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AN OPERATIONAL PREDICTION FOR FAR FIELD AIRBLAST EFFECTS :

PRACTICAL EXPERIENCE AT CAEPE.

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abstract

During the firings of explosives or during the testing of solid rocket motors, detonation or deflagration generates high amplitude aerial shockwaves. Before performing a large-scale test, the commander of the facility must know what risks it can create for nearby populated areas according to local weather conditions : this corresponds to the French Z5 security zone.

The prediction system used at CAEPE is presented : the physical assumptions and numerical discretizations are reviewed. Key factors are studied and verifications are computed on two real situations. This prediction has been operationnally used since 1987 and this experience is summarized : the complexity of the numerical code is sufficient. However, the knowledge of weather conditions has to be improved in order to secure operational prediction.

Long range acoustic levels due to high noise generation is also discussed. An example for the noise of ARIANE 5 launcher is described.

KEYWORDS : Far-field focusing, shockwaves, Z5 limits, operational prediction, explosives, rocket motors, static firings.

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1 - INTRODUCTION

1.1 - ENVIRONMENTAL NEEDS FOR A TEST CENTER

Any test center must know what potential environmental problems can be created before deciding to perform a new test. For example, static firings of solid rocket motors or of explosives can generate risks outside the facility area in the following fields :

a) high aerial shockwave due to a detonation of a 1.1 pyrotechnical object or due to the pneumatical explosion of a highly pressurized volume (especially at the end of a firing)
b) high noise due to the generation of sounds by the exhaust jet of combustion gases
c) artificial cloud created by the combustion gases and pollutant species such as HCL
d) X Ray propagation if a high generator is used during a firing in order to investigate combustion phenomena.

Other risks can happen such as fragment hazards or high thermal flux but they are restricted to the close surrounding of the test site.

The DGA/CAEPE - Centre d'Achèvement et d'Essais des Propulseurs et Engins - is a rocket test center under the authority of the «Délégation Générale pour l'Armement» - French Ministry of Defence. It is mainly responsible for static firings of rocket motors or for security tests of explosive systems. Twelve different test facilities are used. Figures 1 and 2 shows photographs of tests bays during and after explosions. In particular the facility for large security tests is designed for potential detonations up to 20 tons of 1.1 propellant or explosive and for a few hundreds tons of 1.3 pyrotechnical products.

The use of these facilities has implied CAEPE in the field of environmental predictions :

- the effect c) has been operationaly predicted at CAEPE since 1980 because of the use of composite propellants containing a high content of hydrochloric acid.
- the effect d) has been solved with the use of huge blocks of concrete or sand.
- the effect b) has been studied at CAEPE since 1985 because of the increasing exhaust flowrate of combustion gases for large size motors.

1.2 - OBJECTIVE OF THE PRESENT PAPER

In the present article, the subject a) «Far-field airblast predictions» is studied and the following approach is considered :

- description of the obligations due to the French legislation and description of risk philo sophy used at CAEPE (part 2 of the present paper).
- description of the general system of prediction used at CAEPE (part 3)
- description of the numerical model (part 4)
- checking of the model on real cases (part 5)
- uncertainties of the general system of prediction used at CAEPE (part 6)
- usefulness of improvements (part 7)

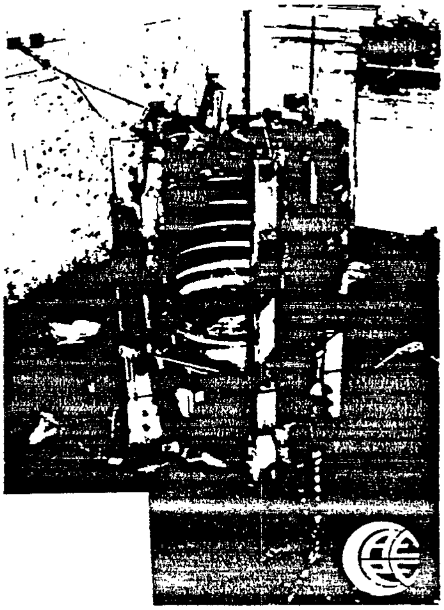
In the present paper, no new theoritical, computational or experimental development will be made compared to what has been already written in the scientific literature. In all the further paragraph, the emphasis will be put on practical comments and «every-day» uses.

The subject b) «far-field noise prediction» has many similarities with the airblast one. This similarity is presented in appendix and an example is described for firings of the motors of the launcher ARIANE 5 in French Guyana.

- Figure 1.a -
Explosion of a 1.3 motor

- Figure 1.b -
Close view of an explosion

- Figure 2.b -
Result after another explosion during a nozzle up firing.The emission of shockwaves has been mainly on a side of a motor



- Figure 2.a -
Result after an explosion

2 - FRENCH LEGISLATION OBLIGATIONS AND GENERAL PHILOSOPHY USED AT CAEPE FOR PREDICTING

2.1) FRENCH LEGISLATION

The French legislation about pyrotechnical safety has been thoroughly made uniform between 1979 and 1981 in order to be easily applied by any factory or test center (references 1, 2, 3). The area surrounding the pyrotechnical facility is classified in five safety areas (table 1) : the Z5 area correspond to light destructions of windows and to very unlikely injuries. The main hazards inside the limits Z1 to Z5 are due to aerial shockwave, fragments throwing and heat flux : the limits for each safety aera are given in table 2. For Z5 aera, over-pressure peaks are less than 50 hPa (0.7 psi).

Definition of safety zones

SAFETY AREA	Z1	Z2	Z3	Z4	Z5
Damages to human beings	Deadly wounds for more than 50 per 100	Important wounds which can be deadly	Wounds	Possibilities of wounds	Very unlikely possibilities of light wounds
Damages to materials	Very heavy damages	Heavy damages	Damages	Light damages	Very light damages

TABLE 1 (Table taken from reference 2)

Physical limits of safety zones

SAFETY AREA	Z1	Z2	Z3	Z4	Z5	OBSERVATIONS
Relative over-pressure peak (in hPa)	600	300	100	50		Higher values than these printed ones may be considered if duration of positive phase of over pressure signal is not above a certain value (of the order of 20 ms for the limits of Z1 and Z2 areas)
Energy of a flung fragment with no sharp corners (in Joule)	50	20	8			These values have to be reduced if the flung fragment has sharp or cutting parts
Heat flux (averaged density in Watt/cm2)	1,5	0,6				This averaged density of heat flux has to be calculated over a duration according to the combustion conditions

TABLE 2 (Table taken from reference 3)

The reference 2 authorizes that the extent of Z5 area may be outside the test center perimeter. However, any crowded places such as hospitals, factories, schools or large buildings are not allowed inside the Z5 aera.

