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PROP-FAN NOISE PROPAGATION

Final Report

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CONTENT

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INTRODUCTION AND SUMMARY

This report summarizes studies of enroute propfan noise propagation involving noise data obtained by DOT/TSC at ground stations during fly-over tests on October 30-31, 1987. These data have been analyzed by DOT/TSC for comparison with in flight data obtained by NASA. An important question which has been raised in this context concerns the large fluctuations in the measured sound pressure level at the ground station, and this was one of the focal points in the present study.

The overall objective of the Low Frequency Propfan Noise Propagation Project at DOT/TSC is the prediction of the noise exposure on the ground caused by profans flying at altitudes of the order of 20,000-35, 000 ft at and Mach numbers 0.7-0.8. An essential aspect is then the determination of the overall sound attenuation in the atmosphere along the path from the source to the receiver on the ground.

Enroute levels of the propfan blade passage tone at the ground, measured by DOT/TSC, together with the SAE proposed standard procedure for computation of the sound attenuation has been used by DOT/TSC to predict the sound pressure level of the blade passage tone of the propfan at a cylindrical reference surface of radius 500 ft surrounding the flight path. These predicted values have been compared with experimental data obtained by NASA.

We present here an independent analysis of the sound propagation problem; the geometrical aspects of refraction are given in Section 1 and the calculation of the overall sound attenuation in the atmosphere is summarized in Section 3. The analysis of the experimental noise data and the comparison with the NASA data is dealt with in Section 4, and a review of the meteorological conditions is given in Section 2. Section 5 contains a discussion of the the problem of fluctuations in the sound pressure level measured at the ground station, and, finally, Section 6 contains the computer programs used in the analysis.

The following may serve as a brief summary of the observations made in this report.

- **Refraction and Shadow formation.** Due to the gradients of temperature and wind in the atmosphere and the related refraction of sound, acoustic rays emitted only within a certain angular range will reach ground; outside this range the ground observer will be in an acoustic geometric shadow (Figs. 1.1 and 1.2). For example for a source at an altitude of 35,000 ft and a Mach number of 0.8, the range of emission angles is approximately 30-150 degrees (corresponding view angle range is approximately 60-170).

However, the background noise on the ground typically limits the relevant range of emission angles to roughly 60-120 for measurements of the propfan blade passage tone with a broad band receiver, and shadow formation is then of academic interest only. Actually, in this angular range, the effect of the curvature of the acoustic paths due to refraction is small under normal weather conditions, as illustrated in Fig. 3.4.

With proper filtering, the angular range can be extended, of course, and if good data can be obtained at angles down to the region 30-50 degrees, refraction must be accounted for. Below 30 degrees, shadow formation is to be expected, and good data will be difficult (if not impossible) to get even with narrow band filtering.

- **Altitude dependence of sound absorption.** The bulk of the attenuation due to sound absorption in the air occurs below 7000 m with a pronounced peak at an altitude of approximately 5000 m (Fig. 3.1). As a result, the corresponding total attenuation along the path from the source to the receiver on the ground will be essentially the same for source altitudes of 35,000 ft and 20,000 ft. The difference between the *total* attenuation in these two cases, ($\approx$ 7.5 dB, see Fig. 3.5) is then due solely to spherical divergence and the variation of wave impedance with altitude (Fig. 3.4).

- **Ground reflection.** The reflector plate at the ground station has a diameter of only 40 cm which is approximately 3 times smaller than the average wavelength. Then, unless the surrounding ground has a very high acoustic impedance, it appears that diffraction effects would be significant and that the correction to the measured sound level due to reflection will depend on the ground impedance and the angle of incident. Following DOT/TSC, we have used a reflection correction of 5 dB, independent of the angle of incidence.

- **Comparison with preliminary NASA data.** An example of the predicted noise level at the 500 ft reference cylindrical surface surrounding the flight path is given in Fig. 4.2. In that case, the range of emission angles in which the overall sound pressure level is dominated by the propfan tone (in comparison with background noise) is approximately 65-120 degrees.

- **Fluctuations.** Strong fluctuations in the received blade passage tone from the propfan are to be expected because the propeller cannot be regarded as a point source in this context; it is an *extended* sound source with a diameter which is more than twice the wavelength. Actually, the propeller can be simulated approximately by a distribution of point sources (dipoles and monopoles) along a circle with a diameter approximately equal to the propeller diameter (Fig. 5.2).

The received sound is a superposition of the contributions from these sources; the corresponding waves have travelled along different paths to the receiver, and although the separation of these paths is relatively small (a few feet), the difference in the average sound speed along these paths required to produce a relative phase shift of 180 degrees (and hence large fluctuations) is so small, of the order of 0.01 %, that it is expected to be present in a real atmosphere under all conditions.

As a result of the motion of the source (through the small inhomogeneities referred to above), temporal fluctuations of the received sound will occur even if the atmospheric characteristics are time independent.

Systematic experimental and theoretical studies of fluctuations[1,2] in short range sound propagation over ground in an inhomogenous atmosphere are consistent with the observations made here.

1. KINEMATIC RELATIONS

1.1. Real atmosphere

The 'real atmosphere' in this context refers to the atmosphere defined by the altitude dependence of temperature, wind, humidity, and pressure, as measured in conjunction with the enroute noise studies considered here. In Sections **1.2** and **1.3**, we consider for comparison, sound propagation in simplified models of the atmosphere for which closed form simple mathematical expressions for some sound field characteristics can be derived. These models can then be used as benchmarks for the extended numerical analysis of the real atmosphere.

Refraction. The temperature $T(z)$ and the wind velocity $U(z)$ in the atmosphere are assumed to depend only on the vertical coordinate z. A ray, indicating the direction of propagation of a sound wave, then remains in one and the same vertical plane from the source to the receiver on the ground. The intersection of this plane and the ground plane is chosen as the x-axis. In this report we shall consider the case when the flight path is in the plane of sound propagation, either in the positive or negative x-direction. Then, according to the DOT/TSC terminology, the corresponding noise data on the ground are the "centerline" data.

The component of the wind velocity in the x-direction is

$$U_x = U(z)\cos\Phi$$

where Φ is the angle between the wind direction and the x-axis.

We consider a sound wave emitted from the the altitude H in a direction specified by the emission angle ψ_1, as illustrated in Fig. 1. The angle between the ray and the x-axis at the altitude z is denoted by ψ and the component on the wind in the x-direction, $U_x(z)$, will be denoted by U_x, for short. Then, with c being the sound speed, and the subscript 1 signifying the value at the altitude H, the wave will be refracted in such a way that the trace velocity

$$c_t = \frac{c}{\cos\psi} + U_x = \frac{c_1}{\cos\psi_1} + U_{1x}$$

$C_T = \frac{c + U_x}{\cos\psi}$?

remains constant. Thus, the directional cosine of the ray at the altitude z is then

$$\cos\psi = \frac{(c/c_1)\cos\psi_1}{1 + M_x\cos\psi_1} \qquad (1.1)$$

where $M_x = (U_{1x} - U_x)/c_1$.

Shadow formation. Critical emission angles. As indicated in Fig. 1, a sound ray emitted at an angle below a certain critical angle ψ_c will not reach the ground so that the point of observation will lie in the (geometrical) acoustic shadow caused by the refraction.

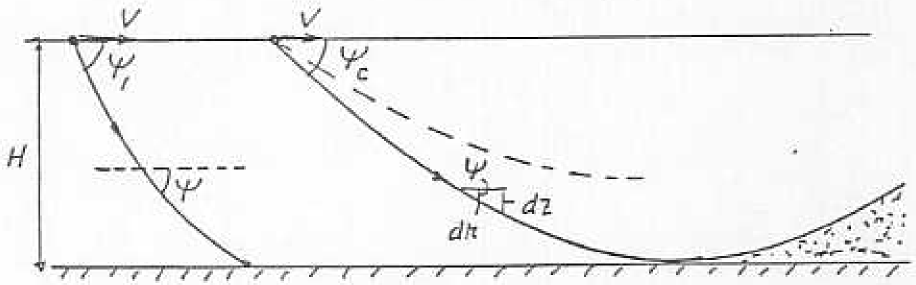


Fig. 1.1. Refraction in a temperature and wind stratified atmosphere. Shadow formation occurs below a critical angle of emission ψ_c. For a source at an altitude of 35,000 ft, this angle typically is between 25 and 30 degrees.

The critical angle ψ_c is obtained from Eq. 1 by requiring $\psi = 0$ (or $\psi = \pi$)at $z = 0$, and we obtain

$$\cos\psi_c = \frac{\pm 1}{c/c_1 \mp M_x} \tag{1.2}$$

Both c and M_x vary with altitude, and there will be a critical angle for each altitude. The largest (for $\psi_c < 90$ deg) and the smallest (for $\psi_c > 90$ deg) of these define the angular range of the shadow boundary at the ground level and are determined by the maximum values of $c/c_1 - M_x$ and $c/c_1 + M_x$, respectively. Normally, but not always, these maxima occur at the ground level.

The first of the two days of enroute noise measurements, October 30, 1987, was relatively windy, particularly during the first flight, early in the morning. With a flight direction of 0 degrees (north), the maximum of $c/c_1 - M_x$ then occurred at an altitude of 705 m with a corresponding critical angle of 24.2 degrees. The maximum of $c/c_1 + M_x$ occurred at 165 m and the related critical angle was 145.8 degrees. For the opposite flight direction (180 degrees), the corresponding values were 525 m, 33.7 degrees and 45 m, 153 degrees.

The dominant refractive effect was due to temperature. The relatively small effect of the wind caused the angular asymmetry in the shadow boundaries with respect to 90 degrees. In a windless atmosphere, a shadow boundary angle of 30 degrees on one side would correspond to 150 degrees on the other.

October 31 was considerably less windy, and the critical angles were found to be 31.1, 150.5 and 29.6,149 for flight directions 0 and 180 degrees, respectively.

Travel distance. The elementary distance of wave travel that corresponds to an altitude interval Δz is $\Delta r = \Delta z / \sin\psi(z)$ For emission angles within the critical angles, the total travel distance of sound from the source to the receiver is (Fig. 1.1)

$$r = \sum_0^H \Delta r = \sum_0^H \Delta z / \sin\psi(z)$$

where $\sin\psi(z)$ is obtained from Eq. 1.1.

In regard to the present analysis, atmospheric data (temperature, wind, pressure, and relative humidity) were available at 70 altitudes from 15 to 2085 m with $\Delta z = 30\,\mathrm{m}$, thus covering the range from 0 to 2100 m, at 20 altitudes from 2175 to 5025 with $\Delta z = 150$, covering the range from 2100 to 5100 m, and at 22 altitudes from 5250 to 11550 m with $\Delta z = 300\,\mathrm{m}$, covering the range from 5100 to 11700 m. Thus, the altitudes at which met. data are available are

$$z_i = \begin{cases} 15 + (i-1)30, & \text{if } 1 \le i \le 70; \\ 2175 + (i-71)150, & \text{if } 71 \le i \le 90; \\ 5250 + (i-91)300, & \text{if } 91 \le i \le 112. \end{cases}$$

For an altitude of 35,000 ft (10,668 m) the closest altitude interval corresponds to $i = 109$, (10,650 m) with the upper value of the interval being $10650 + 150 = 10800\,\mathrm{m}$, i.e. exceeding the flight altitude by 132 m.

Similarly, a flight altitude of 20,000 ft (6096 m) corresponds to $i = 94$, (6150) with the upper altitude of the interval being 6300 m, exceeding the flight altitude by 204 m.

In terms of these numerical values, the expression for the acoustic travel distance can be expressed as

$$r = \sum_{i=1}^{70} \frac{30}{\sin\psi(z_i)} + \sum_{i=71}^{90} \frac{150}{\sin\psi(z_i)} + \sum_{i=91}^{n} \frac{300}{\sin\psi(z_i)} - \frac{\Delta_n}{\sin\psi(z_n)} \qquad (1.3)$$

where

$$n = \begin{cases} 109, & \text{if } H = 35,000\,\mathrm{ft}; \\ 94, & \text{if } H = 20,000\,\mathrm{ft}. \end{cases}$$

and

$$\Delta_n = \begin{cases} 196\,\mathrm{m}, & \text{if } H = 35,000\ \mathrm{ft}; \\ 204\,\mathrm{m}, & \text{if } H = 20,000\ \mathrm{ft}. \end{cases}$$

Travel time. To obtain the time of travel t_r of the sound wave along the refracted path from source to receiver, we merely have to replace $\Delta z/\sin\psi(z)$ by $\Delta z/c(z)\sin\psi(z)$ in Eq. 1.3. and compute the sum in a completely analogous manner. We shall normalize the travel time with respect to H/c_1 and express it as

$c_1(z) = c(z) + U_x \cos\psi(z)$

$$t_r = (H/c_1)F_1(\psi_1) \qquad (1.4)$$

where $F_1(\psi_1)$ is computed from the modified Eq. 1.3, as descsribed above.

Arrival time. The sound which was emitted at the time t_e arrives at the ground station at the time $t = t_e + t_r$. In this report, we choose $t = 0$ to be the time when the source passes overhead at the observers position $x = 0$ (view angle of 90 deg). The x-coordinate of the source is then given by $x = Vt$, where V is the velocity of the source in the x-direction.

During the acoustic travel time from the emission point to ground, the source has moved forward along the path of travel a distance Vt_r, as indicated in Fig. 1.2. where the angle under which the source is viewed at the arrival time t of the sound is denoted by ψ_v. We shall refer to it as the *view angle.*

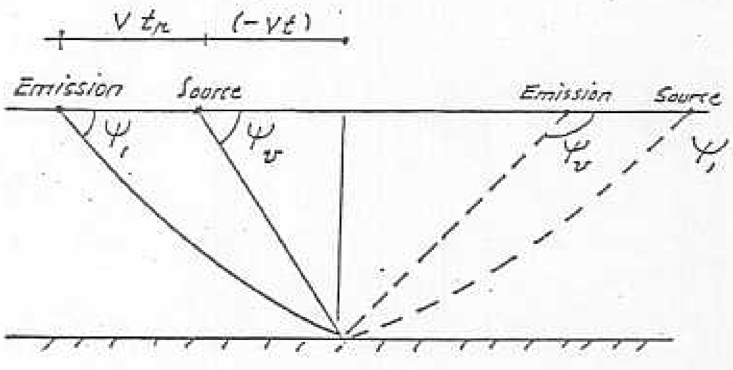


Fig. 1.2. Definition of emission angle and view angle.

At the source position shown in Fig. 1.2, x and t are negative (according to our choice of $t = 0$) and the magnitude of the distance of the source from the origin is $(-Vt)$. Then, with reference to Fig. 1.2, the relation between the arrival time and the emission angle is obtained from

$$Vt_r + (-Vt) = \sum_{0}^{H} \frac{\Delta z \cos\psi(z)}{\sin\psi(z)} \equiv HF_2(\psi_1) \tag{1.5}$$

where, as before $\cos\psi = (c/c_1)\cos\psi_1$. The sum on the right hand side is the x-projection of the travel path. According to Eq. 1.1, it is a function of the emission angle ψ_1 and we have expressed this function as $HF_2(\psi_1)$.

Then, if we introduce the normalized time $\tau = t/(H/c_1)$ and use the expression $t_r \equiv (H/c_1)F_1(\psi_1)$, as defined in Eq. 1.4, we obtain from Eq. 1.5

$$\tau = F_1(\psi_1) - (1/M)F_2(\psi_1) \tag{1.6}$$

where $M = V/c_1$ is the local Mach number of the source. This is the desired relation between the normalized arrival time τ and the angle of emission ψ_1. The characteristic times used in the normalization is, with $c_1 \equiv c(H)$,

$$\frac{H}{c(H)} = \begin{cases} 35.7\,\text{sec}, & \text{if } H = 35,000\,\text{ft}; \\ 19.1\,\text{sec}, & \text{if } H = 20,000\,\text{ft}. \end{cases}$$

Assumes T = -51°C at 35K and cond. to ground ?

which correspond to a temperature at 35,000 ft of 222 K.

View angle. It follows from Fig. 1.2, that the view angle is obtained from

$$\psi_v = \arctan(H/(-Vt)) = \arctan(-1/M\tau) \tag{1.7}$$

where, as before, $M = V/c_1$ is the local flight Mach number and τ the normalized time of arrival, as obtained above in terms of the emission angle.

1.2. Windless atmosphere with a constant temperature gradient

The measured temperature profile, shown in Fig. 2.1 indicates ~~that~~ that as a first approximation the temperature gradient can be considered to be constant, or somewhat better, to have two values of the gradient, one between ground and about 5000 m and another, somewhat larger, from 5000 m and up.

In this and the following subsection, we shall reaxamine the kinematic relations, first considering a calm atmosphere with a constant temperature gradient and then a uniform atmosphere.

As will be apparent shortly, the travel distance obtained from Eq. 1.3 is affected but slightly by the wind (even at wind speeds of 30 knots) and it is an excellent approximation to treat the atmosphere as calm with a temperature which decreases linearly with altitude. Under these conditions, the travel distance and the travel time can be expressed by simple closed form mathematical relations.

Thus, if the temperature at $z = H$ is $T_1 = T_0 - \Delta T$, where T_0 is the temperature at $z = 0$, we have for a linear temperature distribution,

$$T(z) = T_0 - (z/H)\Delta T$$

and $c^2/c_1^2 = T/T_1$. Furthermore, Eq. 1.1 reduces to

$$\cos^2\psi = \cos^2\psi_1[1 + \Delta T/T_1(1 - z/H)]$$

and the critical angles for shadow formation are given by

$$\cos\psi_c = \pm\sqrt{T_1/T_0}$$

which replaces Eq. 1.2.

