. The BZ has a particularly significant impact when surrounding very small areas of ash predicted to be at levels $>2e^{-3}g/m^3$, such as the predictions over Northern Scotland as shown in Figure 2; in this case the BZ and therefore the NFZ, exceeds the predicted extent of the Enhanced Procedures Zone (EPZ).

Eurocontrol is clear[2] that there was no scientific basis for its proposal, but at that time in the crisis it was felt that there was enough uncertainty to justify the decision. Both

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[1] NAT VCP, September 2009; EUR Doc 019
[2] Telecon between P Roberts / B Redeborn (Eurocontrol) on 27 April 10, and B. Alcott / B. Redeborn 5 May 10

Eurocontrol and the ICAO Regional Office have also confirmed[3] that a reasoned proposal from the UK for the removal of the BZ would be acceptable to them.

Impact of the Buffer Zone

Whilst the high ash concentration is offshore, the BZ has limited impact on operations at UK airports although it may affect significantly tracks available for trans-oceanic flight. However, aerodromes that lie within the BZ as ash moves across the UK have been affected (e.g. closure of Edinburgh and Belfast airports). It is vital that whether there is any safety rationale for continuing to impose the BZ is well understood with respect to the risk to continued safe flight and landing, and therefore the risk of an aircraft accident. This paper contends that an analysis of the safety benefit leads to the conclusion that the retention of the BZ is not necessary. Data should continue to be collected and models enhanced so as to increase confidence and provide ongoing assurance that this remains the case as this volcanic ash event develops.

The Risk to Be Addressed

The key risk to be addressed is one of airworthiness: the ability of an aircraft to continue safe flight when exposed to volcanic ash. The available data suggest that in high-density ash encounters severe engine damage is the most likely reason for continued safe flight to be put in jeopardy. It must however be the case that, there are lower concentrations of ash which will not prejudice continued safe flight but will cause damage resulting in accelerated engine wear and a need for increased engineering interventions. However, if addressed by appropriate inspection and maintenance procedures, such damage will not put at risk the continued safe flight of the aircraft.

Removal of the Buffer Zone

To propose removal of the BZ, the CAA must be satisfied that the risk of an aircraft being unable to continue safe flight and landing is acceptably low. For this criterion to be met, the CAA must be satisfied that:

[3] Telecon between B Alcott / B Redeborn on 5 May 10; telecon between P Roberts / B Redeborn 8 May 10 and P Roberts / K Theil (ICAO Paris) 8 May 10

- The airworthiness limits, particularly with respect to engine damage, are understood and there is sufficient margin between the levels of ash likely to be observed and levels of ash likely to cause damage that may prevent continued safe flight and landing;
- the likelihood of an encounter with ash concentrations that would cause damage that may prevent continued safe flight and landing is acceptably low, i.e. understanding of the actual amount of ash that is likely to be in the air where aircraft will be operating. This will in turn require the CAA to be satisfied that:
    - confidence in the dispersion model's predictions and stability is sufficient;
    - the validity of the model predictions against time are understood;
    - available test data do not undermine the model's predictions
    - any additional levels of conservatism are understood;

The following sections describe the evidence for each of the above criteria being satisfied.

Airworthiness Limits

Data on volcanic ash ingestion are limited and it is therefore not possible to determine at this time a general level of ash contamination which precludes continued safe flight and landing. However, the level of ash which analysis has judged to have resulted in two multiple engine shutdown events[4] is understood to be approximately $2g/m^3$ ($2e^0g/m^3$). At this level of ash density, engine shutdown occurred after a matter of minutes of exposure. The current maximum tolerable level for continuous operation, as determined by manufacturers[5] based on engineering judgement and other data, is $2e^{-3}g/m^3$, **three** orders of magnitude less.

The boundary of ash contamination between damage which may prevent continued safe fight and landing, and damage that would cause accelerated engine wear and increased engineering interventions is not known. The manufacturers have

[4] BA B747 at Jakarta; KLM B747 at Anchorage
[5] Agreement reached on 20 April 10 which led to UK airspace being reopened

specified their requirements and for the vast majority of products, they have prescribed little in the way of engineering interventions for continuous operations in the EPZ, i.e. concentrations up to $2e^{-3}g/m^3$. For some older engine types from certain OEMs, a borescope inspection has been required at an increased frequency.

No MOR report received by the CAA to date has indicated damage from flying in the EPZ. The results from pathfinder flights conducted in the early stages of the crisis were also positive.

Rationally, the procedures put in place by the manufacturers indicate that *at* $2e^{-3}g/m^3$, there is *no risk* of significant damage and very little risk of any damage requiring additional maintenance. There is no evidence to the contrary from MORs received to date.

Although the exact rate of change of damage with ash concentration is not known, it can be said with certainty that the level of engine or airframe damage will not be subject to a step change at ash concentrations of $2e^{-3}g/m^3$.

