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White Feather: Fire Control and Crosswind Sensing for Sniper Applications

by Raymond Von Wahlde

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14. ABSTRACT

Project White Feather was a concept to apply advanced fire control technology to extend the effective range of the sniper. The original scope was for a full ballistic solution that compensated for residual weapon motion, accepted sensor input from a range and crosswind sensor, provided a dynamic corrected aim point to the shooter, and automated the firing time selection. The focus eventually narrowed to address crosswind determination, which is one of the most significant sources of error in extended range sniper applications. This report provides a summary of the research and experiments done in support of White Feather.

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Dedication

Dedicated to the memory of Gunny Sergeant CARLOS N. HATHCOCK II
AKA “White Feather”
Semper Fi

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Introduction

Sponsored by the United States Special Operations Command (USSOCOM), Project White Feather began in the early 1990's as a concept to apply advanced fire control technology to extend the effective range of the Special Operations Force (SOF) sniper. The goal was to greatly increase probability of kill against a man-sized target at 1200 m. The original scope was for a full ballistic solution that compensated for residual weapon motion, accepted sensor input from a range and crosswind sensor, provided a dynamic corrected aim point to the shooter, and automated the firing time selection. At the direction of the end user, the focus eventually narrowed to address crosswind determination, which is the one of the most significant sources of error in extended range sniper applications. This report provides a summary of the research and experiments done in support of White Feather. The appendix gives a chronology of the work done under Project White Feather showing its extensive scope.

Inertial Reticle Fire Control

When accounting for range and windage, a typical military shooter will either manually adjust the scope knobs or physically elevate and slew the weapon to correct the aim point. However, the envisioned fire control system would provide a dynamically changing aim point corrected for varying winds and possibly range as well as any unwanted weapon motion. Therefore, a stabilized or inertial reticle was to be an integral part of the fire control. Weapon motion in pitch (up and down) and yaw (side to side) are measured by a pair of inertial sensors. Roll motion (about the lengthwise axis of a sniper weapon) was assumed to be minimal and therefore need not be measured.

Figure 1 illustrates the function of the inertial reticle as implemented on a sniper weapon. Two reticles are presented to the shooter as overlays in the sight picture. Upon selection of the inertial reticle fire control, the inertial reticle and corrected aim point are centered on the bore sight. The shooter then positions the reticle over the target by slewing the weapon and releases the inertial reticle. The inertial reticle is driven in opposition to the weapon motion and therefore appears to remain fixed in space over the target.

An often-asked question is, if the shooter has the reticle over the target at this point, why don't they simply fire. The answer is twofold. First, although snipers are particularly good at holding their aim point, there may be some undesired weapon motion during the firing sequence due to an unstable platform for example. This is illustrated in step 3 where the inertial reticle or desired hit point has moved away from the bore sight because of unwanted weapon motion. An inertial reticle would enable shooters to fire in less stable firing positions. Second, and more important, the inertial reticle is only part of a full fire control. An aim point would be presented to the shooter corrected for ballistic effects such as range to target and crosswind. In the sight image for step 3, the aim point is corrected for a hypothetical crosswind blowing from right to left and for a range to target further than the range for which the sight was zeroed. If the shooter were to fire at this step, the bullet would strike low and to the left of the target.

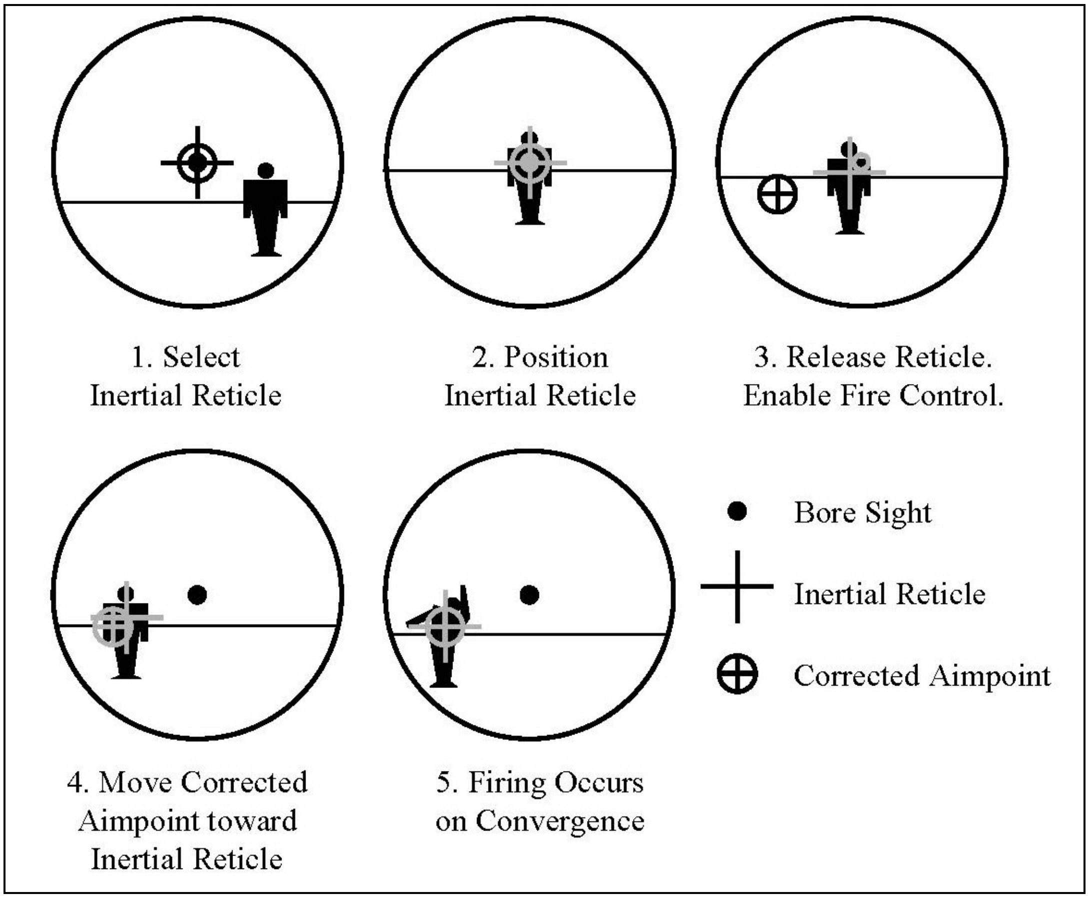

Figure 1. Operation of the inertial retile fire control.

The corrected aim point would likely be dynamically changing especially for real time measurements of varying crosswind. Thus a shooter must continue to exercise control over the firing sequence by moving the corrected aim point toward the inertial reticle. This is accomplished by moving the weapon. The fire control anticipates when the two reticles will cross and begins the firing so that the bullet will exit the muzzle when the two are aligned, provided that the shooter has enabled the firing circuit. In the illustration, the result is that the bore sight is up and to the right in order to compensate for the crosswind and range.

Many of the snipers who viewed the inertial fire control seemed reluctant to relinquish the timing of the firing to the system despite the fact that they were still the ones pulling the trigger. The final step shown need not be controlled by the system. A shooters task would then be to bring the two reticles into convergence and fire the shot. However, field experiments where the corrected aim point was continually updated by real time measurements of downrange crosswind have shown that it is difficult to converge the two reticles when one is dynamically moving.

Application of Inertial Reticle Technology to an M16 Rifle

One of the first applications of the inertial reticle was to an M16 rifle. Figures 2 and 3 show the off-the-shelf components that were used to demonstrate the functionality of the system. This prototype was in no way intended to be a fielded system. Figure 2 shows the miniature quartz rate sensors that were used to detect weapon motion. They were about 38 mm (1.5 inches) in diameter. Figure 3 shows the inertial reticle-equipped M16 rifle. A camera and lens served as a sight. The video image was viewed on a commercial portable television screen. Overlaid on the image were an inertial reticle and the bore sight. No ballistic corrections were applied so the bore sight served as the aim point. The inertial reticle was positioned over the target by means of a joystick moved with the thumb of the firing hand. The trigger finger enabled the system to fire by depressing a switch. The operator's task was to slew the weapon. The system tracked the weapon motion and would only fire if the inertial reticle and bore sight converged. This enabled very accurate "firing from the hip" of the M16 rifle.

Figure 2. Miniature quartz rate sensors and 3-axis mount.

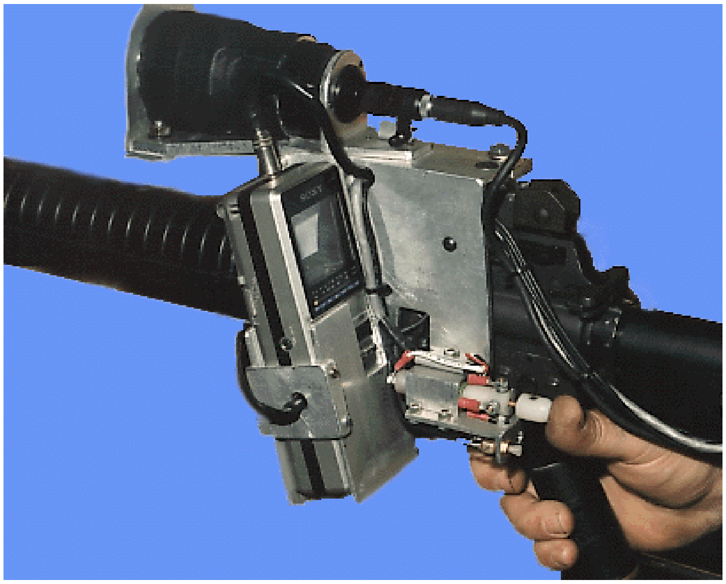

Figure 3. Inertial reticle on M16 rifle.

