# INVESTIGATIONS OF DUST IN THE UPPER ATMOSPHERE BY OPTICAL RADAR

FINAL REPORT



on

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Grant NGR 22-009-(114)

covering the period

July 1, 1966 – July 31, 1968

November 30, 1968

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# INVESTIGATIONS OF DUST IN THE UPPER ATMOSPHERE BY OPTICAL RADAR

This grant has helped to partly support research on a variety of problems related to the presence of dust in the upper atmosphere and to applicable techniques. Support for research on related problems was also obtained from NASA through Grant NGR 22-009-131. Several publications have been issued. A summary of the most important published contributions follows.

1. Giorgio Fiocco, "On the Production of Ionization by Micrometeorites" (J. Geophys. Res. 72, 3497-3501 (1967)).

The large influx of micrometeorites in the earth's atmosphere may be responsible for the production of ionization in amounts comparable to those needed in the E region at night and in some types of sporadic-E irregularities. The problem is reconsidered, and the ionization resulting from neutral-neutral collisions of the ambient gas induced by the meteoroid is calculated.

2. Gerald Grams and Giorgio Fiocco, "Stratospheric Aerosol Layer during 1964 and 1965" (J. Geophys. Res. 72, 3523-3542 (1967)).

Observations of stratospheric aerosols have been made with an optical radar at Lexington, Massachusetts, during a two-year study. Some observations were also conducted at College, Alaska, in the summer of 1964. Vertical profiles of aerosol concentration were obtained by comparing the optical radar echoes with the expected return from a molecular atmosphere; the observed signal from 25- to 30-km altitude was used to calibrate the instrument. The observations show that the aerosol layer near 20 km exhibited little temporal variability, with a generally decreasing trend. The observed return from the layer was approximately 1.9 times the return from a molecular atmosphere; the daily rms fluctuation of this scattering ratio was about 0.3 and hourly fluctuations were smaller. Comparisons with previous measurements indicate that the concentration of stratospheric aerosols was one order of magnitude higher, presumably because of the eruption of Mount Agung in March 1963. The data have been compared with various meteorological parameters associated with conditions in the lower stratosphere. A significant negative correlation between fluctuations of dust and ozone has been found.

3. G. Fiocco and J. B. DeWolf, "Frequency Spectrum of Laser Echoes from Atmospheric Constituents and Determination of the Aerosol Content of Air" (J. Atmos. Sci. 25, 488-496 (1968)).

Spectral analysis of the echoes obtained from atmospheric constituents in optical radar experiments yields information related to wind motion, temperature, and composition. In particular, air with suspended aerosols is considered, and preliminary experiments are described showing that apparatus of limited resolution yields the ratio of the aerosol-to-molecular component. In the experiments, radiation from a cw He-Ne laser was scattered by air with a variable aerosol content. Spectral analysis of the scattered light was performed with a pressure-scanned Fabry-Perot interferometer.

4. Giorgio Fiocco, "Possibility of Continuous Measurement of the Influx on Earth of Extraterrestrial Dust by Optical Radar" (NASA Sp-150 (1967). (Paper presented at the International Symposium on the Zodiacal Light and the Interplanetary Medium, University of Hawaii, 29 January – 2 February 1967).

Previous work directed to the detection of atmospheric dust by optical radar is reviewed and it is proposed to implement a continuous monitor of the influx of extraterrestrial dust on Earth.

5. H. C. Koons and G. Fiocco, "Anisotropy of the Electron Velocity Distribution in a Reflex Discharge Measured by Continuous-Wave Laser Scattering" (Phys. Letters 26A, 614-615 (6 May 1968)).

CW $Ar^+$ laser scattering observations in a reflex discharge indicate a temperature of approximately 30 800°K and 13 570°K for the velocity components respectively parallel and perpendicular to the magnetic field. The anisotropy is related to the randomizing processes in the discharge.

6. H. C. Koons and Giorgio Fiocco, "Measurements of the Density and Temperature of Electrons in a Reflex Discharge by Scattering of cw $Ar^+$ Laser Light" (J. Appl. Phys. 39, 3389-3392 (1968)).