Travel distance. For sound rays which reach the observer on the ground, the distance of wave travel between source and observer can be written

$$\begin{aligned} r &= \int_0^H \frac{dz}{\sin\psi} = \int_0^H \frac{dz}{\sqrt{\sin^2\psi_1 - (\Delta T/T_1)(1 - z/H)\cos^2\psi_1}} \\ &= \frac{2T_1 H}{\Delta T}\frac{1}{\sin\psi_1\cot^2\psi_1}\left[1 - \sqrt{1 - (\Delta T/T_1)\cot^2\psi_1}\right] \end{aligned} \tag{1.8}$$

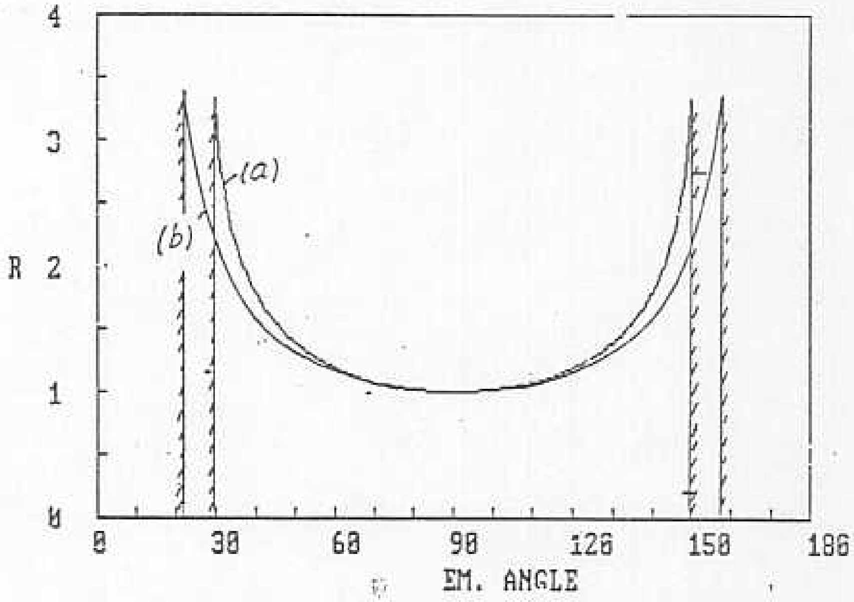


Fig. 1.3. Normalized wave travel distance as a function of the emission angle indicating "shadows" formed by refraction.
(a) Source height=35,000 ft. Mach number=0.8
(b) Source height=20,000 ft. Mach number=0.7
Calm atmosphere with a constant temperature gradient.
$T(0) = 293\,\mathrm{K}$. $dT/dz = -71/35,000\,\mathrm{K/ft}$.

For $H = 35,000$ and $H = 20,000\,\mathrm{ft}$, $T_0 = 293\,\mathrm{K}$ (20 C), and a temperature gradient $dT/dz = -80/35,000\,\mathrm{K/ft}$, the relations between travel distance r and the emission angle ψ_1 are shown in Fig. 1.3.

From a geometric acoustic standpoint, acoustic rays will reach the observer only in the range between emission angles indicated. In reality, this range can be markedly reduced because of background noise masking of the propfan tone.

Travel time. The time of travel of a sound wave from emission to arrival at the ground station is

$$t_r = \int_0^H \frac{dz}{c(z)\sin\phi} = \frac{H}{c_1}\int_0^1 \frac{dy}{(c/c_1)\sin\psi}$$

where $y = z/H$.

Again, assuming a linear decrease of temperature with height, we have

$$c(z)/c_1 = \sqrt{1+\epsilon(1-y)}$$

where $\epsilon = \Delta T/T_1$, and it follows that

$$t_r = (H/c_1)\int_0^1 \frac{dy}{\sqrt{[1+\epsilon(1-y)][1-\cos^2\psi_1(1+\epsilon(1-y)]}}$$

This can be rewritten in the form of a standard elementary integral with the result

$$t_r = (H/c_1)\frac{1}{\epsilon \cos\psi_1}\left[\arcsin(2\epsilon\cos^2\psi_1 + \cos 2\psi_1) - \arcsin(\cos 2\psi_1)\right]$$
$$\equiv (H/c_1)F_1(\psi_1) \tag{1.8}$$

Arrival time. Eq. 1.5 now becomes

$$Vt_r + (-Vt) = \int_0^H \frac{dz\cos\psi}{\sin\psi} \equiv HF_2(\psi_1) \tag{1.9}$$

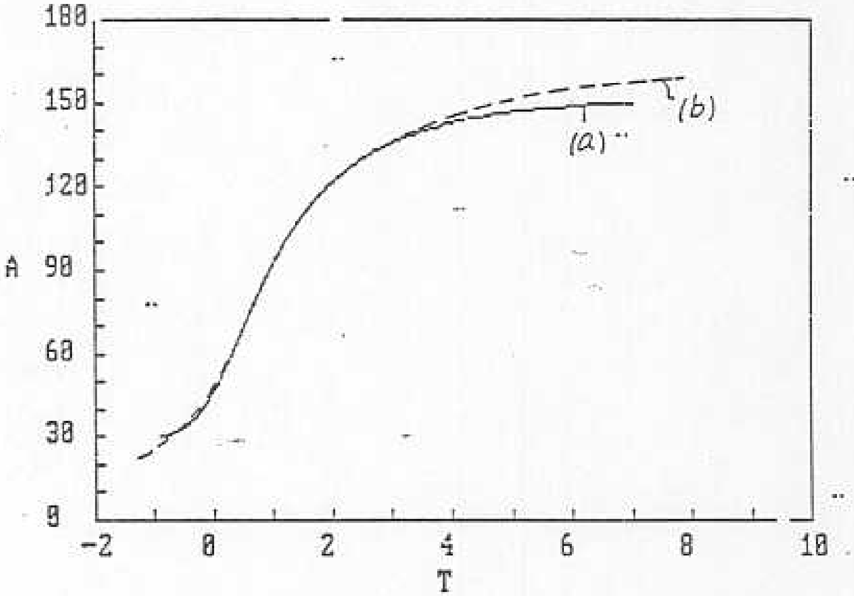


Fig. 1.4. Emission angle vs normalized arrival time $\tau = t/(H/c_1)$, where c_1 is the sound speed at height H. Time is measured from the moment ($t = 0$) when the sound source passes $x = 0$, the x-coordinate of the observer on the ground.
(a) $H = 35,000$ ft, $M = 0.8$. (b) $H = 20,000$ ft, $M = 0.7$. Calm atmosphere with the temperature decreasing linearly from 293 K at the ground level to 222 K at 35000 ft.

In Fig. 1.4 is shown the emission angle as a function of the normalized time of arrival of the emitted sound from a source is at 35,000 ft and the flight Mach number is 0.8. The ground temperature is 293 K and the temperature at 35,000 ft is 222 K.

Because of shadow formation, discussed above, no ray can reach the observer at normalized times less than -0.87 and greater than 6.5. In

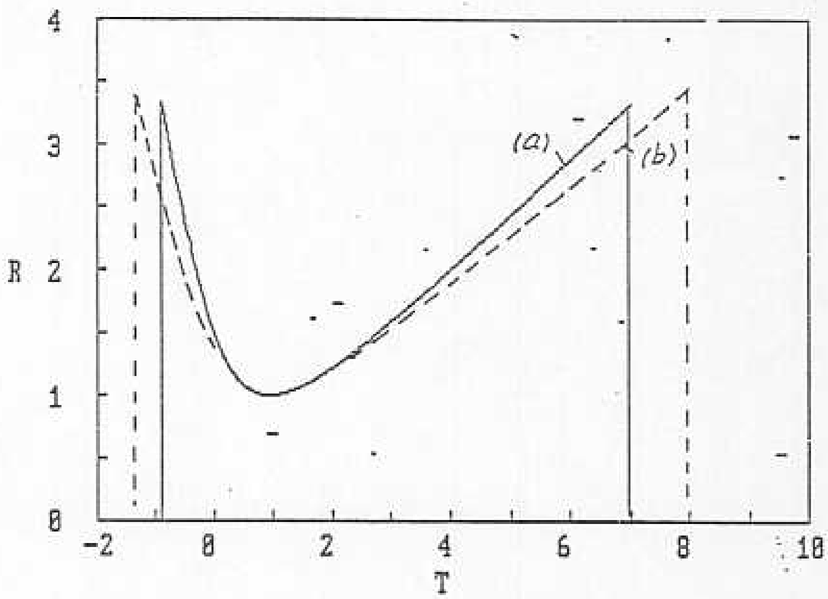


Fig. 1.5. Wave travel distance as a function of the normalized arrival time of the wave at the ground station when the source height is $H = 35,000$ ft and the Mach number is 0.8.
$T(0) = 293$ K, $T(H) = 222$ K. Calm atmosphere with temperature decreasing linearly with altitude.

reality, this range is reduced because of masking of the propfan tone by background noise.

Under the same conditions, we have shown in Fig. 1.5 the wave travel distance as a function of the normalized arrival time.

Finally, the view angle

$$\psi_v = \arctan(H/(-Vt)) = \arctan(-1/M\tau)$$

is shown in Fig. 1.6 as a function of the emission angle.

1.3. Windless isothermal atmosphere

If we ignore the nonuniformity of the atmosphere altoghether and assume no wind and a temperature equal to that at the altitude of the source, the relation between the normalized travel distance and the emission angle is simply

$$R = \frac{1}{\sin \psi_1}$$

In terms of the normalized time of arrival, the travel distance is given by

$$R = \frac{\sqrt{M^2\tau^2 + 1 - M^2} - M^2T}{1 - M^2}$$

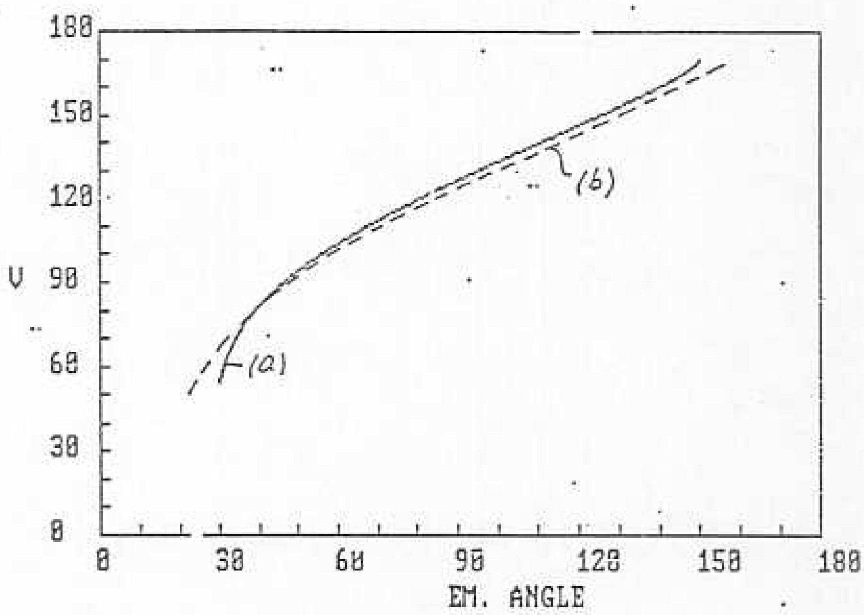


Fig. 1.6. The view angle vs the emission angle.
(a) $H = 35,000$ ft and $M = 0.8$. (b) $H = 20,000$ ft and $M = 0.7$.
$T(0) = 293$, $T(H) = 222$ K (H=35,000 ft). Calm atmosphere with temperature decreasing linearly with altitude.

and the relation between the view angle and the emission angle takes the form

$$\cos\psi_1 = \frac{M\sqrt{\cot^2\psi_v + 1 - M^2} + \cot\psi_v}{M\cot\psi_v + \sqrt{\cot^2\psi_v + 1 - M^2}}$$

1.4. Comparisons

A comparison of the results obtained from the approximate procedures in Sections 1.2 and 1.3 and the direct calculations in Section 1.1 is made in Fig. 1.7, where the travel distance is plotted as a function of the emission angle. In the direct calculations, using meteorological data at the 109 altitudes as discussed earlier, we have chosen the conditions at 7:35 AM on October 30 which exhibited the highest wind (about 30 knots at some altitudes) encountered during the two day enroute noise study.

The wind was predominantly in the positive x-direction. This means that for emission angles less than 90 degrees, the average refractive effects of wind and thermal gradients work in opposition, the temperature gradient bending an acoustic ray upwards and the wind bending it downwards; the wind has the effect of reducing the curvature of the rays caused by the temperature gradient. For emission angles larger than 90 degrees, on the other hand, the two effect cooperate, both bending a ray upwards; the presence of wind increases the ray curvature.

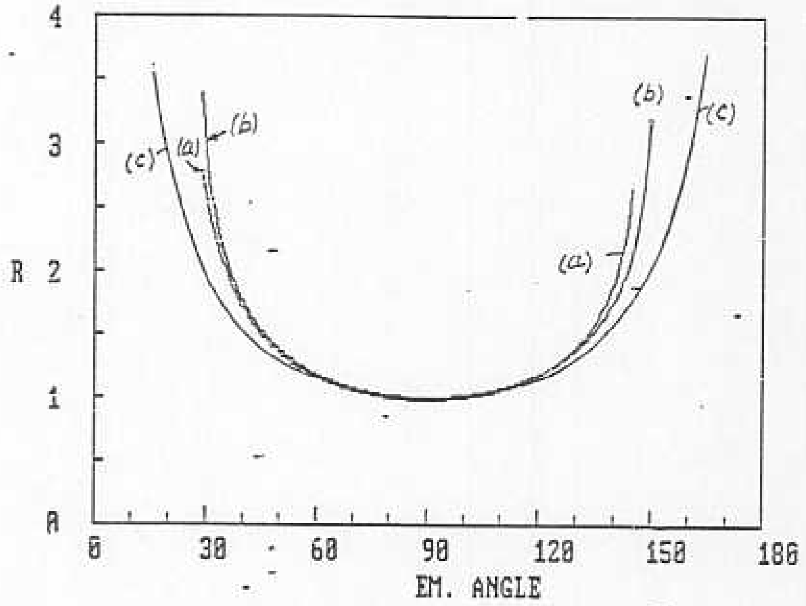


Fig. 1.7. Normalized travel distance vs emission angle.
(a) Real atmosphere (7:35 AM, October 30, 1987).
(b) Windless atmosphere with a temperature decreasing linearly with altitude from 293 K at ground level to 222 K at 35,000 ft.
(c) Uniform atmosphere.

Under such conditions we expect the presencee of wind to result in a decrease in travel distance for emission angles less then 90 degrees and an increase for angles larger than 90 degrees. By comparing with the travel distance obtained in the windless isothermal atmosphere in Fig. 1.7, we see that the results are indeed consistent with this observation. In the angular region usually of interest, 55-120 degrees, the difference is so small that it barely noticesable in the graph. The same holds true for other kinematic relations, such as the travel distance vs arrival time, etc.

For the uniform atmosphere, the rays are straight and the travel distance is smaller than for the other two cases, and the difference is large enough to be noticeable.

REVIEW OF METEOROLOGICAL CONDITIONS

In the analysis of sound propagation, the atmosphere is assumed to be vertically stratified according to data on temperature, relative humidity, pressure and wind velocity, as provided by DOT/TSC. The dependence of these quantities on the height above ground have been given at intervals of 30 m between 15 m and 2085 m, 150 m between 2175 and 5025 m, and 300 m between 5250 m and 11850 m. The data refer to the the times 7:35, 8:50, 12:00, and 13:56 on October 30, 1987 and the times 8:30, 11:31, and 14:09 on October 31, 1987.

Temperature distribution

The temperature data are summarized in Fig. 1. As can be seen, there is little variation between Oct. 30 and 31, and, as far as sound propagation from heights of 20,000 or 35,000 ft is concerned it is a good approximation to assume the temperature to decrease linearly with height. (The data for Oct. 30 at 7:35 and 8:50 were found to be identical, so that out of the four curves, two fall on top of each other).

Pressure distribution

With a temperature decreasing linearly with height, the static pressure distribution can be computed from the relation

$$P(z) = P(0)(1 - \alpha y)^{(\gamma g/c^2)(1/\alpha)} \qquad (2.1)$$

where $\gamma = 1.4$, $g = 9.81\,\text{m/sec}^2$, c the sound speed at the ground level, $\alpha = (1/H)|\Delta T/T(0)|$, and $\Delta T = T(0) - T(H)$ the difference in temperatures on the ground and at the height H.

The plot of P vs the height y (Eq. 1) with $|\Delta T| = 71$ ($H = 35,000\,\text{ft}$), $T_g = 293$ is shown in Fig. 2. It is in good agreement with the measured pressure distribution.

Relative humidity

Unlike the temperature, the relative humidity for the two days under consideration are significantly different, as can be seen from Fig. 3. This has a noticeable effect on sound attenuation, as discussed later. (The relaxation frequency for vibrational excitation of Oxygen and Nitrogen depends on the ratio beteen the vapor pressure and the atmospheric pressure and this in turn depends on the relative humidity, temperature, and static pressure.)

Wind distribution

The wind speed and direction for October 30 and 31, 1987 depends on altitude as shown in Figs. 4-5. The wind speeds differ considerably for these days and also with the time of the day.