Application of Inertial Reticle Technology to a Sniper Rifle

Figure 4 shows the main components of the inertial reticle technology (IRT) initially applied to a Remington 700 sniper rifle. This was a proof-of-concept prototype not intended for fielding. Off-the-shelf parts were used to show functionality. Efforts to ruggedize and miniaturize electronics would have to be made in the future. Later in the program, the camera and lens were replaced by a video riflescope (figure 5). The video riflescope split the image via a beam splitter allowing the target to be seen on an external video screen or viewed through the scope. Quartz-rate sensors measured the weapon motion in pitch and yaw. The inertial reticle was positioned over the target by depressing a thumb switch and slewing the rifle. This switch is on the top of the stock behind the bolt which is the natural position of the thumb when firing the weapon. Firing was enable by pulling back on the trigger on which was mounted another switch. A solenoid fired the weapon upon convergence of the inertial reticle and corrected aim point. A more detailed description of the IRT applied to the Remington 700 sniper rifle can be found in (*1*).

Figure 4. Inertial reticle on a sniper rifle.

Figure 5. Inertial reticle on a sniper rifle with Video Scope.

Inertial Reticle versus Sniper Field Experiment

To demonstrate the utility of the IRT, a field experiment was conducted in September 1995, at Romney Creek, Aberdeen Proving Ground, MD (APG), between an Army Research Laboratory (ARL) engineer firing an IRT-equipped sniper rifle from a sitting position and an Army sniper firing a standard rifle from a prone position (figure 6). Lying prone is a more stable firing position than sitting. The sniper was well skilled in his art. The engineer had limited firing experience. Six downrange anemometers provided real-time crosswind measurement correction to the fire control of the IRT. The sniper relied on his wind reading skills to correct his shots. Windage estimation was challenging because the wind was predominately a “fish-tailing” headwind, i.e., a wind blowing from up range into the face of the shooter that continually switched directions between left-to-right and right-to-left. As observed on the video image from the IRT, the corrected aim point danced between the left and right sides of the target. For this reason, it would have been difficult without the IRT for a shooter, using a dynamic aim point corrected for crosswind, to pull the trigger at the precise time the corrected aim point was over the target.

Figure 6. Inertial reticle versus sniper field experiment.

Figure 7 shows the results of two ten-round firing groups at an 800 m target. The sniper fired a very tight group with a radial standard deviation of 0.22 mils, a horizontal and vertical dispersion of 0.18 and 0.22 mils respectively, and an extreme spread covering circle of 0.72 mils. However, the center of impacts was 0.46 mils to the right of the center of the target and only one round hit the target. During the approximately 3 minutes it took to fire the group, the anemometers would have predicted the uncorrected center of impacts to be 0.33 mils with a standard deviation of 0.18 mils. This indicates that the sniper made a windage correction of about 1/8 of a mil and was able to hold his aim very accurately. The horizontal deviation was due mostly to the crosswind variation and ammo dispersion.

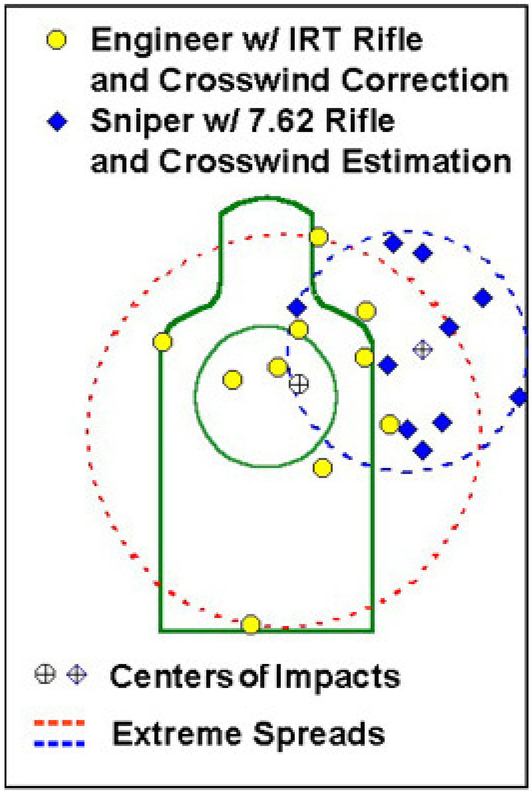

Figure 7. Inertial reticle versus sniper field experiment results.

The engineer fired a group with a radial standard deviation of 0.26 mils, a horizontal and vertical dispersion of 0.21 and 0.31 mils respectively, and an extreme spread covering circle of 1.17 mils. The center of impacts was only 0.1 mils to the right of the center of the target and all but one round hit the target in the horizontal direction. The horizontal dispersion is comparable to the sniper's group. The single, vertical flyer shot at the bottom of the target is mostly responsible for the larger vertical spread and large covering circle. This shot may have been due to random walk error in the inertial sensors. Technological and processing improvements in inertial sensors have greatly reduced this source of error. During the time to fire the group, the anemometers would have predicted the uncorrected center of impacts to be 0.22 mils with a standard deviation of 0.21 mils. The image from the video scope was recorded. Therefore, it was possible to determine the area in which the inertial reticle was dropped by the engineer. His desired aim point was within an area centered on the target that had a horizontal and vertical dispersion of 0.12 and 0.1 mils respectively, and an extreme spread covering circle of 0.42 mils. This is the circle over the target center shown in figure 7.

Test Bed Bench Rest-Grade Precision Rifle

Assuming an IRT fire control could minimize aim point error and accurately correct for range and crosswind, it became apparent that for present sniper rifles, the inherent inaccuracies of bullets at extended range would become the dominating factor in hit probability. The most effective fire control system would need to be combined with an ultra-accurate rifle-ammunition system. Development of a new rifle system was not part of the scope of White Feather. However, in order to be able to demonstrate the value added of the Fire Control at long ranges, two bench-rest-grade, precision rifles were built and a precision bullet was designed. The rifle is shown in figure 8. Funding and other constraints prevented application of the IRT to this weapon. More information on this rifle including its dispersion data can be found in (*2*).

Figure 8. .338-.416 test bed rifle.

Application Of Inertial Reticle Technology to a Ground and Air Vehicles

Although not part of Project White Feather, the IRT was also applied to two ground vehicles and fired from a hovering helicopter (figures 9 through 11). The objective was to demonstrate that Inertial Reticle fire control could be used on a variety of platforms. A semi-automated weapons station including IRT fire control, operator control unit, and a semi-automatic weapon on a simple pan and tilt platform was developed. Image stabilization for operator display was used. IRT was integrated with a M16 rifle on a Fast Attack Vehicle and a 0.50 caliber weapon on a HMMWV. Experiments were conducted against moving and stationary targets from both moving and stationary platform. IRT comparisons were made with manned platform. More information can be found in (*3*,*4*).

Figure 9. Inertial reticle on fast attack vehicle.

Figure 10. Inertial reticle on HMMWV.

Figure 11. Inertial reticle on helicopter.

Crosswind Estimation and Ballistic Effect

Snipers, by necessity are very adept at reading windage. In fact, it is one of the skills that set them apart as a sniper from the average shooter. However, when pressed, they will confess that it is a difficult task. At a Sniper Conference sponsored by the Joint Service Small Arms Program Office in 1993 (*5*), several shooters were asked the following question: What is the single most difficult challenge that you face in successfully engaging a target at long range?" Their answers had a common theme:

> "Wind and all elements."
>
> Carlos Hathcock, USMC (ret.)
>
> "Wind and distance [estimation.]"
>
> Carlos Hathcock, USMC (ret.)
>
> "Wind reading."
>
> Carlos Hathcock, USMC (ret.)

All of them, including Hathcock (a.k.a., White Feather) listed wind (meaning crosswind) as a top challenge. Crosswind is the horizontal component of the wind vector perpendicular to the line-of-fire.

Crosswind Estimation

Presently, shooters determine the wind direction and speed by using certain indicators (6, *7*). Shooters have even reported carrying a small anemometer in their rucksack to make an actual measurement at the firing position. But generally, shooters rely on their observation skills to read the wind. How does the wind feel on their face? Is it steady, gusty, or fishtailing that is, changing directions? They watch the grass, trees, and other signs. Are the leaves rustling or in constant motion? Are trees swaying? They use a clock face system to gauge direction. Is it a full-value wind, blowing directly from 3 or 9 o'clock (i.e., from the right or left). Or, is it a no-value wind blowing directly from 6 or 12 o'clock (i.e., from the front or back?) Perhaps it is a half-value wind, blowing from roughly 1 to 2 o'clock, or one of the other quadrants. A half-value wind will affect the strike of the bullet approximately half as much as a full-value wind of the same speed.

A favored technique is "mirage," which refers to the heat waves or refraction of light through layers of air of different temperatures and densities (*7*). As observed through a defocused sight or spotter scope, this shimmer will appear to move with the same velocity as the effective wind.

