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A Millimeter-Wave Radiometer for Detecting Microbursts

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ABSTRACT

This paper describes a millimeter-wave radiometer for the detection of wind shear from airborne platforms or at airport terminals. This proposed instrument will operate near the group of atmospheric oxygen absorptions centered near 60 GHz, which it will use to sense temperature from a distance. The instrument will use two channels to provide two different temperature measurements, providing the basis for solution of two equations in two unknowns, which are range to the wind shear plume and its temperature. A third channel will measure ambient atmospheric temperature. Depending on the temperature difference between the wind-shear plume and ambient, the standard deviation of range measurement accuracy is expected to be about 1 km at 5 km range, while the temperature measurement standard deviation will be about one-fourth the temperature difference between plume and ambient at this range. The instrument is expected to perform usefully at ranges up to 10 km, giving adequate warning of the presence of wind shear even for high performance jet aircraft. Other atmospheric hazards which might be detected by this radiometer include aircraft wakes and vortices, clear-air turbulence, and wind rotors, although the latter two phenomena would be detected by an airborne version of the instrument. A separate radiometer channel will be provided in the proposed instrument to detect aircraft wakes and vortices based on perturbation of the spectrum of microscopic atmospheric temperature fluctuations caused by the passage of large aircraft.

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1. Introduction

It has been estimated that one-half of all aircraft fatalities are caused by inclement weather. One of the most significant manifestations of severe weather, and one which is of great concern with regard to aviation safety, is the phenomenon of wind shear, which is a severe downdraft associated with thunderstorms or other atmospheric instabilities. Since wind shear apparently originates at high altitudes, it is characterized by temperatures lower than the surrounding atmosphere, which provides some basis for building devices for its detection. A strong correlation has been established between the temperature of a wind-shear event and its severity. As an example, Figure 1 [1] shows the measured velocity of a downdraft as a function of its temperature difference compared to the surrounding air. Figure 2 shows the actual measured temperature profile of a wind-shear event which was severe enough to pose danger to aircraft [2].

This proposal describes a device for remote detection of wind shear based on a millimeter-wave (MMW) radiometer which operates on a frequency located on the low-frequency skirt of the group of oxygen absorptions broadly centered at 60 GHz. Such a radiometer was originally described by Haroules and Brown [3] in 1969, but the availability of much better and more sophisticated components since the publication of Reference [3] makes the MMW approach much more attractive. Furthermore, careful measurements of the oxygen absorption coefficient as a function of frequency have been made by Liebe and his coworkers [4], and provide the basis for accurate determination of both the range to the event and its temperature differential, which is a measure of its severity. Range and Temperature measurements are discussed in Section 2.

To detect a temperature change in the atmosphere with a radiometer, it is necessary that the frequency of operation be chosen to lie in an absorption band; otherwise the area of affected atmosphere will be invisible to the radiometer. It is also important that the absorption coefficient not be too large, since the radiometer must be able to see through the atmosphere between itself and the region of modified temperature. For these reasons, the frequency of operation must be chosen to lie in a mildly absorbing region of the atmosphere. The band of oxygen absorptions located near 60 GHz is a good choice for this application because it is broad enough so that the absorption does not change rapidly with frequency and low enough in frequency that excellent components are available for radiometer construction. It will be shown in Section 2 that it is possible to measure both the range to the microburst plume and the difference in temperature between it and the surrounding atmosphere. This paper gives details on the design and construction of a microburst detection radiometer operating in this absorption band.

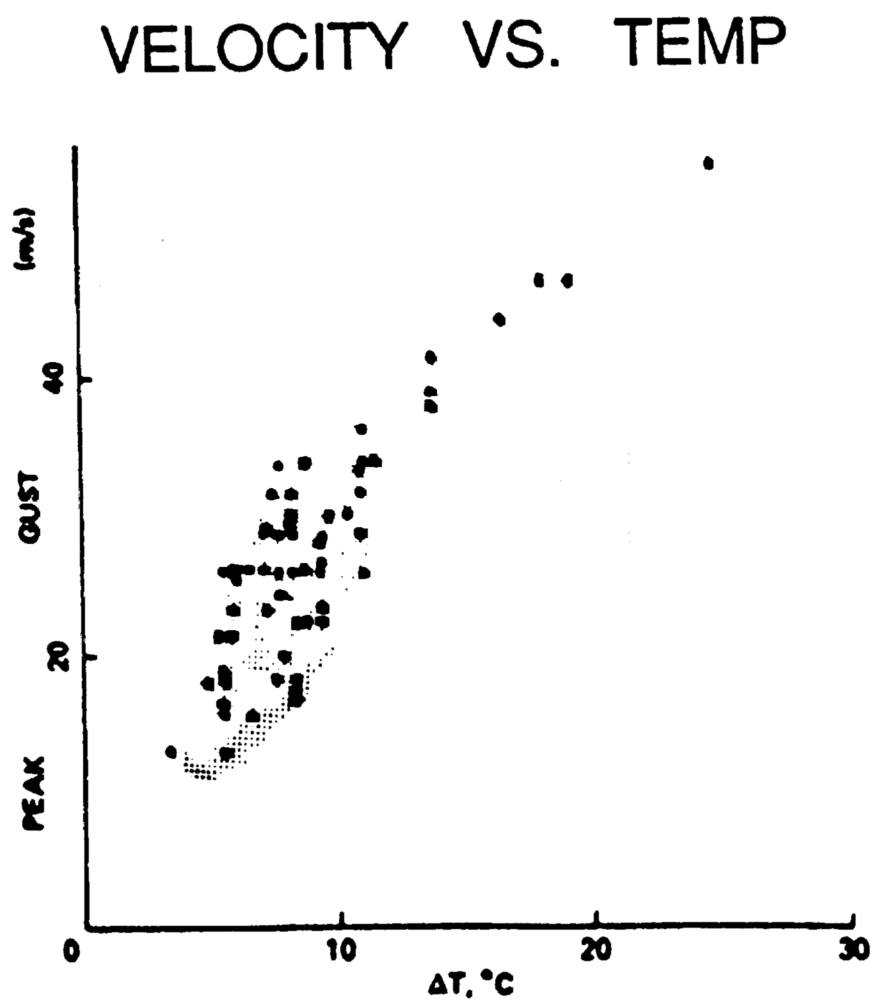

Figure 1. Scatter plot of downdraft velocity as a function of its temperature difference compared to the surrounding air.

