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Detecting Ultra-Light Aircraft Using Passive Acoustic Technology

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Sensing and System Integration Solutions

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Introduction

Ultra-Light aircraft have a significant acoustic signature that can be exploited by low power passive acoustic detection equipment. By using properly deployed passive acoustic detection stations, a "Trip Wire" barrier may be formed to provide robust aircraft detection and timely localization reports over a wide area.

Consider the sensor field deployment geometry of figure 1. For this example, rows of sensor stations are spaced so that the reliable coverage areas of adjacent sensors slightly overlap. Each sensor coverage area is represented by a circle whose radius is equal to the sensor's Maximum Reliable Detection Range (MRDR) against the intruding aircraft.

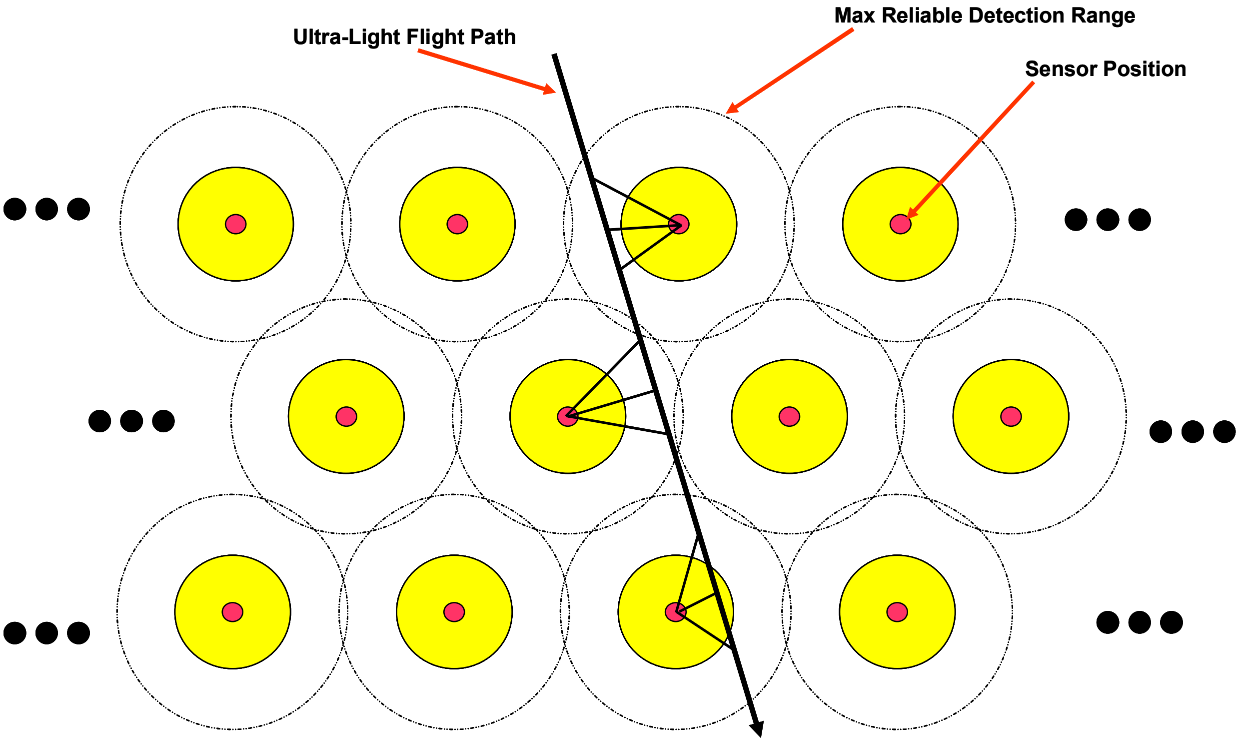

Figure 1 Passive Acoustic Detection Sensor Field

Obviously, the number of sensor stations needed for a given coverage area is dependent on each passive acoustic sensor's Maximum Reliable Detection Range (MRDR). The MRDR is dependent on sensor design parameters (array gain and directivity), environmental factors affecting propagation of sound in air (line of sight, spreading loss, and absorption loss), and the level and directionality of the aircraft's acoustic source (acoustic signature).

