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PROPELLER AIRCRAFT NOISE AROUND GENERAL AVIATION AIRPORTS

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by
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1. ABSTRACT

In recent years systematic flyover noise measurements of propeller driven general aviation airplanes were performed. This paper presents a brief description of the measurement and data reduction techniques together with some results. Computation methods are given to estimate the effect of powersetting on the noise level and to approximate the shape of the noise field around these aircraft. They are used to compute Leq-Contours around general aviation airports. Contour plots are used to compare the relative effects of several measures for noise reduction on the ground. Noise reduction at the source is the most effective way to achieve this goal.

2. INTRODUCTION

Noise is one of the most annoying byproducts of aircraft operations. This is not only true for "big jets" but also for general aviation type aircraft.

In the Netherlands, the general aviation fleet consists mainly of light single engine propeller driven airplanes. Although they produce less decibels than "big jets", an increasing number of people living around general aviation airstrips find them annoying. In 1977, the Director General of the "Rijksluchtvaartdienst", the Dutch equivalent of the FAA, wrote a letter to all holders of a private pilot's licence, urging them to operate their airplane in such a manner that the noise on the ground is reduced as
as much as possible.

A revision of the Dutch Aviation Act will enable the government to establish noise zones around airports. Inside such zones the construction of new housing will be restricted or prohibited, existing buildings will receive additional noise insulation. Around big airports, such as Schiphol (Amsterdam), noise contour plots based on the so-called "Kosten-Unit" will be used for this purpose. This unit, developed in the sixties, is based on a social survey around Schiphol, a description can be found under "Total Noise Load" in (1)\textsuperscript{*}. It takes into account the maximum A-weighted noise level of each airplane. For the surroundings of general aviation airports, where a high percentage of aircraft operations consists of touch-and-training, this unit may be less suited to describe the noise environment. An inventory of complaints from people living there, showed that the long duration of the noise, especially from airplanes in the traffic pattern, is a major contributing factor to the annoyance. This implies the use of a Leq-type unit for these areas. Such a unit requires the evaluation of at least a part of the noise time-history of the airplanes using the field.

In this paper a method is presented to approximate these time histories and to determine Leq-contours within a reasonable amount of computing time. These approximations are based on results of systematic field measurements. The method is then used to describe the noise climate around a typical Dutch general aviation airstrip and to study the effects of several measures to achieve noise reduction on the ground.

3. MEASUREMENT TECHNIQUES AND DATA REDUCTION

Examples of typical test aircraft are presented in figure 1. The maximum take-off weight is of the order of 1000 kg, they are equipped with a piston engine producing 150 hp at 2700 rpm and a 1.88 to 1.93 m diameter direct drive two bladed propeller. Airplanes like these represent more than 90\% of the Dutch general aviation fleet.

Noise data are obtained during flyovers at predefined conditions regarding power setting, engine rpm and flightpath (horizontal or climbing). Figure 2 shows the test-range, laid out by the department of Geodesy of Delft University. All relevant distances between the points marked on this figure (such as AB, A to houses etc.) are known. The airplane moves along a straight flightpath, its track runs over or

\textsuperscript{*} Numbers in parenthesis designate References at end of paper.
parallel to a clearly marked reference track. The microphone, at 1.2 m above groundlevel, is mounted on top of a preamplifier at B. During the entire fly-over, the noise signal is recorded on tape. The acoustic chain is calibrated before and after the actual measurements. Background noise is registered between test runs.

Flightpath data such as airspeed climbing speed, track etc., are obtained from two photocameras. An automatic camera, located at point A of figure 2, takes a series of pictures from the side as the airplane passes by. Sound-picture synchronization is obtained from a pulse generator, triggered by this camera. A second camera at B, pointing vertically upwards, is used to obtain distance BC.

Atmospheric data are derived from a portable weather station. Since no reliable correction procedures for disturbing factors such as windgradients, turbulence, inversions etc. exist, the measurements are performed only under near standard weatherconditions. A maximum windspeed of approximately 3 m/s at 2 m height is allowed.

