NOAA Technical Memorandum ERL WPL-8

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Environmental Research Laboratories

Report on the July 1972 Workshop in Atmospheric Acoustics

F. F. HALL, JR.

Wave Propagation Laboratory
BOULDER, COLORADO
October 1973

ENVIRONMENTAL RESEARCH LABORATORIES

WAVE PROPAGATION LABORATORY

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NOTICE

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F. F. Hall, Jr.

This memorandum is an informal report on the proceedings of a Workshop on Atmospheric Acoustics, held in Boulder, Colorado, 6 and 7 July 1972. Primary attention is given to acoustic echo sounders, their design, construction, and interpretation of the atmospheric structure they depict.

1. INTRODUCTION

Because of the increasing number of atmospheric acoustic programs for remote sensing of meteorological variables active during 1971 and 1972, the Atmospheric Acoustics Group of the Wave Propagation Laboratory hosted a Workshop on Atmospheric Acoustics at the Boulder NOAA Laboratories on 6 and 7 July 1972. This Technical Memorandum reports on the Workshop, the topics discussed, and conclusions reached. This informal report is to serve as a working paper, perhaps making it easier for those working in the field or those interested in entering the field to communicate with their colleagues having similar interest.

2. WORKSHOP PROCEEDINGS

The two days of the Workshop were devoted to discussions of the engineering aspects of acoustic systems on the first day and considerations of the atmospheric science payoffs from acoustics on the second day. The workshop opened with welcoming remarks by C. G. Little, Director of the Wave Propagation Laboratory.

2.1 Engineering of Acoustic Sounders

The lead-off speaker for the technical discussions was John Wescott of the Wave Propagation Laboratory, who described the echo sounding systems which have been developed in Boulder since the program was initiated in 1969. Design details of the sounders have been published (J. W. Wescott et al., 1970; W. R. Simmons et al., 1971; F. F. Hall et al., 1971; F. F. Hall, 1972). Mr. Wescott emphasized the all solid state switching that has been used in the WPL sounders, the "off-the-shelf components" construction philosophy used in the early sounders, design of the later control units for the Mark III and subsequent sounders, and the ability of tracking filters to provide a reliable measure of the Doppler shift in the return echo.

Mel Sanders, Systems Development Office of the National Weather Service, Silver Spring, Maryland,described the operation of the NWS sounder, featuring an antenna composed of 100 driver-horn units. At first the horns were 22" in aperture but were cut down to 10 1/2", less than one-half the wavelength, to avoid grating lobe problems. Each driver is 30 watts and the horns are arranged in sub-arrays of four each with 120 watt cards for each sub-array. The 25 sub-arrays are driven by a power amplifier capable of delivering 4 kW. Mr. Sanders explained that it is necessary to test each driver for its phase properties but that 110 out of 125 delivered were within 5° in phase (University ID 30s). This high power sounder was designed specifically to enable the monitoring of synoptic weather fronts, although operation has been somewhat frustrated by the sounders location at the Sterling test facility, adjacent to Dulles Airport. Numerous vertical stripes on the facsimile records obtained there attest to the air traffic at Dulles.

Neil Shaw of the Royal Australian Air Force Academy, University of Melbourne, and during 1972 at the Argonne National Laboratories in Chicago, reported on the evolution of three models of the RAAF sounders. The goal was to achieve a high power but inexpensive sounder. Facsimile records displayed by Dr. Shaw revealed synoptic subsidence inversions. Some elevated inversions showed strong echoes while others, with equivalent temperature gradients, show essentially no echo, evidently because of differences in the wind shear at the inversion. Range ambiguity sometimes occur with 6 sec pulse repetition rates, where inversions 5000 ft above the surface may be improperly depicted much lower; 12 sec repetition rates avoid this problem. He reported on studies of A-scope integration at 2, 4, 6, 8, and 10 min times but it would appear that the ubiquitous facsimile machine does a better job in showing the nature of atmospheric structure.

Gene Walker of the Department of Electrical Engineering, University of Oklahoma described the sounder developed in Norman over the past 18 months. Their interest is principally in the Ekman layer. Their sounder operates at 1500 Hz utilizing a 12 ft dish antenna. They shape the pulse with a third octave filter and have been able to over drive their Altec transducer by a factor of three with little voice coil failure.

Richard DeLoach, NASA Langley Research Center, reported on their program for utilization of the sounder to monitor atmospheric turbulence which may have an influence in the propagation of sound from aircraft. Noise level measurements have been obtained to date using a 6 ft diameter, cone off-axis paraboloid antenna constructed of aluminum. DeLoach pointed out it will be necessary to damp this antenna since present ringing time exceeds 1 sec.