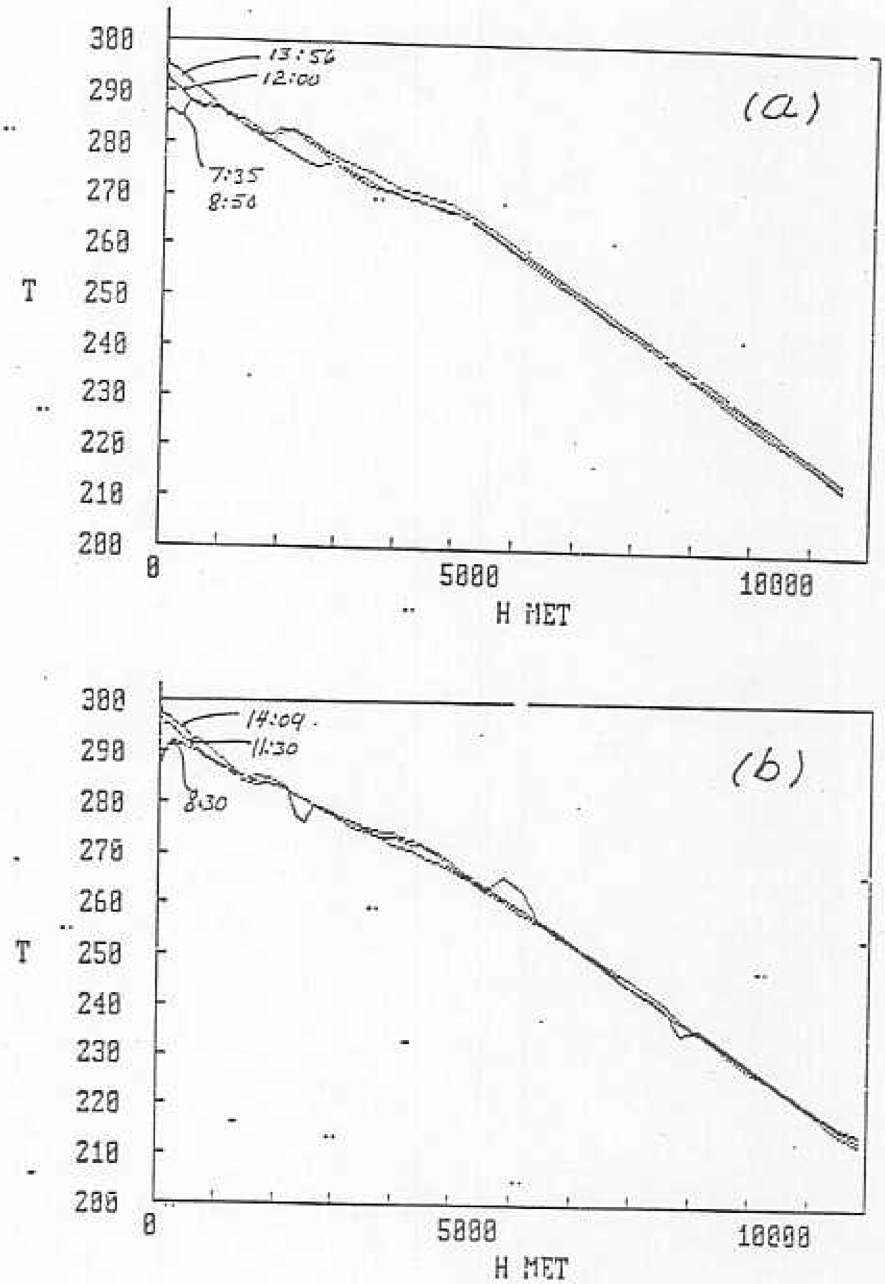


Fig. 2.1. Measured temperature distribution.
(a) October 30, 1987.
(b) October 31, 1987

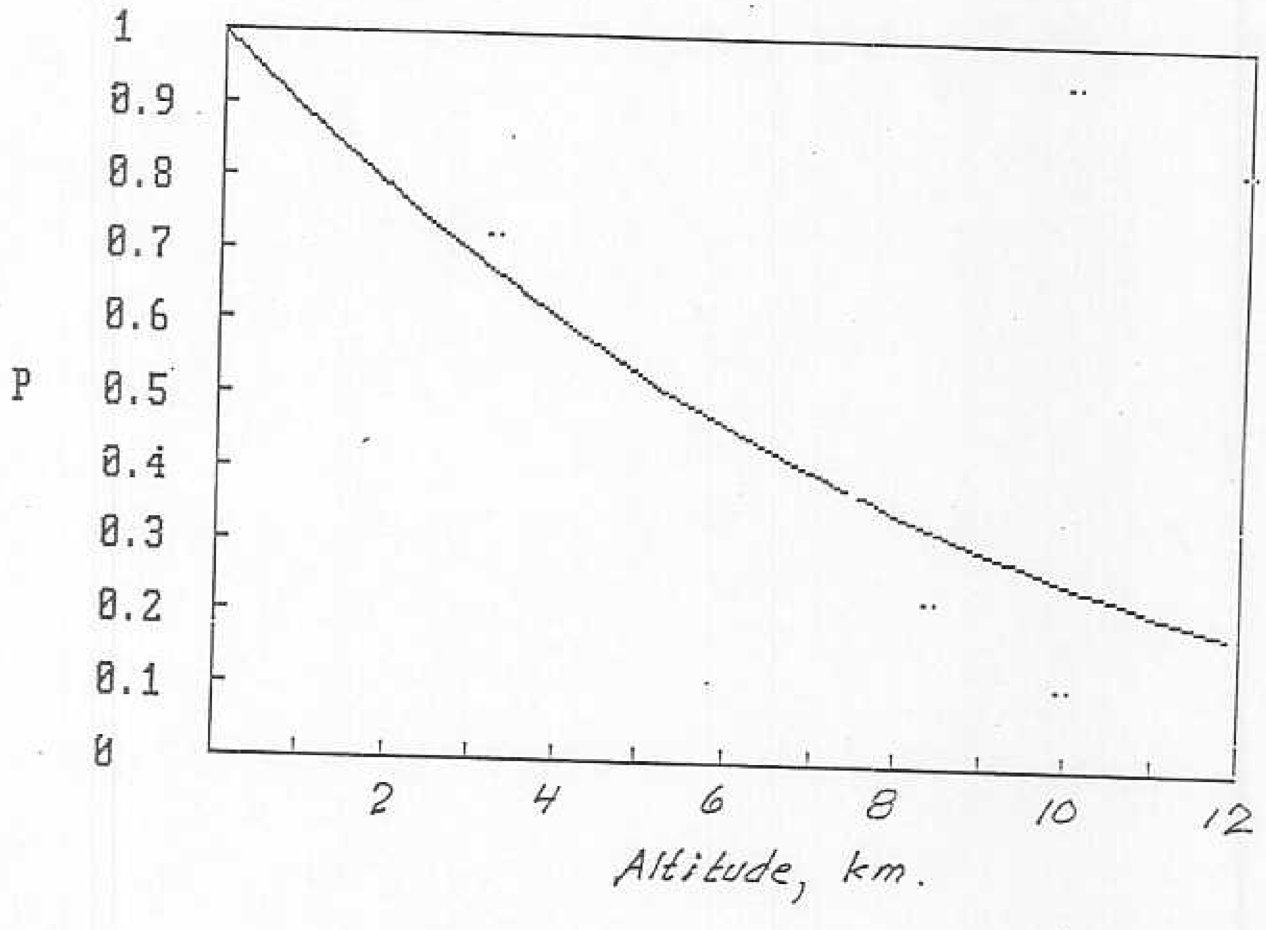


Fig. 2.2. Static pressure distribution.

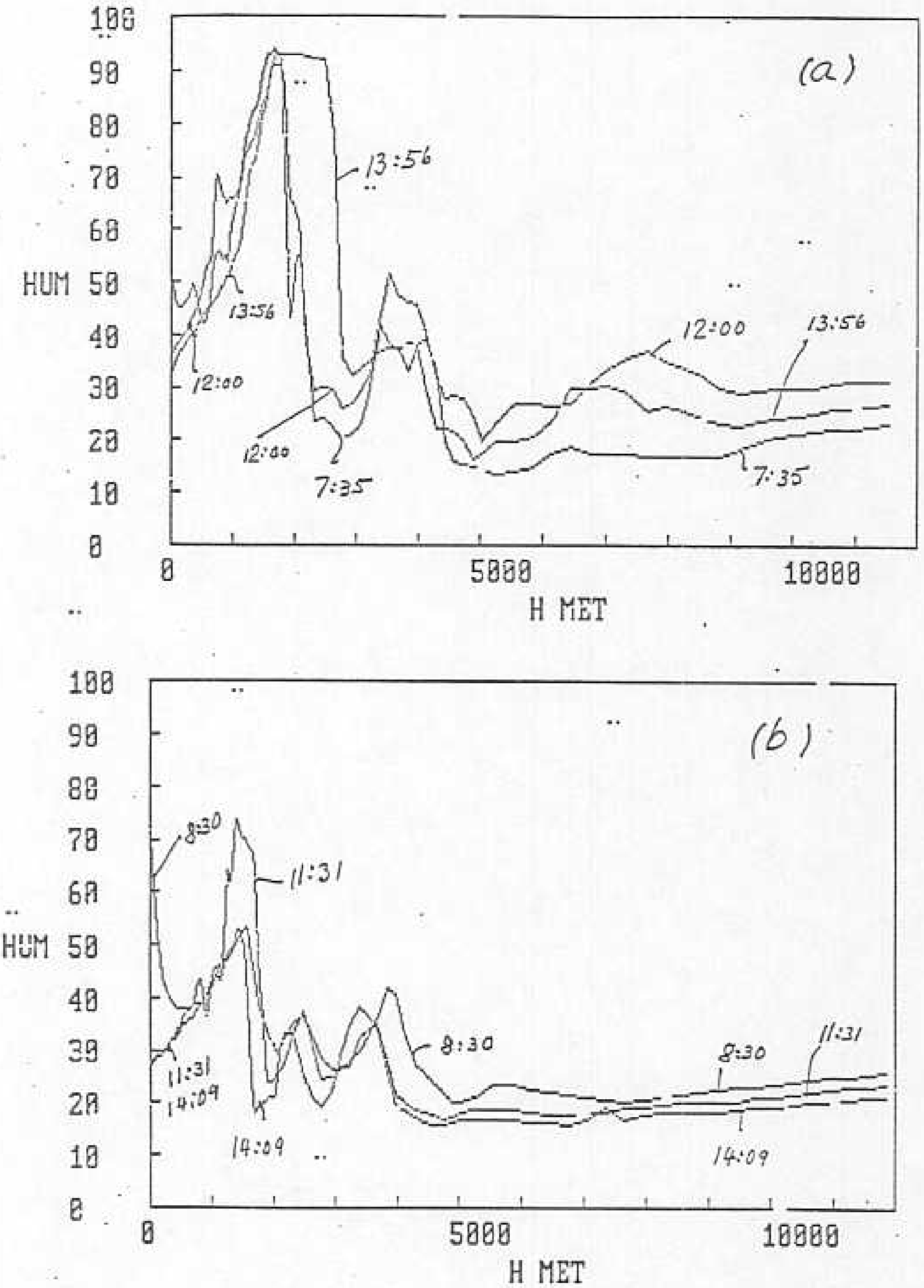


Fig. 2.3. Relative humidity vs height.
(a) October 30, 1987.
(b) October 31, 1987.

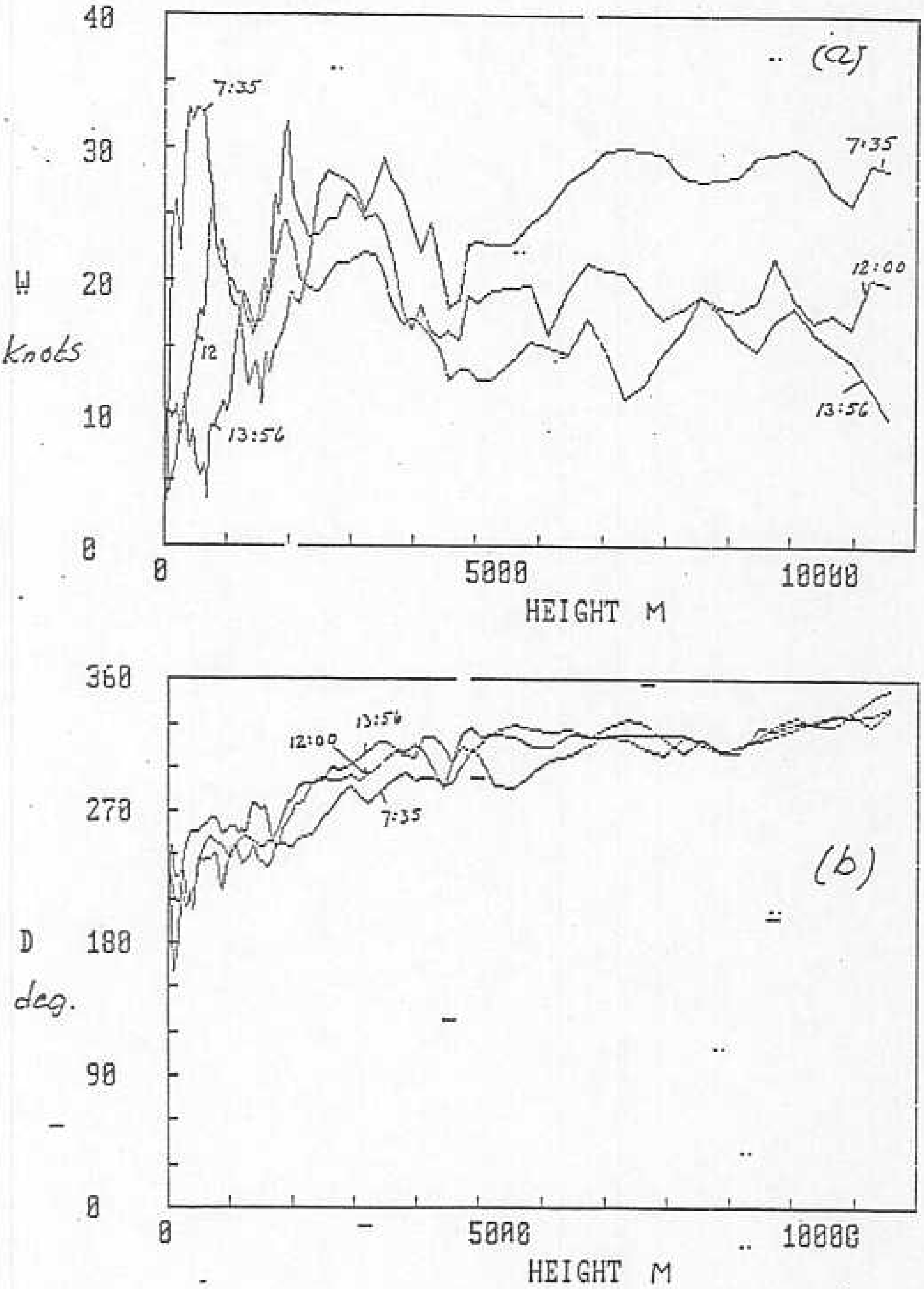


Fig. 2.4. Wind data, October 30, 1987.
(a) Speed. (b) Direction.

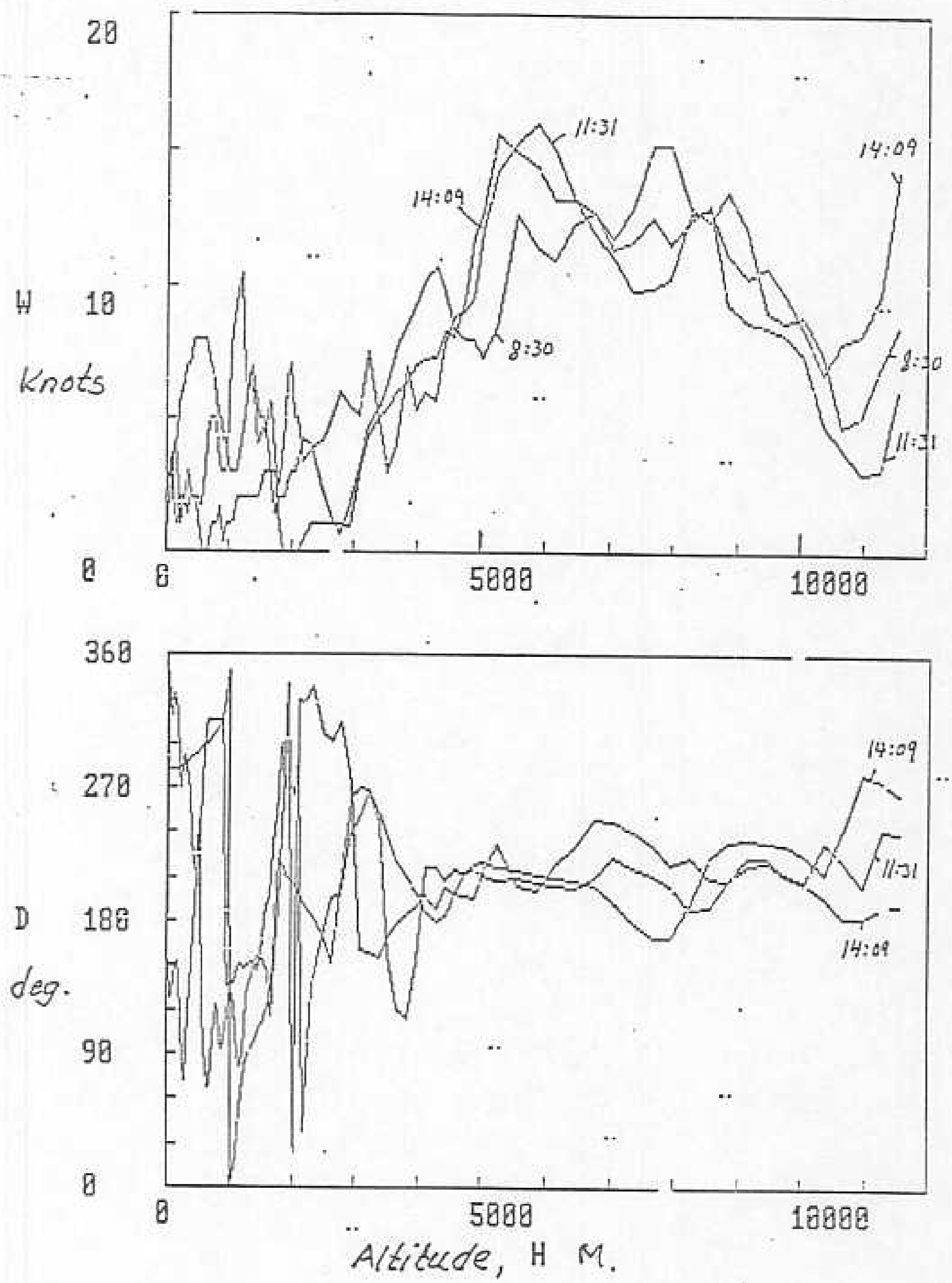


Fig. 2.5. Wind data, October 31, 1987.
(a) Speed. (b) Direction.

3. CALCULATION OF SOUND ATTENUATION

Attenuation due to sound absorption in the air

The blade passage frequency of the propfan under consideration was 237.6 Hz, and the Doppler shifted frequencies observed on the ground ranged from approximately 150 to 500 Hz. In this frequency range, the bulk of sound attenuation in air is due to the vibrational relaxation of the Oxygen molecules in the air. The corresponding contribution from the Nitrogen is relatively small, as will be demonstrated shortly. The attenuation due to translational (visco-thermal losses, "classical") and rotational relaxation effects are negligible.