<u>Confidence in the model's prediction and stability</u>

The level of confidence of some aspects of routine Met Office data that are used, such as wind and temperature, in the model's prediction capability have been regularly reviewed at Quarterly Regulatory meetings with the Met Authority in DAP[6]. A recent scientific study[7] compared the models used by London, Darwin, Washington, Montreal and Toulouse Volcanic Ash Advisory Centres (VAAC). It concluded, *inter alia,* that despite the differing methodologies applied, all the models gave very similar results.

The Met Office has provided further supporting information as to the veracity of their input parameters, including how various observations, including satellite images are used. Their responses are shown at Appendix 1.

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[6] Minutes of Met Office Quarterly Regulatory Meetings with CAA
[7] Witham C et al., Comparison of VAAC atmospheric dispersion modes using the 1 November 2004 Grimsvötn eruption (007),Meteorological Applications 14: 27-38

In addition with respect to this particular eruption:

- All data from the Do228 and BAe146 research flights, ground based LIDAR and Met Office weather balloons have been used to improve the model's output. Cloud base recorders have been used as LIDARs and these have also been fed back into the model.
- The UK Met Office has established direct contact with the Icelandic Met Office and this has given higher confidence in the efflux data from the volcano. The Met Office has sent two staff to Iceland to improve communications further. The UK Met Office has also noted any new ash from the volcano takes approximately a day to reach the UK by which time variations in the eruption strength to the model will have been corrected. In addition in the event of a major increase in eruption strength, the model will be rerun immediately and an emergency chart issued. This has occurred on one occasion on the morning of 6 May 10, when it was identified that the volcano had been erupting at a higher rate and to higher altitudes continuously and not in an episodic manner as had been previously reported. New charts were issued in a timely fashion and the next VAAC run showed the upper plume extending from the source and connecting the 'floating area' of high ash concentration in the eastern Atlantic.

<u>Time validity</u>

The above statements deal with the prediction of the levels within the ash cloud. It is also important to understand the validity of the model boundaries with time. The following has been determined:

- The key component in the time validity is the wind prediction. The Met Office Numerical Weather Prediction (NWP) model has consistently met the KPI relating to error in wind velocity.
- A representative sample of T+0 versus the previous T+6 plots have been made to help improve the understanding of the likely errors in the model.. The general observation that may be made is that, for the part of the boundary with low rate of change of direction, the two plots have a very good correlation. It should also be noted that the errors are concentrated at the extremities of the predicted ash cloud, and the error is much lower where the boundary as defined is smooth.

- The requirement for accurate time validity of the model to ensure safety is proportional to the ash density gradient. In other words, the lower the ash density gradient, the lower the requirement for accurate time validity.
    - Closer to the volcano, the time validity is more critical, since the ash gradient will be high. It is in this area that the model will be most accurate, since it is closest to the eruption event and the volcanic eruption can be observed.
    - Further away from the volcano, the time validity will be lower, but so will the ash density since more time has elapsed and more dispersion has occurred. An example of this can be seen in Figure 5.
    - The conclusion is that where the ash density gradient is likely to be highest, the accuracy of the model is highest. This mitigates against the likelihood of an unexpected ash encounter significantly above the levels agreed by the manufacturers.
- With the BZ removed, CAA would continue to compare T+0 with the previous T+6 and make changes to the notified NFZ if necessary based on the new information. This may be beneficial at times, but at other times there would have to be an acceptance that it could mean the need to accelerate closures, although this is considered to be an unlikely event unless the there is a step change in modelling due to particularly strong winds or a higher outflow rate from the volcano. This would provide additional mitigation against error in time validity.

Flight test and Ground based instrument data

- The readings taken by the Do228 and the BAe146 have not been fully analysed at this time and each aircraft can only ever measure along a narrow track, however a review of the raw data (Table 1) shows that the maximum values measured have never exceeded those predicted by the model. There therefore exists a general data set which has not, to date, given any indication of ash levels which are likely to impact on continued safe flight and landing outside the NFZ..
- In addition, some work has been completed to correlate FAAM flight ground tracks correlated with predicted ash concentration data, for the 20 and 21 April.

