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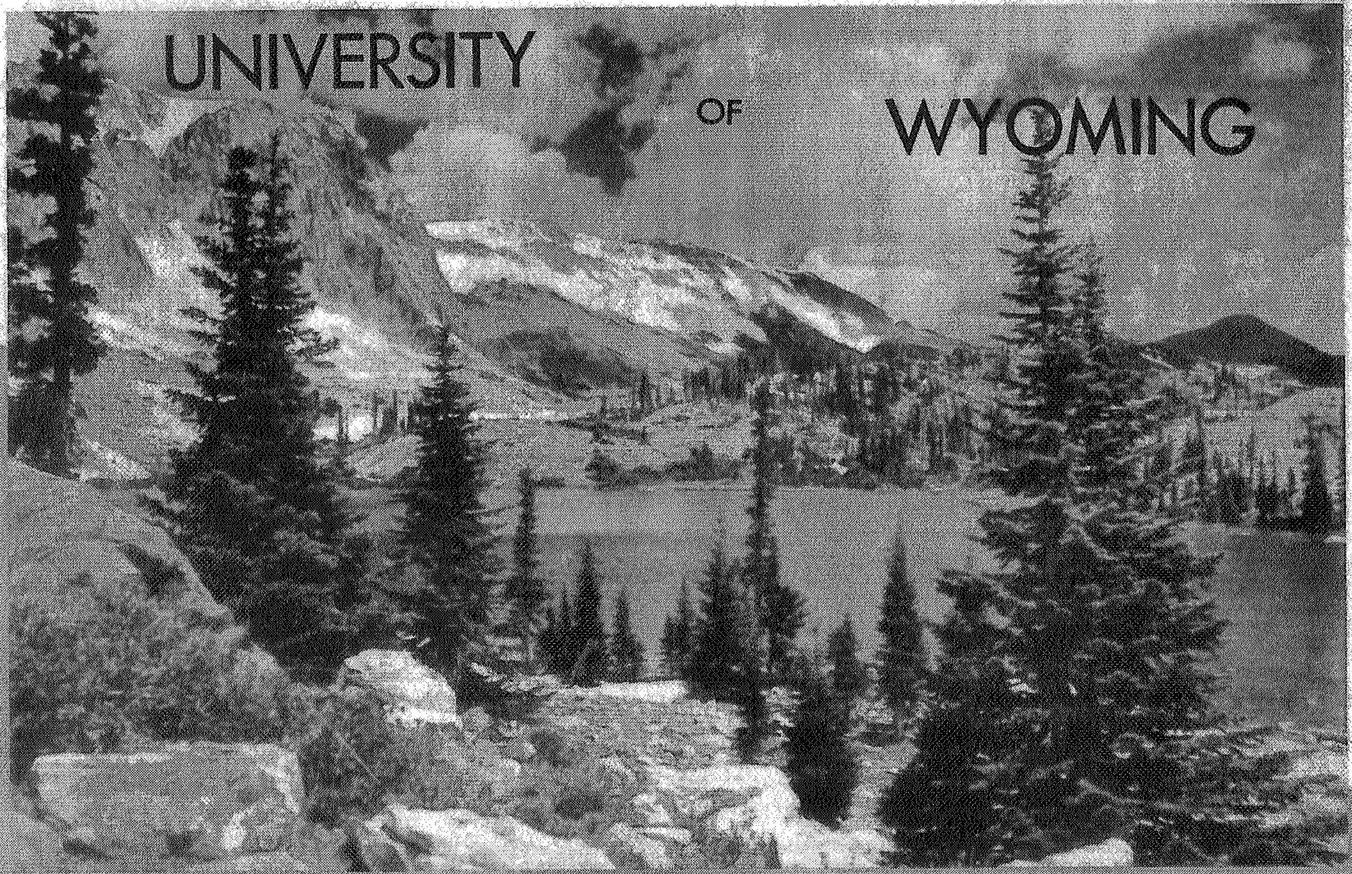

LAKE MARIE IN THE SNOWY RANGE—A SHORT DRIVE FROM CAMPUS

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SUMMARY

Meteorological parameters are often used to map and study regions of atmospheric turbulence that are otherwise invisible to the eye. Trace atmospheric constituents such as aerosols can also be mapped, thereby in a sense rendering the turbulence visible. This approach can provide physical insight for developing models of turbulence.

The mapping of atmospheric aerosols in the past has been hindered somewhat by the lack of adequate technology. The development of a suitable aircraft borne detector is not a trivial task. The instrument must be capable of operating over extreme pressure and temperature ranges as well as surviving a severe vibrational environment. In addition, the problem of sampling an aerosol from a high speed aircraft without distorting the size distribution cannot be overlooked.

A beginning effort to develop and test an air borne photoelectric particle counter for measuring atmospheric aerosols has been initiated. The performance of the instrument under simulated environmental conditions are reported. Field tests of the instrument were performed with a jet aircraft and an attempt was made to observe mountain lee wave phenomena.

INTRODUCTION

Recent years have seen increasingly more interest in clear air turbulence (CAT). With the advent of large aircraft the interaction between the aircraft's structure and CAT becomes even more important. Yet understanding of CAT has not reached an adequate level. If more were known about this phenomenon, it could perhaps be avoided altogether.