The classification 1.1 correspond to pyrotechnical object which can detonate : their distances for Z1 to Z5 (on a flat ground and uniform weather conditions) are given by Table 3.

Safety distances for1.1 pyrotechnical objects

SAFETY AREA	Z1	Z2	Z3	Z4	Z5
Distance from the charge whose weight is equal to Q	$0 < R_1 < 5 Q_{1/3}$	$< R_2 < 8 Q_{1/3}$	$< R_3 < 15 Q_{1/3}$	$< R_4 < 22 Q_{1/3}$	$< R_5 < 44 Q_{1/3}$

R : in meters
Q : in TNT - equivalent kilograms

TABLE 3 (Table taken from reference 3)

The text of reference 3 mentions that special conditions such as relief can induce variations of the limits Z1 to Z5. The variations of weather do not induce major changes for the extents of Z1 to Z4. The propagation of shockwaves whose peaks are above 50 hPa (0.7 psi) are not highly dependent of temperature or wind variations their prediction is relatively easy a long time in advance (with subcale studies or numerical computations). This can be performed for the primary safety analysis during the design of the test bay. The test site has to be sufficiently large to include the Z4 area. So there is no need for an operational and near-real time prediction for the limits of Z1 to Z4. However, under 50 hPa (0.7psi) aerial shockwave propagation depends highly on the weather stratification : focusing of shockwaves can happen during thermal inversion phenomena or (and) during strong vertical wind shear. So the extent of Z5 can vary according to the local weather conditions on the test day and there is a need for an operational prediction.

2.2) GENERAL PHILOSOPHY USED AT CAEPE

According to the weather conditions, the extent of Z5 can be quite large (e.g. several kilometers beyond CAEPE limits). So, the commander of a test center has the following solutions

Wrong solutions

- One possibility would be to try to reduce the shockwaves near its sources : the design of underground or indoor facilities is nearly impossible, because the combustion gases have a high flowrate (up to 0.3 tons per second at CAEPE). The only solution would be to build an expensive ejector tube and diffuser. This solution is performed only in altitude simulation facilities. For the other test bays, the costs are prohibitive.

- The use of barricades is efficient only for an horizontal distance equal to the height of the barricade multiplied by a factor of 4 (see reference 2). Beyond this distance, the use of barricades is useless in order to protect from aerial shockwaves.

- The purchase of additional ground surfaces is impossible for economical and political reasons.

Chosen solution

The knowledge of Z5 limits is mandatory before performing a large test with tons of 1.1 pyrotechnical products. The solutions chosen by CAEPE is to use the test facility according to the weather solution : before performing a firing, the CAEPE commander has to know where is located the Z5 extent in order to decide to do the firing or to postpone it until better weather conditions. This situation implies a reduction of the operational availability of the test bay but it is the easiest one to apply as far as predictions are not overly pessimistic.

For that reason, CAEPE has developped an operational prediction system which produces a map of the area surrounding its bay perimeter : the levels of shockwave amplitude and the densities of population are shown on this map.

However the commander of CAEPE (or of any large test center) do not care for precise predictions : his only worry is to be sure to clearly understand what are the maximum risks according to the local weather conditions. This implies a prediction of risks and not an accurate prediction of phenomena.The difference between these two aspects are the following :

- no detailed account for complex phenomena as far as their effects are maximized in the risk prediction
- a clearly readable map : to avoid a messy map, only two levels of pressure peaks are drawn
- 20 hPa : possible breakings of windows
    - 10 hPa : unsignificant damages. (This means the end of the Z5 extent).
- time duration and integrated energies of shockwaves are commonly used to estimate potential damages. These factors are not taken in account. Only peak amplitude criteria is used.

In the present paper, the description of prediction system will only deal with predictions of risks. This will allow a lot of simplifications in the computations.

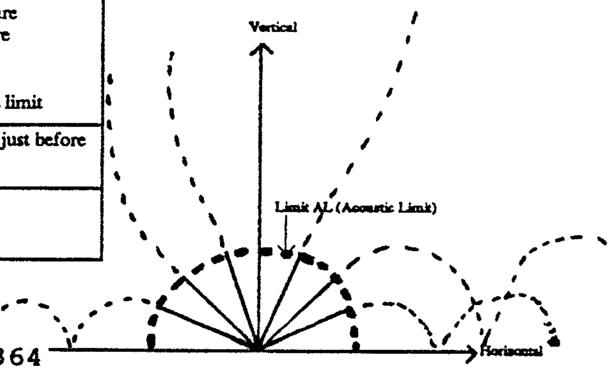
3 - PREDICTION SYSTEM

3.1) GENERAL VIEW

Table 4 gives a general view of the problem for aerial shockwave predictions. As indicated in paragraph 2.1, the close-field for aerial shockwave can be predicted independently to the weather conditions : this prediction is not easy but has to be done only once for every kind of tested pyrotechnical object (e.g. motor, military head...). For the far-field the prediction model is more simple but has to be used just before the test.

	HIGH-LEVEL SHOCKWAVE	SMALL-LEVEL SHOCKWAVE (summation of acoustic waves)
Model	non linear	linear (Frequencies are conserved during propagation)
Principal parameters to take in account	Source directivity Test bay relief Ground nature	Ground nature Temperature Wind Humidity Location of AL limit
Availibility for prediction	Can be forecast a long time in advance	Can only be forecast just before the firing
Limit	Between 30 and 50 hPa (0.4 and 0.7 psi)	

Table 4 : General features for prediction of shockwaves
(For energy generated less than 200 TNT - equivalent tons)



3.2) SYNOPTIC OF THE SYSTEM USED AT CAEPE

Table 5 shows a synoptic of the prediction system used at CAEPE. The knowledge of the local weather conditions in the lower atmosphere are the first step. However, the key point is obtaining the map with critical danger areas. This is the result of a numerical prediction model which uses acoustic ray theory and which is detailed in paragraph 4. (The need for the knowledge of weather conditions depend on what are the inputs in the numerical code).