- Figure 3 shows the ground track and the VAAC prediction which was subsequently transcribed into the NFZ for the 20 April 2010. The SW - NE track flown on the west side of Scotland was deliberately flown within the tip of the no-fly zone; albeit with sampling and measuring equipment recording particle density from above using the BAe 146 and from below using the Do 228. Typically the flight was operated between FL 230 and FL 280 for the BAe146 and, for the southern portion, up to FL 200 for the Dornier. The track depicted in the figure is that recorded by the 146. Figure 4 is a similar diagram for the following day, 21 April 2010. As for 20 April, the track was planned to encounter the no-fly area of the plume for data gathering and sampling purposes, however altitudes were adjusted to ensure safe separation from the densities required for safe operation of the aircraft and clearly identified in the risk assessment before the flight. Following departure, the aircraft was operated to the North towards the UK FIR boundary at 61N, where conveniently the plume was positioned so that tip sampling could be accomplished. The southbound track was positioned so as to get the best "proximity" results.
- At no time was a particle count in excess of 0.08E-3 g/m^3 observed; well below the safe OEM agreed level of 2.0E-3 g/m^3. The results obtained on these two flights, which were deliberately close to the NFZ, were consistent with earlier sampling from more distant observations.
- In summary, the FAAM test aircraft was operated into and around the NFZ at least twice and for several hours during sampling science flights. During these flights, measurements indicated a particle density well below the maximum considered safe for commercial transport.

- The readings from the airborne LIDAR[8] show values in the ash layers approximately equal to the model prediction for the EPZ of $2e^{-4} g/m^3$. These have been backed up readings from ground-based LIDAR in the south of the UK at the early stages of this event.

[8] Data produced by DAP for NACME 5 May 10 from BAe146 flight on 5 May 10

Additional Conservatism in the System as a whole, and other mitigations planned

The following additional points are of note:

- The flight data attained by test aircraft from on board sensors, LIDAR and flight reports from crew all indicate that the ash presents in layers, not in a homogeneous way with altitude and that these layers do not exceed the VAAC predictions. Thus the actual ash ingested by an engine climbing or descending through this ash will be less than if the ash was at the predicted level through the entire vertical extent. The concentration of ash being in layers will continue to be monitored by ongoing flight test.
- The revised NFZ would still be a NOTAM area based on smoothing of the $2e^{-3}g/m^3$ boundary. The VAAC will determine the boundary to ensure all areas inside the $2e^{-3}g/m^3$ boundary are covered. This will inevitably mean the NOTAM area will be greater than that of the predicted area, thereby further increasing the margin for safety.
- In conducting this work it has become evident that it is necessary to review the appropriateness of using the T+6 forecasts, in light of a better understanding of the dispersion model. . This review will further enhance/validate the accuracy of the model and improve the time validity of the prediction.

Ability for industry to operate safely up to the $2e^{-3}g/m^3$ model boundary (revised NFZ)

At the onset of this crisis, operators accepted the original ash concentration area (the red line on the VAAC charts) as being the limit of safe flight. No further boundary was required, as outside the line was considered to be satisfactory for normal flight. This was replaced by justification for operation in the EPZ and it is this that must continue to be the basis of safety cases from the industry.

It is essential that any safety cases are operator specific and tailored to their individual circumstances. The safety cases provided to CAA to date have met both these criteria and it is not expected that they would change if the BZ is eliminated. The same is true for aerodromes. However, what must be made clear to the operators is that the CAA will not direct ANSPs to open airspace or provide take-off/landing clearances if the ANSP does not believe they can make a safety case to do so. In the case of high altitude en-route tracks, it will be for the ANSP to determine which tracks will be available and to inform the operator of the proximity to the revised NFZ; there is therefore no change from the current situation.

In reviewing any safety case, the CAA will expect the boundary of the revised NFZ to be treated as in the same manner as a Danger Area and CAA's normal safety case approval procedures will apply. *Inter alia*, CAA will require that any safety case includes:

- Assessment of risk, based on aerodrome operations, local geography operator procedures etc.
- Confirmation that pilots will be advised by ATC of reports of any incidents that may be related to an ash encounter. Suitable procedures are contained in CAP 493 (MATS Part 1).
- How PIREP information will be used by the operators/ANSPs to determine whether to continue or modify operations.
- Understanding of how all PIREPS related to ash encounters are communicated back to the CAA.
- Procedures for the closure of an aerodrome for non-safety diversions.
- How arrival and departure procedures will be used to ensure aircraft are safely directed away from the revised NFZ boundary at the earliest opportunity. This would need to cover the situation where the revised NFZ boundary was off one end of the runway (i.e 'dead-end valley procedures'). If these situations are not already covered by an ANSP's procedures they will need specific ANSP safety assessment, on a case-by-case basis.

Civil Aviation Authority

Conclusions

The risk to be addressed when determining whether the BZ should be removed is the likelihood of an encounter with ash which results in the aircraft being unable to continue safe flight and landing. To address this risk the CAA needs to be satisfied that the airworthiness limits are well understood and the likelihood of an ash encounter at concentrations that would result in the aircraft being unable to continue safe flight and landing is acceptably low.

With regard to airworthiness limits, the lowest ash concentration that would result in an aircraft not being able to continue safe flight and landing is not known, however the current tolerance level agreed by the manufacturers is **three** orders of magnitude lower than the concentration thought to have caused multiple engine shutdown.

