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DATA REPORT: "EN ROUTE" NOISE OF TWO TURBOPROP AIRCRAFT

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Braunschweig, im Juni 1989

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To be published as DLR-Mitt. 89-18

Propellerlärm, Reisefluglärm

Datenbericht: Reisefluglärm von zwei Turboprop-Flugzeugen

Übersicht

Zur Beurteilung des Reisefluglärms künftiger Verkehrsflugzeuge mit Propfanantrieben werden Vergleichsdaten von herkömmlichen Turboprop-Flugzeugen benötigt. Als Beitrag zu einer solchen Datenbank wurden Reisefluglärmmessungen an zwei zweimotorigen Turboprop-Flugzeugen in Flughöhen zwischen 5182 m und 6401 m durchgeführt. Die Geräuschpegel werden zusammen mit den Betriebsdaten der Antriebspropeller und den meteorologischen Umgebungsbedingungen angegeben. Schmalband-Frequenzanalysen zeigen die besonderen Eigenschaften des gemessenen Propellergeräusches, nämlich die Dominanz des Pegels der Propellerdrehklangfundamentalen und das Auftreten von akustischen Schwebungen durch unterschiedliche Drehzahlen der zwei Antriebspropeller.

Propeller Noise, En route Noise

Data Report: "En route" Noise of two Turboprop-Aircraft

Summary

In order to weigh en-route noise immissions originating from future propfan powered aircraft, a data base of immission levels from conventional turboprop aircraft is needed. For this reason flyover noise measurements on two twin-engine turboprop aircraft were conducted at flight heights between 17000 ft and 21000 ft. Acoustic data are presented together with propeller operational parameters and environmental meteorological data. Narrowband spectral analyses demonstrate the characteristic features of the measured propeller noise signatures: Noise spectra are dominated by the propeller rotational noise fundamental frequency and pronounced noise beats occur as a consequence of different rotational speeds of the propellers.

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List of symbols

BLN	-	Number of propeller blades
BPF	Hz	Blade passing frequency =(N/60) BLN
f	Hz	Sound frequency
H	m	Flight height
HN	-	Harmonic number
L	dB	Overall sound pressure level
L_A	dB	Overall A-weighted sound pressure level (A-sound level)
M	-	Flight Mach number
M_{Hel}	-	Helical propeller blade-tip Mach number
N	1/min	Propeller rotational speed
p	N/m^2	Sound pressure amplitude
r	m	Distance between sound source and observer
t	sec	Time
t_s	sec	Cycle-time of sound beats
T	°C	Temperature
V	m/s	Flight speed
ω	Hz	Circular frequency $=2\pi f$
Θ	deg	Elevation angle

Subscripts

o	-	Reference
max	-	Maximum value

Note: Sound pressure levels are referenced to $p_o=20\,\mu Pa$

1. Introduction

The significant and world wide increase in air-traffic during the last decade has led to a noise nuisance caused by aircraft in cruise, operating at high altitudes. Complaints are reported both from resort areas with inherently low background noise and from areas underneath crowded air-traffic junctions.

The issue of the so called "en route noise" has been raised recently within the Working Groups of the ICAO-Committee on Aircraft Environmental Protection (CAEP). A potential problem is foreseen with the development and introduction of new propfan-powered aircraft within the next few years. In fact, it is the low-frequency harmonic noise signature of such propeller-type propulsion systems which worries the acoustics engineers and administrators alike, who expect an increase in en route noise related complaints.

In the United States the first flyover noise measurements on a propfan powered research type aircraft were recently conducted. In order to check measured noise characteristics in terms of their "annoyance" potential they need to be compared against some adequate reference. An appropriate reference could be the noise characteristics of conventional turboprop-aircraft that have been in operation for many years and are more or less accepted by the public.

The task at hand, therefore, is to define a "level-number" which, in combination with the particular propfan/propeller noise characteristics, would be acceptable as not to further aggravate the present en route noise problem. Since no extensive data base exists for such a comparison, en route noise data from turboprop aircraft must be collected to provide a reference as an acceptable noise limit.

This report presents flyover noise data as measured from two different turboprop aircraft at typical cruising altitudes along with local meteorological and aircraft operational data. The

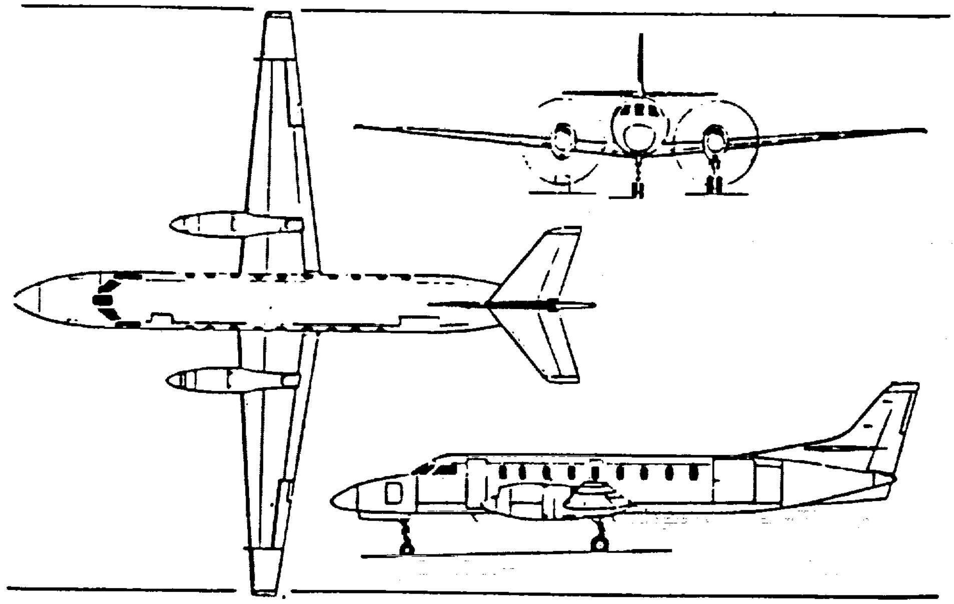

Fig. 1 Fairchild Metro III aircraft

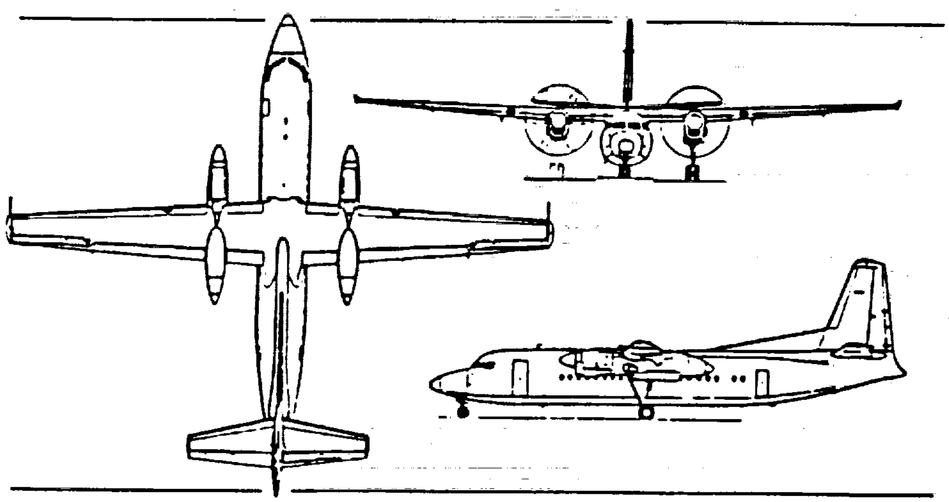

Fig. 2 Fokker 50 aircraft

measurement campaign was initiated and organized by the "Noise Abatement Commissioner of the Hessian Minister for Economics and Technology at Frankfurt Airport", Herr Held, and funded by the "Flughafen Frankfurt Main AG".

2. Test aircraft

Two different types of aircraft were selected, the Fairchild Metro III (Fig. 1) and the Fokker 50 (Fig. 2). Both aircraft are powered by two turboprops each, the Metro III representing a smaller but somewhat noisier aircraft compared to the larger Fokker 50. Some overall design parameters are listed in Table I:

TABLE I: Test aircraft parameters

	Metro III SA 227	Fokker 50
Wing span (m)	17.37	29.00
Max. T.O. Mass (kg)	6577	18990
Typical Cruising Speed (kts|km/h)	248|459	282|522
Power Plant:	Garret TPE 331-11U-612G	Pratt & Whitney PW 125 B
Number of Engines	2	2
Engine Power (kW)	745.5	1864.0
Propeller:	Dowty Rotol	Dowty Rotol
Number of Blades	4	6
Diameter (m)	2.69	3.66

3. Test matrix and measurement site

Acoustic data were taken for three level flyover heights, i.e. 17000 ft (5182 m), 19000 ft (5791 m) and 21000 ft (6401 m) in respectively two opposite flight directions with the engines operating at cruise-power setting. Since relatively low flyover noise levels were expected the measurements were taken at night (between 0.00 am and 3.00 am) in a flat agricultural area located south of Frankfurt airport. This site was selected to benefit from existing navigational aids installed near airports and to thus realize a precise and reproducible flight path over the measurement station.

4. Environmental and operational data acquisition

In order to correctly evaluate acoustic test results, the local meteorological conditions and pertinent aircraft operational data were recorded.

4.1 Meteorological data

Simultaneously with the acoustic flyover measurements, a weather-balloon was raised by the "Deutscher Wetterdienst" near the test site to obtain profiles of atmospheric pressure, temperature, humidity and wind conditions versus height. Respective data records are presented in Figs. 3 and 4 up to a height of 2000 m. A complete data listing of wind conditions up to 6672 m and of temperature and humidity up to 4245 m are presented in Appendix I.

4.2 Aircraft operational data

No external devices were used to determine the aircraft operational data, but the pilots were instructed to read and record flight-height and -speed as well as air-temperature and power-

AUFSTIEGSORT: GRIESHEIM BEMERKUNGEN:
RADIOSONDENTYP: TOFS
UHRZEIT: 02.10 MESZ DATUM: 30.04.89
STATIONSHÖHE: 90 m (NN)

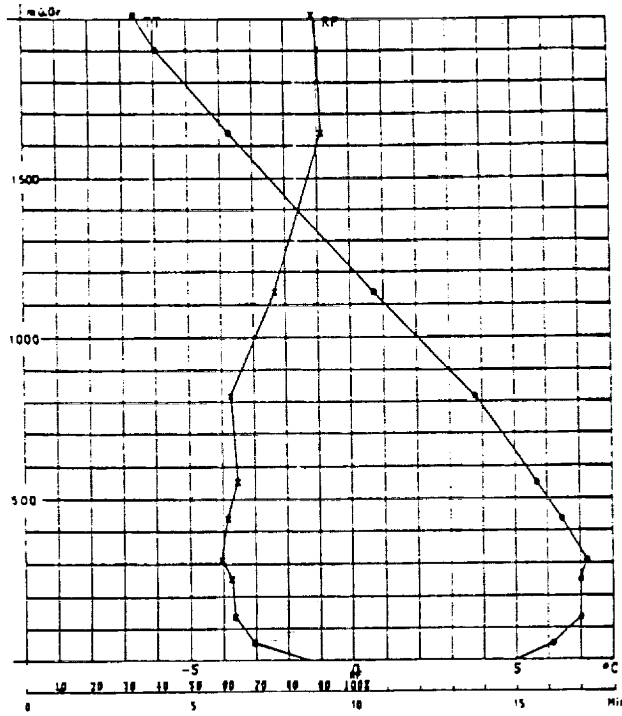

Fig. 3 Air-temperature (TT) and Relative Humidity (RF) versus height (in meters) above ground

AUFSTIEGSORT: GRIESSHEIM BEMERKUNGEN:
DATUM: 30.04.89 RADARWIND (GEGLAETTET)
UHRZEIT: 02.10 MESZ
STATIONSHÖHE: 90 m (NN)

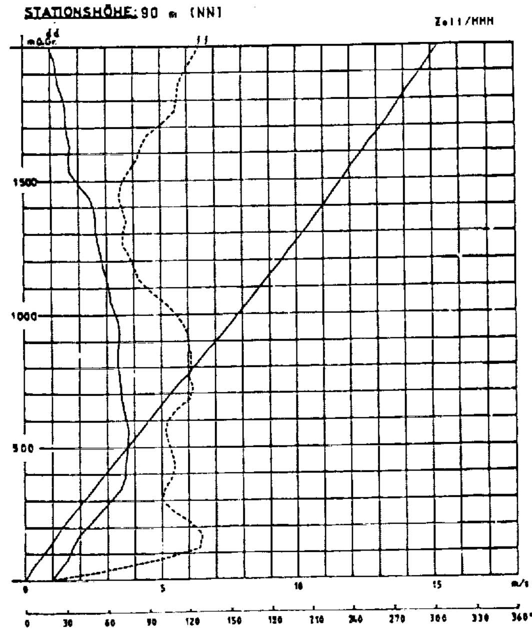

Fig. 4 Wind-direction (dd) and -magnitude (ff) versus height (in meters) above ground

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Inflight - Info - Sheet

Type of aircraft: METRO III SA 227
Registration : D-CFEP
Type of engine : TPE 331

	T.O.W. : ATD : Pos. 7DME RID R 359	5400 kg 2200 z 2203.. z .8000.. Alt.	
1	4DME south of RID FL 170 northbound on R 359/179 RID	2212 z	IAS/TAS 195 / 230 kts Temp.: -14 Clouds: CLEAR Power: 600 EGT 97% anti ice: ~~on~~ off
	13DME north of RID FL 170 southbound on R 359/179 RID	2221 z	IAS/TAS 195 / 23 kts Temp.: -14 Clouds: CLEAR Power: 600 EGT 97% anti ice: ~~on~~ off
2	4DME south of RID FL 190 northbound on R 359/179 RID	2229 z	IAS/TAS 190 / 230 kts Temp.: -20 Clouds: CLEAR Power: 600 97% anti ice: ~~on~~ off
	13DME north of RID FL 190 southbound on R 359/179 RID	2237 z	IAS/TAS 190 / 230 kts Temp.: -20 Clouds: CLEAR Power: 600 EGT anti ice: ~~on~~ off
3	4DME south of RID FL 210 northbound on R 359/179 RID	2244 z	IAS/TAS 188 / 232 kts Temp.: -26 Clouds: CLEAR Power: 600 EGT 97% anti ice: on off
	13DME north of RID FL 210 southbound on R 359/179 RID	2251 z	IAS/TAS 170 / 232 kts Tem.: -26 Clouds: CLEAR Power: 600 EGT 97% anti ice: ~~on~~ off
	Pos. 4DME south of RID, FL 210 End of testflight request clearance to Frankfurt	2256	z

Fig. 5 Data sheet as filled out by the Test-pilot of the Metro III aircraft

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Inflight - Info - Sheet

Type of aircraft: Fokker 50
Registration : D-AFKG
Type of engine : PW 125B

29/30 April 1989

	T.O.W. : 15.765 kg ATD : 2300 z Pos. 7DME RID R 359 ... 2304 z ... 7.100 ft Alt.		
1	4DME south of RID FL 170 northbound on R 359/179 RID	2310 z	IAS/TAS 211 kts / 274 kts Temp.: -15° Clouds: cavok Power: 80% TRQ cruise anti ice: ~~on~~ off
	13DME north of RID FL 170 southbound on R 359/179 RID	2317 z	IAS/TAS 218 kts / 283 kts Temp.: -14° Clouds: cavok Power: 80% TRQ cruise anti ice: ~~on~~ off
2	4DME south of RID FL 190 northbound on R 359/179 RID	2324 z	IAS/TAS 209 kts / 281 kts Temp.: -20° Clouds: cavok Power: 78% TRQ cruise anti ice: ~~on~~ off
	13DME north of RID FL 190 southbound on R 359/179 RID	2331 z	IAS/TAS 212 kts / 286 kts Temp.: -19° Clouds: cavok Power: 79% TRQ cruise anti ice: ~~on~~ off
3	4DME south of RID FL 210 northbound on R 359/179 RID	2338 z	IAS/TAS 201 kts / 278 kts Temp.: -24° Clouds: cavok Power: 72% TRQ cruise anti ice: ~~on~~ off
	13DME north of RID FL 210 southbound on R 359/179 RID	2345 z	IAS/TAS 203 kts / 282 kts Tem.: -24° Clouds: cavok Power: 74% TRQ cruise anti ice: ~~on~~ off
	Pos. 4DME south of RID, FL 210 End of testflight request clearance to Frankfurt		End of test in the air 2352 " " " on ground 0012 z

Fig. 6 Data sheet as filled out by the Test-pilot of the Fokker 50 aircraft

C-2

setting from the cockpit instrumentation during each flyover. "Inflight-Info-Sheets" are presented as Figs. 5 and 6.

