"D-REGION TURBULENCE STUDY"

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Approved by: Vincent P. Goddard
Vincent P. Goddard
Co-principle Investigator

Prepared by: V. P. Goddard
C. F. Knapp

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INTRODUCTION AND OBJECTIVES

Since about 1954 the use of various alkali metal vapor trails, particularly sodium vapor trails, as a research tool in the study of the earth's upper atmosphere has become quite extensive (Reference 1). Suitable vehicles (e.g. sounding rockets) are sent aloft into and above the D and E regions of the atmosphere during twilight, releasing along their trajectories a continuous filament of sodium vapor. The solar radiation illuminates the sodium vapor causing it to fluoresce with the distinctive D-line yellow. Since at twilight the sun is depressed from 6 to 9 degrees the background illumination is low and so the sodium vapor trails appear quite visible and because of the contrast are fairly easy to photograph.

A sodium vapor trail will persist for several minutes during which time the winds rapidly distort the trail from its original shape. From time lapse photography usually taken during the first few minutes after the initial formation of the trail the wind field can be determined accurately from the gross movements of the trail. Observation of the expansion rate of the trail permits the determination of diffusion coefficients.

Still other studies reveal that below about 110 km there are irregularities, and in some cases at the same time some sort of organization, in the structure of the trail. Currently the exact nature and/or

origin of these characteristics of the trails are not fully understood. It is not known for example if the random irregularity is due to either actual turbulence of the atmosphere or simply a manifestation of the wake of the rocket or even a result of the sodium vapor ejection techniques. (Reference 2 page 15).

The principle objective of this investigation is to consider the use of the alkali metal vapor trails as a visualization medium which will allow the study of details in the trail structure. A similar technique using smoke for visual flow studies in Wind Tunnels has been used for many years in the Aero-Space Department at the University of Notre Dame. As a result, a sizable compendium of photographic data depicting laminar, organized, and turbulent motion has been acquired. Considerable experience has been developed in the interpretation of such data. As a consequence it is felt that a valuable contribution in this area can be made by reviewing NASA's vapor trail data and comparing it with UND's data seeking out any correlation that may exist. The results of such a study will lead to a better understanding of some of the upper atmospheric phenomena and the mechanism involved, whether it be laminar, organized or turbulent motion.

DISCUSSION AND PROGRESS

Literature Survey

As indicated in the introduction the basic conclusion of this investigation will result from the study and interpretation of the vapor trails themselves. However, a search of the literature must and has been made. This necessity exists if the results of this investigation are to be correlated with the postulates and findings of other investigations. Considerable effort has been expended in the extraction from the literature of relevant information.

Photographic Study

Thirty six vapor trail photographs and the associated wind data from four different rocket launching have been acquired to date.* These photographs have been carefully studied and compared with appropriate smoke photographs. The principal result, thus far, is the identifying of four basic and discernible characteristics in the structure of the vapor trails. The first three of the characteristics appeared in nearly all the photographs. They describe in an overall and general manner how the vapor trail structure varies as a function of altitude. With increasing altitudes these characteristics are as follows:

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*These data were made available through the courtesy of Dr. J. F. Bedinger of the Geophysics Corporation of America and Dr. S. Zimmerman of the U. S. Air Force Cambridge Research Laboratory.

1. Irregular - or - (turbulent-like)
2. Globula - or - (a bead like array)
3. Smooth - or - (lamina-like)

This variation with altitude can easily be seen in Figures 1 and 2. These observations are obviously not unique to this investigation. The literature survey has revealed these same observation were noted by others namely References 2 and 3. It is interesting to note this same type of variation with altitude is not peculiar to rocket vapor trails alone. The exact same variation exists in the trails left by meteors descending into the earth's atmosphere (Reference 3).

The irregular or turbulent like structure of the trail appears to be similar in many ways to that observed in the smoke patterns of turbulent flow. Further study is necessary, however, before a reasonably accurate comparison can be made and explicit conclusions stated.

