Environmental Research and Consultancy Department

Civil Aviation Authority

R&D REPORT 9842

The UK Civil Aircraft Noise Contour Model ANCON: Improvements in Version 2

J B Ollerhead
D P Rhodes
M S Viinikainen
D J Monkman
A C Woodley

www.caa.co.uk

The authors of this report are employed by the Civil Aviation Authority. The work reported herein was carried out under a Letter of Agreement placed on 23 July 1999 by the Department of the Environment, Transport and the Regions. Any views expressed are not necessarily those of the Secretary of State for Transport.

ISBN 0 86039 924 9

Prior to 1 April 2000, the Environmental Research and Consultancy Department (ERCD) was known as the Environmental Studies section of the Department of Operational Research and Analysis (DORA) of National Air Traffic Services Ltd (NATS). NATS was part of the Civil Aviation Authority until 1 April 2000. Although this document has been republished by ERCD in electronic format, its content and appearance remain unchanged from the original NATS R&D Report 9842.

Enquiries regarding the content of this publication should be addressed to:
Environmental Research and Consultancy Department, Directorate of Airspace Policy, Civil Aviation Authority, CAA House, 45-59 Kingsway, London, WC2B 6TE.

The latest version of this document is available in electronic format at www.caa.co.uk, where you may also register for e-mail notification of amendments.

Published by TSO (The Stationery Office) on behalf of the UK Civil Aviation Authority.

Printed copy available from:
TSO, PO Box 29, Norwich NR3 1GN
Telephone orders/General enquiries: 0870 600 5522
Fax orders: 0870 600 5533
www.tso.co.uk/bookshop
E-mail: book.orders@tso.co.uk
Textphone: 0870 240 3701

R&D Report 9842

The UK Civil Aircraft Noise Contour Model ANCON: Improvements in Version 2

J B Ollerhead
D P Rhodes
M S Viinikainen
D J Monkman
A C Woodley

Prepared on behalf of the Department of the Environment, Transport and the Regions by the Department of Operational Research and Analysis, National Air Traffic Services Ltd, June 1999, Price £10.00

Department of Operational Research and Analysis
National Air Traffic Services Ltd

File Reference
8RD/13/004/01

R&D REPORT 9842

The UK Civil Aircraft Noise Contour Model ANCON: Improvements in Version 2

J B Ollerhead
D P Rhodes
M S Viinikainen
D J Monkman
A C Woodley

SUMMARY

Version 1 of the UK aircraft noise contour model (ANCON-1) is described in DORA Report 9120. This supplementary report describes changes that have been made to upgrade the model to 'Version 2' standard (ANCON-2). Until a planned self-contained replacement for DORA Report 9120 is released, the two reports together provide an interim technical description of the ANCON-2 noise model as of June 1999.

The process by which ANCON-2 calculates noise exposure is, for the most part, the same as that of ANCON-1. The main change is that the contribution to Sound Exposure Level from an aircraft flight segment is now derived from Noise-Power-Distance tables as a function of engine thrust rather than from wholly empirical Reference Noise Levels (RNLs).

The first edition of the updated ANCON-2 model ('ANCON-2.1'), used to produce the 1996 and 1997 L_{eq} contours for the London airports, is described briefly in an appendix; however, like its predecessor, ANCON-2 will be subject to continuing development as the DORA database expands and internationally agreed modelling procedures are improved.

Prepared by DORA on behalf of the Department of the Environment, Transport and the Regions, June 1999

CONTENTS **Page No**

CONTENTS **Page No**

Appendices

GLOSSARY

This report is intended to be read in conjunction with DORA Report 9120 (Reference 1). As indicated below, some terms and symbols have exactly the same meaning as in that report while others are not used there. However, to accord with normal conventions in the field of aircraft performance, a few symbols used in this report, principally in Section 4, have meanings different from those used in 9120.

Defined as in DORA Report 9120

dB	Decibel units describing sound level or changes of sound level.
dB(A)	Units of sound level on the A-weighted scale (often written elsewhere as dBA).
F	Noise Fraction - the ratio of the noise energy received from an aircraft traversing a flight path segment of finite length to that which would result if the segment were extended indefinitely in each direction.
Field point	A point on the ground at which noise exposure variables are to be determined.
Ground track	The vertical projection of an aircraft flight path onto level ground.
INM	Integrated Noise Model: aircraft noise contour model maintained by the USA Federal Aviation Administration.
L(t)	The sound level (instantaneous or short-term average value) at any particular time t.
L_{eq}	Equivalent Sound Level of aircraft noise in dB(A) (often called equivalent continuous sound level). The sound level averaged over a specific period of time, e.g. 16 hours, 24 hours etc. It is sound *energy* that is averaged, not the decibel level - whence the expression 'energy-averaging'. An accurate value can normally be estimated by averaging sound energy during those restricted periods of time when the aircraft noise exceeds the background noise.
L_{eq}(16-hr)	L_{eq} averaged over a 16-hour period, specifically for the designated airports, 0700 - 2300 local time.
L_{max}	The maximum value of L(t) recorded at a field point during an aircraft fly-by.
L_{ref}	The value of RNL (q.v.),dB(A).

L_{SE}	The value of SEL (q.v.), dB(A).
RNL	Reference Noise Level which defines the amount of noise emitted by an aircraft. It is a nominal L_{max} sound level in dB(A) at a distance of 500 feet (152.5 metres) from the aircraft.
s_p	Perpendicular distance from field point to flight path or its extension.
SAE	Society of Automotive Engineers (USA).
SEL	Sound Exposure Level - a measure of the noise event generated by a single aircraft fly-by, in dB(A). This accounts for the duration of the sound as well as its intensity; it is equal to the sound level of that 1-second burst of steady sound which contains the same (A-weighted) acoustic energy as the aircraft sound.
t	Time.
V	Aircraft speed (relative to the ground), m/s.
ΔL_{SE}	Sound exposure level contribution from single finite flight path segment.
$\Delta L_{SE\infty}$	Sound exposure level contribution from single infinite flight path segment - with no lateral attenuation.
λ	Sound level threshold or cut-off.

Defined differently than in DORA Report 9120

D	Total aircraft drag force.
L	Total aircraft lift force.
T	Total propulsive thrust force.
δ	Ratio of air density at aircraft altitude to that at sea level.
θ	Climb gradient (see Figure 3).
ϕ	Bank angle (see Figure 4).

Not used in DORA Report 9120

a	Aircraft acceleration in direction of flight.
a_n	Vertical (upwards) component of aircraft acceleration.
C_D	Total aircraft drag coefficient.
C_{D_0}	Total aircraft profile (shape) drag coefficient.
C_L	Total aircraft lift coefficient.
DETR	Department of the Environment, Transport and the Regions.

DORA	Department of Operational Research and Analysis (of National Air Traffic Services Ltd).
Flight profile	Variation of height, speed and engine power along flight path.
g	Acceleration due to gravity.
k	Induced drag coefficient.
M	Aircraft mass.
n	Overall wing load factor (total lift/aircraft weight).
n_n	Normal wing load factor.
n_t	Turn load factor.
NTK	Noise and Track Keeping Monitoring System (used by Heathrow, Gatwick and Stansted Airports).
NPD	Noise-Power-Distance (relationships).
R	Turn radius.
S	Wing area.
V_{ref}	Standard reference speed (relative to ground) for NPD relationships; V_{ref} = 160 kt (not to be confused with the variable V_{ref} used in aircraft operations.
V_t	True airspeed.
ρ	Air density.

Intentionally Blank

1 INTRODUCTION: THE NEED FOR AN UPDATE

1.1 This report describes improvements that have been made to the UK Civil Aircraft Noise Contour Model ANCON which is described in DORA Report 9120 (Reference 1). As Section 6 of that report states, the model is subject to continuing development and a number of changes have been made since it was first introduced. Read in conjunction with Reference 1, this document provides a technical description of ANCON as of June 1999.

1.2 ANCON is the mathematical model used to produce the annual L_{eq}(16-hour) aircraft noise exposure contours[1] published by the Department of Environment, Transport and the Regions (DETR) and previously by the Department of Transport (DoT). It is also used to produce noise exposure forecasts for use in airport planning studies and similar aircraft noise models are used in many other countries. In general, such models may be described as being either empirical or deterministic[2]. Empirical models are those which mainly rely on relating aircraft noise and flight path measurements made around the airports of interest, whilst deterministic models synthesise aircraft flight paths and noise emissions, making use of aircraft noise and performance data (usually provided by aircraft manufacturers). To calculate noise exposure patterns, both types of model define ground tracks of arriving and departing aircraft along with their 'flight profiles' - the variations of height and speed along the flight tracks, which are then related to noise emissions.

1.3 ANCON calculates L_{eq} at a point on the ground by summing the SELs caused by all passing aircraft. The SEL caused by one aircraft depends upon its flight path (in three dimensions), the amount of noise it emits along that path and the way the sound propagates from the aircraft to the ground. A crucial factor governing SEL is that, for each aircraft, the flight path and the noise emission are linked: both depend upon the way the aircraft is flown, i.e. upon the operating procedure - particularly the way in which engine power is varied. For this and other reasons, noise event levels caused by different movements of the same or similar aircraft type can vary markedly.

1.4 ANCON Version 1, described in Reference 1 and known simply as ANCON-1, was empirical. It used 'Reference Noise Levels' (RNLs) to define aircraft noise emission levels for each different aircraft type at various points along its average flight profile. These were expressed as maximum levels (L_{max}) in dB(A) at a standard reference distance of 500 ft (152 m) from the aircraft. RNLs were average values, determined from large numbers of noise and radar flight path measurements made regularly at the London airports by DORA. Noise contours were then calculated taking into account the average flight

---

[1] For the 'designated' airports Heathrow, Gatwick and Stansted.

