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14. ABSTRACT
It is well known that infrasonic wind noise levels are lower for arrays placed in forests. In this study, the the wind noise levels, turbulence spectra, wind velocity profiles and convection velocity were measured in and above a pine forest and in a mixed deciduous forest. The wind velocity differ from those in the meteorological literature in having zero displacement length. A prediction of the measured wind noise from the measured meteorological data based on fluid dynamic theory has been developed and compared to the measured wind noise. Very good

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Report Title

Final Report: Measurement and Prediction of Infrasonic Wind Noise in Forests

ABSTRACT

It is well known that infrasonic wind noise levels are lower for arrays placed in forests. In this study, the the wind noise levels, turbulence spectra, wind velocity profiles and convection velocity were measured in and above a pine forest and in a mixed deciduous forest. The wind velocity differ from those in the meteorological literature in having zero displacement length. A prediction of the measured wind noise from the measured meteorological data based on fluid dynamic theory has been developed and compared to the measured wind noise. Very good agreement between measurement and theory was achieved. Low frequency wind noise is due to the turbulence-shear interaction above the trees, while the higher frequency wind noise is due tot he turbulence-turbulence interaction within the tree canopy. Initial measurements demonstrated the necessity of measuring the convection velocity.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received		Paper
03/10/2015	1	Jeremy Webster, Richard Raspet. Wind noise under a pine tree canopy, The Journal of the Acoustical Society of America, (02 2015): 0. doi: 10.1121/1.4906587
TOTAL:		**1**

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received	Paper
TOTAL:	

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Infrasonic wind noise in a pine forest; convection velocity
Richard Raspet and Jeremy Webster
J. Acoust. Soc. Am. 135 , 2381 (2014) ; http://dx.doi.org/10.1121/1.4877866 (abstract only)

Number of Presentations: 1.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received Book

TOTAL:

Received Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

none

Graduate Students

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Richard Raspet	0.12	
FTE Equivalent:	**0.12**	
Total Number:	**1**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

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The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED
Jeremy Webster	0.05
FTE Equivalent:	**0.05**
Total Number:	**1**

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

Scientific progress and accomplishments:

Introduction:

It is well known that infrasonic wind noise levels in forests are lower than the wind noise levels at sites with less vegetation. Measurements by Shields(Ref. 1) in forests and under crops displayed a more complicated dependence where the higher frequency wind noise was reduced, but the low frequency wind noise was comparable to or higher than the wind noise level measured at a sparsely vegetated site. The research proposed and performed under ARO W911NF-12-0547 "Measurement and Prediction of Infrasonic Wind Noise in Forests," measured the wind noise under low forests plantings along with meteorological measurements of the wind speed profile and turbulence above the canopy and within the canopy. Measurement in the low young forests was required so that portable instrumentation could be used and still be able to measure above the canopy. The effect of pine forests were investigated first since evergreen forests will provide the same reduction year round. After successfully modeling the wind noise in the pine forest, measurement were performed in a mixed deciduous forest in late winter through late spring and predictions prepared and compared to measurement with good agreement.

Goals:

The goal of this research was to develop a prediction of the infrasonic wind noise measured under pine forests and deciduous forest and develop a prediction of the wind noise based on the measured wind velocity profile and turbulence spectra above and within the tree canopy.

Accomplishments:

Pine forest:

A measurement system using a portable 10 m tower was developed for this study. Two 3-D high resolution ultrasonic anemometers were mounted at 10m and at 1 m. An array of 1D ultrasonic anemometer was used to measured the wind velocity profile in and above the trees. Extensive data sets were taken in the pine forests and predictive methods developed. Earlier research had shown that infrasonic wind noise is due to the quasi static pressure fluctuations due to the interaction of the turbulence with itself(the turbulence-turbulence interaction) or the interaction of the turbulence with the wind velocity profile (turbulence-shear interaction). The formulations of Raspet, Yu and Webster,(Ref. 2) and the two papers by Yu, Raspet, Webster, and Abbott,(Refs. 3 and 4) for the turbulence - turbulence and turbulence shear interaction pressures were extended and modified to produce predictions of the wind noise at the ground generated by the turbulence in and above the trees. The extensions involved the necessity of fitting the measured wind velocity profile to an arbitrarily shaped profile within the trees. The wind velocity profile above the trees was well fit by a logarithmic curve as used by Yu et al.(Ref. 4) The resulting prediction matched the measurements quite well and the results reported at the 2013 Fall Meeting of the Acoustical Society of America. (Ref. 5) The high frequency portion of the spectrum(>1Hz) was well fit by the calculated turbulence- turbulence interaction pressure near to the ground. The low frequency peak (<1Hz) was well fit by the turbulence-shear interaction pressure generated by the turbulence above the canopy.