The frequency dependence of the attenuation of each of these effects is expressed through the ratio of the frequency and the corresponding relaxation frequency. The vibrational relaxation frequencies of Oxygen and Nirogen depend on the ratio between the water vapor pressure and the total static pressure. The vapor pressure P_v, the product of the vapor saturation pressure P_s and the relative humidity, depends strongly on the temperature through the temperature dependence of P_s. Furthermore, through its dependence on the intermolecular collision frequency, the relaxation frequency is proportional to the static pressure.

The data on the relative humidity as a function of the height above ground are shown in Fig. 2.3. The calculation of the corresponding vapor pressure involves the use of an empirical expression for the temperature dependence of the saturated vapor pressure, and the relaxation frequency is obtained from the vapor pressure through another empirical relation. There exist several such empirical relations which have been justified on the basis of experiments. We have used here the relations in the SAE proposed standard computation procedure (Nov. 1986). For comparison, computationof the attenuation were carried out also with another set of formulas for the vapor pressure and the relaxation frequency. Although the dependence of the attenuation per unit length with the altitude showed marked differences, the integrated attenuation over the entire distance of sound propagation was essentially the same in the two cases.

The computed altitude dependence of the attenuation per unit length is shown in Fig. 3.1 at two different times of the day. It is interesting to note that the attenuation is concentrated to a region below approximately 7000 m with a pronounced peak around 5000 m. This has the important consequence, that the attenuation over the entire path of sound propagation will be *essentially the same* at the two source heights of interest here, 35,000 ft and 20,000 ft.

There is a noticeable variation of the attenuation curves with the time of the day. In the midddle of the day (13:56) the the attenuation "band" is somewhat wider than in the morning (7:35 AM), and the integrated attenuation over the entire path of sound propagation will be somewhat larger, as will be shown later.

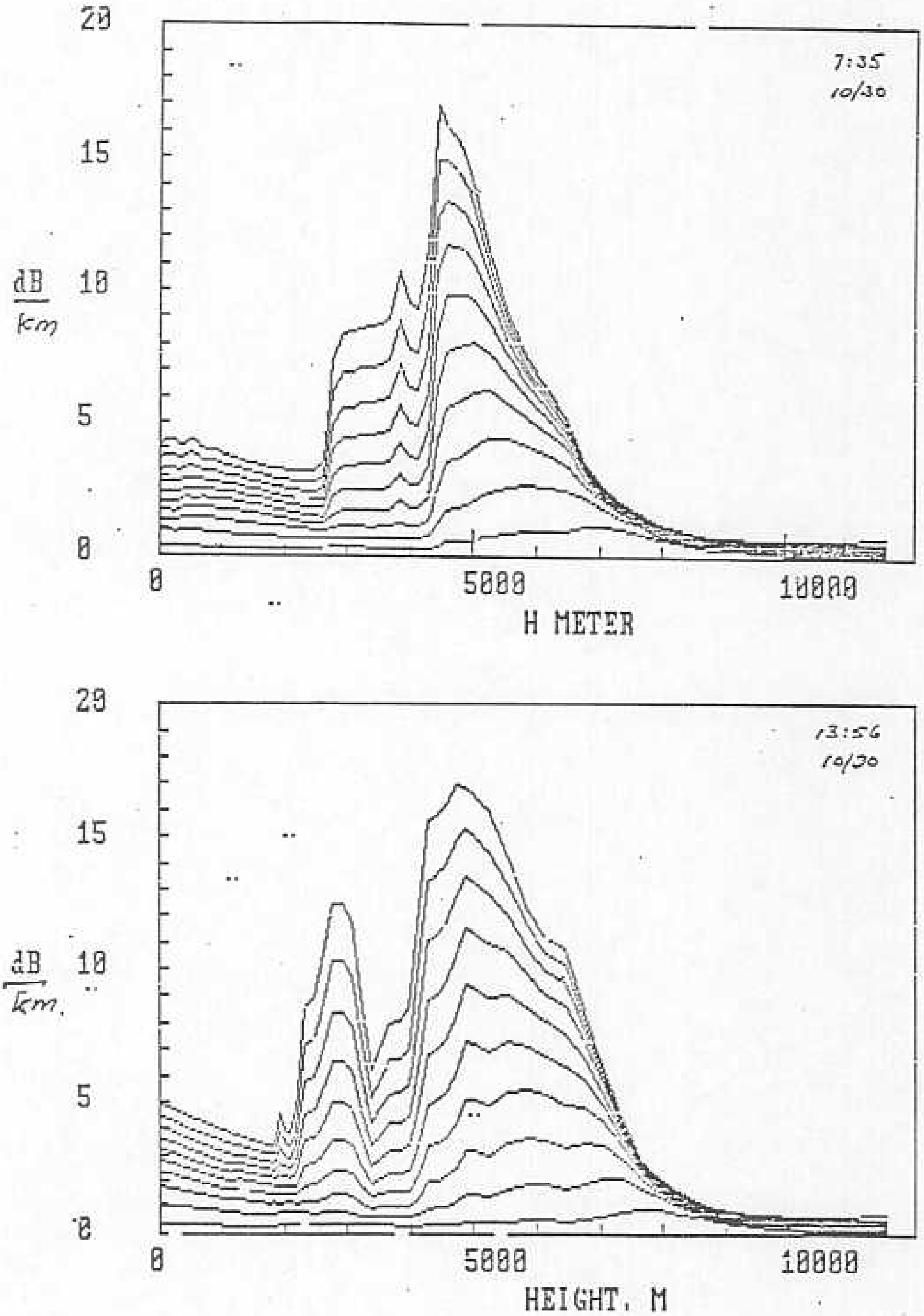


Fig. 3.1. Attenuation (in dB/km) due to sound absorption in the air as a function of height above ground with frequency f as a parameter, $f = 100$, 200, 300,..1000 Hz.
October 30, 1987.
(a) 7:35 AM. (b) 13:56.

Similar result were obtained for October 31, 1987.

To demonstrate explicitly the dominant role of Oxygen in regard to sound attenuation, we have shown in Fig. 3.2 the contribution to the attenuation from the vibrational relaxation of Oxygen alone. This attenuation differs only slightly from the total attenuation in Fig. 3.1, the difference occurring at lower altitudes, where the role of Nitrogen is not negligible.

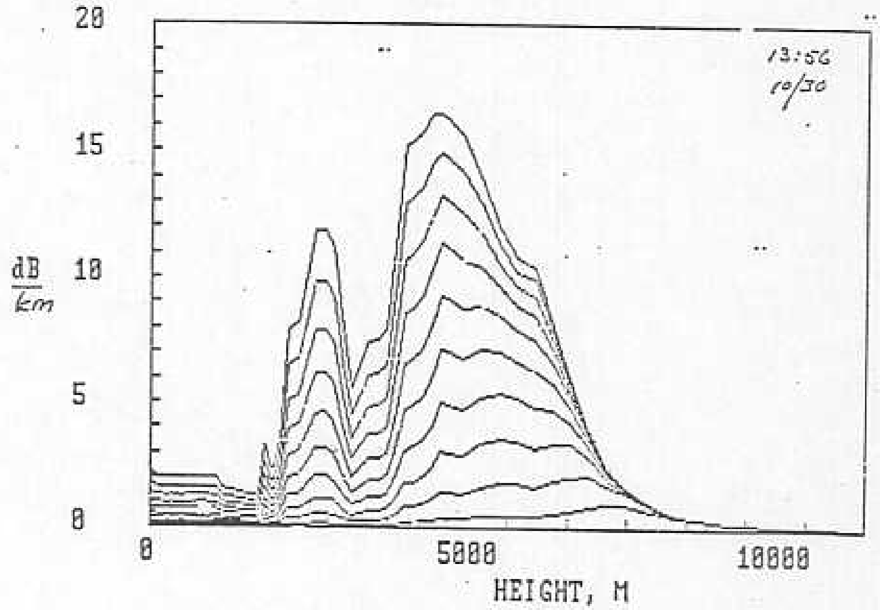


Fig. 3.2. Attenuation (in dB/km) due to the vibrational relaxation of the Oxygen molecule alone. The difference between it and the total attenuation in Fig. 1 is significant only at low altitudes where the contribution from the vibrational relaxation of Nitrogen is noticeable.
October 30, 1987, 13:56.

Integrated attenuation. If we denote the attenuation per meter by $A(z)$, where z is the altitude (in meter), the total attenuation due to air absorption along the refracted path from the source to the receiver is computed from Eq. 1.3 by multiplying each term (under the summation sign) by $A(z_i)$ (and the last term by $A(z_n)$.

Attenuation due to spherical divergence

The "geometrical spreading" of the wave gives rise to a level reduction

$$A_{sph} = 20\log(r/r_0) \tag{1}$$

where r is the distance of sound propagation along the (curved) refracted path of the sound. This distance, obtained from Eq. 1.3, depends on the angle of emission, as shown in Fig. 1.7. The reference r_0 is the distance from the source defined by the intersection of the sound path with a cylinder of radius 500 ft surrounding the straight path of the source. For the case considered here (centerline data),

$r_0 = 500/sin\psi_1$ ft. Thus, for an emission angle of 90 degrees, we have $r = H$ and $r_0 = 500$ ft so that for $H = 35,000$ and $H = 20,000$ ft, we get $A_{sph} = 36.9$ and $A_{sph} = 32$ dB, respectively.

Sound pressure reduction due to wave impedance variation

Even if spherical divergence an sound absorption in the air are neglected, there will be a dependence of the sound pressure with altitude as as result of the variation of the wave impedance $Z = \rho c$, where ρ is the density and c the sound speed.

For a plane wave travelling in the vertical direction, conservation of acoustic energy requires that $p^2/\rho c$ remains constant, independent of height. Consequently, the relation between the sound pressure amplitudes at $z = 0$ and $z = H$ is

$$p(y)/p(0) = \sqrt{Z(0)/Z(H)} = [T(0)/T(y)]^{1/4}[P(y)/P(0)]^{1/2} \qquad (2)$$

With $T(z) = T(0) - [T(0) - T(z)/T(0)](z/H)$ and the expression for the z-dependence of the static pressure in Eq. 3 in Appendix 1, we have computed the sound pressure level variation $\Delta L = 20\log[p(z)/p(0)]$ with altitude, as shown in Fig. 3.3.

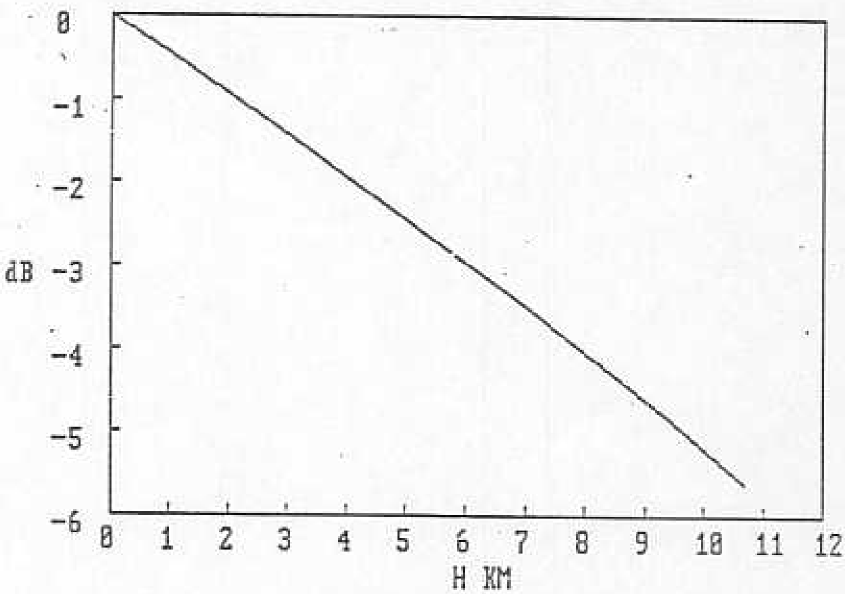


Fig. 3.3. Sound pressure level variation with altitude as a result of wave impedance variation. $T(0) = 293$ K, $T(H) = 222$ K ($H = 35,000$ ft).

With $T(0) = 293$ K, $H = 35,000$ ft, and $\Delta T = 71$ K, we get $\Delta L \approx -5.6$ dB and for $H = 20,000$ ft, the corresponding value is -3.0 dB.

Total attenuation

The total attenuation in sound pressure amplitude is the sum of the contributions from (a) the integrated attenuation due to sound absorption in the air, (b) the effect of spherical divergence, and (c) the effect of the variation of wave impedance with altitude which results in a *decrease* of amplitude with altitude as indicated above.

For the atmospheric conditions that existed during the flight on October 31 at 14:09 PM, we have shown the computed total attenuation as a function of the emission angle in Fig. 3.4. The source height is 35,000 ft and the flight Mach number 0.8. Shown separately are the contributions to the total attenuation due to air absorption (including the effect of variation of wave impedance with altitude) and spherical divergence. For comparison are shown the corresponding results if refraction of sound is not accounted for.

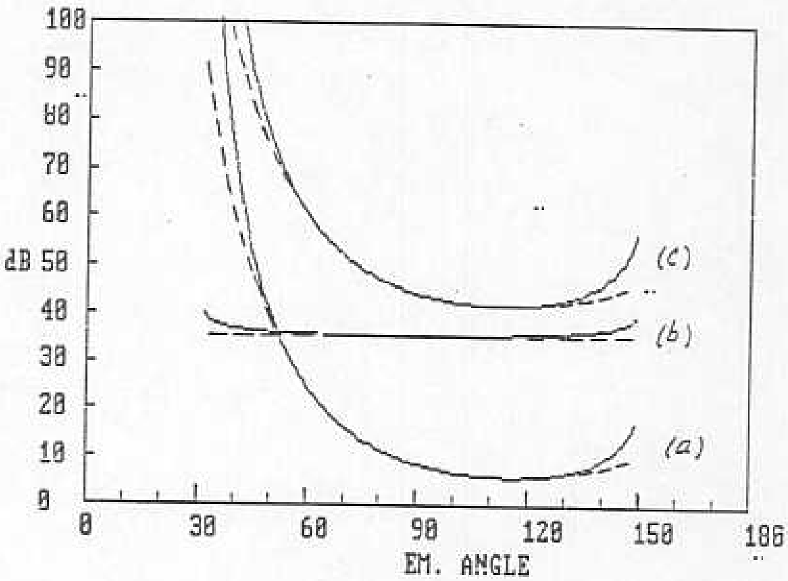


Fig. 3.4. Total attenuation vs emission angle of the blade passage tone from a propfan travelling at an altitude of 35,000 ft., Mach number 0.8. Blade passage frequency =237.6 Hz. The atmospheric conditions refer to the date 10/31/87 and time 14:09.
Dashed curve: Refraction omitted, i.e straight line propagation. (a) Attenuation due to absorption in the air and the effect of the altitude dependence of the wave impedance.
(b) Pressure attenuation due to spherical divergence.
(c) Total attenuation.

The difference between the curves obtained with and without account for the wind is so small that it is not noticeable, and only one curve is shown. If the refraction effect is omitted, however, so that the sound propagates along straight rather than curved path, the predicted attenuation is noticeably smaller at low and large emission angles. However, the background noise on the ground limits the relevant emission angles to values typically between 55 and 120 degrees, and the omission of the refraction effect does not markedly affect the predicted attenuation in that angular range.

It is noteworthy that the attenuation due to sound absorption in the air is for an altitude of 20,000 ft is essentially the same as for 35,000 ft because of the altitude dependence of the absorption per unit length, as discussed in connection with Fig. 3.1. The difference in the total attenuation for the two heights ($\approx$ 7.5 dB) is due to spherical divergence and the variation in wave impedance.

It is also important to note that for small emission angles the total attenuation depends strongly on the emission angle. This angle is computed from the measured acoustic arrival time at the ground station and the flight trajectory, and an error of 1 degree can lead to a significant error in the total attenuation.

Physically, the reason for the strong angular asymmetry of the total attenuation curve with respect to an emission angle of 90 degrees is the increase of the Doppler shifted frequency with decreasing angle of incidence coupled with the (strong) frequency dependence of the attenuation due to absorption in the air.

4. COMPUTED "SOURCE" LEVELS

The received propfan blade passage tone at the ground station is Doppler shifted and has the frequency

$$f(\psi_1) = \frac{f_0}{1 - M\cos\psi_1} \tag{4.1}$$

where $f_0 = 237.6$ is the blade passage frequency, ψ_1 the emission angle, and M the local flight Mach number of the source.

The lower and upper curves in Fig. 1 are examples of the measured A-weighted and overall sound pressure level noise level at the ground station during a fly-over. The background noise at the measuring station was dominated by relatively low frequencies since the average difference between the overall and A-weighted noise levels of the background noise was at least 12 dB. In the important range of emission angles between 50 and 90 degrees, the Doppler shifted frequency of the blade passage tone in the approximate range 276-500 Hz with a corresponding A-weight correction between approximately 8 and 3 dB (significantly smaller than 12 dB). It is possible, then, to check whether a measured sound level is tone-dominated or contaminated with noise by compared the measured overall sound pressure level (OASPL) with the value obtained by adding the A-weight correction to the mesured A-weighted level.

This has been done in Fig. 4.1, in which the top curve is the measured overall sound pressure level, OASPL, and the next curve down is the OASPL-value obtained from the sum of the measured A-level and the A-weight correction. Above and emission angle of about 65 degrees, these curves fall almost on top of each other. Below 65 degrees, however, there is a significant difference, indicating that the blade passage tone is buried in noise and that it is difficult to determine its true value from these data.

