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WIND STUDY AND GPS DROPSONDE APPLICABILITY TO AIRDROP TESTING

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Abstract

Wind measurement accuracy has been demonstrated to be a significant factor in airdrop accuracy. The U.S. Army Yuma Proving Ground (YPG) has undertaken a study to better understand the behavior of winds both over a wide geographic area and over time. In addition, multiple systems for measuring and modeling winds have been evaluated. This paper addresses the following three areas: (1) documentation of the data collection and processing methods currently being used at YPG, (2) comparison of the performance of the wind estimation systems in use at YPG, and (3) assessment of the effectiveness of the Global Positioning System (GPS) Dropsonde techniques for wind estimation and post-processing of airdrop data in support of airdrop testing. Specifically, the paper assesses the ability of the GPS dropsonde techniques to sufficiently estimate true wind velocity for airdrop testing. The evaluation of the applicability of GPS-based dropsondes has involved addressing the following issues: (1) impact of the descent rate of the GPS dropsonde system on the wind estimate, (2) errors involved with using the GPS ground track velocities as the wind. estimate directly, (3) difference of accuracy of the two systems and the degree of accuracy required for this technique, and (4) the usefulness of the GPS dropsonde ground track data in post-processing when attempting to derive the actual trajectory of the payload.

Introduction

The Radiosonde Wind Measuring System (RAWIN) has been the accepted standard of wind estimation used throughout the test community. RAWIN balloon launches are done about 2500 times per year at YPG. RAWIN balloon launches are automatically conducted every few hours daily at YPG, which provides a good record of the weather at YPG, year-round. For airdrop tests, to determine airdrop release points and for post-processing wind-corrected data, RAWIN balloons are launched at approximately 1-hour intervals near the release time in the vicinity of the Drop Zone (DZ). Throughout the history of airdrop testing, it has been shown that the RAWIN data, as collected, are insufficient for flight dynamic evaluations. Therefore, an alternative method for estimating winds is being implemented. This technique involves dropping a calibrated system along with the test items instrumented to measure winds. This study documents the current methods for wind measurement and evaluates each of these systems.

System Description

One of the objectives of this paper is to document the methods currently utilized for atmospheric data estimation at YPG. This effort has focused on two methods used for wind estimation to include the LORAN based RAWIN balloons and GPS equipped dropsondes. This paper documents the types of raw measurements being obtained, the types of sensors used for data acquisition, the data collection and recording/transmission rates for each measurement, and the processing methods for each of the measurement systems. In some cases, detailed documentation was not available for each system. Therefore, interviews of system operators and physical system investigations have been recorded.

Vaisala RS80 Radiosondes are used at weather stations all over the world for synoptic observations as well as in numerous defense and research programs. The RS80 is the radiosonde model YPG utilizes. Radiosondes are weather measurement instruments that measure upper air profiles of pressure, temperature, and humidity when launched into the upper atmosphere on a weather balloon. The accuracy of the temperature sensor is to 0.2 degrees C, the humidity to 3 percent, and the pressure to 0.5 millibars. The radiosonde is checked against ground conditions before being launched. Each radiosonde has a receiver for Loran-C navigation

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signals. Wind speed and direction are determined from successive positional fixes by the Loran-C receiver. The wind speed and directions are then interpolated between pressure surfaces. The altitude of the pressure surfaces above ground level (AGL) or mean sea level (MSL) is calculated inside the Vaisala software. Positional fixes and wind calculations are complete within this software. The observed data are transmitted to the ground equipment that processes the data into weather messages. The transmission frequencies are in the 400.15 to 406 megahertz (MHz) or 1668 to 1700 MHz Meteorological Aids Band. Externally, these data can be examined at intervals of 5 seconds until 8 minutes have elapsed, then at intervals of 10 seconds. The balloon's progress is monitored from ground level up to 30 kilometers (km).

In order to measure winds closer in time to the airdrop, and as close as possible to the drop coordinates, YPG has developed a system called the WindPack. The WindPack is based upon a 12-channel GPS receiver and, in addition to the receiver, includes a small computer, a power supply, and a flash card recording device. These components are housed in an extruded aluminum container 4 inches high and approximately 6 inches in diameter. Power for the WindPack is provided by a 5-amp-hour, lead acid gel-cell battery that is contained in a bracket attached to the bottom of the container. The container, with battery, weighs approximately 10 pounds. An antenna attached to a small ground plane is connected to the GPS receiver in the container through a 3-foot cable. This allows the antenna to be located external to the rigging. The WindPack is illustrated in Figure 1.