[2] The distinction here between 'empirical' and 'deterministic' is not a rigorous one; most, if not all, noise contour models rely to some extent on empiricism.

tracks and their associated lateral dispersions which were also determined from the radar measurements.

1.5 Although this approach produced reliable ‘historical’ contours (the principal purpose for which the model and its predecessors were developed), a disadvantage was that ANCON-1 could not readily be adapted for forecasting the noise consequences of possible future changes, to the aircraft types and/or their operating procedures, which alter both flight profiles and noise emissions. This was because RNLs and the associated flight paths were tied together; i.e., they reflected average day to day operations of existing aircraft. Certain comparative studies could be performed independently using other (deterministic) models but the results may not have been fully consistent with existing noise exposures that had been determined empirically.

1.6 To produce historical contours and forecast future trends in a fully consistent manner, the model has now been modified - and the product is ANCON Version 2. This combines the strengths of both empirical and deterministic noise modelling. In most respects ANCON-2 is unchanged from ANCON-1. The key improvement is that noise emission, previously defined purely empirically via RNL, is now linked to engine power via so-called noise-power-distance (NPD) relationships. Engine ‘power’ is a collective expression and may, for example, be ‘thrust’ for jet engines or shaft ‘power’ for turboprops. The essential differences between ANCON-1 and ANCON-2 are illustrated in Figure 1.

1.7 For the purposes of modelling the ‘historical’ annual contours (a form of noise monitoring), average flight profiles are still determined from operational radar data. From these the corresponding engine thrust levels, and hence noise emissions, are then calculated using information or inferences about the flight configuration, especially the aircraft weight and flap settings, and aircraft performance characteristics. For forecasting, the sequence is usually reversed; first the aircraft weights and operating procedures are defined, the latter in terms of the management of flap and engine thrust schedules; then the resulting flight profiles are calculated using appropriate aircraft and atmospheric data.

1.8 DORA Report 9120 describes the ANCON Version 1 model in detail and, apart from the section defining how SEL is derived from RNL, still generally applies to the revised Version 2 model. In due course, that report will be replaced by a comprehensive self-contained report describing Version 2. For the present, this interim report supplants the out-of-date sections of Reference 1.

1.9 The rest of this report is divided into six sections and two Appendices. Section 2 replaces paragraph 4.13 of Reference 1, setting out the steps by which the base sound exposure level due to a hypothetical, infinite flight path segment is determined from engine thrust rather than RNL. Section 2 also discusses the sound level threshold cut-off (paragraphs 4.8 to 4.12 of Reference 1). Section 3 explains the noise-power-distance relationships and the structure of NPD tables.

Section 4 reviews the aircraft performance analysis used to relate engine thrust to the weight, height, speed, acceleration and flight configuration of the aircraft. Section 5 describes the revised structure of the ANCON-2 database and the ways in which the flight profiles are established for historical and forecast modelling. Section 6 describes other minor improvements to the model that have been made from time to time and which have previously been summarised in the reports describing production of, and accompanying, the DETR annual contours (e.g. see References 2 - 4). Section 7 outlines anticipated future developments to the ANCON model. Appendix A explains the construction of the database used with the first edition of ANCON-2 (Version 2.1) to produce the ('historical') 1996 and 1997 L_{eq}(16-hr) contours for Heathrow, Gatwick and Stansted airports. It also compares 1995 and 1996 contours produced by ANCON-1 and ANCON-2. Appendix B lists the aircraft types used to produce those contours.

1.10 Paragraphs 2.5 to 2.7 of Reference 1 explain that, although ANCON-1 implemented noise modelling practices that have been recommended internationally, it stopped short of relating engine noise emissions to aircraft performance characteristics and flight configuration. Noting that this was 'not ruled out for the longer term', it was considered preferable at the time to maintain commonality with the previous Noise and Number Index (NNI) model by continuing to use the same empirical database. The following section explains how ANCON-2 now introduces the more sophisticated procedure without losing the benefit of empirical corroboration.

2 DETERMINATION OF SOUND EXPOSURE LEVEL: IMPROVED PROCEDURE

Revised method for determining base sound exposure level $\Delta L_{SE\infty}$

(This section replaces paragraph 4.13 of Reference 1)

2.1 For noise modelling purposes, the flight path of each aircraft movement is represented by a sequence of contiguous straight line segments. The SEL generated at a field point by a single aircraft movement is calculated by summing contributions ΔL_{SE} from each of the segments (see Figure 5 of Reference 1). The procedure for calculating ΔL_{SE}, the segment sound exposure level, is the core of ANCON. For any particular segment, a hypothetical 'base' sound exposure level $\Delta L_{SE\infty}$ is determined initially assuming the path of the aircraft to be infinitely long. This is the sound exposure level the aircraft would generate if it flew along a coincident but infinite path at uniform speed, emitting constant noise. (The definition of these 'base values' of speed and noise is explained below in paragraph 6.1.) But the segment's finite length restricts the actual noise energy from the segment to a fraction F of the infinite line value. This is termed the noise fraction of the segment and it is calculated as a function of the geometry of the segment relative to the field point (see Reference 1,

Figure 7). Except at high angles of elevation, this modified value is further reduced by the effects of ‘lateral attenuation’ - a combination of source lateral directivity and overground attenuation.

2.2 In ANCON-1, the base event level $\Delta L_{SE\infty}$ was calculated as a simple function of (i) L_{max}, the maximum ‘instantaneous’ noise level in dB(A) experienced during the passage of an aircraft, (ii) the minimum (slant) distance s_p between the flight path and the field point, (iii) the speed of the aircraft V and (iv) an adjustment to account for source directionality (Reference 1, Equation 10). The calculation of L_{max} from L_{ref} assumed that for air-to-ground sound propagation L_{max} falls by 8 dB with each doubling of distance from the aircraft. However, paragraph 6.5 of Reference 1 noted that this assumption may not be reliable at long slant distances and that alternative algorithms needed to be evaluated.

2.3 In ANCON-2, this possible limitation is removed through the adoption of noise-power-distance (NPD) relationships which allow flexible representation of sound attenuation. These simply express $\Delta L_{SE\infty}$ values for a standard reference speed V_{ref} (160 kt) as functions of slant distance for a range of engine power settings (i.e. engine thrust levels)[3] and are normally determined from noise measurements made under the strictly-controlled conditions of aircraft noise certification. An example set of NPD data (taken from the FAA/INM database) is shown in both graphical and tabular form in Figure 2. For each aircraft type, values of $\Delta L_{SE\infty}$ are tabulated for computational purposes; they are given for a number of power settings at a number of standardised distances. Noise levels at intermediate distances or thrust levels are obtained by interpolation: linear interpolation between power settings and logarithmic interpolation between distances. Variations of aircraft speed V are accounted for by adding the adjustment $10 \log(V_{ref}/V)$. The procedures by which the necessary engine thrust levels are determined at any point on the flight path is described in Section 4.

Event level threshold (cut-off)

(This section refers to paragraphs 4.8 to 4.12 of Reference 1)

2.4 In ANCON-1 a means was devised to avoid unnecessary and time-consuming calculations for flight path segments that did not make significant contributions to the total sound energy at the field point. The criterion of significance was whether or not, while the aircraft was on the segment, the received A-weighted level exceeded a specified ‘cut-off’ level λ at the field point. In ANCON-1, this was readily determined because the noise level algorithm yielded ‘instantaneous’ sound levels, L(t); any flight path segment that did not generate

---

3 Although the expressions ‘power’ and ‘thrust’ tend to be used interchangeably, they are different entities. Thrust describes the propulsive force of a jet engine and, so far, it has been the accepted ‘power-related indicator’ (see Reference 7) for the noise emissions of jet aircraft - even though, for high bypass ratio engines, fan conditions may be equally important. For propeller-driven aircraft a better indicator is engine shaft-power (although, similarly, propeller tip speed is an important secondary variable). The acronym NPD should therefore be viewed as a general expression; for jet aircraft the ‘power’ variable is in fact engine thrust.

a level greater than λ was excluded from the summation. Normally, λ was set to 55 dB(A).

2.5 However, in ANCON-2, the noise level at the field point is calculated directly in terms of time-integrated sound exposure level L_{SE}, rather than instantaneous sound level L(t). A different method was therefore required to accommodate the cut-off. To date, in order to retain a similar cut-off mechanism, the values of L(t) corresponding to particular flight paths segment have been estimated by 'reverse transformation' of functions of slant distance and speed using equation 10 of Reference 1.

2.6 Because this procedure is quite cumbersome, more recently, the use of a directly specified sound exposure level threshold λ_{SE} has been explored. Tests have shown that putting λ_{SE} equal to 65 dB(A) produces practically identical results to a segment L(t) threshold λ of 55 dB(A). Subject to continuing verification, this simpler alternative will be adopted in future.

3 NOISE-POWER-DISTANCE (NPD) RELATIONSHIPS

3.1 The NPD data for specific aircraft (i.e. for particular airframe/engine combinations) are derived by the aircraft manufacturers, usually as part of their noise certification flight test programmes. Together with information describing (i) the aircraft lift and drag characteristics and (ii) engine thrust characteristics, these are published, for many aircraft, in a database supplied with the Integrated Noise Model (INM), a computer program developed, maintained and released for public use by the USA Federal Aviation Administration (FAA) (Reference 5).

3.2 Yet, despite its unique industry endorsed status, this public database is not fully comprehensive. Although it contains over 170 NPD files, because it is primarily a US domestic tool, many specific airframe/engine combinations operating at the London airports are not included. Furthermore, in some cases, the published data need to be adjusted because of inherent differences between certification testing and airport operational conditions and monitoring processes which cause variances with measured in-service levels.