The shooter may also read the wind at several downrange locations and in some manner average them together in their head. But largely, a sniper relies on "Kentucky Windage," an intuitive sixth sense that a shooter develops with experience wherein he consciously or unconsciously recalls similar experiences and just "knows" by how much to adjust his aim point (*8*). However he arrives at a value, the underlying assumption is that the wind velocity is constant from shooter to the target.

Crosswind Deflection

It can be shown from first principles that the deflection of a bullet, caused by a crosswind constant with range (figure 12), can be closely approximated by a simple, time-honored equation (*9*):

$$Z = W_Z * (t - R / V_0)$$

where:

Z = Deflection

W_Z = Crosswind Speed

R = Range to Target

t = Time of Flight to R

V_0 = Starting Velocity

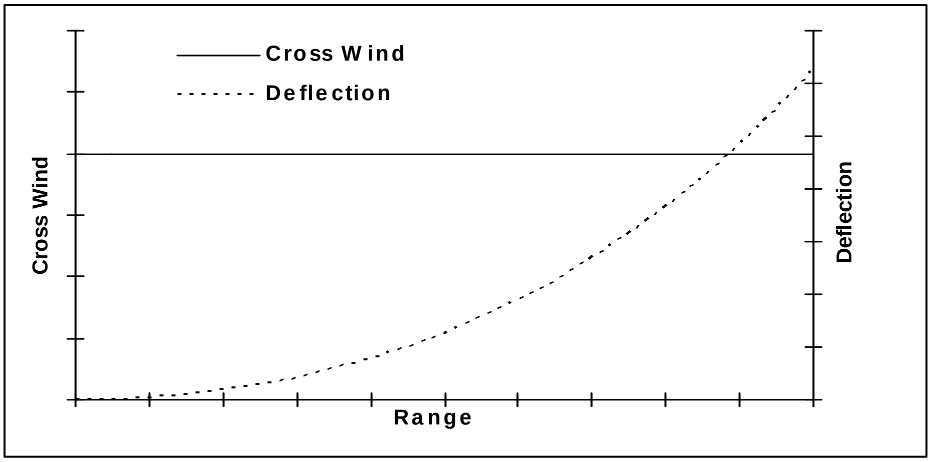

Figure 12. Crosswind deflection.

An examination of this equation, reveals its intuitive nature. Deflection is, of course, proportional to crosswind speed, that is, the greater the wind speed, the greater the deflection. Deflection is also proportional to time of flight and range to target. The longer a bullet takes to reach the target and the further the range, the more it will be deflected. It is inversely proportional to muzzle velocity. The faster a bullet travels, the less it will be affected by crosswind. The quantity R/V_0 is the time it would take a projectile to reach a distance R if there were no drag acting on it. And $(t - R/V_0)$ is known as the "lag time." The lag time loosely captures the drag characteristics of a bullet. The lower the drag, the smaller the lag time; thus, crosswind deflection is proportional to drag. As an example, a 190-grain Sierra .300 WinMag, fired at 884 m/s (2900 ft/s), has a time of flight to 1000 m of 1.75 seconds. So, a 1 m/s crosswind (2.25 mph) would deflect the bullet about 62 cm (25 inches) at 1000 m.

Crosswind Sensitivity

With a little modification, that equation can be used to compute the deflection due to a small, constant crosswind segment like the one labeled "Segment 1" in figure 13. While a bullet is within the wind segment, it is deflected, and it also has a lateral velocity imparted to it that causes the bullet to continue to move off the line of fire even after it has exited that segment (figure 14.) Imagine a wind segment of the same width and speed but farther down range, "Segment 2" in figure 13. The bullet has slowed down, so it remains within Segment 2 longer and is deflected more while it is in that segment. The wind segment also imparts a greater lateral velocity to the bullet, but the time over which the bullet can continue to move off the line of fire before reaching the target is less than the first case. So the resulting deflection at the target is less from the second segment than from the first.

Now imagine moving the wind segment along the range and computing the resulting deflection at a given target distance. If you divide that deflection by both the wind segment's width and its speed, you can come up with a bullet's "crosswind sensitivity" for that target distance. Crosswind Sensitivity = (Deflection at Target Distance) / (Crosswind Speed) / (Wind Width).

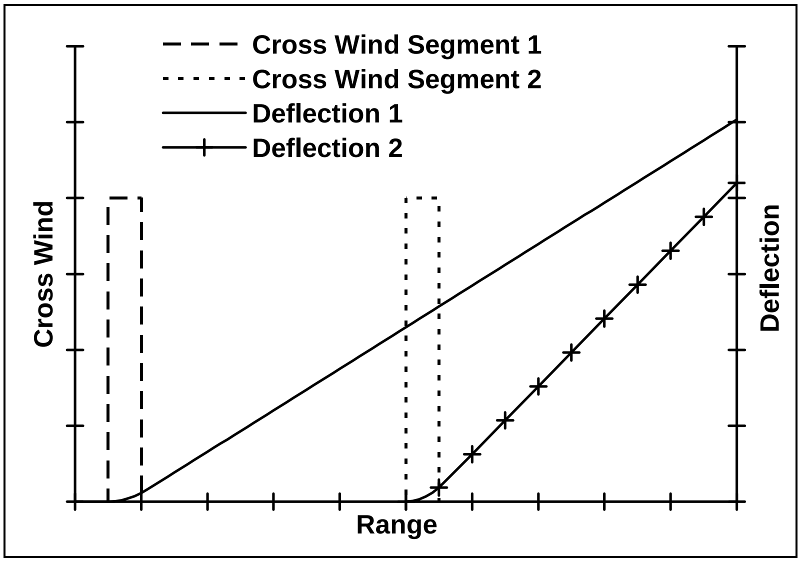

Figure 13. Crosswind segment, projectile deflection.

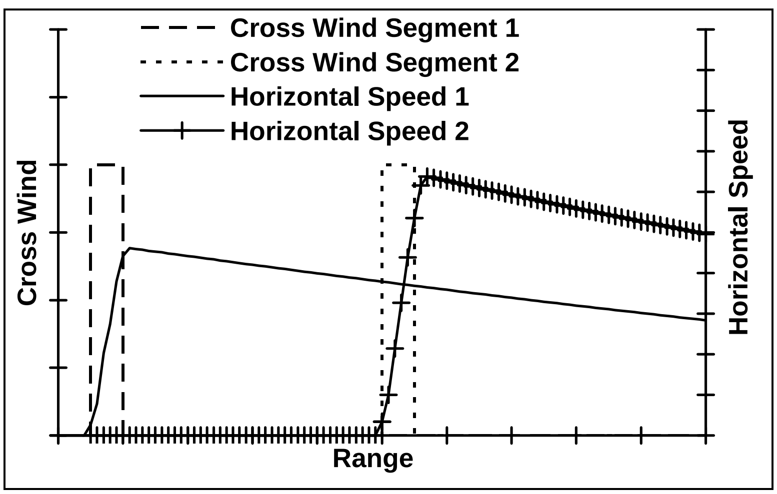

Figure 14. Crosswind segment, projectile horizontal speed.

There is a sensitivity curve for each target distance. For example, figure 15 shows typical crosswind sensitivity curves for several ranges. What this shows is that, in general, bullets tend to be more sensitive to crosswind that they experience nearer the shooter than the same crosswind closer to the target. This is fortuitous because presumably a shooter can better estimate wind near his position than he can downrange, and presumably, a crosswind sensor may more accurately measure the wind closer in than further out.

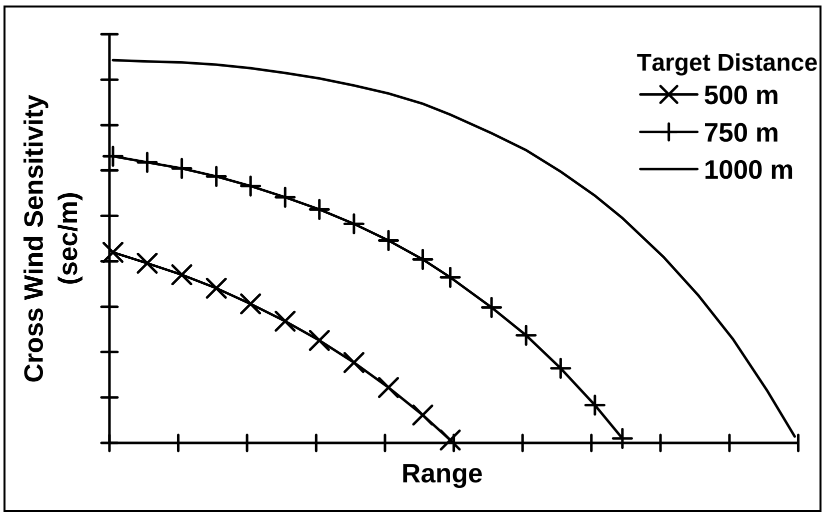

Figure 15. Crosswind sensitivity.

Of course, wind is a very dynamic phenomenon. The wind experienced by a bullet in flight can, and most likely does, vary with terrain. If the solid curve in figure 16 were a crosswind profile experienced by a bullet, it would deflect as shown by the short dashed curve. A shooter would need to make a windage correction for a deflection at the target distance by the amount indicated at the end of the deflection curve. For any given bullet deflection at a particular range, there are an infinite number of intervening crosswind profiles that would result in the same deflection. Only one of these is a constant, uniform wind. It is this effective crosswind profile (long dashed line) that a shooter or sensor is tasked with determining.