The fourth item of extreme interest that does not, however, appear in the trail structure in every case is what can be referred to as "fingers" see Figure 2. Again for obvious reasons this observation is not unique. These "fingers" have on occasions been referred to as "tendrils" (Reference 4). This type of formation appears to evolve when a vapor trail of an appropriate width becomes so distorted that a portion of the trail alines itself with the local wind direction. This type of flow pattern has been found in boundary layer studies (Figure 3). It is known from boundary layer investigationsthat this type of flow pattern exists where

there is a perturbed shear layer and the depth of the smoke sheath is less than the height of the critical layer (Reference 5). Presumably the existence of these "fingers" in the vapor trail can be accounted for by some type of perturbed shear layer. It remains then to show some sort of possible analytical verification of this conclusion.

Analytical Verification

It is always desirable to posulate, even in visual flow studies, some sort of a mathematical model representing the physical mechanism involved so that an analytical verification of the results can be made. With this in mind and knowing that the "fingers" in boundary layer flow can be produced by a perturbed shear layer, a simplified model employing a velocity profile similar to that found in a half jet emanating into a fluid at rest and perturbed by an unamplifying traveling sinusoidal wave was used. The numerical analysis begins with a defined array of vertical time lines that represent the initial position of a vapor trail. The number of time lines represent the width of the trail which for simplicity was held constant during any given run. Computations show qualitatively that with the passage of time the array of time lines become distorted and assumes a variety of shapes. Figure 4 shows the distortion that occurs with the passage of time for a given initial trail width. The results produced by starting with different initial widths for the same time period (trail width corresponds to smoke depth in boundary layer studies) are also shown.

Inspection of this figure shows that the neutrally perturbed shear layer as posulated offers a possible explanation for the outgrowth of "fingers" from vapor trails and to some extent the production of the beadlike array and the fine turbulent-like structure. It should be emphasized that the atmospheric model as posulated was wholly organized and did not possess any random motion, however, the computer output shows the trail structure to be quite "irregular" or "turbulent-like" and globular".

CONCLUSIONS

The study of vapor trail photographs, and the comparison of these data with boundary layer smoke photographs and together with the computer output of a simplified mathematical atmospheric model, thus far, has led to the following conclusions:

1. The trail structure varies with altitude in the following way; irregular, gloublar and smooth, with transition to smooth taking place at an altitude of about 110 km.
2. On some occasions an out-growth of "fingers" or "tendrils" from the main body of the tail appears.
3. A simplified mathematical model representing a possible atmospheric circumstance offers convincing evidence that the "fingers" (item 2) can evolve under certain conditions from a perturbed shear layer.
4. The computer output of item 3 also indicates that a perturbed shear layer can also account for the irregular and globular structure of the trail (item 1).

FUTURE PLANS

Future plans include the following:

1. The acquisition of much more data. This step is necessary if organized motion such as a perturbed shear layer is to be separated effectively from pure random, motion solely from the interpretation of the trail structure and its change with time.
2. Development of a more generalized computer program to account for more realistic velocity profiles, trail expansion with time and three dimensional effects.
3. Explanations other than perturbed shear layers for the existence of the "irregular" and "globular" structure of the trails will be sought.
4. The determination of, within the frame work of the investigation, the reason(s) for the smooth part of vapor trails and the transitional altitude.
5. Experimentally an endeavor will be made to produce in the wind tunnel a perturbed free shear layer and to introduce smoke initially normal to the flow and observe the resulting deformation and structure. Other analogous laboratory experiments will be devised to verify other significant conclusions reached during the remaining part of the investigation.

REFERENCES

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3. Blamont, J. Nuages artificiels de sodium. Vitesse du vent, turbulence et densite de la hante atmospere. Comptus Redus. Vol. 249, Oct. 1959, page 1248.

4. Hibben, R.D. Launch Vehicle Dynamics - Part I. Aviation Week and Space Technology, Vol. 80 June 8, 1964, page 36.

5. Knapp, C.F., Roache, P.J. and Mueller, T.J. A Combined Visual and Hot-Wire Anemometer Investigation of Boundary Layer Transition. University of Notre Dame, UNDAS-TR-666 CK (May 1966).