Hans Ottersten, of the Research Institute of the Swedish National Defense reported on another sounder built around a large aluminum horn with an aperture 2x2.5 m. Mr. Ottersten showed some impressive inversion records taken along the Baltic Coast and indicated he also had in situ measurements from aircraft.

Cal Easterbrook from Cornell Aeronautical Laboratories (now Calspan) was unable to attend the symposium but sent a report on their sounder, set up at Point Arguello in an attempt to monitor the depth of fog layers and any effects produced by fog modification experiments. His sounder uses a 5 ft parabolic dish with driver and coupling horn at the focus. CRT photography is used for facsimile presentation.

Madoka Fukushima of the Radio Research Laboratories, Ministry of Posts and Telecommunications, Tokyo, Japan, was also unable to attend the Workshop but had visited Boulder several weeks earlier. He left a report on their sounder to be read to the meeting. The sounder is operated at the Radio Research Laboratories in Tokyo and is equipped with concrete paraboloidal antenna of 16 m diameter, 4 m focal length. The operating frequency is 850 Hz, peak power 100 W, pulse width 60 or 120 ms, pulse repetition frequencies of 3, 6, and 12 sec with the transducer being a horn speaker providing a sound pressure level of 113 dB and a receiving sensitivity of -47 dB. The receiver bandwidth is 40 Hz with a minimum input voltage of 1 μV. Turbulent returns up to 200 m in height were almost always observed during the winter season 1971-72 but further improvements need to be made in the dynamic range of the receiver, which is 14 dB, but can be adjusted in 10 dB steps over a 40 dB range.

Frank Manov of the Aerospace Corporation in California was unable to attend the Workshop, but notified NOAA by telephone that they have accomplished preliminary experiments with a separated horn transmitter and microphone in a parabolic dish receiver in the Los Angeles area. The objective of the experiment will be to monitor mixing depths during rocket launches where the dispersion of objectionable exhaust gas products must be predicted.

Tim Gething, of the Department of Meteorology, University of Melbourne, Australia, summarized their program, which has been underway for several years. They use a "growing pulse" technique to apply the transmit voltage through an RC network to the horn-driver at the focus of a surplus radar parabolic dish in transmit. Operating at 2 kHz, they obtain consistent monostatic returns from as high as 600 m. Fiberglass bats are used to limit sidelobes. The excess attenuation from scattering has been studied at several frequencies. They have participated in several RF scatter and air pollution oriented experiments at a number of locations within Australia.

The Illinois Institute of Technology Research Institute Sounder Program was reported by R. Damkevala. They have a 4 ft dish on top of a 20 story building near downtown Chicago. They have studied the sound pressure level characteristics of the background noise. Operating at 1320 Hz they use a resonator tube on the driver and have obtained ranges of only several hundred feet, with the short range principally caused by ground clutter and noise which at times saturate the return to ranges of 400 ft.

Probably the lowest cost sounder in operation was described by Ed Miller of Oregon State University. Using a 40 watt driver at 2 kHz in an 8 ft dish, and a 3-hour drum audiogram Sefax type facsimile, some impressive records of gravity waves in temperature inversions, thermal plumes, and returns from the top of fog layers were displayed. Miller estimated that less than $500 in parts went into the sounder (excluding the available dish and drum fax). The objective of the study is to document the boundary layer characteristics in the Oregon region.

Michel Aubry, CNET, Paris, reported on plans his group has for Doppler experiments, ray tracing programs, and attenuation experiments. They hoped to have their sounder in operation by October 1972.

Richard Bennett, of the Department of Physics, University of Toronto, reported on the operation of a sounder he has installed on top of the Physics Building in downtown Toronto. He has measured 95 dB noise peaks in the 20 Hz - 20 kHz region where his transducer has relatively flat response. He experiences an "organ pipe" noise effect from wind at 25 Hz, probably caused by his cylindrical shielding cuff or perhaps from eddies shed by nearby building structures.

Gerhardt Peters, of the University of Hamburg, Germany, reported on their plans to employ a sounder during the GATE experiments in 1974. Objectives of the ship-borne sounder will be to measure heat and momentum flux over tropical oceans, to study the characteristics of trade inversions, and the nature of the planetary boundary layer to heights of 1000 ft in the planned GATE region off the coast of Africa.