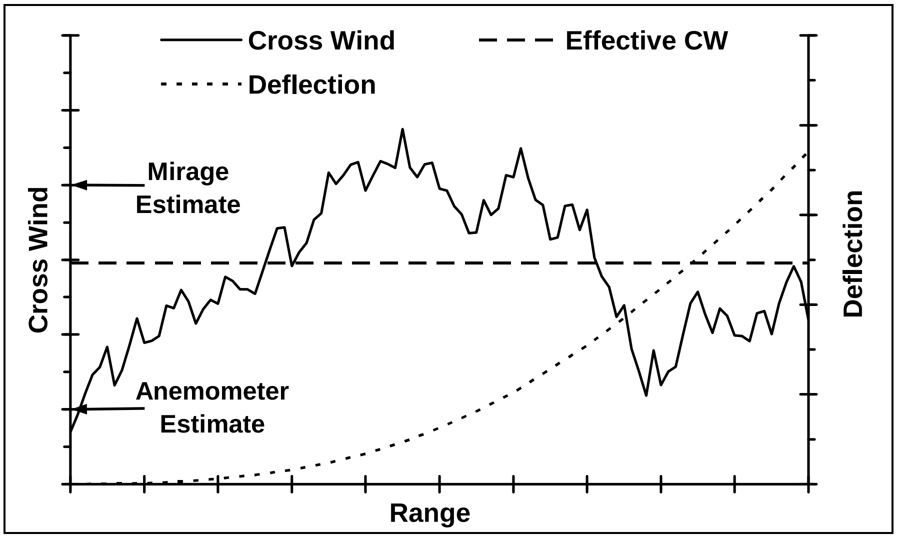

Figure 16. Variable crosswind profile.

Suppose a shooter took an actual measurement of the wind at his position and based his correction on that (figure 16). In this case, he would underestimate the effective crosswind and under correct for the deflection. Suppose a shooter estimated the wind by observing the mirage at about midrange (figure 16). In this case, he would overestimate the effective crosswind and overcorrect for the deflection.

Now, suppose there was some sort of crosswind sensor that was capable of taking a reading of the wind at a finite number of ranges, to within some degree of accuracy. Such a “measured” crosswind profile might look like the dashed line wind profile in figure 17. The predicted deflection at the target distance, for which a shooter would make a correction, would be the amount indicated by the filled circle. How good a prediction that is would depend on how closely the sensor captured the actual crosswind profile (solid line). Obviously, the more range bins there are and the more accurate each measurement is, the better the prediction would be.

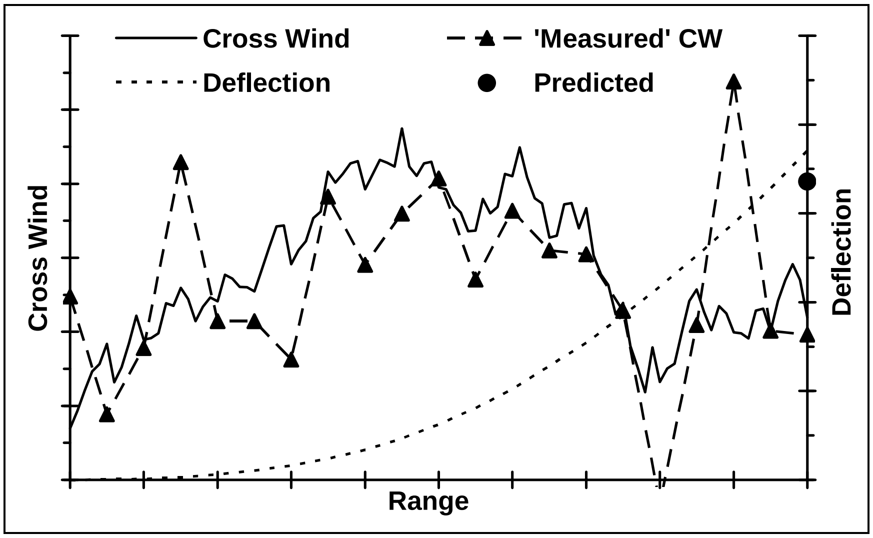

Figure 17. “Measured” crosswind profile.

In order to assess the value added by the application of fire control technology to sniper weapons, a weapons effectiveness study was done (*2*). In addition, a large field experiment involving many sniper teams firing at targets at various ranges was conducted (*10*). As expected, these analyses and tests showed that range and crosswind are two large error sources contributing to missing a target. Although reference 10 made a somewhat counterintuitive conclusion:

“In this test, the wind corrections generated from the wind instrumentation and algorithms did not demonstrate an improvement in hit performance when compared to the corrections provided by the sniper/observer team.”

This is an accurate and indisputable statement of fact based on the data for the “Known Wind” case. The report also states, “For this test, the hit performance did not differ between the sniper estimating the wind or the experimenter estimating the wind.” This is because the anemometer emplacement that gave the “Known Wind” really only provided the experimenter with an “estimate” of the wind. This is understandable given the spatial and temporal differences in the wind that was measured as opposed to the wind actually experienced by any given bullet. Add to that the assumptions made interpolating between anemometers or extrapolating past them as well as the uncertainties in the algorithm used to compute deflection. At the most, the “Known Wind” condition provided at least as well a wind estimate as trained snipers.

A device that could account for the range and crosswind factors would go a long way in improving first-round hit probability. For example, as predicted in reference 2, for a 300 WinMag round against a human-sized target at 700 m, a stand-alone crosswind sensor would double the hit probability of a standard rifle, while a complete fire-control system, including IRT, would triple it.

Accurate range finders already exist or are underdevelopment. Crosswind sensing was identified as the technological gap that needed to be filled. Therefore, Project White Feather shifted its focus away from a full-up fire control system to fostering the development of a sensor capable of reading crosswind. The crosswind sensor would also include a range finder at little added complexity.

Laser Crosswind Sensors

Project White Feather was able to partner with other government labs, as well as industry and academia to help foster the development of a crosswind sensor. Several laser-based wind sensing techniques that had potential for providing a real-time crosswind measurement were identified. These include aerosol backscatter light detection and ranging (LIDAR), laser Doppler velocimetry, and laser scintillation. A U.S. Army Research Laboratory, Small Business Innovative Research (SBIR) topic titled "Laser Crosswind Sensor" (SBIR topic: A96-032) resulted in several contracts. The objective was to develop and demonstrate a compact, lightweight, rugged, and eye-safe wind sensor capable of measuring crosswind profiles for ballistic wind corrections. Also specified was that the measurement should be real time, with an accuracy of 1 m/s or better, and provide crosswind profiles out to 1500 m. Range wind (i.e., the wind parallel to the line-of-fire) and range to target were desirable features but not critical.

Aerosol Backscatter Crosswind Sensor

In 1995, White Feather teamed with the Los Alamos National Laboratory that was developing an incoherent aerosol backscatter LIDAR technique for wind sensing. Aerosols are small particles, such as water vapor, dust, pollutants, etc., that are suspended in the atmosphere. These particles will scatter a laser beam with some of the incident light reflecting back to a detector at the laser source. The amplitude of the return signal is proportional to the density of the particles. Using the time-of-flight of the laser, the aerosol density versus range is known along the beam. By sweeping the beam back and forth through a fan, the technique is able to detect aerosol patches of similar densities or "structures" that drift with the wind. By tracking the velocity of these structures, crosswind can be determined.

In the fall of 1995, LANL tested an aerosol backscatter LIDAR at APG's Romney Creek. This very large system (figure 18) was intended to be flown on a helicopter in order to scan large volumes of atmosphere at tens of kilometers range to track possible biological or chemical agent clouds. It was in no way representative of the size of a sensor intended for sniper use for which only a relatively small area and short range would need to be scanned. It was simply the device that was available at the time.

The test setup included downrange anemometers and actual firings from a bench-mounted rifle at a target 800 m downrange from the gun. Because of the geometry of the LIDAR, there was a 100 to 200 m zone out in front of the LIDAR from which data could not be obtained. Therefore, the LIDAR was positioned behind the bench-mounted rifle. During the test, the data was displayed as a false color image of the fan swept through by the LIDAR beams. The color was assigned according to the intensity of the return signal. By watching this display, one could see the aerosol structures that the LIDAR would use to measure wind speed and direction. It was interesting to observe the image immediately after the gun fired when the expelled gun gases could be seen spewing from the muzzle and being blown with the wind.

For various reasons, the data collected from the test could not be analyzed but the feasibility of the technique was evident. One disadvantage of the method is the need to scan the beam and to sweep an area in front of the shooter rather than simply a single downrange beam.

Figure 18. Los Alamos aerosol backscatter crosswind sensor.

Laser Doppler Velocimeter Crosswind Sensor

Laser Doppler velocimetry works on the same principle as the radar guns used to catch speeders. There, an officer fires a beam at a vehicle and, based off the Doppler shift of the return, determines the car's speed. In the same way, one can measure the velocity of aerosols in the atmosphere along a laser beam. And these velocities can be obtained at a number of ranges. If these beams are directed at an angle on each side of the firing line, then, at least theoretically, the velocities can be resolved into range and crosswind components. The advantage to this technique is that it could provide a range-resolved crosswind profile rather than simply a single, weighted reading of the intervening crosswind. One disadvantage to this method is purely a practical one. Because of the need to angle the beams off the line of fire, the divergent beams could impinge on downrange obstacles (e.g., a tree line). Another problem, as discovered in testing, is that unless the wind is constant from beam to beam, the measured velocities cannot be directly resolved into a crosswind. However, there are proposed methods for overcoming that limitation.