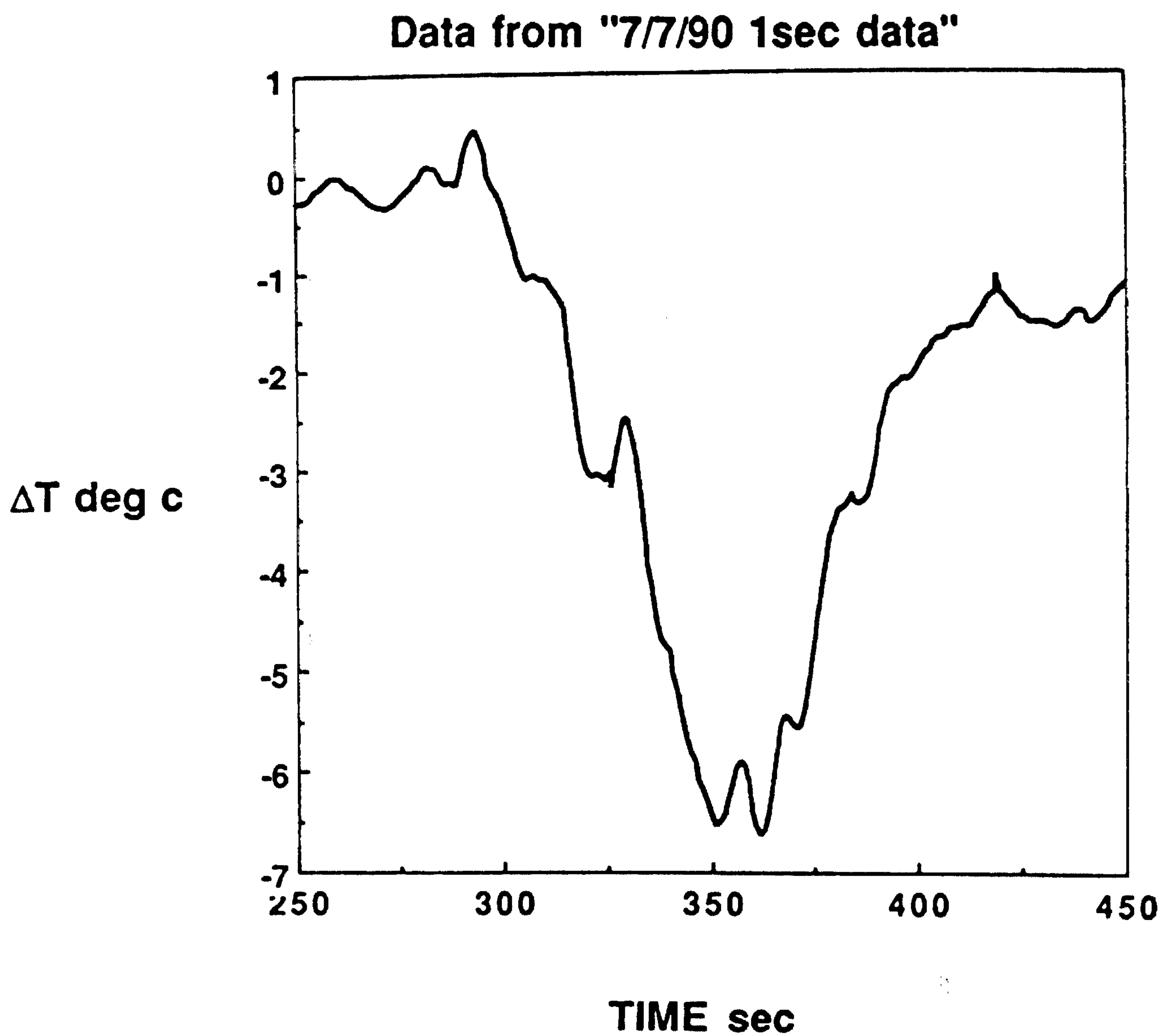

Figure 2. Measured temperature profile of an actual wind shear event.

2. Theory of Operation

2.1 Measurements of Range and Temperature of Wind Shear Event

The radiometer equation gives the temperature observed by a radiometer located at position z = 0 looking through a volume of the atmosphere characterized by temperature $T(z)$ and absorption coefficient $\alpha(z)$ as

$$T_A = \int_0^{\infty} \alpha(z) T(z) \exp[-\int_z^{\infty} \alpha(z') dz'] dz, \quad (1)$$

where T_A is the antenna temperature measured by the radiometer. This equation is simply the sum of the temperature contributions of all elements of length dz in the path attenuated by the atmosphere between the radiometer and the length element. If a horizontal path and homogeneity of the individual regions of the atmosphere are assumed, the integration is trivial, and interesting and useful results are obtained.

In this section, the antenna temperature which one would expect to observe with a radiometer pointing at a wind shear plume through a region of absorbing atmosphere will be calculated. In this analysis, it is assumed that the temperatures and absorption coefficients are reasonably constant in each of the volumes of the atmosphere considered. This requirement will be met if the paths are fairly nearly horizontal, although it is expected that this concept will still be viable for slant-path geometry, although the integrations will be more complex. Consider the geometry shown in Figure 3 in which a radiometer antenna at location h is embedded in a region of temperature T_1 and absorption coefficient α_1 extending to h. The radiometer looks through this medium at a second region extending to infinity which has a temperature T_2 and absorption coefficient α_2. This geometry will be recognized as that which occurs in the atmosphere when a wind shear event which is totally absorbing occurs. If the plume is not totally absorbing, i.e. if it is possible to see through it to the other side, range and temperature measurements will not be accurate, but the presence of the wind-shear event will still be detected. This case will be discussed briefly later, but it is likely that most wind shear events are characterized by total absorption, which is certainly the case for wet microbursts. For dry microbursts of limited horizontal extent, the radiometer will not work as well, but the addition of other channels would provide better detection of these types of events. The number of radiometer channels and their frequencies must be the subject of further study.

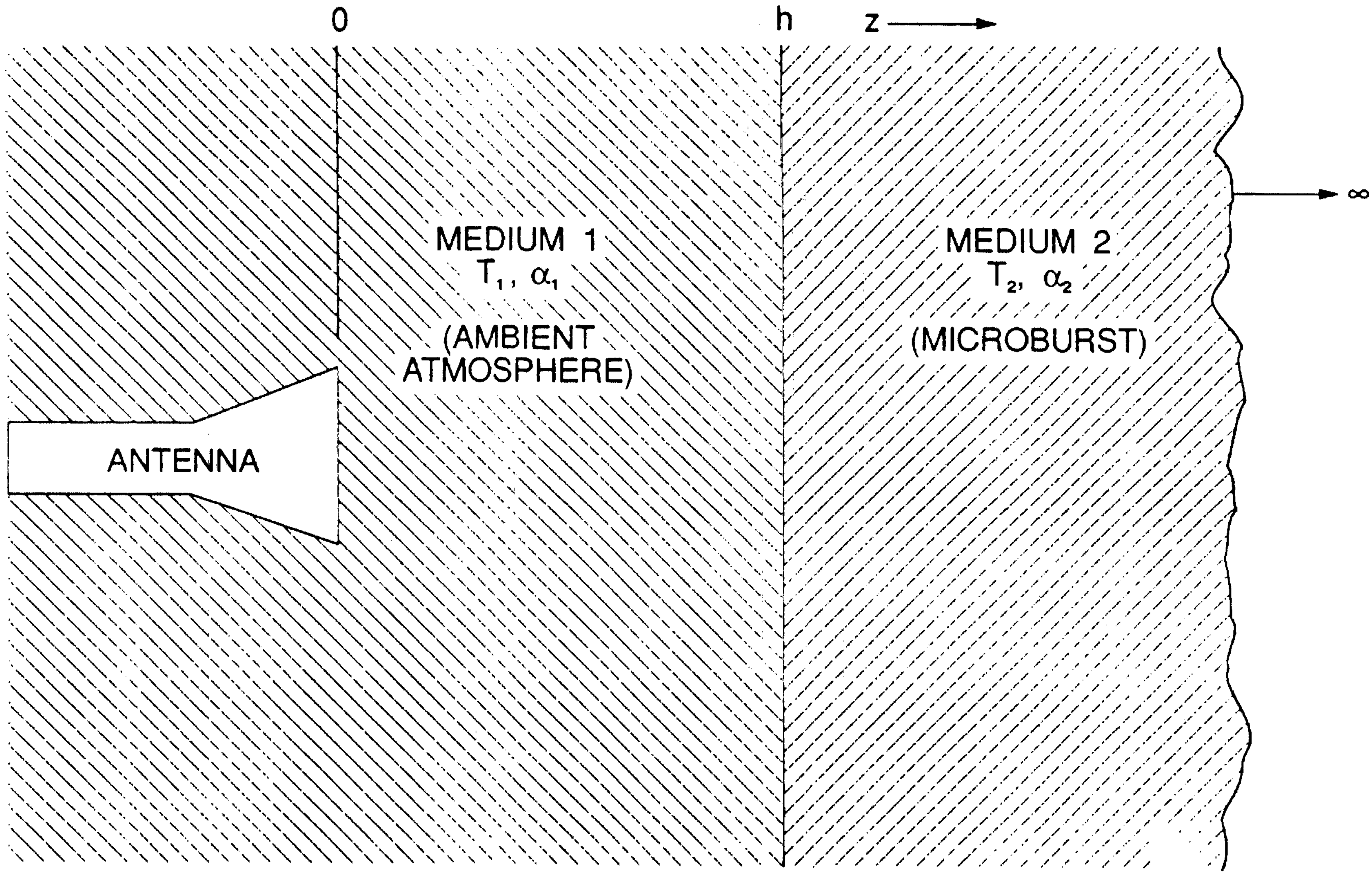

Figure 3. Atmospheric temperature geometry used for calculation of range and temperature of a wind shear event.