Although the agreement between the prediction and measurement was quite good, further examination of the prediction process led to the realization that the estimated convection velocity of the turbulence was based on measurements and guidelines developed by Yu et. al.(Ref. 3) for work on a grass covered plane and might not be accurate for the forest.

The research plan was modified to include multiple infrasonic sensors in the direction of the average wind velocity in order to calculate the convection velocity appropriate to the two source regions. Additional measurements sets were made in the pine forest. Correlation analysis showed the convection velocity of the infrasound generated above the canopy was quite large, corresponding to wind speeds at 30 m above the ground. Surprisingly, the calculated convection velocity of the higher frequency turbulence was vanishingly small. This indicates that high frequency wind noise is generated in the bottom few tenths of a meter above the ground. This is a new and unexpected finding. With this addition, the predictions and measurements of the infrasonic wind noise in the pine forest agreed well within experimental limits and with no adjustable parameters.

The high frequency portion of the wind noise spectrum was well predicted by the turbulence-turbulence interaction pressure alone. The predicted turbulence-shear interaction pressure was negligible with respect to the turbulence- turbulence interaction pressure in the canopy. The low frequency peak in the wind noise spectrum was well predicted by the turbulence-shear interaction pressure due to the flow above the canopy. The detailed results of these measurements are presented in Raspet and Webster.(Ref. 6)

It is interesting to note that the wind velocity profiles above the planted pine forests can be fit by a logarithmic curve with no displacement depth. This is different from typical profiles in the literature which need both a roughness length and displacement depth to model the wind velocity profile above the trees.(Ref. 7) We speculate this is due to the sparseness of the planting versus naturally occurring mature forest.

Deciduous forest:

The measurements and predictions were repeated in a mixed deciduous forest for two measurement days before the leaves came out and for two measurement days after the trees were fully leaved. This portion of the study investigated the following questions:

1. Is the wind noise reduction by the deciduous canopy comparable to that provided by the pine forest?
2. Does the presence or absence of leaves affect the wind noise reduction?
3. Does the turbulence-shear interaction within the canopy contribute significantly in either situation?
4. Does the theory predict the wind noise at the ground surface under a deciduous canopy within experimental uncertainty?

The wind velocity profile above the trees without leaves was again fit without a displacement depth. The deciduous tree planting was also sparse with respect to a natural forest. The measured wind speed was much higher within the canopy than in the pine forest as were the high frequency wind noise levels. Even though the wind speed was higher, the turbulence-shear contribution was still much lower than the turbulence-turbulence contribution from within the canopy. The low frequency peak in the spectrum was well modeled by the turbulence-shear interaction above the canopy. The low frequency contribution was about the same magnitude as the low frequency contribution from the pine forest. The high frequency wind noise was approximately 10dB louder than the high frequency contribution in the pine forest. The calculations agreed with the measured levels within the experimental limits of the measurement.

The corresponding measurements with leaves were very similar to the results from the pine forest. Both the high frequency portion and low frequency peak matched the levels measured in the pine forest. The measured levels were well predicted by the theory developed in the pine forest study. The detailed results are presented in a paper submitted to the Journal of the Acoustical Society of America.(Ref. 8) In addition, the theoretical results were extended to taller forest to develop guidelines for the height of forest necessary to reduce wind noise at low frequencies.

Accomplishments and conclusions:

Previous to this study there was no qualitative or quantitative model of the generation of infrasonic wind noise at the ground under forests by turbulence in the atmosphere. This study has developed quantitative calculations of the wind noise contributions and has shown which interactions are involved in the generation. These results can be used to develop predictions of wind noise under different canopies for use in selecting sites for infrasound measurement stations. The necessity of making convection velocity measurement in addition to the standard meteorological measurements is important for future experimental design.

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Technology Transfer

The tech transfer for this research is accomplished by the presntations to the Acoustical Society and by the publication of the two papers. Preliminary results ahve been supplied to scientist at ARL, CRREL and at NCPA.