In 1996, White Feather teamed with Wright Laboratory at Wright Patterson Air Force Base, and a company, Coherent Technologies Inc. (CTI). CTI was building a Laser Doppler-based wind sensor for Wright Labs to be used for ballistics correction and precision air drop. It was at a test of the CTI system on a Colorado mesa in July 1996 that the mathematical shortcoming of resolving the wind components into range and crosswind was discovered. CTI also was a participant in Phase I of the SBIR. Figure 19 shows a conceptual representation of a prototype device.

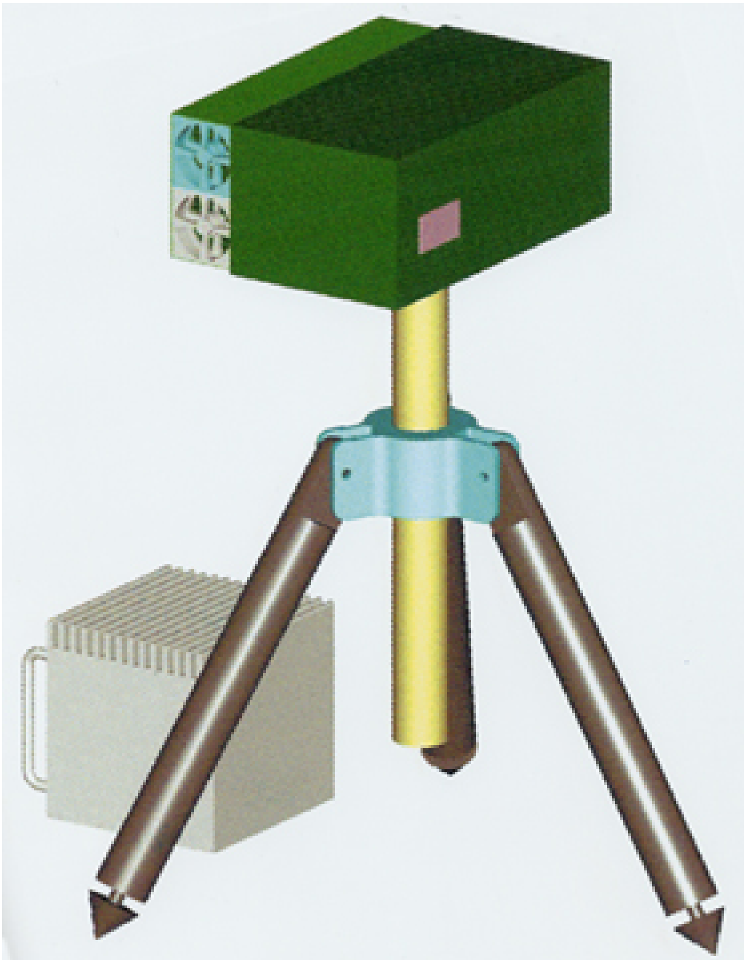

Figure 19. CTI laser Doppler velocimeter crosswind sensor.

Another Phase I SBIR contract went to Optical Air Data Systems (OADS). OADS made some breakthroughs in obtaining heretofore unobtainable power levels from fiber-optic laser components. Use of these rather than bulk laser components holds the greatest potential in achieving an ultra-compact, rugged system. OADS' small wind sensor could possibly operate off AA batteries. A mockup is shown in figure 20.

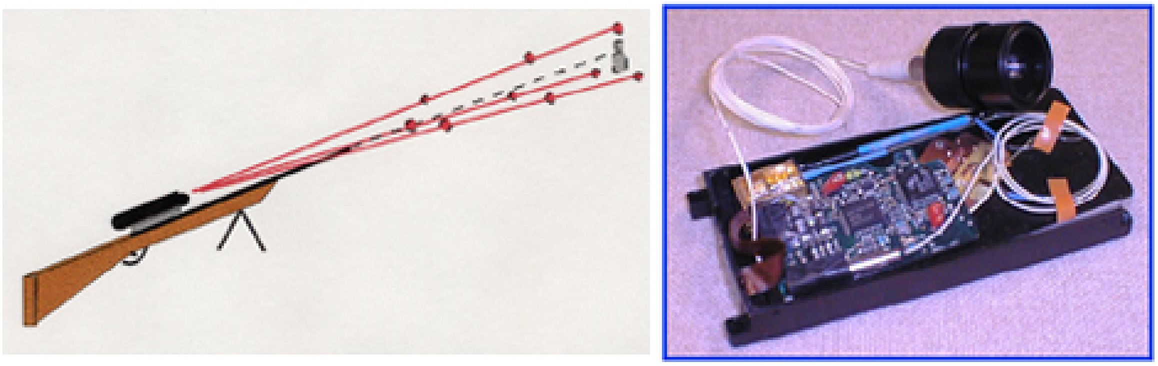

Figure 20. OADS laser Doppler velocimeter crosswind sensor

Both OADS and CTI proposed methods for overcoming the laser Doppler velocimetry technique's problem in resolving the crosswind component. OADS planned to make use of a unique application of signal-processing techniques. CTI came up with a novel velocity pattern algorithm that potentially could reduce the scan angle required and also provide a gauge of the confidence level of the crosswind measurement, which may require a slightly longer update time.

Laser Scintillation Crosswind Sensor

A layman's understanding of the scintillation method is that it is somewhat akin to the mirage technique employed by shooters. There, the shooter is viewing the distortion of light from the target as the distortion-causing turbulence cells drift with the wind. In a similar way, for the scintillation technique, a laser (or even some other source such as the sun, or a street light) illuminates the target. A pair of detectors senses the distortion of the light off the target. By correlating the signals from the detectors, the time for the distortion-causing turbulence cells to move across the detectors can be determined. With a known distance between the detectors (approximately 50 mm or less) a velocity can be calculated (figure 21).

This method provides a weighted reading of the intervening crosswind rather than a range-resolved profile. That weighting is a function of, among other things, the wavelength of the source, the range to the target, the size of the light source and receivers, and the separation of the detectors. Ideally, one would want that weighting to ballistically match the crosswind sensitivity of the bullet so that the reading obtained is the effective uniform (constant) crosswind. The advantage to this technique is that it requires only a beam directed down the firing line. The disadvantage is that it gives only a weighted reading of the crosswind. Multiple weighted readings (e.g., multiple pairs of detectors each weighting a different portion of the range) may better capture a crosswind profile.

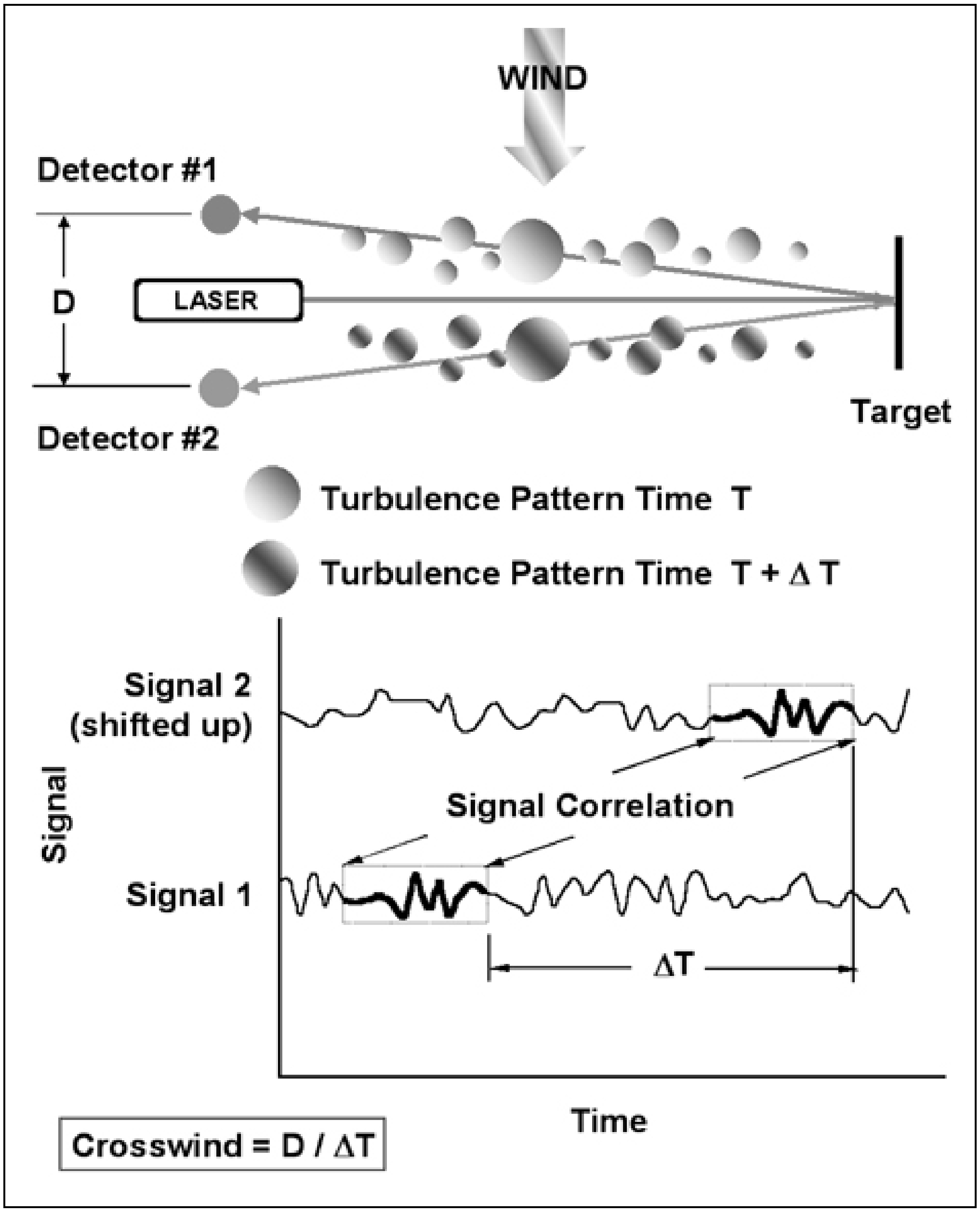

Figure 21. Laser scintillation crosswind sensing principle.