The noise recordings are analyzed with a 1/3-octave filter set (center frequencies from 50 Hz to 10 kHz according to ISO 226) to obtain 1/3-octave SPL noise time-histories. From the photos, any point on these time-histories can be related to a value for the soundwave travel distance and emission angle, \( r \) and \( \theta \), see figure 2. Using standard methods such as the inverse square law, SAR-ARP 866 for atmospheric attenuation etc., the SPL in each 1/3-octave band \( i \) at a reference distance of 1 m as a function of emission angle \( \theta \), denoted by \( SPL_{1}(\theta, i) \), is computed. This quantity forms the basis for the calculation of power watt levels and directivity indices. It is also used to compute (weighted) noise levels at any point relative to the flight path, from which noise time-histories and annoyance contours are obtained. A more detailed description can be found in (2).

In the near future, narrow band analysis will be part of the data recudtion procedure.

4. SELECTED RESULTS

Some results are presented in figures 3 6, and in (3). Figure 3 shows three noise time histories in weighted and unweighted decibels. They were obtained from direct filtering of the recorded noise signal. In matters concerning the annoyance caused by light airplanes, the A-
weighted level is most commonly used. Note that the maximum levels occur just after the airplane passes overhead, caused by the finite travel time of the noise signal and the shape of the noise field. An example of the latter is presented in figure 4. It clearly shows the non-spherical sound radiation of the 160 Hz 1/3-octave band of a Piper Seneca; the maximum SPL is found at emission angle behind the propeller plane. Emission patterns like the one presented, are also found in other 1/3-octave bands, and are predicted by several propeller noise prediction methods. Figure 5 gives an impression of the effect of propeller helical tip Mach Number on the emitted sound power. The difference between horizontal and climbing flights at given Mach Number is attributed to different blade loading, although a further research is needed to verify this. Figure 6 shows an example of the noise field in terms of curves of constant A-weighted decibels. This figure is the result of a complete 50-10000 Hz 1/3-octave computation. Again note the direction for maximum noise radiation and the shape of the noise-field.

5. NOISE TIME HISTORIES

As stated before, the evaluation of noise time histories is needed to compute Leq-type noise levels. In the following the A-weighted level will be used exclusively.

Figure 7 shows an example of a computed time history. Each dot in this figure is the result of a complete 1/3-octave spectrum computation based on the SPL(θ,i) measurement data. The agreement with a time history obtained from direct A-filtering of the recorded noise signal is quite good; the computing method tends to smooth the real time history.

One way to describe a time history is the use of the single event exposure level, LAX, and the duration allowance, ΔA. The former is defined as

\[ L_{AX} = 10 \log \left[ \left( \frac{1}{T_{ref}} \right) \int_{t_1}^{t_2} \text{antilog} (L_A / 10) \, dt \right] \]  

(1)

where LA is the "running value" of the A-weighted noise level, while t1 and t2 define the beginning and the end of the event. Often they are taken to be the first and last instants at which LA is within 10
dBA of its maximum value, \( L'_{A_{max}} \), the integrand usually contributes a negligible amount to the total outside this interval. The normalizing time \( T_{ref} \) is 1 second. The duration allowance is defined as

\[
\Delta_A = 10 \log \left( \frac{T}{T_{ref}} \right)
\]

(2)

It is computed so, that

\[
L'_{AX} = L'_{A_{max}} + \Delta_A
\]

(3)

Combining these equations yields:

\[
T = \int_{t_1}^{t_2} \text{antilog} \left\{ \frac{(L_A - L'_{A_{max}})}{10} \right\} \, dt
\]

(4)

According to (4), this may be approximated by

\[
T = 0.5(t_2 - t_1)
\]

(5)

where \( t_2 - t_1 \) is the 10 dBA down interval as defined above. The value for the duration allowance only depends on the shape of the time history, not on the decibel levels. In figures 8 and 9 the effect of some flight parameters on \( \Delta_A \) are presented. These values were computed c.f. equation (4) and (2) from complete \( \frac{1}{3} \)-octave spectra.