3.3 Thus, although the ANCON-2 database is derived from the industry sources, modifications have had to be made to provide good agreement with monitored noise levels around the London airports - both those obtained from the airport's NTK systems and special *ad hoc* measurements made by DORA. Moreover, for the latest aircraft not yet featured in the FAA database but which operate at the London airports, data have had to be specially compiled. Information is based on measured data where available, otherwise estimated from noise certification data and/or by comparisons with other aircraft with similar flight and performance characteristics. The construction of the initial ANCON-2 database is summarised in Appendix A.

4 RELATIONSHIP BETWEEN AIRCRAFT MOTION AND ENGINE THRUST (POWER)

4.1 The base sound level $\Delta L_{SE\infty}$ for a particular flight path segment is determined from the aircraft noise-power-distance relationships. These give 'Noise' ($\Delta L_{SE\infty}$) for any particular combination of 'Power' (for jet aircraft, normalised engine thrust - see paragraph 2.3) and 'Distance' (perpendicular slant distance s_p) - for a specified reference speed.

4.2 In these relationships, 'thrust', the forward propulsive force generated by the aircraft engines, is a normalised value known as 'corrected net thrust' which makes appropriate allowance for the effects of changes of ambient air density on engine performance and noise (air density changes with altitude as well as with ground meteorological conditions). This is equal to the actual thrust force divided by the relative air density δ which is the ambient density expressed as a fraction of a standard sea level value.

4.3 The actual thrust force at any time is that necessary to sustain the aircraft flight, i.e. to overcome gravity and resistance (drag) forces and to increase speed where necessary. The drag forces themselves depend on the air density and the configuration of the aeroplane, especially its weight, flap angles, turn rates and undercarriage position. Provided the aerodynamic characteristics are known, it is possible to determine engine thrust as a function of the aircraft motion - or vice versa. In other words, if the air state and aeroplane configuration are known, the engine thrust can be determined from the aircraft motion or, alternatively, the aircraft motion can be determined knowing the thrust. Either inference might be made in the production of noise contours depending on the application; this is considered in Section 5. First, the basic relationships between thrust and aircraft motion are reviewed.

Thrust in straight flight

4.4 Figure 3 illustrates the forces acting on an aircraft flying in a straight line (i.e. where lateral forces are zero). Although the diagram depicts climbing and accelerating flight during departure, the forces are equally applicable to descent and deceleration during landing (in which case acceleration, a, and gradient, θ, are negative).

4.5 For this analysis, it is assumed that the thrust and drag forces are aligned parallel to the aircraft body axes (along and normal to the fuselage). This approximation is reasonable for relatively low angles of attack (between the longitudinal axis and direction of flight) typical of normal operation. Resolving forces along the longitudinal axis gives the following expression for total aircraft thrust:

$$T = D + Ma + Mg \sin \theta \qquad \text{... (1)}$$

where D is the aircraft drag, Ma (the product of mass and acceleration) is the inertia force associated with increasing speed and Mg sin θ is the relevant component of aircraft weight.

4.6 Aircraft drag D is dependent on ambient atmospheric conditions, airspeed and aircraft configuration, especially flap settings and undercarriage position. It is expressed as a function of a non-dimensional drag coefficient C_D:

$$D = \tfrac{1}{2}\rho V_t^{\,2} S C_D \qquad \text{... (2)}$$

where ρ is the ambient air density, V_t the aircraft true airspeed (relative to the surrounding air), S the aircraft gross wing area and C_D is an aircraft drag coefficient. In still air (no wind), $V_t = V$, the speed of the aircraft relative to a fixed (ground) reference point. Otherwise, the wind velocity (speed and direction) has to be taken into account when calculating V_t[4].

4.7 The aircraft drag coefficient in equation (2) is given by a 'parabolic drag polar':

$$C_D = C_{D_0} + kC_L^{\,2} \qquad \text{... (3)}$$

The first term on the right hand side of equation (3) represents the profile or shape drag coefficient of the aircraft. The second term represents additional drag resulting from the generation of wing lift and is a function of the induced drag coefficient, k, and the aircraft lift coefficient C_L which is given by:-

$$L = \tfrac{1}{2}\rho V_t^{\,2} S C_L \qquad \text{... (4)}$$

The coefficients C_L and C_D relate to basic performance characteristics of the aircraft which are defined by the aircraft manufacturer for different flight configurations and operating conditions.

4.8 In steady linear flight, the 'lift' force L is approximately equal to the aircraft weight. However, during an accelerating climb, lift is greater than the aircraft weight. The increase in lift is expressed as a 'normal wing load factor'

$$n_n = 1 + \frac{a_n}{g} \qquad \text{... (5)}$$

---

4 Of course, wind velocity varies with time and altitude. At present, ANCON-2, like other models, assumes it to be constant and equal to the ground level value.

where a_n is the vertical acceleration and g is the acceleration due to gravity.

4.9 During the arrival and departure operations that dictate the sizes and shapes of the noise exposure contours, the aircraft configuration changes. During departures, after undercarriage retraction, flap angle is gradually reduced as airspeed increases whilst, during arrivals, flap angle is gradually increased to maintain lift as approach speed is reduced; at some point the landing gear is also deployed. These configuration and speed changes alter the aircraft drag characteristics and hence the engine thrust required as computed using equation (1). Flap angle changes and landing gear deployment alter the aircraft profile drag coefficient in equation (3); speed changes alter the corresponding lift coefficient C_L (following equation 4).

Thrust in turning flight

4.10 ANCON-2, like other aircraft noise models, disregards changes to flight profiles that might be attributable to curved flight tracks. In general, the effects of such changes on noise exposure contours are considered to be small. However, circumstances can arise in which the effects cannot be disregarded, for example where movements of noisier aircraft are concentrated on routes with large turn angles.

4.11 The forces acting on an aircraft in steady turning flight are shown in Figure 4. During turning flight, the lift vector no longer acts in the vertical plane and extra lift must be produced to counter the effects of centrifugal force; this in turn results in increased aircraft drag (again through increased C_L).

4.12 Resolving forces in the plane of the wing gives

$$Mg\sin\phi = \frac{MV^2}{R}\cos\phi \qquad \text{... (6)}$$

from which it follows that:

$$\tan\phi = \frac{V^2}{Rg} \qquad \text{... (7)}$$

Resolving forces normal to the wing plane gives

$$L = Mg\cos\phi + \frac{MV^2}{R}\sin\phi \qquad \text{... (8)}$$

Defining a turn load factor n_t as the ratio of lift required during the turn to that required in straight flight, equations (7) and (8) combine to give:

$$n_t = \cos\phi + \tan\phi\sin\phi \qquad \text{... (9)}$$

In order to use equation (9), aircraft bank angle, ϕ must first be computed using equation 7.

4.13 For combined climbing/descending, accelerating and turning flight, the turn load factor (9) can be multiplied by the normal load factor (5) to define an overall wing load factor:-

$$n = n_t . n_n \qquad \text{... (10)}$$

Putting total lift L = n.W, equations (3) and (4) can then be obtained using the drag coefficient C_D.

4.14 The aircraft performance coefficients in the above equations, C_{D0}, C_L and k, together with the relevant wing-area (used to normalise the coefficients), are specific to individual aircraft and are functions of its design and configuration. The total aircraft mass[5] M depends on its passengers, cargo and fuel loading etc. The motion variables, V, V_t, a, R, θ and ϕ are all functions of time which, together, define the aircraft flight path in three-dimensional space. For ANCON noise contour calculations, the flight path is represented by a sequence of contiguous straight line segments sufficient to represent changes of direction and speed in adequate detail. The local turn rates and accelerations are defined in terms of the corresponding changes of speed and positioned between the segment end-points.

5 DEFINITION OF AIRCRAFT FLIGHT PATHS

Historical contours

5.1 Section 5 of Reference 1 describes the general process by which annual historical contours have been generated using ANCON from input information describing

- the approach and departure routes or flight tracks
- the traffic upon them in terms of the numbers of different aircraft types
- the dispersion of individual flight tracks (represented by subsidiary side tracks), and
- the average flight profiles (of height, noise emission and speed).

An aircraft 'type' is defined in relation to its noise and performance characteristics and its significance to the noise climate surrounding the airport(s) of interest. Aircraft models and variants which are 'noise-significant' by virtue of their large numbers and/or the levels of their noise emissions are represented

---

[5] It is common (but strictly incorrect) practice to refer to aircraft tonnage as 'weight' rather than mass. In the equations of motion, weight, like lift, thrust and drag, is a force (in newtons) = mass (kg) x g (ms^{-2}).

individually by type, e.g. B747-400, or grouped together with other types or variants with very similar noise characteristics, e.g. B737-300, 400, 500. Those of lesser significance are combined into broader groupings and categories such as ‘large twin turboprops’.

5.2 When using ANCON-2 to produce contours retrospectively, the approach remains unchanged from that of ANCON-1; average flight profiles of height and speed versus track distance are still determined from analyses of radar data for each aircraft type/category at each of the three London airports and, where necessary, for different routes. These average profiles are then subdivided into appropriate linear segments with specified end-co-ordinates and speeds.

5.3 For each profile segment, the engine thrust levels at each of its ends are calculated using the equations of Section 4. Each vertical profile segment is defined by eight variables - the track distances, heights, speeds and thrusts at its beginning and end[6]. To calculate the contours, the vertical profiles are combined with individual ground tracks to describe the full three-dimensional average flight paths.

Forecast contours

5.4 In studies made to forecast the noise consequences of possible future changes to airports, aircraft and/or their operating procedures, including new noise mitigation measures, the sequence of defining flight profiles is usually reversed. First, the operating procedures are defined in terms of aircraft weights, flap management and engine thrust schedules; the resulting flight profiles are then calculated using appropriate aircraft and atmospheric data using the SAE methodology described in Reference 7.