Scientific Technology, Incorporated (STI), Crosswind Sensor

Figure 22 shows a prototype scintillation-based crosswind sensor resulting from the Army-sponsored Phase II SBIR. It was built by Scientific Technology, Incorporated (STI) now Optical Scientific, Inc. The emphasis of the SBIR was to demonstrate the functionality of the device not to minimize its size. The housing box is mostly empty volume. An approximately 20 cm (8 inch) square digital signal processor board (DSP) primarily dictated the boxes dimensions. The

DSP was chosen for its availability and relative low cost. With sufficient effort and resources, a custom electronic chip or chip set could be built. There is much potential for size reduction in the design.

Figure 22. SCTI laser scintillation crosswind sensor.

This device was used in a field experiment conducted in July of 1999 on APG's Main Front firing range to determine if the sensor was measuring crosswind. Downrange anemometers were used as "ground truth". Trained, two-man, sniper teams (shooter and spotter) fired on a man-sized target at 770 m. Groups of shots were fired with the team calling the windage on their own. In addition, the readings from both the anemometers and the sensor were in turn provided to use to correct their shots.

Figure 23 shows some of the best agreement between the sensor and the anemometers. The anemometer output is the solid line. The sensor output is the dashed line. The plot shows the effective uniform crosswind out to 770 m versus time, that is, a crosswind, constant with range, which would result in the same deflection at 770 m as the crosswind profile measured by the anemometers. The effective crosswind is what the sensor attempts to provide with its weighted average of the intervening crosswind.

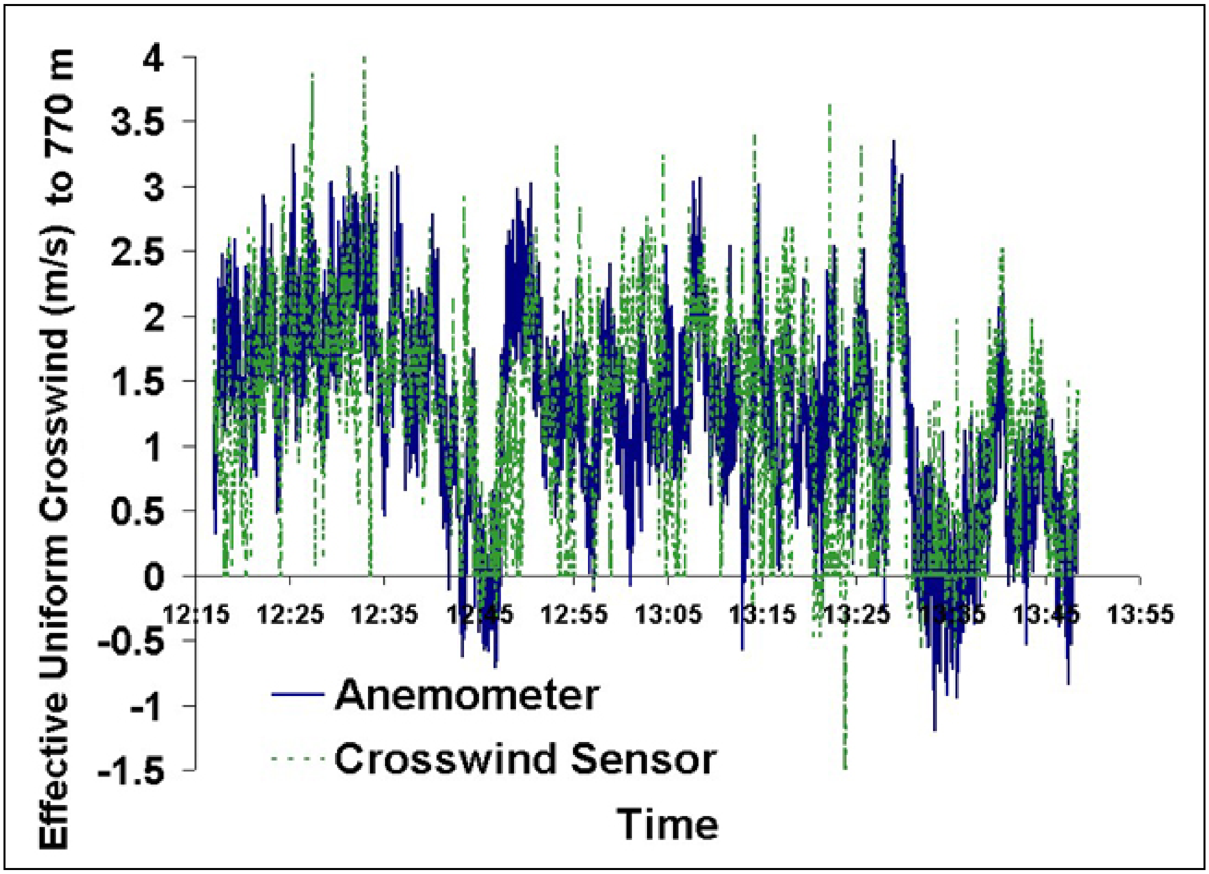

Figure 23. SCTI laser crosswind sensor test results.

It appears that the sensor was making some reasonable measurement of the intervening crosswind. There is very good agreement between the sensor and the anemometers, at least over this long time interval (about 1 1/2 hours). The fact that it is hard to distinguish the two is the point. This does not mean that there is instantaneous agreement between the two at every second.

There was less agreement between anemometers and the sensor in the morning when there was little temperature difference between the ground and air, and only light winds. Because this is a scintillation reading device, if there is no or little scintillation, then there is nothing for the sensor to detect in order to read the crosswind. Shooters also have difficulty reading the mirage under such conditions.

Figure 24 shows the predicted deflection at the target for M118 7.62 mm Special Ball ammunition over an interval of time during a firing event. There is a more noticeable variation between the crosswind sensor and the anemometers. This is expected because the line of anemometers and the sensor line of sight were offset from the line of fire. Therefore, they were not exactly reading the crosswind experienced by the bullet. Also, the two systems sensed the wind by different methodologies. Nevertheless, one can see that the two are following the same trend. Also on this plot are the windage calls from the spotter. There is fairly good agreement between all three.

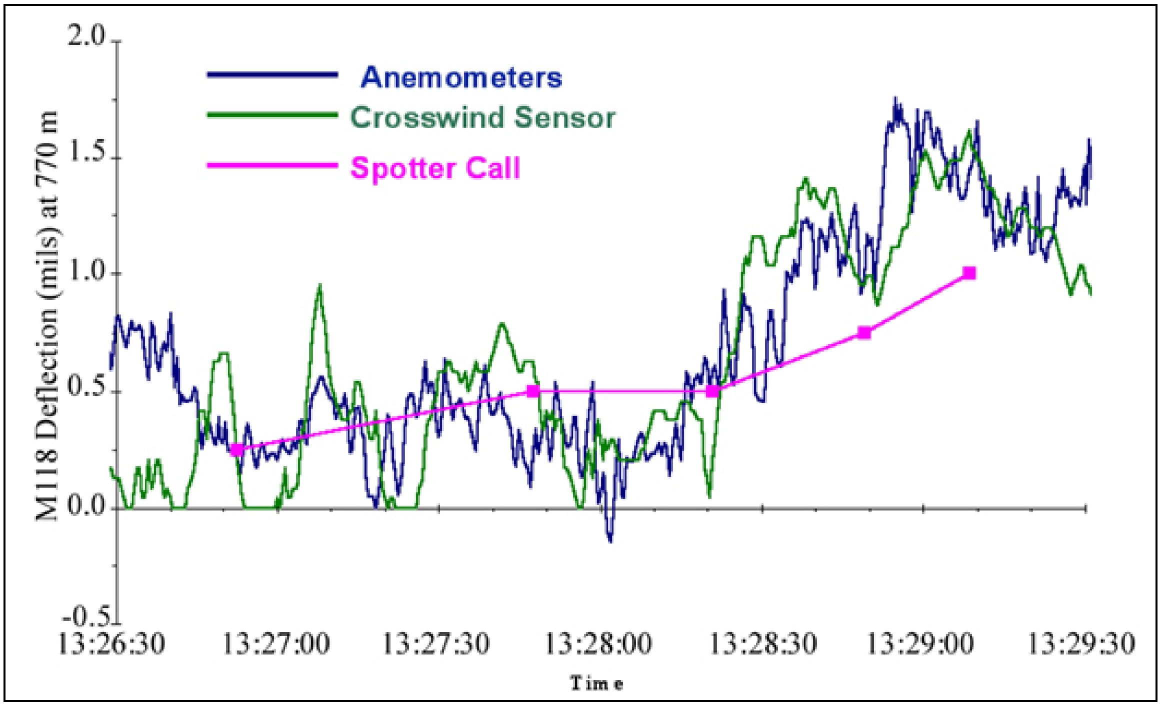

Figure 24. SCTI laser scintillation crosswind sensor deflection prediction.