The aircraft is still the only recognized detector of CAT, but considerable effort has been made to develop remote sensors which detect some parameter thought to be associated with CAT. This approach is somewhat unsatisfactory because the relation between the measured parameter and CAT is generally not well understood, both from a theoretical and experimental standpoint. The prospect of developing a useful remote sensor of CAT or an accurate forecasting method would be greatly enhanced if the detailed structure of the atmosphere in and around regions of CAT could be adequately probed. The knowledge of the setting in which CAT occurs is fundamental to its understanding.

The long range goal of the research described here is a detailed mapping of the aerosol concentration in a region of turbulence. By using the naturally occurring aerosol as a short term tracer, the actual physical motions of the atmosphere can be inferred or reconstructed. This "visible" picture along with the associated meteorological parameters will lead to a better physical understanding of CAT and its development.

Before this goal can be achieved, however, the necessary instrumentation must be developed and extensively tested. The essence of the following report deals with this beginning effort. Basically there were three development stages associated with this research: 1. initial development of the air borne instrumentation, 2. environmental testing of the instrument and 3. field testing the instrument on a jet aircraft provided by Edwards Flight Research Center.

INSTRUMENTATION

Development of the Aerosol Particle Counter

Many types of aerosol detectors have been developed, but the photoelectric particle counter is one of the few instruments ideally suited for air borne measurements. The sample is made in situ, which eliminates any possibility of volatile aerosols changing in size or evaporating before they can be detected. The response of the instrument is very fast, resulting in good spacial resolution even with high speed aircraft. If the response time were of the order of two or three seconds, for instance, the resolution would be several thousand feet. The actual response time of the instrument is about .1 second, giving a resolution of 80 feet or better.

Several commercial versions of the photoelectric particle counter are available, but none of them are suitable for direct application to high performance aircraft. The commercial instruments are not designed to operate over the required temperature and pressure range or sustain the vibrational environment. In addition, these instruments respond in an unsatisfactory manner to the cosmic ray maximum near 50,000 feet. An instrument designed specifically for aircraft use is therefore necessary.

The photoelectric particle counter developed under this contract is very similar to the one used by the author (Rosen 1968) for high altitude balloon borne measurements. By preserving the geometry of the detector itself in the aircraft application, the ambiguity in a comparison of the balloon sounding with the aircraft sounding can be eliminated. The basic detector is schematically shown in figure 1 and is essentially a dark field microscope with a photomultiplier as the sensing device. Air being sampled is directed in a well-defined stream through the focal point of the condenser lens where individual particles scatter light into the microscopes and photomultipliers. The photomultiplier pulse height is then a function of particle size and its index of refraction. The instrument requires simultaneous pulses from both photomultipliers for a particle count to be registered. This feature increases the signal to noise ratio and eliminates background counts produced by cosmic ray scintillation in the photomultiplier glass.

A four channel pulse height analyzer was used to process the signals from the photomultiplier and coincidence circuits. The triggering levels were set to