Confidence in the model has grown significantly through the experience gained in this volcanic event and, in light of this, there are plans to improve the way the output of model is utilised. The boundary of $2e^{-3}g/m^3$ provided by the model is a probability of a mean value and should not be taken to be a fixed line in space. There can, therefore, never be complete certainty of the position of the ash. However, the model is considered to have a satisfactory level of accuracy and to include a level of conservatism. In addition, there are additional levels of conservatism in the system which do mitigate the risk.

Where available, flight test data validates the levels predicted by the model and, even where flights have been conducted over and around the $2e^{-3}g/m^3$ boundary, no readings have been reported that exceed the levels predicted.

Importantly, no reports of damage have been received from aircraft operating in the EPZ.

Operational procedures are in place both with the ANSPs and the operators to deal with an ash encounter.

There was no scientific basis for the application of the BZ in the first instance, but it was a sensible precaution in terms of a rapid, initial response. The information contained in this paper supports the view that there is a level of conservatism in the process as a whole and that the BZ should be removed. Any residual risk should be managed by ANSPs and aircraft operators by way of their own risk assessments of when they wish to fly in the proximity of the modified NFZ.

Recommendations

- Inform Eurocontrol and other European partners that in the UK, the BZ will be removed and the NFZ will be based on the $2e^{-3}g/m^3$ boundary.
- Once accepted by Eurocontrol, announce to industry and inform them that the CAA will review safety cases for how operations would be managed by operators and ANSPS under the new arrangements.
- Confirm to industry that we will be prepared to review safety cases for operations en-route and at aerodromes.
- Modifications to established service provision arrangements will be safety assessed by ANSPs in accordance with European legislative requirements.

With this being the case, the NFZ(s) promulgated by NOTAM will be defined by smoothed coordinates best fitting the edge of the $2e^{-3}g/m^3$ boundary.

The CAA will continue to monitor the situation and ongoing actions required will be:

- Continued flight of the BAe146 around and over the NFZ to continue increase confidence in the modeling.
- Monitor PIREP and MOR information to determine the effectiveness of the revised policy and require revision of industry safety cases or the CAA position as appropriate
- Continue to refine the model with all available data.