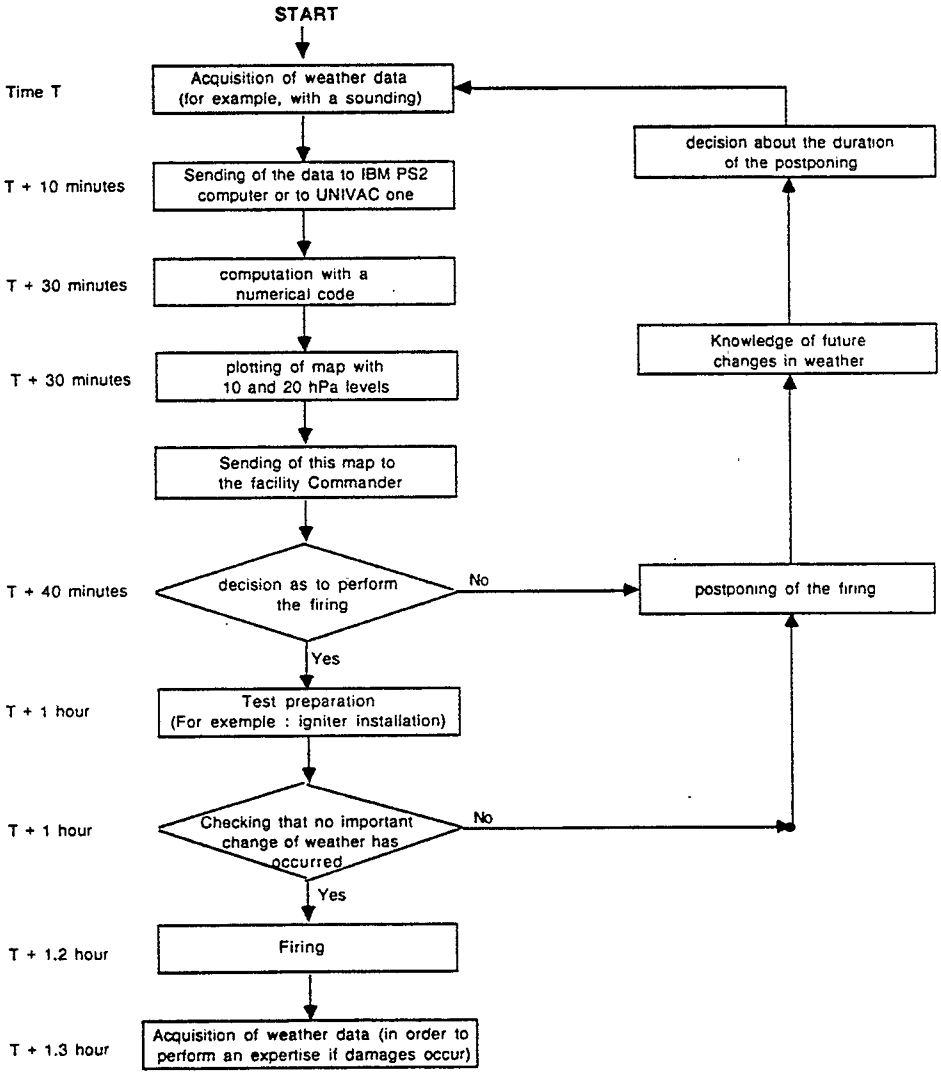


Table 5 : Synoptic of whole chain of decision. For small firings, some steps can be excluded. For complicated firing with a long preparation of the test equipment, weather sounding and predictions can be performed all along the day in order to allow an early postponing.

4 - NUMERICAL MODEL

4.1) STATE OF ART

Far field acoustic propagation has long been studied (see reference 4 for example). Predictions were highly dependent on poor capabilities of computers : in 1977, REED used a simple ducting criteria for sound velocity gradient in order to allow launching of TRIDENT 1C4 missiles from CAPE CANAVERAL. Nowadays, prediction uses mainly the two following methods :

- ray theory.
  This assumes that sound propagation can be separated in small energy tubes with no interference between one and the others. So, the equations can be locally solved for each tube. The computation is performed with every tube along its path : this a lagrangian method.
  For practical purposes (helicopter noise detection or road design), ISL and CSTB have recently developped models according ray theory (see references 6 and 7 for more details).

- parabolic method.
  The equation for the whole field are solved : it is an Euler method. This method is more accurate than the ray theory method for low frequencies, but it needs a lot of computation time. ONERA has recently developped a model according to this theory, and has compared it with other models (references 8 and 9).

A lot of numerical work has also been performed for the study of longe range propagation of noise in the underwater field because of the needs in discretion or detection of submarines. Most of this work can be applied in aerial acoustics.

4.2) MODEL USED AT CAEPE

4.2.1) Basic assumption

A shockwave can be considered as the sum of short duration sinusoidal "acoustic" waves (this is a simple Fourier transform). For small amplitude shockwaves, it is assumed that these acoustic waves can be studied independenly : thereare no interferences during theirs propagation. So, the propagation of small-amplitude shockwave can be modelized with summing the results of propagation of these independant acoustic waves. This "independance" assumption may be theorically unsatisfaying byt it is enough for a risk prediction.

4.2.2) Choice of ray theory

Parabolic methods do better predictions in low frequencies than acoustic ray ones. However detaled comparisons between models show that small discrepancies in the case of focusing of acoustic energy. Figure 9 of reference 9 exibits less 3 dB between ray and parabolic results at 80 Hz and 200 Hz.

So the ray theory has been chosen by CAEPE. Its main advantages are the following :

- fast computations
- ability to separate the following physical phenomena : i) geometrical propagation inside the air, ii) absorbtion by ambiant, iii) rebounds on the ground. This allows the creation of codes with separated modules
- an easy qualitative view of insight phenomena : the plotting of rays in a vertical plan enable to visualize where are the focusing aeras.

4.2.3) Two-dimensional model

In case of transverse wind, the acoustic propagation can be curved, due to the term dVE/dY ROSEN (reference 7) has studied this effect. Its Figure 11 (reference 7) shows that focusing areas are not so different with or without transverse wind : the difference in location is less than the order of 1 km at a distance of 10 kilometers from the source. This accuracy is beyond the scope of risk prediction (see paragraph 2.2). So, the model used at CAEPE is only two-dimensional and takes no account of effects of transverse winds.