The top half of figure 8 shows for three aircraft the effect of flyover altitude, or more generally the effect of minimum slant range, on the values for the duration allowance. High level flyovers produce rather flat time histories and hence high values for \( \Delta_A \). Low values are associated with low altitude flights, when the time history tends to be more "peaky". Of course \( L'_{AX} \) itself decreases with increasing altitude as can be seen in the bottom half of figure 8. From this figure it can be deduced that, as a rule of thumb, the duration allowance increases by 2 - 3 dBA, while the single event exposure level decreases by 4 - 5.5 dBA per doubling of altitude. Also note the high values for \( \Delta_A \) for the PA-18-150 Super Cub. This aircraft was flying at a very low airspeed while towing a 40 m advertising banner during the measurements on which these calculations are based. Although, at the given power setting, the maximum noise levels of this airplane are lower than those of the PA-28, the \( L'_{AX} \) levels turn out
to be higher than those of the Cherokee.

Figure 9 further illustrates the effect of airspeed on the duration allowance. Increasing airspeed leads to peaky time histories and decreasing values for $\Delta_A$.

Until now only linear flyovers were considered. Figure 10 compares two time histories for a Cessna 172 in low speed cruise. The minimum slant range is the same in both cases, the only difference is the shape of the flight track. The dotted curve represents a linear flight, the solid curve one round in the traffic pattern. The maximum noise levels are of course the same for both flights, the flight in the pattern produces a longer noise duration as illustrated by the 10 dB-down times and the different values for $L_{AX}$. While they would contribute equally to an annoyance measure that only takes into account the maximum noise level (such as the "Kosten unit" mentioned before), the flight in the circuit is equivalent to almost two linear flights in terms of $L_{AX}$. There is a difference between $L_{AX}$-values resulting from an integration of the complete time history c.f. equation (1) and the approximation a according to (4), equations (2), (3) and (5). Especially for nonlinear flights, the approximation tends to overestimate $L_{AX}$, see figure 10.

6. COMPUTATION OF THE EQUIVALENT NOISE LEVEL

The equivalent (A-weighted) noise level is used in several countries to quantify the overall noise impact of non-steady noise sources. It is defined as:

$$Leq = 10 \log \left[ \left( \frac{1}{T} \right) \int_0^T \text{antilog} \left( L_A/10 \right) \, dt \right]$$  \hspace{1cm} (6)

where

$T$ = relevant period, that is the total period of time under consideration, in seconds

$L_A$ = instantaneous noise level in dBA.

Adaptations of this concept, the day night level $L_{dn}$ and the community noise equivalent level CNEL are used in the U.S. for aircraft noise. They differ from Leq in that night penalty factors are included to
account for the extra annoyance caused by aircraft operations at night, between 22.00 and 07.00 hours, \( \left( L_{dn} \right) \) and for operations during the evening hours, 19.00 - 22.00 h (CNEL). Here Leq without night penalty factor is used because the airstrips considered are not equipped for night flying.

The equivalent noise level is widely used to describe railway, road traffic and industrial noise. The use of this measure for aviation noise makes it possible to quantify the total noise climate from all these sources together, provided one accepts the idea that such different sources may be summed at all.

Using the single event exposure level concept described previously, the value for Leq caused by \( N \) airplanes passing during the relevant period \( T \) follows from:

\[
\text{Leq} = 10 \log \left( \frac{T_{\text{ref}}}{T} \sum_{i=1}^{N} \text{antilog} \left( \frac{L_{AXi}}{10} \right) \right) \quad (7)
\]

The normalizing time constant \( T_{\text{ref}} \) is 1 second as before. All Leq values quoted hereafter are based on a relevant period of 12 hours. The single event exposure level is calculated according to equation (1) for reference atmospheric conditions (temperature 25\(^\circ\) C, relative humidity 70\%) and no wind. The integration is not limited to the top 10 dBA but extends over the entire (approximated) time history.

6.1 APPROXIMATION OF TIME HISTORY— Around airfields airplanes operate at various power settings such as take-off, climb, cruise, low speed cruise (traffic-pattern) and approach. To compute \( L_{AX} \)-values at a large number of points around the field from complete \( \frac{1}{3} \) -octave spectra, for all these conditions and several flightpaths, would require too much computing time. Therefore the instantaneous noise level \( L_A \) in equation (1) is approximated by

\[
L_A = L_{A1} (\bar{\theta}) + \text{DIA}(\theta) - \Delta L_A (r) \quad (8)
\]

The first term in the right hand side of this equation is the maximum A-weighted noise level at the reference distance of 1 m observed at the emission angle for maximum noise radiation (\( \bar{\theta} \)). Ideally, this quantity is obtained from measurements of each airplane using the field at all power-settings employed around the field. If only the maximum true noise level from noise certification tests is
available (maximum continuous power and rpm at 1000' without "performance correction") these levels may be derived from figure 11. It shows an empirical relationship between noise level, engine power and propeller tip mach number based on a large number of measurements described earlier in this paper. Typical flight conditions are indicated on this figure. Figure 12 shows a comparison of this method with results of measurements.