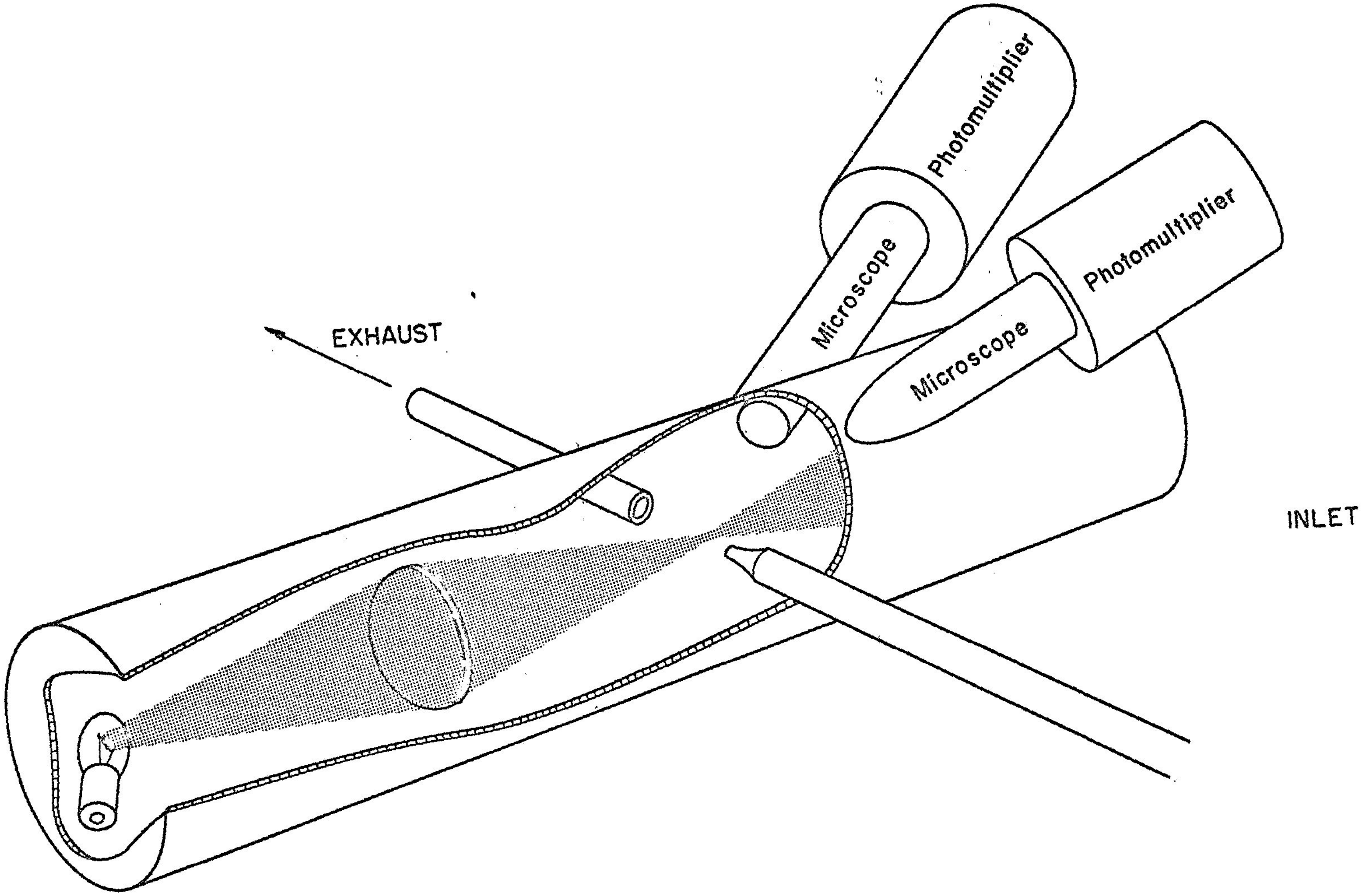

Figure 1. A schematic diagram of the photoelectric particle counter.

count four particle sizes between .5 and 1.2 microns diameter. The exact levels were determined by calibration with an aerosol of known concentration and size distribution.

Controlled Environmental Tests

The environmental tests were performed at Ball Brothers Research Corporation in Boulder, Colorado. The instrument was first subjected to simultaneous temperature and pressure extremes. The temperature was varied from 160^{0}F to -65^{0}F, while the pressure varied from sea level to 70,000 ft. A cold soak temperature of -65^{0}F at a pressure equivalent to 70,000 ft. was maintained over a period of four hours. During this time the internal temperature of the instrument slowly decreased with a several hour time constant and finally ceased to function normally. Since the expected flight time of the instrument was only one half hour, additional heating for the instrument was not considered necessary.

The vibration test was performed in accordance with NASA FRC Process Specification No. 21-2, Curve B, figure 1. This curve requires that the instrument be subjected to a one to 5 g acceleration between 5 and 50 Hz and 5 g acceleration between 50 and 500 Hz. The frequency sweep rate was such as to require 15 minutes on each axis and a two minute dwell on each resonance. The response of the instrument to this driving force was similar to that of a driven damped harmonic oscillator with the resonance between 30 and 50 Hz depending on the axis of vibration. In this case the restoring force and damping are attributed to the six shock mounts supporting the instrument. Superimposed on the basic response curve are various resonance peaks due to internal resonances of the components. The presence of resonances are undesirable because the instrument can respond with more than 50 g's at these particular frequencies. However, the primary resonance can never be avoided when shock mounts are used.

After the first shake test the instrument was modified in order to eliminate some of the internal resonances and reduce the primary resonance due to shock mounts. The response of the instrument during the second shake test was adequate with a few minor exceptions. Since the instrument was beginning to show signs of fatique, further modification and testing were considered imprudent. The primary result of the shake tests showed that the delicate structures and critical alignment necessary in the photoelectric particle counter could be made to withstand severe vibrational environmental conditions.

Field Tests

The aerosol particle counter was field tested on a F-5D jet aircraft stationed at NASA FRC in Edwards, California. Originally 20 flights were scheduled during early sping when mountain lee wave activity would be at maximum. Due to the age and condition of the aircraft this stage of the research was besieged with problems. During one of the early flights the aircraft caught fire and subsequently sustained damages that took many months to repair. The major portion of the flights were therefore conducted during late spring and early summer when the mountain lee wave activity had ceased. After five successful flights the amount of ground support required to keep the craft airworthy had increased considerably, which in turn necessitated the decision to terminate the project. However, a considerable amount was learned from the five successful flights.

The instrument itself was mounted in the nose of the aircraft and a short probe led directly to the outside airflow. The geometry of the probe is shown in figure 2. Ambient air enters a small hole in the end of the tube and deccel erates as the tube becomes larger in diameter. The holes in the tube near the aerosol counter assure a continuous flow of ambient air and prevent the counter from becoming pressurized.

The four channels of information from the aerosol counter were tape recorded by on-board instrumentation provided by FRC. In addition, pressure, temperature and acceleration were also measured by sensors provided by FRC. The pilot's remarks were recorded during the flight and later correlated with the data.

All of the data received has been reduced, but only a small portion of it is significant enough to reproduce here. A discussion of the entire set of data would only serve to obscure the few important results.

The specific objectives of the aircraft flights were twofold: first, a significant effort was devoted to testing the instrument in atmospheric conditions fairly well understood in order to confirm the reliability of the data. The second objective was to probe an atmospheric condition that is not so well understood, namely turbulence associated with mountain lee waves.