6 OTHER IMPROVEMENTS SINCE DORA REPORT 9120

Variation of noise emission and speed between segment end points

(Reference 1: paragraph 5.10)

6.1 It was explained in paragraph 2.1 that flight profiles are described by a sequence of straight segments reflecting changes in climb angle, speed and noise emission (L_{ref} or engine thrust). In ANCON-1, constant values of aircraft speed and L_{ref} were originally specified for each single flight path segment. To better simulate aircraft accelerations and to avoid unrealistic discontinuities in the resulting contours, later editions of Version 1 incorporated refinements to allow speed and L_{ref} to vary along segments; this was achieved by defining speed and L_{ref} separately at the two ends of each segment. When the closest point of approach (s_p) fell somewhere between the end points, the base speed and L_{ref} (see

[6] The end values for one segment being the start values of the next.

paragraphs 2.1 and 2.2 above) were obtained by interpolating linearly between the segment end values. For any segment behind or in front of the field point, the base speed and L_{ref} were set equal to the values at the nearest end. Exactly the same process is used in Version 2 except that L_{ref} is replaced by engine thrust.

Automatic segmentation of the take-off ground roll
(Reference 1: paragraph 4.28).

6.2 To improve the simulation of the rapid changes of speed that occur as an aircraft accelerates during the take-off ground roll on the departure runway, provision has been made to allow the number of 'ground' segments to be increased automatically when required. Speed and thrust are still assumed to increase linearly with distance in each ground segment. The segments are not equal in length - rather they become progressively longer to represent equal intervals of time rather than of distance.

Directivity of the noise behind the aircraft at start-of-roll
(Reference 1: paragraphs 4.29 and 4.30)

6.3 ANCON-1 included special algorithms to model the 'fishtail' directivity pattern of rearwards propagating jet noise at the start of take-off roll (see Figure 15 of Reference 1). These were developed by the SAE (Reference 6). Although these algorithms generated realistic noise lobes at short distances from the aircraft, they did not make allowance for the fact that, principally due to the scattering of sound by atmospheric turbulence, the lobes become less pronounced at greater distances - eventually disappearing completely. In ANCON-2, if the radial distance d from start of roll is greater than 2500 feet (762 metres) then equations 20 and 21 in paragraph 4.30 of Reference 1 are multiplied by a factor of 762/d. The effect of this adjustment is to progressively diminish the fishtail effect such that the propagation becomes less directional at distances beyond 762 metres, eventually becoming spherical. This adjustment was developed by the FAA on the basis of studies carried out at Baltimore airport in 1992 (Reference 8).

Noise during landing roll
(Reference 1: paragraph 4.28)

6.4 Originally, noise during landing roll, including that of thrust reversal, was disregarded as it generally makes a relatively insignificant contribution to the overall noise exposure around an airport (if the areas affected by landing noise also experience departures using the opposite runway direction, contour changes are usually imperceptible). However, to improve accuracy when modelling situations where runway usage is predominantly one-way, later editions of ANCON-1 calculated the noise associated with thrust reversal during deceleration. Reverse thrust RNLs were defined for each aircraft type capable of utilising thrust reversal and additional ground path segments, together with appropriate speeds, were added to the arrival flight profiles. In ANCON-2, the

RNLs associated with thrust reversal have been replaced by appropriate thrust levels (i.e. those which generate the appropriate noise levels).

7 FUTURE DEVELOPMENT OF ANCON

Improvement of lateral attenuation modelling
(Reference 1: paragraphs 4.20 - 4.24)

7.1 Lateral attenuation is a general term used to define the difference between sound radiated vertically downwards and that radiated sideways. The relationships defining lateral attenuation that are used in ANCON were developed by the SAE (Reference 6). These have been retained in Version 2. However, studies are currently being undertaken - within DORA and internationally - to separate 'overground' and source directivity effects. Any new recommended practices that emerge will be introduced into ANCON at the appropriate time.

Processing of individual radar tracks

7.2 Currently, to produce historical noise contours, 'swathes' of aircraft flight paths are represented by average flight profiles and ground tracks together with a number of laterally dispersed side tracks. However, using the thrust estimation methodology outlined in Section 4, ANCON-2 is able theoretically to calculate the contribution of each single aircraft movement to the total noise. Processing the radar profiles of individual flights would deal automatically with the large variation of both flight profiles and flight tracks.

7.3 Of course, such calculations would be very time-consuming but, by further developing the structure of the software and making use of advancing computer hardware technology, it should eventually be possible to link ANCON directly to the airport flight monitoring systems, i.e. to compute the contours directly from the large quantities of individual radar tracks stored in NTK databases.

Turning flight

7.4 It was acknowledged in paragraph 4.10 that in some circumstances, turns can have a significant effect upon flight profiles. At present, such effects are accommodated in an ad-hoc manner when they are judged likely to have an impact upon the noise contours. There is a longer-term need to formalise this process, preferably through the relevant international advisory bodies.

Expansion of the aircraft database

7.5 Initial flight profiles and associated NPD data have been generated for 34 aircraft types/categories (see Appendix B). Analyses are currently underway which will increase this number by sub-dividing some of the more noise dominant aircraft types by mark and engine. Where necessary, further sub-divisions will be made in terms of take-off weight or stage length. In addition to its own efforts to develop and validate ANCON data, DORA will also, through the international organisations, seek and make use of updated aircraft noise and performance database from industry and this is one focus of current work in ICAO.

REFERENCES

1 Ollerhead J B, The CAA Aircraft Noise Contour Model: ANCON Version 1, Civil Aviation Authority, DORA Report 9120, November 1992.

2 Monkman D J, Edmonds L E, Rhodes D P and Lee J, Noise Exposure Contours for Heathrow Airport 1997, National Air Traffic Services Ltd. R&D Report 9902, February 1999

3 Monkman D J, Edmonds L E, Rhodes D P and Lee J, Noise Exposure Contours for Gatwick Airport 1997, National Air Traffic Services Ltd. R&D Report 9903, February 1999

4 Monkman D J, Edmonds L E, Rhodes D P and Lee J, Noise Exposure Contours for Stansted Airport 1997, National Air Traffic Services Ltd. R&D Report 9904, February 1999

5 Olmstead J et al, Integrated Noise Model (INM) Version 5.1 User's Guide, Federal Aviation Administration, Office of Environment and Energy, Washington, December 1996

6 Society of Automotive Engineers, Prediction Method for the Lateral Attenuation of Airplane Noise during Take-off and Landing, Aerospace Information Report AIR 1751, 1981

7 Society of Automotive Engineers, Procedure for the Calculation of Airplane Noise in the Vicinity of Airports, Aerospace Information Report AIR 1845, January 1986

8 Horonjeff R D, Analysis of Aircraft Noise Levels in the Vicinity of Start of Take-off Roll at Baltimore - Washington International Airport, FAA-EE-92-01 and DOT-VNTSC-92-5, May 1992