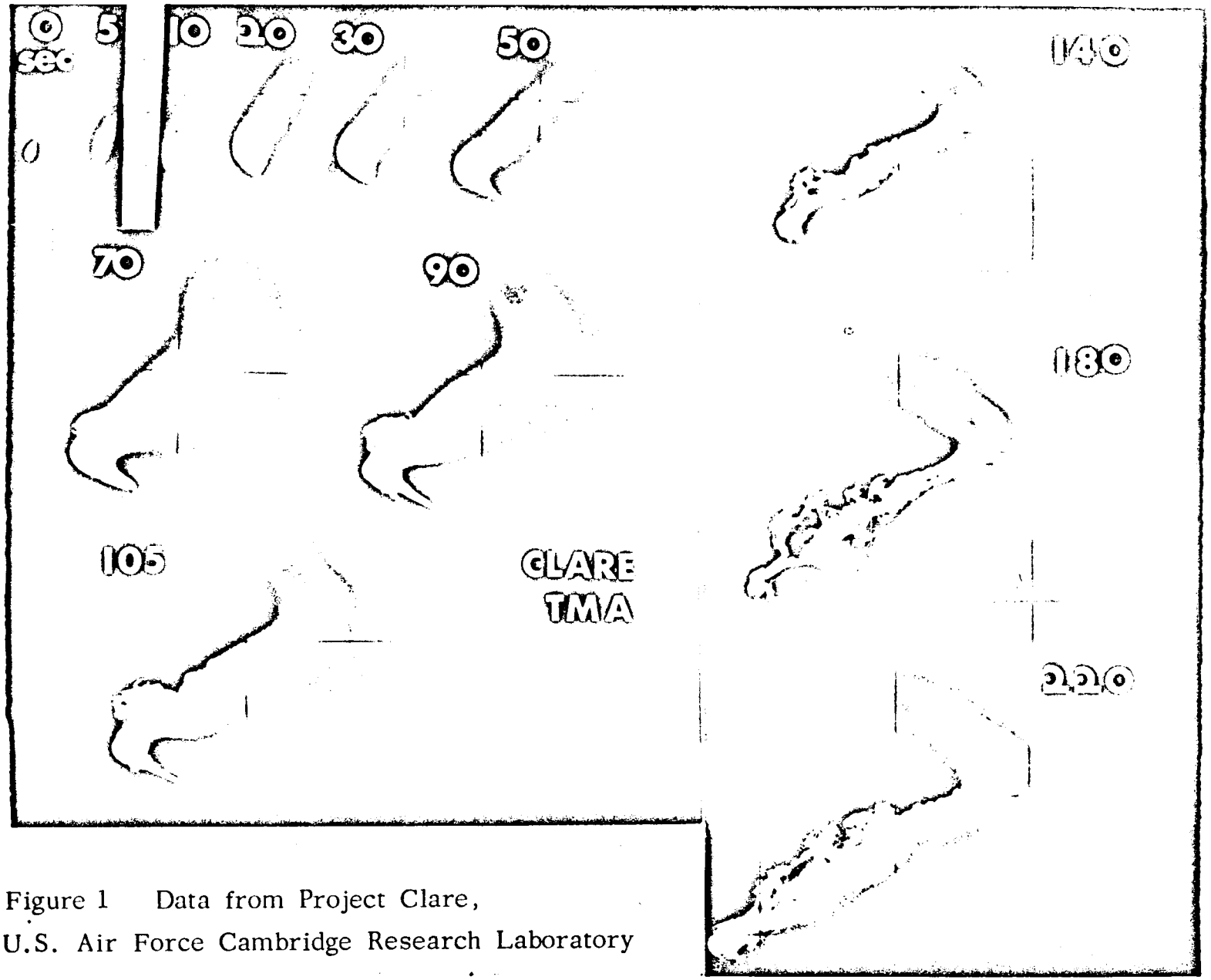
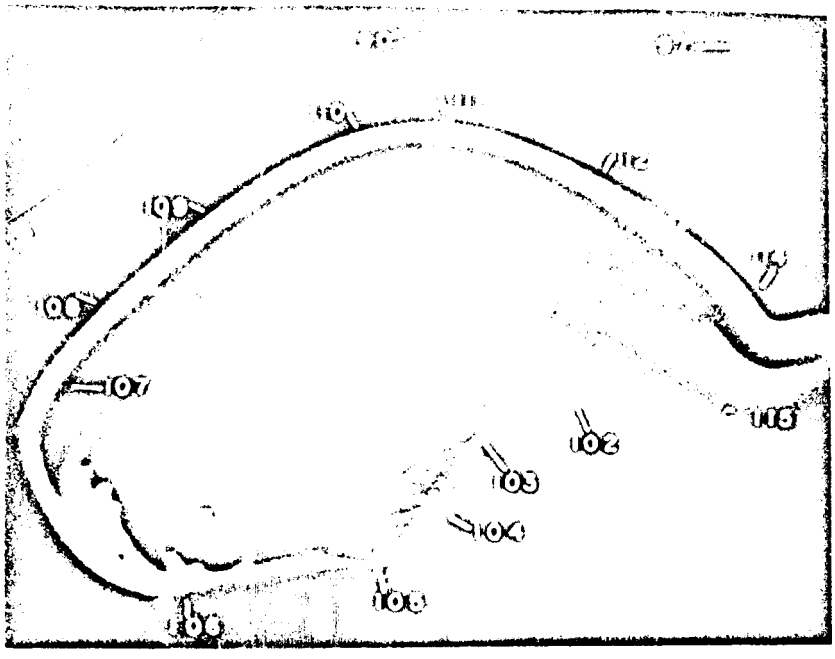