Both aircraft are equipped with constant-speed propellers. Hence power is adjusted automatically by blade-pitch setting to maintain a constant rotational speed corresponding to the following values:

	Metro III	Fokker 50
Propeller rotational speed (rpm)	1543.	1025.

5. Acoustic data acquisition

Two Brüel & Kjaer 1/2"-Condenser Microphones (Type 4145) were positioned (in close proximity) underneath the flight path. The microphone signals were stored on an analog tape recorder. While one of the microphones was mounted on a 1.2 m pole, according to established noise certification regulations, the other microphone was installed close (and inverted) to a 0.4 m diameter ground board. This latter arrangement is frequently employed in scientific measurements since it represents the best device (other than a flush mounted microphone in a large concrete surface) to avoid ground reflection interferences. Such ground reflections tend to heavily distort source noise spectra, depending on the particular relation between microphone height and the fundamental frequency wavelength of the signature to be measured.

Examples of such microphone arrangements are presented in Fig. 7. However, for the tests described herein, the microphones were located on a hard and flat "earthy" surface.

From basic priciples it is known that pressure doubling occurs at an acoustically hard surface. Levels obtained by ground based microphone arrangements are higher by up to 8 dB(!) compared to those from pole-microphone installations. If however the microphone height selected (accidentally) corresponds to multiples of

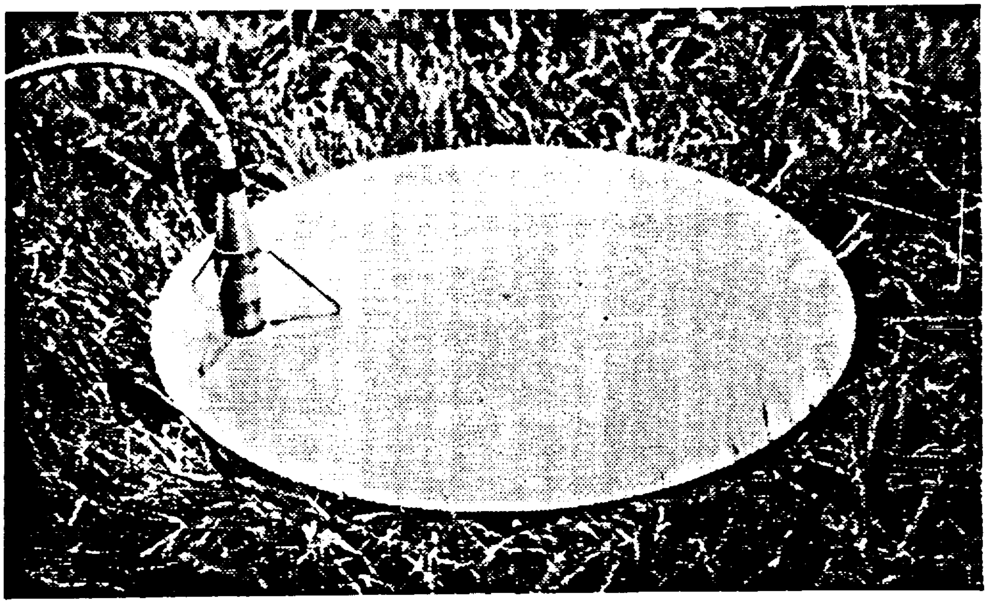

Fig. 7 Illustrations of ground-board (top) and 1.2 m pole microphone (bottom) arrangements

Original figures not available.

the sound signature's wavelength both microphone arrangements may give identical results.

A detailed discussion of ground reflection effects on propeller aircraft flyover noise measurements is provided in [1].

6. Acoustic test results

Noise data will be presented as measured in terms of overall levels, level time-histories, and narrowband spectra. Since no acoustical significant variations in flyover height could be tested and acoustic signatures turned out to be dominated by the low-frequency (about 100 Hz) fundamental of propeller rotational noise, no correction is applied to the data with respect to flight height, air-temperature, atmospheric attenuation, etc.

Such corrections indeed should not be applied in an overall manner, since the magnitude of respective level differences would equal the observed data scatter caused by stochastic atmospheric disturbances. Application of such corrections should therefore be left to specialists who are then to apply sophisticated computer codes for the calculation of the transmission attenuation based on detailed meteorological data.

6.1 Maximum linear- and A-weighted overall sound pressure levels

Tables II and III contain maximum linear (analyzed with time constant "fast") and A-weighted (analyzed with time constant "slow") overall levels numbered in the order of test flights except the first flight of the Fokker 50 aircraft at 17000 ft height which had been missed due to communication problems. The first measurement in that listing (Table II) does not pertain to the en route noise test series, but represents the climb-out signature of the test aircraft Metro III and has only been listed for completeness.

Table II

En-Route Noise Measurement (Frankfurt/Griesheim; 30.4.89)

Aircraft Type: Metro III SA 227
Propeller Diameter = 2.692 m (4 Blades)

Operational Conditions: TAS = 230.0 kts
Propeller Rot. Speed = 1543.3 rpm (BPF = 102.9 Hz)

No.	Flight Height ft	Air Temp. °C	M_{Hel}	$L_{A,max}$ (Slow) dB(A) Ground Mic	$L_{A,max}$ (Slow) dB(A) 1.2 m Mic	L_{max} (Fast) dB Ground Mic	L_{max} (Fast) dB 1.2 m Mic
1*	8000	-	-	61.7	56.9	78.4	74.2
2	17000	-14	0.7675	52.9	48.9	70.3	67.2
3	17000	-14	0.7675	54.1	50.5	72.0	68.5
4	19000	-20	0.7764	50.6	47.5	68.0	65.7
5	19000	-20	0.7764	50.2	47.5	68.1	65.9
6	21000	-26	0.7858	52.1	48.2	68.7	65.9
7	21000	-26	0.7858	49.9	46.0	68.0	64.9
Level Averages (without No. 1)				51.6	48.1	69.2	66.4
Level Differences (Ground -1.2 m)				Δ = 3.5		Δ = 2.8	
Background Noise Levels:				39.0	37.9	54.0	53.0

* Take-off Power Setting

Listing of measured maximum overall noise levels from Metro III aircraft fly-overs

Table III

En-Route Noise Measurement (Frankfurt/Griesheim; 30.4.89)

Aircraft Type: Fokker 50
Propeller Diameter = 3.66 m (6 Blades)

Operational Conditions: TAS (Average) = 280.5 kts
Propeller Rot. Speed = 1025.0 rpm (BPF = 102.5 Hz)

No.	Flight Height ft	Air Temp. °C	M_{Hel}	$L_{A,max}$ (Slow) dB(A) Ground Mic	$L_{A,max}$ (Slow) dB(A) 1.2 m Mic	L_{max} (Fast) dB Ground Mic	L_{max} (Fast) dB 1.2 m Mic
8	17000	-14	0.7554	51.0	48.5	67.5	64.4
9	19000	-20	0.7643	53.9	51.1	70.9	68.8
10	19000	-19	0.7628	46.9	43.5	63.7	----
11	21000	-24	0.7704	45.9	43.9	63.0	60.8
12	21000	-24	0.7704	46.6	44.0	63.7	60.1
Level Averages				48.9	46.2	65.8	63.5
Level Differences (Ground -1.2 m)				Δ = 2.7		Δ = 2.3	
Background Noise Levels:				39.0	37.9	54.0	53.0

Listing of measured maximum overall noise levels from Fokker 50 aircraft fly-overs

Together with the flyover noise levels these tables also contain the calculated values of respective helical propeller blade-tip Mach numbers, referenced to the air temperature at flight height.

Calculated level averages (as determined from flyovers at different heights!) may be taken to correspond to the average flight height of 19000 ft. From the measured and listed background noise levels, on average a sufficiently large signal-to-noise ratio of almost 10 dB is observed.

Levels on the ground turn out to be higher by some 3 dB compared to those from the 1.2 m pole microphone. This level difference can be taken as an order-of-magnitude value which may be considered as typical for conventional propeller-driven aircraft. Not to hamper further data interpretation by accounting for ground reflection effects, only ground microphone obtained noise signatures will be discussed.

In Figs. 8 and 9 overall linear and A-weighted noise levels are plotted versus flyover height for both aircraft. As a simple reference, the level attenuation for spherical spreading ($1/r^2$-law) is indicated. Except for one data point (No. 9/Fokker 50) noise levels are quite close to this reference. As will be shown later there is no explanation for the noise level of flyover No. 9 to be almost 7 dB higher than expected. Effects of stochastic atmospheric disturbances may have caused this discrepancy.

From an inspection and comparison of the data as presented in Figs. 8 and 9 the Metro III aircraft seems 2.5 dB noisier compared to the Fokker 50 aircraft. From the experience gained within extensive wind tunnel propeller noise tests [2] such a result may be assumed to originate from a slightly higher helical blade-tip Mach number as observed for the Metro III compared to that of the Fokker 50.

For both aircraft the differences between linear and A-weighted noise levels range from 17 dB to 18 dB. This difference roughly