Practically, for the geometrical propagation, this induce to solve the equations :

Ray paths :

$$\frac{d^2Z}{dx^2} = \frac{-1}{C + Ve}\left[\frac{dC}{dz} + \frac{dVe}{dz}\right] \qquad (1)$$

Z = vertical coordinate
X = horizontal coordinate
Y = horizontal coordinate perpendicular to «X»
C = modulus of sound velocity
Ve = modulus of wind velocity

In case of constant gradients, the equation (1) has parts of circles as solutions. Theseeasy analytical solutions were used by scientists in the past before the improved performaces of computers.

4.2.4) Source modelisation

The inputs for acoustic propagation are the shockwave field at the limit AL between short and long ranges areas of table 4. In CAEPE, we have simply taken 50 hPa for this limit even if this is not so clear in the scientific litterature. The knowledge of the geographical position of this limit is taken in diagrams published for T.N.T explosions. At CAEPE, we use ISL diagrams (reference 10) for flat grounds with T.N.T - equivalent mass of explosives or propellants.

For simplification of computations, the energy is supposed to be uniform for the part of limit AL close to the ground with angle less than 20°. Actually, focusing computations use only the rays which creates rebounds. If one ray has no rebound (which means it goes straight up in the sky), the above rays will not rebound. So «uniform» assumption is necessary only for rebounding rays : these ones are located generaly between the horizontal direction and an angle less than 20°.

4.2.5) Computation of energy levels

Equation (1) describes the propagation path of acoustic rays. Two situations can accur :

a) - the rays impact the ground at a certain distance from the source and they rebound according to the nature of the soil and of the vegetation

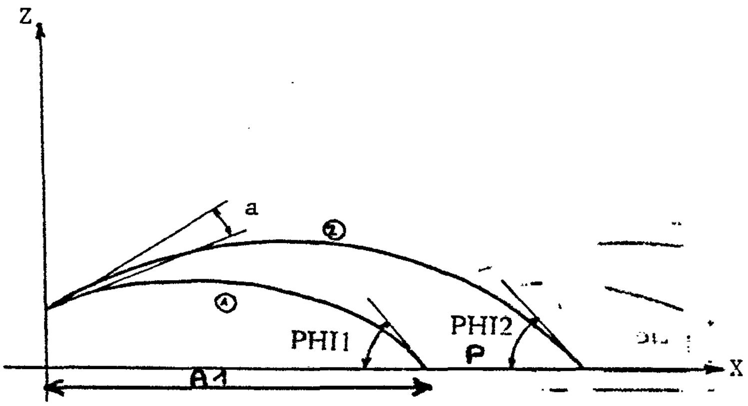
b) - the rays go up in the sky and no energy tube reach the ground.

Rebounds on the ground

For case a), the model used at CAEPE assume the conservation of energy in the acoustic tubes. This gives the equations (2) with notations explained in Figure 2.

$$\left.\begin{aligned} S &= b\ (A2 - A1)\ \frac{(\sin PHI1 + \sin PHI2)}{2}\ \frac{(A1 + A2)}{2} \\ I &= \frac{W}{S} \end{aligned}\right] \quad (2)$$

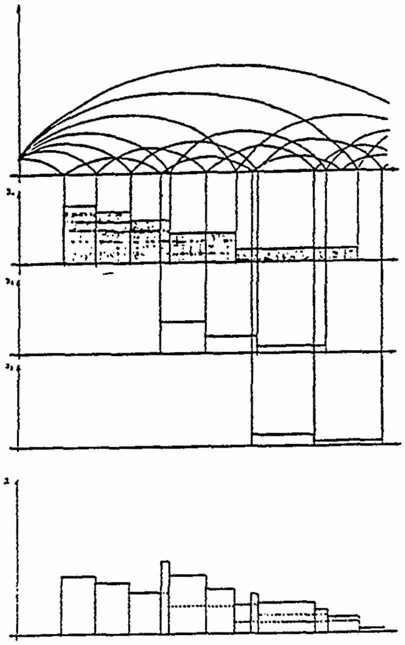
with b = horizontal discretization angle
W = energy in the elementary tube
I = intensity of energy at the point on the ground level



- Figure3 -
Elementary acoustic rays which are downwards

The summation of first rebounds from all acoustic tubes is a simple summation of the arithmetic modules of energy brought by each tube. As ever in this article, the phase aspect is not taken in account : the phase variations are complicated to compute: turbulence or local errors on the weather are important for these variations. So an easy maximization (see paragraph 2.2) is to suppose that all the waves are with the same phase.

The summation of all succesive rebounds is performed in the same manner. This gives the scheme described in Figure 4.



- Figure 4 -
Summation of energy due to rebounds

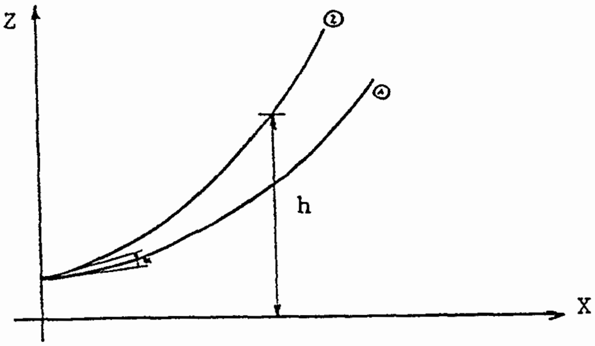
No rebound on the ground

For case b), ray theory indicates that no energy reaches the ground. So, no noise should be heard at the ground level. However, diffraction and diffusion effects induce a small amount of noise and they are not taken in account in ray theory. These phenomena are to be maximized by simple methods.

In addition, the case of atmospheric neutral conditions (no gradients of wind and temperature) is between cases a and b. It produce an hemispheric solution with a decrease law in $R^{1/2}$.

For a risk prediction, a maximization of case b) can be performed with the equations (3) with notations explained in Figure 5.

$$\left.\begin{aligned} I &= \frac{W}{S} \\ S &= h \, x.a \end{aligned}\right] \quad (3)$$



- Figure 5 -
Elementary acoustic rays which are upwards

4.2.6) Atmospheric absorption

Humidity and temperature in the air can induce important attenuations of sound. In hot and humid weather, this induce a fast decrease of amplitudes of sound waves. To take in account this factor, CAEPE use tables from reference 11.

4.2.7) Absorption during reflection on the ground

This effect happens each time that there is a rebound of an acoustic path on the ground : the induced attenuation can be important on soft soils such as mud, damps, or snow and on thick vegetation.