Figure 1 – Zone Diagram

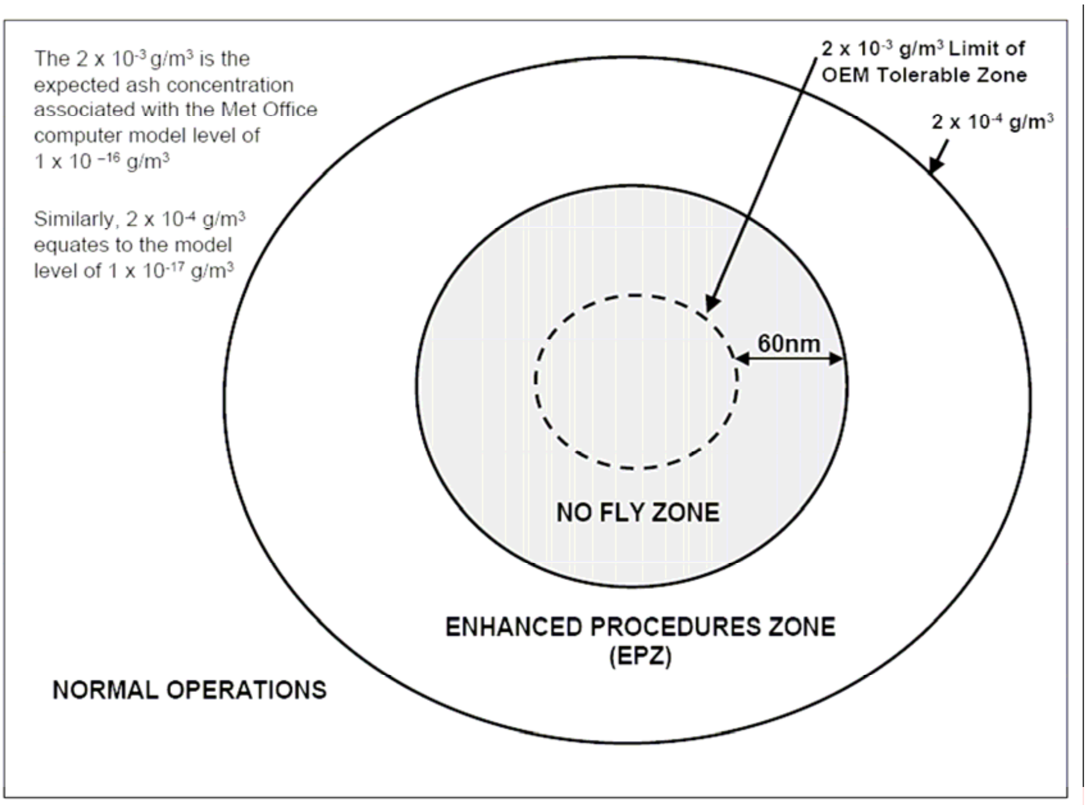

Figure 2 - Valid time 20100508/1800

Volcanic Ash concentrations FL000 to FL200

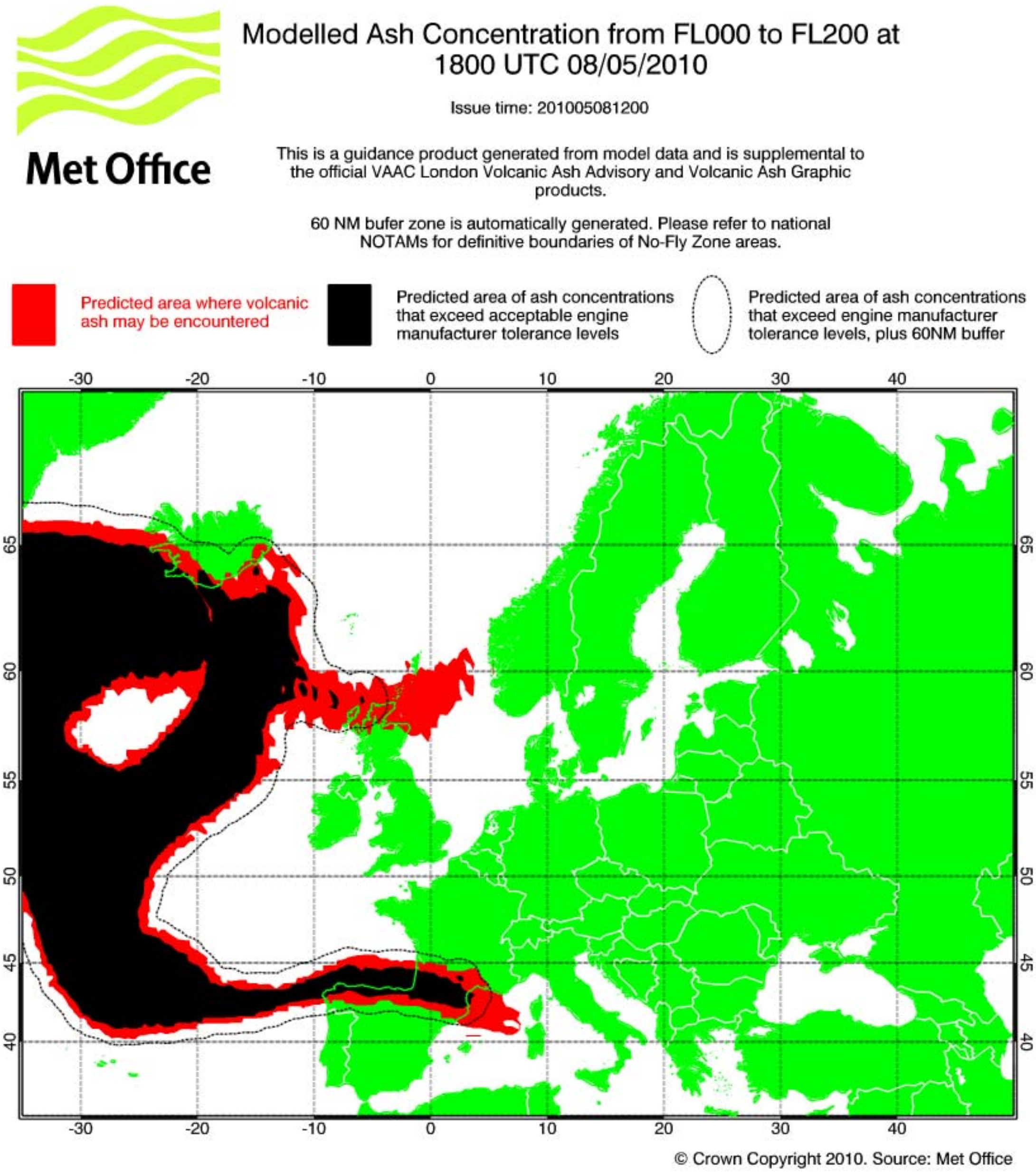

Table 1 – Maximum ash concentrations measured by Test Flights between 19 and 22 April 2010

Date	19/4/10	19/4/10	20/4/10	22/4/10
Location	Scotland	South of the North Sea	North of Northern Ireland	Prestwick
Flight Level	FL80	FL110	FL210	FL120-150
Concentration ($e^{-3}g/m^3$)	0.08	0.13	0.02	0.035

FAAM Test Flight report 04/05/10

FAAM test flight on 04/05/10 did not measure ash concentrations greater than the aircraft operation threshold level of $2e^{-3}g/m^3$. Several layers were encountered in the descent (at FL195, FL154 –142, FL99, 8kft) with the cloud physics probes indicating concentrations between 0.01 and $0.1e^{-3}g/m^3$. The layers and values were highly variable during the descent.

