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DEPARTMENT OF PHYSICS AND GEOPHYSICAL SCIENCES
SCHOOL OF SCIENCES AND HEALTH PROFESSIONS
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA

Technical Report PGSTR-PH76-26

DETERMINATION OF TRANSFER FUNCTION OF COPE CORRELATION INTERFEROMETER INSTRUMENT

By

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Prepared for the
National Aeronautics and Space Administration
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The separation of these signals is accomplished by an empirical approach using a set of calibration data and computer algorithms. Concern over the reliability of this empirical approach prompted the present study.

BACKGROUND STUDIES

Two background studies indicated the need to estimate the transfer function of the instrument. Both of these used the field data obtained during the July 1974 field tests in Washington, DC. A large quantity of data was gathered in and around Washington from a helicopter. The original analysis was done by General Electric and is reported in COPE - National Capital Air Quality Control Region Field Test Report (1975), to be released as a NASA Technical Memorandum. An example of the resulting analysis is shown in figure 1. Although the CO variation shows very plausible variations with high burdens over heavy traffic regions, the methane variation gives no such interpretation. Large local sources of CH_4 would be required to register such changes in total burden.

The question as to whether the variation of the methane gas amount in the Washington data is real or produced by the method of data reduction is not easily answered. But one can consider the following proposition: Can random noise simulate the observed variations in the data? Do the following: determine a noise figure for an individual interferogram point, generate random numbers (a flat distribution between + and - the noise figure was used), apply the exact weight algorithm used in the original analysis, and take 60-second running means of 10-second averages. The result of this approach is shown in figures 1 and 2. Note the similarity between the simulated data in figure 2 and the real data in figure 1. The amplitude and period of the "time" series are strikingly similar. This does not prove that the signal is all noise. It does show that it is consistent with the hypothesis and that the periodic structure can be induced by the running mean processing used in the General Electric analysis.

Since a realistic noise figure was used in the simulated data, any real signal should be superimposed on this noise variation. Thus the signal tc noise (S/N) for the variation must be less than unity. It should be noted that the simulated data do not predict the same average value as the real data. Since the weight analysis is a linear process, the inclusion of the average interferogram with noise would correct for this. Thus the mean interferogram may be a meaningful measure of the gas amount, also sufficiently low frequencies in the time series may have a sufficiently high S/N to give a measure of the gas amount. The high noise coupled with the high v/h sampling rate gives little hope of observing this, however.

In the above analysis, it was assumed that the weight algorithm did not degrade the actual signal. An empirical orthogonal function analysis was conducted on one flight of the Washington data. Deviations from the mean were used. In this calculation, the eigenvectors are ordered by their significance in the total variation, with the associated eigenvalue measuring the percent of variance explained by the corresponding eigenvector. The first eigenvalue explains 66 percent of the variance. The first eigenvector is shown in figure 3. Also shown is the average interferogram. The similarity of these leads one to conclude that a large part of the variance can be explained by instrument instability in the form of a drift in amplitude. Since most of the signal is due to methane, the weight algorithm will yield changes in methane.

Further evidence for instrument instabilities can be seen in laboratory data. Figure 4 shows the variation of the amplitude of a single data point (interferogram delay point 16) throughout an 8-hour period. The light source and gas amounts were controlled. The slow linear increase in signal indicates internal changes in the instrument. This variation correlates well with a change in room temperature. The total variation is in excess of 10 percent. Thus this is a serious stability problem. Since the variation is similar to that found in the Washington field data, this instability may be the explanation for that variation.

TRANSFER FUNCTION

The transfer function of an instrument is that function which "transfers" the incoming signal, in this case radiation, into the output voltage, in this case, interfercgram amplitudes. The total transfer function may be written formally as follows:

$$T(x) = V(x)\int_{t_i}^{t_{i+1}}\int_{\xi,\phi}\int_{dA}\int_{\nu} S(\nu)R(\xi,\phi,x(t),y,z,\nu)F(\xi,\phi,\nu)Q(t)$$

$$\times\, d\xi d\phi dA d\nu dt(x)$$

where:
- x = delay
- t = time
- ξ,ϕ = field of view angles
- y,z = aperture stop positions
- S = atmospheric spectra
- V = interferometer visibility function
- F = the filter (optical) transmission function
- Q = the electronic processing and filtering (including synchronous detection process)
- t_i = the integration time for a single data point.