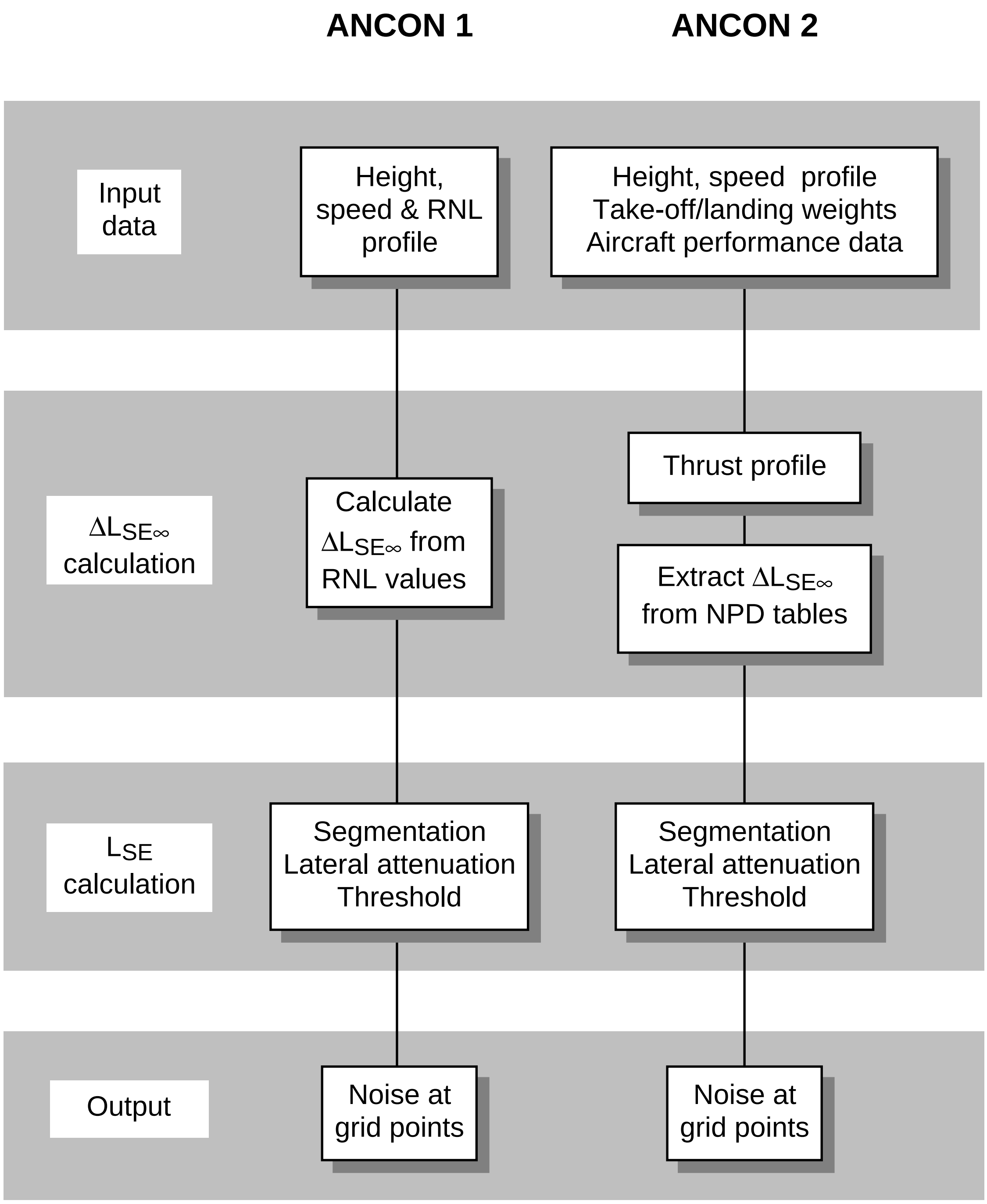
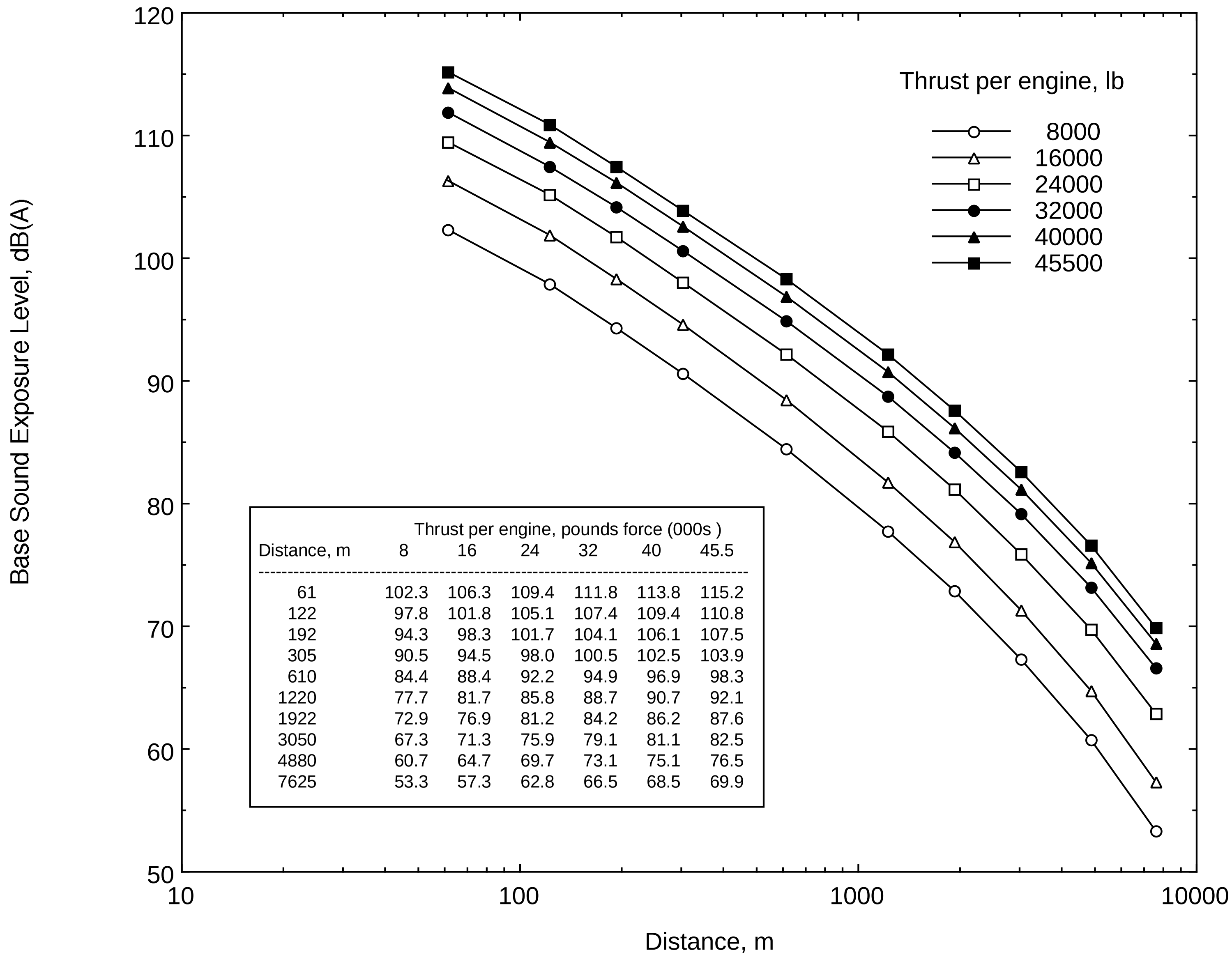


Figure 1 - Noise calculation processes in ANCON Versions 1 and 2



Distance, m	Thrust per engine, pounds force (000s) 8	16	24	32	40	45.5
61	102.3	106.3	109.4	111.8	113.8	115.2
122	97.8	101.8	105.1	107.4	109.4	110.8
192	94.3	98.3	101.7	104.1	106.1	107.5
305	90.5	94.5	98.0	100.5	102.5	103.9
610	84.4	88.4	92.2	94.9	96.9	98.3
1220	77.7	81.7	85.8	88.7	90.7	92.1
1922	72.9	76.9	81.2	84.2	86.2	87.6
3050	67.3	71.3	75.9	79.1	81.1	82.5
4880	60.7	64.7	69.7	73.1	75.1	76.5
7625	53.3	57.3	62.8	66.5	68.5	69.9

Figure 2 - Noise-Power-Distance relationships: PW JT9D-7A Engine

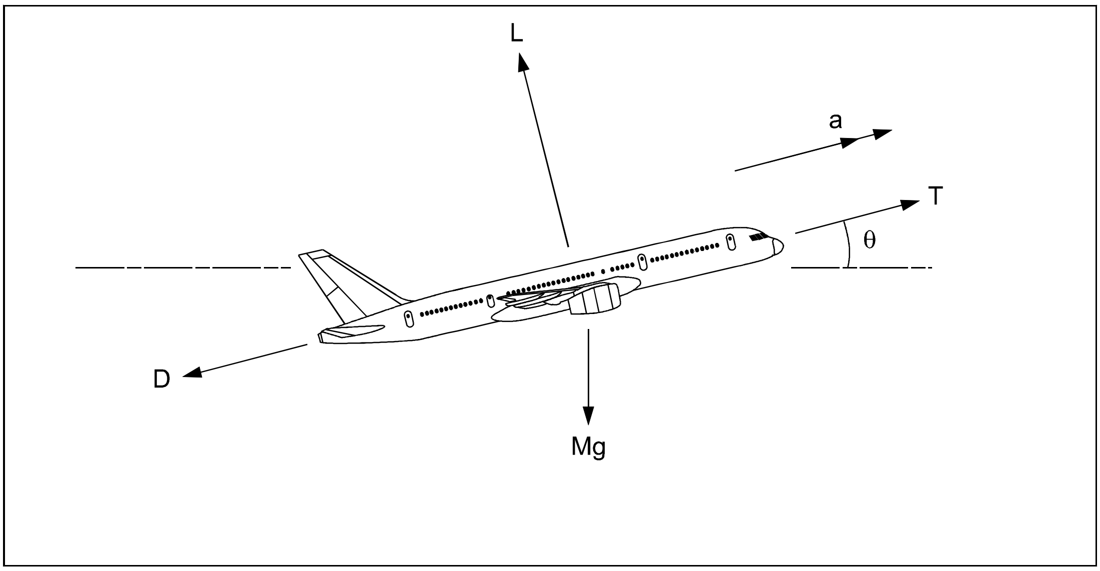


Figure 3: Forces acting on a climbing accelerating aircraft

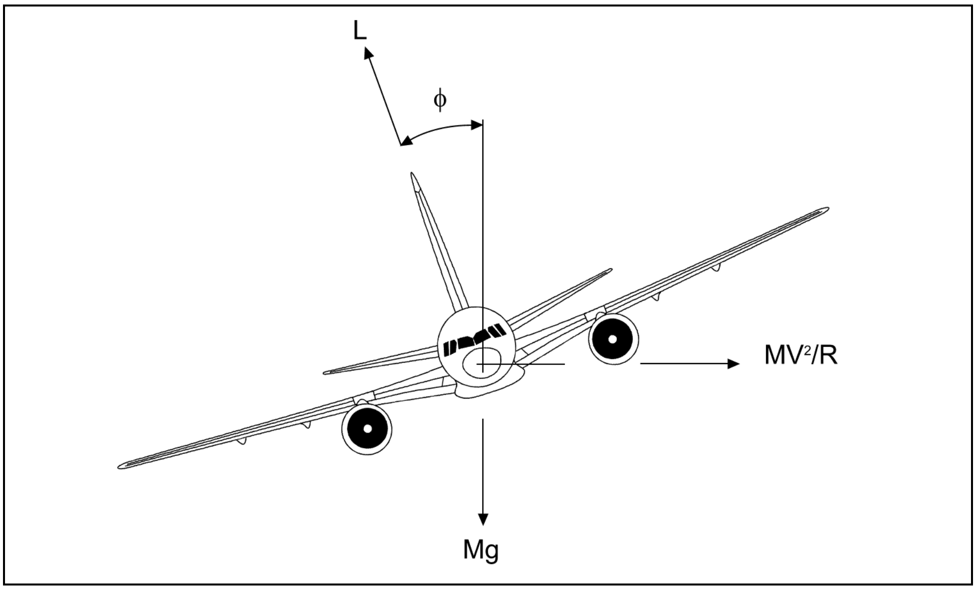


Figure 4: Forces acting on turning aircraft

Intentionally Blank

APPENDIX A

HISTORICAL CONTOURS: ANCON-2.1

The database

A1 The initial edition of the updated model, which has been used to produce the 1996 and 1997 historical contours, is designated ANCON-2.1. Its database was developed from two sources of information: (1) the industry database compiled for use with the INM by the FAA and (2) the ANCON-1 database which has been compiled over a long period of time from comprehensive data taken from the airport NTK systems and from special *ad hoc* measurements made by DORA.