The A-weighted directivity index, DIA (θ), approximates the shape of the noise field. Figure 13 illustrates the reason for including this term. The time history of an airplane is compared with that of a sound monopole of the same source strength and frequency content. Apart from overestimating the maximum level a little, the point source time history yields a value for \( L_{AX} \) that is 2.7 dBA higher than that of the real airplane. If errors of the same order are made for all aircraft, the total Leq error is the same that would result from overestimating the number of operations by about 85%. By definition, \( DIA = 0 \text{ for } \theta \), it is negative for other emission angles. Figure 14 shows an example of this concept. The shape of the noise field varies with distance from the source. For the computation of \( L_{AX} \) values at distances up to about 4-5 km, however, this shape may be approximated by one rather simple equation presented in table 1.

The final term in equation (8) includes the inverse square law, atmospheric attenuation and ground absorption. Atmospheric attenuation as a function of sound wave travel distance \( r \) is approximated by equations like the one presented in figure 15. For ground absorption, a method developed by the Dutch National Aerospace Laboratory (NLR) and the Organization for Industrial Research (TNO) was adopted.

If measurement data for airplanes using the field are available, it is quite easy to determine the constants in the equations for DIA and atmospheric attenuation. In table 1 typical values for several flight conditions, derived from a large number of Delft University measurements, are gathered.

Finally, the approximated time history results from the repeated computation of soundwave travel distance \( r \) and emission angle \( \theta \), which are then substituted in equation (8).
7. LEQ-CONTOURS

The above method is employed to compute Leq-contours around a general aviation airfield. Four situations-scenarios are considered. The equivalent noise level was computed in 350 points around the airstrip, interpolation produces the constant Leq-contours.

7.1 AIRFIELD USE - Figure 16 shows the flight tracks for the scenarios, the lay out is typical for a general aviation airfield in the Netherlands.

A righthand circuit is flown, radii of turns are 500 m. The area covered by the circuit is approximately 3.5 x 1.5 km. Circuit altitude is 152.4 m (500') in scenarios I, III and IV, 213.4 m (700') in scenario II. Cruise altitude is 305 m (1000') in all scenarios. There are three directions for departing flights, one for arrivals. The noise abatement departure is used in scenario III only. Arriving airplanes perform the descent to circuit altitude at the "dead side" of the circuit, the pattern is joined at cross wind leg. Is is assumed that the flight tracks are equally spaced over the corridors in figure 16.

Based on performance and noise data, the airplanes using the field are divided into several categories such as light trainers, 2+ seat sport, single engine touring, heavy singles and twins. The first three categories are responsible for 92% of the aircraft operations (1 operation is a take-off or a landing). A single aircraft type was then chosen as representative of each of these categories. Operational performance data were derived from the operating manuals, interviews with active pilots and the author's own experience, they are summarized in table 2.

A total number of 520 aircraft operations is considered. This number, used in all scenarios, represents the traffic figure for a busy airstrip on a sunny weekend day. The distribution of operations over departures, arrivals and circuit flights (touch-and-go training) is presented in figure 16 and was obtained from airport authorities. Again, this distribution is held constant in all scenarios.

The computations are performed for a relevant period of twelve daylight hours, only one runway is in use. The contours presented are for aircraft noise only, in absence of other noise sources.
7.2 SCENARIO 1 - This is the baseline scenario, results are presented in figure 17. As a reference, the centre lines of the flight corridors are included in this figure. In table 3 Leq-values in various points around the circuit as well as some particulars concerning the contours are given. The locations of these items are also indicated in figure 17.

As could be expected, the worst situation from a noise point of view is found near the extended runway centre line. Initial climb is performed at full throttle, resulting in high noise levels at the source. This, combined with short distances to the ground, produces high Leq-values. Lower values are found near the turn to final. Here the power is reduced to approach power while the airplane is still circuit-altitude. The effect of the prolonged climb to 305 m (1000') is illustrated by the shape of the 45 and 50 dBA contours along the main departure route in the upper right hand part of figure 17.