S. P. Singal of the National Physical Laboratory, New Delhi, India, was unable to attend the Workshop, but sent a description of their sounder and accomplishments to date. A cross array of loudspeakers is used for the transmitter with 6 watts acoustic power peak, 10 ms pulse duration and carrier frequencies of 1-2 kHz and a pulse repetition rate of 3 sec. Beam divergence is 20^{o} from the crossed array. A microphone in a parabolic bowl area 2.5 m^2 serves as the receiving antenna. Echoes have been obtained from the clear night sky at ranges up to 200 m. Some difficulties are experienced with sidelobe reflections from nearby buildings and trees. To date, CRT displays have been photographed using Z-axis modulation, but there is interest in adding a facsimile machine with perhaps a larger dynamic range than the group has been able to achieve to date. The objective of the project is to monitor and study atmospheric structure and motions at Delhi.

The Canadian Atmospheric Environment Service sounder, operated in Downsview, Ontario, was described by William Clink of that organization. His slides displayed a beautifully constructed antenna (varnished woods with impressive grain patterns) of high acoustic efficiency, a folded cone-hyperbolic transceiver. A single University ID 75 driver is used, although the horn could handle six drivers. Echoes at 400 m range at an operating frequency of 3 kHz have been observed in a suburban area. They seem to see fewer striations in the city echoes, possibly the result of greater turbulence in the built-up regions ...? They plan to cast future horns of a graded density plastic and hope to obtain dual frequency operation to learn more about the scattering mechanisms.

2.2 Bistatic Sounders and RASS

Following the first morning and early afternoon discussions of sounders to investigate atmospheric structure, operating predominantly in the monostatic mode, the afternoon sessions continued on bistatic, even forward scatter programs, for monitoring aircraft trailing vortices. A presentation was also given on the hybrid Acoustic-Radio Sounding System, RASS under development at Stanford University.

Martin Balser of the Xonics Corporation, Van Nuys, California, reported on their company and FAA sponsored acoustic studies of aircraft wake vortices. The first experiments used a bistatic, forward scattering geometry. They can monitor vortex structure with an array of microphones in a single dish receiver to study Doppler shifts in vortex regions over 40 ft across. An 88 element, electronically steerable transmitting array provides a 2^o beam at 5 kHz with a typical transmitter to receiver distance of 1500 ft. Displays of the Doppler spectrum from aircraft vortices were given and a lively discussion followed on the actual scattering mechanism involved - is this mechanical turbulence only or does entrained heat from the engines enhance the scatter. Xonics is also constructing a bistatic, total wind sensor. They have done some tests and compared the Doppler shift with anemometer returns at a height of 140 ft.

David Burnham of the Department of Transportation, Transportation System Center, described their vortex detection methods. They utilize a fan beam transmitter with smaller scattering angles than employed in the Xonics experiment so that refraction in the vortex may be the principle signal producing mode. They use two receivers to measure the difference in arrival time of sound refracted through the vortex structures and by this method have calculated the scattering angles actually being experienced. They have tracked vortices for up to 142 sec from a jumbo jet and their desk top, hand data analysis is now progressing to on-line computer processing.

Professor Allen Peterson of the Electronic Laboratories, Stanford University described their Radio Acoustic Sounding System, RASS, designed to obtain temperature profiles in the lower atmosphere. The concept is a progression from the earlier Electro-Magnetic and Acoustic (EMAC) investigation at Midwest Research Institute. RASS operates at a significantly lower frequency, so that coherent backscatter of the probing radio frequencies can occur from the more nearly smooth spherical acoustic wave fronts. Typical radio frequencies used are near 40 MHz with the acoustic frequency being a rather low 80 Hz. An array of 9 horns bouncing off a 24 x 24 ft concrete reflector is used for the transmitter with several kW input electrical energy for the acoustic horns and a probable acoustic output of about 100 W. The probing electromagnetic energy is continuously transmitted with 5 watts of power and the Doppler frequency shift produced by vertical temperature profiles measured with a receiver bandwidth of about 6 Hz. Comparisons of temperatures derived with RASS and radiosondes are generally within 1°C, with fairly consistent ranges to heights of 1 km. The effects of wind blowing the acoustic beam out of the radar beam and the question of acoustic wavefront coherence provide still unresolved performance analysis questions.

2.3 Antennas and Transducers

After some discussion on the bistatic and RASS programs, a session of about one hour was devoted to the discussion of acoustic antennas and transducers. F. Hall described the NOAA Wave Propagation Laboratory experience with dishes, reflector horns, and absorbing cuffs. F. Carsey of WPL described his design of a linear "zipper" array to obtain a fan beam for bistatic wind and C_v structure.

A paper written by Alan Mahoney of the Weapons Research Establishment, Australia, was distributed, describing the WRE electrostatic transducers which are now under test there. Mr. Mahoney visited Boulder several weeks before the Workshop. Unfortunately, no members of this pioneer acoustic group, headed by Lindsay McAllister, could attend the Workshop.