Now assume that the radiometer has three channels, one of which lies in a strongly absorbing region of the atmosphere. This channel, since its range is limited by absorption, will simply measure the ambient air temperature T_1. The other two channels, denoted by A and B, are chosen to lie in low and moderately absorbing regions, respectively. If it is assumed that these two regions are homogeneous in temperature and absorption coefficient, it is not difficult to show that the antenna temperatures observed by these two channels are:

$$T_A = T_1 + (T_2 - T_1)e^{-\alpha_A h}, \tag{2}$$

$$T_B = T_1 + (T_2 - T_1)e^{-\alpha_B h}, \tag{3}$$

Where α_A and α_B are the absorption coefficients of the atmosphere in region 1 in the low and moderately absorbing bands, respectively. Note that the absorption coefficient of region 2 does not appear in these equations because region 2 is considered to be infinite in extent. These two equations can be solved for the range h to the plume and the temperature difference between it and the surrounding air. These calculations give:

$$h = \frac{1}{\alpha_B - \alpha_A} \ln\left(\frac{T_1 - T_A}{T_1 - T_B}\right), \tag{4}$$

$$T_1 - T_2 = (T_1 - T_A)^{\frac{\alpha_B}{\alpha_B - \alpha_A}} (T_1 - T_B)^{-\frac{\alpha_A}{\alpha_B - \alpha_A}}. \tag{5}$$

The parameters of interest to the detection of wind-shear plumes can thus be determined by a radiometer operating in an absorption band of the atmosphere. Section 3 describes the design and construction of such a three-channel radiometer operating on and near the absorption band due to oxygen, which lies near 60 GHz.

2.2 Detection of Other Atmospheric Hazards

To the extent that other atmospheric hazards are characterized by changes in temperature, or by changes in the spectrum of microscopic temperature fluctuations, the proposed radiometer would also be able to detect them. It is possible that detection of clear-air turbulence (CAT), wind rotors, and aircraft wakes and vortices could be made using the proposed instrument, although detections of CAT and wind rotors are primarily airborne applications. The original proposal for this type radiometer by Haroules and Brown [3] addressed specifically the detection of CAT, which causes dozens of injuries every year. Several people were injured recently when a Delta Airlines flight encountered CAT over North Georgia. Since this problem was caused by a severe downdraft, it is likely that the temperature of the air mass in front of the aircraft was lower than ambient, and could therefore be detected by the proposed instrument. Updrafts could also be detected because of temperature differences between them and ambient.

Wind rotors have been observed primarily in the Western U.S. where they result from winds descending mountain slopes, resulting in a "horizontal tornado" effect. A wind rotor has been cited as a possible cause of the crash of a commercial airliner in Colorado Springs in 1990 [5], with resultant heavy loss of life. Since the air masses resulting in wind rotors originate at high altitudes, it is very likely that their temperature differences from ambient are significant, and might therefore be a basis for detection of these events by a millimeter-wave radiometer. Apparently little is known about the temperature profiles of these phenomena, since they have heretofore been considered rather benign, but if an airborne radiometer were to sense a sharp temperature difference between the air mass ahead and ambient, it would be wise for a pilot to take evasive action.

Wakes and wing-tip vortices have long been recognized as hazards during takeoff and landing operations, especially when smaller aircraft follow larger. To avoid problems with this type of turbulence, it is necessary to space takeoffs and landings at fairly large time intervals so that the disturbances have time to dissipate. If a means could be found to detect these disturbances, it is possible that the frequencies of takeoffs and landings could be increased significantly.

It is possible that the proposed instrument could detect wakes and vortices by one of two methods. The first involves sensing the average ambient temperature in the wake of an aircraft. Since the passage of a large aircraft will mix warmer air from the boundary layer with cooler air from higher altitudes, the average ambient temperature of the air behind an airplane will increase. By using a radiometer with an integration time of 1 second, it is possible to detect a temperature difference of about 0.1 degrees Kelvin. Assuming a temperature lapse rate in the atmosphere of 6 degrees per kilometer, the temperature at an altitude of 100 m would be about 0.6 degrees lower than that on the surface. If after the passage of an aircraft the temperature is observed to be higher than that observed before passage, the presence of a disturbance might be indicated. When the observed temperature returns to its nominal value, the disturbance will have passed. Although this method might work, an approach based on sensing the temperature spectrum of the disturbance is considered more viable, and is discussed in the following paragraphs.

The atmosphere is very dynamic, even under apparently stable conditions of light winds, moderate temperatures, and no precipitation. Its parameters are constantly changing on a microscopic scale, and these changes affect many observables, for example the propagation of electromagnetic radiation. A commonly cited example of the effects of these microscopic changes is the twinkling of stars and the shimmering of images when viewed through long atmospheric paths. One of the parameters which changes on a microscopic scale is temperature. The instantaneous temperature of the atmosphere at a given location may be expressed as the sum of an average value and a fluctuating component:

$$T = T_{avg} + T_{fluc} \tag{6}.$$

The radiometer channel with the long integration time mentioned above measures T_{avg}, and the channel to be discussed below measures T_{fluc}.

The fluctuating component of the atmospheric temperature has a power spectrum that has been studied extensively [6,7,8], and is well understood, provided there are no disturbances in the atmosphere to perturb it. Measurements of the spectrum of temperature fluctuations are usually made under controlled conditions in open areas far from natural features which would cause perturbation. Since carefully controlled conditions are required for precise measurements of the temperature fluctuation spectrum, it is reasonable to expect that the passage of a large body, such as an airplane, through the atmosphere would significantly perturb this spectrum. It is suggested that this perturbation of the fluctuation spectrum be studied as a possible basis for the detection of wake and vortex turbulence. One of the channels of the three-channel radiometer designed to detect wind shear would be used for this purpose. It would not even be necessary to add another channel, since a separate integrator could be added to an existing channel. The output of this integrator, which would have a very short time constant for detection of fast fluctuations, would be fed into a computer which would calculate the fourier transform of the amplitude fluctuations, thus giving the power spectrum. This process would be continuous, so that any short-term change in the spectrum could be detected in a very short time. The dissipation time of the turbulence would then be the time required for the spectrum to return to normal within prescribed limits. As mentioned above, this characteristic of the atmosphere might also be used to detect wind rotors, or might serve as a method complementary to that involving average temperature changes. The next section discusses in detail the design of a radiometer for detection of wind shear and other atmospheric anomalies.