In order to study this effect, CAEPE has used the simple theory which takes in account the acoustic ground impedance Z and the angle between the ground and the incident reflected ray. Values for Z were taken from references. The computations were performed only with amplitudes of sound waves and not with phases. After studies with the natures of soils around CAEPE, it was found to be no too pessimistic to use a perfect reflection ground. This induced a simplification of CAEPE model and was consistent with a risk prediction.

4.2.8) Raised relief effects

The CAEPE is located in the pine trees forest of LANDES near Bordeaux. It is the largest forest in France and its ground is flat : altitudes varies for less than 15 meters for distances in tens of kilometers. So, for CAEPE computations, the ground was supposed to be uniformly flat.

4.2.9) Necessary weather inputs

In order to run our numerical model, the following weather imputs are needed :

- vertical profile for temperature
- vertical profile for wind (direction and amplitude)
- averaged humidity

These values are needed locally. Because of its uniform nature of the LANDES aera, weather conditions are taken as uniform for the area surrounding CAEPE. So, only one vertical sounding in a close location from the test site is considered. According to the hour of CAEPE firings, the sounding from the close BORDEAUX International Airport or from CAEPE own weather station is used. For less than 10 Tons of TNT-equivalent, only the first vertical 1000 meters are used as inputs for the prediction computations. Up to 200 Tons, the first 2000 meters are considered to be useful. The time delay between weather CAEPE firing has to be minimum. As described in table 5, this depends on the remoteness of the location of test site, on the performances of numerical program for prediction and on the preparation of the firing. In anti-cyclonic conditions, weather conditions ca n be quite steady in time. However, this is not the case during the passage of fronts. This matter will be discussed in paragraph 6.

5 - CHECKING OF THE CHOSEN MODEL

5.1) Verification of theoretical ray paths

As explained in paragraph 4.2.3) these paths are relatively simple. The ones from CAEPE models were checked with the ones of Figures 20 to 23 of reference 12. In addition, the numerical stability was checked on the repeatability of curves after numerous rebounds.

5.2) Souge explosion

On the 21 November 1986, a large detonation occured during the destruction of 1.5 Tons of old explosives in a site called SOUGE which is west from BORDEAUX. This phenomena created a few problems around. The larger damages happen in a factory located at place X in Figure 6. A strong «bang» sound was also heard in the dashed area.

Legend : ▨ Villages where a strong "bang" was heard

☒ Location of the factory where the biggest damages occur.

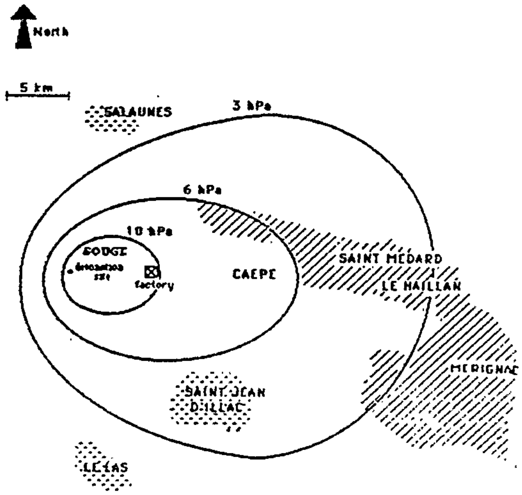
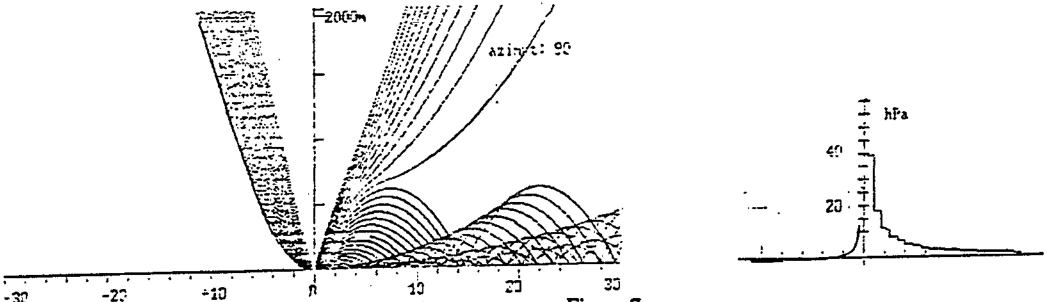


Figure 6

Map of the area around SOUGE detonation site

Predicted overpressure contours are also shown

The explosion site was less than 10 kilometers away from BORDEAUX airport where was performed weather sounding at about the same time (an half hour) than the explosion. CAEPE prediction model was used with these data. Figure 6 shows an example of computation for 270° - 90° directions. Figure 7 show the predicated amplitude level for the aera surrounding the sites. The predicted level 10 hPa (0.14 psi) is coherent with the penomena encountered in the factory. The areas where the «bang» noise was heard, correspond with the predicted levels above 3 hPa (0.04 psi).



- Figure 7 -

Example of prediction computation in a vertical plane

5.3) MEDINA EXPLOSION

On the 13 November 1963, a detonation of a huge quantity of chemical explosives happened at Medina facility, on the outskirts of San Antonio, Texas(Figure 8). Reference 13 describes the damages created by this accident and contains ray theory computations. The TNT equivalent was taken as 140 tons. The weather conditions were known because of temperature and wind sounding at the close San Antonio International Airport.

With the east-west wind and the temperature profiles described in reference 13, predictions were performed with CAEPE code. For example, Figure 9 shows ray paths for the 90° - 270° direction. The North-South component of the wind was supposed to be nul (Reference 13 indicated that the wind gradients were predominantly in the east-west direction).