The SmarTek Systems' passive acoustic traffic sensor (SAS-1) represents the type of technology that can be easily utilized to provide effective ultra-light aircraft detection and localization. The SAS-1 has been in production and operation for the past 12 years. The SAS-1 is ruggedized and extremely reliable and uses an array of microphone sensors and advanced adaptive spatial processing algorithms to provide 180 degrees of coverage (cross road) for multi-lane traffic monitoring.

The SAS-1 traffic sensor configuration is not optimized for longer range aircraft detection and localization; however, it can be used in controlled ultra-light flight tests with some parameter changes to quantify existing detection performance. The demonstrated SAS-1 detection range performance results along with appropriate acoustic array design (required gain and directivity to overcome propagation losses at longer ranges) will facilitate accurate operational performance estimation (Maximum Reliable Detection Range-MRDR) for an appropriately designed passive acoustic sensor.

The remaining sections of this report describe each of the following steps used to determine the expected Maximum Reliable Detection Range (against an ultra light aircraft) for a properly designed passive acoustic sensor utilizing SmarTek Systems' SAS-1 technology:

Step 1) Perform Controlled ultra light detection testing using SAS-1 sensor and analyze controlled test results to determine the observed maximum ultra light detection range.

Step 2) Use well known acoustic propagation models/equations to quantify propagation loss (spreading and absorption) as a function of range.

Step 3) Use basic sensor parameter comparisons between the existing SAS-1 used in testing and a properly designed passive acoustic sensor to quantify the expected increase in array and processing gains for the properly designed sensor.

Step 4) Using the results of Step 1 (observed detection range), Step 3 (expected array and processing gained for a properly designed sensor), and Step 2 (propagation loss calculations) determine the expected Maximum Reliable Detection Range against an ultra light aircraft).