One advantage of the SCTI sensor was that, given enough ambient light, e.g., a sunlit target, the device could work passively, that is without needing to illuminate the target with a laser. The field test occurred on a bright sunny day. As it turned out, the onboard laser was woefully underpowered to have illuminated the target on its own. This meant that it had been operating passively for the APG test. This unfortunately was not discovered until a subsequent demonstration of the device to a sniper community on a cloudy day when it failed to work at all leaving a very bad impression with the shooters. Further work would readily overcome this design flaw.

SOREQ Crosswind Sensor

The Israeli Laboratory SOREQ has been developing a scintillation based crosswind sensor since the early 1990's. Their latest prototype at the time was called The CARMEL II for Crosswind and Range Measurement Lidar. As the name implies, it was the second iteration of the device. That sensor was about 20 cm wide, 13 cm tall and 30 cm long (figure 25). SOREQ holds a U.S. patent on the fire control device.

In December 2001, the CARMEL II was brought to APG's Main Front where data was collected from it and anemometers as well as target impacts at 700 m for bullets fired from a bench-mounted rifle. Figure 26 shows the crosswind versus time agreement between the anemometers and the CARMEL II. The two follow the same trends indicating that they are responding to the same phenomenology. Figure 27 shows the deflections of the bullets on the target as predicted by the anemometers and the sensor as well as the actual impacts. It is apparent that there is reasonable agreement.

Figure 25. SOREQ CARMEL II laser crosswind sensor.

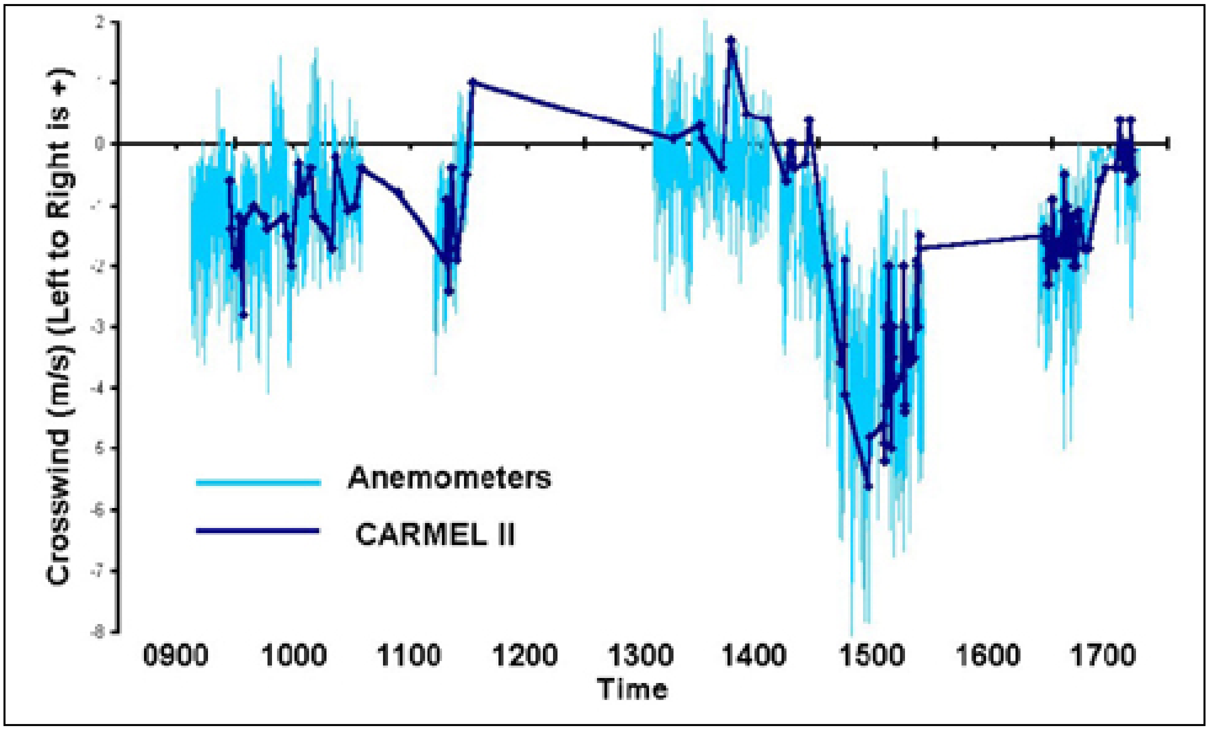

Figure 26. SOREQ CARMEL II crosswind versus time.

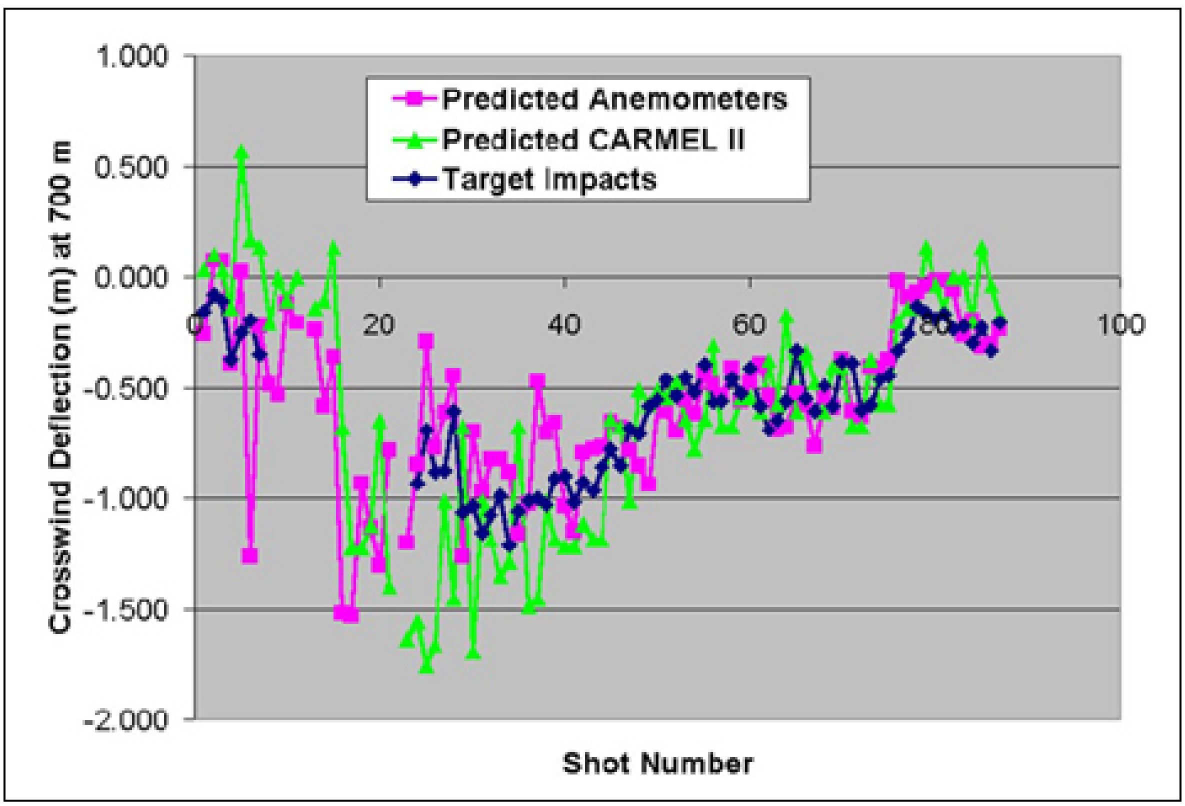

Figure 27. SOREQ CARMEL II crosswind deflections.

Conclusion

Project White Feather was an effort to apply advanced fire control technology to sniper weapons and thus extend the kill range of snipers. Despite hopes for exotic weapons such as directed energy, for the foreseeable future the only feasible kill mechanism for the upcoming sniper engaging targets at extended ranges is a precision bullet and rifle coupled with a fire control capable of getting it downrange accurately. At a minimum, the fire control would need crosswind and range measurements. Maximum benefit would be achieved by including the Inertial Reticle Technology. Other ballistic corrections could readily be made such as for temperature, slant angle, etc.

It is evident from the sniper versus engineer experiment that there is value added by IRT. The state-of-the-art for crosswind sensing has been greatly advanced and is on the cusp of resulting in a compact system usable to the sniper. The rapid advance in electronics makes application of White Feather technology more possible than ever.