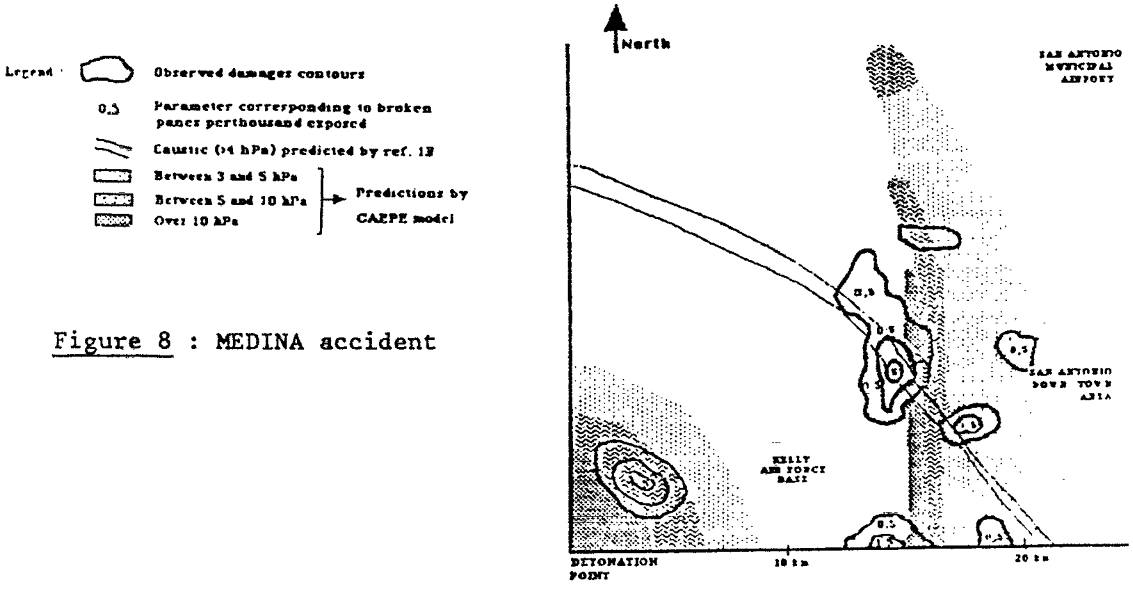
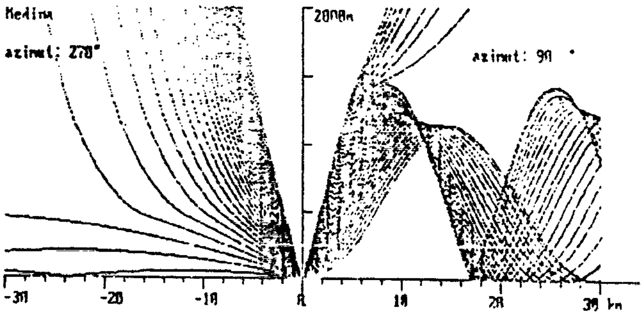


Figure 8 : MEDINA accident

Figure 8 shows CAEPE predictions. Its main features correspond with real observations (taken from reference 13) : a focusing due to the wind gradient occur 15 kilometers away from Medina site. The extent of this focusing area is about 3 kilometers large. The encountered levels range from 8 hPa (0.12 psi) to 3 hPa (0.04 psi) : these levels are enough to break glasses in an urban area. For directions close to the north one, larger discrepancies occur between CAEPE observations and reference 17 results : the planned obtention of North South component of the wind will perhaps enable to solve these discrepancies.



- Figure 9 -
Example of focusing for Medina explosion
(azimuth 270° - 90°)

6 - ESTIMATION OF UNCERTAINTIES

6.1) GENERAL COMMENT

The uncertainties and errors in CAEPE predictions are due to the following origins :

- physical phenomena which are not taken or badly taken in account by CAEPE model
- numerical imperfections of CAEPE code
- wrong estimation of weather conditions

These three problems are detailed in the next paragraphs.

6.2) PHYSICAL PHENOMENA WHICH ARE NOT TAKEN IN ACCOUNT BY CAEPE MODEL

6.2.1) Turbulence :

According to scientific litterature (see ref 9, 12, 14 and 15 for example), turbulence modifies amplitudes and phases of acoustic waves. Reference 9 indicate variation of 10 dB over short periods, typically a few seconds. Sophisticated models can take in account turbulence, such as KE, Kε or higher order closure equations. However, this requires the precise knowledge of surrounding flowfield. This is beyond our operational capabilities.

For shockwaves prediction, the result is the summation of different acoustic waves (see paragraph 4.2.1.) Turbulence has a different effect on each wave according to its wavelength. So, turbulence effect is perhaps less important for shockwave levels than for mono-chromatic sounds. In addition, the loss of coherences for phases will induce a decrease in overpressure peak. This decrease is not predictable by CAEPE model.

6.2.2) Diffusion and diffraction

These effects are difficult to take in account. They have a weak importance for prediction of focusing levels. They are predominant in «silent» zones where no acoustic rays arrive, but they still induce very low level of noise. So, these effects can be neglected in an operational prediction.

6.2.3) Source directivity

The assumption of uniform emission for rays paths close to the ground (see paragraph 4.2.4) is certainly wrong. On a 1/50° subscale test of an open air test bay, ISL has performed measurement of pressure waves at the angle 5° and 10° all around the source (reference 16). Variations of only 20 % were found between all these measurements.

This result is satisfying because of the relatively small induced error. However this scheme can be wrong in case of peculiar accident : detonation in a rocket motor can start in an anormal way and can even be only partial. This can give peculiar diagrams of directivity.

6.2.4) Existence of caustic

When different ray paths merge at the border of a silent zone, this give a caustic curve where energy density is supposed to be infinite. This is obviously not true in reality, but considerable enhancements of pressure peaks can nevertheless happen near this caustic. This effect is of prime importance in a risk prediction. A relatively correct account for this is to have a sufficient vertical angular discretization:this allow to simulate enough ray paths (see paragraph 6.3.2. for numerical details).

6.3) NUMERICAL IMPERFECTIONS

6.3.1) Horizontal angular discretization

The computation is performed for vertical planes with an angle b between each plane. Usually, the value for b is taken equal to 10°, 15°, 20° or 30° according to the needed accuracy. An angle of 15° is largely enough to detect dangerous situations. So, this discretization induces no important error in a risk prediction.

6.3.2) Vertical angular discretization

In a vertical plane, the computations are performed in order to show results similar to the outputs presented in Figure 7. The angle "a" between two beginnings of rays is a key point for computation time.

Focusing-case

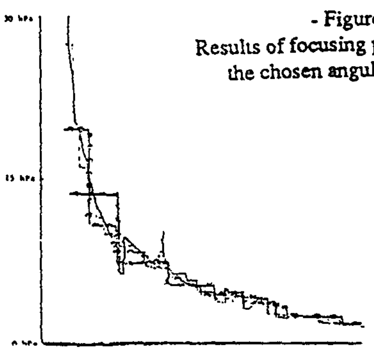
Figure 10 a shows results with "a" values equal to 0.1°, 0.3°, 1°, 2° for a focusing case. Obviously more detailed results are obtained for small angle increments (0.1°, 0.3°) than for large increments. Local increases of 4 hPa compared to a mean value of 8 hPa are observed. This is due to the close encounter of two adjacent rays (see previous discussion about caustics).