Some of the first data obtained with the instrumented aircraft was on a steady climb from 4,000 feet to 15,000 feet. The results are shown in figure 3. Channel I refers to particles .53 microns and larger, and Channel III refers to particles .71 microns diameter and larger. Not shown in the figure is a temperature inversion which occurs between 8,000 and 9,000 feet. These results are

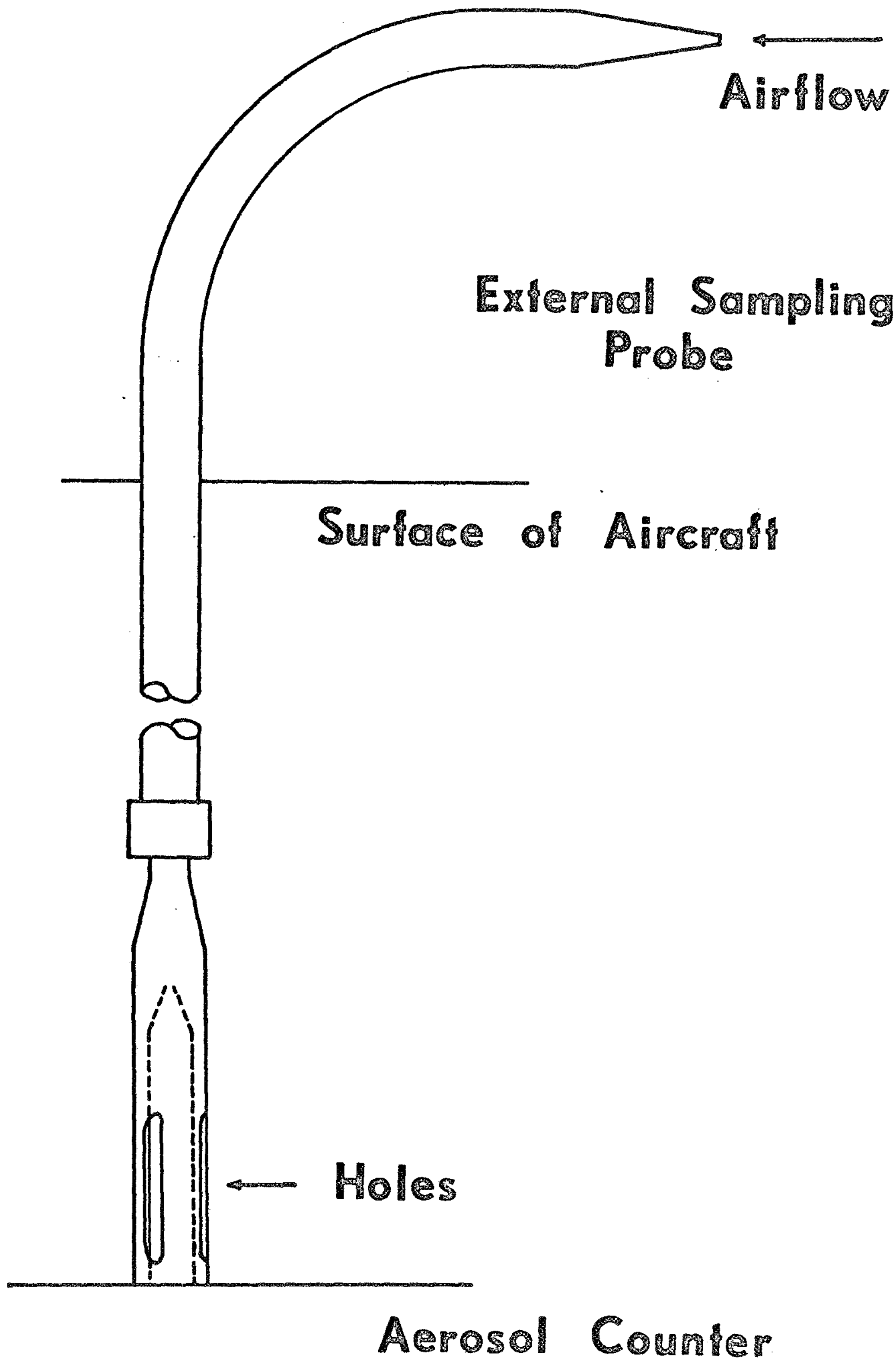

Figure 2. A schematic diagram of the sampling probe used for the aircraft field tests.