A practical laser crosswind sensor would use fiber optic components in order to be compact, lightweight, and rugged. This would enable it to fit in the form factor of a spotting scope, sharing the scope's optics that would still function as a spotting scope. Conceivably, it could even be made to fit within the weapon's sight. Fiber optic laser components also will be relatively cheap in production and could use standard batteries. The scintillation technique for crosswind is most promising because it doesn't need beams off the line of fire. The Doppler technique could still be used to measure range wind directly. In the near term, the device would present a crosswind correction to the spotter or shooter who would still make a manual adjustment. In the longer term, the wind reading could be fed directly into a fire control system. Although the crosswind may not be determined to an absolute degree of accuracy, its greatest value may be in simply telling the shooter when not to shoot. The device would also function as a laser range finder and it would be eye-safe.

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2. Von Wahlde, Raymond; Metz, Dennis. *Sniper Weapon Fire Control Error Budget Analysis*; ARL-TR-2065; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, August 1999.

3. Brosseau, Timothy L.; et. al. *The Inertial Reticle Technology (IRT) Applied to an M16A2 Rifle Firing From a Fast Attack Vehicle*; ARL-TR-2209; U.S. Army Research Laboratory, MD, April 2000.

4. Brosseau, Timothy L.; et. al. *The Inertial Reticle Technology (IRT) Applied to a .50-cal M2 Heavy-Barrel Machine Gun Firing from a High-Mobility Multipurpose Wheeled Vehicle (HMMWV)*; ARL-TR-2210; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, April 200.

5. Small, Stephen C.; Goldman, Joel M. The Joint Service Small Arms Program (JSSAP) 1993 Sniper Conference. *Proceedings*; April 1993

6. *Correcting for Environmental Factors, Summary Sheet (8315)*; United States Army John F. Kennedy Special Warfare Center and School, Fort Bragg, North Carolina; January 1986.

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8. Von Wahlde, R. Kentucky Windage Goes High Tech. *Tactical Shooter* **1999**, *2* (2),. 44–48.

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Appendix. Project White Feather Chronology

Project White Feather Chronology:

- 1991
  - July – Concept Briefing to W. Williams at USSCOM
  - August – Concept Briefing to Maj. Kelly USMC Quantico
  - September – Kick Off Meeting with D. Bennett

- 1992
  - February – 1st Tech. Demo (IRS)
  - “ “ – LANL Accomplishments: Wind-Resolved Crosswind Measurements briefing
  - March – Concept Briefing to FBI at Quantico
  - May – 2nd Tech Demo (IRS on M16)
  - June – LANL LIDAR study
  - November – Briefing SOTD at Ft. Washington
  - December – Coordination Meeting at APG

- 1993
  - February – 3rd Tech Demo, APG (M16 rifle w/IRS)
  - W.F. Briefing to FBI at Quantico
  - April – 1st JSSAP Sniper’s Conference with Carlos Hathcock at Picatinny Arsenal, NJ
  - May – 4th Tech Demo, APG (M16 rifle w/IRS “live fire”)
  - September – W.F. Briefing at ADPA Small Arms Symposium, Virginia Beach, VA
  - “ “ Robert McCoy’s report “Cal. .338 For Use In The Advanced Medium Sniper Rifle” FTB-IR-3
  - November – W.F. Summit Meeting at Ft. Washington, MD
  - December – W.F. Meet at APG

- 1994
  - January – 4th Tech Demo, APG – Remington 700, N. Ward, 5th Group SOF sniper
  - “ “ – Briefing SOTD at Ft. Washington
  - February – Briefing at SOF Sniper Conference, Mac Dill AFB
  - March – W.F. Meet with Bob McCoy and John Whiteside at APG
  - April – 2nd JSSAP Sniper Conference, APG
  - May – W.F. Summit Meeting at APG
  - June – Sniper User Advisory Group Meeting at 5th Group SF, FTCKY
  - July – W.F. IPR

- August – Briefing SOTD at Ft. Washington
- September – W.F. IPR at LANL
- “ “ – Briefing SOTD at Panama City, FL
- “ “ – WF Briefing to ARL Battlefield Environment Directorate, White Sands Missile Range, NM
- October – W.F. Summit Meeting at APG
- November – 4th Tech Demo, APG

- 1995
- New Start 1st Qtr. FY ‘96
  - February/March – W.F. LIDAR Test, APG
  - April – W.F. Summit Meeting, APG
  - May – W.F. SOREQ LIDAR Tech Demo, APG
  - “ “ – LANL critique of LIDAR Tech Demo
  - August – Battelle Sniper Report meeting
  - “ “ – Ballistic Winds Meet at Wight-Patterson AFB, OH
  - September – Follow-up meet at Wright-Patterson AFB, OH
  - October – Objective Sniper Weapon/Objective Personal Weapon (OSW/OPW) meeting at ARDEC
  - “ “ – LANL interim report “W.F. Lidar Wind Velocimeter Concept Verification: Progress Report” by B. Newnam

- 1996
  - January - JSSAP 2nd Sniper Shooters Meeting, ARDEC
  - “ “ – LANL interim report “W.F. Lidar Wind Velocimeter Concept Verification” by B. Newnam
  - February – W.F. Summit Meeting, APG
  - “ “ - Briefing SOTD at NAB Coronado, CA
  - “ “ DRAFT MNS “Advanced Sniper Weapon Fire Control System (ASWFCS)
  - “ “ - ARL report “Application of an Inertial Reticle System to an Objective Personal Weapon”
  - March - Follow-up meet at Wright-Patterson AFB, OH
  - “ “ – LANL report “Directional Wind-Measurement Derived from Elastic Backscatter Lidar Data in Real-Time” by B. Newnam
  - May – OSW/OPW Conference at Lackland AFB, TX
  - “ “ – W.F. Summit Meeting, APG
  - June – W.F. Meeting with W. Williams at McDill AFB, FL
  - “ “ – Boulder, CO Wind-Sensing Test (Dr. Harmon)
  - July – Coordination meet at Wright-Patterson AFB, OH
  - September – Briefing SOTD at Mac Dill, AFB
  - “ “ – Dr. Hannon’s “Doppler Lidar Crosswind Sensing” report
  - October – Briefing to Col. Voorhees at Mac Dill, AFB
  - “ “ – W.F. Meeting at Ft. Washington, MD

- December - “Accuracy Performance Comparison for Selected Sniper Weapon Systems” by K. R. Pfleger

- 1997
  - January – W.F. Summit Meeting, APG
  - February – Meeting w/EAI Corp. P. Smoak – Weaponeering Study
  - April – W.F. Coordination meeting, APG
  - May – Weaponeering Study meet at Mac Dill AFB
  - June – ADPA Small Arms Symposium Sniper Briefing, Reno, NV
  - “ “ - W.F. Meeting at OST, Ft. Washington, MD
  - August – SOST Review at Mac Dill AFB
  - September – W.F. Briefing to Associate Tech Director ARDEC, J. Hedderich
  - October – W.F. Summit meeting, APG
  - “ “ - W.F. Meeting at Crystal City, MD
  - November – W.F. Briefing to USMC Snipers at Quantico, VA
  - “ “ - EAI Corp. P. Smoak – Weaponeering Study update

- 1998
- SBIRS – SCTi, Brimrose, and Optical Air
  - February – OST Review at Ft. Washington, MD
  - April – W.F. Summit Meeting, APG
  - May – Meet with W. William at Ft. Washington, MD
  - August – Brief SOTD at Ft. Bragg, NC
  - “ “ – P. Smoak’s “OSW Weaponeering Update Brief
  - November – Brief Col. Bailer, Mac Dill, AFB
  - “ “ – W.F. Summit Meeting, APG

- 1999
  - January – Follow up meeting with Col. Bailer, Mac Dill, AFB
  - “ “ - Brief SOTD at Ft. Bragg, NC
  - February – W.F. Coordination Meeting, APG
  - March – Von Wahlde Tactical Shooter article “Kentucky Windage Goes High Tech”
  - April - MNS “Advanced Sniper Weapon Fire Control System (ASWFCS)
  - May - W.F. Coordination Meeting, APG
  - July - 5th Tech Demo, (SCTi), APG
  - August – W.F. Meeting at Mac Dill, AFB
  - “ “ - W.F. Summit Meeting, APG
  - “ “ R. VonWahlde’s report: “Sniper Weapon Fire Control Error Budget Analysis.” ARL-TR-2065
  - September – SCTi Tech. Demo at Ft. Bragg, NC
  - December – W.F. Meet at Ft. Washington with G. Shock

- 2000
  - March – W.F. Meet at Ft. Washington

- April – W.F. Summit Meeting, APG
- May - Dr. Kregel's report "The Inertial Reticle Technology (IRT) Applied to a Remington 700 Sniper Rifle." ARL-TR-2231
- June - W.F. Meet at Ft. Washington
- " " – Battelle Meeting for Engineering Assessment of SCTi device
- July – W.F. Conference Call with Battelle OH
- August – W.F. Planning meeting, APG
- " " – W.F. Planning meeting, APG
- " " – Rutgers University Scintillometer Test, APG ,
- October - W.F. Planning meeting, APG
- November – Briefing to USMC AAAV, Abington, MD with Battelle (Ohio)

- 2001
  - June - W.F. Planning meeting, APG
  - September – Mistral Wind-Sensing (Carmel II) Conference Call
  - " " - Planning Conference Call for test of Carmel II
  - December - Field Test of Mistral Wind-Sensor (Carmel II)

- 2002
  - May – Von Wahlde, NDIA presentation "Field Experiment Results of the CARMEL II Laser"

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