3. Approach

Figure 4 is a block diagram of the radiometer. Radiation is collected by the horn/lens antenna and fed into a full waveguide band mixer covering the 40 - 60 GHz band This mixer is pumped by a Gunn local oscillator operating at a frequency of 43 GHz. The signal input from the antenna is through a waveguide section with dimensions chosen to cut off all radiation at frequencies lower than about 45 GHz, so that the superheterodyne image frequencies are effectively eliminated, making this instrument a single-sideband radiometer. The output of this mixer feeds an intermediate frequency amplifier covering the range 6 - 18 GHz. The output of this amplifier is split into three channels of 6 - 8, 9

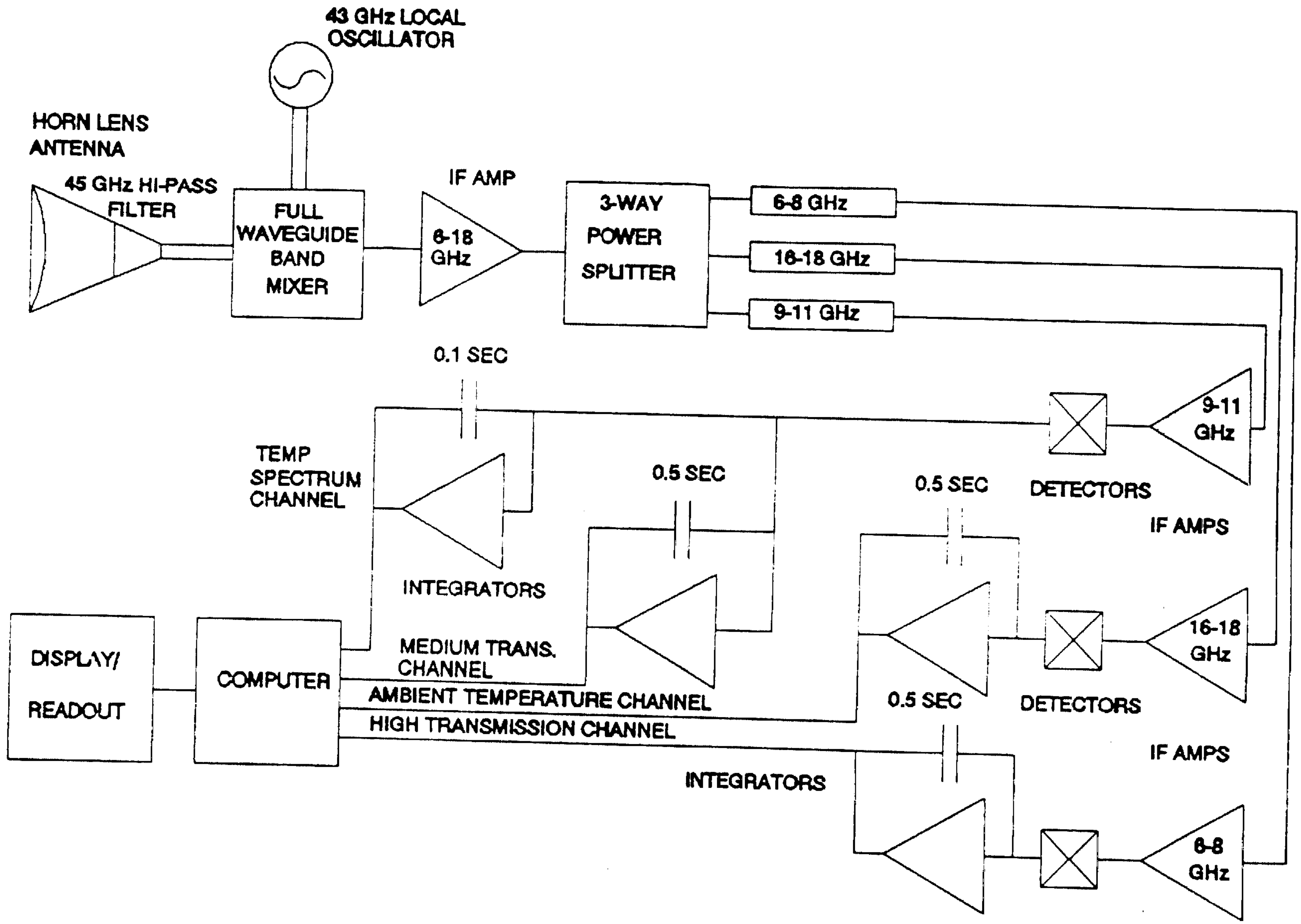

Figure 4. Block diagram of the three-channel radiometer for detecting microbursts.

- 11, and 16 - 18 GHz by a power splitter followed by bandpass filters. These three bands correspond to the signal frequency bands of 49 - 51, 52 - 54, and 59 - 61 GHz, with the images of these frequencies cut off by the input waveguide filter. The receiver will then see the atmospheric temperature in each of the above three channels without the necessity for averaging with image channels. Each of these IFs is fed into an amplifier, whose output is detected and passed into the data processing system. Figure 5 shows the relationship of the three radiometer channels to the 60 GHz oxygen absorption band, calculated using the method devised by Liebe and Layton.

Measurements of the temperature fluctuation spectrum are made by providing a separate integrator with a short time constant for the 52-54 GHz channel. Figure 4 shows that this channel may be added by simply coupling the 9-11 GHz detector output into two separate integrators. The time constant of this spectrum channel must be short enough to resolve the highest frequency fluctuations of interest, but not so short that system noise becomes comparable to temperature fluctuations. Some experimentation will be required to determine the optimum time constant for this channel, although Figure 4 shows a value of 0.1 sec. The output of this spectrum channel is input to the computer, which calculates a fourier transform to arrive at the temperature fluctuation spectrum. This process is done continuously, so that changes in the fluctuation spectrum caused by the passage of aircraft can be easily observed by comparing these spectra before and after.

The existing 9-11 GHz radiometer channel, which has a time constant of 0.5 sec, will be used to measure the average temperature of the air mass behind the aircraft to look for changes due to turbulence. It is possible that a separate integrator will also be used for this purpose, since one might prefer a slightly longer time constant for better resolution.

The radiometer is calibrated by periodically using the input to the antenna to look alternatively at hot and cold loads of known temperatures. Calibration is necessary to negate the effects of changes in gain of the mixer and IF amplifiers. In the future, if these components can be made more stable and housed in a temperature controlled enclosure, it may be possible to build a radiometer requiring calibration only at the beginning of a measurement cycle, so that the wind-shear radiometer could be built with no moving parts.

In the data processing system, the range to the plume and its temperature are calculated using Equations (4) and (5). If no microburst is present, all of the channels will read the same temperature, and the result of calculating range and temperature difference will just be random fluctuations whose amplitude will be a function of system noise. It will be possible to devise algorithms which will recognize a given threshold temperature change and be able to determine whether the change is consistent over some given number of samples. If so, the data processor will calculate a range and give a warning based on the measured