Non-Focusing case

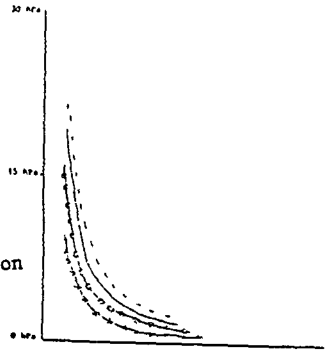
The equation (3) is an artificial use of an extrapolation of results from neutral conditions. The angle "a" is the angular discretization. The path of the first ray above the horizontal (see Figure 4) is supposed to give the energy at ground level. The case of convex ray paths is most common for non-focusing rays. So, the rougher is the angular discretization, the higher is the «computed» value for pressure peak. This obvious feature is illustrated in Figure 10 b. This feature has no importance because the military perimeter around the test site is large enough to insert any non-focusing situation especially the neutral conditions ones.

6.3.3) General reliability of the numerical code

Some peculiar situations can happen if the software has not been fully analyzed. For example, rebounds close to the external corner near the external border (usually 15 or 30 kilometer) can stop the computation. Similar problems happen also if mistakes have been done during writing of code lines. This is a weak point for CAEPE code because it was written by engineers and not by specialistss of software quality. This kind of worry are well known, in software development. They are beyond the scope of the present paper.



- Figure 10.a -
Results of focusing prediction according
the chosen angular discretization



- Figure 10.b -
Results of non focusing prediction
according to the chosen angular discretization

6.4) METEOROLOGICAL INPUTS

6.4.1) Errors in the sounding

Usual radio sounding give temperature, humidity and windspeed with a high rate of values in less than one hundred meters. However the results can be wrong if the gauges are badly calibrated or badly installed. In addition, the local sounding can be non-representative of the general conditions, for example with a sounding performed under a cumulo- nimbus.

In order to investigate these errors, various typical weather situations were studied with artificial variations. First, variations of temperature profile were introduced inside general conditions with no temperature inversion and a strong wind gradient. These conditions are shown in Figure 11 a. The result of computation with CAEPE code are shown in Figure 11b. Secondly, the same method was applied inside general conditions with a weak wind gradient and a strong temperature inversion (Figure 12a and b). Thirdly, variations of wind profile were introduced inside general conditions with a strong wind gradient and no thermal inversion (Figure 13a) ; the computation results are shown in Figure 13b.

These results show strong variations of pressure peaks. The order of magnitude of 6 dB corresponds to the multiplication of the signal by a factor equal to 2.

6.4.2) Time evolution of weather conditions

Table 5 indicates the synoptic of operations before a firing. About one hour happen between the obtention of radio sounding and the firing time. This delay can induce changes of weather. Some minor changes can happen without changing the general pattern of the risk prediction. However, others can be more important, especially during a front passage.

The only way to protect oneself against such strong changes is to have a precise weather forecast station. At CAEPE, the one from Centre d'Essais des Landes (D.G.A /C.E.L.) is used : D.G.A/C.E.L. station is part of French National Weather Service (METEO FRANCE) and has a general code for all the Eastern North Atlantic and a detailed code with a local grid of 30 kilometers over BORDEAUX area.

6.5) SUMMARY : SYNOPTIC OF ERROR SOURCES

	ACCOUNT IN MODEL	INDUCED UNCERTAINTY
1 - Physical phenomena		
Turbulences	no account	large uncertainty
Diffusion + diffraction	no account	small in focusing cases
Rebound on ground	maximized	no uncertainty because of the maximization
application of ray theory to low frequencies	————	small in focusing cases
Absorption by air	account	weak
2 - Numerical imperfections		
Horizontal angular discretization	————	no large uncertainty with 10° to 20° angles
Vertical angular discretization	————	large uncertainty for 1° and 2° angle weak uncertainty for 0.1° to 0.5° angles
3 - Weather account		
Input errors	————	large uncertainties
Weather variations	no account	large uncertainties but can be planned with a good meteorological forecast.

Note 1 : these two effects were already discussed in paragraph 4 and have not been

6.6) OPERATIONAL APPLICATION

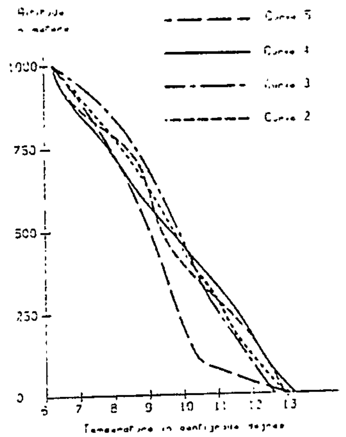
Except for strong turbulence situations or for a wrong use of radiosounding materials, the study described in previous paragraphs show that a realistic risk prediction can be performed : the assumed uncertainty is taken as equal to 5 hPa (0.07 psi) for a 15 hPa (0.22 psi) signal and to 3 hPa (0.04 psi) for a 7 hPa (0.1psi) signal. So the levels 20 hPa (0.29 psi) and 10 hPa (0.15 psi) shown on the prediction map to CAEPE commander are actually the levels 15 hPa (0.22 psi) and 7 hPa (0.1 psi).

7 - CONCLUSION

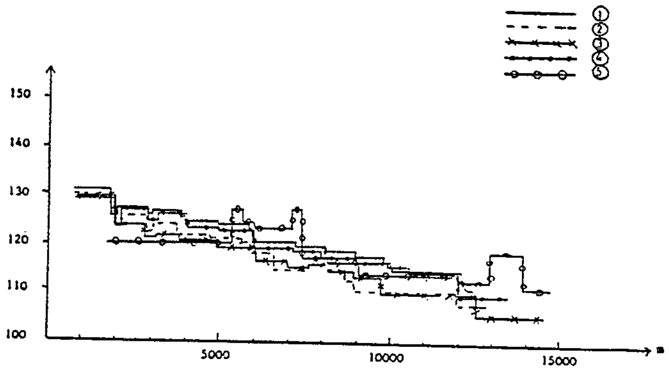
For a risk analysis, the code used at CAEPE is sufficient : the approximated aeras of focusing and the order of magnitude of pressure peaks are relatively well predicted or at least maximized.

The main problems are due i) to the approximate values of sounding results and ii) to the time delay between weather sounding and actual test. With an IBM PS2 this delay is rather independent of minutes of computer time for map producing : it is partly due to the duration of operations and possible delays before and after the agreement of the commander to perform the firing.