Appendix 1 – Responses to questions posed to Met Office by DAP regarding the input parameters used for their model.

What Satellite(s) is/are used in measuring the actual eruption height.

Eruption Height is determined by a number of means. This includes weather radar, direct observation by aircraft and human observation from the ground. Estimates of ash height can be also be made from a number of satellite instruments such as MODIS[9] and CALIPSO[10]. Most observation methods are hampered by the presence of normal (water/ice) clouds.

What steps do they take to assess the ash type and density being dispersed.

Some satellite instruments (e.g. MODIS) are able to determine ash density if the depth of the plume is known. Particle size distribution can be directly measured by flying research aircraft through the plumes. Ground based LIDAR can also be used to measure particle density. None of these methods however provide a continuous and widespread coverage and again are hampered by the presence of clouds.

What satellite(s) is/are used to confirm the presence of visual ash and to update the model.

MODIS is a key instrument aboard the Polar-orbiting Terra (EOS AM) and Aqua (EOS PM) satellites. Differencing techniques (comparing infra-red channels of different wavelengths on Meteosat) can be used to determine the presence of volcanic ash. However, there is no agreed definition of what constitutes a visual ash cloud or not. If ash is not visible on satellite imagery it does not mean that there is no ash. Ash is not visible on Satellite imagery if the ash is mixed with or lying underneath water/ice clouds. Actual measurements of ash from research aircraft have been used to verify the forecasts. The source parameters are updated whenever new observations are received that indicate a change in the level of activity.

How was the decision to increase the modelled source release rate on Sunday by a factor of 5 arrived at.

- Ash reports from Icelandic Met Office indicated consistently increasing activity from around 0600Z on 2/5/2010; plume height increasing during the day; reports at 1800 and 2100 state plume height 13000-18000ft.
- Pilot report from a research flight at ~1500Z on 2/5/2010 indicated enhanced ash concentrations at 60N,15W FL100.
- In an EMARC telecon with Iceland suggested increasing the source strength by a factor of 5.

Previous changes had seen the release rate reduced by a factor of 10 at least twice, so this represents a relatively modest increase.

On what basis was the 1x10^-17 threshold (red line) arrived at originally to determine the forecast area of ash that was considered hazardous to aviation (i.e. not 10^-18 or 10^-16 etc.)

[9] NASA Moderate Resolution Imaging Spectroradiometer
[10] NASA Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation

The VAAC London model originally used a threshold of 1x10E-17 for a medium-sized eruption. A comparison between the other VAACs output following the Grimsvotn eruption in 2004 showed that all five produced very similar results to determine the ash area. The rate of 1x10E-17 is used by a number of the VAACs when considering a medium-sized eruption and a unit release rate of 1g per 6 hours. 10E-18 would be used for a large eruption (say with a plume > 40,000 feet), while 10E-16 would be used for a smaller eruption. As the eruption decreased in intensity a lower release rate (or higher threshold) is utilised to determine the area affected by ash. This then produces a smaller area of ash, once the dispersion processes are taken into account.

The figure of 1x10E-17 is not an absolute quantity of ash, but is consistent with the use of a release rate of 1g per 6 hours. If more realistic scaling is used e.g. 2x10E09g per second of ash release then this equates to an ash concentration of ~2x10E-4, which is a similar order to the amount of ash that has been observed.

The 6-hr average concentration plots mean that airports/airspace are closed for a minimum of 6 hours at a time. Is it possible to produce hourly concentration plots to provide more granularity

This can be developed if requested by the CAA; however is not a trivial task and is likely it would take several weeks of effort to complete. Further analysis of the detailed resource requirements is being undertaken.