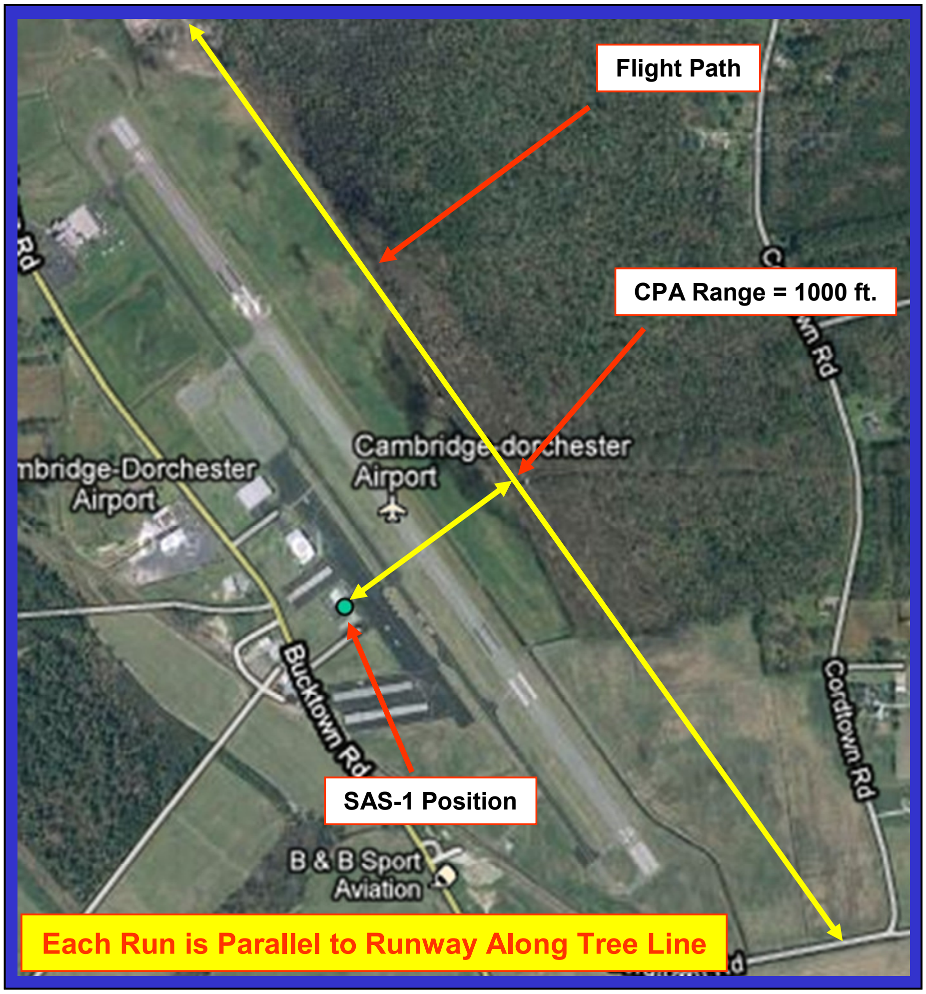

Figure 2 Ultra Light Test Flight Paths

Controlled Ultra Light Detection Test

On October 13, 2010, SmarTek Systems conducted controlled ultra light aircraft detection testing using their SAS-1 traffic sensor. The SAS-1 configuration was not altered except for changing the processing frequency band from that used for highway traffic monitoring to a lower frequency band (centered at 2 KHz). The tests were conducted at an airport located in Maryland, using specified flight trajectories and a modern ultra light aircraft equipped with the most up to date quieting technology. Crossing flight trajectories (maintaining approximately 150 to 200 feet altitude) were used to observe and record real time detection results which could be used later to quantify the maximum detection range for the test. These flight trajectories (shown in Figure 2) consisted of several crossing runs along established landmarks (tree line) and were parallel to the airport runway. Also during testing the relative humidity was not measured precisely, however was considered to be low and the temperature during testing was approximately 50 degrees F.

Consider the detection test geometry shown in figure 3. For this geometry, the ultra light aircraft flies along the crossing flight path from left to right. The range from the SAS-1 position to the aircraft decreases until the Closest Point of Approach (CPA) is reached. The range from the

SAS-1 position to the aircraft then increases. At the CPA, a line (range vector) connecting the aircraft position and the SAS-1 position is perpendicular to the aircraft flight path. Using the known flight path CPA (Closest Point of Approach) range and measured azimuth angles from the SAS-1, the maximum observed detection range (detection at end points of trajectory) can be determined geometrically.