The "good" values of the OASPL, i.e. for emission angles above 65 degrees, are now used for the prediction of the OASPL at the 500 ft reference cylinder surrounding the flight path by adding to the ground data the total attenuation, including the effects of sound attenuation in the air, the spherical divergence, the variation of wave impedance with altitude, and the correction due to the reflection at the ground. Under ideal conditions of total reflection, the measured sound pressure level at the ground will be 6 dB higher than the corresponding free field level. However, the reflector plate used in the experiments appears to be too small (diameter of 40 cm, which is less than one third of the average wavelength of interest) to produce total reflection. The ground impedance is expected to play a significant role in the reflection, and if the ground impedance is small compared to that of the plate, the angular dependence of the reflection correction may have to be considered. In the present computation, we have followed the DOT/TSC convention of using 5 dB as a reflection correction.

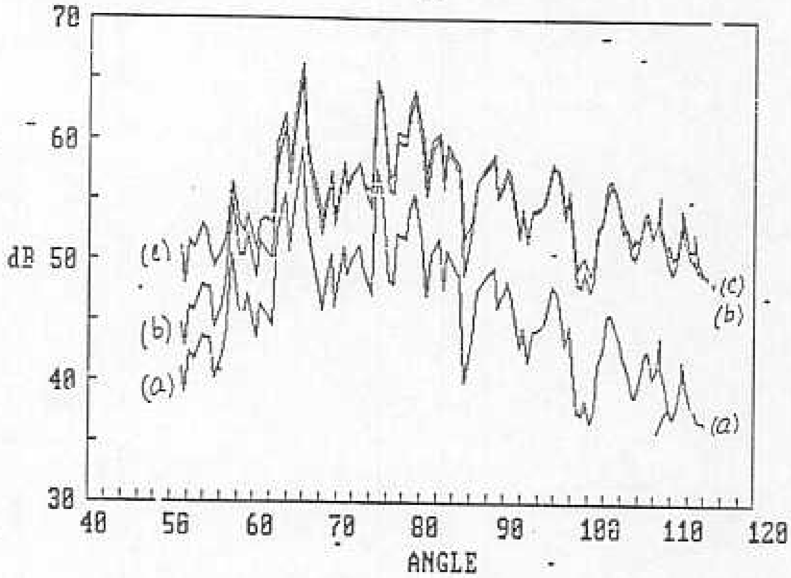


Fig. 4.1. (a) Measured A-weighted noise level at the ground station as a function of the emission angle during flight 54-17 (October 31, 1987, $H = 34925\,\text{ft}$, $M = 0.8$.)
(b) Measured overall sound pressure level (OASPL).
(c) Calculated OASPL from the A-weighted levels.

The result of such a prediction is illustrated in Fig. 2 which concerns a propfan at an altitude of 35,000 ft with a flight Mach number of 0.8.

The lower curve is the measured noise level at the ground station, plotted as a function of the emission angle. The upper curve (with fluctuations) is the predicted level at the 500 ft reference cylinder, the "corrected" noise data, using DOT/TSC terminology. The data points represent the preliminary NASA chase plane data extrapolated to the 500 ft reference cylinder. As can be seen, there is rough agreement between the predicted and measured "source" levels at emission angles above 70 degrees, which is close to the lower angular limit of 65 degrees below which the measured sound is not dominated by the propfan tone (this angle is marked by an arrow). It should be kept in mind, though, that the NASA chase plane data have been labelled preliminary and that more detailed comparisons will be forthcoming.

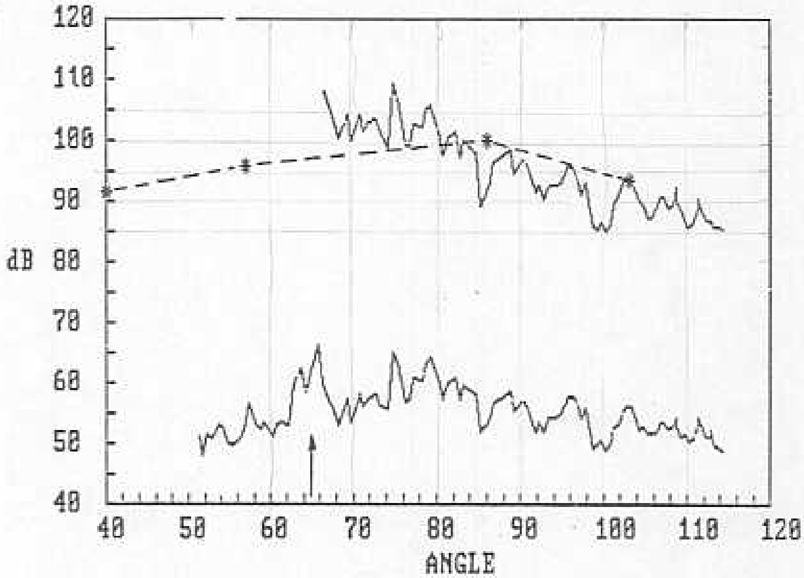


Fig. 4.2. (a) Measured noise level at the ground station during flight 54-17, 10/31/87, 13:09, plotted as a function of the emission angle.
(b) Predicted level at the 500 ft reference cylinder surrounding the flight path obtained by adding to (a) the total sound attenuation along the acoustic travel path.
(c) Measured levels (chase plane data) extrapolated to the 500 ft reference cylinder.
The arrow at the angle of 65 degrees indicates the lower range below which the measured OASPL is not dominated by the propfan tone but contaminated by background noise.

5. FLUCTUATIONS

The observed large fluctuations in the measured sound level at the ground station is typical for pure tone sound propagation in the atmosphere in which interference between two or more sound waves transmitted over different paths to the receiver. This problem has been studied in controlled experiments for a point source over a plane ground surface[1]. As long as the source or the receiver is not placed in the ground surface itself, the signal received by the observer will be a superposition of the contributions from a direct sound wave from the source and a time (phase) delayed reflected wave the from the ground, as indicated schematically in Fig. 1.

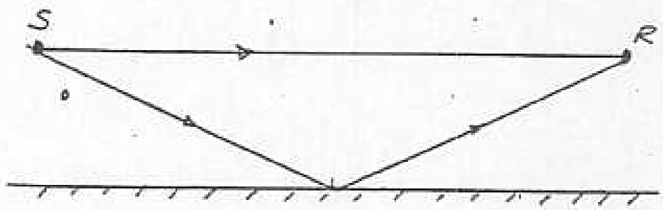
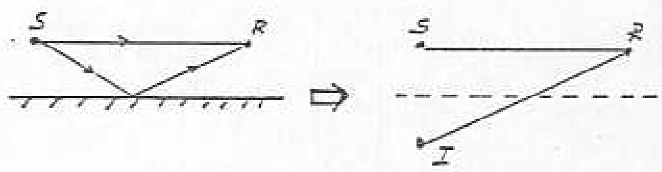


Fig. 5.1. Large fluctuation in received sound pressure level will occur as a result of the interference between the direct and the reflected sound due to (slight) temporal fluctuations in the relative average sound speed along the two paths.

In the measurements referred to, the source and receiver were located 4 ft above ground and the sound level fluctuations were measured as a function of source-receiver separation over a range from 10 to 300 ft. For these distances, level fluctuations of 10 dB were common when the difference in travel path between the two waves exceeded half a wavelength. The fluctuations were found to be larger at locations where, in a uniform atmosphere, destructive interference occurs. The spatial variation in the fluctuation amplitude could be understood theoretically accounting for the fluctuations both in amplitude and phase of the interfering direct and reflected sound waves.

In the present case of propfan sound propagation, the receiver, in essence, is placed *in* the ground surface (actually 7 mm above), and there is no significant path length (or corresponding phase) difference between the inciden and the relected sound. Thus, the situation is not the same as in the fluctuation experiments above, which relied on the the acoustic path length difference and inteference between a direct wave and a wave reflected from the ground.

The propfan is *not* a single point source, however, but rather an *extended* with a diameter ($D = 108$ inches), approximately twice the wavelength of the blade passage tone. Actually, the fan is approximately equivalent to a distribution of point sources (dipoles and monoples) of different signs placed along a circle of diameter D, as indicated schematically in Fig. 2 and interference of the individual sound waves emitted from these separate sources (rather than the interference between a direct and a reflected wave as in the case above) will give rise to fluctuations.



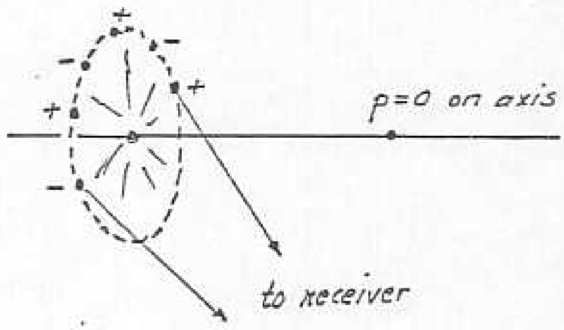


Fig. 5.2. (a) Sound level fluctuations observed in the field from a single point source above a reflecting plane will be esentially the same as from two point sources in free space.
(b) The propfan is an *extended* source with a diameter about twice the wavelength of the blade passage tone. The fan can be simulated approximately by a distribution of point sources (monopoles and dipoles) with alternating signs along a circle. Interference between the sound waves emitted from these sources will give rise to fluctuations.

The directional characteristics of the sound from the propeller is determined by the interference of the sound from these sources. For example, at a point on the axis of the propeller, the acoustic path length to all the sources is the same and the sound waves from the positive and negative sources then cancel each other, making the total sound presssure equal to zero. In other directions, there will be difference in the path lengths, and the interference no longer will be destructive so that a sound pressure different from zero will result.

In a nonuniform atmosphere, with a nonuniform acoustic index of refraction, the acoustic path lengths from the observer to the various sources and the corresponding directional characeristics will be affected. For example, the sound pressure on the axis no longer will be zero, in general. If the atmospheric characteristic are time dependendent, this leads to fluctuations in the observed sound pressure.

For an observer on the ground, the sound waves from the individual sources along the circle has travelled over a long distance (of the order of 35,000 ft) along different paths through the atmosphere. Even if the separation between these paths is relatively small (a few feet on the average), the difference in the average sound speed along these paths required to produce a phase shift of 180 degrees at the blade passage frequency is exceedingly small, of the order of 0.01 %. Consequently, such phase shifts are expected to occur with correspondingly large fluctuations in the received sound pressure level.

It should be pointed out in this context, that since the source is in motion, temporal fluctuations in the received sound pressure will occur even if the atmospheric characteristics are time independent. All that is required is a small spatial nonuniformity in the direction of flight. If the characteristc length of such a nonuniformity is L, the characteristic fluctuation time will be L/V, where V is the speed of the source. As an example, a fluctuation period in the range 0.1-0.5 sec and a flight Mach number of 0.8 corresponds to a characteristic scale of approximately 80-400 ft, which is not unreasonable.

A measurement of the sound pressure distribution about the propeller at a sufficiently small distance leads to an insignificant phase shift between the sound waves from the individual source and the this yields an approximately stationary sound pressure distribution with little or no fluctuation. The phase relationship between the sound pressure contributions from the various elementary sources of the propeller is determined solely by the acoustic path lengths. In a certain direction of observation, these contributions generally are not all in phase.

For long range propagation, with phase fluctuations entering the picture, the probability of a resulting increase in the received sound pressure should be approximately the same is the same as as decrease. Although a decrease yields a larger excusion on a logarithmic scale, it is important to realize that, since several elementary sources are involved, the peak level in a fluctuation can, in principle, be considerably larger than the level that corresponds to the near field level. This should be borne in mind in the analysis of the experimental data and the calculation of the "corrected" levels for comparison with the levels at the 500 ft reference cylinder.

Another important point to consider in this comparison is that scattering of sound from turbulence tends to redistribute the sound, transferring acoustic energy from regions of high to regions of low sound pressure level. Thus, deep and pronounced minima in the near field directivity pattern, (such as in the forward direction) will be less distinct in the far field directivity pattern.

References.

1. Uno Ingard and George Maling, "On the Effect of Atmospheric Turbulence on Sound Propagated over Ground", *J. Acous. Soc. Am.*

35, 1056-1058, 1963.
2. Uno Ingard, "On Sound Transmission Anomalies in the Atmosphere", *J. Acous. Soc. Am.* 44, 1155-1156, 1968.

6. COMPUTER PROGRAMS

The predicted "source" level at the 500 ft reference cylinder was computed as follows:

1. From the program "CRITANGL" the relevant range of emission angles is determined within which the sound will reach the ground.

2. Using the program "DTAHANDL" the primary 1/2 second records of measured noise levels at the ground station are converted to files with measured levels versus the *emission angle* rather than the record number used in the original files (including the time of the first record). In making this conversion, we first identify the record number at which corresponds to our chosen origin of time $t = 0$ (and a view angle of 90 degrees). Then we use a table, obtained from program "KIN-ATT", relating the normalized arrival time of the sound at the ground station and the emission angle.

3. The attenuation due to air absorption is obtained as a function of the emission angle from program "KIN-ATT" and the attenuation due to spherical divergence from the computed travel distance vs emission angle in the same program. The effect of wave impedance variation with altitude is obtained from the altitude dependence of pressure and altitude, as described in the text.