An experiment to measure the electron temperature and density in a low-density reflex discharge in helium, by scattering of continuous-wave $Ar^+$ laser radiation at 4880 Å, has been successfully carried out. The scattering measurements indicate a density of $4.8 \times 10^{18}$ $m^{-3}$ and a temperature of 1.18 eV: these values are in good agreement with those obtained with a Langmuir probe.

MANUSCRIPTS IN PREPARATION

1. Giorgio Fiocco and Gerald W. Grams, "Optical Radar Observations of Mesospheric Aerosols in Norway during the Summer 1966" (in preparation).

In the summer of 1966 an optical radar was operated in the vicinity of Oslo, Norway, to obtain measurements of the aerosol content of the mesosphere at times when noctilucent clouds might be present. The work was a continuation of similar experiments conducted in Alaska and Sweden in the summer of 1964. The measurements indicate that the altitude region 60-70 km contains an appreciable amount of particulate material in the summertime at high latitudes during periods of noctilucent cloud activity, as suggested by our earlier results. The observed vertical distribution of aerosols has been related to the general circulation of the upper atmosphere to produce an estimate of the meridional flux of particulate material at high latitudes. Also, improved resolution of the apparatus made it possible to observe transient features of a noctilucent cloud: the height was approximately 74 km, the geometric thickness was appreciably less than 1 km, the vertical-wave amplitude was approximately 2 km, and the optical thickness was approximately 10 km.

2. Some work is now being carried out as a cooperative effort between Giorgio Fiocco at the European Space Research Institute (ESRIN), Frascati, Italy, Gerald W. Grams at NASA, and John B. DeWolf at the Research Laboratory of Electronics, M.I.T. It is a continuation of work previously supported in part, by this grant.

The problems that we have been working on during the past year are threefold.

(i) G. Fiocco and G. W. Grams have been working on a study of the meridional circulation of dust in the upper atmosphere. Using the wind velocities obtained through the model of O. G. Murgatroyd and J. P. Singleton, the patterns of circulation in the upper atmosphere are being studied.

(ii) Data obtained during 1964 and 1965 are being reduced in order to obtain an idea of the seasonal variability of mesospheric dust content. Preliminary results point to a seasonal variation that can be interpreted through the use of the previously mentioned theoretical model.

(iii) Studies are being conducted on the spectrum of coherent light scattered from turbulence. This research is now being carried out, for the most part, by J. B. DeWolf in doctoral thesis research. A brief report follows.

## Spectrum of Coherent Light Scattered from a Turbulent Jet

It has been thought that information about turbulence and aerosol diffusion might be obtained by studying the spectrum of the light scattered by the aerosols with the use of an optical homodyne spectrometer.[1] A preliminary study using a steam jet showed, however, that the homodyne spectrum was masked by intensity fluctuations caused by intermittent behavior and density fluctuations in the jet. Fluctuation spectra of this sort have been observed by Becker, Hottel, and Williams.[2] In order to clarify the situation and to see if a homodyne spectrum could be obtained from a turbulent fluid, a study was begun of the spectrum of coherent light scattered from a water jet marked by uniform spherical particles. This portion of the report will summarize what has been learned thus far, by using the turbulent water jet.

The homodyne spectrum gives information about the density correlation function of the particles.[3] It is observed by measuring with a wave analyzer the low-frequency spectrum of the current from a photomultiplier tube which is illuminated by the scattered light. In order to interpret the observed spectrum simply in terms of a density correlation function, the following conditions should be satisfied.

a. The fluctuations in scattered light intensity caused by a change in the total number of scattering particles within the volume should be small. In order to determine whether or not this is the case, it is useful to measure the photocurrent spectrum when incoherent light is used as the source. The homodyne spectrum is only observable with a laser source.

b. The turbulence should be statistically stationary over the time of the measurement.

c. The volume that is observed should be large enough so that the broadening caused by the finite lifetime of the scattering from a particle moving through the volume can be neglected. If the mean velocity of the particles is v, and the width of the homodyne spectrum that is to be observed is $\Delta f$, then the size of the scattering volume L should satisfy

$$L \gg \frac{v}{\Delta f}.$$

This may be the major source of broadening in experiments in which the mean velocity of the fluid is large or the scattering volume small.

d. Ideally, the volume that is observed should be small enough so that the mean volocity of the fluid is essentially constant within the volume. This is desirable so that the density correlation function will be more or less homogeneous over the scattering volume.