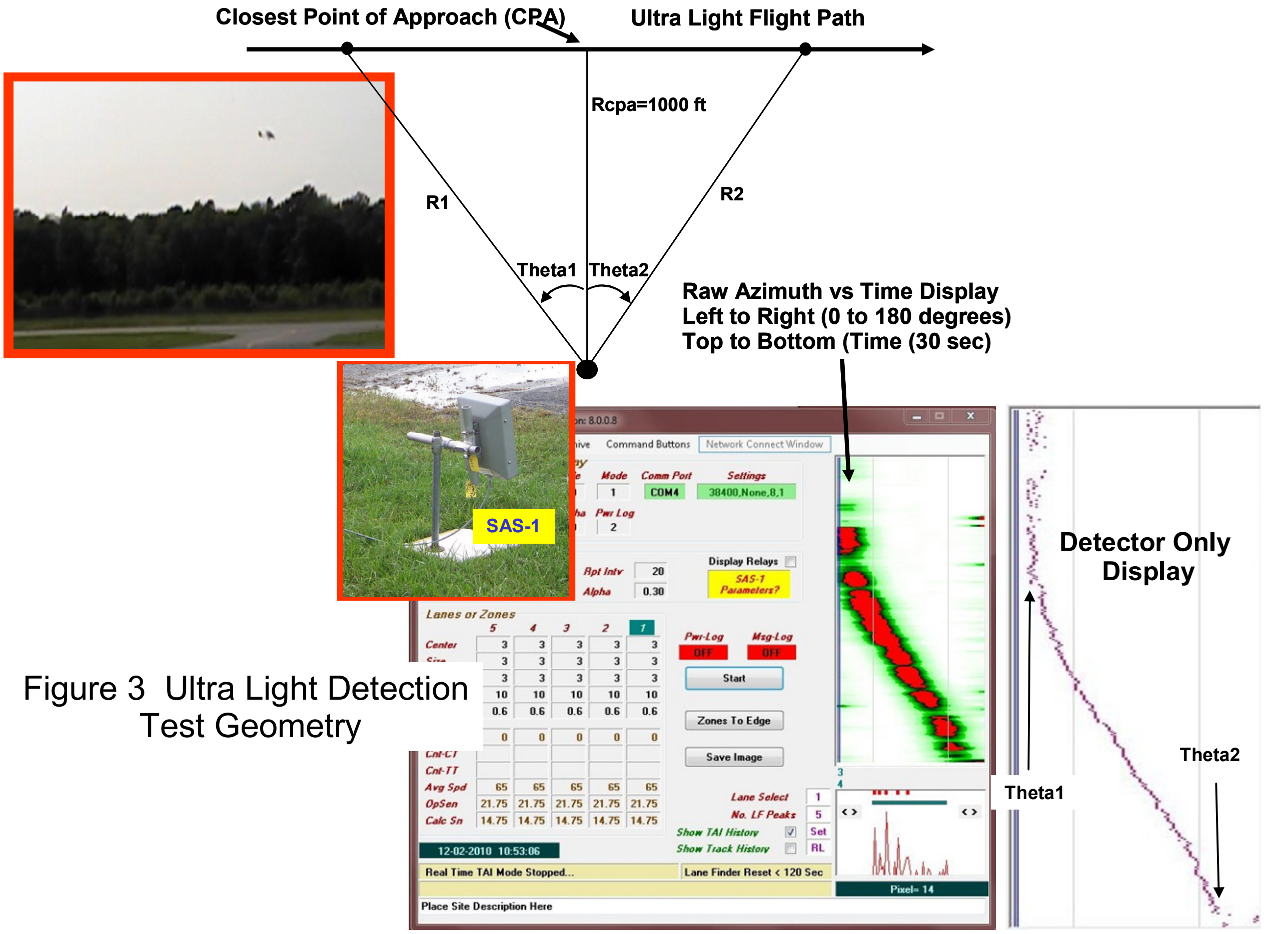

Figure 3 Ultra Light Detection Test Geometry

The SAS-1 setup program known as SAS Monitor and Setup provides a display to observe both the raw and detected acoustic signal power as a function of azimuth (or bearing) and time. This display shows the trace with amplitude or signal strength color coded with white/light green being weakest and dark green/red being the strongest. The horizontal axis is azimuth from 0 degrees (left end fire) to 180 degrees (right end fire). Wall time advances from top (oldest) to bottom (newest) with the extent of the display being 30 seconds.

An aircraft crossing the SAS-1 position from left to right would produce a trace starting on the left and then moving to the right. The slope of the trace indicates bearing rate with a more horizontal trace being high bearing rate and a more vertical trace being a lower bearing rate. The observed bearing rate is obviously dependent on the range, trajectory, and speed of the aircraft.

Figure 4 shows a representative azimuth versus time display for a complete run. Both the raw and detected acoustic power traces are shown. The azimuth angles of the detector trace at the point where detection begins during the aircraft approach (Theta1=58 deg) and where detection ends during the aircraft departure (Theta2=68.9 deg) can be used to determine the maximum observed detection ranges at each end of the flight path.