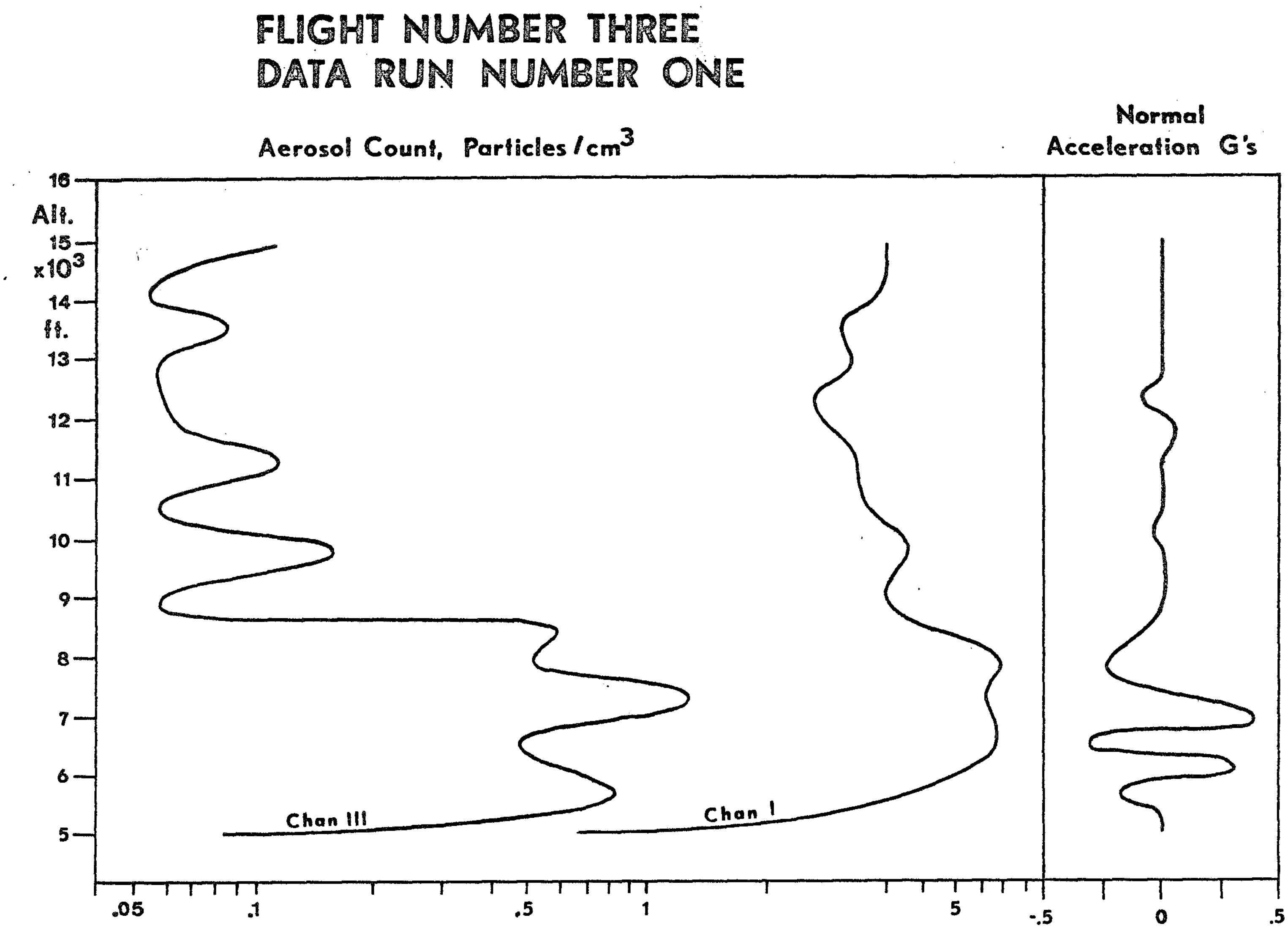

Figure 3. A vertical aerosol concentration profile obtained with the instrumented aircraft.

in good general agreement with the results of balloon soundings (Rosen 1969). The concentration in the boundary layer next to the surface of the earth should be relatively large and then decrease abruptly above the temperature inversion. The strong, vertical mixing usually present in the boundary layer is noted in the normal acceleration experienced by the aircraft. The data from a descent through a cirrus cloud is presented in figure 4. The position of the cloud as determined by the aerosol concentration profile agrees very well with the pilot's remarks concerning the position of the cloud. Several maneuvers of this type were performed and the results were all very similar.

Figure 5 is a comparison between a typical balloon sounding and two vertical soundings obtained with the aircraft. The difference in concentration between the two profiles is due largely to the difference in particle size: .2 microns diameter for the balloon ascent and .53 microns diameter for the aircraft ascent. The general agreement of the two types of soundings is considered very good for the troposphere (below 35,000 feet). Above 35,000 ft. the balloon entered the stratosphere, whereas the aircraft did not. Thus a comparison of the two sounding methods at the higher altitudes cannot be made from this data.

In general the sampling probe and the speed of the aircraft would be expected to have some effect on the measured concentration and size distribution of the aerosols. An attempt was made to estimate the size of this effect by making several passes through the same area at different speeds. The results of this effort are shown in figure 6, but unfortunately are highly suspect. If the instrument had been functioning properly, the aerosol concentration during each pass should have remained constant rather than decreasing. Before this problem could be fully investigated, the project was terminated. Thus the affect of the probe on the measured aerosol has not yet been satisfactorily investigated.

Several attempts were made to fly through mountain lee waves, but this type of atmospheric condition was almost non-existent during the time of year in which the flights were made. Figure 7 shows the results obtained from a constant altitude data run during a time when meteorological conditions were favorable for lee wave development. The results suggest that a sub-visible lee wave was detected. The large fluctuations in the aerosol concentration correspond closely with the temperature fluctuations. In addition, the normal accelerations resulting from the pilot's efforts to keep the aircraft at a constant altitude seem to correspond somewhat with the other parameters. The normal accelerations are associated with updrafts and downdrafts.