The electrostatic transducers which are under development and are in production at Globe Universal Sciences, at El Paso, Texas, were described by D. Ramsdale. He showed their clever use of hexagonal spacing cells and Mylar diaphragms and described the close control necessary to achieve uniform spacing from the stator plate in their 36" square microphone. The diaphragm moves as a piston and a bandwidth from 600-3900 Hz is obtained. Sensitivity of the microphone is 0.01V/dyne cm^2 or -40 dB. The 90° sidelobe rejection is 40 dB. Although limited to low power as a transmitter, Ramsdale outlined a tentative push-pull, resonator type transceiver design.

William Cronenwett of the Department of Electrical Engineering, University of Oklahoma, described the digital timing circuits operating in their sounder, pointing out the inexpensive designs which can be put together with integrated circuit operational amplifiers and gates.

2.4 Data Analysis Techniques

The final session in the first day of the Workshop was concerned with methods to extract quantitative data from sounder returns. William Neff of NOAA/WPL described the quantitative analysis utilized to extract C_T information from an experiment performed in 1969, next to the 150 m tower which WPL operates in Haswell, Colorado. He pointed out the necessity for accurately knowing the temperature and humidity profile so that molecular absorption losses can be accounted for properly. Grids of C_T plots were shown compared with fast response, spaced temperature sensors from the tower. During periods of convective activity, the agreement between <u>in situ</u> and sounder values for C_T were generally within 3 dB. On occasions, low wind shear, stratified, nocturnal returns seem to show an excess sounder return, possibly because of the inapplicability of the assumption of homogeneous, isotropic turbulence for these atmospheric conditions.

B. Willmarth of NOAA/WPL described the several methods he has employed in the Doppler analysis of backscattered echoes. One problem is the deep fade in the echo strength. The first analysis method in preliminary experiments was accomplished on a TD-100 spectrum analyzer and although some information on turbulent structure can be obtained from the shape of the spectrum, a single frequency output is all that is required to obtain the mean line-of-sight wind at the scattering volume. An investigation of zero-crossing Doppler extraction gave poor performance because of severe echo fades and varying signal-to-noise ratios from one pulse to the next. A method whereby the phase shift of the return signal is monitored by passing the signal through a narrow band electrical filter was described and this method provides rather good results so long as the signal-to-noise ratio is high. The most promising results obtained to date utilize a tracking filter which automatically drops out at low signal-to-noise ratios, thus helping to alleviate improper Doppler interpretation when echoes are weak or absent. E. Bartz, Oregon State University, described a phase lock loop he has looked into for Doppler analysis, during the discussion.

The afternoon terminated with a wide open discussion on the abilities of facsimile recorders to accurately depict echo strengths, and the shortcomings which many users have experienced in adapting facsimile machines to the sounder. Informal discussions continued during a western style cookout on Flagstaff Mountain overlooking Boulder, which terminated the first days proceeding.

3. ATMOSPHERIC SCIENCE INVESTIGATIONS WITH ACOUSTICS

On the second day of the Workshop, the first session was concerned with a review of the turbulent planetary boundary layer, our present state of knowledge about this part of the atmosphere, and what knowledge can be obtained using conventional in situ meteorological sensors.

3.1 The Planetary Boundary Layer

Opening remarks for the session were delivered by the moderator, H. A. Panofsky, of Penn. State University. He pointed out that we must be interested in the planetary boundary layer because we live there, our food grows there, and our pollution originates there and is frequently trapped there. We need to know the effects of wind and turbulence on manmade structures and how large scale momentum from the atmosphere interacts with the boundary layer. He described the usual breakdown of height regions within the planetary boundary layer as:

1. The surface layer, the lowest 30 m, where in general we have a fairly good understanding through application of direct sensing methods.
2. 30-200 m or the "tower layer" where our knowledge is much more limited because of a more limited number of direct measurements and
3. 200 m - 1 km which he described as a data gap region with most in situ information provided by radiosondes, or pilot balloons,

which travel through this region so fast that little structural understanding can be obtained. This is the region where remote sensing techniques have the potential of being very important.

J. Deardorff of NCAR, described our present status in numerical modeling of the planetary boundary layer. He has been able to model, from primitive equations, convective structures which develop from surface heating, using a 40x40x20 grid to describe what goes on in a box several km on a side from the surface to 1 or 2 km in height. The model predicts thermal plume structures much like those seen with acoustic echo sounders, and with higher winds, predicts elongated or helical vortices. To properly model the stable planetary boundary layer, Deardorff feels that perhaps even a finer grid scale may be necessary for numerical modeling because of the steeper dropoff in the spectrum of turbulent energy so that smaller scale structures may be very important in contributing to momentum flux values.