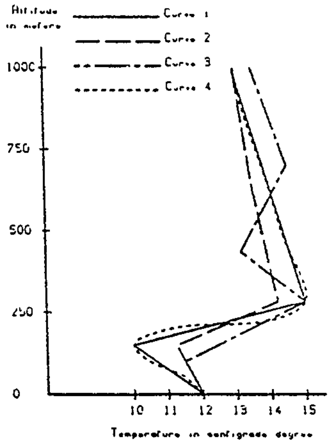
In order to improve our prediction, emphasis has to be put on immediate acquisition of weather data : even the best prediction model will perform a wrong output if its inputs are unreliable. Real time sounding apparatus gave been developped in industrial world for the last ten years. For example, SODAR using acoustic diffraction gives real time wind profiles every minute. Presently, at CAEPE, a study is going on in order to modify our weather station. This will lead to an improved reliability of the prediction results.



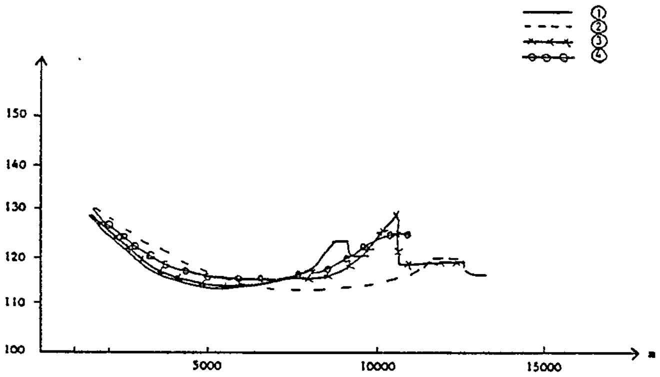
- Figure 11.a -
Different temperature profiles studied in case of a strong wind gradient and no thermal inversion



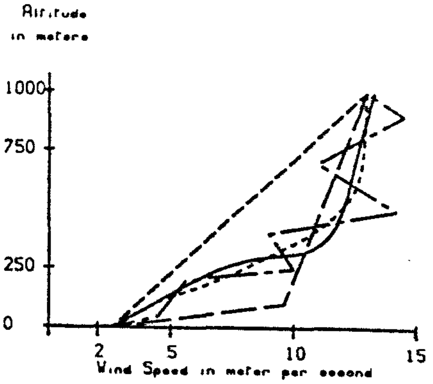
- Figure 11.b -
Long-range predictions with the temperature profiles described in Figure 11.a



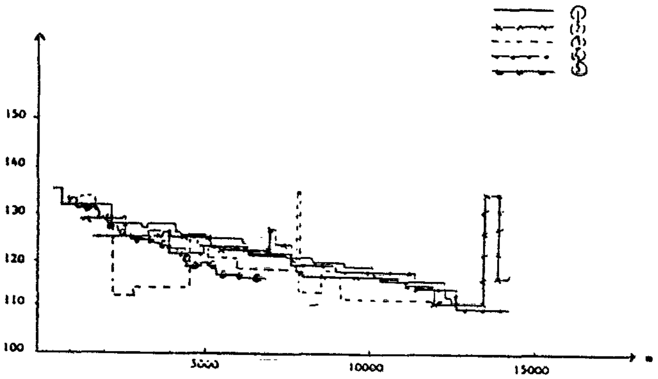
- Figure 12.a -
Different temperature profiles studied in case of a strong thermal inversion



- Figure 12.b -
Long-range predictions with the temperature profiles described in Figure 12.a



- Figure 13.a -
Different wind profiles studied in case of a strong wind gradient an no thermal inversion



- Figure13.b -
Long-range predictions with wind profile described in figure 13.a

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APPENDIX

PREDICTION OF LONG DURATION HIGH NOISE

Table A1 shows a comparison between high noise predictions and shockwaves ones.

	SMALL SHOCKWAVE	HIGH NOISE
Legislation	rules about the areas with potential light damages (references 1,2,3)	no surrounding area over 160 dB Limited level over the whole year : integration of all noises during a year : (see reference 17)
Computations	ray theory for the far field	ray theory
Source	limit of shockwaves near 50 hPa	nearly a pinpoint source
Outputs	map in hPa	map in dB (for building response) and in dB a (for human response)

Table A1 : Comparison between high noise predictions and shockwave ones.

A version of CAEPE model inserts noise sources and produces maps with levels in dB and dBA. An example is given in Figure 14 : it shows the far field noise generated by the launcher ARIANE 5 before it lifts off from the ELA3 platform. The induced levels are very weak for the areas far from the launching pad : they are even weaker than the ambiant normal noise.

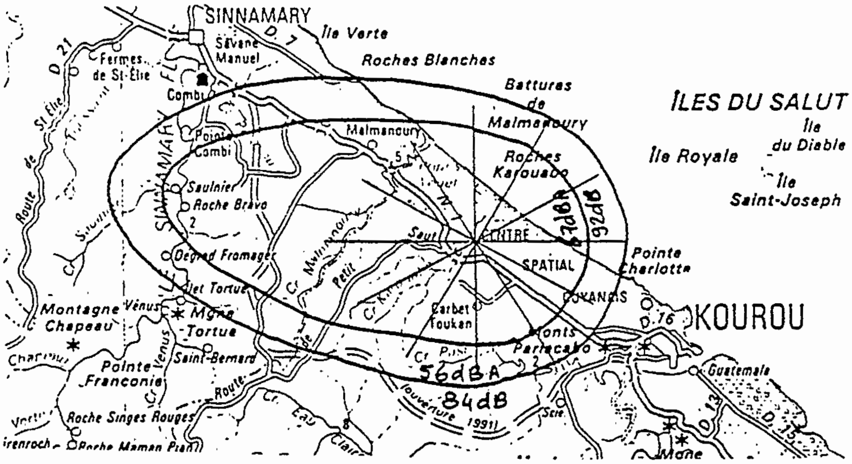

Figure 14 : Far field levels generated by the launcher ARIANE 5 before its lift off. This prediction work was performed on account of CNES/CSG.
(Curves in dB and dBA are normally not the same : the attenuation of sound due to air or to ground rebounds are different according to frequencies. However, for ARIANE 5 computations, these curves are only slightly different. So, on the map, each curve represent a level in dB and one in dBA).