A2 The variables tabulated in the ANCON database, like those of the FAA/INM, are fully defined in SAE AIR 1845 (Reference 7) and include, for each aircraft type and operation, a flight profile of track distance, height, speed and engine thrust at the beginning and end of each flight path segment and an NPD table. A key difference between the ANCON and FAA/INM databases is the number of aircraft operations represented: 34 for ANCON-2.1 as against approximately 170 (airframe engine combinations) in the latest FAA database. The reason for the much smaller ANCON set is that it only covers aircraft categories and operations representative of the London airports; in contrast, the FAA database is used world-wide but excludes numerous types common at the London Airports.

A3 The ANCON-2.1 aircraft types/categories are listed in Appendix B. Each aircraft is represented by its average arrival and departure flight profile and an NPD table. The average profiles of track distance, height and speed are determined from an analysis of radar data (as for ANCON-1); the thrust profiles that are consistent with the height and speed profiles are generally calculated using aircraft performance information from the FAA/INM database - making appropriate inferences about choice of airframes, flight configurations and weights. However, two significant modifications have had to be made to match ANCON-2 predictions fully to a large, representative sample of SEL measurements made close to the London airports.

A4 First, some NPDs have had to be adjusted piecemeal to account for observed (under-flight path) differences at heights in the range 150-600m (500-2000 ft) at both the high thrusts used for takeoff and low thrusts for landing approach. Second, at higher slant distances, typically over 1500m, the slopes of some SEL versus distance curves have had to be been reduced slightly. The latter adjustments are necessary (1) because the construction of the curves is not always consistent with advice given in Reference 7, and (2) to compensate for the fact that the current internationally recommended algorithm for lateral attenuation (Reference 6) accounts for both source and overground effects in a single relationship (see paragraph 7.1), whereas these two components are essentially independent. Work to separate them in contour modelling is in progress and the results will be incorporated as soon as practicable.

A5 Additionally, in order to model the latest aircraft that are not yet included in the FAA compilation, special data sets have had to be constructed, based on airport data. These will be updated as new information is available.

Comparison of ANCON Versions 1 and 2: 1995 and 1996 historical contours

A6 L_{eq}(16-hour) contours for 1995 have been calculated using ANCON Versions 1 and 2.1. Figures A1, A2 and A3 compare the results for Heathrow, Gatwick and Stansted respectively. At most positions the two contour sets match very closely; the enclosed areas are shown in Table A1. The mean difference between L_{eq} values calculated by the two models over the area of contours at the three airports is 0.03 dB which, with a standard deviation of 0.10 dB, is statistically insignificant.

A7 Some differences in contour detail are only to be expected when an improvement in methodology is implemented. The differences are mainly in areas well away from the airport where RNL data for ANCON-1 was sparse - due to relatively low aircraft noise levels which are more difficult to measure. The use of more comprehensive information on source noise and sound propagation, verified against monitored data, should afford an improvement in reliability in these areas.

A8 Figures A4, A5 and A6 and Table A2 present comparable results for 1996. As was the case for the 1995 results, at almost all points, the contours match to within the thickness of the lines.

Table A1

1995 AVERAGE MODE CONTOURS ANCON-1 and 2

HEATHROW

Leq LEVEL dB(A)	AREA SQ KM	
	1995 ANCON-1	1995 ANCON-2
>57	169.2	169.8
>60	93.2	94.5
>63	58.3	58.9
>66	39.3	39.6
>69	26.1	26.1
>72	15.6	15.5

GATWICK

>57	87.0	87.3
>60	53.1	53.5
>63	31.1	31.4
>66	17.9	18.1
>69	10.4	10.6
>72	6.2	6.3

STANSTED

>57	41.6	41.5
>60	25.3	25.4
>63	15.5	15.5
>66	9.6	9.6
>69	5.8	5.8
>72	3.5	3.5

Table A2

1996 AVERAGE MODE CONTOURS ANCON-1 and 2

Leq LEVEL dB(A)	AREA SQ KM	
	1996 ANCON-1	1996 ANCON-2
HEATHROW		
>57	166.6	164.7
>60	91.8	91.8
>63	55.7	56.0
>66	35.9	36.1
>69	23.8	23.8
>72	14.1	14.1
GATWICK		
>57	90.5	90.6
>60	54.1	54.4
>63	31.4	31.8
>66	18.0	18.3
>69	10.5	10.7
>72	6.3	6.4
STANSTED		
>57	42.7	42.7
>60	25.5	25.6
>63	15.4	15.4
>66	9.5	9.6
>69	5.9	5.9
>72	3.6	3.6

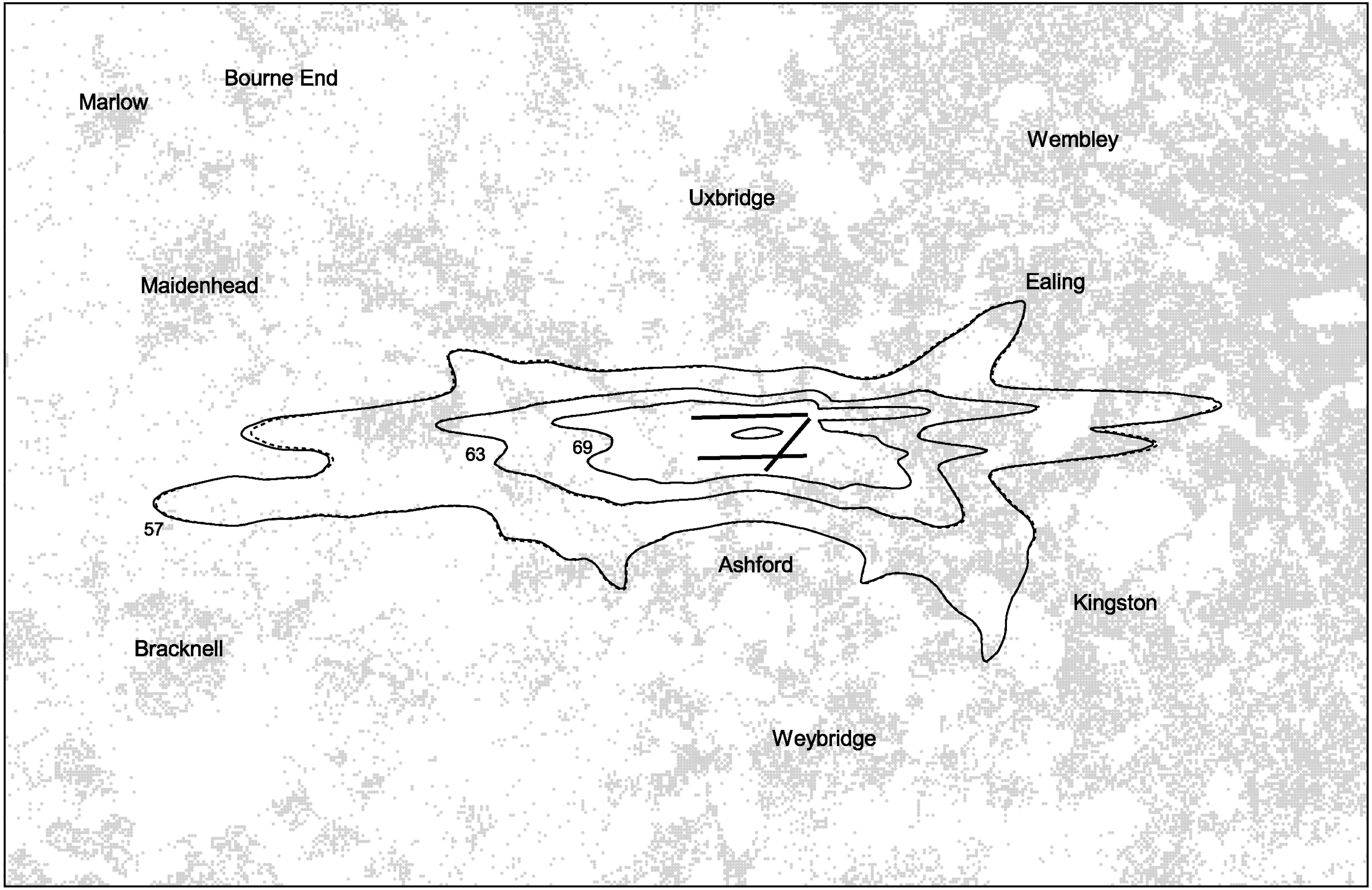


Figure A1 Heathrow 1995 average mode 16hr Leq contours (ANCON-1 = bold, ANCON-2 = dotted) on population map