This figure also shows an important property of Leq-contours in general. At the inside of a turn Leq-values are higher than at the outside. While the maximum noise levels are the same at both sides of the track, the values for the duration allowance are higher at the inside of a turn. As a result of this, the distance between for instance, the track and the 50 dBA contour at the inside of the turn to the downwind leg of the circuit is larger than at the outside of this turn. Away from turns Leq-contours run parallel to the track of a horizontal flight, such as near downwind leg of the circuit, point D in figure 17.

In the case of annoyance caused by noise, it is difficult to establish a good relation between dose (noise levels) and effect (amount of annoyance). Yet such a relation is needed to judge the result of a noise contour computation. For the equivalent noise level a set of standards was defined by the Dutch National Health Council, based on ISO1996 (6). The maximum allowable values for Leq according to these standards are presented in table 4. They should be considered as long term goals not as short term rules of law. Although they were primarily developed for traffic and industrial noise, their use for general aviation noise is not precluded. Researchers in the U.S. found that complaints
around general aviation airstrips started at $Leq = 50$ dBA for circuit flights (touch-and-go training) while a level of 55 dBA was tolerated for "normal" arrivals and departures (7). In the near future, social surveys around general aviation airstrips in the Netherlands will be conducted to investigate the reaction to aircraft operations of people living there.

General aviation airstrips in the Netherlands are often located near suburban areas. If the situation in figure 17 is judged according to table 4, it can be concluded that the 45 dBA daylight limit is exceeded by aircraft noise alone in a large area around the field. The 50 and 55 dBA limits from (7) are exceeded near the circuit track and the extended runway centre line.

7.3 SCENARIO II - This scenario differs from the baseline scenario in that the circuit altitude is increased to 213.4 m (700') as a measure to reduce the noise levels observed on the ground.

The result is presented in figure 18, table 3 shows the changes from the baseline scenario in selected locations. The increased altitude implies longer climbs at full throttle for touch-and-go flights in the circuit. This means that noise levels are increased in the surroundings of the turn to crosswind leg. The effect of this is illustrated by the size of the 55 dBA contour: the area it encloses is increased by more than 10%, the width of the area bordered by this contour at the end of the turn to crosswind is almost doubled. On the downwind track, point D, the noise level is indeed diminished by about 2 dBA, some distance from the track however, at point E, this gain is reduced to less than 1 dBA. More spectacular is the noise level reduction on the base leg track. Because of the long descent from the increased circuit altitude, which is performed at low power, the noise level in point F is reduced by more than 4 dBA. The difference between the 45 dBA contours in the upper parts of figures 17 and 18 is caused by the fact that for arrivals cruise power is maintained longer in scenario II, since the descent from 1000' to circuit altitude can be initiated farther along the arrival track. The situation in the built-up area is not affected by the increased circuit altitude.
7.4 SCENARIO III - In an attempt to reduce the noise levels in the built-up area somewhat, departure A was re-routed, figure 16. Instead of climbing straight ahead after take-off, a right and left turn is performed so as to avoid flying over the houses. The circuit altitude is again at 500'.

The result of this noise abatement procedure is presented in figure 19. The 50 dBA contour no longer covers the built-up area, the Leq level in point A is reduced by more than 4 dBA compared with the baseline scenario, table 3. Such a noise abatement procedure clearly shifts the noise to places where it may be less annoying instead of diminishing it. As can be seen in table 3, the area enclosed by the 55 dBA contour is increased by more than 9%, the width of the area bordered by this contour at the end of the turn to crosswind increases by 75%. All this is caused by the concentration of traffic in the crosswind area of the circuit. The noise abatement procedure does not influence the situation at downwind and base leg.

7.5 SCENARIO IV - This scenario anticipates an advancement of noise technology. An overall noise reduction at the source of 3 dBA is assumed, which corresponds to halving the number of aircraft operations without noise reduction at the source.

As can be seen in figure 20 and table 3, this really would be a step in the right direction. The area enclosed by the 55 dBA contour is about halved. The 50 dBA contour in no longer present in the downwind and base leg area, and the noise levels in the built-up area are down to an acceptable level even by the standards of table 3, without a special noise abatement procedure.