Figure 1 Data from Project Clare,
U.S. Air Force Cambridge Research Laboratory



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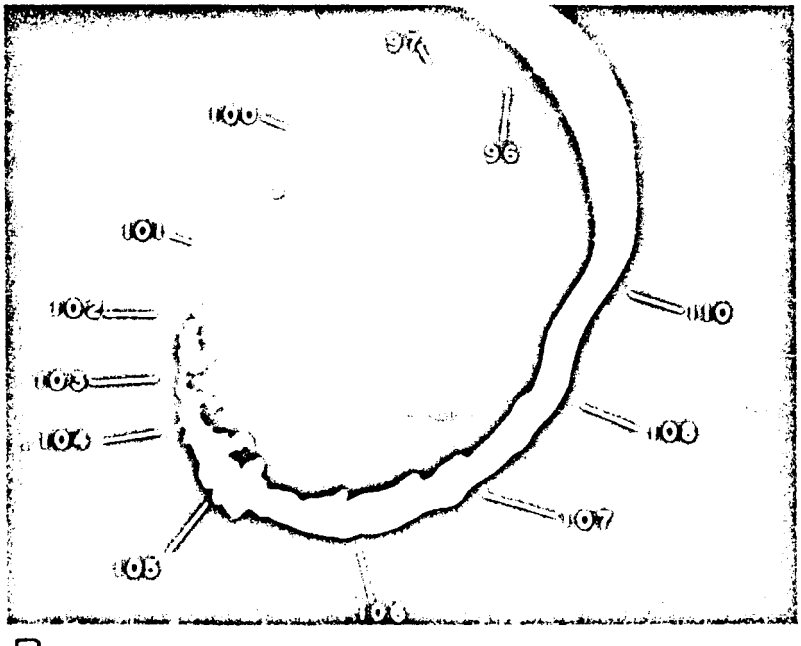
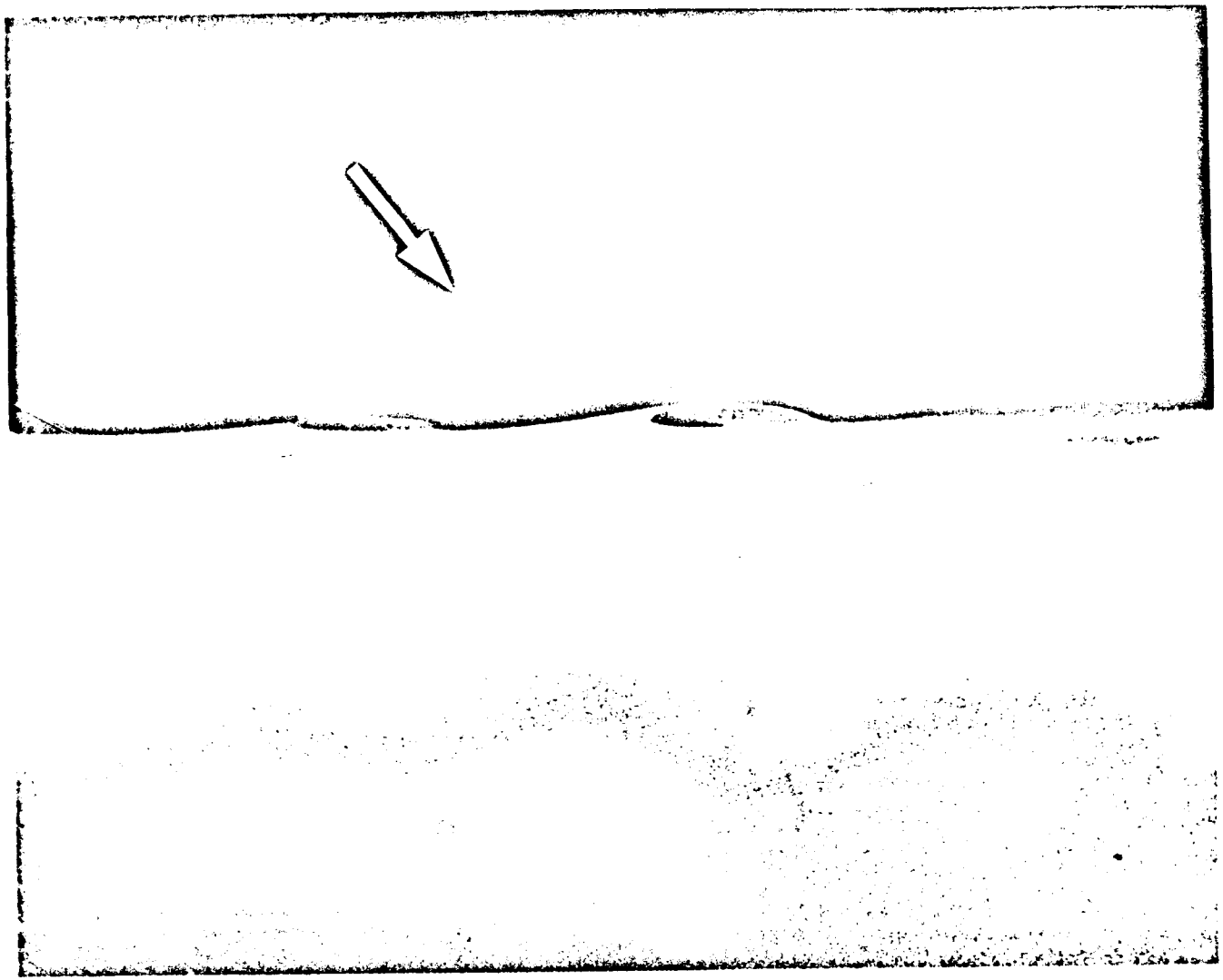