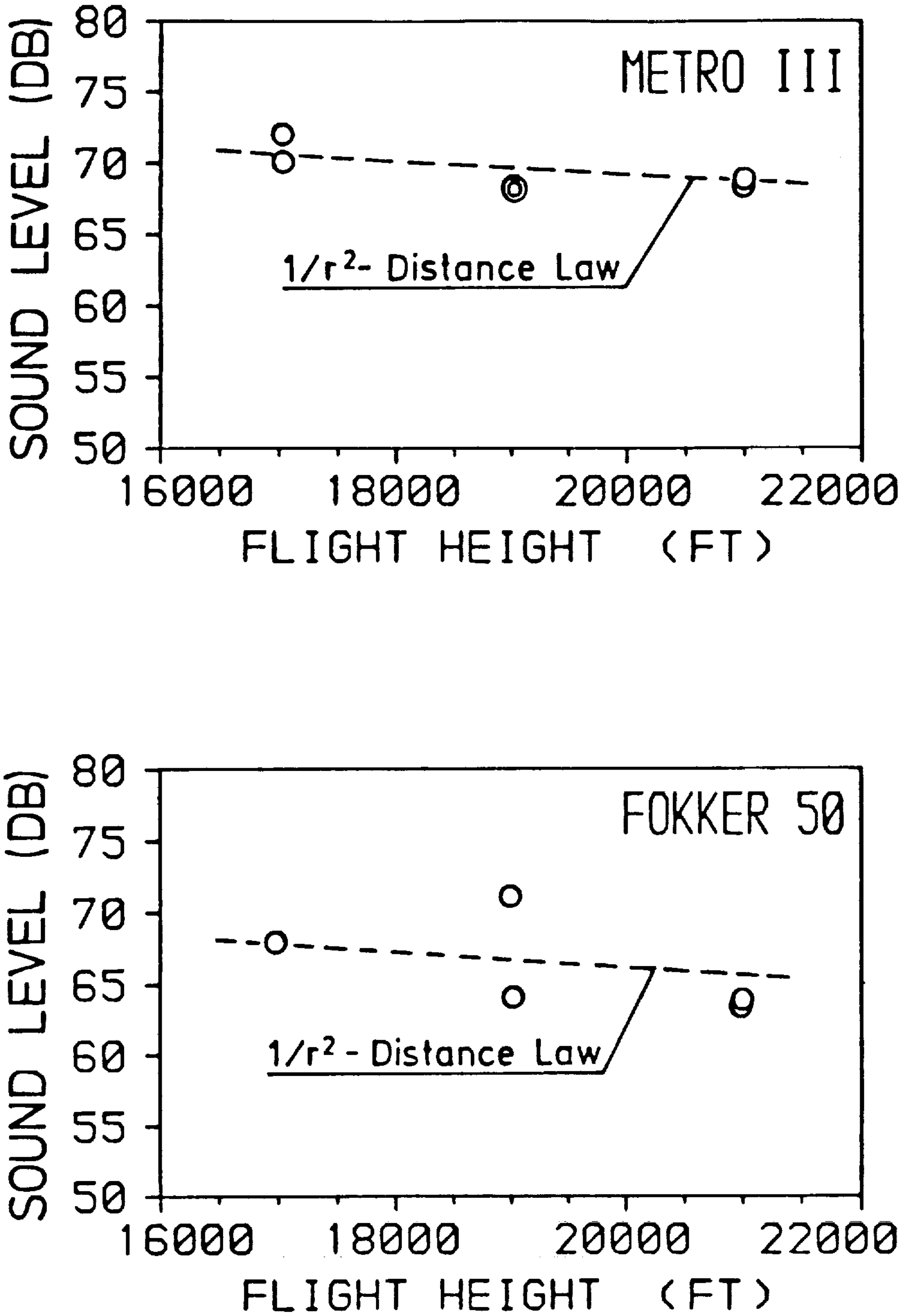

Fig. 8 As measured maximum overall flyover noise levels versus flight height

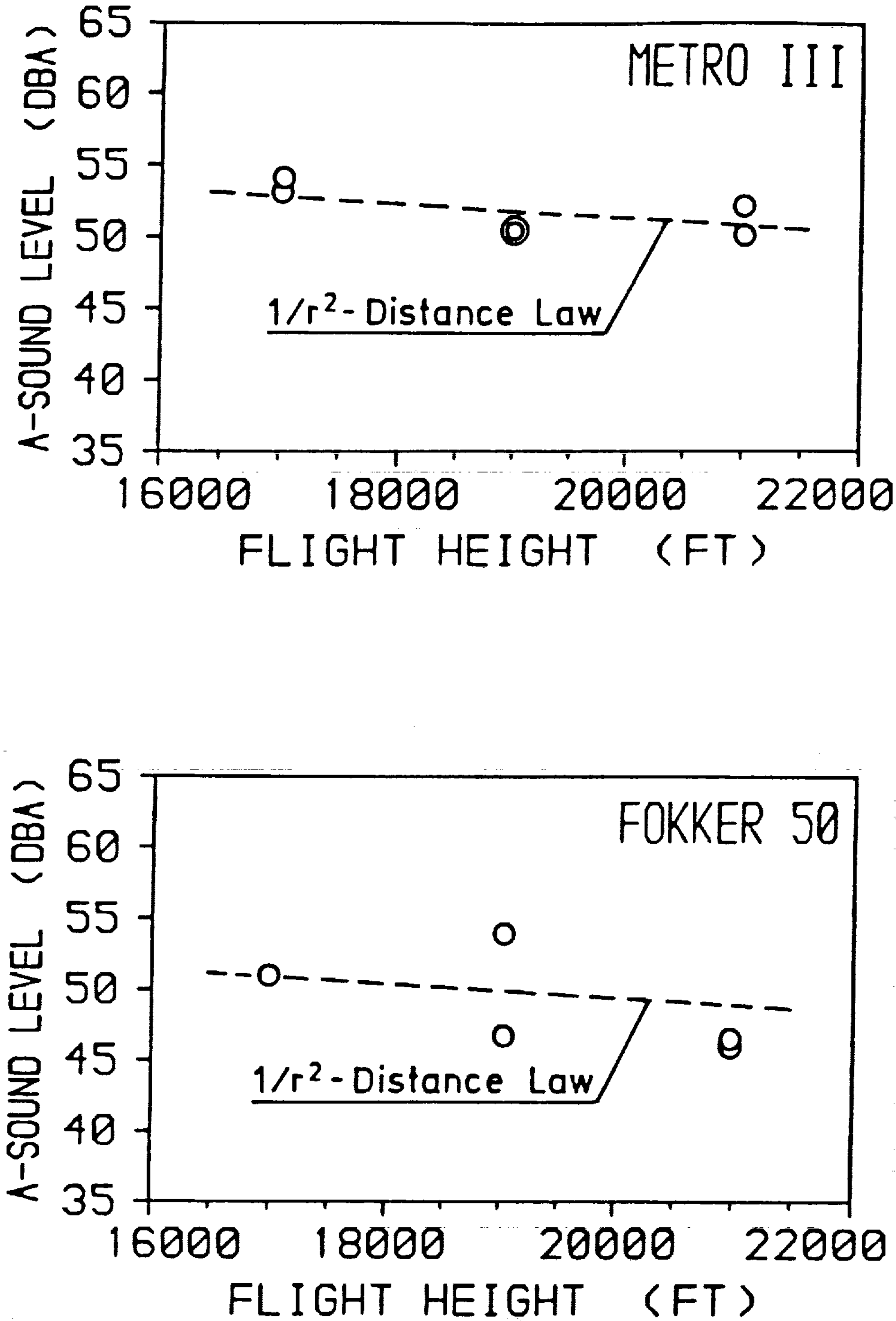

Fig. 9 As measured maximum A-weighted overall fly-over noise levels versus flight height

corresponds to the A-weighting attenuation at a frequency of 100 Hz to 125 Hz which happens to coincide with the respective blade passing frequencies of both aircraft. Already at this stage of data analysis, one may safely conclude that flyover noise signatures are entirely governed by the blade passing frequencies.

6.2 Sound level time-histories

In order to select appropriate instances in flyover time for later spectral analysis it is necessary to initially plot overall level time histories. Such information is presented in Appendix II both in terms of linear (time constant "fast") and A-weighted (time constant "slow") overall level time-histories.

Typically all of these histories exhibit level fluctuations which range up to 15 dB (!) for the representations of overall linear levels. Two explanations may be offered: There are either atmospheric effects during sound transmission over long distances, or sound beats due to the superposition of sound signatures originating from two noise sources (propellers) radiating at slightly different frequencies (rotational speeds).

To definitely prove that in fact sound beats are the reason for these (periodic) level fluctuations, some more analysis is necessary: If two pure-tone noise sources with identical pressure amplitudes p_o are considered, one operating at a circular frequency of ω_1 and the other at ω_2, the time history of the combined pressure amplitude may be written as follows:

$$(1) \qquad p = 2\, p_o \cdot \cos\left[(\Delta\omega/2) \cdot t \right] \cdot \cos(\omega_1 \cdot t)$$

$$(\text{with } \Delta\omega = \omega_1 - \omega_2).$$

From this equation it is obvious that the pressure amplitude may be doubled ($\hat{=}$ +6 dB) or tends to zero ($\hat{=}$ minus ∞ dB) as a periodic function of time corresponding to the cosine of the beat frequency which is defined as

(2) $\omega_s = \Delta\omega/2 = 2\pi/t_s$.

Now the effect of such beats on different source frequencies may be determined as a function of propeller rotational speed from the relation

(3) $\omega = 2\pi f_{Harm.} = 2\pi\,(N/60)\cdot BLN\cdot HN$

and thus

(4) $\Delta\omega = 2\pi\,(\Delta N/60)\cdot BLN\cdot HN$.

From eqs. (2), (3) and (4) the time period of pressure fluctuations may be calculated as

(5) $t_S = 2\pi/(\Delta\omega/2) = 2/\left[(\Delta N/60)\cdot BLN\cdot HN\right]$

exhibiting faster repetitions in time of pressure minima and maxima with increasing source frequency, i.e. for higher harmonic numbers HN. It is this particular feature of pressure level fluctuations which allows the distinction between the stochastic effects of long range sound transmission through a turbulent atmosphere and the periodic effects of noise beats.

In order to demonstrate that effect from the measured data, it is necessary to compare time histories of different rotational harmonic levels. Such analysis, however, is somewhat difficult because of the Doppler-shift in frequency with flyover time. As will be shown later, tracking filter techniques could not be applied since - as a result of beats and the marginal signal-to-noise ratio - harmonic levels frequently submerge into the background noise floor. Therefore flyover signatures were analysed in terms of adjacent 1/3-octave band level histories with the fundamental frequency moving (continuously) from the 125 Hz band (aircraft in approach) into the 100 Hz band and finally into the 80 Hz band for the aircraft receeding from the measuring station. When combining such plots (synchronized in time) one may obtain continuous level time traces at least for the first two

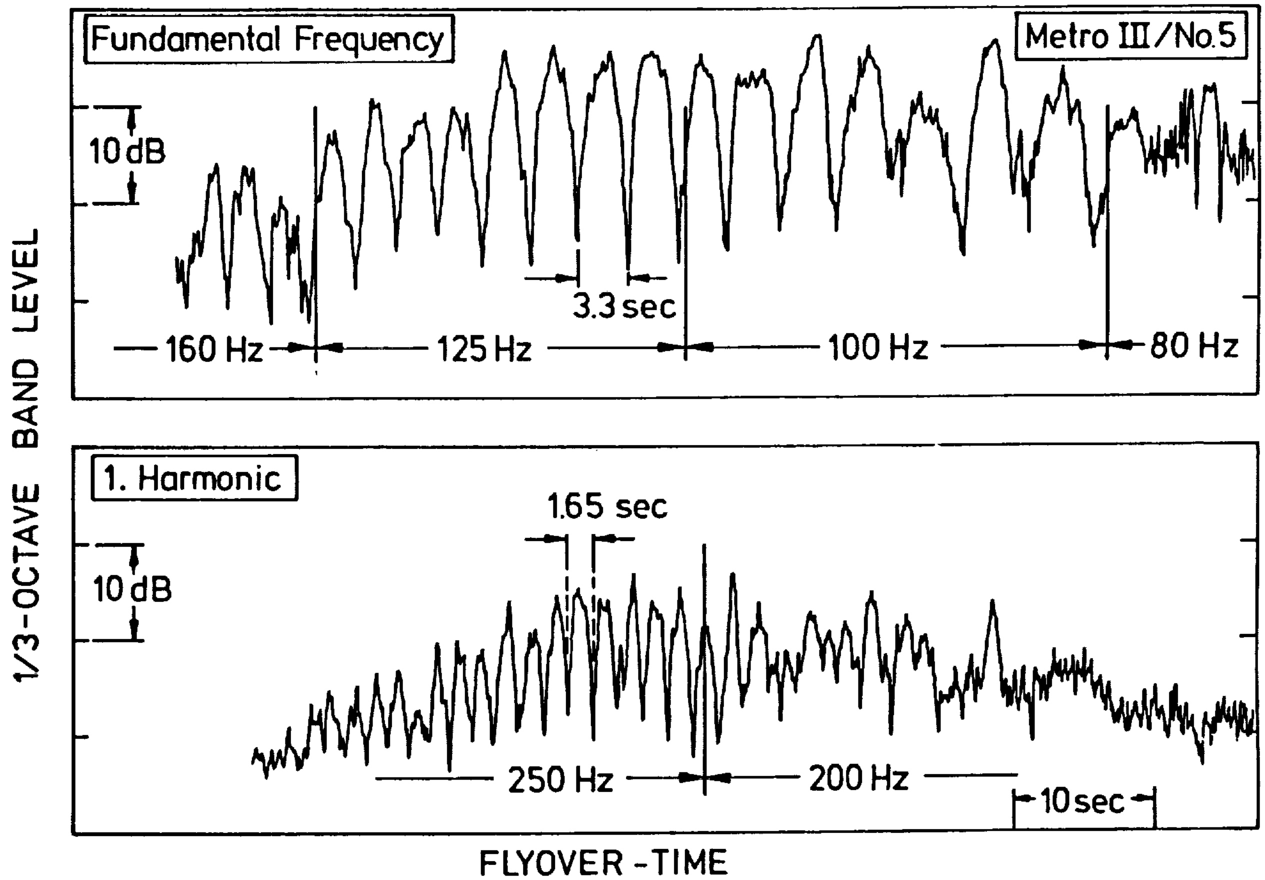

Fig. 10 1/3-octave band level time-histories of Metro III flyover No. 5

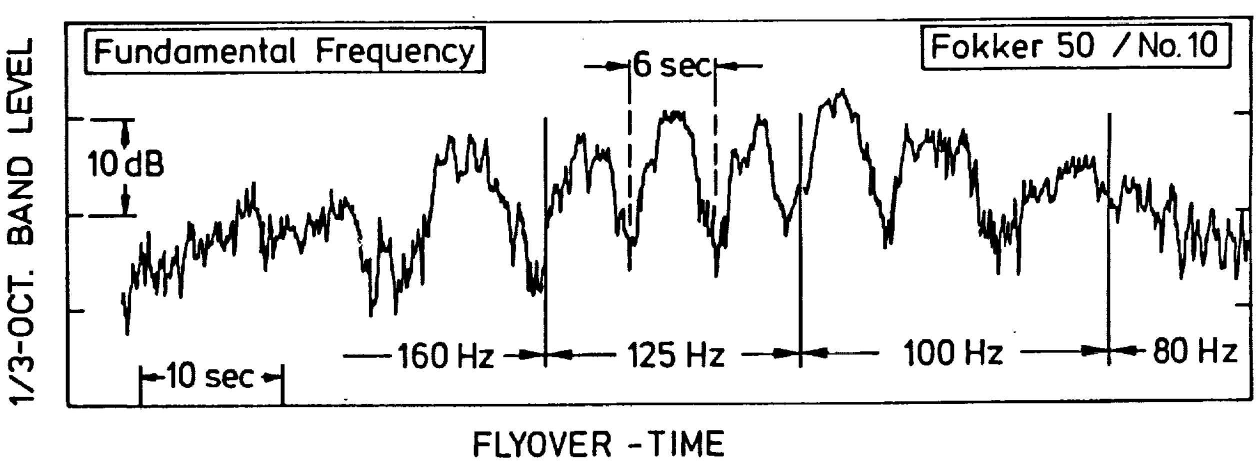

Fig. 11 1/3-octave band level time-history of Fokker 50 flyover No. 10

rotational frequencies, which are apart by about 100 Hz and thus never contribute to the same 1/3-octave band level.

An example of such an analysis is presented in Fig. 10 for both the fundamental frequency of the Metro III flyover noise signature and for the first harmonic level. From a comparison of level fluctuations in time for both frequencies, the first harmonic ($f \sim 200$ Hz) exhibits twice the beat frequency value (i.e. half the corresponding time period) as is observed for the fundamental frequency, thus proving that level fluctuations are a result of beats due to slightly different rotational speeds of both propellers. From this example a difference in rotational speed of 9 rpm can be calculated from eq. (5), to be responsible for these rather significant level fluctuations.

Similar effects can be observed from the Fokker 50 flyovers. An example is given in Fig. 11 for the fundamental frequency only, because no harmonic emerges from the background noise floor. In this case a difference in rotational speed between both propellers of 3 rpm is determined.

6.3 Narrowband spectra

As is obvious from the level time-traces presented in the preceding paragraph, the results of narrowband spectral analysis will heavily depend on the instant in flyover time selected. To first demonstrate the variety of spectral characteristics occurring during one flyover event, to further determine the relevant (Doppler-shifted) values of the fundamental frequency and to thus attempt a correlation of the flyover signatures with noise emission time (radiation angle), narrowband spectra (bandwidth Δf = 3.125 Hz) were obtained at numerous instances in time for each of the flyovers of the Metro III and the Fokker 50.