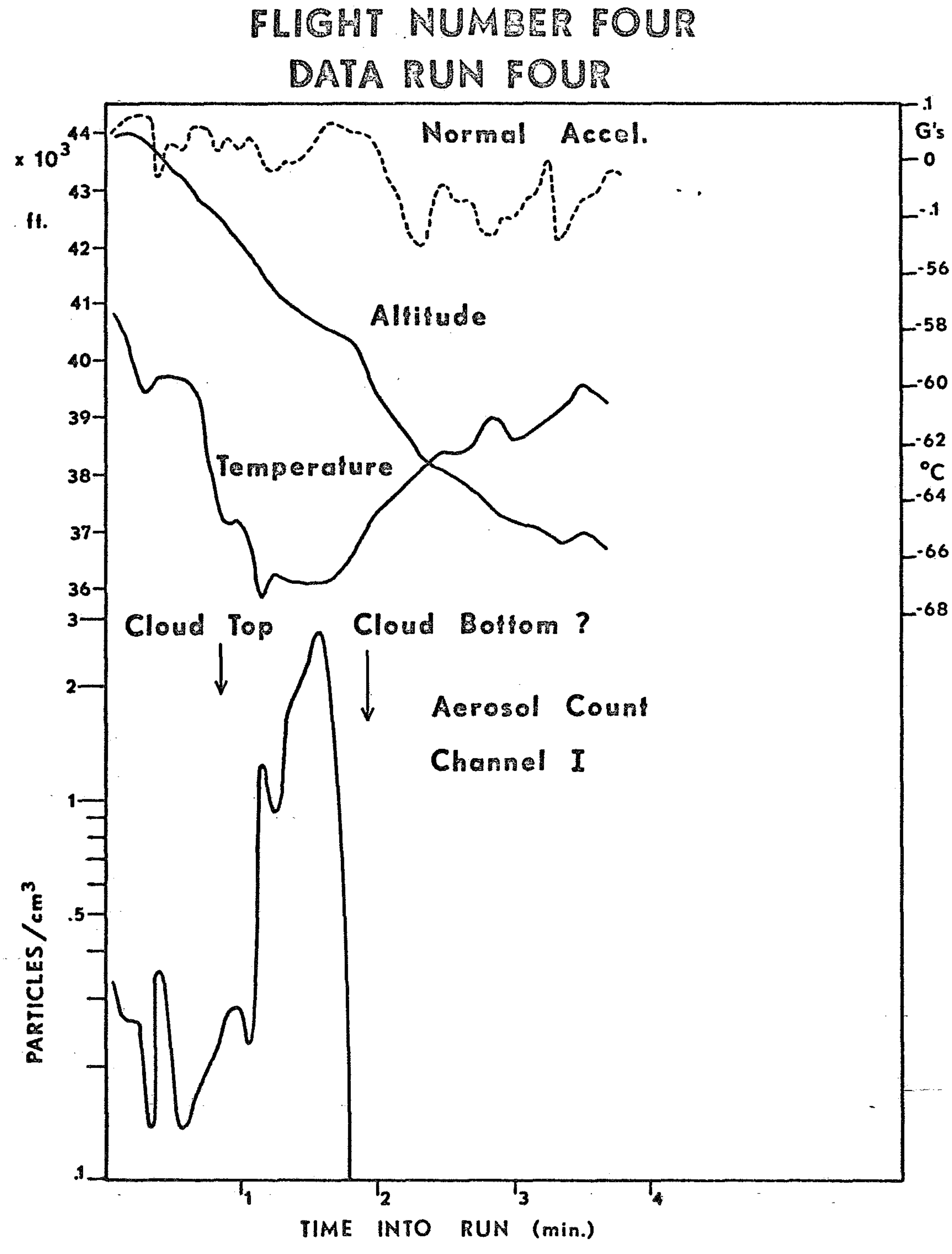

Figure 4. A data run taken through a cirrus cloud by the instrumented aircraft.