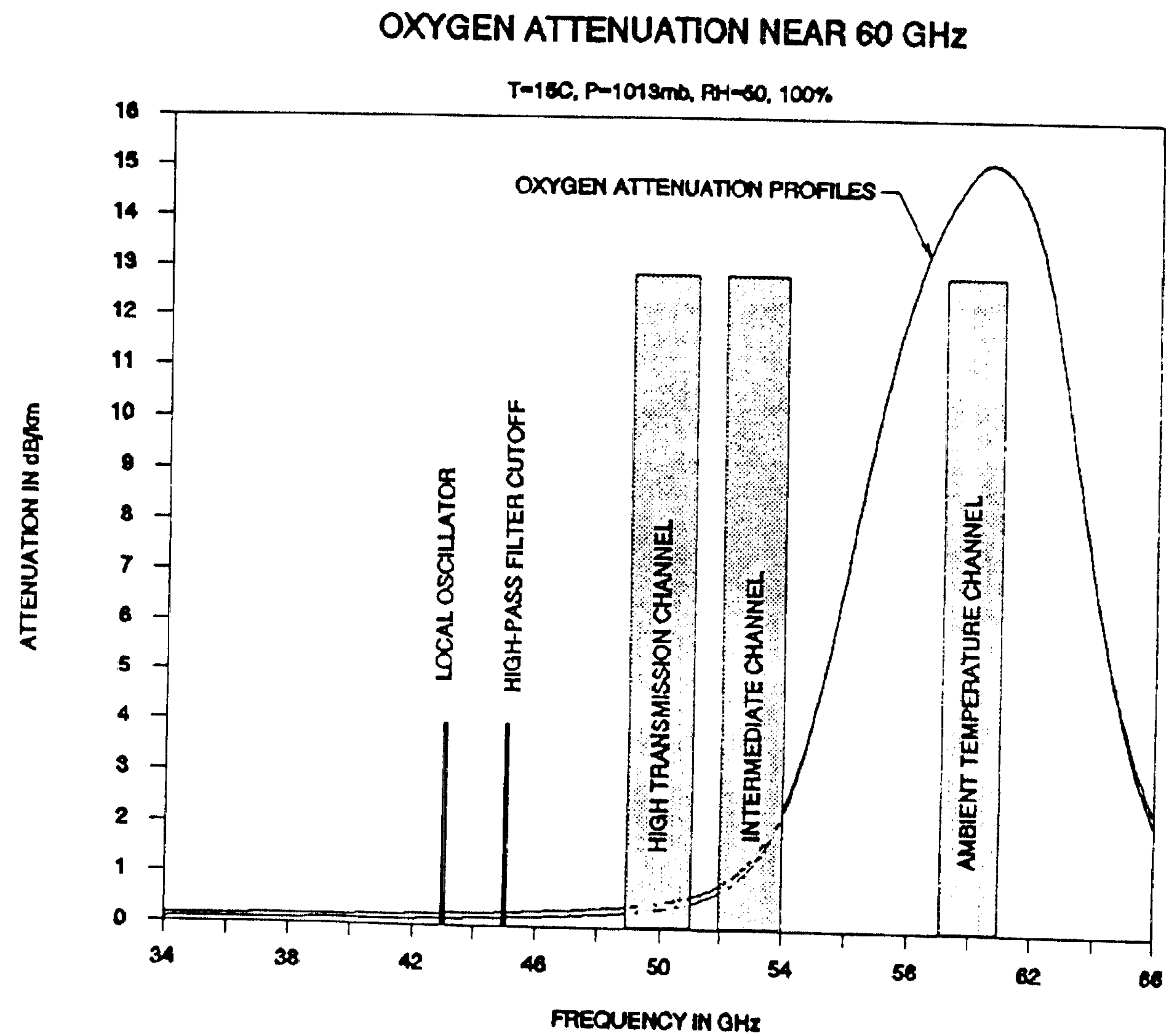

Figure 5. Relationship of the three radiometer channels to the 60 GHz oxygen absorption.

ΔT. As the wind shear comes closer to the radiometer, the range and temperature measurements will become more accurate, and false alarms will happen less often.

The absorption band of oxygen lying near 60 GHz is the ideal range of frequencies in which to operate a temperature sensing radiometer. Unlike water vapor, another possibility, which varies widely in concentration from one location to another, the mixing ratio of oxygen is constant throughout the world. Furthermore, due to the careful work of H. J. Liebe and coworkers [4] at the National Telecommunications Information Agency, the absorption coefficients of oxygen are known to an accuracy of 0.1 dB/km over the range of atmospheric conditions likely to be encountered under microburst conditions. These measurements include the effects of water vapor, rain, snow, and fog. Liebe is currently engaged in a project which has the goal of increasing this accuracy to the order of 0.01 dB/km, which will improve the performance of the wind-shear radiometer, as will be discussed in Section 4.

The fact that the three radiometer channels respond to regions of the atmosphere at different ranges is accounted for by the concept of the weighting function, which is defined as the coefficient of temperature in the antenna temperature integral Equation (1). For horizontal propagation, where α and T vary little with range, the weighting function is just $\alpha(z)\exp[-\alpha(z)]$ where z is range. Since α varies little with range for a horizontal path, it is taken to be constant for the case of interest. It will be recognized that equations (1) and (2) result from solving this integral for constant α and T for the two regions considered. The weighting functions for the three radiometer channels defined by Figure 3 are shown in Figure 6. Note that the weighting for the 59-61 GHz channel is heavily biased to short ranges, while that for the 49-51 GHz channel shows nearly uniform weighting independent of range. This result is in contrast to the downlooking weighting functions normally shown for the oxygen absorption, which show well-defined peaks because of decreasing attenuation as frequency deviates from the center of the oxygen absorptions.

The concept of the weighting function provides a means for measuring the horizontal temperature profile of the atmosphere. By choosing several radiometer channels centered at different frequencies on the low-frequency skirt of the oxygen absorption, it would be possible to sense the temperature at as many different ranges in front of the radiometer, giving the desired profile, assuming the various regions have sharply defined boundaries. Since these weighting functions are not peaked as are those used for downlooking radiometry, the measurements would not be as accurate as for the downlooking case, but the possibility exists for probing fairly complex temperature profiles within wind shear events, such as that shown in Figure 2. However, for general aviation use, the three-channel radiometer described above is considered adequate.

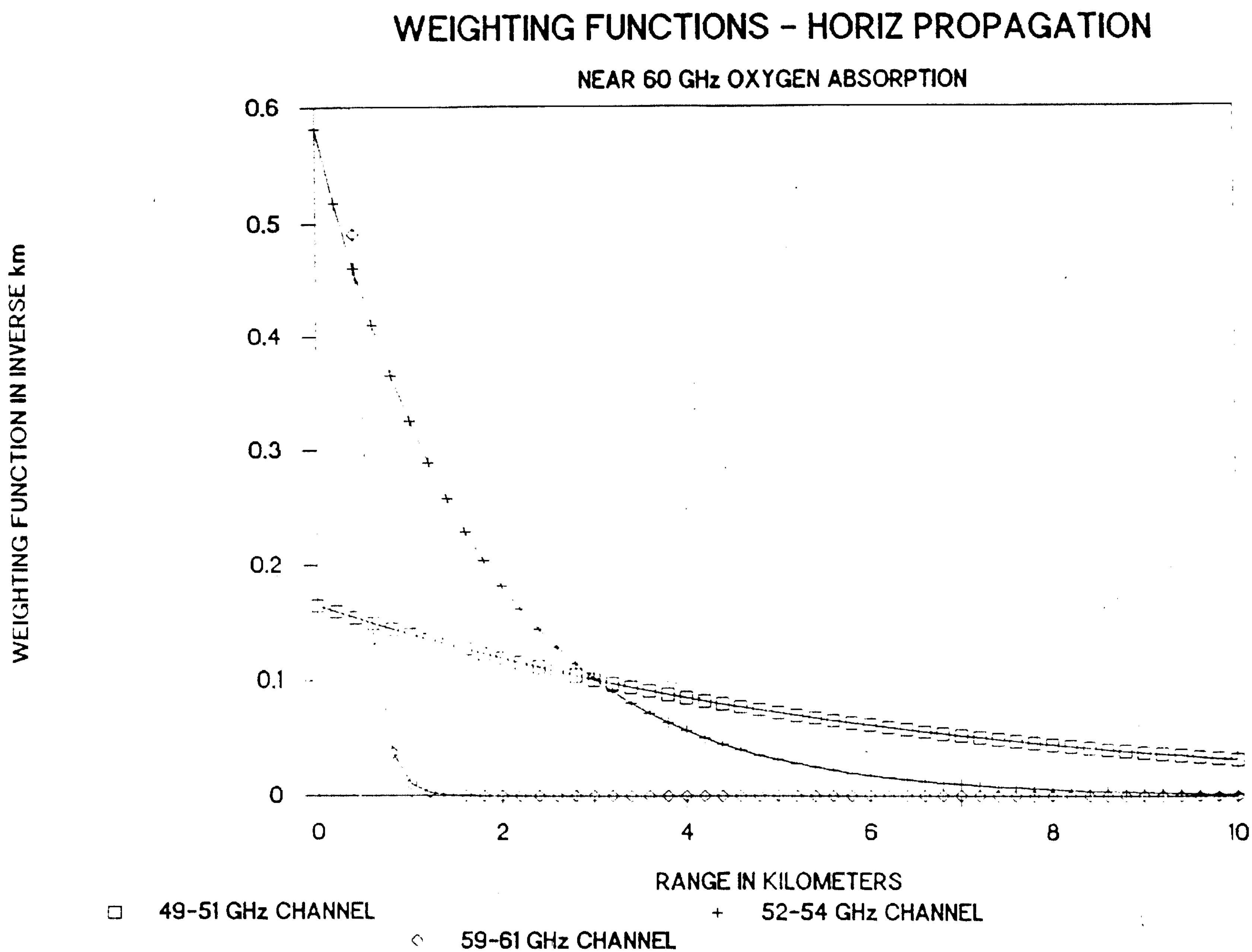

Figure 6. Weighting functions for the three radiometer channels shown in Figure 5.