It is very difficult to measure this function directly. In particular, the measurement of R requires a tunable monochromatic high resolution source with narrow field of view and a small spot size. The approach taken here is to calculate theoretically $T(x)$ for an ideal transfer function and to compare the instrument output with this calculation. Differences are used to infer changes in one of the internal functions contributing to the transfer function. Some simplifying assumptions were made to isolate the least known part of

the transfer function. R is assumed to be ideal. In that case, it may be written:

$$R(x,\nu) = V(x) \cos(\nu x)$$

independent of ϕ, ξ, y, and z. This is equivalent to all flat surfaces and perfect alignment. Under laboratory conditions, with uniform sources and uniform gas mixtures, variations from ideal for this function should not affect the comparison with theory. The effect is to decrease the visibility and thus the efficiency of the instrument. Still another transfer function parameter which had not been determined was the actual delay range of the data in the interferogram. This caused a great deal of confusion in the interpretation of the interferogram. This delay range was determined to be:

$$0.287 \text{ cm} < x < 0.418 \text{ cm}$$

This was determined from the comparison of the interferograms with theoretical calculations as part of the transfer function determination.

TRANSFER FUNCTION COMPARISONS

Under laboratory conditions, with a constant source and a nominal .12 atmosphere cm of CO in a gas cell, data were obtained. CO was chosen because the signal peaks in the instrument delay range and the line parameters necessary to make the theoretical calculations are well known. The optical filter function used was that given by the manufacturer. The calculated interferogram got a poor fit to the measurement.

To test this interference filter transmission function, the filter was removed and the transmission measured at several incidence angles by P.J. LeBel at NASA/Langley. The variation was found to be large. Since the optical system focuses the large aperture of the interferometer onto the filter, and since the direct normal incidence light is deflected by a small mirror for use by the reference channel, only

light at angles between 9 and 22 degrees is incident on the filter. A new response curve was calculated using the actual geometry within the instrument. A comparison of these curves is shown in figure 5.

Two additional factors were included in the final comparison. These are the visibility function V(x) as calculated for the field widened conditions and actual elements used in the instrument. Also the "vacuum" interferogram was subtracted from I and Q. The vacuum interferogram represents the interferogram due to the filter alone and possibly due to some as yet unknown reasons. When this is compared with the measurement, the results are shown in figures 6 and 7. Qualitative agreement is apparent for both CO and a mixture of CH_4 and CO. The CO comparison shows that the theory and the instrument data have the same shape. Two discrepancies are to be noted. First, a slight shift between the two curves. Second, the absence of the high frequency (0.011-cm period) component present in the theory is not seen in the instrument. The source of the first is likely to be a slight shift in the center frequency of the filter relative to the determined filter response. A shift of 3 cm^{-1} could account for this shift in the interferogram. The second discrepancy is more disturbing. The sampling in the instrument is sufficient to detect the ripple seen in the theory. Also, the data shown in figure 7 for CH_4 and CO in the cell shows frequency components as high as that missing in the CO interferogram. Extensive checks on the theoretical program have been made and no errors have been found which could account for these ripples. Further tests on the theoretical and experimental aspects of this problem are continuing.

CONCLUSIONS

Comparison of theoretical and instrument response functions has been demonstrated as a method for determining the instrument transfer function of the COPE correlation interferometer. It has been shown that qualitative agreement can be obtained when discrepancies between theory and instrument are investigated and the instrument components are analyzed in detail.

Empirical approaches to the analysis such as that used in the original analysis by General Electric cannot separate instrument-induced noise from actual signal variations. The instrument instabilities that are presented here are not easily distinguished from real variations in gas amount. An analysis based on the theory can correct these problems. However, the only way such an analysis can proceed is through the transfer function of the instrument. The approach presented here for determining the transfer function and the problems encountered in this work indicate the degree of knowledge of the construction and fabrication of the instrument that is needed to ascertain even an approximate function. A further conclusion is that a more direct approach to the determination of the transfer function is desirable with the same comparison of theory and instrument responses as the test of goodness of the determination.