Nigel Gait
4/5/2010

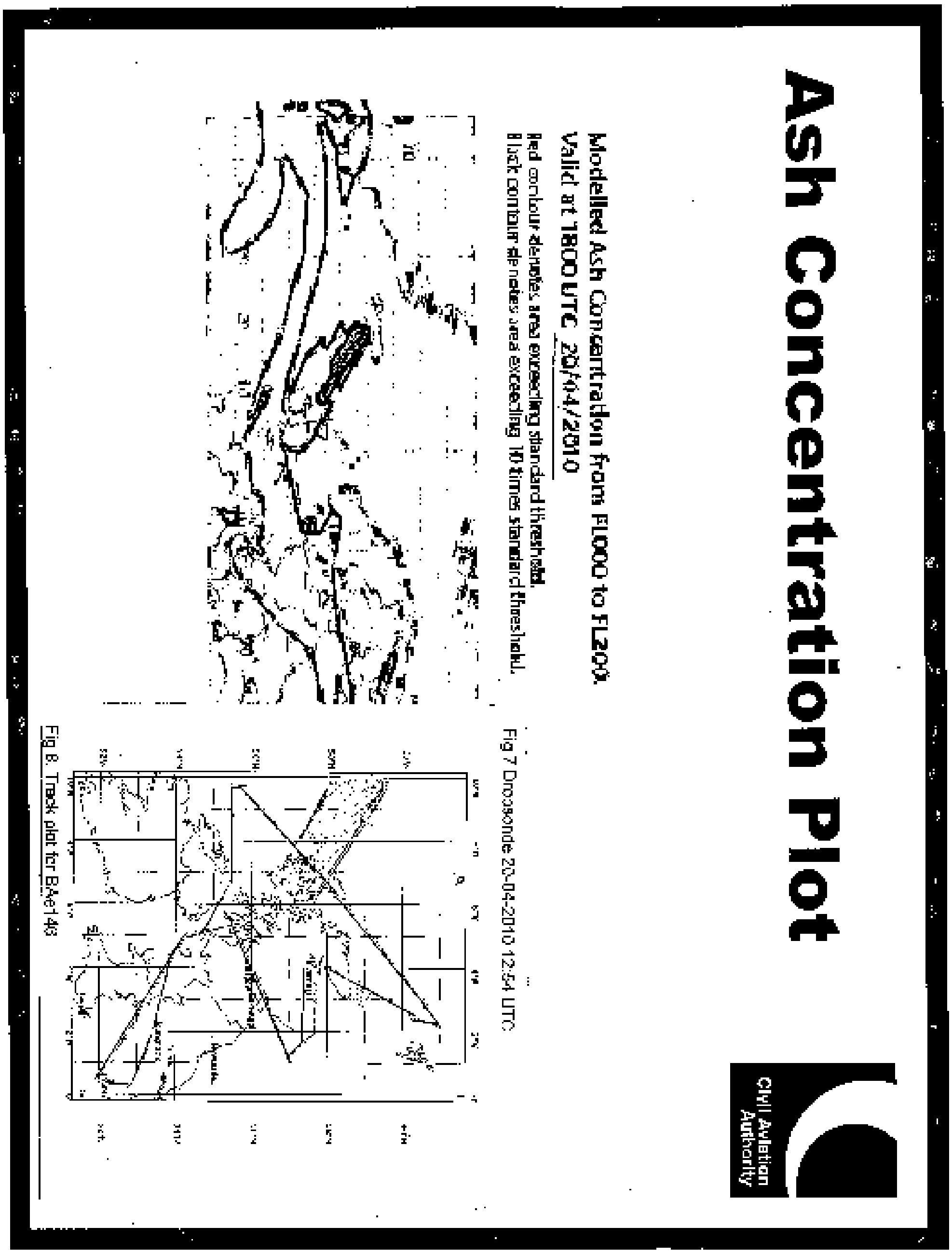

Figure 3 – plots from test flights flown 20 April 2010

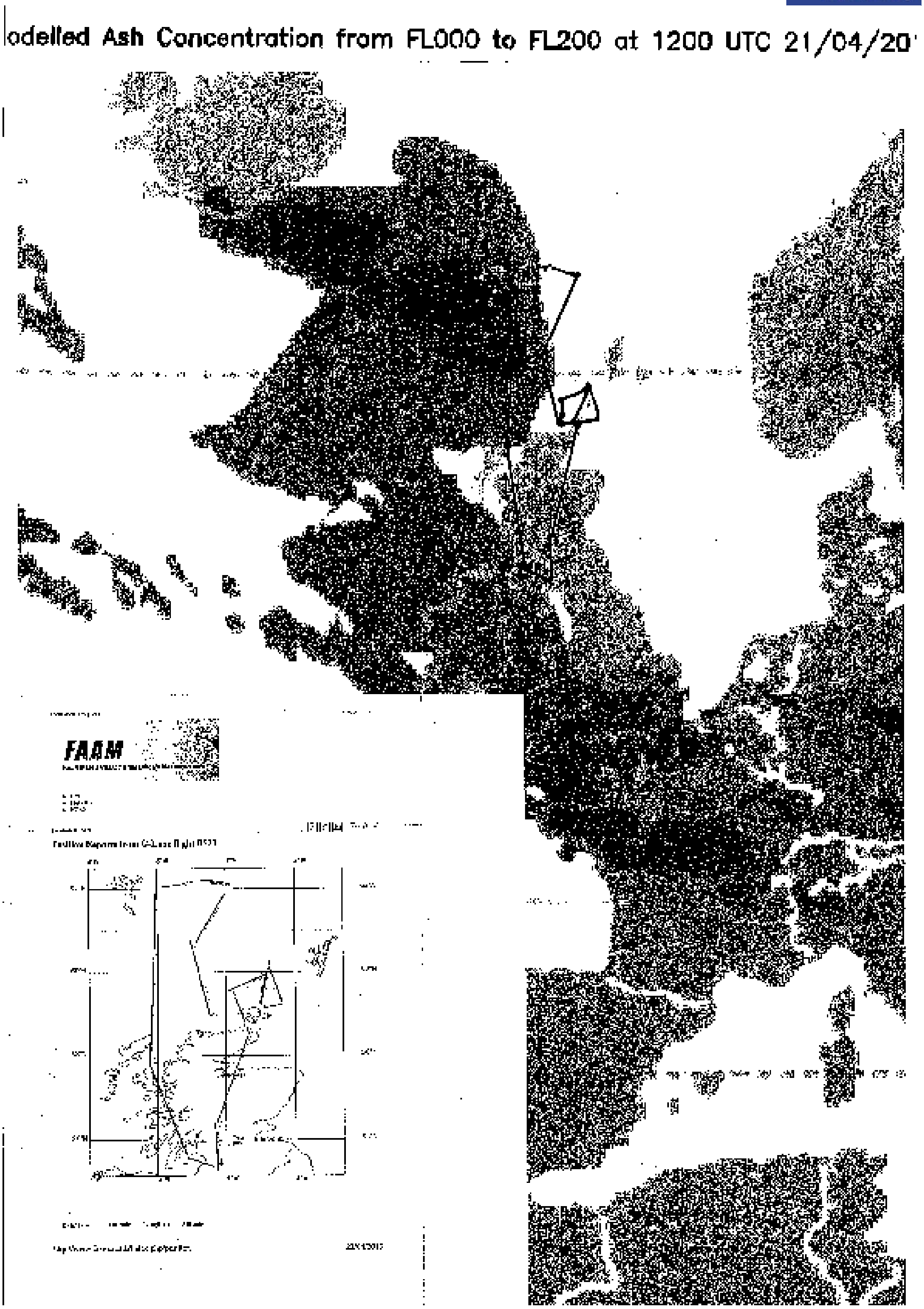