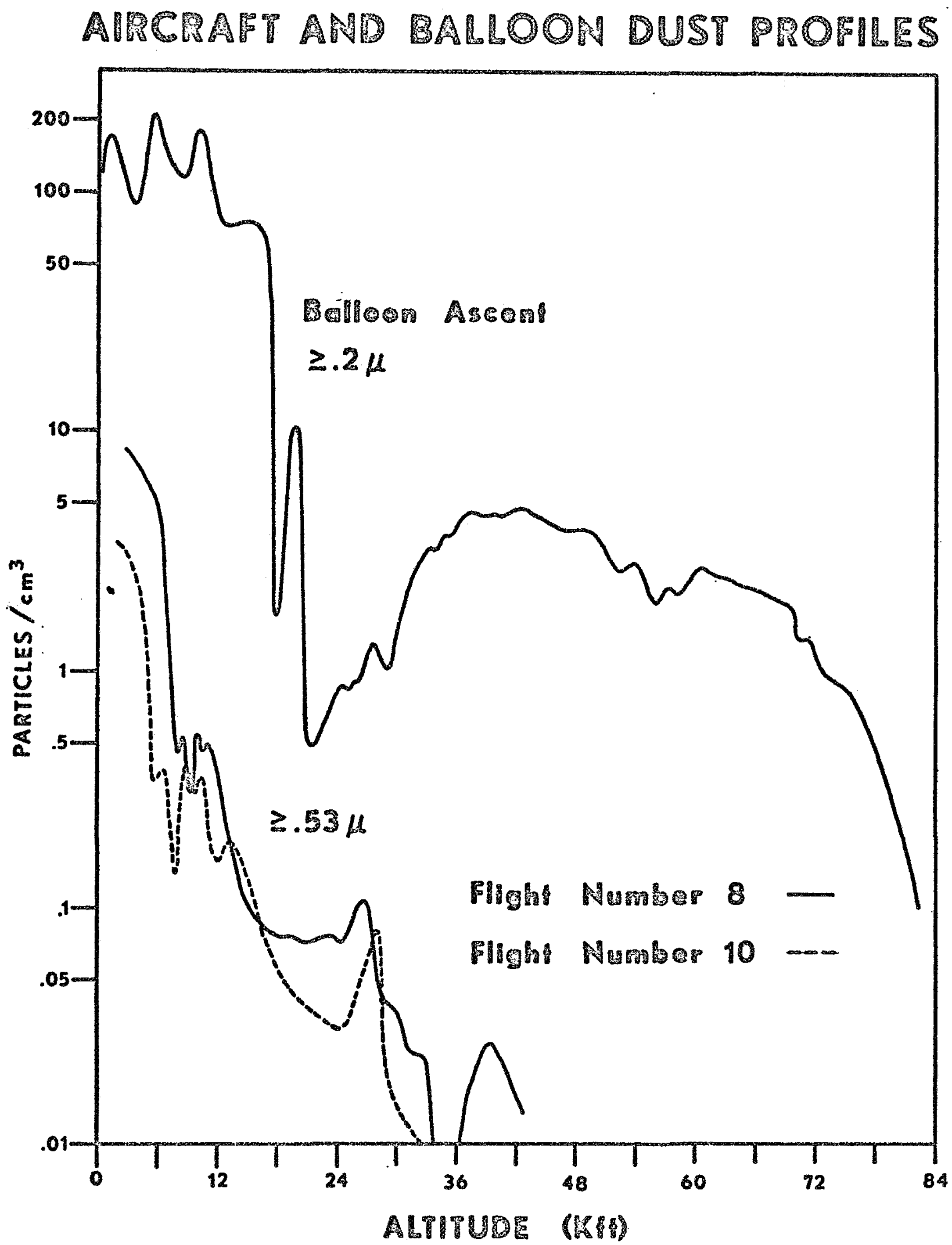

Figure 5. A comparison of typical results obtained by the balloon sounding technique and the instrumented aircraft.

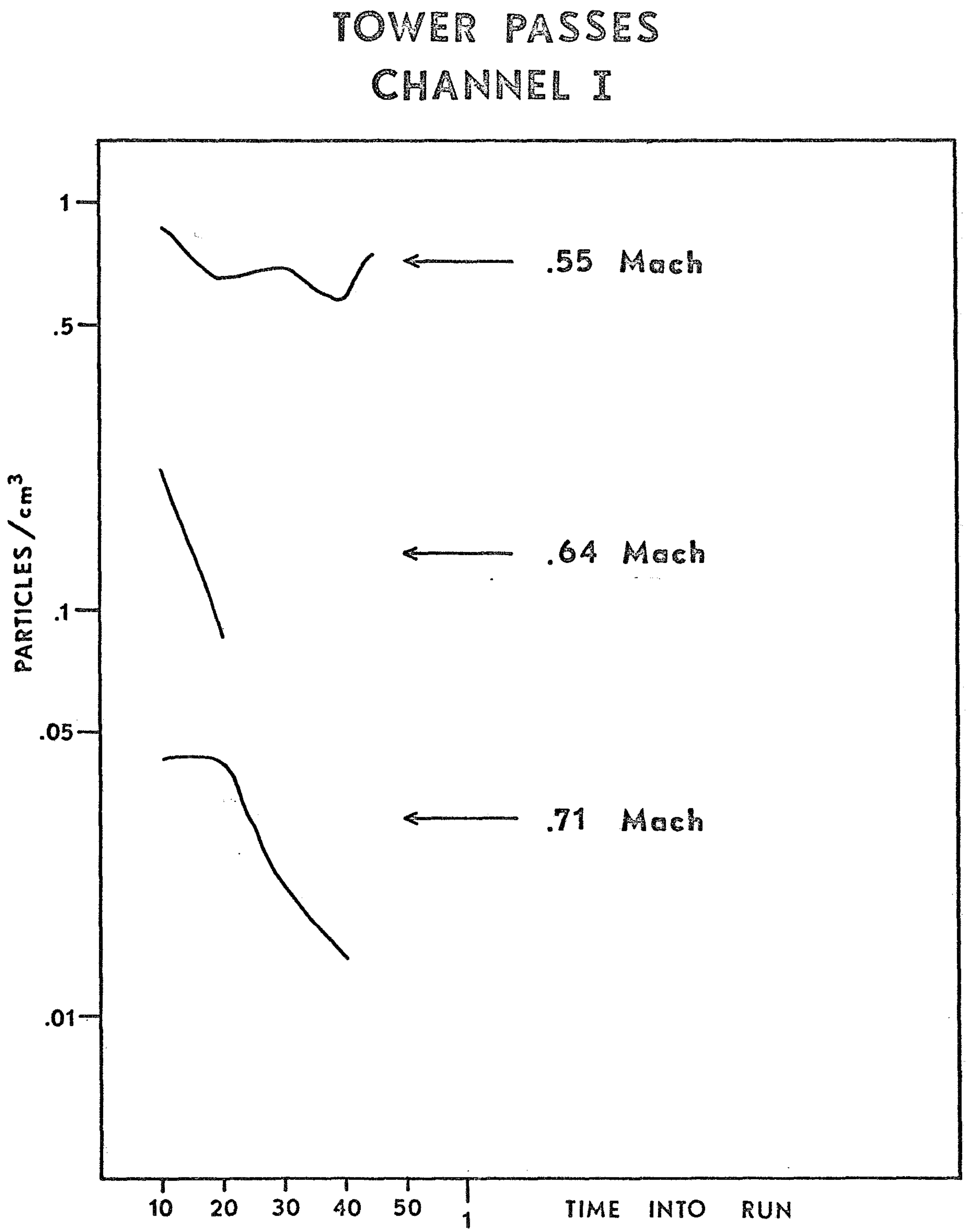

Figure 6. The effect of the aircraft speed on the dust concentration measured at a fixed location.