For this purpose it was felt to be sufficiently accurate to obtain single sample spectra, manually released and correlated with flyover time by eye-tracing of a simultaneously created

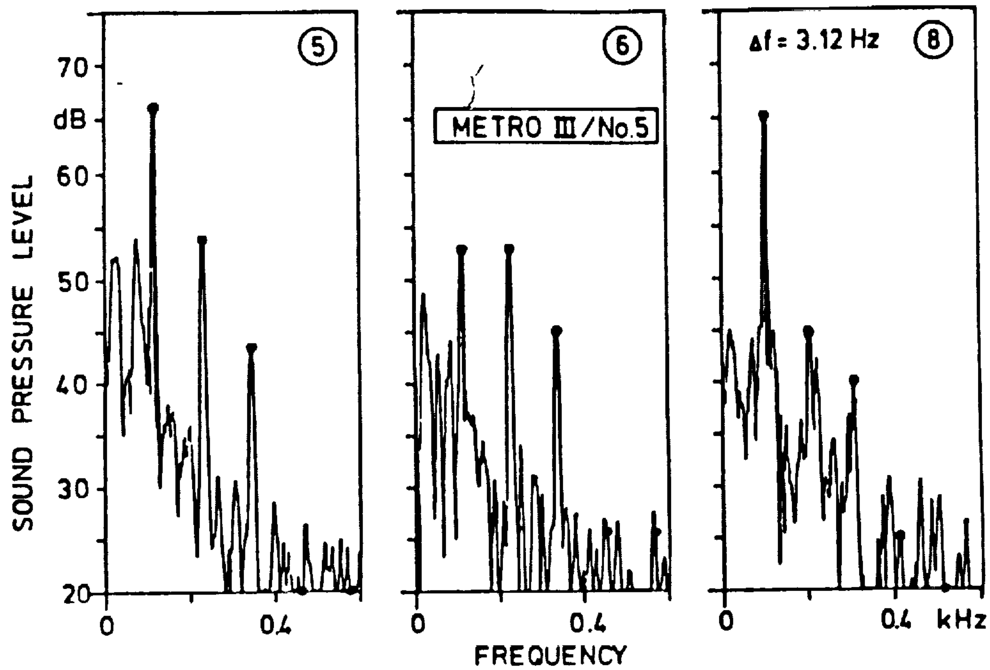

Fig. 12 Narrowband frequency spectra at different instances in time for Metro III flyover No. 5

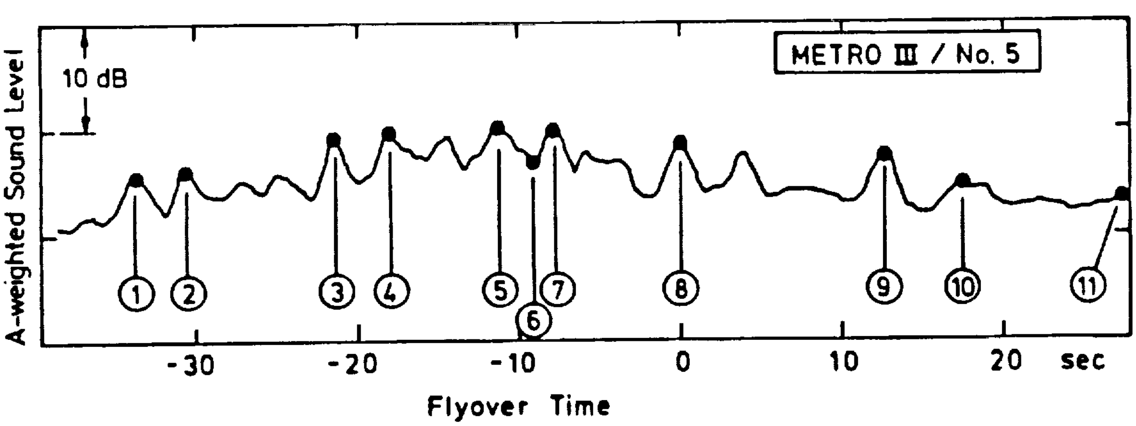

Fig. 13 Overall A-sound level time history of Metro III flyover No. 5 indicating 11 instances in time where narrowband spectral analysis was performed

plot of the respective overall level time history. Fig. 12 presents examples of narrowband spectra as obtained in the course of that procedure for the Metro III flyover No. 5, indicating a seemingly chaotic variation of propeller harmonic levels for different instances in time. Respective times - corresponding to all samples taken - are indicated in the overall level trace as presented in Fig. 13 (in the spectra of Fig. 12 reference is made to corresponding sample numbers of Fig. 13).

From every spectrum the instantaneous value of the fundamental frequency is obtained. Its variation with time can therefore be checked against the calculated Doppler-shift in frequency. From basic principles, a frequency shift with flyover time is due to the relative motion of a source with respect to the observer and is determined according to

$$(6) \qquad f(t) = f_o/(1-M \cos\theta)$$

with the elevation angle

$$(7) \qquad \theta = 180 \text{ deg} - \text{arcctg}\,(v \cdot t/H).$$

In eq. (7) "negative times" pertain to noise radiated from the aircraft in approach, time t is zero for noise radiated from overhead and "positive times" pertains to noise radiated during departure.

Since the value of the Mach number M in eq. (6) is determined from the relative speed of the aircraft with respect to the measuring microphone, the effects of wind speed and -direction at the flight height must be accounted for. From the meteorological data-records the wind direction can be determined as near zero degrees (i.e. from north) and its average magnitude to be approximately 4 m/s. Since flight No. 5 was conducted from north to south, the aircraft's speed over ground is obtained by summing up both IAS (see Fig. 3) and wind speed to end up with a value of 122.3 m/s. To finally determine the corresponding Mach number the speed of sound needs to be approximated. In order to reduce

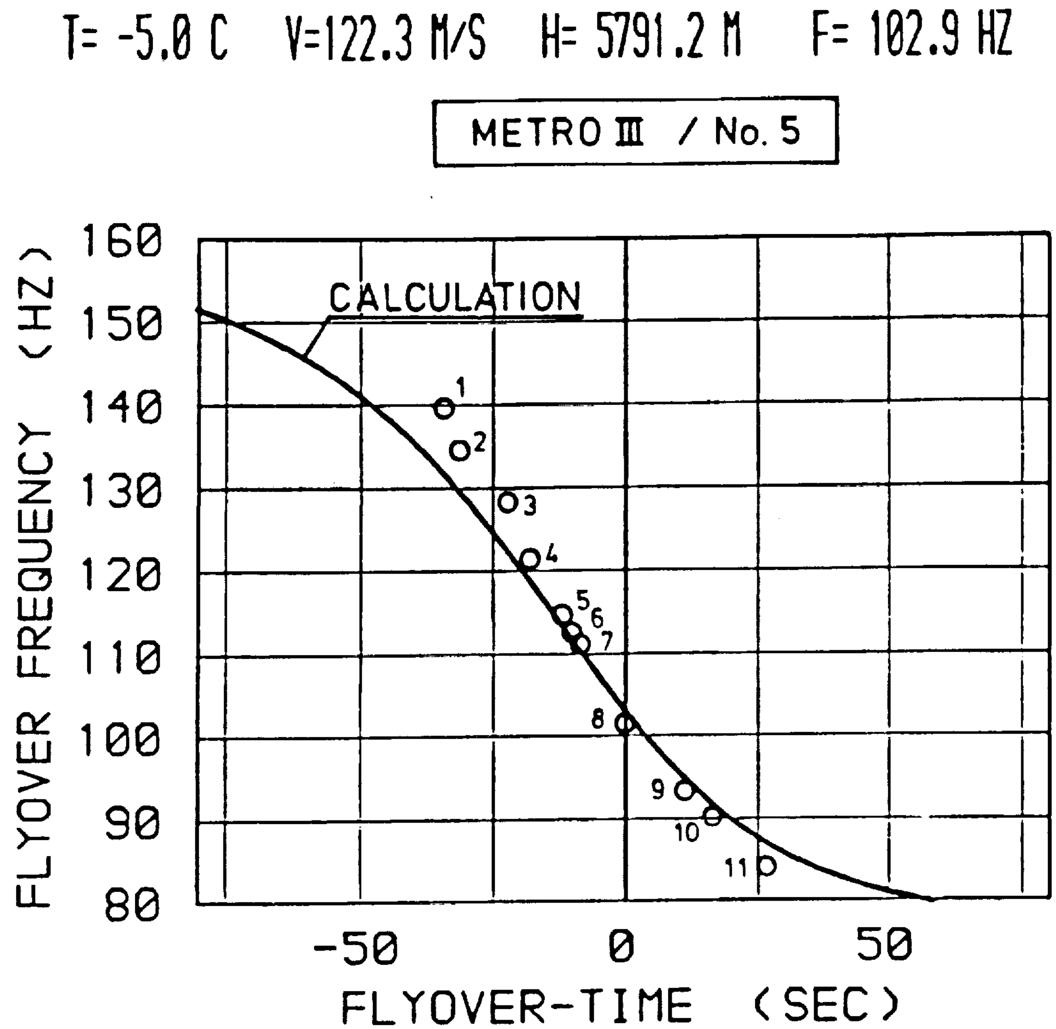

Fig. 14 Comparison of measured and calculated Doppler-shift in blade passing frequency versus time for the Metro III flyover No. 5

calculation efforts for the purpose of this rather qualitative analysis an average speed of sound was determined to correspond to an average (from ground level to flight height) air-temperature of -5°C.

Following this argumentation and using eqs. (6) and (7), the calculated frequency variation is plotted in Fig. 14 versus noise emission time. The correlation of that time-scale with measured level time histories can now be obtained by time-shifting the measured data points (frequency values) to yield a best fit between calculated and measured curves. From this procedure (which however assumes flight- and propeller rotational speed to be correctly measured) the absolute time scale had been determined as indicated on the abszissa of Fig. 13. That figure now indicates that maximum noise levels are emitted for the aircraft in approach.

The same type of analysis was conducted for the Fokker 50 flyover No. 10 (again with direction from North to South) yielding similar results, as presented in Figs. 15 and 16.

Finally some narrowband analyses were performed to check on the reason of the overall level difference of about 7 dB for the two Fokker 50 flyovers at 19000 ft height (No. 9 and No. 10). Fig. 17 presents spectra which pertain to approximately corresponding maxima and minima of level time-traces from flyovers No. 9 and No. 10. The observed difference in overall levels is dominated by level differences at the fundamental frequency. Since no contribution of extraneous noise sources can be detected from the spectra, no explanation other than strong atmospheric effects on noise transmission can be offered as a reason for this significant level difference.

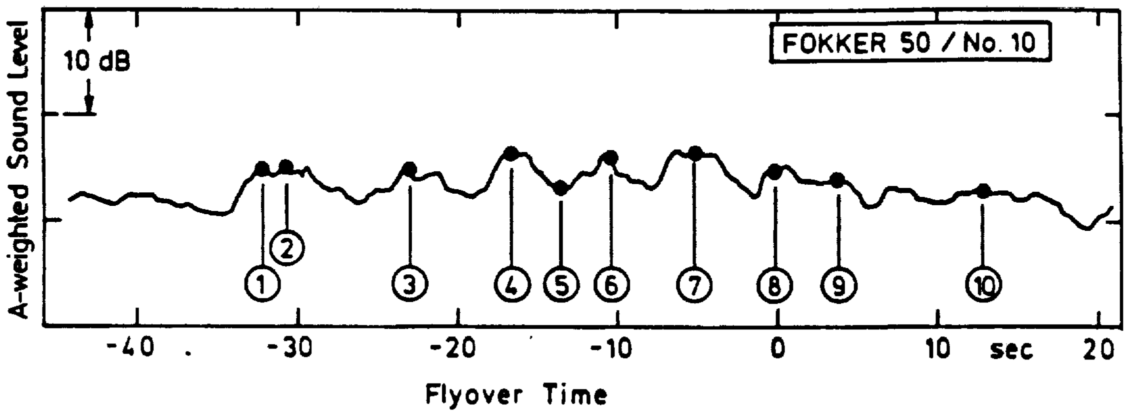

Fig. 15 Overall A-sound level time history of Fokker 50 flyover No. 10 indicating 10 instances in time where narrowband spectral analysis was performed

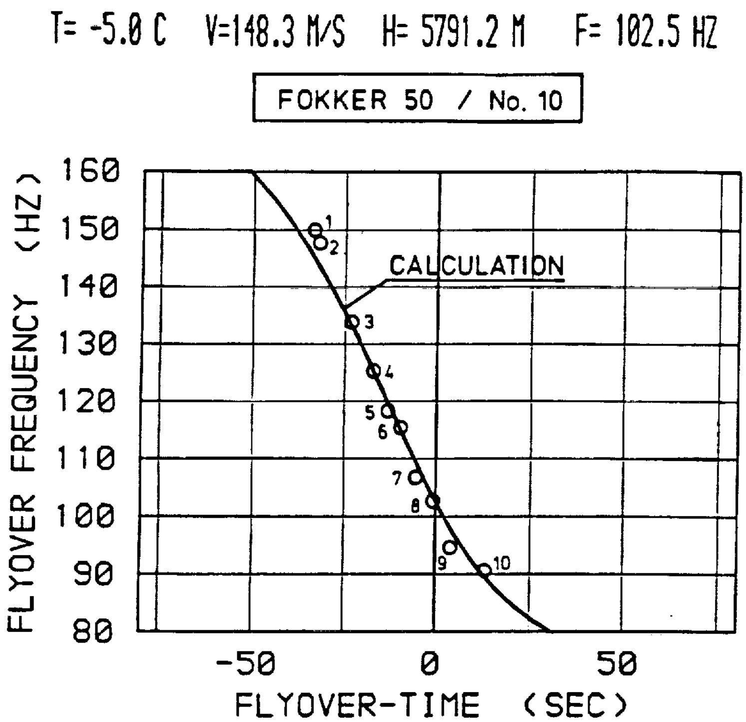

Fig. 16 Comparison of measured and calculated Doppler-shift in blade-passing frequency versus time for the Fokker 50 flyover No. 10

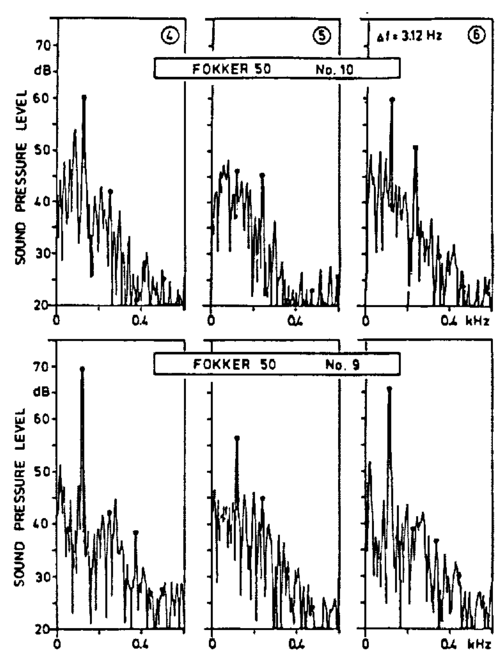

Fig. 17 Comparison of narrowband spectra at different instances in time for Fokker 50 flyover No. 10 (upper row) with spectra taken at corresponding times but for flyover No. 9 (lower row) at the identical flyover height

7. Conclusions

Since this report is thought as an initial contribution to a reference data base which will allow judgment of the extent of annoyance caused by propfan powered aircraft, no final conclusions should yet be drawn from the results. However, two observations should be emphasized which are thought as typical for propeller powered aircraft noise immission:

- First, the propeller rotational noise fundamental (at a frequency of about 102 Hz) dominates the overall en-route noise level and thus yields an "attenuation" of almost 18 dB due to the A-weighting. This might be considered a problem since the A-weighting function is suspected to not correctly simulate the human noise perception at low frequencies.

- Second, noise beats were found to cause periodic A-sound level fluctuations in the order of 5 dB, due to inadequate or altogether missing synchronization of propeller rotational speeds. Such effects are felt to represent an additional annoyance factor and efforts should therefore be undertaken to solve this problem for future propfan powered aircraft.

8. Summary

Increasing complaints about aircraft en route noise shows the necessity to judge en route noise characteristics of advanced propfan powered aircraft. Such new type aircraft are expected to be in service within the next few years. For this purpose an extensive data base on en route noise levels of conventional turboprop aircraft is needed. Respective measurements have been undertaken on two twin-engine turboprop aircraft at different flight heights. Noise data are presented together with operational parameters and meteorological data. No noise level correction has been performed with respect to environmental parameters influencing noise generation and transmission through the atmosphere. Data analysis is performed in terms of overall linear and

A-weighted noise level time histories. Corresponding level maxima are listed for two microphone arrangements, i.e. using a ground board and a 1.2 m pole. Examples of narrowband spectral analyses are presented to demonstrate the characteristic features of noise signatures, namely the dominance of the low frequency propeller rotational noise fundamental and the occurrence of noise beats due to different rotational speeds of the two propellers. This latter effect causes periodic A-sound level fluctuations of up to 5 dB.