4. Range and Temperature Error Calculations

Using the above equations for range and temperature difference, the known accuracies in the determination of oxygen attenuation coefficients, and the expected noise performance of the three radiometer channels, it is possible to calculate the rms error in the measurement of these important parameters. For any function of n variables $f(x_1, x_2, \ldots x_n)$, the variance is given by

$$\sigma_f^2 = \sum_{i=1}^{n} \left(\frac{\partial f}{\partial x_i} \right)^2 \sigma_i^2 . \qquad (6)$$

Since we have closed-form expressions for h and $T_1 - T_2$, it is not difficult to calculate these errors, but first it is necessary to determine the errors for the variables x_i. We assume that we know the oxygen absorption to an rms accuracy of 0.1 dB/km. The accuracies with which we know the temperatures are determined by the radiometer equation for minimum detectable temperature

$$\Delta T_{\min} = \frac{K(T_{sys} + T_{ant})}{\sqrt{B\tau}}, \qquad (7)$$

where K is a constant (taken to be 1.5 which accounts for gain fluctuations), T_{sys} is system noise temperature, T_{ant} is antenna temperature, B is system bandwidth, and τ is integration time. The typical single-sideband noise figure of the mixer-amplifier combination proposed for use in this application is 10 dB over the range 49-61 GHz. Using Equation (7), the minimum detectable temperature of the three channels is then 0.14 degrees, assuming an integration time of 0.5 s and a bandwidth of 2 GHz for all channels. These values then become the standard deviations of the errors in measuring T_1, T_A, and T_B which are substituted into Equation (6) for calculation of the range and temperature measurement errors. The other errors used in this calculation are the errors in the determination of the O_2 attenuation, which have a standard deviation of 0.1 dB/km = 0.04 km^{-1} as mentioned above.

Using the equations for range and temperature difference derived above, the error Equation (6), and the standard deviations discussed in the last paragraph, it is possible to calculate the errors in determination of range and temperature difference for a radiometer with the given noise performance. The results of the range measurement error calculations are given in Figure 7 as a function of range for ΔTs of 5, 10, 20, and 30 degrees. Note that range measurement is more accurate for the larger temperature differences, as expected. The temperature measurement errors are shown in Figure 8, using the same parameters. At a range of 5 km, the range measurement error has a standard deviation of about 2 km, and the temperature

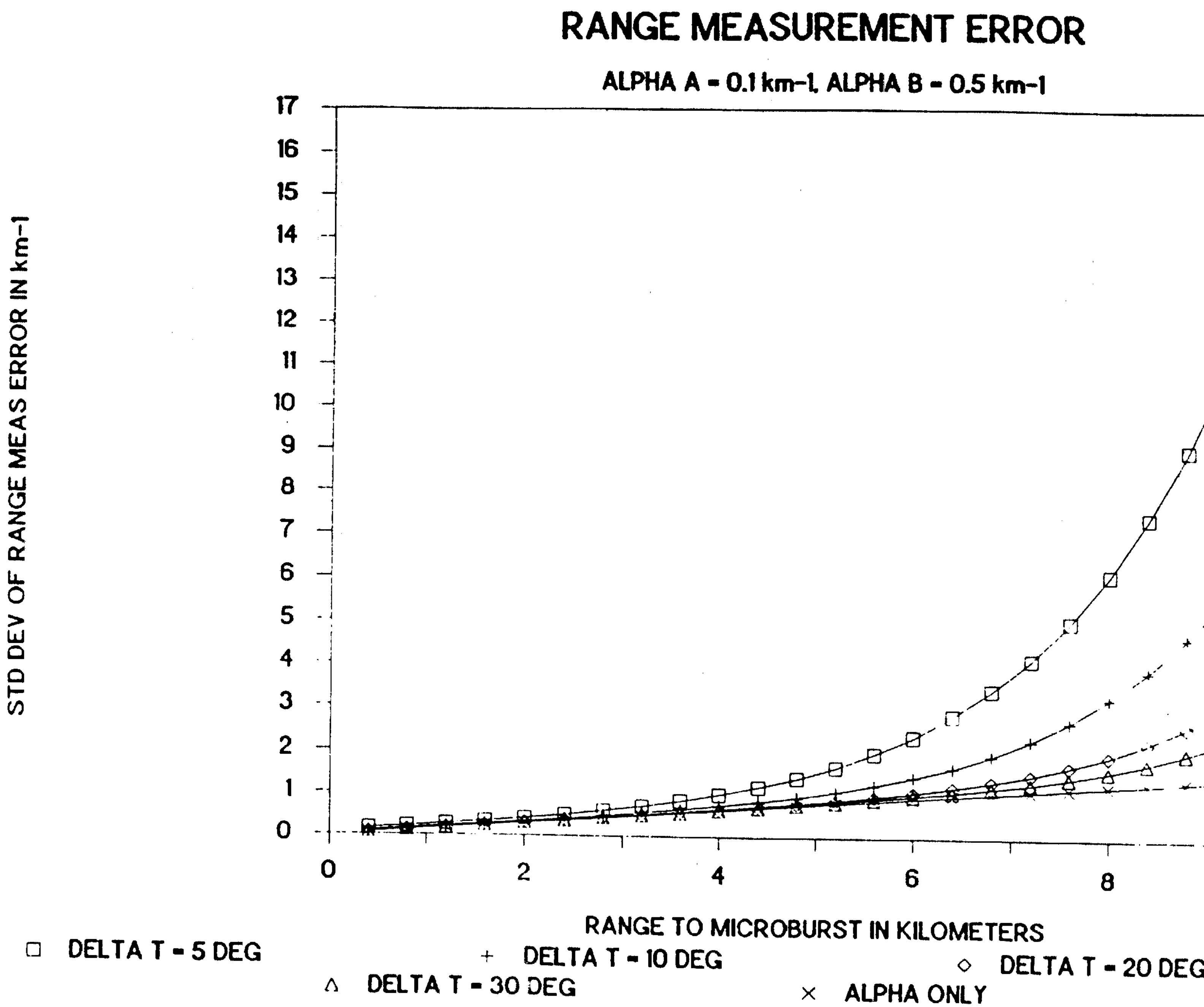

Figure 7. Range measurement errors for the wind shear radiometer as a function of range.