Some measurements of the spectrum of light scattered by particles suspended in a submerged water jet have been made in such a way that these conditions are reasonably well satisfied. The jet emerges from a nozzle, 1 mm in diameter, into a glass-walled circular duct, 5.33 cm in diameter. Both the water emerging from the jet and the water in the duct are marked with uniform latex spherical particles having a diameter of 910 Å ± 58 Å. The jet can be moved relative to the laser beam and the photomultiplier in such a way that the position of the scattering volume can be precisely located with respect to the center line of the jet and the nozzle. The flow rate is measured with a calibrated flowmeter. The homodyne spectrometer is similar to the one described by Dubin, Lunacek, and Benedek.[1] The photocathode is at right angles to the laser beam.

Fig. 1. Spectrum of light scattered from spheres of 910 Å diameter undergoing Brownian motion in a water solution. Solid curve is Lorentzian with 674 Hz width.

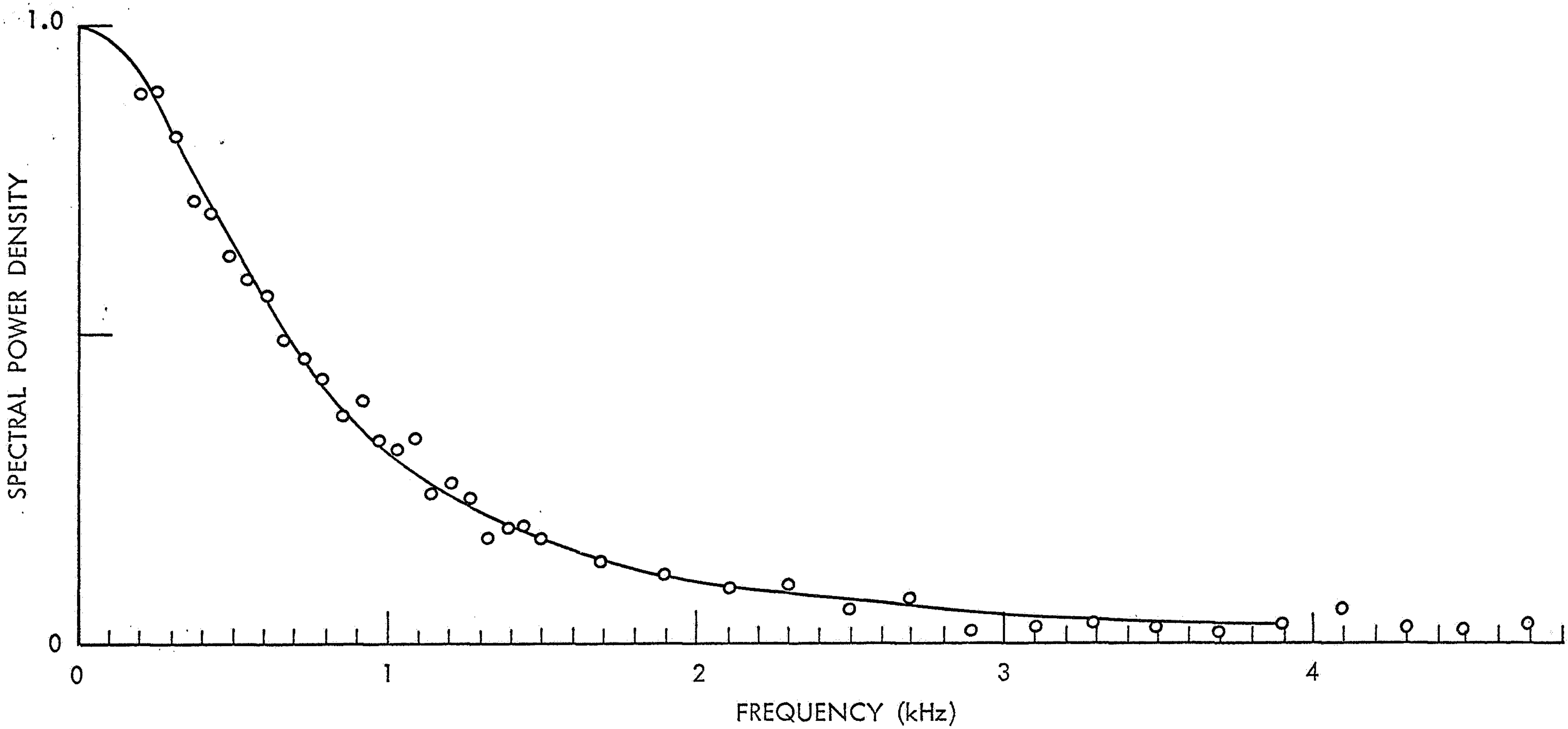
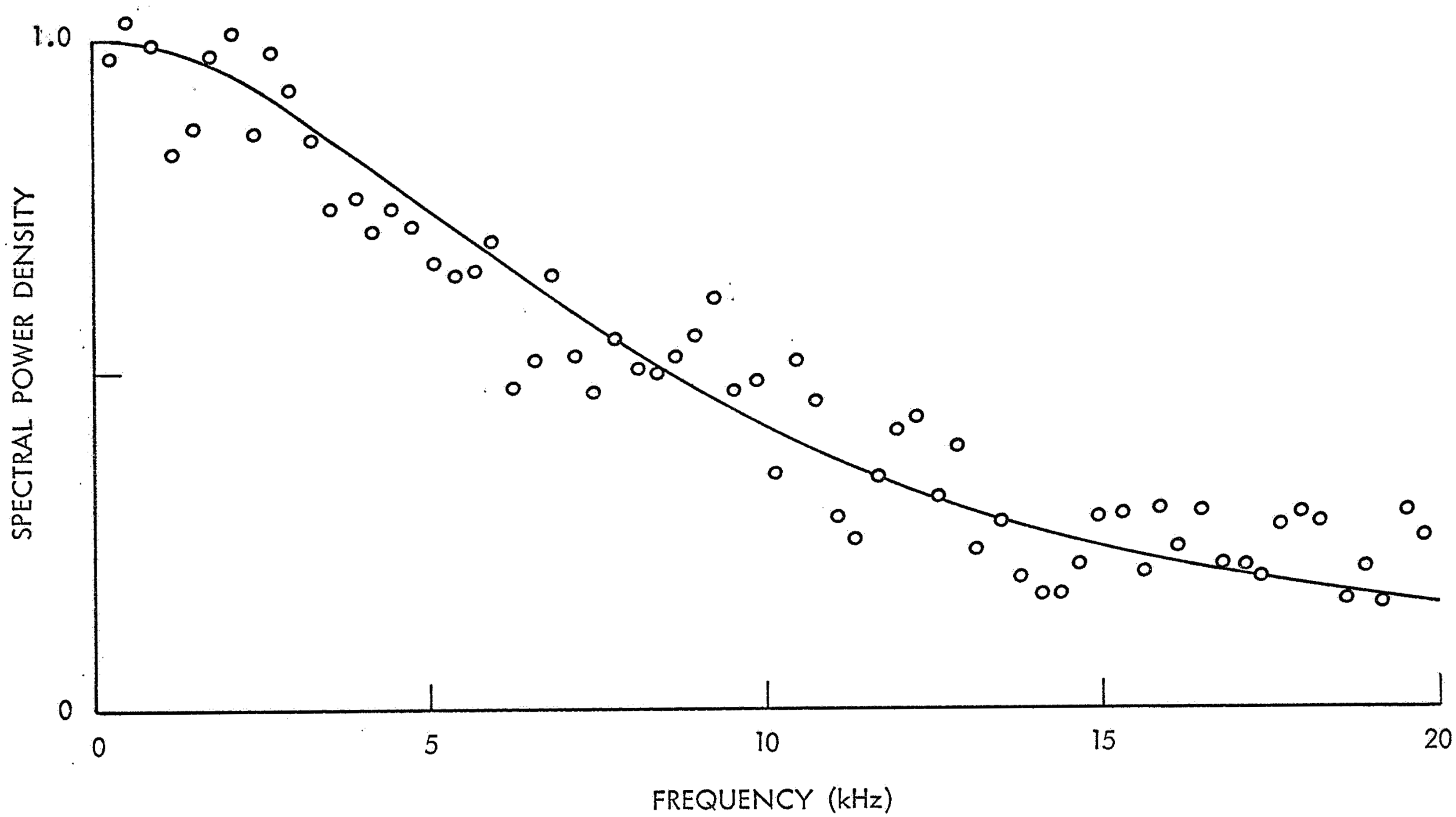