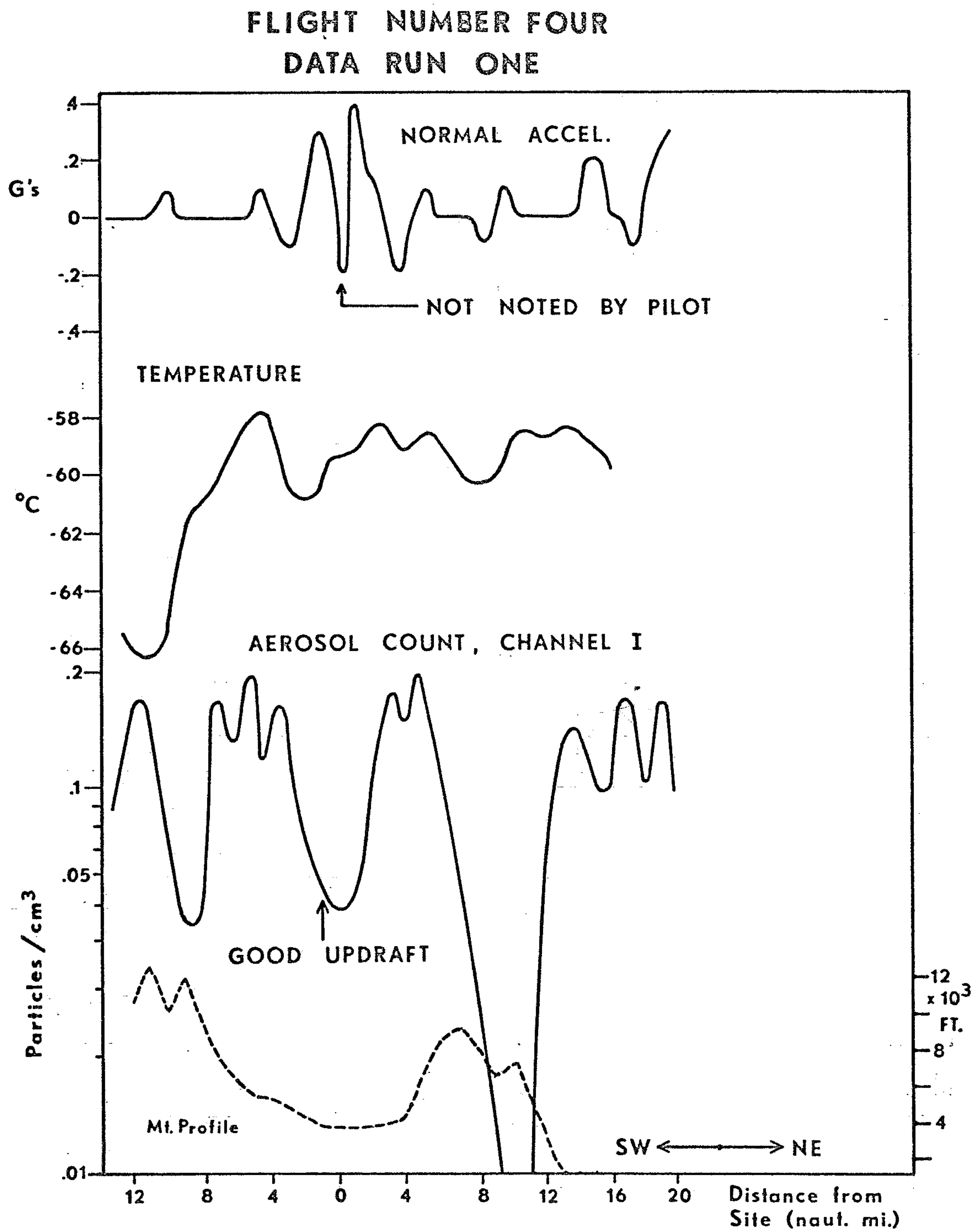

Figure 7. The structure of the aerosol concentration in a probable mountain lee wave condition.

CONCLUSION

The results of the field tests show that at least a qualitative measurement of atmospheric aerosols can be made using an air borne particle counter. The testing was not extensive enough to adequately assess the quantitative accuracy of the instrument. The effect of the sampling technique on the ambient aerosol concentration and size distribution needs to be further investigated because the results obtained during the present testing were not conclusive. The major problems of adopting a photoelectric particle counter for use on high performance aircraft have been solved, and another useful atmospheric probe is now closer to a reality.

References

Rosen, J. M., Simultaneous Dust and Ozone Soundings over North and Central America, J. Geophys. Res. 73, 1968, pp. 479-486.

Rosen, J. M., The Vertical Distribution of Dust Near the Surface of the Earth, J. Air Pollution Control, 19, 1969, pp. 105-108.