4. For each emission angle, the predicted level at the 500 ft reference cylinder is obtained (from program "SOURCELV") by adding to the "good" sound pressure levels at the ground (sorted out by the program "DTAHANDL") the total attenuation, including the effects of sound absorption in the air, spherical divergence, wave impedance variation with altitude, and the reflection correction at the ground.

```
100 REM "CRITANGL", UNO INGARD, FEBR. 4, 1989
110 REM DETERMINES THE ANGULAR RANGE OUTSIDE WHICH SHADOW FORMATION OCCURS
120 REM ACCOUNTS FOR WIND AND TEMP DISTRIBUTION IN ATM, 112 STRATA
130 ! **********************************************************************

200 CALL Input_temp_wind
205 CALL Critangles
210 END
220 ! ----------------------------------------------------------------------

7000 SUB Input_temp_wind
7001   INPUT PROMPT "FLIGHT ALTITUDE, FT: " ALTER "35000":H
7002   IF H=35000.0 THEN I1 = 109 ELSE I1 = 93
7005   INPUT PROMPT "FLIGHT DIRECTION 0-360: " ALTER "0":Fdir
7010   INPUT PROMPT "NAME OF FILE WITH DOT MET DATA: ":N$
7011   IF N$="M-10-30.DAT" THEN Nc = 8 ELSE Nc = 6
7012   DECLARE LOCAL V,Vd,V1,Vd1,Vx,V1x ! DIM Th[112,Nc],Ma[112],Sp[112],T[112]
7013   INP PRO "TIME OF DAY PARAMETER 1/2/3 FOR 10-31, 1/2/3/4 FOR 10-30: ":Nt
7014   T1 = 2*Nt-1
7015   OPEN #2:N$,"R"
7020   INPUT #2:Th
7021   CLOSE #2
7024   FOR I = 1 TO 112 ! T[I] = Th[I,T1]+273 ! NEXT I
7026   FOR I = 1 TO 112 ! Sp[I] = 1123*SQR(T[I]/293) ! NEXT I
7030   INPUT PROMPT "FILE NAME WITH WIND DATA: ":W$
7031   INPUT PROMPT "TIME OF THE DAY PARAMETER 1/2/3: ":Nt
7032   J = 2*Nt ! K = J-1
7035   DIM Wd[112,6]
7040   OPEN #3:W$,"R"
7050   INPUT #3:Wd
7060   CLOSE #3
7078   FOR I = 1 TO 112
7080     Vd = Pi/180*Wd[I,J] ! V = Wd[I,K]*1.597 ! V1 = Wd[I1,K]*1.597 ! Vd1 = Pi/
180*Wd[I1,J]
7082     Vx = V*COS(Vd-Fdir) ! V1x = V1*COS(Vd1-Fdir)
7088     Ma[I] = (V1x-Vx)/Sp[I1]
7089     PRINT I,ROUND(Ma[I],4)
7090   NEXT I
7100 END SUB
7110 ! ----------------------------------------------------------------------

9000 SUB Critangles
9005   DIM Mx[I1],Mx1[I1]
9008   Mx[1] = Sp[1]/Sp[I1]-Ma[1] ! Mx1[1] = Sp[1]/Sp[I1]+Ma[1]
9010   FOR I = 1 TO I1-1
9020     Mx[I+1] = MAX(Mx[I],Sp[I]/Sp[I1]-Ma[I+1])
9025     Mx1[I+1] = MAX(Mx1[I],Sp[I]/Sp[I1]+Ma[I+1])
9030   NEXT I
9040   PRINT "MAX=";Mx[I1]," MAX1=";Mx1[I1]
9045   I = 1
9050   IF Mx[I]=Mx[I1] THEN 9070
9060   I = I+1 ! GOTO 9050
9070   PRI I ! Crit1 = ACO(1/Mx[I1]) ! PRI "CRIT A1=";ROU(180/Pi*Crit1,1)
9080   I = 1
```

```
9Ø9Ø   IF Mx1[I]=Mx1[I1] THEN 91ØØ
9Ø95   I = I+1 ! GOTO 9Ø9Ø
91ØØ   PRI I ! Crit2 = ACO(-1/Mx1[I1]) ! PRI "CRIT A2=";ROU(18Ø/Pi*Crit2,1)
911Ø END SUB
```

```
100 ! PROGRAM "KIN_ATT", UNO INGARD, NOV, FEB 5 1989. DOT/TSC PROPFAN PROJECT
110 ! DISTANCE OF SOUND TRAVEL FROM MOVING SOURCE IN A TEMP-WIND STRATISFIED ATMO
SPHERE EXPRESSED AS A FUNCTION OF THE ANGLE OF EMISSION FROM SOURCE AT A HEIGHT H A
BOVE GROUND.
115 REM OTHER KIMEATICAL QUANTITIES ARE INCLUDED: TRAVEL TIME, ARRIVAL TIME
121 ! TOTAL ATTENUATION IS ALSO COMPUTED USING DATA ON ATTEN PER KM FROM PROGRAM
APKM_ALT (ATTEN PER KM)
122 ! IN THE NONUNIFORM ATMOSPHERE 112 STRATA ARE CONSIDERED. DATA FROM ORIGINAL
DOT MET-FILES ARE USED.
124 ! FOR A UNIFORM ATM THE KINEM RELATIONS CAN BE EXPRESSED IN CLOSED FORM AND A
T THE END WE HAVE INCLUDED THIS FOR COMPARISON WITH GENERAAL COMPUTATIONS. HAS TO B
E CALLED SEPARATELY
125 ! N O T E ! WE HAVE ACCOUNTED FOR THE VARIATION OF WAVE IMPEDANCE WITH ALTITU
DE IN THE COMPUTED ATTENUATION IN AIR BY SUBTR 5.5 DB AND 3.5 DB FOR SOURCE HEIGHTS
 OF 35000 AND 20000 FT RESP.
130 ! ********************************************************************8
140 INP PRO "NEW CALC OF INPUT FROM FILE N/F: ":C$ ! IF C$="N" THE 180 ELS 145
145 INPUT PROMPT "FILE NAME ":N$
150 OPEN #2:N$,"R"
160 INPUT PROMPT "NR OF COLUMNS IN THE ONE DIM ARRAYS: ":Nw
165 DIM Wdeg[Nw],Va2deg[Nw],Rdiscr[Nw],Arrt[Nw],Atten[Nw],Sphdiv[Nw]
166 INPUT #2:Wdeg,Va2deg,Rdiscr,Arrt,Atten,Sphdiv
170 M = 0.8 ! CAL Printouts ! CHECK WHAT OTHER PARAMETERS MAY BE REQUIRED TO RUN
PRINTOUTS
175 END
176 ! *********************************************************************

180 INPUT PROMPT "UNIFORM ATM Y/N ":U$
190 INPUT PROMPT "INCLUDE EFFECT OF WIND? Y/N ":W$
200 PRINT "Inputs:" ! CALL Inputs ! PRINT ! AT LINE 500
205 PRINT "Read_temp_wind:" ! CALL Read_temp_wind ! PRINT
207 PRINT "Emissionangles:" ! CALL Emissionangles ! PRINT
208 IF W$="N" THEN 233
210 PRINT "Angles:" ! CALL Angles ! PRINT ! AT LINE 700
233 PRINT "Traveldist_times_atten:" ! CALL Traveldist_times_atten ! PRINT
234 PRINT "Viewangle:" ! CALL Viewangle ! PRINT
235 ! PRINT "Doubleemission:" ! !CALL Doubleemission ! PRINT
240 PRINT "Printouts:" ! CALL Printouts ! PRINT ! AT 1100
250 PRINT "Filing:" ! CALL Filing ! PRINT ! AT LINE 1500
270 END
280 ! ------------------------------------------------------------------
500 SUB Inputs
505   DECLARE LOCAL V11,V21,M12,C0,Wc1,Wc2,Wc,Wcc
506   INP PRO "FLIGHT DIRECTION IN DEG 0-360 " ALT "0":Fdir ! Fdir = Pi/180*Fdir
507   INPUT PROMPT "LOCAL MACH NUMBER: " ALTER "0.8":M
510   INP PRO "HEIGHT, FT" ALT "35000":H ! H1 = H*0.3048 ! TO CONVERT TO METER
515   GOTO 600
520   INPUT PROMPT "ABS TEMP AT H " ALTER "222":T1
525   ! IF H=35000.0 THEN T1 = 222 ELSE T1 = 252
530   INPUT PROMPT "ABS TEMP AT GROUND " ALTER "293":T0
535   ! T0 = 293
540   INP PRO "WIND VEL IN KN AT H " ALT "7.9":V1 ! V1 = 1.597*V1 ! FT/SEC
541   INP PRO "WIND DIR IN DEG AT H " ALT "184":Dir1 ! Dir1 = Pi/180*Dir1
```

```
542    INPUT PROMPT "WIND VEL IN KN AT GROUND " ALTER "2":V2 ! V2 = 1.587*V2
543    INP PRO "WIND DIR IN DEG AT GROUND " ALT "147":Dir2 ! Dir2 = Pi/18Ø*Dir2
544    V11 = V1*COS(Dir1-Fdir) ! V21 = V2*COS(Dir2-Fdir)
545    CØ = 1123*SQR(TØ/293) ! M12 = (V11-V21)/CØ
546    Wc1 = ACO(SQR(T1/TØ)/(1-M12)) ! Wc2 = ACO(-SQR(T1/TØ)/(1+M12)) ! Wc = ACO(S
QR(T1/TØ)) ! Wcc = Pi-Wc
547    Wc1 = INT(18Ø*Wc1/Pi+1) ! Wc2 = INT(18Ø*Wc2/Pi-1)
548    PRINT Wc1,Wc2," NW=";Wc2-Wc1+1
55Ø    Wc = INT(18Ø/Pi*Wc+1) ! Wcc = INT(18Ø*Wcc/Pi-1)
555    PRINT Wc,Wcc,Wcc-Wc+1
56Ø    INPUT PROMPT "LOWEST ANGLE, DEGREES ":Wld
57Ø    INPUT PROMPT "HIGHEST ANGLE, DEGREES ":Wud
59Ø    INPUT PROMPT "ANGLE INTERVAL ":Delta_angle
595    Nw = INT((Wud-Wld)/Delta_angle+1)
6ØØ END SUB
61Ø ! ------------------------------------------------------------------
7ØØ SUB Emissionangles
7Ø2    INPUT PROMPT "MIN ANGLE " ALTER "32":Wld
7Ø3    INPUT PROMPT "MAX ANGLE " ALTER "15Ø":Wud
7Ø4    INPUT PROMPT "ANGLE INTERVAL " ALTER "1":Delta_angle
7Ø5    Nw = (Wud-Wld)/Delta_angle+1
71Ø    DECLARE LOCAL J ! DIM W[Nw],C[Nw],S[Nw],Wdeg[Nw]
712    ! DIM W2[Nw],C2[Nw],S2[Nw]
715    Wl = Pi/18Ø*Wld ! Wu = Pi/18Ø*Wud
72Ø    FOR J = 1 TO Nw
725      Wdeg[J] = Wld+(J-1)*Delta_angle
73Ø      W[J] = Wl+(J-1)*(Wu-Wl)/(Nw-1)
735      S[J] = SIN(W[J]) ! C[J] = COS(W[J])
736      ! C2[J] = C[J]*SQR(267/222) ! !S2[J] = SQR(1-C2[J]^2)
738      ! W2[J] = ACOS(COS(W[J])*SQR(267/222))
74Ø      ! PRINT ROUND(Wdeg[J],2)
75Ø    NEXT J
76Ø END SUB
77Ø ! -------------------------------------------------------------------
775 SUB Angles
778    DECLARE LOCAL I,J ! DECLARE INTEGER I,J ! DIM Co[Nw,I1]
78Ø    FOR J = 1 TO Nw
781      FOR I = 1 TO I1
782        IF W$="Y" THE Co[J,I] = C[J]/(1+Ma[I]*C[J])*SQR(T[I]/T[I1]) ELS Co[J,I]
 = C[J]*SQR(T[I]/T[I1])
783        ! PRINT Wdeg[J],ROUND(18Ø/Pi*ACOS(Co[J,I]),1)
784      NEXT I ! NEXT J
785 END SUB
786 ! -------------------------------------------------------------------

1Ø3Ø SUB Viewangle
1Ø35   DECLARE LOCAL J ! DIM Va2[Nw],Va2deg[Nw]
1Ø36   FOR J = 1 TO Nw
1Ø39     IF Arrt[J]<Ø THE Va2[J] = ATA(-1/(M*Arrt[J])) ELS Va2[J] = Pi-ATA(1/(M*Ar
rt[J]))
1Ø4Ø     Va2deg[J] = ROUND(18Ø/Pi*Va2[J],1)
1Ø41     PRINT Wdeg[J],Va2deg[J] ! NEXT J
1Ø42 END SUB
1Ø43 ! --------------------------------------------------------------
```

```
1050 SUB Doubleemission
1055   DECLARE LOCAL J ! DIM Gamma[Nw]
1056   FOR J = 1 TO Nw
1060     Gamma[J] = Rdiscr[J]/SQR((M*Tau[J]-M*Arrt[J])^2+1) ! RATIO BETWEEN TRUE T
RAVEL DISTANCE AND THE STRAIGHT LINE DRAWS FROM EMISSIONI POINT TO OBSERVER ON GROU
ND
1065     PRINT ROUND(180*W[J]/Pi,2),ROUND(Gamma[J],2),ROUND(Arrt[J],2)
1070   NEXT J
1075 END SUB
1076 ! ----------------------------------------------------------------------

1100 SUB Printouts
1105   CLEAR GRAPH ! OPEN #1:"PRN","W"
1110   INPUT PROMPT "WANT PRINTOUTS, Y/N ":P$ ! IF P$="N" THEN 1140 ELSE 1120
1120   PRI #1:"EM ANGLE";" VIEW ANGLE";" ARR.TIME";" TR DIST"," ATTEN DB"," SPHDIV
"," TOTATTEN"
1130   FOR I = 1 TO Nw ! PRI #1:Wdeg[I],Va2deg[I],ROU(Arrt[I],2),ROU(Rdiscr[I],2),
ROU(Atten[I],2),ROU(Sphdiv[I],2),ROU(Atten[I]+Sphdiv[I],2) ! NEX I
1140   INPUT PROMPT "PLOT R VS T? Y/N ":G$ ! IF G$="N" THEN 1220 ELSE 1150
1150   Xmin = -2 ! Xmax = 10 ! Ymin = 0 ! Ymax = 4 ! Xstep = 1 ! Ystep = 0.5 ! Xls
tep = 2 ! Ylstep = 1 ! X$ = "T" ! Y$ = "R" ! CAL Linlin
1191   MOV Arrt[1],Rdiscr[1] ! FOR I = 1 TO Nw ! DRA Arrt[I],Rdiscr[I] ! NEX I
1195   PRINT "M=";M
1200   INPUT PROMPT "WANT HARD COPY Y/N ":G1$ ! IF G1$="N" THEN 1220 ELSE 1210
1210   PRINT #1:A$
1211   SET GRAPH 0
1215   INPUT PROMPT "ANOTHER COPY":C$ ! IF C$="N" THEN 1220 ELSE GOTO 1150
1220   SET GRAPH 0 ! CLEAR GRAPH
1230   INP PRO "WANT PLOT R VS E-ANGLE ":P$ ! IF P$="N" THE 1280 ELS 1240
1240   Xmin = 0 ! Xmax = 180 ! Ymin = 0 ! Ymax = 4 ! Xstep = 10 ! Ystep = 0.5 ! X1
step = 30 ! Ylstep = 1 ! X$ = "EM. ANGLE" ! Y$ = "R" ! CAL Linlin
1252   MOV Wdeg[1],Rdiscr[1] ! FOR I = 1 TO Nw ! DRA Wdeg[I],Rdiscr[I] ! NEX I
1256   PRINT "M=";M
1260   INPUT PROMPT "HARD":H$ ! IF H$="N" THEN 1280 ELSE 1270
1270   PRINT #1:A$
1272   SET GRAPH 0
1275   INPUT PROMPT "ANOTHER COPY":C$ ! IF C$="N" THEN 1280 ELSE 1240
1280   SET GRAPH 0 ! CLEAR GRAPH
1290   INPUT PROMPT "PLOT W VS T":P$ ! IF P$="N" THEN 1340 ELSE 1300
1300   Xmin = -2 ! Xmax = 10 ! Ymin = 0 ! Ymax = 180 ! Xstep = 1 ! Ystep = 10 ! X1
step = 2 ! Ylstep = 30 ! X$ = "T" ! Y$ = "A" ! CAL Linlin
1315   MOVE Arrt[1],Wdeg[1] ! FOR I = 1 TO Nw ! DRAW Arrt[I],Wdeg[I] ! NEXT I
1320   INPUT PROMPT "HARD":H$ ! IF H$="N" THEN 1335 ELSE 1330
1330   PRINT #1:A$
1332   SET GRAPH 0
1335   INPUT PROMPT "ANOTHER COPY":C$ ! IF C$="N" THEN 1340 ELSE GOTO 1300
1340   SET GRAPH 0 ! CLEAR GRAPH
1350   INPUT PROMPT "PLOT W VS VA":P$ ! IF P$="N" THEN 1385 ELSE 1355
1355   Xmin = 0 ! Ymin = 0 ! Xmax = 180 ! Ymax = 180 ! Xstep = 10 ! Ystep = 10 ! X
lstep = 30 ! Ylstep = 30 ! X$ = "EM. ANGLE" ! Y$ = "V" ! CAL Linlin
1360   MOV Wdeg[1],Va2deg[1] ! FOR J = 1 TO Nw ! DRA Wdeg[J],Va2deg[J] ! NEX J
1365   INPUT PROMPT "HARD":H$ ! IF H$="N" THEN 1385 ELSE 1370
1370   PRINT #1:A$
1375   SET GRAPH 0
```

```
1380   INPUT PROMPT "ANOTHER COPY":C$ ! IF C$="N" THEN 1385 ELSE GOTO 1355
1385   SET GRAPH Ø ! CLEAR GRAPH
1386   INPUT PROMPT "PLOT ATTEN VS WDEG":P$ ! IF P$="N" THEN 1466 ELSE 1396
1396   Xmin = Ø ! Ymin = Ø ! Xmax = 18Ø ! Ymax = 1ØØ ! Xstep = 1Ø ! Ystep = 1Ø ! X
lstep = 3Ø ! Ylstep = 1Ø ! X$ = "EM. ANGLE" ! Y$ = "dB" ! CAL Linlin
1406   MOVE Wdeg[1],Atten[1] ! FOR J = 1 TO Nw ! DRAW Wdeg[J],Atten[J] ! NEXT J
141Ø   MOV Wdeg[1],Sphdiv[1] ! FOR J = 1 TO Nw ! DRA Wdeg[J],Sphdiv[J] ! NEX J
1415   MOV Wdeg[1],Atten[1]+Sphdiv[1] ! FOR J = 1 TO Nw ! DRA Wdeg[J],Atten[J]+Sph
div[J] ! NEX J
1426   INPUT PROMPT "HARD":H$ ! IF H$="N" THEN 1446 ELSE 1436
1436   PRINT #1:A$
1446   SET GRAPH Ø
1456   INPUT PROMPT "ANOTHER COPY":C$ ! IF C$="N" THEN 1466 ELSE GOTO 1396
1466   SET GRAPH Ø ! CLEAR GRAPH
147Ø END SUB
148Ø ! ------------------------------------------------------------------

15ØØ SUB Filing
151Ø   INPUT PROMPT "FILING Y/N":F$ ! IF F$="N" THEN 16ØØ ELSE 152Ø
152Ø   INPUT PROMPT "NAME FILE ":N$
153Ø   OPEN #2:N$,"W"
1535   PRINT #2:Wdeg,Va2deg,Rdiscr,Arrt,Atten,Sphdiv