Fig. 2. Spectrum of light scattered from spheres of 910 Å diameter suspended in a turbulent water jet. Scattering volume is on the axis, 40 nozzle diameters downstream from the nozzle. Flow rate: 20 ml/min. Solid curve is Lorentzian with 8.48 kHz width.



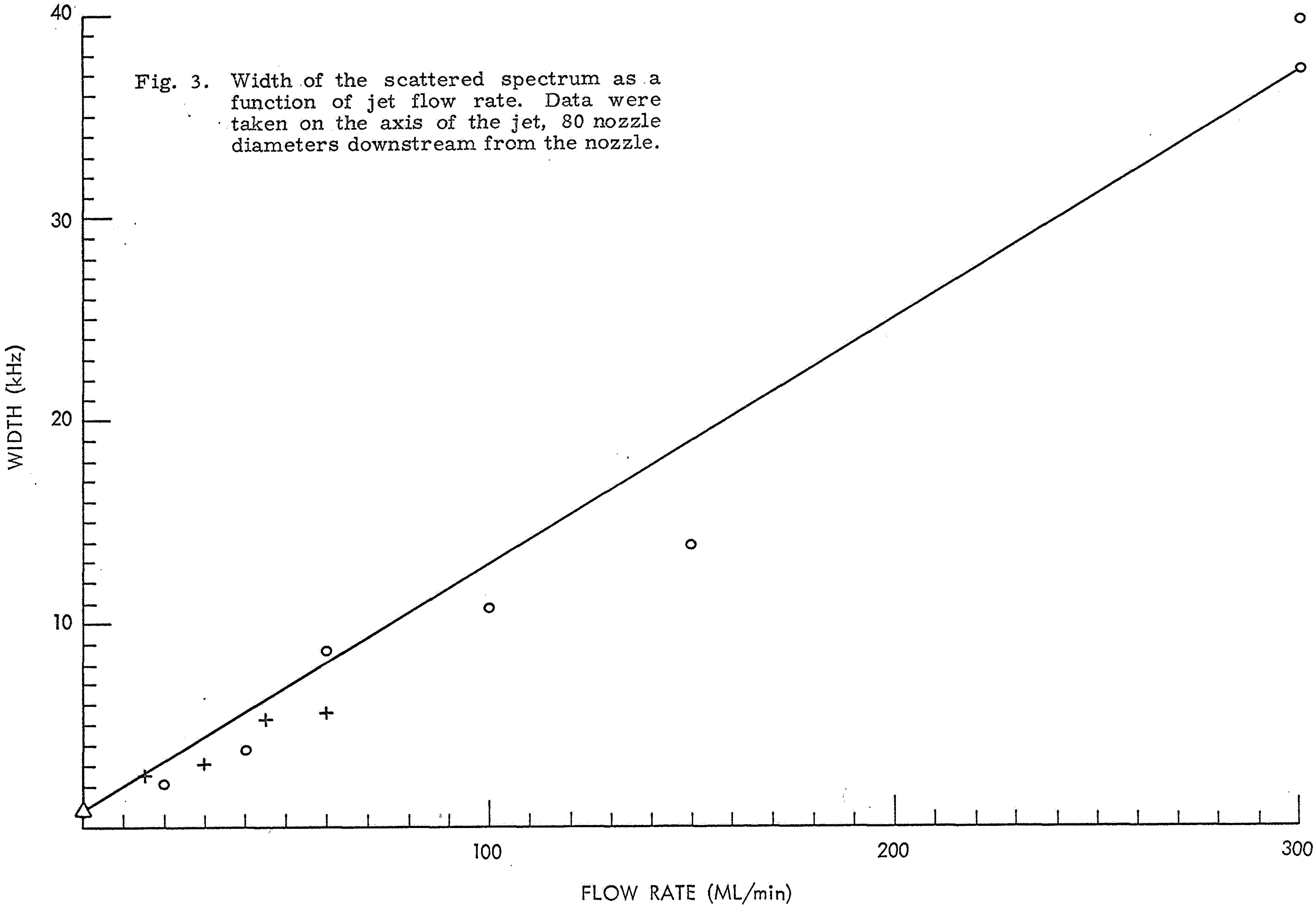



Fig. 3. Width of the scattered spectrum as a function of jet flow rate. Data were taken on the axis of the jet, 80 nozzle diameters downstream from the nozzle.

A detailed analysis of the data has not yet been completed, but the following general picture emerges.

First, when the jet is turned off the particles undergo Brownian motion. The density correlation function and the spectrum of the light observed in this case are well understood. The line shape is Lorentzian and has a width that is proportional to the diffusion coefficient. Since the diffusion coefficient for the uniform spherical particles can be calculated from the Stokes-Einstein relation, the width of the spectrum can be calculated and compared with experiment. Figure 1 shows the spectrum of the light observed when the jet is turned off. The solid curve is a Lorentzian having a width of 0.674 kHz, which agrees well with the calculated value.

Second, when the jet is turned on, the spectrum of the light scattered from the jet region is observed to broaden. It is inferred that the broadening of the spectrum is caused by an increase in the effective diffusion coefficient because of the turbulence. The observed spectrum maintains a Lorentzian shape as the jet velocity increases. Figure 2 shows the spectrum of the light observed 40 nozzle diameters downstream from the nozzle on the axis of the jet when the nozzle velocity is approximately 42 cm/sec. The curve has a width of approximately 5.6 kHz. Figure 3 shows the width of the spectrum as a function of the flow rate in the jet when the scattering volume is 80 nozzle diameters downstream from the nozzle on the jet axis.