9. Acknowledgment

The measurement campaign was initiated by Herr Held, Noise Abatement Commissioner of the Hessian Minister for Economics and Technology at Frankfurt Airport , and funded by the Flughafen Frankfurt Main AG . Herr Held perfectly organized the cooperation between the Hessisches Landesamt für Umwelt , Deutscher Wetterdienst and the aircraft flight crews. The permission given to DLR to take noise data at the same time is highly appreciated.

10. References

[1] Dobrzynski, W. Interferenzwirkungen durch Bodenreflexionseffekte bei Fluglärmmessungen an Propellerflugzeugen. DFVLR-FB 81-28, 1981. Ground Reflection Effects in Measuring Propeller Aircraft Flyover Noise. Techn. Transl. ESA-TT 742, 1982.

[2] Dobrzynski, W., Heller, H., Powers, J., Densmore, J. DFVLR/FAA Propeller Noise Tests in the German-Dutch Wind Tunnel DNW. (6 Appendices) DFVLR-IB 129-86/3, 1986 FAA Report No. AEE 86-3, 1986.

A P P E N D I X   I

Detailed listing of

meteorological data versus height

Griessheim 30.04.89 02.10 mesz Nr.

Richtung u. Geschw.geglaettet

Punkt	Zeit	DDD/Gr.	FF/m/s	Hoehe-mi	Hoehe-abs
0	0.00	20	1.0	0	0
1	0.20	23	2.7	27	54
2	0.40	31	5.0	75	96
3	1.00	34	6.4	119	143
4	1.20	40	6.5	170	198
5	1.40	49	6.0	219	241
6	2.00	56	5.4	261	282
7	2.20	63	5.0	302	322
8	2.40	76	5.1	344	366
9	3.00	73	5.4	386	407
10	3.20	74	5.5	428	450
11	4.00	75	5.3	490	531
12	4.20	76	5.2	552	573
13	4.40	74	5.2	594	616
14	5.00	72	5.6	637	659
15	5.20	70	6.1	680	701
16	5.40	70	6.2	722	744
17	6.00	69	6.0	761	779
18	6.20	68	6.1	800	821
19	6.40	68	6.1	843	866
20	7.00	69	6.0	884	902
21	7.20	69	6.0	923	945
22	7.40	68	5.8	965	986
23	8.00	66	5.5	1008	1030
24	8.20	63	5.1	1051	1073
25	8.40	62	4.6	1094	1115
26	9.00	60	4.2	1136	1158
27	9.20	57	4.0	1177	1197
28	9.40	56	3.9	1221	1246
29	10.00	54	3.6	1266	1287
30	10.20	52	3.5	1308	1329
31	10.40	52	3.8	1352	1375
32	11.00	51	3.6	1396	1417
33	11.20	48	3.5	1441	1466
34	11.40	40	3.6	1488	1510
35	12.00	33	3.9	1535	1561
36	12.20	33	4.2	1582	1603
37	12.40	34	4.3	1627	1652
38	13.00	32	4.6	1671	1691
39	13.20	31	5.1	1714	1737
40	13.40	31	5.6	1762	1788
41	14.00	29	5.7	1811	1835
42	14.20	26	5.7	1857	1880
43	14.40	24	5.9	1904	1928
44	15.00	23	6.2	1952	1977
45	15.20	19	6.5	2002	2027
46	15.40	13	6.8	2049	2072
47	16.00	9	7.0	2096	2121
48	16.20	5	7.1	2145	2169
49	16.40	2	7.2	2193	2217
50	17.00	357	7.4	2242	2268
51	17.20	354	7.6	2291	2315
52	17.40	352	7.5	2342	2370
53	18.00	350	7.7	2394	2418
54	18.20	350	7.8	2442	2467
55	18.40	353	7.6	2490	2513
56	19.00	358	7.8	2538	2563
57	19.20	6	8.6	2586	2609

Punkt	Zeit	DDD/Gr.	FF/m/s	Hoehe-mi	Hoehe-abs
58	19.40	10	8.8	2627	2645
59	20.00	13	7.9	2665	2685
60	20.20	18	6.6	2706	2727
61	20.40	19	5.7	2745	2764
62	21.00	19	5.2	2784	2805
63	21.20	19	5.1	2825	2845
64	21.40	20	5.6	2865	2886
65	22.00	24	6.5	2910	2934
66	22.20	30	7.4	2958	2982
67	22.40	36	7.9	3004	3026
68	23.00	39	8.1	3051	3077
69	23.20	36	8.3	3099	3122
70	23.40	28	7.9	3147	3172
71	24.00	19	7.3	3197	3222
72	24.20	8	6.5	3247	3272
73	24.40	5	5.2	3294	3316
74	25.00	12	4.1	3340	3365
75	25.20	15	3.4	3386	3407
76	25.40	15	3.5	3432	3457
77	26.00	15	4.0	3482	3507
78	26.20	14	4.5	3527	3547
79	26.40	16	5.1	3571	3596
80	27.00	16	5.6	3619	3643
81	27.20	16	5.9	3664	3686
82	27.40	19	5.8	3707	3729
83	28.00	20	5.5	3753	3777
84	28.20	16	5.2	3801	3826
85	28.40	13	5.0	3848	3871
86	29.00	16	6.0	3895	3920
87	29.20	18	6.6	3960	4001
88	29.40	17	4.9	4019	4038
89	30.00	15	3.7	4072	4107
90	30.20	9	3.8	4133	4159
91	30.40	359	4.0	4183	4208
92	31.00	356	4.0	4230	4253
93	31.20	7	3.8	4278	4303
94	31.40	13	3.8	4327	4351
95	32.00	6	3.8	4373	4395
96	32.20	1	4.0	4417	4440
97	32.40	353	4.3	4467	4494
98	33.00	346	4.5	4514	4535
99	33.20	345	4.5	4557	4579
100	33.40	344	4.5	4602	4625
101	34.00	345	3.9	4648	4671
102	34.20	345	3.0	4692	4714
103	34.40	341	2.5	4742	4771
104	35.00	341	2.5	4790	4810
105	35.20	348	2.6	4829	4849
106	35.40	352	2.5	4871	4893
107	36.00	350	2.4	4922	4951
108	36.20	358	2.5	4973	4995
109	36.40	12	2.6	5019	5043
110	37.00	22	2.7	5065	5088
111	37.20	21	2.8	5114	5141
112	37.40	15	2.9	5160	5180
113	38.00	25	3.0	5203	5227
114	38.20	39	3.2	5249	5271
115	38.40	44	3.1	5298	5325
116	39.00	49	3.0	5350	5375
117	39.20	57	3.3	5400	5425
118	39.40	55	3.6	5452	5480
119	40.00	49	3.9	5506	5533
120	40.20	48	4.1	5556	5580

121	40.40	48	4.2	5603	5627
122	41.00	48	4.1	5650	5674
123	41.20	45	4.1	5701	5728
124	41.40	44	4.3	5753	5779
125	42.00	47	4.4	5805	5831
126	42.20	50	4.5	5849	5867
127	42.40	51	4.8	5898	5929
128	43.00	51	4.4	5950	5972
129	43.20	50	4.1	6001	6031
130	43.40	48	2.8	6058	6086
131	44.00	46	3.5	6105	6124
132	44.20	41	3.8	6148	6172
133	44.40	36	4.1	6193	6214
134	45.00	36	4.1	6240	6266
135	45.20	37	3.7	6288	6310
136	45.40	41	3.7	6332	6354
137	46.00	53	4.1	6384	6414
138	46.20	65	4.3	6434	6454
139	46.40	66	4.7	6478	6502
140	47.00	65	5.2	6529	6556
141	47.20	64	5.4	6579	6602
142	47.40	61	5.5	6627	6653
143	48.00	60	5.7	6672	6691

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pkt	ppp	tt	tftf	rf	td	tddiff	h.ue.gr	dt/100m	bemerk.
1	1012.6	5.0	4.0	86	2.8	2.2	0	0.00	
2	1006.0	6.2	3.9	69	1.0	5.2	54	2.22	
3	996.0	7.1	4.2	63	0.5	6.6	136	1.10	
4	982.0	7.1	4.1	62	0.3	6.8	253	0.00	
5	975.0	7.3	4.0	59	-0.2	7.5	311	0.34	
6	960.0	6.5	3.5	61	-0.4	6.9	439	-0.63	
7	947.0	5.7	3.0	64	-0.5	6.2	550	-0.72	
8	917.0	3.8	1.1	62	-2.8	6.6	813	-0.72	
9	881.0	0.7	-0.8	76	-3.0	3.7	1136	-0.96	
10	828.0	-3.8	-4.3	91	-5.1	1.3	1631	-0.91	
11	801.0	-6.0	-6.5	90	-7.4	1.4	1892	-0.84	
12	780.0	-7.3	-7.9	87	-9.1	1.8	2100	-0.63	
13	753.0	-9.9	-9.9	100	-9.9	0.0	2373	-0.95	
14	740.0	-10.9	-10.9	100	-10.9	0.0	2508	-0.74	
15	730.0	-11.9	-12.0	98	-12.2	0.3	2612	-0.96	
16	721.0	-11.0	-12.4	57	-17.8	6.8	2708	0.94	eis
17	715.0	-10.0	-12.1	45	-19.8	9.8	2772	1.56	eis
18	704.0	-10.0	-12.2	43	-20.2	10.2	2892	0.00	eis
19	695.0	-10.2	-12.1	49	-18.8	8.6	2991	-0.20	eis
20	680.0	-10.7	-11.3	77	-14.0	3.3	3159	-0.30	eis
21	667.0	-11.3	-11.8	79	-14.3	3.0	3307	-0.41	eis
22	658.0	-10.0	-12.1	47	-19.1	9.1	3412	1.24	eis
23	590.0	-14.8	-15.7	64	-20.1	5.3	4245	-0.58	eis

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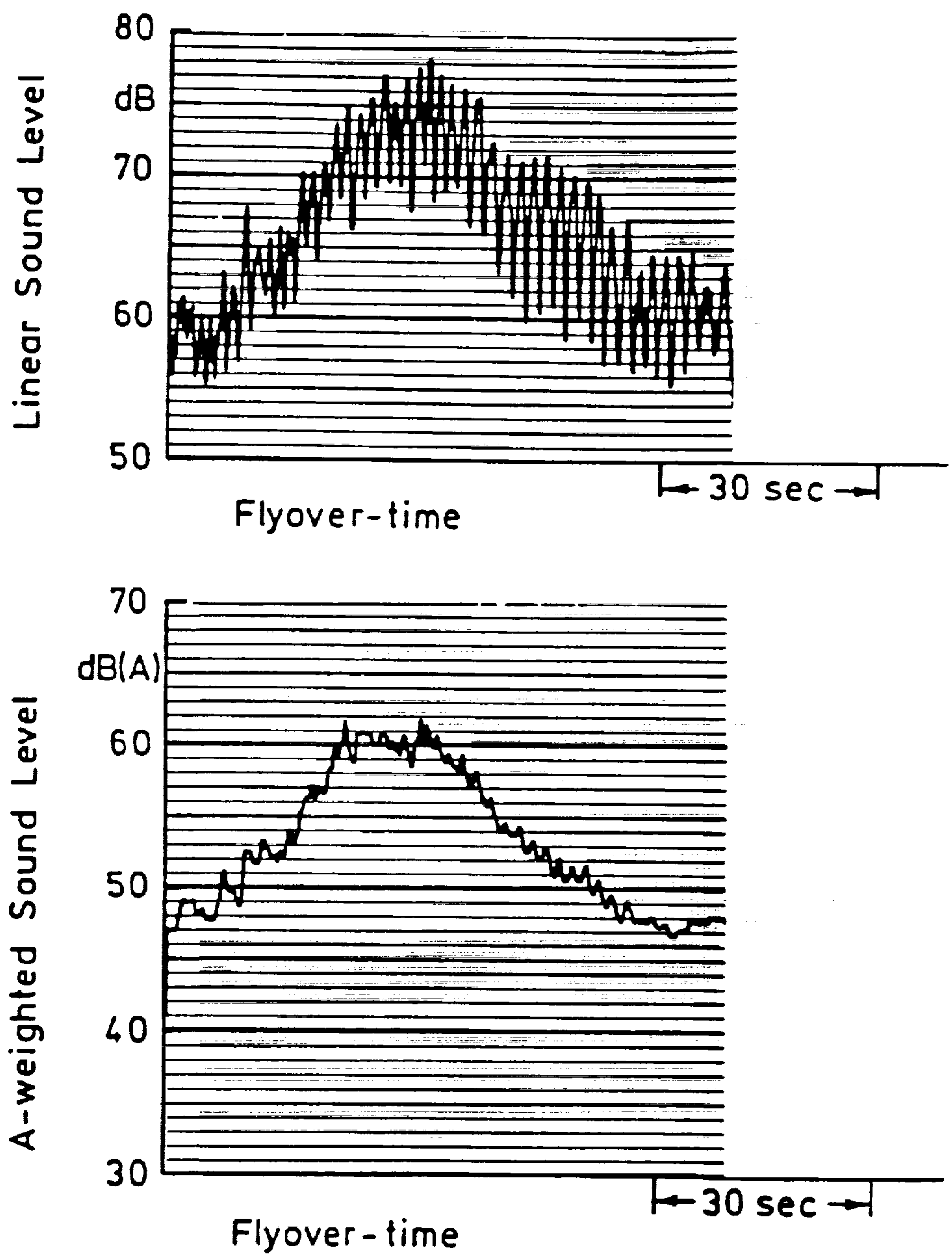
APPENDIX II

As measured overall noise level time histories

Type of Aircraft: Metro III Flyover No.: 1

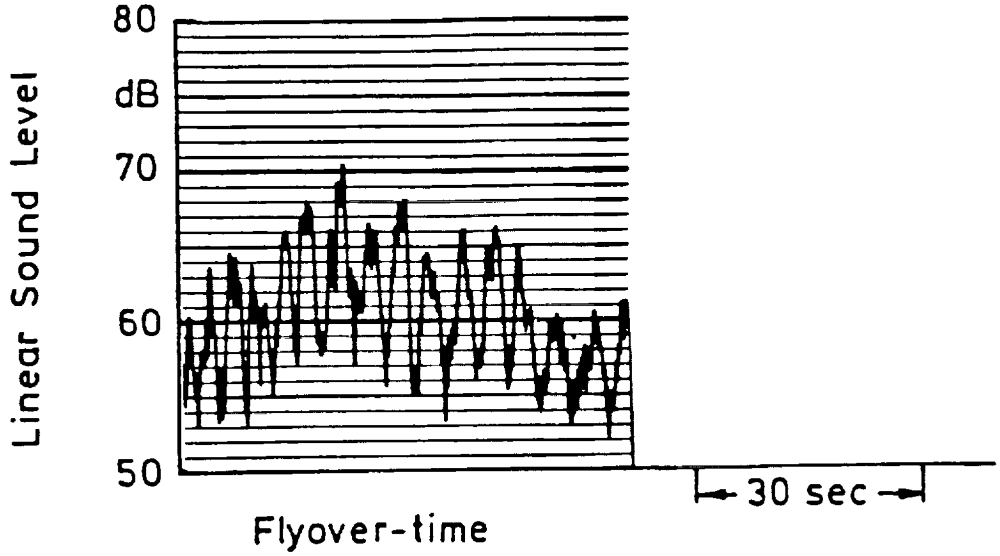
Microphone Position: Ground-board Microphone