154Ø   PRI #2:"EM ANGLE, VIEW ANGLE, TRAVEL DISTANCE,ARRTIME,ATTEN,SPHDIV ATT"
1545   PRINT #2:"FROM PROGRAM 'KIN_ATT'"
1546   PRINT #2:"DATA TO BE USED IN 'SOURCELV' FOR COMP OF SOURCE LEVEL"
1547   PRINT #2:"DOT/TSC PROPFAN PROPAGATION PROJECT, 1988-1989"
155Ø   CLOSE #2
16ØØ END SUB
161Ø ! ------------------------------------------------------------------

3ØØØ SUB Prngraph
3Ø1Ø   A$ = CHR$(12)
3Ø2Ø   OPEN #1:"PRN","W"
3Ø3Ø   PRINT #1:"MMAP 6,8192,Ø,-24486,4,Ø,1;"
3Ø4Ø   PRINT #1:"SHOWA 6,BØØØH:Ø Ø,Ø 72Ø,348 5Ø,5Ø 4,6;"
3Ø5Ø END SUB
3Ø51 ! ----------------------------------------------------------------------
32ØØ SUB Linlin
32Ø5   DECLARE LOCAL X,Y
321Ø   CALL Prngraph
322Ø   ! INPUT PROMPT "x-min":Xmin ! INPUT PROMPT "x-max":Xmax
323Ø   ! INPUT PROMPT "y-min":Ymin ! INPUT PROMPT "y-max":Ymax
324Ø   ! INPUT PROMPT "x-tic spacing":Xstep
325Ø   ! INPUT PROMPT "y-tic spacing":Ystep
326Ø   ! INPUT PROMPT "x-label spacing":Xlstep
327Ø   ! INPUT PROMPT "y-label spacing":Ylstep
328Ø   ! INPUT PROMPT "X-AXIS LABEL":X$
329Ø   ! INPUT PROMPT "Y-AXIS LABEL":Y$
33ØØ   Xcorr = Ø.Ø9*(Xmax-Xmin) ! Ycorr = Ø.Ø7*(Ymax-Ymin)
331Ø   Xlcorr = 1.4*Xcorr ! Ylcorr = 2*Ycorr
332Ø   Xlshift = Ø.48*Xstep ! Ylshift = Ø.18*Ystep
333Ø   SET VIEWPORT 2Ø,1ØØ,2Ø,8Ø
334Ø   SET WINDOW Xmin,Xmax,Ymin,Ymax
335Ø   ! IF Ymin<Ø THEN MOVE Xmin,Ø ! !RDRAW Xmax,Ø
```

```
3360   MOV Xmin,Ymin ! RDR Xmax-Xmin,0;0,Ymax-Ymin;-(Xmax-Xmin),0;0,-(Ymax-Ymin)
3370   MOVE Xmin,Ymin
3380   FOR X = Xmin TO Xmax STEP Xstep ! MOVE X,Ymin ! RDRAW 0,(Ymax-Ymin)/60
3390   NEXT X
3400   MOVE Xmin,Ymin
3410   FOR Y = Ymin TO Ymax STEP Ystep ! MOVE Xmin,Y ! RDRAW (Xmax-Xmin)/80,0
3420   NEXT Y
3430   SET CLIP OFF ! SET TEXT STYLE 0
3440   MOVE Xmin,Ymin
3450   FOR X = Xmin TO Xmax STEP Xlstep ! TEXT AT X-Xlshift,Ymin-Ycorr:X
3460   NEXT X
3470   SET TEXT STYLE 0
3480   IF Ymin<0 THEN 3490 ELSE 3560
3490   TEXT AT Xmin-Xcorr,-Ylshift:0
3500   FOR Y = Ymin TO -Ylstep STEP Ylstep
3510     TEXT AT Xmin-Xcorr,Y-Ylshift:Y
3520   NEXT Y
3530   FOR Y = Ylstep TO Ymax STEP Ylstep
3540     TEXT AT Xmin-Xcorr,Y-Ylshift:Y
3550   NEXT Y ! GOTO 3590
3560   FOR Y = Ymin TO Ymax STEP Ylstep
3570     TEXT AT Xmin-Xcorr,Y-Ylshift:Y
3580   NEXT Y
3590   SET TEXT ALIGN 3,5
3600   TEXT AT (Xmax+Xmin)/2-Xlshift/2,Ymin-Ylcorr:X$
3610   TEXT AT Xmin-Xlcorr,(Ymax+Ymin)/2-Ylshift:Y$
3620 END SUB
4000 SUB Hardcopy_pressure
4010   INPUT PROMPT "WANT PRINTOUT Y/N ":P$ ! IF P$="N" THEN 4040 ELSE 4020
4020   PRINT #1:"STATION #";" HEIGHT";" PRESS/PRESS_G" ! PRINT #1:
4030   FOR I = 1 TO 112 ! PRINT #1:I,Y[I],ROUND(P[I]/Pg,2) ! NEXT I
4040   INPUT PROMPT "PLOT P VS Y? Y/N ":G$ ! IF G$="N" THEN 4130 ELSE 4050
4050   CALL Linlin
4060   MOVE Y[1],P[1]/Pg
4070   FOR I = 1 TO 112
4080     DRAW Y[I],P[I]/Pg
4090   NEXT I
4100   INPUT PROMPT "WANT HARD COPY Y/N ":G1$ ! IF G1$="N" THEN 4120 ELSE 4110
4110   PRINT #1:A$
4120   SET GRAPH 0 ! CLEAR GRAPH
4130 END SUB
4140 ! ----------------------------------------------------------------------

6500 SUB Traveldist_times_atten
6505   INPUT PROMPT "NAME OF FILE WITH ATTEN/KM " ALTER "APKM_313.DAT":N$
6506   DIM Wref[121],A[121,112] ! OPEN #2:N$,"R"
6507   INPUT #2:Wref,A
6508   CLOSE #2
6509   DEC LOC Delta_r,Delta_t,Delta_x,Si1,J,R1,R2,R3,Dr,I,A1,A2,A3,Tt1,Tt2,Tt3,X1
,X2,X3 ! DIM Rdiscr[Nw],Tt[Nw],Arrt[Nw],X[Nw],Atten[Nw],Sphdiv[Nw]
6510   FOR J = 1 TO Nw
6515     Jr = J+Wld-30
6520     R1 = 0 ! Tt1 = 0 ! X1 = 0 ! A1 = 0
6530     FOR I = 1 TO 70
```

```
6532       IF U$="Y" THEN Si = SIN(W[J]) ELSE Si = SQR(1-Co[J,I]^2)
6535       Dr = 3Ø/Si
654Ø       R1 = R1+Dr ! Tt1 = Tt1+Dr*SQR(T[I1]/T[I]) ! A1 = A1+Dr*A[Jr,I]
6545       IF U$="Y" THEN X1 = X1+Dr*COS(W[J]) ELSE X1 = X1+Dr*Co[J,I]
655Ø     NEXT I
656Ø     R2 = Ø ! Tt2 = Ø ! X2 = Ø ! A2 = Ø
657Ø     FOR I = 71 TO 9Ø
6571       IF U$="Y" THEN Si = SIN(W[J]) ELSE Si = SQR(1-Co[J,I]^2)
6572       Dr = 15Ø/Si
6575       R2 = R2+Dr ! Tt2 = Tt2+Dr*SQR(T[I1]/T[I]) ! A2 = A2+Dr*A[Jr,I]
658Ø       IF U$="Y" THEN X2 = X2+Dr*COS(W[J]) ELSE X2 = X2+Dr*Co[J,I]
659Ø     NEXT I
66ØØ     R3 = Ø ! Tt3 = Ø ! X3 = Ø ! A3 = Ø
661Ø     FOR I = 91 TO I1-1
6612       IF U$="Y" THEN Si = SIN(W[J]) ELSE Si = SQR(1-Co[J,I]^2)
6615       Dr = 3ØØ/Si
662Ø       R3 = R3+Dr ! Tt3 = Tt3+Dr*SQR(T[I1]/T[I]) ! A3 = A3+Dr*A[Jr,I]
6625       IF U$="Y" THEN X3 = X3+Dr*COS(W[J]) ELSE X3 = X3+Dr*Co[J,I]
663Ø     NEXT I
6632     IF U$="Y" THEN Si1 = SIN(W[I1]) ELSE Si1 = SQR(1-Co[J,I1]^2)
6635     Delta_r = 169/(H1*Si1) ! Delta_t = Delta_r ! Delta_a = Delta_r*A[Jr,I]
6636     IF U$="Y" THE Delta_x = Delta_r*COS(W[J]) ELS Delta_x = Delta_r*Co[J,I1]
664Ø     Rdiscr[J] = (R1+R2+R3+Delta_r)/H1 ! Tt[J] = (Tt1+Tt2+Tt3+Delta_t)/H1 ! X[
J] = (X1+X2+X3+Delta_x)/H1 ! Atten[J] = (A1+A2+A3+Delta_a)/1ØØØ ! TO ACCOUNT FOR FA
CT THAT DIST ARE MEASURED IN M RATHER THAN KM
6642     IF H>=34ØØØ.Ø THE Atten[J] = Atten[J]-5.5 ELS Atten[J] = Atten[J]-3.5 ! T
O ACCOUNT FOR IMPEDANCE VARIATION WITH ALTITUDE
6645     Sphdiv[J] = 2Ø*LOG1Ø(Rdiscr[J]*S[J]*H1/(5ØØ*Ø.348))
665Ø     Arrt[J] = Tt[J]-X[J]/M
666Ø     PRI Wdeg[J],ROU(Rdiscr[J],2),ROU(Arrt[J],2),ROU(Atten[J],2),ROU(Atten[J]+
Sphdiv[J],2)
667Ø   NEXT J
668Ø END SUB
669Ø ! ------------------------------------------------------------------

7ØØØ SUB Read_temp_wind
7ØØ2   IF H=35ØØØ.Ø THEN I1 = 1Ø9 ELSE I1 = 93
7ØØ5   DECLARE LOCAL V,Vd,V1,Vd1 ! DIM Th[112,6],Ma[112],Sp[112],T[112]
7ØØ6   DECLARE LOCAL Vx,V1x
7Ø1Ø   OPEN #2:"M-1Ø-31.DAT","R"
7Ø2Ø   INPUT #2:Th
7Ø3Ø   CLOSE #2
7Ø32   FOR I = 1 TO 112 ! T[I] = Th[I,5]+273 ! NEXT I
7Ø33   FOR I = 1 TO 112 ! Sp[I] = 1123*SQR(T[I]/293) ! NEXT I
7Ø34   IF W$="N" THEN 71ØØ
7Ø35   DIM Wd[112,6]
7Ø4Ø   OPEN #3:"W-1Ø-31.DAT","R"
7Ø5Ø   INPUT #3:Wd
7Ø6Ø   CLOSE #3
7Ø78   FOR I = 1 TO 112
7Ø8Ø     Vd = Pi/18Ø*Wd[I,6] ! V = Wd[I,5]*1.597 ! V1 = Wd[I1,5]*1.597 ! Vd1 = Pi/
18Ø*Wd[I1,6]
7Ø82     Vx = V*COS(Vd-Fdir) ! V1x = V1*COS(Vd1-Fdir)
7Ø88     Ma[I] = (V1x-Vx)/Sp[I1]
```

```
7Ø89     PRINT I,ROUND(Ma[I],4)
7Ø9Ø   NEXT I
7Ø95   ! CALL Critangles
71ØØ END SUB
711Ø ! ---------------------------------------------------------------------

8ØØØ SUB Dist_vs_angle_unif_atm
8ØØ5   DIM Wdeg[Nw],R[Nw]
8Ø1Ø   INPUT PROMPT "MIN ANGLE " ALTER "Ø":Wmin
8Ø2Ø   INPUT PROMPT "MAX ANGLE " ALTER "18Ø":Wmax
8Ø3Ø   INPUT PROMPT "ANGLE INTERV " ALTER "3":Delta_angle
8Ø4Ø   Nw = (Wmax-Wmin)/Delta_angle+1
8Ø5Ø   FOR I = 1 TO Nw
8Ø6Ø     Wdeg[I] = Wmin+(I-1)*Delta_angle
8Ø7Ø     IF SIN(Pi/18Ø*Wdeg[I])<1.E-Ø6 THE R[I] = 1ØØ ELS R[I] = 1/SIN(Pi/18Ø*Wdeg
[I])
8Ø8Ø   NEXT I
8Ø9Ø   INPUT PROMPT "PLOT ":P$ ! IF P$="N" THEN 82ØØ ELSE 8Ø95
8Ø95   Xmin = Ø ! Xmax = 18Ø ! Ymin = Ø ! Ymax = 4 ! Xstep = 1Ø ! Ystep = Ø.5 ! X1
step = 3Ø ! Ylstep = 1 ! X$ = "EM. ANGLE" ! Y$ = "R"
81ØØ   CALL Linlin
811Ø   MOVE Wdeg[6],R[6] ! FOR I = 6 TO Nw-6 ! DRAW Wdeg[I],R[I] ! NEXT I
812Ø   INPUT PROMPT "C? ":C$ ! IF C$="N" THEN 814Ø ELSE 813Ø
813Ø   PRINT #1:A$
814Ø   SET GRAPH Ø ! CLEAR GRAPH
82ØØ END SUB
821Ø ! ---------------------------------------------------------------------
84ØØ SUB Dist_vs_time_unif_atm
84Ø5   DIM T[1ØØ],R[1ØØ]
841Ø   INPUT PROMPT "MACH NR ":Ma
8411   INPUT PROMPT "MIN TIME ":Tmin
8412   INPUT PROMPT "MAX TIME ":Tmax
8413   INPUT PROMPT "T INT ":Delta_time
8414   Nt = (Tmax-Tmin)/Delta_time+1
842Ø   FOR I = 1 TO Nt
8425     T[I] = Tmin+(I-1)*Delta_time
843Ø     Num = SQR(Ma^2*T[I]^2+1-Ma^2)-Ma^2*T[I]
844Ø     Den = 1-Ma^2
845Ø     R[I] = Num/Den
846Ø   NEXT I
847Ø   INPUT PROMPT "PLOT ":P$ ! IF P$="N" THEN 86ØØ ELSE 848Ø
848Ø   Xmin = -2 ! Xmax = 1Ø ! Ymin = Ø ! Ymax = 4 ! Xstep = 1 ! Ystep = Ø.5 ! Xls
tep = 2 ! Ylstep = 1 ! X$ = "T" ! Y$ = "R"
8485   CALL Linlin
849Ø   MOVE T[1],R[1] ! FOR I = 1 TO Nt ! DRAW T[I],R[I] ! NEXT I
85ØØ   INPUT PROMPT "C? ":C$ ! IF C$="N" THEN 852Ø ELSE 851Ø
851Ø   PRINT #1:A$
852Ø   SET GRAPH Ø ! CLEAR GRAPH
853Ø   INPUT PROMPT "ANOTHER GRAPH ":G$ ! IF G$="N" THEN 86ØØ ELSE 8485
86ØØ END SUB
861Ø ! ---------------------------------------------------------------------

9ØØØ SUB Critangles
9ØØ5   DIM Mx[I1],Mx1[I1]
```

```
9008   Mx[1] = Sp[1]/Sp[I1]-Ma[1] ! Mx1[1] = Sp[1]/Sp[I1]+Ma[1]
9010   FOR I = 1 TO I1-1
9020     Mx[I+1] = MAX(Mx[I],Sp[I]/Sp[I1]-Ma[I+1])
9025     Mx1[I+1] = MAX(Mx1[I],Sp[I]/Sp[I1]+Ma[I+1])
9030   NEXT I
9040   PRINT "MAX=";Mx[I1]," MAX1=";Mx1[I1]
9045   I = 1
9050   IF Mx[I]=Mx[I1] THEN 9070
9060   I = I+1 ! GOTO 9050
9070   PRINT I ! Crit1 = ACOS(1/Mx[I1]) ! PRINT ROUND(180/Pi*Crit1,1)
9080   I = 1
9090   IF Mx1[I]=Mx1[I1] THEN 9100
9095   I = I+1 ! GOTO 9090
9100   PRINT I ! Crit2 = ACOS(-1/Mx1[I1]) ! PRINT ROUND(180/Pi*Crit2,1)
9110 END SUB
```

```
100 ! "DTAHANDL", UNO INGARD, JAN 30, 1989
110 REM CONVERSION OF MEASURED RECORDS OF SOUND LEVELS (1/2 SEC INTERVALS) TO A F
ILE OF LEVELS VS EMISSION ANGLE
112 REM FIRST STEP IS TO CONVERT RECCORD NR TO NORMALIZED TIME
114 REM THEN FROM TABLE OF NORM TIME VS EM ANGLE (FROM PROGRAM "KINEMATN"), DETER
MINE RELATION BETWEEN RECORD NR AND EMISSION ANGLE
116 REM HAVING OBTAINED EMISSION ANGLE THE DOPPLER SHIFTED FREQUENCY OF THE BLAD
PASSAGE TONE CAN BE COMPUTED
118 REM CORRESPONDING A-WEIGHT CORRECTION CAN BE COMPUTED
120 REM BY ADDING TO MEASURED A-WEIGHT LEVEL WE OBTAINED PREDICTED OASPL
121 REM THIS COMPUTED OASPL IS COMPARED WITH THE MEASURED OASPL TO DETERMINE WHAT
 DATA ARE "GOOD", I.E. DOMINATED BY THE PROPFAN TONE.
150 ! ********************************************************************

160 INP PRO "NEW COMP OR INPUT FROM FILE N/F":Q$ ! IF Q$="N" THE 200 ELS 162
162 INPUT PROMPT "NAME OF FILE ":N$
164 DIM Wdeg[110],La[110],Oaspl[110],Oasplc[110] ! OPEN #2:N$,"R"
166 INPUT #2:Wdeg,La,Oaspl,Oasplc
168 L$ = "B10" ! Rows = 110 ! CALL Plots
170 END
180 ! -----------------------------------------------------------------

200 PRINT "Dotfile:" ! CALL Dotfile ! PRINT
205 PRINT "Recordnr_to_normtime:" ! CALL Recordnr_to_normtime ! PRINT
210 PRI "Normtime_vs_angle_reference:" ! CAL Normtime_vs_angle_reference ! PRI
220 PRINT "Normtime_to_angle:" ! CALL Normtime_to_angle ! PRINT
225 PRINT "Frequencies:" ! CALL Frequencies ! PRINT
226 PRINT "Aweight:" ! CALL Aweight ! PRINT
230 PRINT "Plots:" ! CALL Plots ! LA,OASPL,OASPLC VS EMISSION ANGLE
235 PRINT "Printout:" ! CALL Printout
240 PRINT "Filing:" ! CALL Filing ! WDEG,LA,OASPL,OASPLC
250 END
260 ! ----------------------------------------------------------------------
-----------------------------------------------------------------------------

500 SUB Dotfile
515   INPUT PROMPT "NAME OF FILE WITH L VS RECORD NR " ALTER "B10":L$
516   INPUT PROMPT "NR OF ROWS IN FILE " ALTER "110":Rows
517   INPUT PROMPT "NR OF COLUMNS " ALTER "6":Columns
518   DIM T[Rows],L[Rows,Columns],La[Rows],Oaspl[Rows],Oasplc[Rows]
520   OPEN #2:L$,"R"
530   INPUT #2:L !  L[I,1]=RECORD NR, L[I,2]=DBA, L[I,4]=OASPL
540   CLOSE #2
545   FOR I = 1 TO Rows ! La[I] = L[I,2] ! Oaspl[I] = L[I,4] ! NEXT I
546   INP PRO "RECORD NR FOR WHICH T=0 " ALT "0":I0 ! INP PRO "RECORD RNR FOR WHI
CH T=1 " ALT "66":I1
550 END SUB
551 ! -------------------------------------------------------------------

560 SUB Recordnr_to_normtime
561   INPUT PROMPT "SOURCE ALTITUDE FT " ALTER "34925":Height
562   INP PRO "GROUND TEMP, K " ALT "293":Tg ! INP PRO "TEMP AT H " ALT "222":T1
570   Th = Height*0.3048/(343*SQR(T1/Tg)) ! NORMALIZATION TIME
572   IF I0=0 THEN 574 ELSE 578
```

```
574   FOR I = 1 TO Rows ! T[I] = 1+Ø.5/Th*(I-I1)
576     GOTO 58Ø
578     FOR I = 1 TO Rows ! T[I] = Ø.5/Th*(I-IØ)
58Ø       PRINT ROUND(T[I],2),ROUND(La[I],2),ROUND(Oaspl[I],2)
581     NEXT I
582   END SUB
584   ! ------------------------------------------------------------------

6ØØ   SUB Normtime_vs_angle_reference
61Ø     DIM Wref[233],Tref[233]
615     INP PRO "NAME OF FILE WITH COMPUTED T VS EM ANGLE: " ALT "TW3135Ø3.DAT":F