J. Scoggins, Department of Meteorology, Texas A&M University, reviewed the in situ instruments we have been able to use to date for measurements. He discussed frequency response and averaging times of typical temperature and wind sensors.

3.2 Transmission and Scattering of Sound in the Turbulent Atmosphere

S. Clifford, NOAA/WPL, described his theoretical modeling of the effects of propagation on Doppler analysis. He pointed out there is a slight additional Doppler frequency spread during propagation but that refractive effects do not seriously influence the interpretation of Doppler as motion of the scattering center, at least for propagation ranges of 1 km or less.

D. Thomson of Penn. State University, described their work in numerical modeling of propagation and scattering. Their modeling procedures include considerations of temperature profile, humidity, altitude of the scattering layer, spatial distribution of scatterers, effective size of scatterers, angular scattering coefficients, velocity of scattering centers, and the number of scattering layers. In agreement with Clifford's analysis, it is found that a finite beamwidth increases the second moment in the Doppler but does not influence the mean value.

G. Peters of the University of Hamburg described their analytical studies, using a WKB approximation, on the angular dependence of acoustic scattering and the reasons why no scattering is experienced at 90^{o}. Following these theoretical discussions, a number of questions and answers were contributed including the acknowledgment that because of larger scattering from high C_T, buoyant elements in thermals, some misinterpretation of vertical velocities in thermal plumes may result. E. H. Brown of WPL commented on the limitations inherent when a homogeneous turbulence model is employed to explain the scattering observed in real sounders.

3.3 Wind Sensing

The next session of the Workshop considered acoustic sensing of wind in the planetary boundary layer. D. Beran of NOAA/WPL described the angle of arrival method under investigation at WRE, reading the reports submitted by Alan Mahoney of that organization. Good correlation of Doppler and angle of arrival wind sensing is reported by WRE.

Beran went on to discuss the Doppler investigations at WPL. The first studies, conducted during 1970, were concerned with vertically directed, monostatic sounders used to study the vertical velocities in thermal plumes and wave structures in the stable planetary boundary layer. Investigations proceeded to bistatic studies of the horizontal wind with a two antenna configuration, to the complete wind vector determination with a three antenna bistatic arrangement. Subsequently, three sounders, one vertical and two with angled beams, operating in a monostatic mode were used to plot the averaged wind vector in the lowest 500 m of the boundary layer. The investigation is now proceeding with an attempt to develop a real-time wind and wind shear measurement system which may be of use in detecting winds of importance for aircraft operations. This phase of the program is being sponsored by the Federal Aviation Administration.

K. Kraus of the FAA followed with a discussion of wind shear detection requirements now envisioned by his organization. He pointed out that there have been documented landing accident cases traceable to shear regions. Better climatological statistics on the occurrence of such sharp wind shears are required, but the present Category 3 landing criterion is not designed to handle shears of greater than 8 kt in 100 ft altitude increments below altitudes of 500 ft. Even more severe restrictions on acceptable wind shears may occur when VSTOL aircraft operation becomes more commonplace. The types of data display which might be useful for approach controller, emphasizing simplicity and unambiguous readouts, were then discussed.

A. C. Chung of MIT then described a possible method for wind detection using an infrasonic whistle for active probing of the ray paths in the planetary boundary layer. He has shown that it is possible to separate source and receiver by up to 10 km when operating at a frequency of 13.5 Hz.

In the discussion which followed, Dean Parry of NWS pointed out the possibility that RASS may have wind sensing potential. H. A. Panofsky noted that when good mixing occurs in the planetary boundary layer, three minute averaging wind measurement times may be adequate, but at other times, a one hour averaging may be required. Clearly, better detail on the nature of wind shear is necessary before the problem can be considered well understood.

3.4 Atmospheric Structure Investigations

The final afternoon of the Workshop was opened by W. Hooke of NOAA/WPL with a tutorial discussion of gravity waves in the planetary boundary layer and a comparison of acoustic sounder facsimile records with pressure traces from the microbarograph array. He pointed out the need for longer range sounders to study such wave phenomena throughout the troposphere and perhaps also the need for shorter range sounders to look at turbulent motion scales.

R. Inman, Department of Meteorology, University of Oklahoma, described the results of three months of continuous sounder operation in Norman. The sounder has now been moved near the WKY TV tower where seven levels of instrumentation are available to heights of 1500 ft. Facsimile records of stratus clouds, frontal passages, shallow arctic air with subsidence, and breaking gravity waves to heights of 1200 m were shown.