Using the geometry equations R1=Rcpa/cos(Theta1) and R2=Rcpa(Theta2) (Figure 3) yields the maximum observable detection ranges **R1=575 m during the aircraft approach and R2=891 m during the aircraft departure.** The range versus azimuth plot generated from the above equations is shown in figure 4. Note that the difference between the approach observed detection range and the departure observed detection range is due to baffling or blockage of the source signal (engine and prop noise) by the aircraft structure (fuselage and wings).

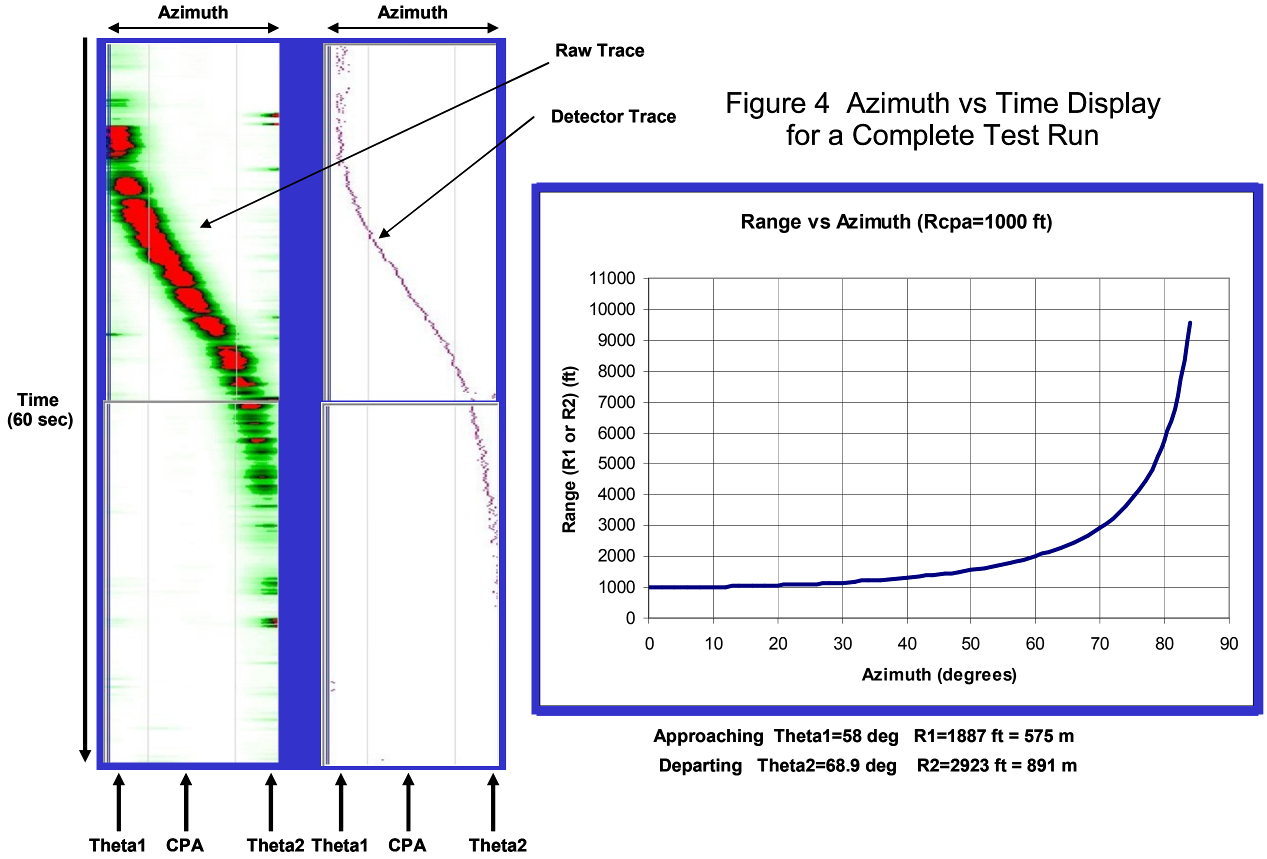

Figure 4 Azimuth vs Time Display for a Complete Test Run

Approaching Theta1=58 deg R1=1887 ft = 575 m

Departing Theta2=68.9 deg R2=2923 ft = 891 m

Attenuation of Sound – Propagation Outdoors

When sound travels in air, it is affected by two basic propagation loss mechanisms. Spreading loss or more specifically spherical spreading loss is described by the equation:

SSL=20 log R (db).