Figure 4 – Plots from test flights flown 21 April 2010

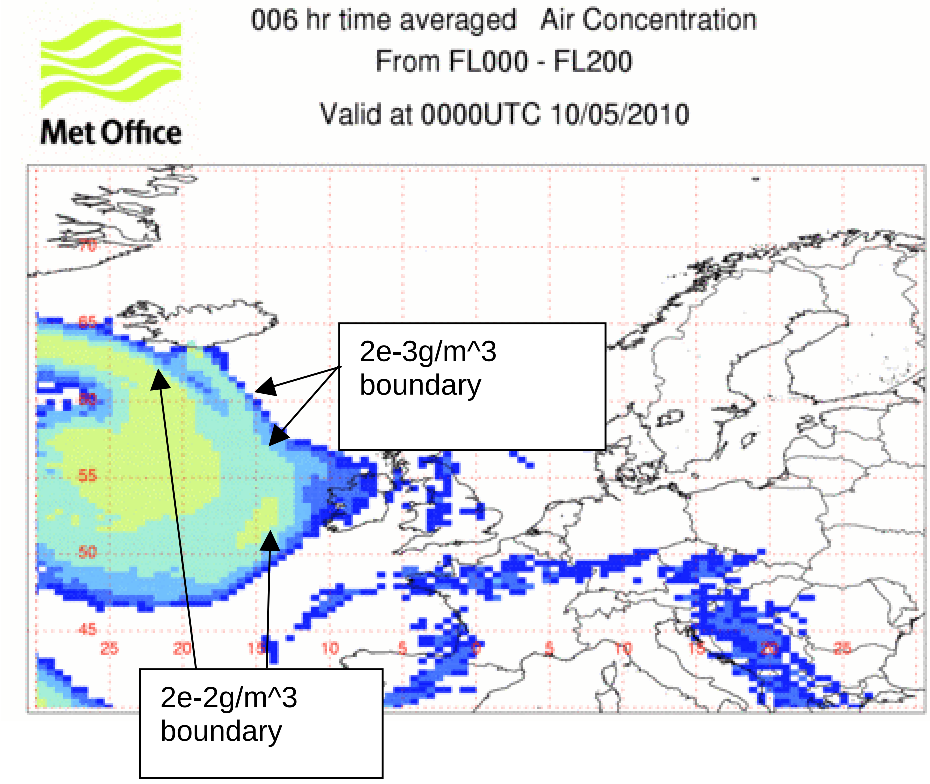

Figure 5 – Example of concentration gradient. Published with the permission of the UK Met Office