Linda Spears, Geophysical Institute of the University of Alaska, described operation of a monostatic and large scattering angle bistatic sounder in Fairbanks. The complexities of the stratified returns in the very stable air in the Fairbanks valley requires high resolution for the in situ comparison measurements. The university has developed a modified version of the NCAR boundary layer profiler balloon borne temperature and wind package for this purpose. Frequently, inflections in the temperature record do not show up as strong echoes in the sounder return, and it is apparent that both wind and temperature profiles are required for a proper understanding of acoustic returns.

D. Parry, Systems Development Office, NWS pointed out the desirability of obtaining remotely the mean profiles of temperature, water vapor pressure, and wind. Lacking this capability at present, he discussed the advantage of the qualitative fax returns in understanding the structure in frontal passages and of the wave motions observed along such fronts.

N. Shaw, previously of the RAAF Academy, Melbourne, and at Argonne Laboratories in 1972, discussed the operation of monostatic sounder developed in Australia and used in Chicago and in St. Louis. He analyzed some 40 cases of warm front passage and also some cold fronts in his dissertation to the university. He pointed up the agreement between the cloud ceilometer records which correlate closely with acoustic echoes obtained. Sometimes ceilometers show the cloud base to be at lower heights than the acoustic records. He has obtained acoustic echoes from cold front passages to heights of 3000 ft.

W. Neff of NOAA/WPL continued the discussion of the previous day on how accurately can sounders measure atmospheric parameters. In the worst case, thin stratified returns may be as much as 20 dB higher than expected from in situ C_T measurements. A lively discussion then followed on where we were going and what are the proper interpretation techniques for our existing and planned sounder systems.

3.5 Natural Sound Sources and Passive Techniques

The final session of the Workshop considered probing the atmosphere with natural sound sources or using passive techniques. C. Holmes of New Mexico Institute of Mining and Technology described results they have obtained with sound probing of thunderstorms. They use an array of microphones on the ground and look for event coherence. Sound rays from lightning channels were then traced for correlation with rain shaft columns detected with electromagnetic radars or rain gauges.

A. Few of Rice University, Houston, has been able to reconstruct the detailed pattern of lightning channels using ground based microphone arrays. He determines the sound source volumes from time of flight for recognized events in the thunderclap. They now utilize a 10 layer temperature and wind ray trace program at Rice which is capable of locating the channel within 50 meters. Good correlation has been found between the acoustic reconstruction of lightning channels and those parts of the channel which can be photographed. Frequently, horizontal channels 10 km long inside clouds, terminated with a 4 km cloud to ground stroke, have been detected.

D. Griffin of Rockefeller University then discussed the possible use of acoustics by birds in long range navigation. He has measured frog trills from a balloon borne microphone to heights of 1 km at frequencies of 2 kHz. Also discussed was the possibility of birds sensing breaking surf sounds to follow a coastline and the possible use of atmospheric wave structures or winds in long range navigation.

D. Ramsdale of Globe Universal Science described aircraft wake vortex studies with ground based arrays of passive microphones which are able to track the motion of the vortices near the ground as they move outwards from the aircraft track. A preliminary setup was made at El Paso airport and a preliminary experiment with directional microphones gave negative results. Then omnidirectional microphones with 15 Hz bandwidth were tried and it was found possible to monitor the position of the vortex.

3.6 Final Discussion Session

The final informal discussions at the Workshop included many questions and answers among participants on what we might plan for the field of acoustic probing in the next year or two. It was clear that we will be able to obtain far better understanding of atmospheric structure and winds and will need significant help from experts in turbulence theory and atmospheric modeling to aid in interpreting our results. It was felt that the time might be appropriate to schedule another Workshop in one year to 18 months time. Gene Walker, University of Oklahoma, volunteered to host the next Workshop in Norman sometime in 1973.

4. CONCLUSIONS

It is concluded that the Workshop did provide a platform for those working in the field to exchange ideas, discuss problems, compare instrumentation techniques and data analysis methods. The Workshop was useful in establishing communication channels among those working in the field and all participants departed with a better knowledge of what is going on, what needs to be done next, and a better appreciation of the complexities in properly interpreting the results of atmospheric acoustics and acoustic echo sounding.