The second source of propagation loss is absorption loss. This loss is a function of relative humidity, temperature, and signal frequency. The frequency dependence is the reason for testing with the SAS-1 frequency set much lower (2 KHz) than in the current implementation using in traffic monitoring. For example, absorption loss at 3 kHz is approximately twice that for 2 KHz. For the much higher SAS-1 design frequency, absorption loss would be very difficult to overcome with array and processing gains at practical detection ranges. Figure 5 shows propagation losses as a function of range and absorption loss for three temperature assumptions.

Note that the observed maximum reliable detection range (MRDR) using the SAS-1 (operating at 2 KHz) is 575 m for the approaching aircraft and 891 m for the departing aircraft. The loss curves in Figure 5 can now be used to determine the additional propagation losses that must be overcome to increase the MRDR from 575 m to 1000 m or to 1500 m.

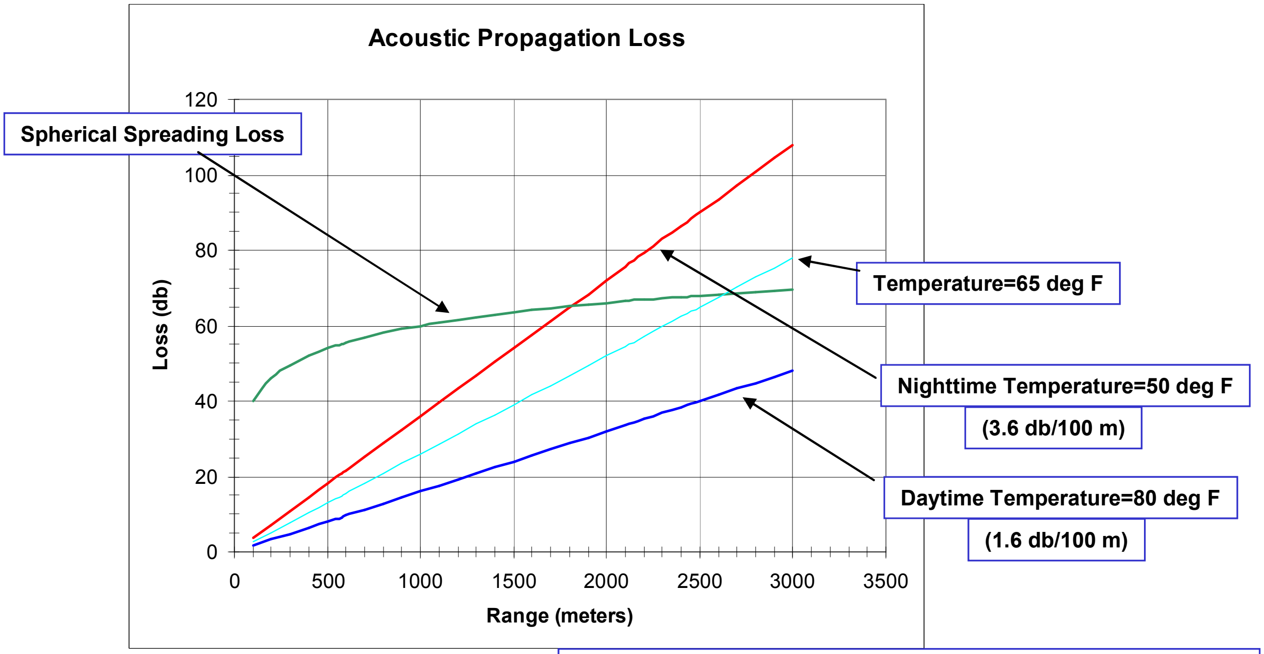

Figure 5 Attenuation of Sound-Propagation Outdoors

Assumptions for Absorption Loss:
Relative Humidity=20%
Daytime Temperature=80 deg F
Nighttime Temperature=50 deg F
Mid-range Temperature=65 deg F
Operating Frequency Band is Centered at 2 Khz
Source: ISO 9613-2: 1996

At 50 degrees F, increasing the approach MRDR from the observed 575 m to 1000m would incur 5 db in additional spreading losses and 15 db in additional absorption losses for a total of 20 db in additional propagation losses. Likewise to increase the approach MRDR from the observed 575 m to 1500 m would incur 8 db in additional spreading losses and 33 db in additional absorption losses for a total of 41 db in additional propagation losses.

At 80 degrees F, increasing the approach MRDR from the observed 575 m to 1000m would incur 5 db in additional spreading losses, but only 7 db in additional absorption losses for a total of 12 db in additional propagation losses. Likewise to increase the approach MRDR from the observed 575 m to 1500 m would incur 8 db in additional spreading losses, with 17 db in additional absorption losses for a total of 25 db in additional propagation losses. By extension, an approaching ultra light similar to the one used in the controlled test could be detected at ranges near 2000 m with at total of approximately 33 db of propagation losses at 80 degrees F.

Sensor Parameter Comparison