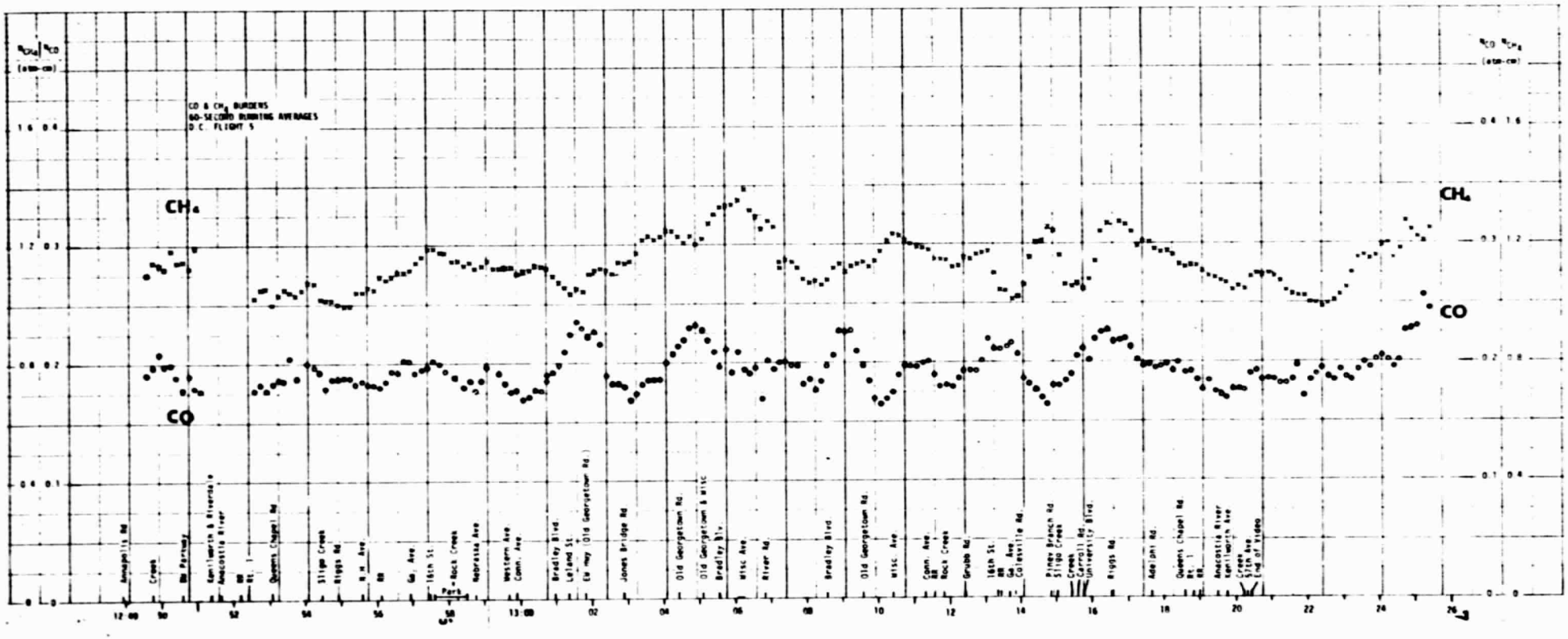

Figure 1. Sample of data from Washington field test as analyzed by General Electric.