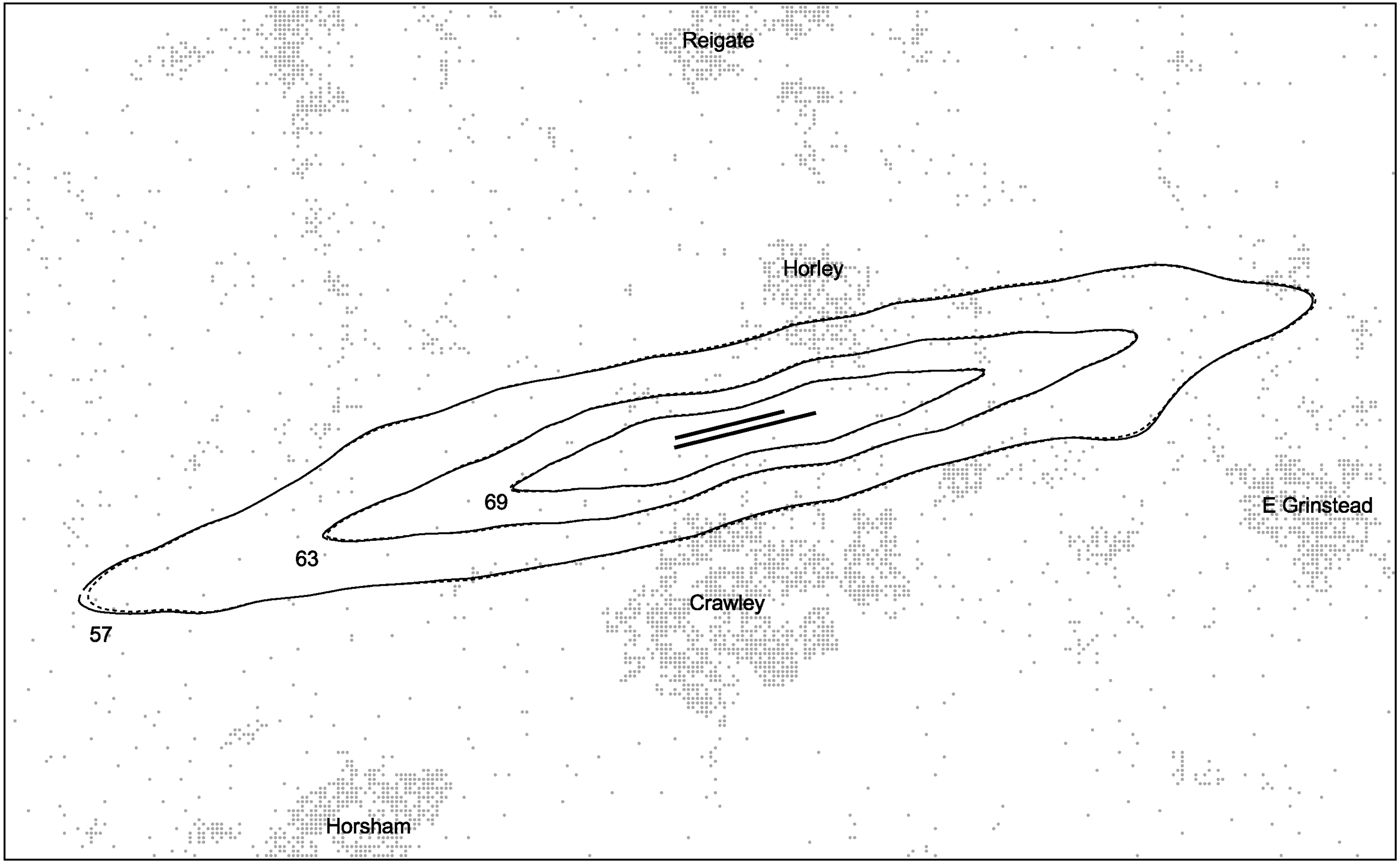


Figure A2 Gatwick 1995 average mode 16hr Leq contours (ANCON-1 = bold, ANCON-2 = dotted) on population map

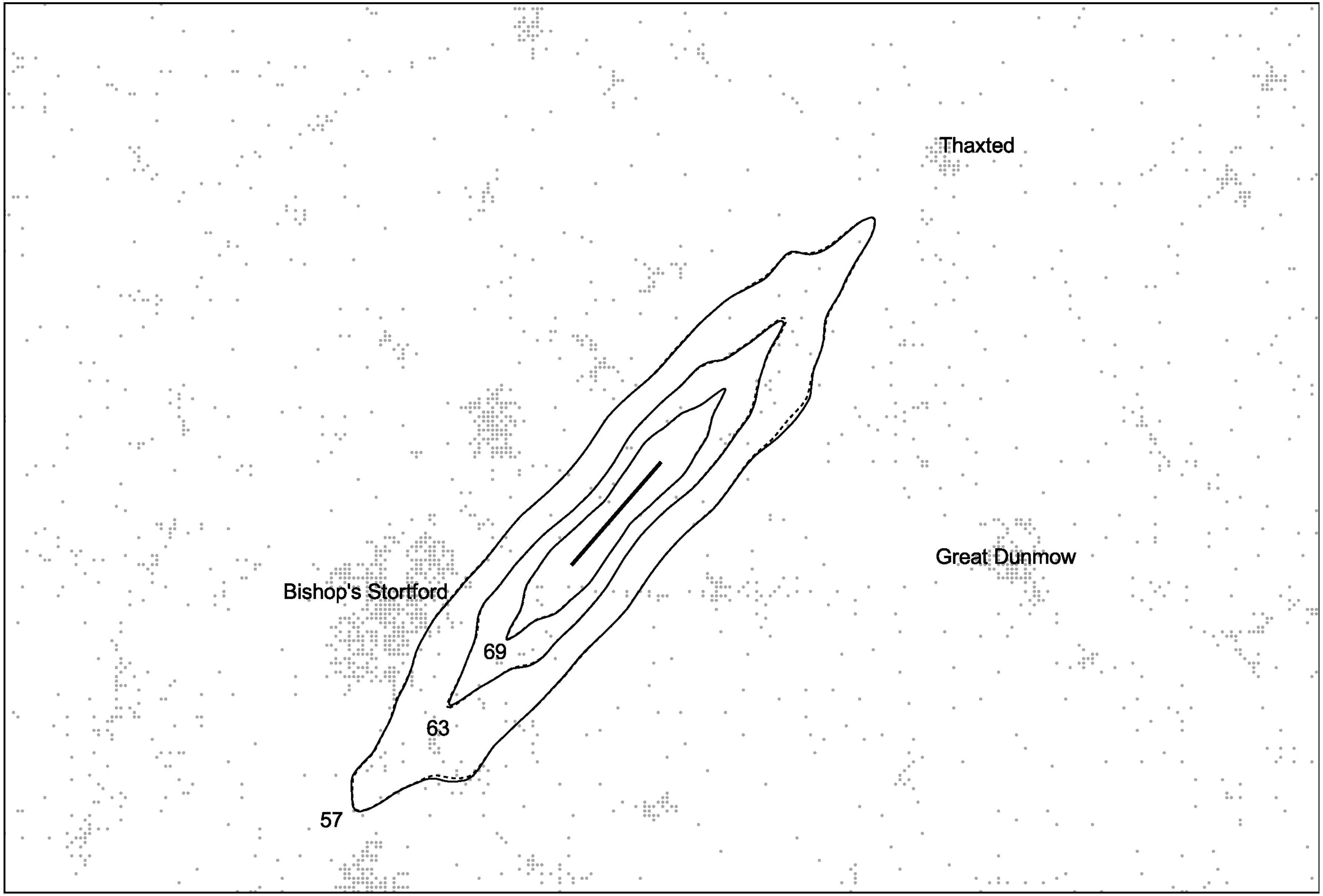


Figure A3 Stansted 1995 average mode 16hr Leq contours (ANCON-1 = bold, ANCON-2 = dotted) on population map

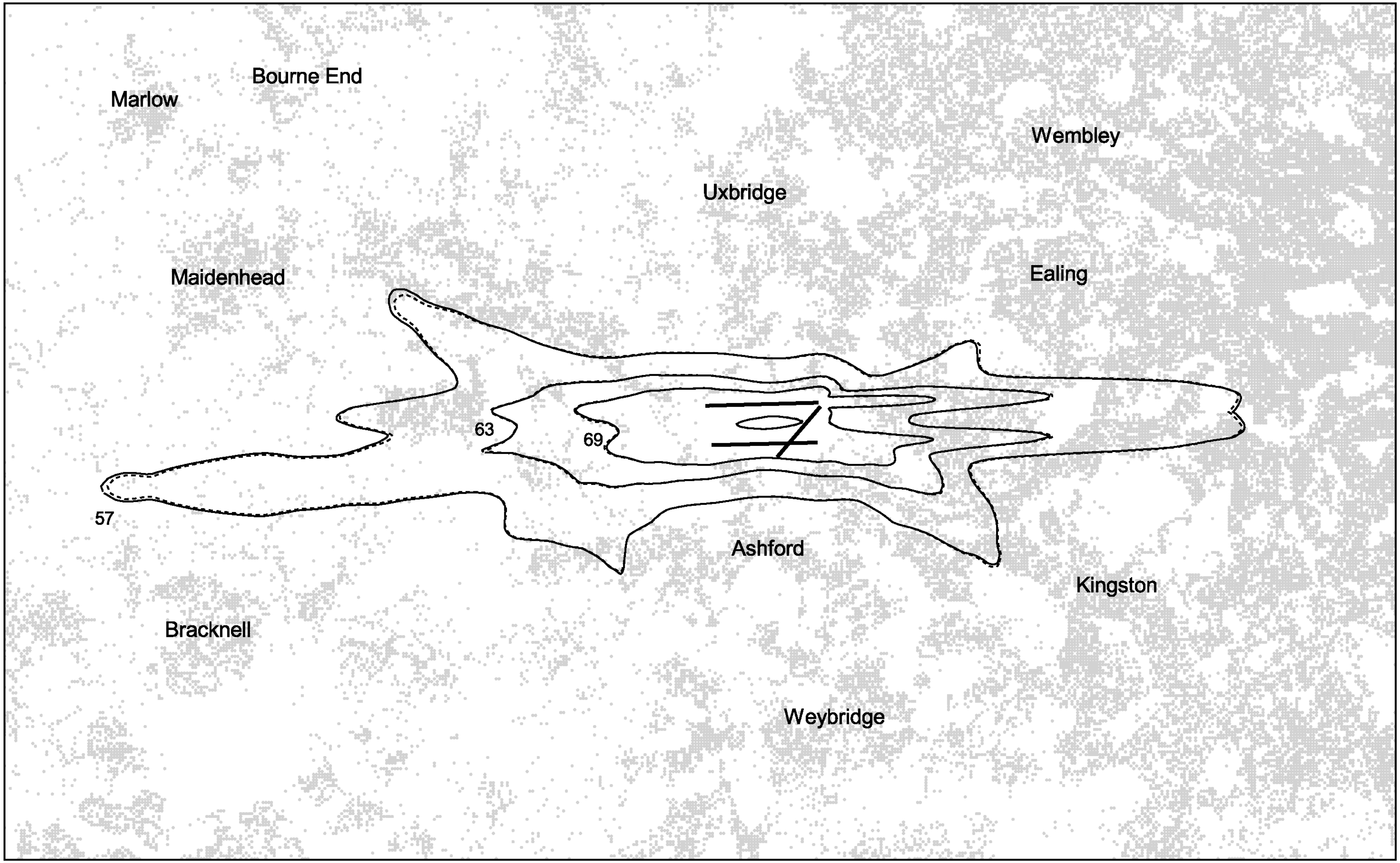


Figure A4 Heathrow 1996 average mode 16hr Leq contours (ANCON-1 = bold, ANCON-2 = dotted) on population map