The controlled test results described above demonstrated detection performance (observed Maximum Reliable Detection Range) for the ***existing*** SAS-1 traffic sensor operating in a frequency band centered at a much lower frequency than that for which it was designed. The SAS-1 array design is based on an operating frequency band optimized for detecting highway vehicles and separating them by lane. In this demanding processing environment, the SAS-1 design requires that sound from very loud trucks do not dominate the received/processed acoustic signal (loud trucks don't swamp quiet cars) in all types of weather, temperatures and in hostile roadside chemical fumes and salt spray.

When operating the traffic version of SAS-1 at the proper frequency, there is approximately 16 db of array gain and approximately 50 db of signal amplification. The *existing* SAS-1 at 2 KHz was used during these tests against Ultra Light Aircraft to quickly observe maximum detection ranges, with the resulting performance reduction to approximately 11 db of array gain and only 8 db of signal amplification. By repositioning the microphones (a minor manufacturing adjustment) a for 2 kHz center frequency and properly placing the signal pass band for the amplifiers to 2 KHz, significant array and signal amplification gain may be achieved. That is, the 47 db of array and signal amplification gains lost by operating the current SAS-1 traffic array at 2 kHz may be easily recovered with properly implementation of the microphone array and signal amplifiers, creating the a significantly increased MRDR over that observed during preliminary testing.

Conclusions

The above analysis shows that at 50 degrees F, 41 db of additional acoustic propagation losses must be overcome to reliably detect an ultra light aircraft approaching at 1500 m as opposed to the observed 575 m. By using an acoustic sensor for operation at 2 KHz, enough array gain and signal amplification gain can be easily obtained to reliably detect the ultra light at 1500 m with 6 db signal excess.

At higher temperatures, there are significantly less acoustic propagation losses and expected MRDR is extended in turn. For instance, at 80 degrees F, the signal loss of approximately 33 db suffered at 2000 m is 8 db less than the loss suffered at 50 degrees F. Array placement in operational scenarios should consider the expected temperature range for the deployment. In both cases, however, there is significant signal excess for detection given the proper array implementation.

These preliminary test results also show that even when operating the SAS-1 at far below its design frequency, there is sufficient azimuth resolution to provide satisfactory azimuth estimates. For a properly designed acoustic array, the azimuth resolution and the resulting azimuth estimates will be excellent.