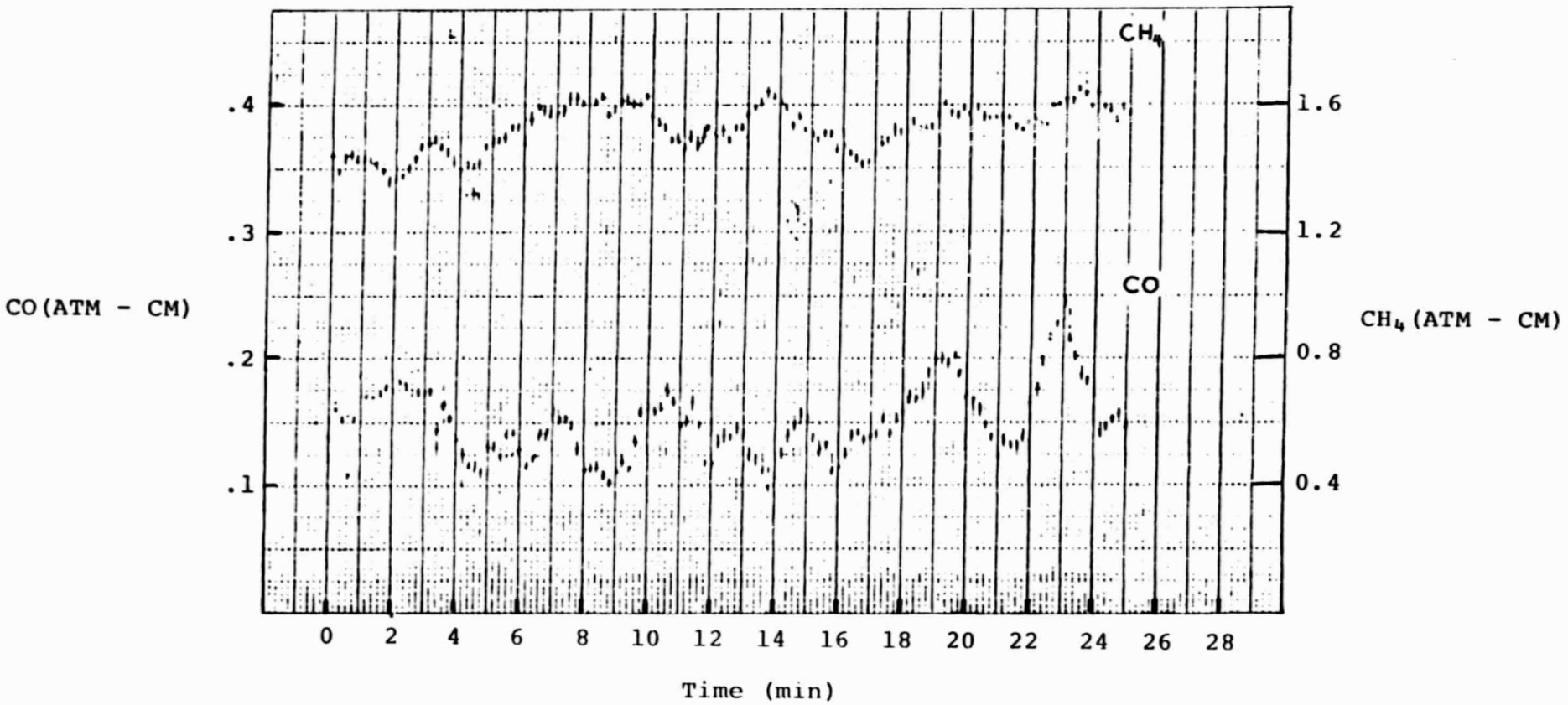

Figure 2. Simulated "data" from this work. Uniform random numbers were used with a range corresponding to noise in the actual data and the same analysis was applied as used in figure 1. Note the similar character and amplitude of the variations.