8. SUMMARY AND CONCLUSIONS

A method is presented to compute Leq noise contours for propeller driven general aviation airplanes within a reasonable amount of computing time. In this method, approximations are used to account for the effects of engine power and propeller rpm, for the non spherical noise radiation of these airplanes and for atmospheric attenuation on the single event exposure levels, observed on the ground. They are based on a large body of in the field flyover noise measurements performed by the Department
of Aerospace Engineering of Delft University of Technology. The measurement and data reduction procedures are briefly described and illustrated by some selected results.

Leg noise contour plots are employed to evaluate the effects of three possibilities to reduce noise levels on the ground around a general aviation airstrip: increasing circuit altitude, rerouting and noise reduction at the source. Results indicate that the last method is by far the most effective to achieve this reduction. It is, however, also a method that will require a considerable amount of additional research and money. Short term solutions to noise problems may be obtained by routing aircraft away from noise sensitive areas. The development of such noise abatement procedures should be based on a study of the local situation, there is no general solution applicable to all airfields. Increasing the circuit altitude is in general not very effective.
9. REFERENCES


Table 1 - Formulæ used in approximation of time histories

<table>
<thead>
<tr>
<th>Noise level at reference distance of 1 meter, figure 11</th>
<th>[ L_{A1}(\bar{\theta}) = L_{A, \text{max. cont. power}} + 51.3 + \Delta L_A ] at 1000'</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Add 1.5 dB for initial climb</td>
</tr>
<tr>
<td></td>
<td>[ \Delta L_A = 10 \log \frac{P}{P_{\text{max. cont.}}} + 85.5 \Delta M + 12.1 \Delta N^2 ]</td>
</tr>
</tbody>
</table>

| A-Weighted Directivity Index, figure 14 | \[ \text{DIA}(\theta) = a \left[ b \sqrt{\frac{1}{a \sin^2 (\bar{\theta} - \theta) + b^2 \cos^2 (\bar{\theta} - \theta)}} \right] - 1 \] |

| Atmospheric attenuation, figure 15 | \[ \Delta L_{A, \text{atm.}} = a \log r + \beta r \] |

<table>
<thead>
<tr>
<th>Typical values for constants</th>
<th>A-Weighted Directivity Index</th>
<th>Atmospheric Attenuation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \theta &lt; \bar{\theta} )</td>
<td>( \theta &gt; \bar{\theta} )</td>
</tr>
<tr>
<td>Take-off &amp; Climb</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Cruise</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Traffic Pattern</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Descent &amp; Approach</td>
<td>4</td>
<td>2</td>
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Table 2 - Operational data used in Leq-contour computations

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<tr>
<th>CATEGORY</th>
<th>TRAINER</th>
<th>SPORT</th>
<th>TOURING</th>
<th>HEAVY SINGLE</th>
<th>TWIN</th>
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<tr>
<td>o/o Operations</td>
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<td>TAPE-OFF</td>
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<td>T/O run, m</td>
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<td>Average speed, m/s</td>
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<td>$L_{A1} (\overline{\theta})$, dBA</td>
<td>115.2</td>
<td>120.0</td>
<td>121.3</td>
<td>128.3</td>
<td>130.2</td>
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<td>CLIMB</td>
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<tr>
<td>Airspeed, m/s</td>
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<td>38.89</td>
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<td>Rate of climb, m/s</td>
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<td>$L_{A1} (\overline{\theta})$, dBA</td>
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<td>120.0</td>
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<td>CRUISE</td>
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<tr>
<td>Airspeed, m/s</td>
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<td>DESCENT TO CIRCUIT</td>
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<td>Airspeed, m/s</td>
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<td>2.03</td>
<td>2.54</td>
<td>2.54</td>
</tr>
<tr>
<td>$L_{A1} (\overline{\theta})$, dBA</td>
<td>96.3</td>
<td>101.0</td>
<td>103.0</td>
<td>114.9</td>
<td>116.4</td>
</tr>
<tr>
<td>CIRCUIT DOWNWIND</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Airspeed, m/s</td>
<td>42.47</td>
<td>44.70</td>
<td>42.47</td>
<td>50.51</td>
<td>59.90</td>
</tr>
<tr>
<td>$L_{A1} (\overline{\theta})$, dBA</td>
<td>106.0</td>
<td>108.8</td>
<td>110.4</td>
<td>121.7</td>
<td>123.1</td>
</tr>
<tr>
<td>APPROACH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Airspeed, m/s</td>
<td>31.29</td>
<td>35.76</td>
<td>31.74</td>
<td>40.23</td>
<td>49.62</td>
</tr>
<tr>
<td>Rate of descent, m/s</td>
<td>3.73</td>
<td>3.12</td>
<td>2.77</td>
<td>3.15</td>
<td>3.89</td>
</tr>
<tr>
<td>$L_{A1} (\overline{\theta})$, dBA</td>
<td>100.4</td>
<td>100.8</td>
<td>105.1</td>
<td>116.3</td>
<td>117.7</td>
</tr>
</tbody>
</table>