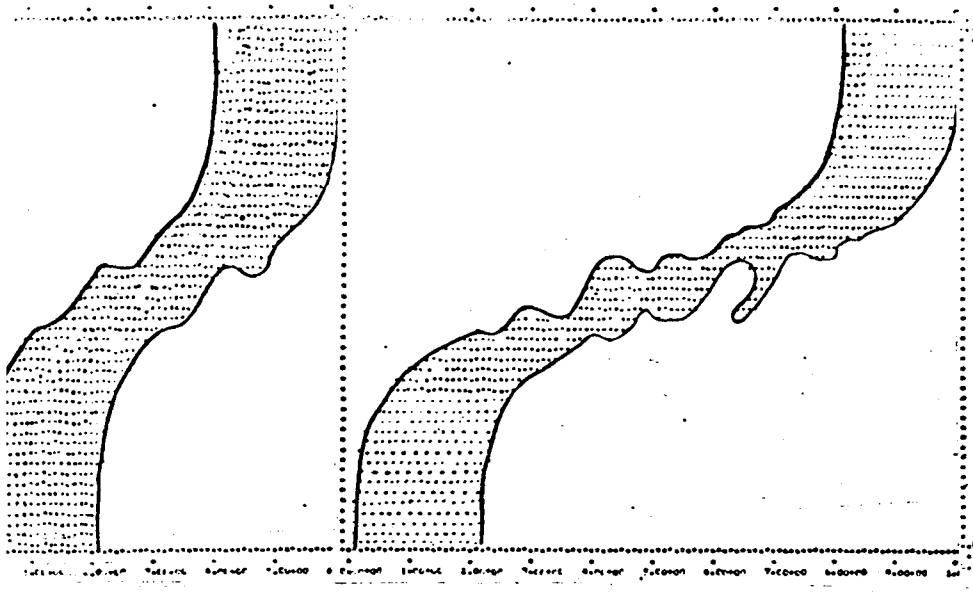
B

Figure 2. Data from Rocket Firing at Wallops Island, January, 1966 (G.C.A. Corp.)