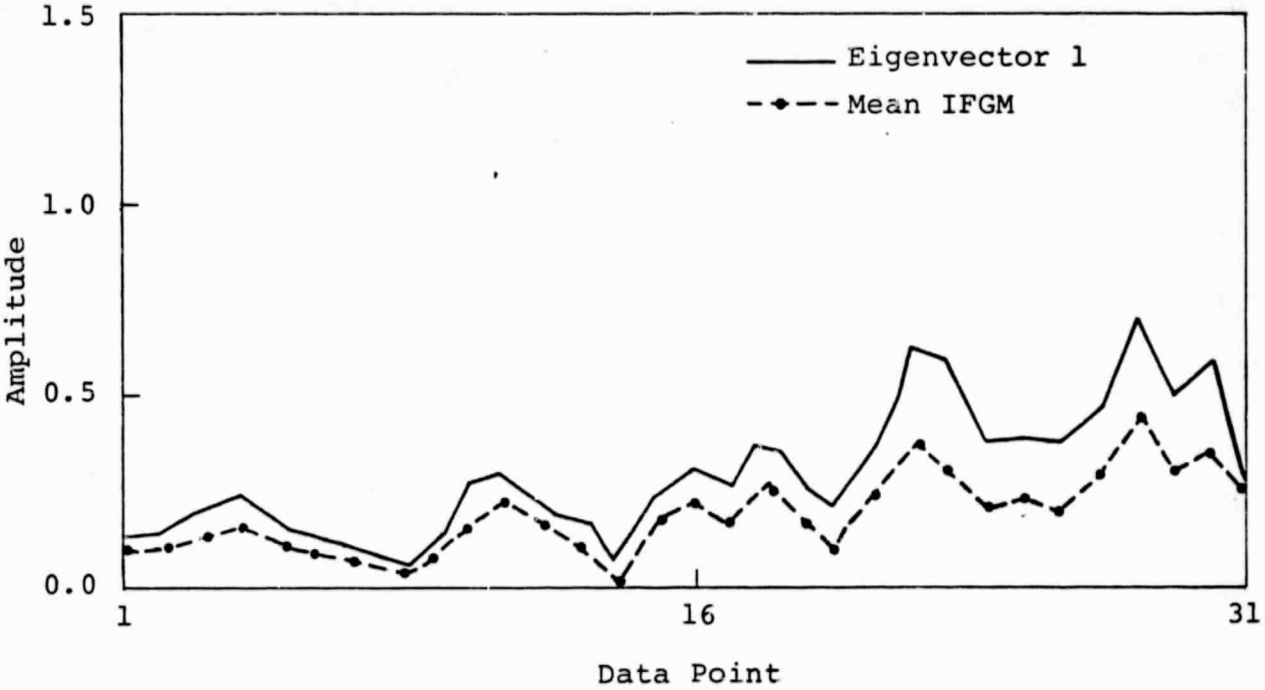

Figure 3. Comparison of mean interferogram for data of figure 1 and first eigenvector obtained by maximizing the variance of the deviations from the mean. The similarity of these indicate that 70 percent of the variance can be explained by a drift in the signal.