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APPENDIX A

ATTENDEES AT
ATMOSPHERIC ACOUSTICS WORKSHOP

Anway, Alan	Sperry Rand Res. Center	Sudbury, Mass.
Ashby, Randolph	USAF	Edwards AFB, Calif.
Aubry, Michel	CNET	Les Moulineaux, France
Balser, Martin	Xonics	Van Nuys, Calif.
Bartz, Robert	OSU	Corvallis, Oregon
Bedwell, Thomas H.	Northern Arizona Univ.	Flagstaff, Ariz.
Bennett, Richard C.	Univ. of Toronto	Toronto, Ontario
Bryant, N. H.	Cornell Univ.	Ithaca, N. Y.
Burnham, David C.	US DOT Transport Sys. Ctr.	Cambridge, Mass.
Cameron, Robert H.	The Polyhedral Corp.	El Paso, Texas
Chung, Andrew C.	Mass. Institute of Tech.	Cambridge, Mass.
Clink, William L.	Atmos. Environ. Service	Downsview, Ontar. Can.
Connell, James R.	Univ. of Wyoming	Laramie, Wyoming
Cronenwett, W. T.	Univ. of Oklahoma	Norman, Oklahoma
Damkevala, Russ	IIT Research Institute	Chicago, Ill.
DeLoach, Dick	NASA-Langley Res. Ctr.	Langley Field, Va.
Deardorff, James W.	NCAR	Boulder, Colorado
DeLorenzo, Joseph D.	Sperry Rand Res. Center	Sudbury, Mass.
Dessler, Alex	Rice Univ. (NCAR Visit. Sci.)	Houston, Texas
Few, Arthur A.	Rice Univ. (Dept. Space Sci.)	Houston, Texas
Gething, Tim	University of Melbourne	Parkville, Melbourne (Australia)
Greenfield, Roy J.	Penn. State Univ	Univ. Park, Pa.
Gregg, Del	FAA	Denver, Colorado
Greyber, Howard D.	Martin-Marietta Corp.	Denver, Colorado
Griffin, Donald	Rockefeller Univ.	New York, N. Y.
Griffiths, Lloyd J.	Univ. of Colorado	Boulder, Colorado
Gutjahr, Allan	N. Mex. Inst. of Min.&Tech.	Socorro, N. M.
Hamiter, Marvin	White Sands Missile Range	Las Cruces, N. M.

Holmes, Charles R.	New Mex. Inst. of Min.&Tech.	Socorro, N. M.
Holmgren, Bjorn	Geophysical Institute	Fairbanks, Alaska
Horst, Tom	Battelle-Northwest	Richland, Washington
Inman, Rex L	Univ. of Oklahoma	Norman, Oklahoma
Keech, Del	FAA	Denver, Colorado
Kraus, Kenneth A.	FAA	Washington, D. C.
MacCready, Paul	AeroVironment Inc.	Pasadena, Calif.
Meyer, Leroy C.	EG&G	Tijeras, N. M.
Miller, Edward L.	Oregon State Univ.	Corvallis, Oregon
North, Max	Stanford, Univ.	Stanford, Calif.
Ottersten, Hans	Res. Inst. of Nat'l Defense	Stockholm, Sweden
Panofsky, H. A.	Penn. State Univ.	University Park, Pa.
Parry, H. Dean	NOAA, Nat. Wea.Ser.SDO,EDL	Silver Spring, Md.
Pearce, Jeff	Ball Bros. Res. Corp.	Boulder, Colorado
Peters, Gerhard	Germany, Meteor. Inst.	Hamburg, Germany
Peterson, A. M.	Stanford Univ.	Stanford, Calif.
Ragent, Boris	Ames Res. Center	Moffett Field, Calif.
Ramsdale, Dan J.	GUS Manuf.	El Paso, Texas
Sanders, Melvin J.	National Weather Service	Silver Spring, Md.
Sargeant, Douglas	NOAA	Rockville, Md.
Scoggins, James R.	Texas A&M Univ.	College Station, Texas
Seymour, E. W.	Ithaco Inc.	Ithaca, N. Y.
Shaw, Neil A.	Argonne Nat'l Lab.	Argonne, Illinois
Shunk, James F.	USAF	Scott AFB, Illinois
Siegrist, Richard	Geophysical Institute	College, Alaska
Spears, Linda M.	Geophysical Institute	College, Alaska
Stansbury, Alan P.	Quan-Tech	Whippany, N. J.
Stewart, Michael	Alden Electronics	Westboro, Mass.
Thomson, Dennis M.	Penn. State Univ.	University Park, Pa.
VandeNoord, Ed.	Ball Bros. Res. Corp.	Boulder, Colorado
Viebrock, Herbert	EPA-NOAA	Triangle Park, N. C.
Walker, Gene B.	Univ. of Oklahoma	Norman, Oklahoma

Weller, Gunter	National Sci. Foundation	Washington, D. C.
Whiton, Roger C.	Hq. Air Weather Service, USAF	Scott AFB, Illinois
Wilson, Charles R.	Geophysical Institute	College, Alaska
Woodhead, Max	Canadian Public Service	Downsview, Ont. Can.
Wyckoff, Robert	National Weather Service	Aurora, Colorado