SMOKE TUNNEL PHOTOGRAPH (ENLARGEMENT)

Figure 3



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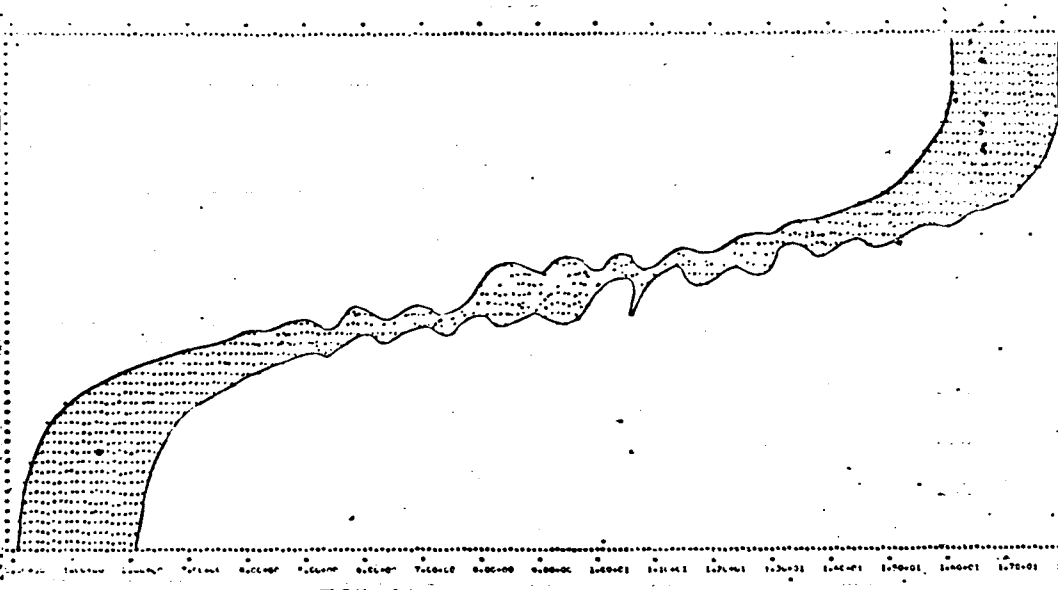

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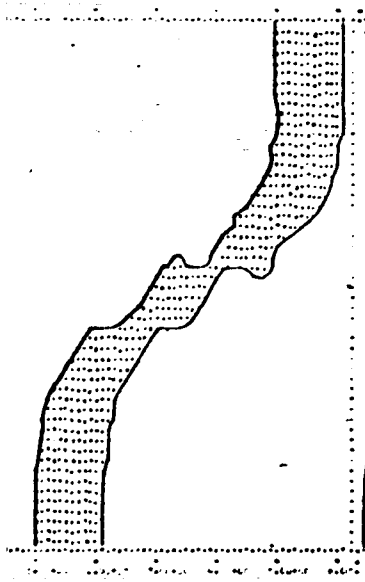

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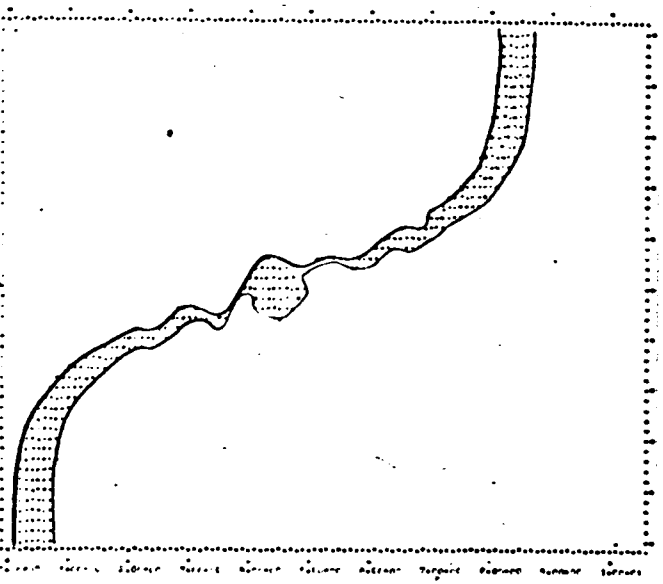

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COMPUTED SMOKE PATTERNS

Figure 4

*W_s=Initial width of smoke