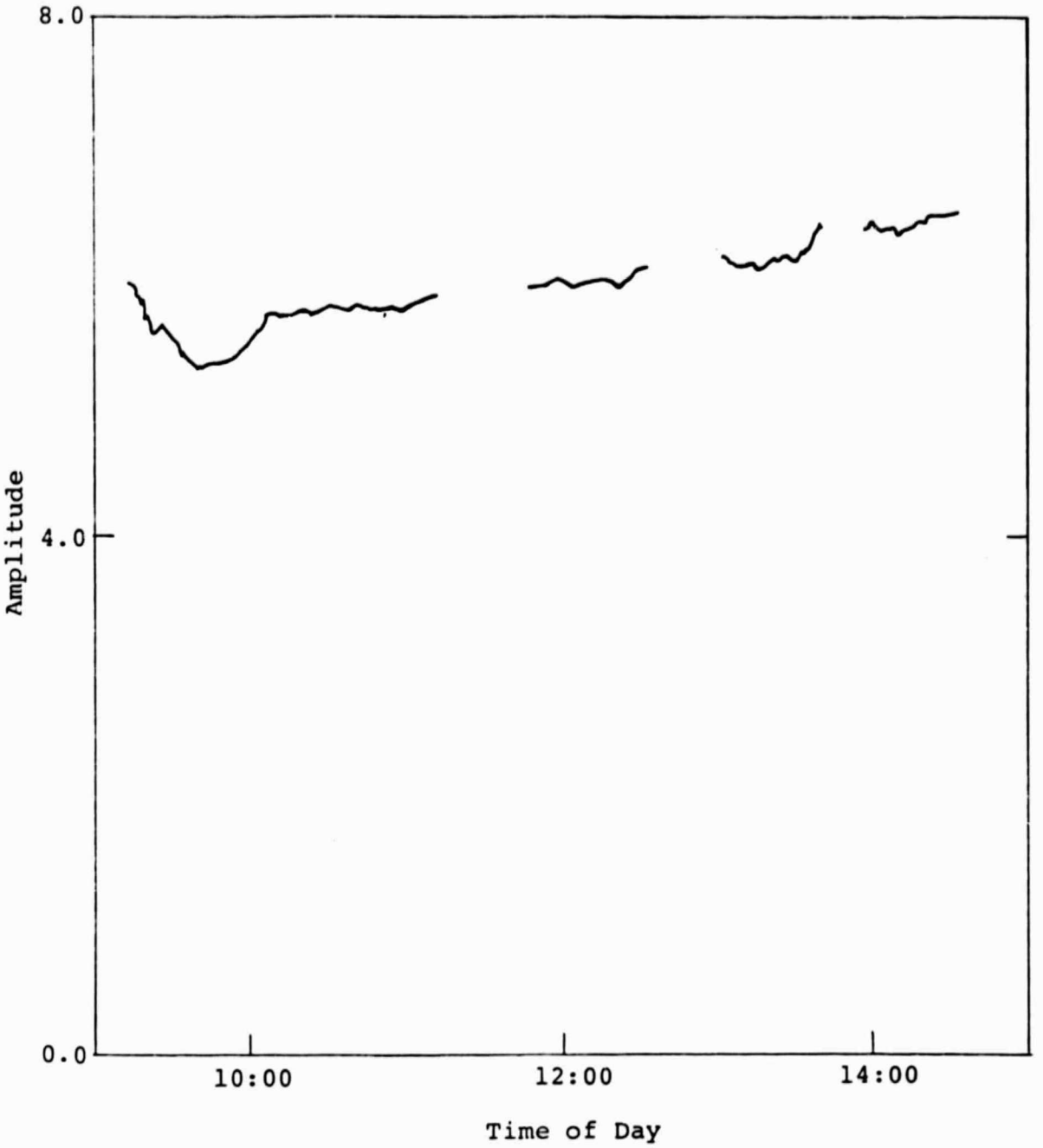

Figure 4. Laboratory demonstration of instrument drift instability during a single day with laboratory conditions held constant. A nearly linear change with time is observed.

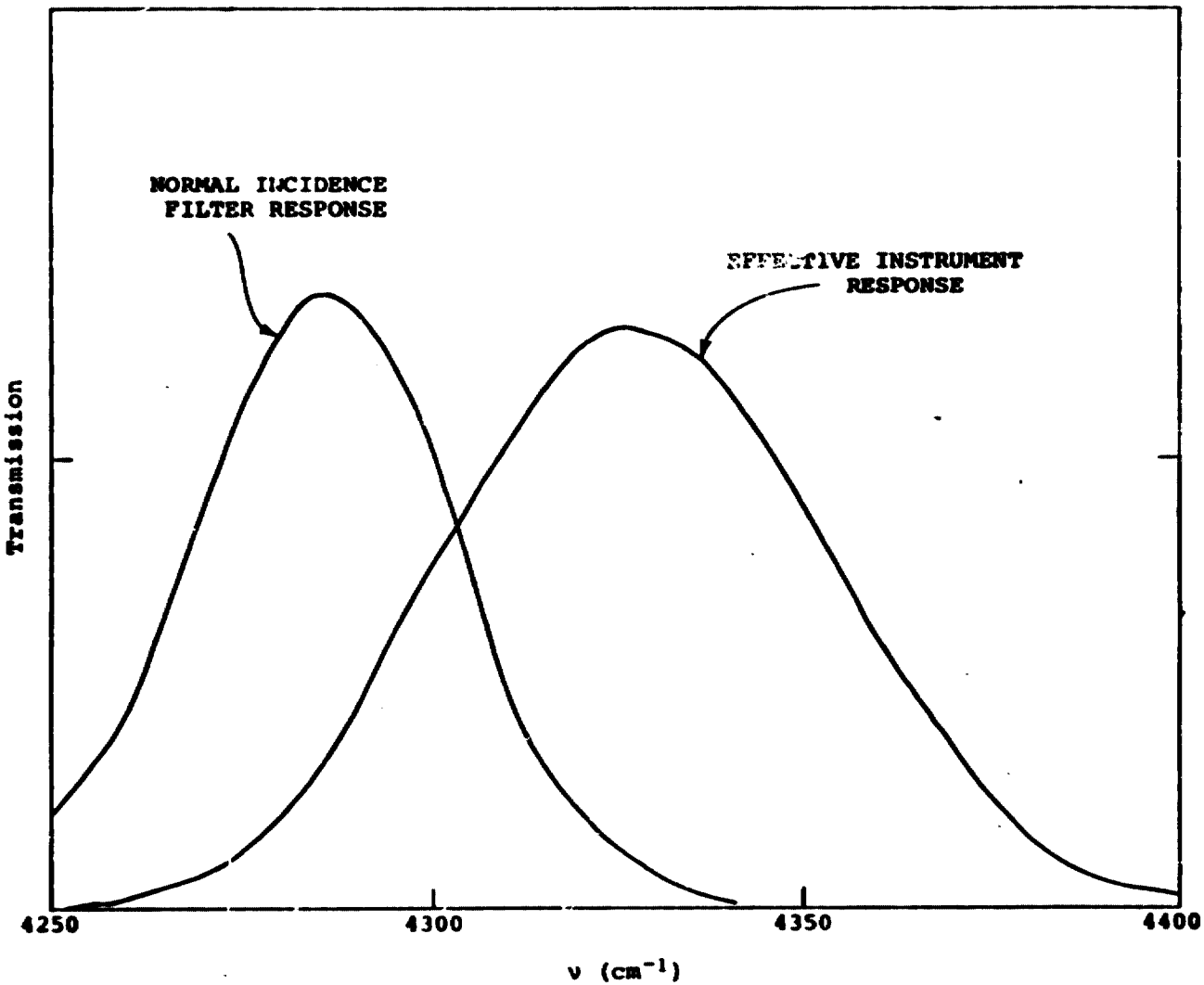

Figure 5. Comparison of normal incidence filter response with effective response of non-normal incidence light of the instrument. Note that most of the bandpass of the actual instrument is outside of the intended bandpass.