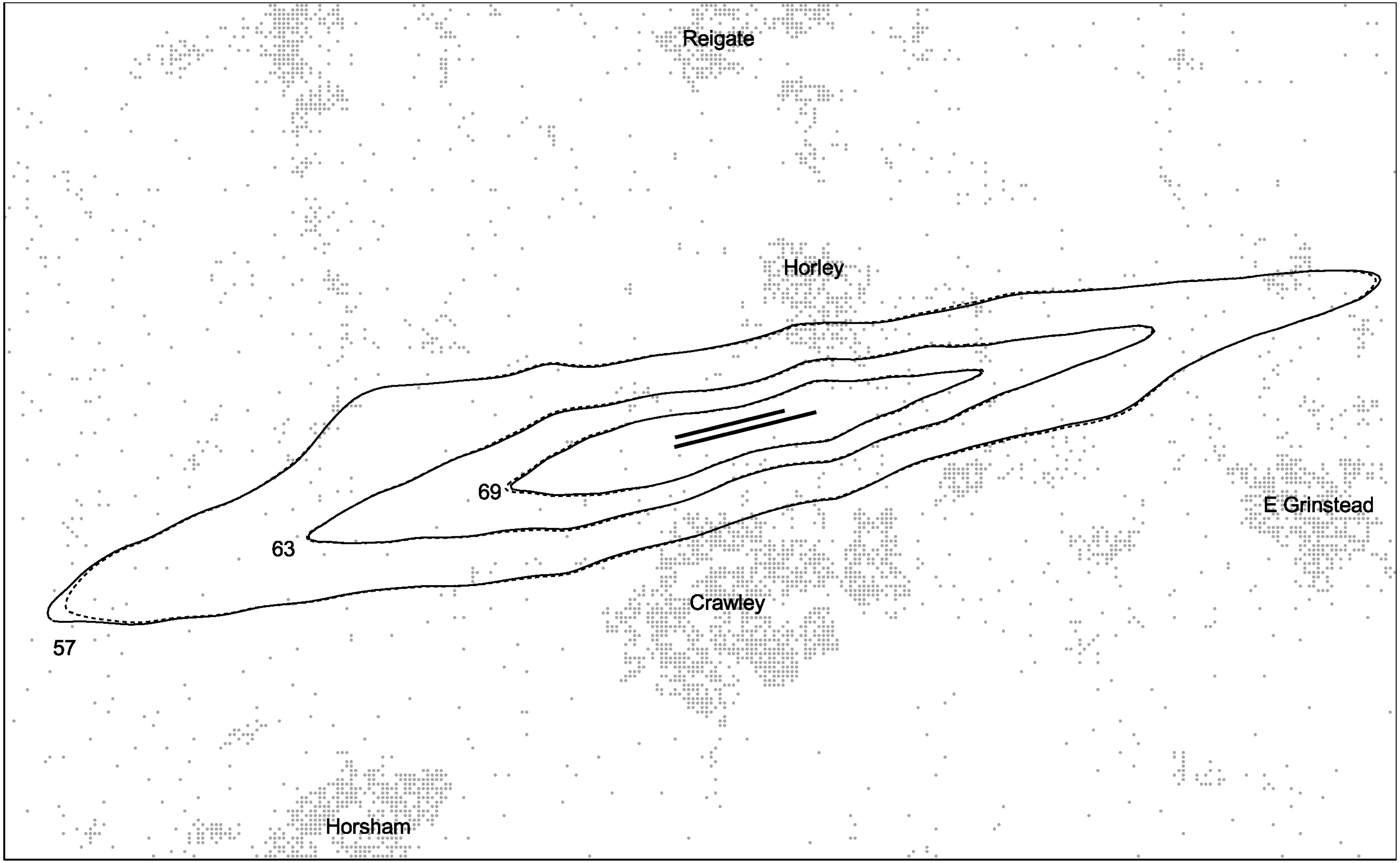


Figure A5 Gatwick 1996 average mode 16hr Leq contours (ANCON-1 = bold, ANCON-2 = dotted) on population map

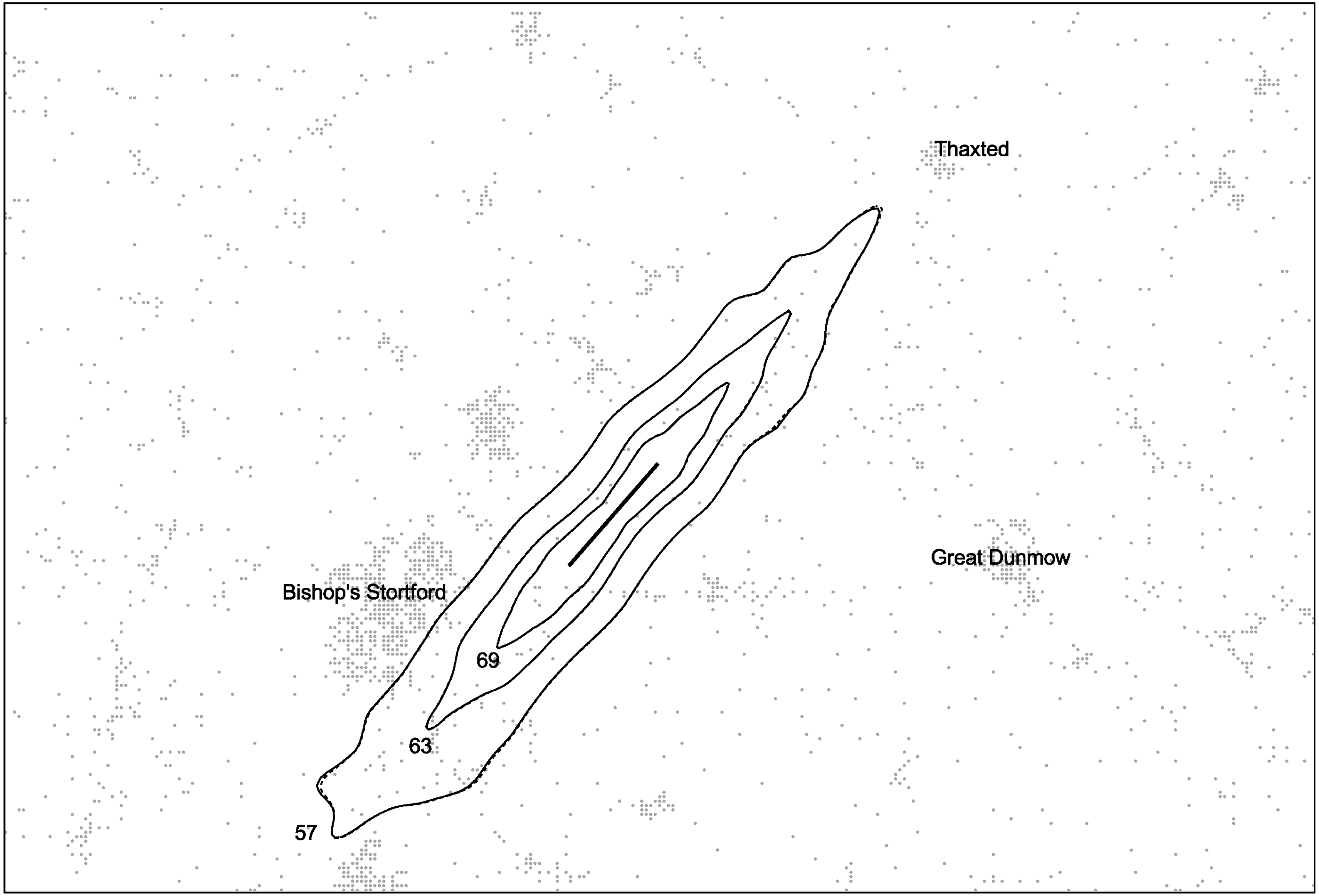


Figure A6 Stansted 1996 average mode 16hr Leq contours (ANCON-1 = bold, ANCON-2 = dotted) on population map

APPENDIX B

ANCON VERSION 2.1 AIRCRAFT CATEGORIES

1	Boeing 707
2	Boeing 727
3	Boeing 737-300,-400,-500
4	Boeing 737-200
5	Boeing 747-100,-200,-300
6	Boeing 747-400
7	Boeing 757
8	Boeing 767
9	Boeing 777
10	BAC 1-11/Tu 134
11	BAe 146
12	Concorde
13	DC8
14	DC9
15	DC10
16	Airbus A300
17	Airbus A310
18	Airbus A320
19	Airbus A330
20	Airbus A340
21	Executive Jet
22	Fokker F28
23	Fokker F100
24	IL62/VC10
25	Lockheed Tristar
26	MD11
27	MD80
28	Tu 154
29	Large 4 engined Turboprop
30	Large Twin Turboprop
31	Small Twin Turboprop
32	Large Twin Piston
33	Small Twin Piston
34	Single Piston

Intentionally Blank