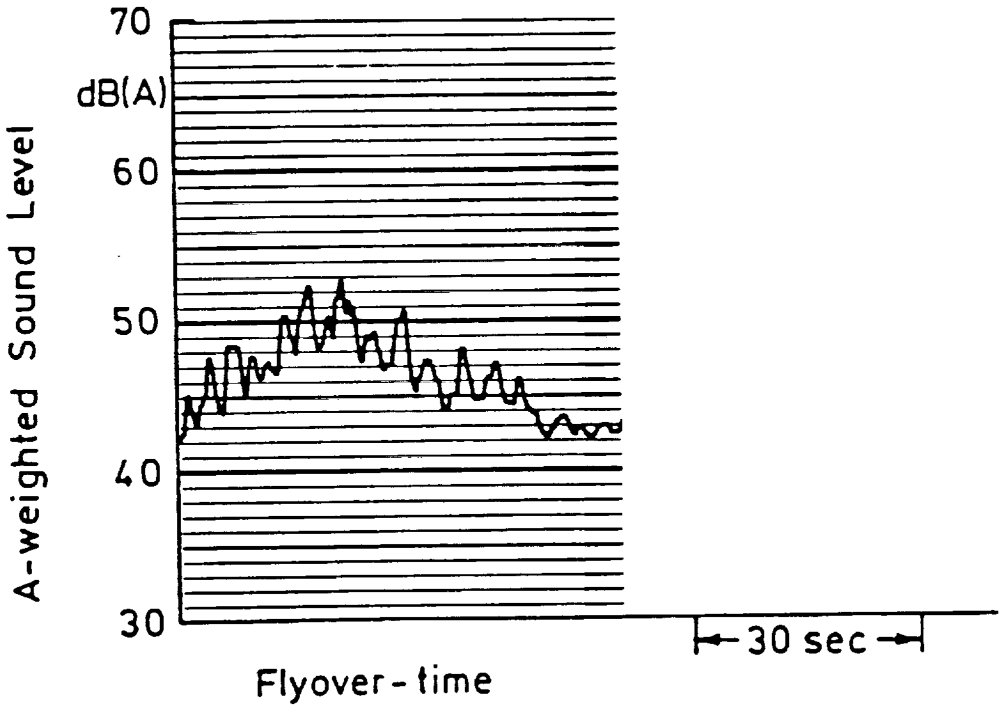


As measured overall level time-histories (Metro III climb out)

Type of Aircraft: Metro III Flyover No.: 2

Microphone Position: Ground-board Microphone

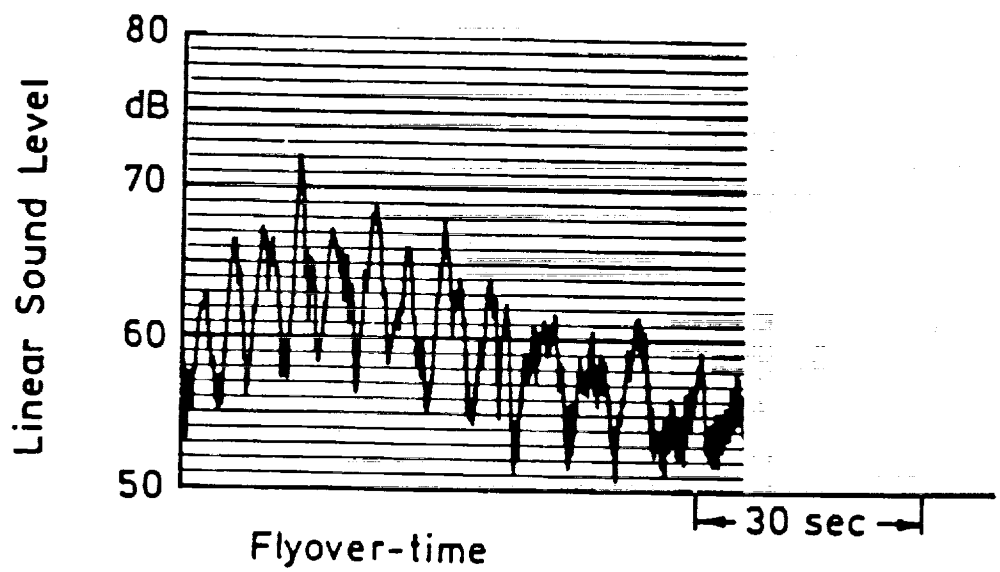


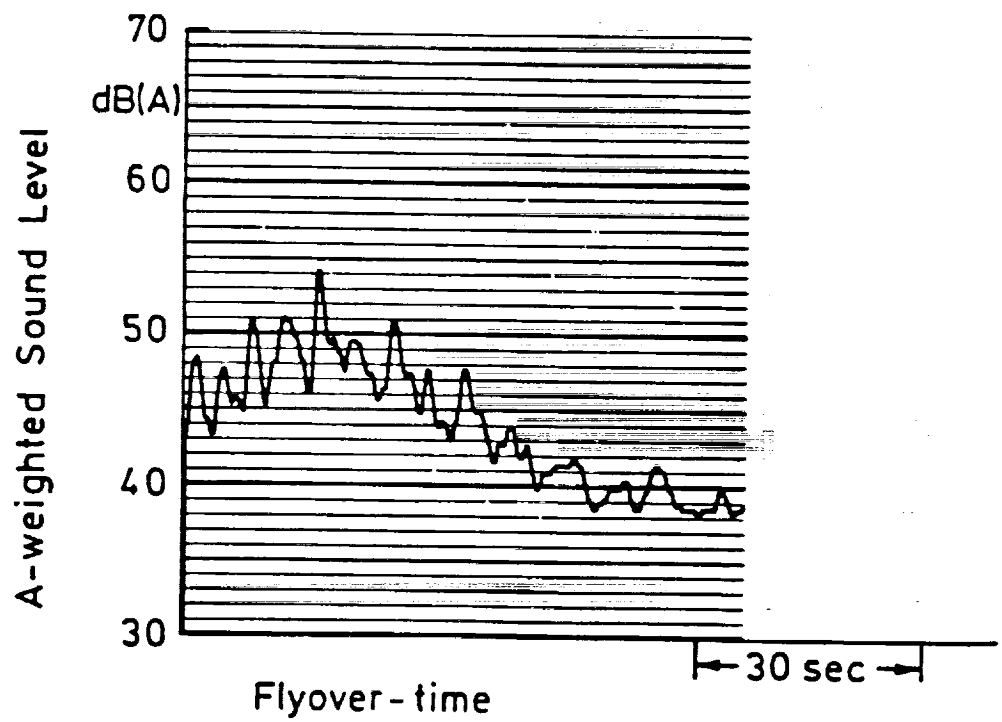


As measured overall level time-histories (Metro III/ No. 2, flight height: 17000 ft)

Type of Aircraft: Metro III Flyover No.: 3

Microphone Position: Ground-board Microphone

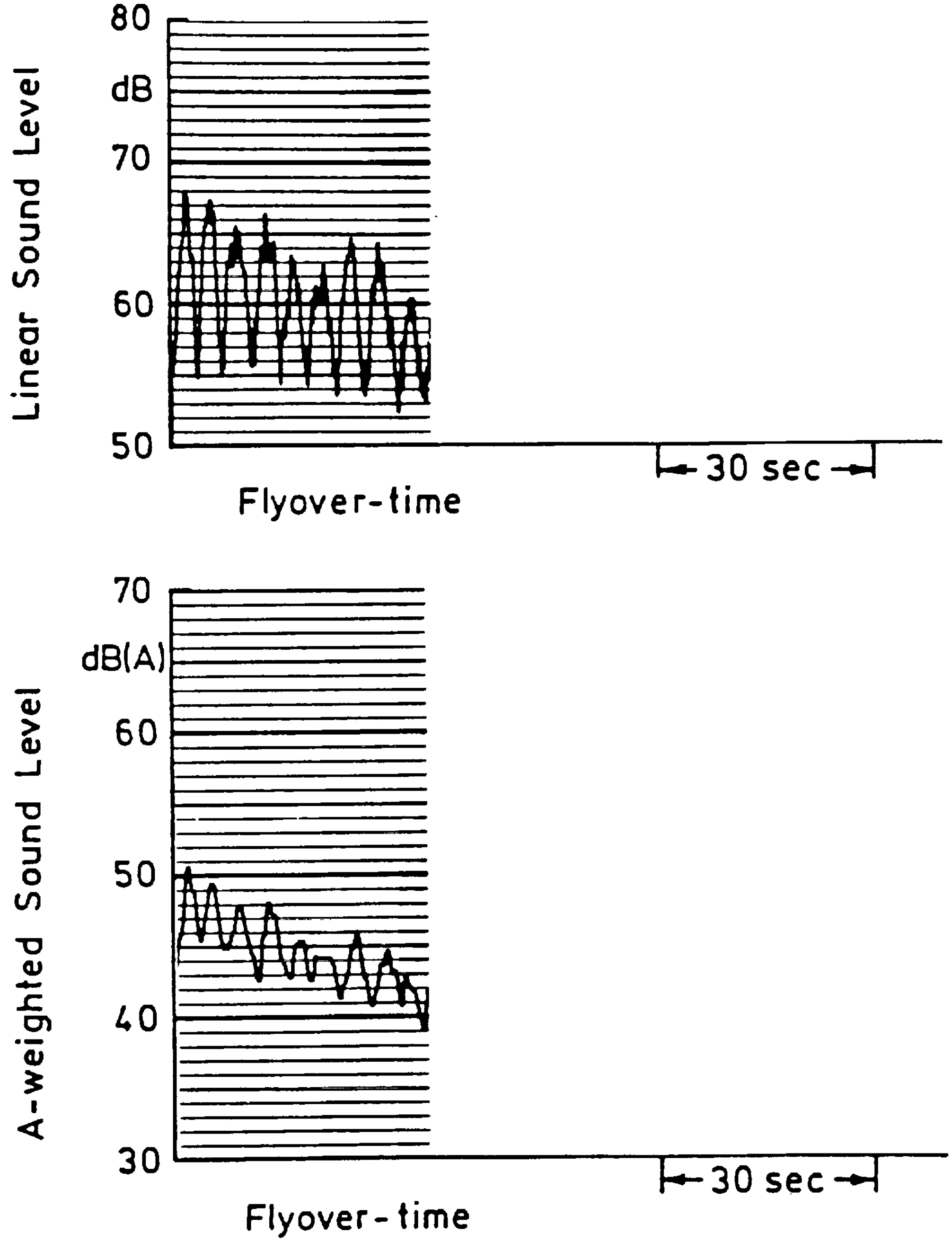




As measured overall level time-histories (Metro III/ No. 3, flight height: 17000 ft)

Type of Aircraft: Metro III Flyover No.: 4

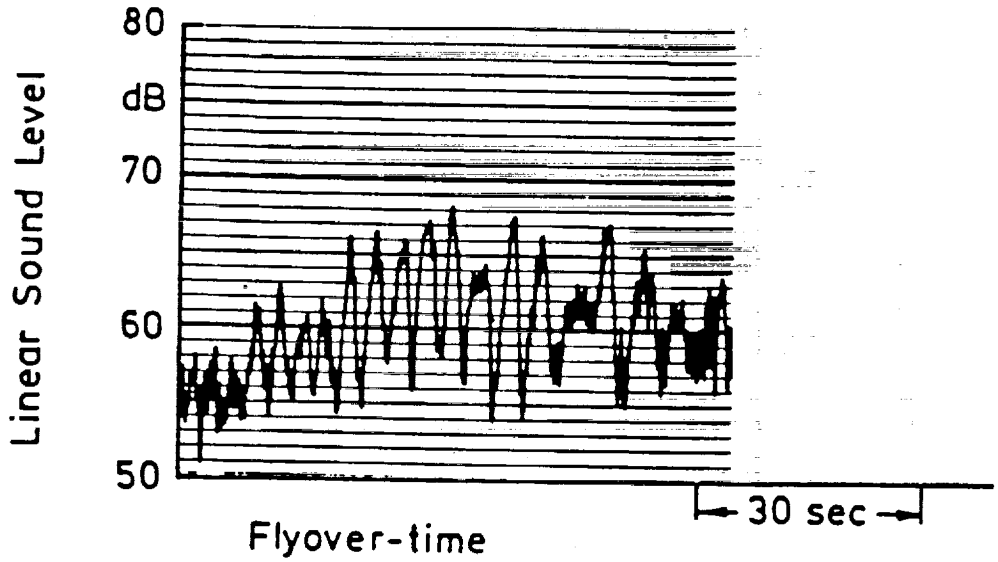
Microphone Position: Ground-board Microphone

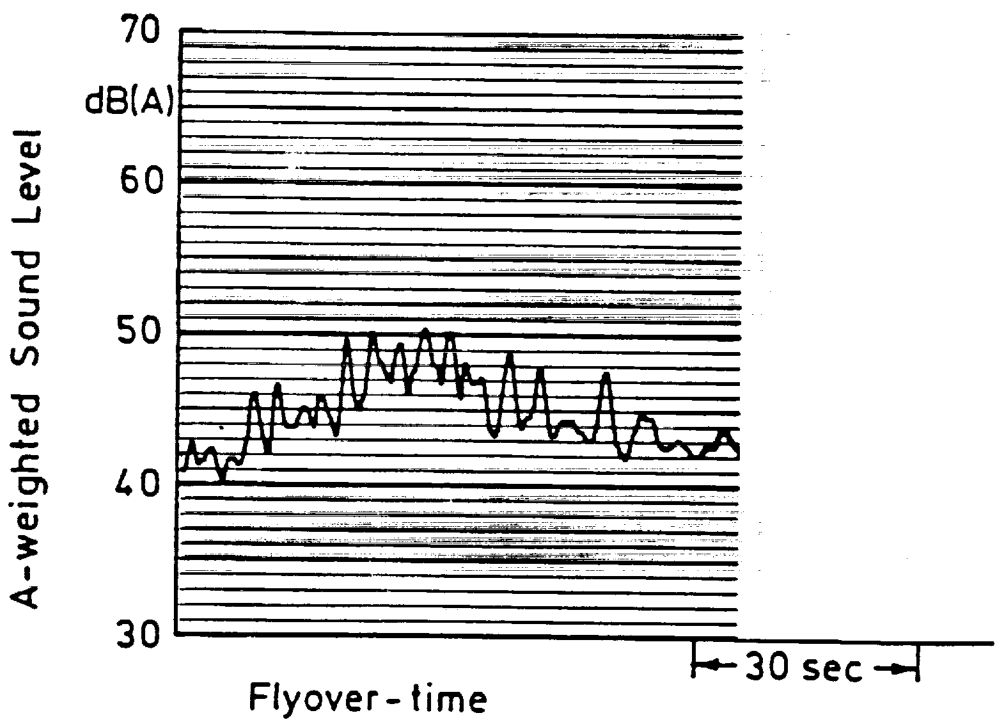


As measured overall level time-histories (Metro III/ No. 4, flight height: 19000 ft)