NOTE: Metrical values for airspeed and rate of climb and descent were computed from integer mph and fpm figures.
Table 3 - Selected results of Leq-contour computations

<table>
<thead>
<tr>
<th>Leq-VALUES</th>
<th>SCENARIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>See figure 17 for locations</td>
<td></td>
</tr>
<tr>
<td>A. 2625 m from start of take-off roll</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>dBa</td>
</tr>
<tr>
<td>B. center of turn to X-wind</td>
<td>52.8</td>
</tr>
<tr>
<td>C. on track, end of turn to X-wind</td>
<td>54.0</td>
</tr>
<tr>
<td>D. on track, downwind</td>
<td>56.4</td>
</tr>
<tr>
<td>E. 250 m aside from track, downwind</td>
<td>52.9</td>
</tr>
<tr>
<td>F. on track, base leg</td>
<td>49.3</td>
</tr>
<tr>
<td></td>
<td>52.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Δ%/re. Scen. I</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. area enclosed by 55 dBa contour</td>
</tr>
<tr>
<td>Width of area bordered by contour:</td>
</tr>
<tr>
<td>2. 55 dBa, end of turn to X-wind</td>
</tr>
<tr>
<td>3. 50 dBa, begin of turn to downwind</td>
</tr>
<tr>
<td>4. 50 dBa, at downwind</td>
</tr>
</tbody>
</table>

Table 4 - Recommended outdoor noise immission limits

<table>
<thead>
<tr>
<th>Type of district</th>
<th>Leq, dBa</th>
<th>Day</th>
<th>Evening</th>
<th>Night</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural residential, hospitals</td>
<td>40</td>
<td>35</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Suburban residential, little traffic</td>
<td>45</td>
<td>40</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Urban residential</td>
<td>50</td>
<td>45</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Urban residential near main roads</td>
<td>55</td>
<td>50</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>City (business, trade, administration)</td>
<td>60</td>
<td>55</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Predominantly industrial area</td>
<td>65</td>
<td>60</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 1: Examples of test aircraft
Fig. 2: Test range layout.
Fig. 3: Examples of measured noise time histories.
Fig. 4: Sound field at reference distance of 1 metre.
Fig. 5: Acoustic power as a function of propeller helical tip mach number.
Fig. 6: Noise field.
Fig. 7: Comparison of measured and computed time history.
Fig. 8: Effect of flyover altitude on duration allowance and single event noise exposure level.
Fig. 9: Effect of airspeed on duration allowance.
Fig. 10: Comparison of two time history.
Fig. 11: Effect of power setting on the noise level of propeller driven general aviation airplanes.

SEE TABLE 1 FOR FORMULAE

TYPICAL POWERSETTINGS

1. CLIMB
2. CRUISE (1000')
3. TRAFFIC PATTERN
4. APPROACH
Fig. 12: Comparison of measured and computed noise levels.

- Delft University Tests
- Dornier Tests, Ref. 4

All data: Flyover Measurements
Fig. 13: Effect of non-spherical noise radiation on the time history.
Fig. 14: The A-weighted directivity index.
Fig. 15: Atmospheric attenuation.
Fig. 16: Flight tracks around a general aviation airstrip.
Fig. 17: Leq contours around a general aviation airstrip, scenario I baseline.
Fig. 19: $L_{eq} =$ 45 dBA, scenario III, noise abatement departure.
Fig. 20: $L_{eq}=45$ dBA, Leq-contours, scenario IV, noise reduction at the source.