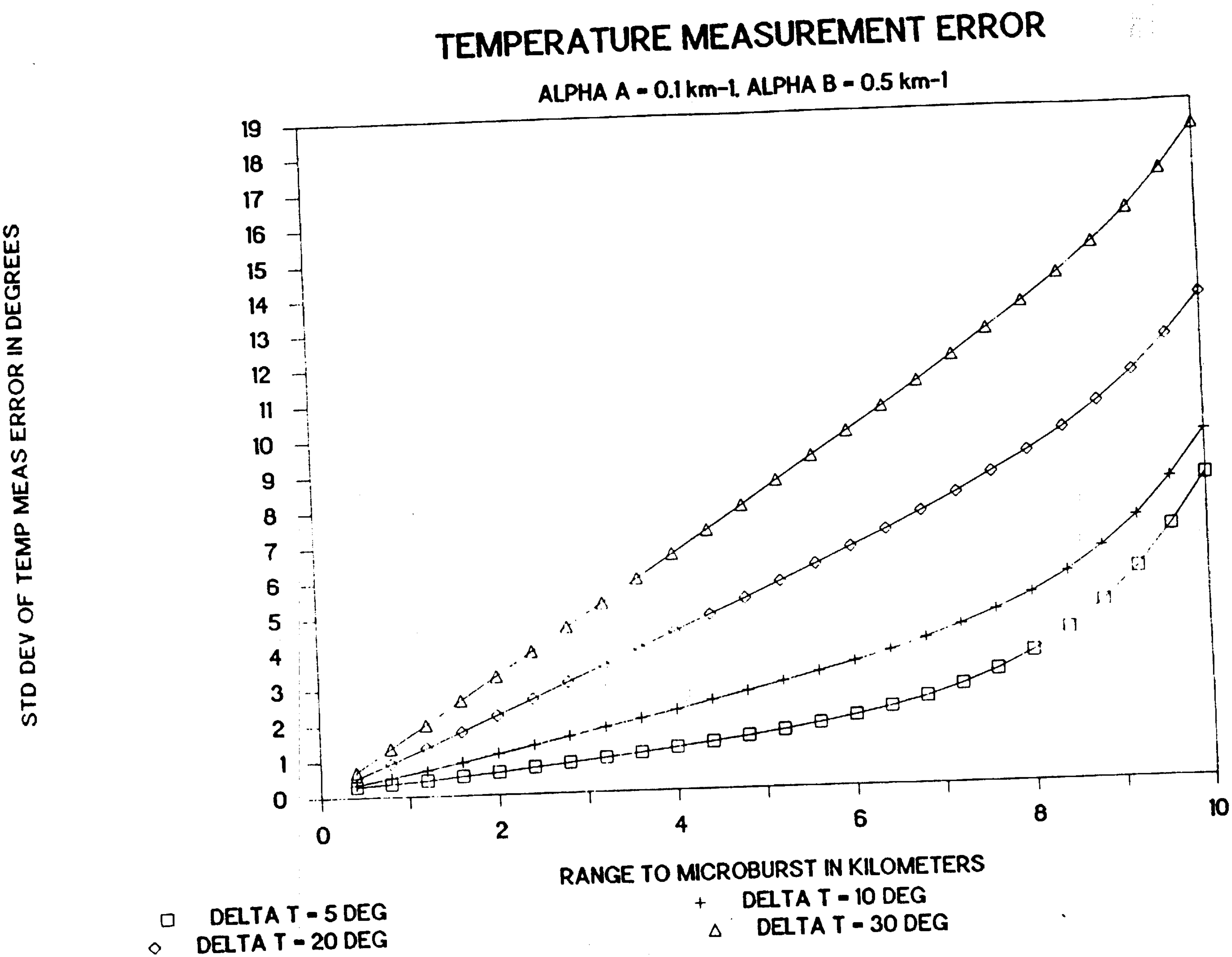

Figure 8. Temperature measurement errors for the wind shear radiometer as a function of range.

measurement error standard deviation is about one-third the temperature difference between the microburst plume and ambient for all cases.

It is possible to show that more than half these errors at 5 km is due to uncertainty in our knowledge of the oxygen absorption coefficient. If the work being done by Liebe [4], in which the accuracy of these absorptions can be known to 0.01 dB/km, can be applied to this radiometer, its range and temperature measurement accuracy can be improved considerably. This feature of the millimeter-wave system emphasizes a significant advantage over the infrared system, which operates at a wavelength of about 16 microns. Absorptions in the infrared are not known to great accuracy, and even if they were, the presence of literally thousands of water vapor absorptions in this region would make the determination of absorption nearly impossible because of the great variation in water vapor concentration from place to place. Because of these limitations, it would probably be impossible to measure accurately the range and temperature of a microburst using an infrared system, although detection of its presence is certainly possible.

5. Evaluation of Wind-Shear Radiometer Performance

Although wind-shear events are very hazardous to aircraft, they still occur very rarely. Because of this rarity in occurrence, adequate testing of the radiometer will be a problem. For proper testing of this instrument, it is necessary for it to view a region of the atmosphere that is at ambient temperature for distances near the point of the test and colder than ambient for regions further away. Fortunately, these requirements are met by the vertical temperature profile of the atmosphere, which will be near ambient temperature near the surface, but will decrease in temperature at an approximate lapse rate of -6 degrees centigrade per kilometer above the surface. The temperature of the atmosphere as viewed by an uplooking radiometer is given by Equation (1), with the addition of a small correction due to the cosmic background temperature attenuated by the atmosphere, which is negligible at these frequencies of interest. By looking upward into the clear sky, the radiometer will see different temperatures in each of its three channels, in a manner similar to what it would see by looking horizontally through the atmosphere at a wind-shear plume. The 59-61 GHz channel would measure the ambient temperature, while the 52-54 and the 49-51 GHz channels would see progressively lower temperatures, since they would see higher into the atmosphere where the temperatures are lower. In this way, the data processing system associated with this instrument would "think" that it is seeing a wind shear plume at a given range. By solving Equation (1) numerically for the temperatures in the three channels corresponding to the prevailing atmospheric conditions, it will be possible to arrive at the range and temperature of the microburst which the radiometer "thinks" it sees. In this way the accuracy of the instrument and its associated data processing algorithms can be assessed. Of course, the instrument will also be used to look horizontally at inclement weather to determine its capability for detecting wind shear if it does occur, but the vertical-looking, clear-sky tests described above will probably yield a more accurate measure of system performance.

For evaluating the ability of the radiometer to detect aircraft wakes and vortices, it will be necessary to place the instrument near an airport so that these phenomena occur with some regularity. The radiometer would simply be pointed at the runway glide path and the observed temperature spectra would be processed as described above.

9. Summary

We have described a three-channel radiometer based on off-the-shelf parts which we expect to be able to detect the difference in temperature between a microburst plume and ambient air with good accuracy. This instrument, which uses the family of oxygen absorptions centered near 60 GHz as an emitter to measure temperature, would have no moving parts (assuming that calibration issues can be resolved) and would not require a cooled detector. This instrument will be capable of measuring both the range to a wind-shear event and its temperature, which is a measure of its severity. A separate radiometer channel senses the atmospheric temperature fluctuation spectrum for detection of aircraft wakes and vortices. Furthermore, it would have a significant advantage over infrared instruments based on the same principle in propagation through atmospheric aerosols such as clouds and dust, and a marginal advantage in propagation through rain. Another advantage of the millimeter wave instrument over the infrared instrument is based on our knowledge of atmospheric attenuation near 60 GHz. This attenuation is known to high accuracy for a wide variety of atmospheric conditions, including fog, rain , high humidity, and even snow. The large number of atmospheric species with transitions in the infrared bands and our lack of knowledge about them means that it is difficult to know the attenuation coefficients at these wavelengths. This problem is made especially severe by the presence of water vapor, which has literally thousands of transitions in the IR bands and whose concentration varies widely from place to place. Because of the careful work of H. J. Liebe and his coworkers, this problem does not exist for the proposed millimeter-wave instrument, since atmospheric absorption coefficients in the oxygen bands are known to an accuracy of 0.1 dB/km, with the promise of even better accuracy based on later work.

The proposed instrument would probably be used most effectively on board aircraft, where it might also be able to detect clear air turbulence and wind rotors. For ground-based applications, it would supplement the existing terminal doppler weather radar systems at large airports and would serve as a stand alone wind shear detector for smaller airports. In ground-based applications, the radiometer might also be able to detect wingtip vortices.

REFERENCES

1. E. J. Fawbush and R. C. Miller, "A Basis for Forecasting Peak Wind Gusts in Non-Frontal Thunderstorms", Bulletin of the American Meteorological Society, Vol. 35, Jan. 1954, pp. 14-19.

2. R. L. Bowles, "Reducing Windshear Risk Through Airborne Systems Technology", 17th Congress of the Aeronautical Sciences, Stockholm, Sweden, September, 1990.

3. G. G. Haroules and W. E. Brown, "A 60 GHz Multi-Frequency Radiometric Sensor for Detecting Clear Air Turbulence in the Troposphere", IEEE Transactions on Aerospace and Electronic Systems, Vol. AES-5, No. 5, Sept. 1969, pp. 712-723.