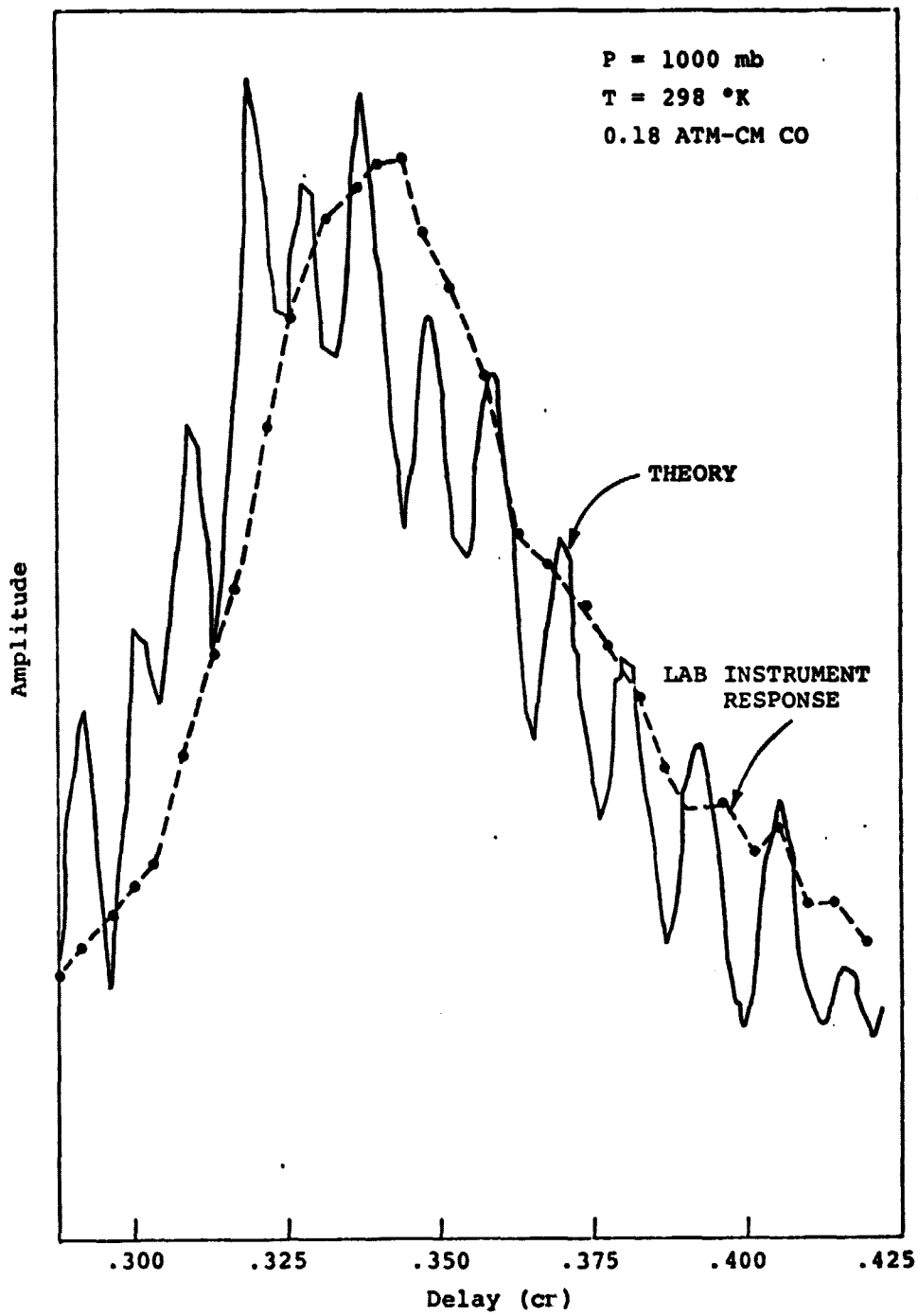

Figure 6. Comparison of instrument response in laboratory with gas cell containing CO with theory. Filter response and visibility functions have been included. The ripples in the theory and their absence in the data is still unexplained.