Type of Aircraft: Metro III   Flyover No.: 5

Microphone Position: Ground-board Microphone

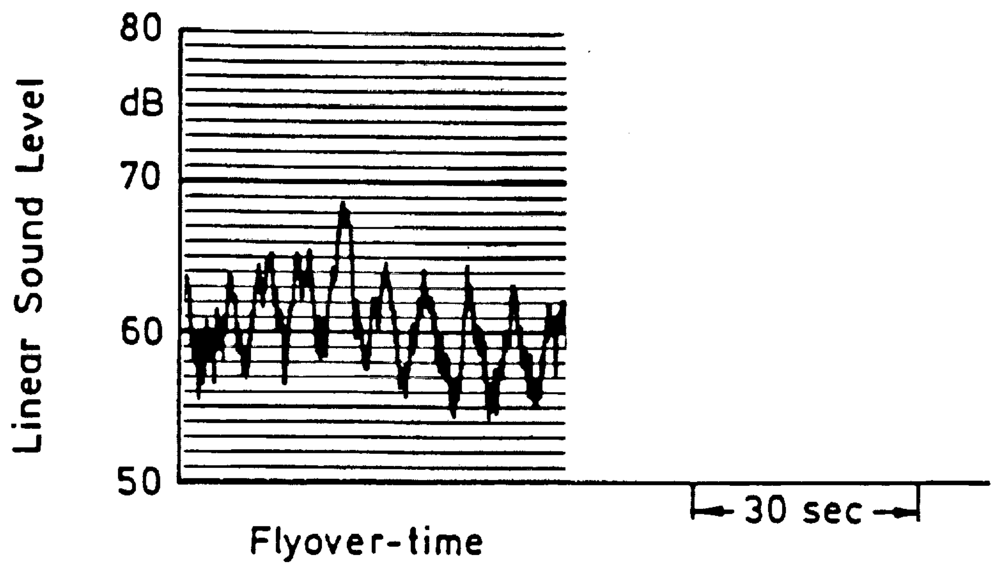


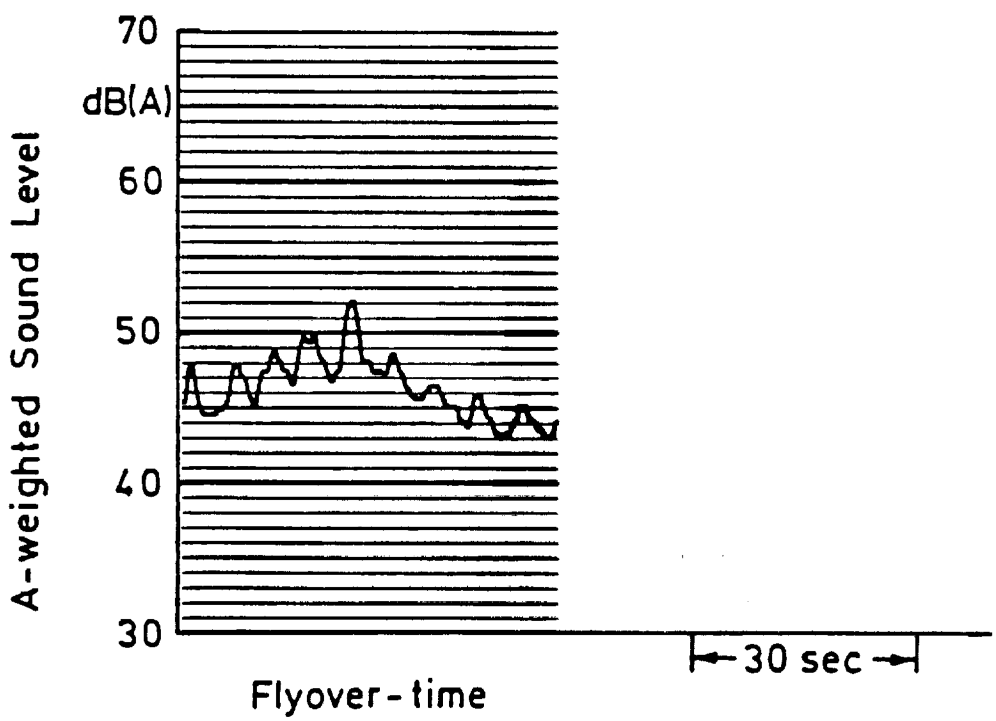


As measured overall level time-histories (Metro III/ No. 5, flight height: 19000 ft)

Type of Aircraft: Metro III Flyover No.: 6

Microphone Position: Ground-board Microphone

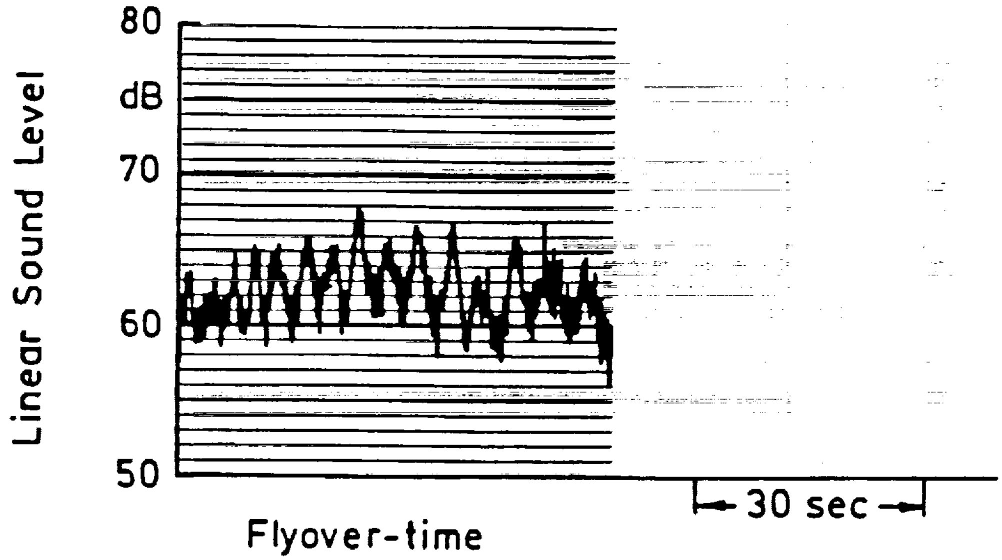


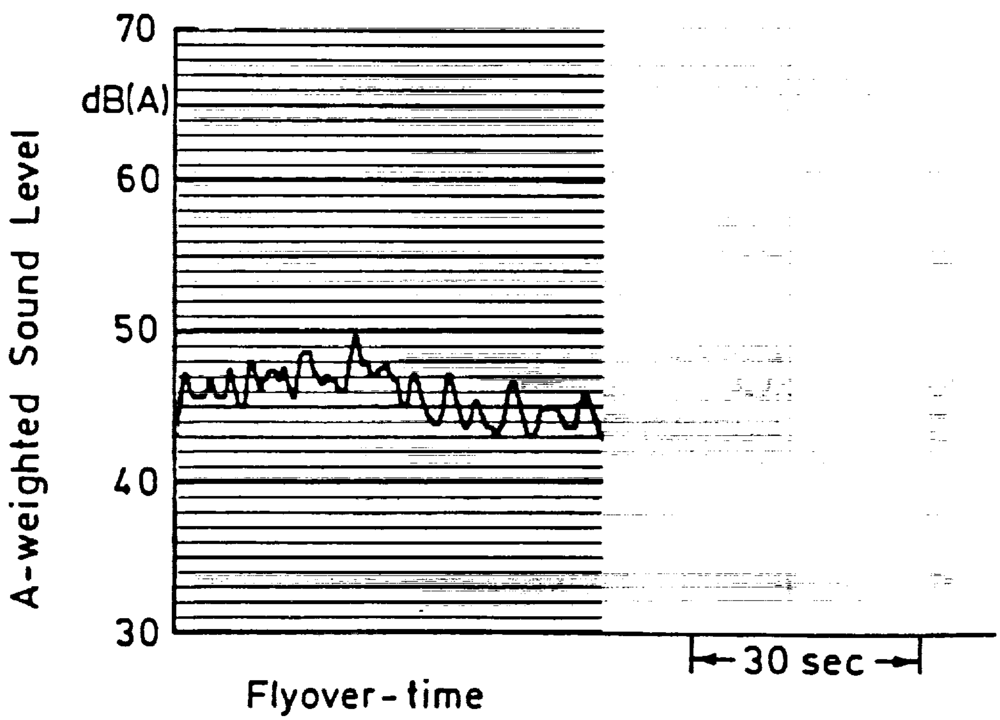


As measured overall level time-histories (Metro III/ No. 6, flight height: 21000 ft)

Type of Aircraft: Metro III   Flyover No.: 7

Microphone Position: Ground-board Microphone

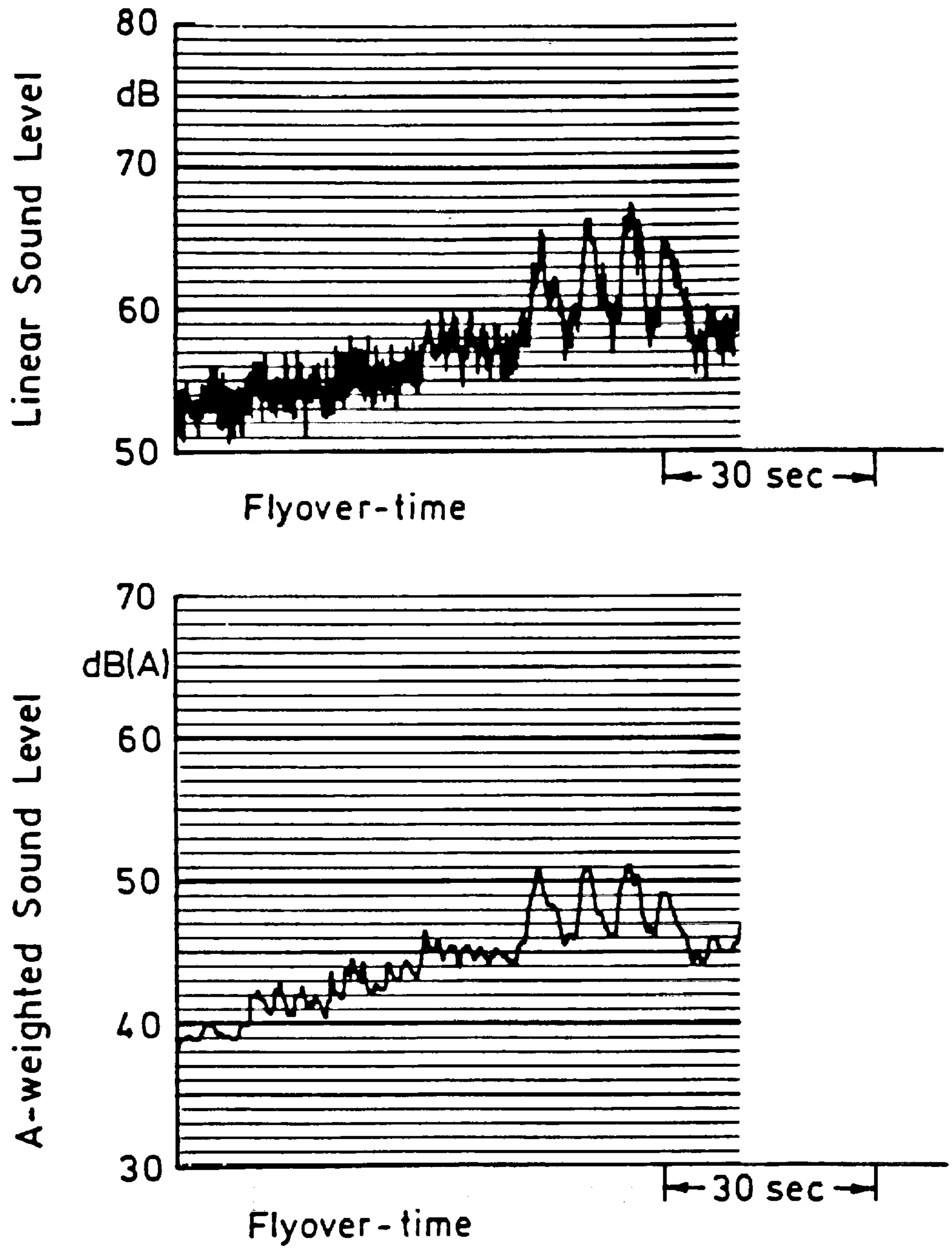




As measured overall level time-histories (Metro III/ No. 7, flight height: 21000 ft)