NOAA/ERL, Wave Propagation Laboratory
Boulder, Colorado

Bean, Brad	Grossman, Bob
Beran, Don	Hooke, Bill
Brown, Ted	Little, C. Gordon
Carsey, Frank	Mandics, Pete
Chacon, Tim	Merrem, Frank
Clifford, Steve	Neff, Bill
Cohen, Ariel	Ochs, G.
Decker, Martin	Owens, Ed
Derr, Vernon	Schwiesow, Ron
Edinger, Jim	Taylor, Bill
Emmanuel, Gus	Vohs, Larry
Frisch, Shelby	Westwater, Ed
Gaynor, John	Wescott, John
Georges, Tom	Willmarth, Ben
Gossard, Earl	Young, Jess
	Hall, F. F.

APPENDIX B

Acoustics Workshop Agenda

6 July 1972

0830 Welcoming Remarks - C. G. Little, WPL Director
Morning Session Moderator - F. F. Hall, WPL

Monostatic Acoustic Echo Sounding Systems

0840 WRE Program - A. Mahoney (read later by D. Beran)
WPL Program - J. Wescott
NWS Program - M. Sanders
RAAF/Argonne - N. Shaw
U. Oklahoma - C. Walker
Open Discussions of System Design and Operation
Included will be brief comments on programs at:

NASA Langley - R. DeLoach
FOA Sweden - H. Ottersten
Cornell Aero. - C. Easterbrook (read by F. Hall)
Japanese Sounder - F. Hall
Aerospace Corp. - F. Manov (read by F. Hall)
U. Melbourne - T. Gething
IITRI - R. Damkevala
Oregon State U. - E. Miller
CNET France - M. Aubry
U. Toronto - R. Bennett
U. Hamburg - G. Stilke, G. Peters
NPL India - S. Singal (read by F. Hall)
AES Canada - W. Clink

1130-1330 Lunch, Darley Commons
Afternoon Session Moderator - H. D. Parry, NWS

Bistatic and RAAS Programs

1330 Xonics Program - Marty Balser
DOT Program - D. Burnham
RAAS Program at Stanford - A. Peterson

Antennas and Transducers

1400 WPL Dishes, Horns, and Cuffs - F. Hall
WPL Horn Arrays - F. Carsey
WRE Electrostatic Transducers - A. Mahoney
GUS Electrostatic Transducers - D. Ramsdale
Digital Timer - Cronnenwett
Discussion

Data Analysis Techniques

1500 Echo Intensity Evaluation at WPL - W. Neff
Doppler Analysis at WPL - B. Willmarth
Discussion
Recorders Discussion

1800 Cookout on Flagstaff Mountain

7 July 1972

0830 Morning Session Moderator - H. A. Panofsky
The Turbulent Planetary Boundary Layer

Opening Remarks - H. A. Panofsky, Penn. State
Numerical Modeling of the Boundary Layer - J. Deardorff, NCAR
Limitations of In Situ Sensors - J. Scoggins, Texas A&M
Discussion

Transmission and Scattering of Sound in the Turbulent Atmosphere

0930 Acoustic Scintillation and Scattering Cross-Sections - S. Clifford, WPL
Numerical Modeling of Propagation and Scattering - D. Thomson, Penn. State
Angular Dependence of Acoustic Scattering - G. Peters, U. Hamburg
Discussion

Wind Sensing

1030 Angle of Arrival - A. Mahoney, WRE (read by D. Beran)
Doppler Investigations - D. Beran, WPL
Wind Shear Detection Requirements - K. Kraus, FAA
Infrasonic Active Probing - A. C. Chung, MIT
Discussion

1145-1330 Lunch, Darley Commons

1330 Afternoon Session Moderator - D. W. Beran

Atmospheric Investigations

1330 Gravity Waves - W. Hooke, WPL
Univ. of Oklahoma Results - R. Inman, U. Okla.
Fairbanks Inversion Studies - L. Spears, U. Alaska
Operational Use of Analog Acoustic Record, D. Parry, NWS
Inversion, Fog, and Cloud Echoes - N. Shaw, Argonne
How Accurate if a Sounder? - W. Neff, WPL
Discussion

Natural Sound Sources and Passive Techniques

1600 Sound Probing of Thunderstorms - C. Holmes, NMT
Lightning Channel Structure - A. Few, Rice
Acoustics in Bird Navigation - D. Griffin, Rockefeller U.
Aircraft Wake Studies - D. Ramsdale, GUS
Discussion