4. H. J. Liebe and D. H. Layton, NTIA Report 87-224, National Telecommunications and Information Association, Boulder, CO, (1987).

5. T. S. Perry, "Wind Rotor Maybe Downed Plane", IEEE Institute, May/June 1991.

6. R. J. Hill, "Spectra of Fluctuations in Refractivity, Temperature, Humidity, and the Temperature-Humidity Cospectrum in the Inertial and Dissipation Ranges", Radio Science, Vol. 13, No. 6, Nov.-Dec. 1978, pp. 953-961.

7. F. H. Champagne, C. A. Friehe, J. C. LaRue, J. C. Wyngaard, "Flux Measurements, Flux Estimation Techniques, and Fine-Scale Turbulence Measurements in the unstable Surface Layer Over Land", J. Atmospheric Sciences, Vol. 34, 1977, pp. 515-530.

8. R. M. Williams, Jr. and C. A. Paulson, "Microscale Temperature and Velocity Spectra in the Atmospheric Boundary Layer", J. Fluid Mechanics, Vol. 83, 1977, pp. 547-567.

A Millimeter-Wave Radiometer for Detecting of Microbursts
Questions and Answers

Q: Phil Brockman (NASA Langley) - I used to do a lot of measurements with passive infrared, and it seemed like the signal would depend on the temperature difference and also a difference in the absorption or emissivity. If you are looking downward you should see a change in water vapor concentration. What happens if you go into rain, where you are coming out of clear air and then you hit some rain? The emissivity and absorption will probably change. Sometime along the line I would like to hear some of the infrared people address this issue.

A: Bob McMillan (Georgia Tech) - Well rain is a problem of course. At any frequency above 30 or 40 gigahertz the attenuation is almost constant because you are in the knee of the absorption/scattering region. I think that this instrument would probably perform very similarly to the infrared instrument in rain. I do not think there is very much difference in absorption or scattering.

Q: Phil Brockman (NASA Langley) - If you are coming out of clear air and then you hit rain, there is a sudden change. Do you have a problem when that happens?

A: Bob McMillan (Georgia Tech) - Some of the pictures that I have seen in the last couple of days have shown a microburst cell imbedded in a huge rainstorm. I think this instrument would have trouble seeing through the rain to that cell. If the rain were maybe less than four millimeters per hour, then it might would be able to detect it. But in Florida for example, I know you get 60 or 100 millimeter per hour rains. I think most of us have trouble with that kind of weather.

Q: Kim Elmore (NCAR) - Aside from this instruments potential to see wing tip vorticies and perhaps clear air turbulence. What do you see as its ability to tell us things that the TDWR could not tell us in a microburst type of environment.

A: Bob McMillan (Georgia Tech) - I don't think there is anything that this instrument can tell us that the TDWR couldn't. Maybe I should address your question from the point of view of the airborne radars. This instrument and the infrared instrument should be able to detect stuff that is associated with clear air and with no scatters, because it depends on temperature and not back scatter. I guess the TDWR has so much power that it sees these things even in clear air.

Pete Sinclair (Colorado State University) - You might consider including the third layer behind the microburst into the model that you have. We have found with the infrared that this is an area that will leak through the back of the microburst, especially in Denver where the precipitation is light. That field of radiance is an important factor and if you do not take that into account the microburst looks a lot better than it really is.

Bob McMillan (Georgia Tech) - That is an excellent point. I think what we would do in the case of clear air is to increase the absorption coefficients so the instrument does not see through. We would move those RF channels up on the oxygen line so it does not see as far. In that case there would be less leakage. We have actually done that. We have looked at the effect of having that.

Session VIII. Passive Infrared Technology

Colorado State University Research

Dr. Pete Sinclair, Colorado State University

Presentation not available

Colorado State University Research

Questions and Answers

Q: Roland Bowles (NASA Langley) - Now that you have done these experiments, how would you relate the measurables, the observables of the IR instrument, to aircraft hazard?

A: Pete Sinclair (Colorado State University) - That is our summer program. Looking at this last example, with the detached or displaced vortex, it is a very weak microburst in terms of temperature difference. But, it is a great hazard, depending on what altitude you are at and what orientation you are flying with respect to the microburst. It is not really clear to us that we should make a forecast from the temperature difference directly without knowing what the trajectory of the aircraft is in relation to the microburst structure. I can't answer how we do that right now, but I think that is the bottom line in this whole thing.

Roland Bowles (NASA Langley) - So I would interpret your comment to mean, that is an unsolved problem in your mind.

Pete Sinclair (Colorado State University) - Well, it is unsolved. We have a lot of data that we could put a model together with and give you a forecast. But, I would be worried right now that with a slightly different approach or departure mode we would have some false alarms. I think more study needs to be made on that.

Roland Bowles (NASA Langley) - Based on our discussion and some of the questions you have asked, you seem to have a very strong opinion about probing these things under five hundred feet, and I think that is good from a scientific point of view. But, the whole idea of the airborne systems technology work, and what operators need, is to avoid getting there based on measurements down there. We are not trying to quantify how strong they can be. We are sitting outside pinging on them, and we are not going to go in there if those measurements show a hazard.

Pete Sinclair (Colorado State University) - If you are going to make a model or a prediction, you have to know what is there, for those critical cases when the measurements that we are making, like you are with the radar, are slightly higher.

Roland Bowles (NASA Langley) - All of the radar data you saw yesterday was two degrees below the horizon. The measurements were being made right down into the ground.

Pete Sinclair (Colorado State University) - That is right. We are trying to verify from the flight measurements, what those radar values really mean, and what our radiometer measurements really mean.

Roland Bowles (NASA Langley) - I can understand the desire to scale the radiometer observable to an expected hazard, but the pulse Doppler systems make a direct measurement.

Pete Sinclair (Colorado State University) - They do. But if you average over a kilometer, I think for some aircraft you miss important parts of the velocity spectrum that can affect them, even for the heavies that get very close to the ground. We have a different hazard factor. In the hazard factor that you developed we have added a height term. When you get down to 50 meters we are jumping that hazard factor way up. Any moderate hazard factor at 50 meters is a lot different than at say 500 meters.

Roland Bowles (NASA Langley) - Obviously, but that is the whole idea of remote sensing. You are sitting outside pinging on it, and making a decision before you go there. The other thing is the scaling on your balsa vanes and picking a 250 meter averaging length, you are looking at scales of motion that just absolutely don't effect airplanes to any great extent. You are seeing small scale, you are not talking about long term effects. With the thrust to weight you have in that airplane, if you encountered a 0.3 hazard you would not be here today, if they were sustained. Those spurious peaks are not of significant interest.

Pete Sinclair (Colorado State University) - No, I disagree with you Roland. They are not spurious peaks, they are continuous values that are building up. We are not looking at, for example, turbulence inside a thunderstorm where we have giant peaks. We are looking at a field that is coherent, that is either downward or upward. It has peak values, but the field is coherent and in the average it is not affected by the spurious peak. It is very strong. The unusual point about this and that concerned us a lot is that once you get close to the ground we are worried about the turbulence because in our airplane turbulence is a big factor. These things are flowing relatively smoothly, not like a thunderstorm or a convective situation. We do not get the G loading and the vane response from turbulence that we would normally. These are definite build ups and definite shear layers.

Roland Bowles (NASA Langley) - We will discuss this some more, but 0.25 and 0.3's in vertical motion, you are talking five to six thousand feet per minute of downdraft. Clearly that Cessna could not handle that for any length of time.

Pete Sinclair (Colorado State University) - Our true airspeeds are about 55 to 60 meters per second. I am talking 10 to 15 meters per second of downdraft. That is going to give you a 0.2 value. You have to remember we are traveling less than half the airspeed of what you guys are.

Roland Bowles (NASA Langley) - But that makes the effect on the airplane flight-path-angle depression even worse, because it is scaled as one over the airspeed. You just would not be here if that were true, for any significant amount of time.

Session IX. Terminal Doppler Weather Radar