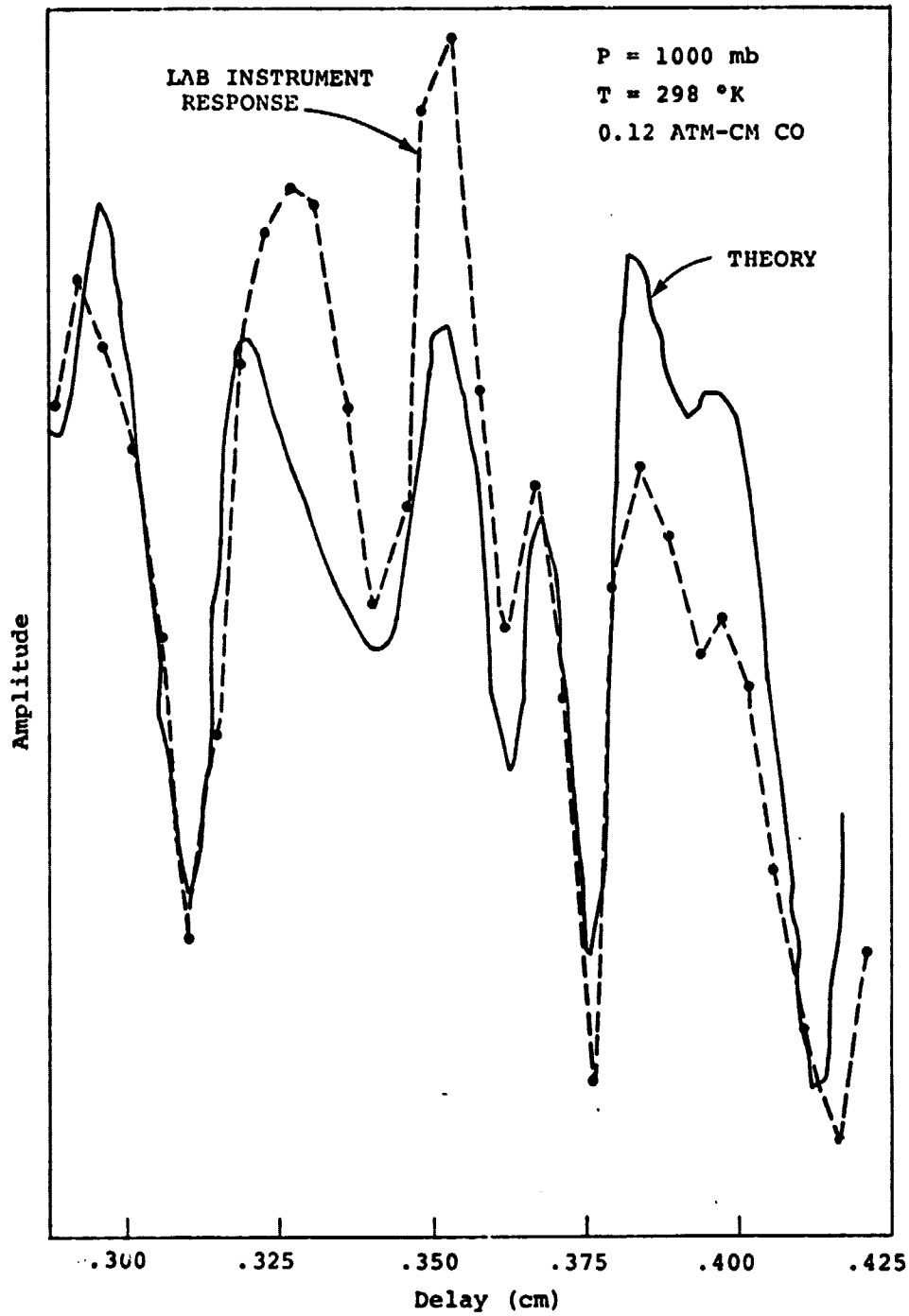

Figure 7. Comparison of instrument response with cell containing CO and CH_4. Qualitative agreement is good but the amplitudes are different. These differences may be due to errors in the line strengths for CH_4 used in the theoretical calculations.