Third, as the scattering volume is moved radially, the width of the spectrum decreases until the minimum width (caused by the equilibrium Brownian motion) is reached. This behavior has been examined as a function of the distance from the nozzle and it is possible to observe in this fashion the spreading of the jet with increasing distance from the nozzle.

Further analysis is being undertaken in the hope that information about the kinetics of turbulent diffusion may be obtained in this manner.

References

1. S. B. Dubin, J. H. Lunacek, and G. B. Benedek, "Observation of the Spectrum of Light Scattered by Solutions of Biological Macromolecules," Proc. Natl. Acad. Sci. U.S. 57, 1164-1171 (1967).
2. H. A. Becker, H. C. Hottel, and G. C. Williams, "On the Light-Scatter Technique for the Study of Turbulence and Mixing," J. Fluid Mech. 30, 259-284 (1967).
3. G. Fiocco and J. B. DeWolf, "Frequency Spectrum of Laser Echoes from Atmospheric Constituents and Determination of the Aerosol Content of Air," J. Atmos. Sci. 25, 488-496 (1968).

## CONCLUSIONS

1. As it appears from the list of papers, the aims of our research have had to be redefined during the period covered by this grant, because of reductions in the financial support needed for the construction of a powerful radar, and lack of a proper site for observations.

2. The observations of upper atmospheric dust obtained during the period covered by this grant were carried out from a trailer, loaned by NASA Goddard Space Flight Center, and then only in Norway during the summer of 1966. It has proved impractical to carry out extended series of measurements under relatively marginal conditions.

3. In conclusion, it is possible to say, however, that, at the present state of development of the techniques involved, the upper atmospheric dust content and its dynamics can be measured by ground-based optical radar with substantial accuracy. A fixed installation of some size is however required such as it is described in NASA SP-150, pp. 115-117 (1967).