Type of Aircraft: Fokker 50 Flyover No.: 8

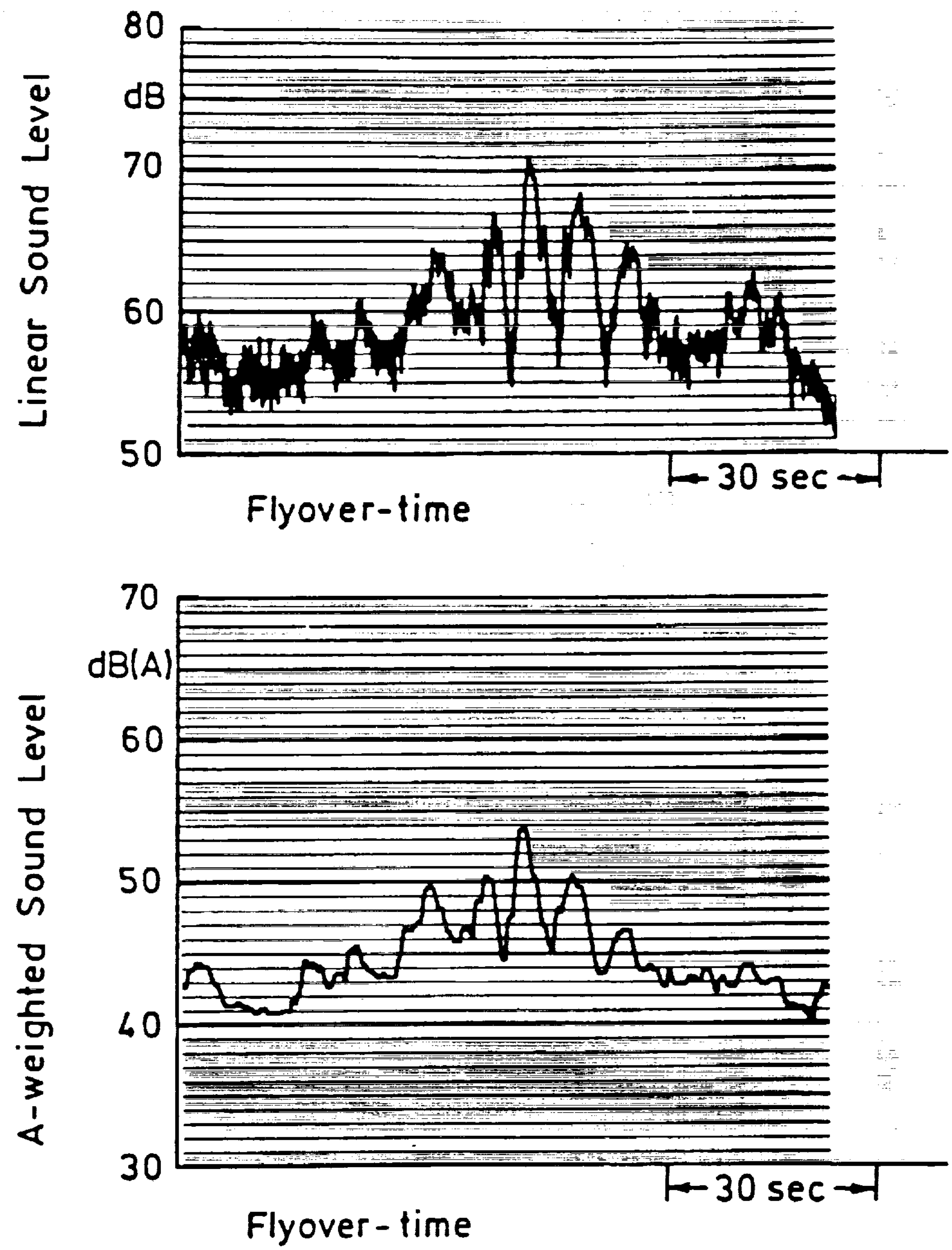
Microphone Position: Ground-board Microphone



As measured overall level time-histories (Fokker 50/ No. 8, flight height: 17000 ft)

Type of Aircraft: Fokker 50 Flyover No.: 9

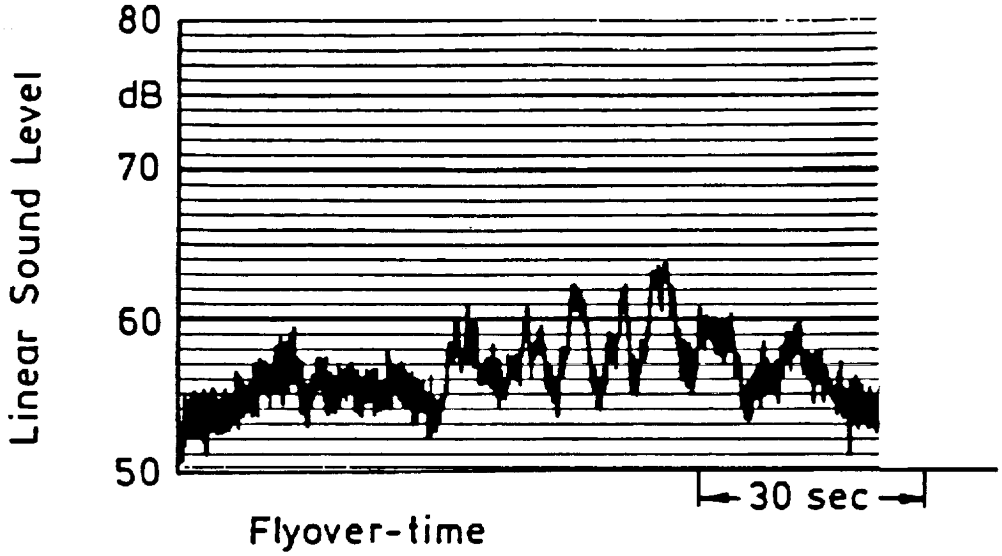
Microphone Position: Ground-board Microphone

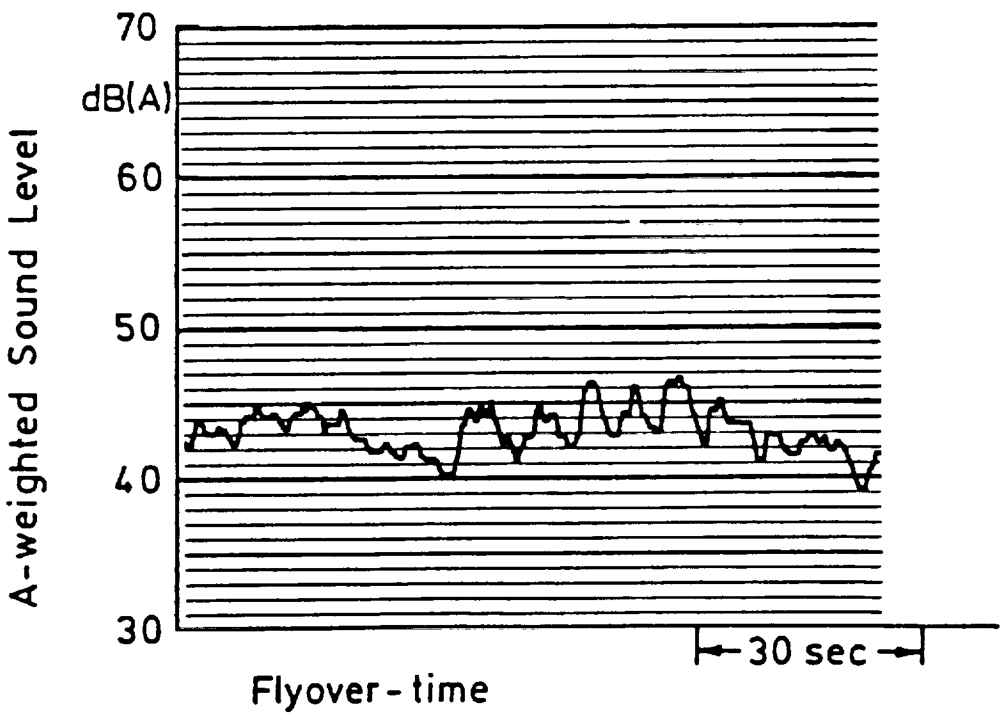


As measured overall level time-histories (Fokker 50/ No. 9, flight height: 19000 ft)

Type of Aircraft: Fokker 50 Flyover No.: 10

Microphone Position: Ground-board Microphone

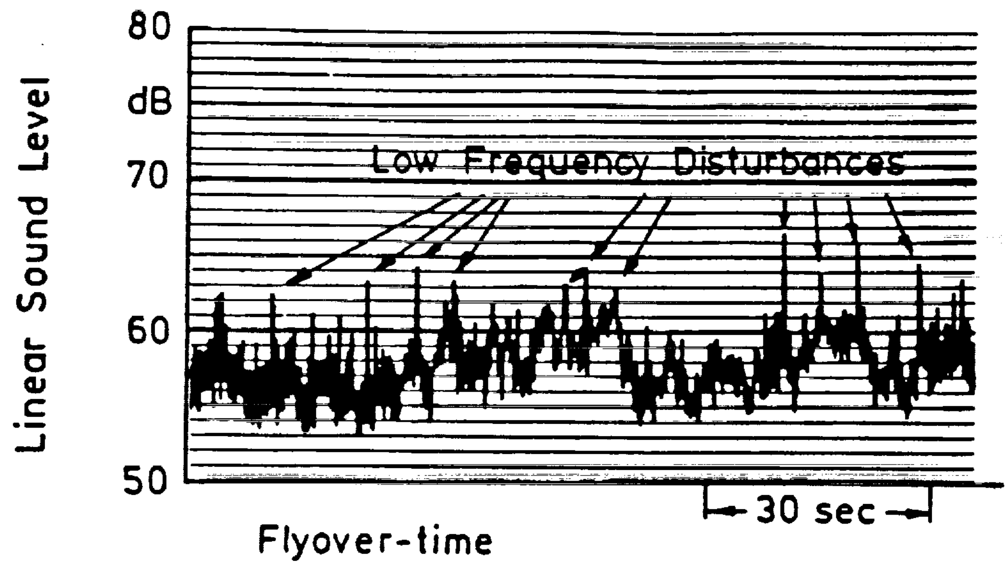


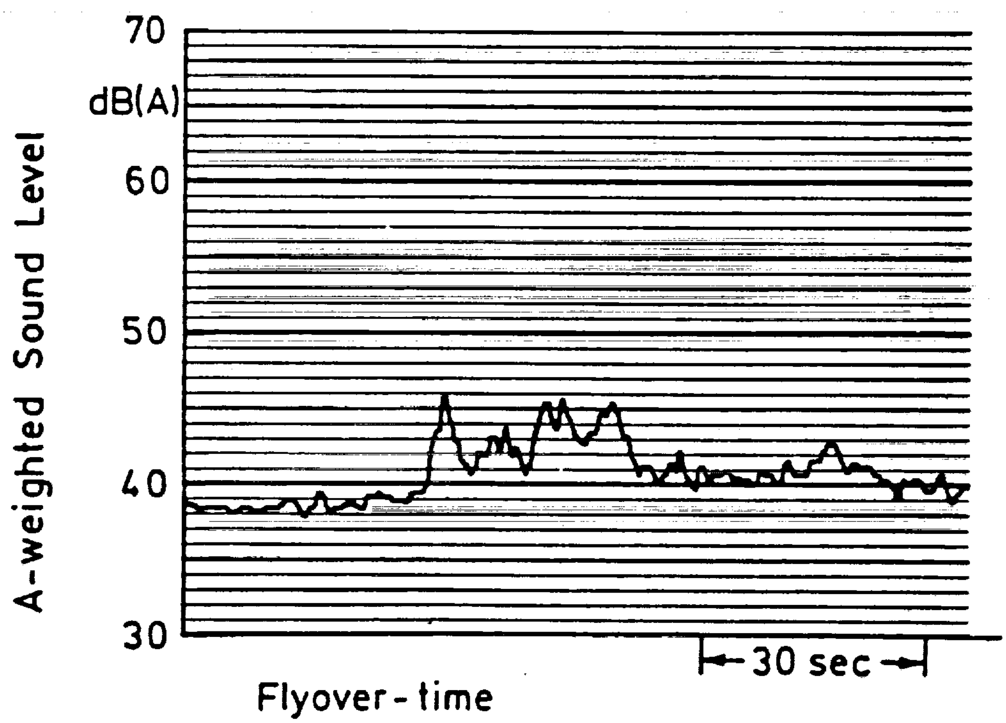


As measured overall level time-histories (Fokker 50/ No. 10, flight height: 19000 ft)

Type of Aircraft: Fokker 50 Flyover No.: 11

Microphone Position: Ground-board Microphone

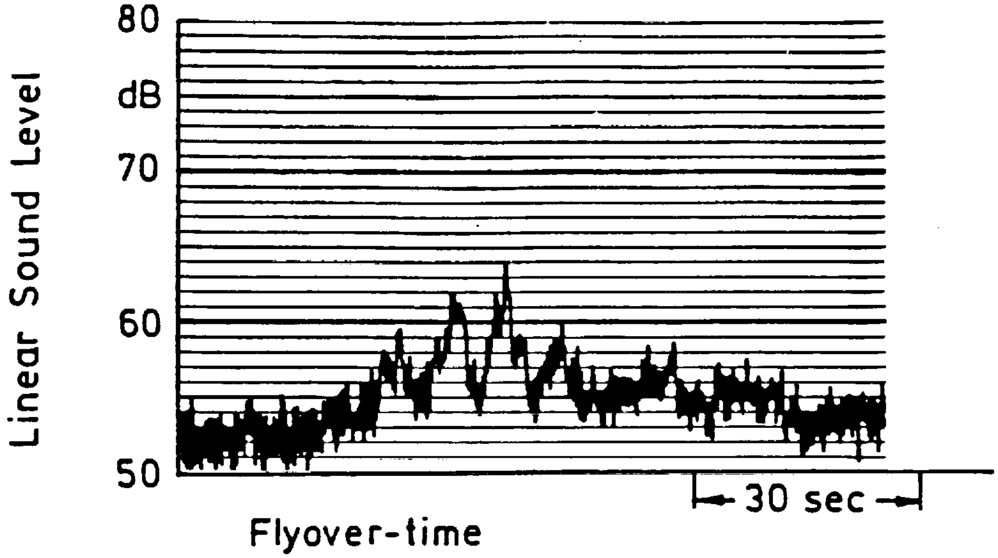


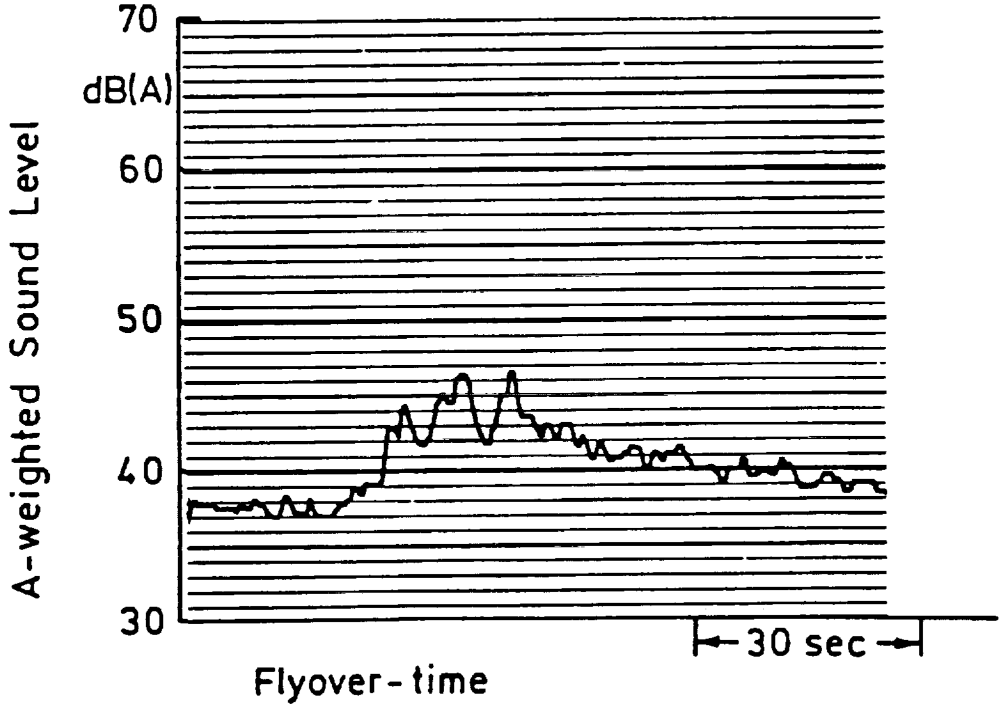


As measured overall level time-histories (Fokker 50/ No. 11, flight height: 21000 ft)

Type of Aircraft: Fokker 50 Flyover No.: 12

Microphone Position: Ground-board Microphone





As measured overall level time-histories (Fokker 50/ No. 12, flight height: 21000 ft)