$
62Ø     OPEN #2:F$,"R"
63Ø     INPUT #2:Tref,Wref
64Ø     CLOSE #2
65Ø   END SUB
651   ! ----------------------------------------------------------------------

7ØØ   SUB Normtime_to_angle
7Ø5     DIM Wdeg[Rows]
71Ø     FOR I = 1 TO Rows
72Ø       FOR J = 1 TO 232
725         IF T[I]-Tref[J]=Ø THEN 732
73Ø         IF SGN(T[I]-Tref[J])+SGN(T[I]-Tref[J+1])=Ø THEN 732 ELSE 735
732         Wdeg[I] = (Wref[J]+Wref[J+1])/2
735       NEXT J
737       PRINT ROUND(T[I],2),ROUND(Wdeg[I],2)
74Ø     NEXT I
75Ø   END SUB
751   ! ---------------------------------------------------------------------

1ØØØ  SUB Printout
1Ø1Ø    OPEN #1:"PRN","W"
1Ø2Ø    PRINT #1:"DOT FILE ";L$
1Ø3Ø    PRINT #1:"EM ANGLE","   LA, dB","  OASPL","   OASPLC" ! PRINT #1:
1Ø4Ø    FOR I = 1 TO Rows ! PRINT #1:Wdeg[I],La[I],Oaspl[I],Oasplc[I] ! NEXT I
1Ø5Ø  END SUB
1Ø6Ø  ! ------------------------------------------------------------------

134Ø  SUB Plots
135Ø    INPUT PROMPT "PLOT?":P$ ! IF P$="N" THEN 148Ø ELSE 136Ø
136Ø    DECLARE LOCAL I
138Ø    CALL Linlin
139Ø    PRINT "FILE: ";L$
14ØØ    MOVE Wdeg[1],La[1] ! FOR I = 1 TO Rows ! DRAW Wdeg[I],La[I] ! NEXT I
141Ø    MOV Wdeg[1],Oaspl[1] ! FOR I = 1 TO Rows ! DRA Wdeg[I],Oaspl[I] ! NEX I
142Ø    MOV Wdeg[1],Oasplc[1] ! FOR I = 1 TO Rows ! DRA Wdeg[I],Oasplc[I] ! NEX I
143Ø    INPUT PROMPT "HARD COPY?":C$ ! IF C$="N" THEN 145Ø ELSE 144Ø
144Ø    PRINT #1:A$
145Ø    CLEAR GRAPH ! SET GRAPH Ø
146Ø    INPUT PROMPT "ANOTHER COPY?":A$ ! IF A$="N" THEN 147Ø ELSE GOTO 138Ø
147Ø    SET GRAPH Ø ! CLEAR GRAPH
148Ø  END SUB
149Ø  ! --------------------------------------------------------------------
```

```
1570   SUB Prngraph
1580     A$ = CHR$(12)
1590     OPEN #1:"PRN","W"
1600     PRINT #1:"MMAP 6,8192,0,-24486,4,0,1;"
1610     PRINT #1:"SHOWA 6,B000H:0 0,0 720,348 50,50 4,6;"
1620   END SUB
1630   ! ------------------------------------------------------------------

1720   SUB Frequencies
1730     DECLARE LOCAL I ! DIM F[Rows]
1740     INPUT PROMPT "MACH NR ":M
1745     FOR I = 1 TO Rows ! F[I] = 237.6/(1-M*COS(Pi/180*Wdeg[I]))
1750       PRINT Wdeg[I],2,INT(F[I])
1755     NEXT I
1770   END SUB
1780   ! ------------------------------------------------------------------

1790   SUB Aweight
1800     DECLARE LOCAL I ! DIM Aweight[Rows],Oasplc[Rows]
1810     FOR I = 1 TO Rows
1820       Aweight[I] = 8*(LOG10(F[I]/1000)-1/LOG10(5)*LOG10(F[I]/1000)^2)
1825       Oasplc[I] = La[I]-Aweight[I]
1830     NEXT I
1840     FOR I = 1 TO Rows ! PRINT INT(F[I]),ROUND(Aweight[I],1) ! NEXT I
1850   END SUB
1860   ! ------------------------------------------------------------------

1870   SUB Linlin
1880     CALL Prngraph
1890     ! INP PRO "x-min " ALT "-1":Xmin ! INP PRO "x-max " ALT "4":Xmax
1895     Xmin = 40 ! Xmax = 120
1900     ! INP PRO "y-min " ALT "30":Ymin ! INP PRO "y-max " ALT "70":Ymax
1905     Ymin = 30 ! Ymax = 70
1910     ! INPUT PROMPT "x-tic spacing " ALTER ".1":Xstep
1915     Xstep = 2
1920     ! INPUT PROMPT "y-tic spacing " ALTER "2":Ystep
1925     Ystep = 5
1930     ! INPUT PROMPT "x-label spacing " ALTER "1":Xlstep
1935     Xlstep = 10
1940     ! INPUT PROMPT "y-label spacing " ALTER "10":Ylstep
1945     Ylstep = 10
1950     ! INPUT PROMPT "X-AXIS LABEL " ALTER "T, NORMALIZED":X$
1955     X$ = "ANGLE"
1960     Y$ = "dB"
1970     Xcorr = 0.08*(Xmax-Xmin) ! Ycorr = 0.07*(Ymax-Ymin)
1980     Xlcorr = 1.5*Xcorr ! Ylcorr = 2*Ycorr
1990     Xlshift = 1.2*Xstep ! Ylshift = 0.18*Ystep
2000     SET VIEWPORT 20,100,20,80
2010     SET WINDOW Xmin,Xmax,Ymin,Ymax
2020     ! IF Ymin<0 THEN MOVE Xmin,0 ! !RDRAW Xmax,0
2030     MOV Xmin,Ymin ! RDR Xmax-Xmin,0;0,Ymax-Ymin;-(Xmax-Xmin),0;0,-(Ymax-Ymin)
2040     MOVE Xmin,Ymin
2050     FOR X = Xmin TO Xmax STEP Xstep ! MOVE X,Ymin ! RDRAW 0,(Ymax-Ymin)/60
```

```
2060     NEXT X
2070     MOVE Xmin,Ymin
2080     FOR Y = Ymin TO Ymax STEP Ystep ! MOVE Xmin,Y ! RDRAW (Xmax-Xmin)/80,0
2090     NEXT Y
2100     SET CLIP OFF ! SET TEXT STYLE 0
2110     MOVE Xmin,Ymin
2120     FOR X = Xmin TO Xmax STEP Xlstep ! TEXT AT X-Xlshift,Ymin-Ycorr:X
2130     NEXT X
2140     SET TEXT STYLE 0
2150     IF Ymin<0 THEN 2160 ELSE 2230
2160     TEXT AT Xmin-Xcorr,-Ylshift:0
2170     FOR Y = Ymin TO -Ylstep STEP Ylstep
2180       TEXT AT Xmin-Xcorr,Y-Ylshift:Y
2190     NEXT Y
2200     FOR Y = Ylstep TO Ymax STEP Ylstep
2210       TEXT AT Xmin-Xcorr,Y-Ylshift:Y
2220     NEXT Y ! GOTO 2260
2230     FOR Y = Ymin TO Ymax STEP Ylstep
2240       TEXT AT Xmin-Xcorr,Y-Ylshift:Y
2250     NEXT Y
2260     SET TEXT ALIGN 3,5
2270     TEXT AT (Xmax+Xmin)/2-Xlshift/2,Ymin-Ylcorr:X$
2280     TEXT AT Xmin-Xlcorr,(Ymax+Ymin)/2-Ylshift:Y$
2290   END SUB
2500   SUB Filing
2510     INPUT PROMPT "FILING? ":F$ ! IF F$="N" THEN 2600
2520     INPUT PROMPT "NAME FILE? ":F1$
2530     OPEN #2:F1$,"W"
2540     PRINT #2:Wdeg,La,Oaspl,Oasplc
2550     PRINT #2:"ANGLE,AWEIGHT LEVEL,OASPL,OASPLC=OASPL+AWEIGHT"
2560     PRINT #2:"DOT PROPFAN PROPAGATION PROJECT"
2570     CLOSE #2
2600   END SUB
3000   SUB Noisecorr_levels
3005     DIM Corrl[Rows] ! DECLARE LOCAL X1,X2
3010     INPUT PROMPT "AVERAGE A-WEIGHT dB OF BACKGR NOISE: " ALTER "13":Lav
3012     FOR I = 1 TO 110
3020       X1 = 10^((Oaspl[I]-La[I]-Lav)/10) ! X2 = 10^((Aweight[I]-Lav)/10)
3030       Corrl[I] = La[I]-Aweight[I]+10*LOG10((1-X1)/(1-X2))
3035       PRINT Wdeg[I],INT(F[I]),La[I],ROUND(Corrl[I],2)
3040     NEXT I
3050   END SUB
```

```
100 REM "SOURCELV", UNO INGARD, JAN 31, 1989
110 REM TO BE USED IN CONJUNTION WITH THE CONVERTED DOT DATA FILES IN WHICH MEASU
RED OASPL ARE GIVEN AS A FNCTN OF EM ANGLE, OBTAIANED FROM PROGRAM "DTAHANDL"
120 REM AND FILES WITH ATTENUATION DATA OBTAINED FROM "KIN_ATT"
130 REM BY ADDING THE MEASURED LEVELS AND THE ATTENUATION FOR EACH ANGLE OF EMISS
ION, THE SOURCE CHARACTERISTICS ARE OBTAINED
140 ! ************************************************************************

150 INP PRO "NEW CALC OR DATA FROM FILE N/F ":Q$ ! IF Q$="N" THE 200 ELS 152
152 INPUT PROMPT "NAME OF FILE: " ALTER "A_SL_B10.DAT":N$
154 DIM Wdeg[110],A1[110],A2[110],Atot[110],Oaspl[110],Sl[110],Wn[4],Ln[4]
156 OPEN #2:N$,"R"
158 INPUT #2:Wdeg,A1,A2,Atot,Oaspl,Sl
160 CALL Plots
162 END
165 ! -----------------------------------------------------------------------

200 PRINT "Dotdata:" ! CALL Dotdata ! PRINT
210 PRINT "Atten_angle_table:" ! CALL Atten_angle_table ! PRINT
220 PRINT "Attenuations:" ! CALL Attenuations ! PRINT
230 PRINT "Sourcelevel:" ! CALL Sourcelevel ! PRINT
235 PRINT "Nasadata:" ! CALL Nasadata ! PRINT
240 PRINT "Plots:" ! CALL Plots
250 END
260 ! --------------------------------------------------------------------------

400 SUB Dotdata
420   INPUT PROMPT "NAME OF DOT-FILE " ALTER "B10_L-W.DAT":D$
425   DIM Wdeg[110],La[110],Oaspl[110],Oasplc[110]
430   OPEN #2:D$,"R"
440   INPUT #2:Wdeg,La,Oaspl,Oasplc
450   CLOSE #2
460 END SUB
470 ! -----------------------------------------------------------------------

600 SUB Atten_angle_table
610   INPUT PROMPT "NAME OF ATTEN FILE " ALTER "KINA_313.WND":F$
615   INPUT PROMPT "NR OF ELEMENTS IN EACH ARRAY: ":Ne
620   DIM Wref[Ne],Va2[Ne],Rdiscr[Ne],Arrt[Ne],Aair[Ne],Asph[Ne]
630   OPEN #2:F$,"R"
640   INPUT #2:Wref,Va2,Rdiscr,Arrt,Aair,Asph
650   CLOSE #2
660 END SUB
670 ! --------------------------------------------------------------------------

800 SUB Attenuations
805   DIM A1[110],A2[110],Atot[110]
810   FOR I = 1 TO 110
820     FOR J = 1 TO Ne-1
825       IF Wdeg[I]-Wref[J]=0 THEN 831 ELSE 830
830       IF SGN(Wdeg[I]-Wref[J])+SGN(Wdeg[I]-Wref[J+1])=0 THEN 831 ELSE 832
831       A1[I] = (Aair[J]+Aair[J+1])/2 ! A2[I] = (Asph[J]+Asph[J+1])/2
832     NEXT J
835     Atot[I] = A1[I]+A2[I]
```

```
 840     PRINT Wdeg[I],ROUND(A1[I],2),ROUND(A2[I],2),ROUND(Atot[I],2)
 850   NEXT I
 860 END SUB
 870 ! ------------------------------------------------------------------

1000 SUB Sourcelevel
1005   DIM S1[110]
1006   DECLARE LOCAL I
1010   INPUT PROMPT "REFLECTION CORRECTION " ALTER "5":Refl
1020   FOR I = 1 TO 110
1030     S1[I] = Oaspl[I]+Atot[I]-Refl
1040     PRINT Wdeg[I],ROUND(S1[I],2)
1050   NEXT I
1060 END SUB
1070 ! ------------------------------------------------------------------

1100 SUB Nasadata
1200   DATA 40,91.5,57,96,86,100,103,93.5
1205   DIM Wn[4],Ln[4]
1210   FOR I = 1 TO 4
1220     READ Wn[I],Ln[I]
1230   NEXT I
1240 END SUB
1250 ! ------------------------------------------------------------------

1400 SUB Plots
1410   INPUT PROMPT "PLOTS? ":P$ ! IF P$="N" THEN 1500 ELSE 1412
1412   INP PRO "atten or sourcelevel? a/s ":S$ ! IF S$="S" THE 1420 ELS 1512
1420   Xmin = 40 ! Xmax = 120 ! Ymin = 40 ! Ymax = 120 ! Xstep = 2 ! Ystep = 5 ! X
lstep = 10 ! Ylstep = 10 ! X$ = "ANGLE" ! Y$ = "dB" ! Xlshift = 1.4*Xstep ! CAL Lin
lin
1430   MOV Wdeg[1],Oaspl[1] ! FOR I = 1 TO 110 ! DRA Wdeg[I],Oaspl[I] ! NEX I
1440   MOVE Wdeg[1],S1[1] ! FOR I = 1 TO 110 ! DRAW Wdeg[I],S1[I] ! NEXT I
1445   SET POINT STYLE 3
1450   FOR I = 1 TO 4 ! PLOT POINT Wn[I],Ln[I] ! NEXT I
1460   INPUT PROMPT "C? ":C$ ! IF C$="N" THEN 1480 ELSE 1470
1470   PRINT #1:A$
1480   SET GRAPH 0 ! CLEAR GRAPH
1490   INPUT PROMPT "ANOTHER COPY ":C$ ! IF C$="N" THEN 1500 ELSE 1420
1500   GOTO 1518
1512   Xmin = 0 ! Xmax = 180 ! Ymin = 0 ! Ymax = 100 ! Xstep = 10 ! Ystep = 10 ! X
lstep = 30 ! Ylstep = 20 ! X$ = "ANGLE" ! Y$ = "dB" ! Xlshift = 0.8*Xstep ! CAL Lin
lin
1513   MOVE Wdeg[1],A1[1] ! FOR I = 1 TO 110 ! DRAW Wdeg[I],A1[I] ! NEXT I
1514   MOVE Wdeg[1],A2[1] ! FOR I = 1 TO 110 ! DRAW Wdeg[I],A2[I] ! NEXT I
1515   MOV Wdeg[1],A1[1]+A2[1] ! FOR I = 1 TO 110 ! DRA Wdeg[I],A1[I]+A2[I] ! NEX
I
1516   INPUT PROMPT "C? ":C$ ! IF C$="N" THEN 1518 ELSE 1517
1517   PRINT #1:A$
1518   SET GRAPH 0
1519 END SUB
1520 ! ------------------------------------------------------------------

2000 SUB Linlin
```

```
2010   CALL Prngraph
2020   ! INPUT PROMPT "x-min":Xmin ! INPUT PROMPT "x-max":Xmax
2030   ! INPUT PROMPT "y-min":Ymin ! INPUT PROMPT "y-max":Ymax
2040   ! INPUT PROMPT "x-tic spacing":Xstep
2050   ! INPUT PROMPT "y-tic spacing":Ystep
2060   ! INPUT PROMPT "x-label spacing":Xlstep
2070   ! INPUT PROMPT "y-label spacing":Ylstep
2080   ! INPUT PROMPT "X-AXIS LABEL":X$
2090   ! INPUT PROMPT "Y-AXIS LABEL":Y$
2100   Xcorr = 0.1*(Xmax-Xmin) ! Ycorr = 0.07*(Ymax-Ymin)
2110   Xlcorr = 1.5*Xcorr ! Ylcorr = 2*Ycorr
2120   ! Xlshift = 1.4*Xstep
2125   Ylshift = 0.23*Ystep
2130   SET VIEWPORT 20,100,20,80
2140   SET WINDOW Xmin,Xmax,Ymin,Ymax
2150   ! IF Ymin<0 THEN MOVE Xmin,0 ! !RDRAW Xmax,0
2160   MOV Xmin,Ymin ! RDR Xmax-Xmin,0;0,Ymax-Ymin;-(Xmax-Xmin),0;0,-(Ymax-Ymin)
2170   MOVE Xmin,Ymin
2180   FOR X = Xmin TO Xmax STEP Xstep ! MOVE X,Ymin ! RDRAW 0,(Ymax-Ymin)/60
2190   NEXT X
2200   MOVE Xmin,Ymin
2210   FOR Y = Ymin TO Ymax STEP Ystep ! MOVE Xmin,Y ! RDRAW (Xmax-Xmin)/80,0
2220   NEXT Y
2230   SET CLIP OFF ! SET TEXT STYLE 0
2240   MOVE Xmin,Ymin
2250   FOR X = Xmin TO Xmax STEP Xlstep ! TEXT AT X-Xlshift,Ymin-Ycorr:X
2260   NEXT X
2270   SET TEXT STYLE 0
2280   IF Ymin<0 THEN 2290 ELSE 2360
2290   TEXT AT Xmin-Xcorr,-Ylshift:0
2300   FOR Y = Ymin TO -Ylstep STEP Ylstep
2310     TEXT AT Xmin-Xcorr,Y-Ylshift:Y
2320   NEXT Y
2330   FOR Y = Ylstep TO Ymax STEP Ylstep
2340     TEXT AT Xmin-Xcorr,Y-Ylshift:Y
2350   NEXT Y ! GOTO 2390
2360   FOR Y = Ymin TO Ymax STEP Ylstep
2370     TEXT AT Xmin-Xcorr,Y-Ylshift:Y
2380   NEXT Y
2390   SET TEXT ALIGN 3,5
2400   TEXT AT (Xmax+Xmin)/2-Xlshift/2,Ymin-Ylcorr:X$
2410   TEXT AT Xmin-Xlcorr,(Ymax+Ymin)/2-Ylshift:Y$
2420 END SUB
3000 SUB Prngraph
3010   A$ = CHR$(12)
3020   OPEN #1:"PRN","W"
3030   PRINT #1:"MMAP 6,8192,0,-24486,4,0,1;"
3040   PRINT #1:"SHOWA 6,B000H:0 0,0 720,348 50,50 4,6;"
3050 END SUB
```