FIGURE 1. WindPack

The WindPack is typically packed in honeycomb to absorb some of the landing shock. The honeycomb is mounted on a plywood structure and secured with A-7A straps. This structure is then attached to the WindPack parachute with a D-ring and clevis. A typical rigging configuration is shown in Figure 2.

FIGURE 2. Rigged WindPack

Two parachute configurations are implemented with the WindPack system. The purpose of the two configurations is to achieve both high and low velocity rates of descent. Vertigo Inc. of Lake Elsinore, California, has developed both tri-lobe canopies. The 9.83-foot tri-lobe, typically weighted to a 15 to 35 feet per second (fps) descent velocity, has a coefficient of drag of 0.560. The 2.75-foot tri-lobe, typically weighted to a 60 to 80 fps descent velocity, has a coefficient of drag of 0.479. The smaller 2.75-foot tri-lobe parachute is initially deployed, and at pre-designated low altitude (~2500 ft AGL) an FF-2 Automatic Activation Device (AAD) triggers the High Altitude Air Release System (HAARS) to deploy the larger tri-lobe and induce a lower rate of descent for impact of the payload. Oscillations of these parachutes are very small. An airdrop of the WindPack system in the low velocity configuration is shown in Figure 3.

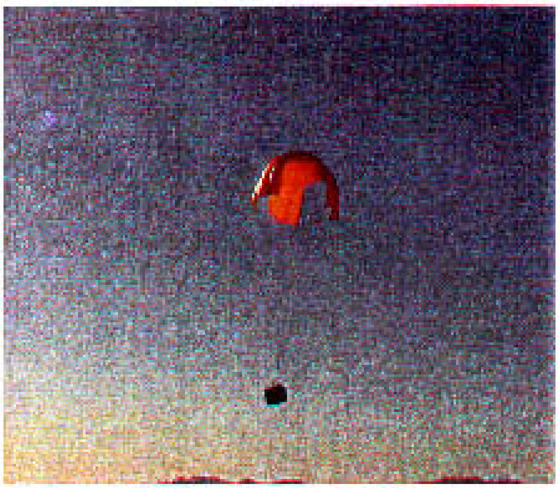

FIGURE 3. WindPack in Flight, Shown is the Tri-Lobe Parachute Built by Vertigo, Inc.

Two scenarios are used to acquire the wind data. One is to airdrop the WindPack as soon as the test item leaves the aircraft. The two systems drop through the same air mass at the same time so the WindPack measurements provide the best possible representation of the wind conditions experienced by the test item. The second scenario is used if several test items are to be launched on multiple passes over the DZ in a short period of time. In this case a WindPack is airdropped during a pass near the beginning of the drop sequence and one near the end of the drop sequence. If the drop sequence is long enough, it is desirable to drop additional WindPacks between the beginning and the end of the test.

As soon as the WindPack leaves the aircraft it acquires the GPS signals and begins to record the GPS data. The recorded parameters include GPS code phase and carrier phase for each satellite tracked by the receiver, as well as the ephemeris from each satellite. These parameters are measured and recorded at a 10 Hz rate and each sample is time-tagged with GPS time. At the conclusion of the drop, the flash card containing these data is retrieved from the WindPack for processing.

During processing, corrections are applied to the WindPack measurements to improve their accuracy. These corrections are derived from measurements recorded from a ground-based receiver during the drop. The ground receiver tracks the same satellite constellation of the WindPack through an antenna that has been precisely surveyed. The difference between the range to the satellite as measured by the receiver and that computed from the known location of the antenna is an error in the measurement. Since nearly all the error is common to both the WindPack measurement and the ground receiver measurement, the error determined by processing the ground receiver measurements can be removed from the measurements recorded by the WindPack during the drop. Once the measurement errors are removed, the position and velocity of the WindPack as a function of time is derived.

Analysis of WindPack Feasibility

As shown above, the WindPack measures ground speed of the tri-lobe parachute system. In order to effectively apply this system, it was crucial to validate the assumption that the ground velocities could be used as an estimate of the true horizontal wind. Figure 4 illustrates the variations of wind estimates over time, demonstrating a need for a timely wind estimation system such as the WindPack.

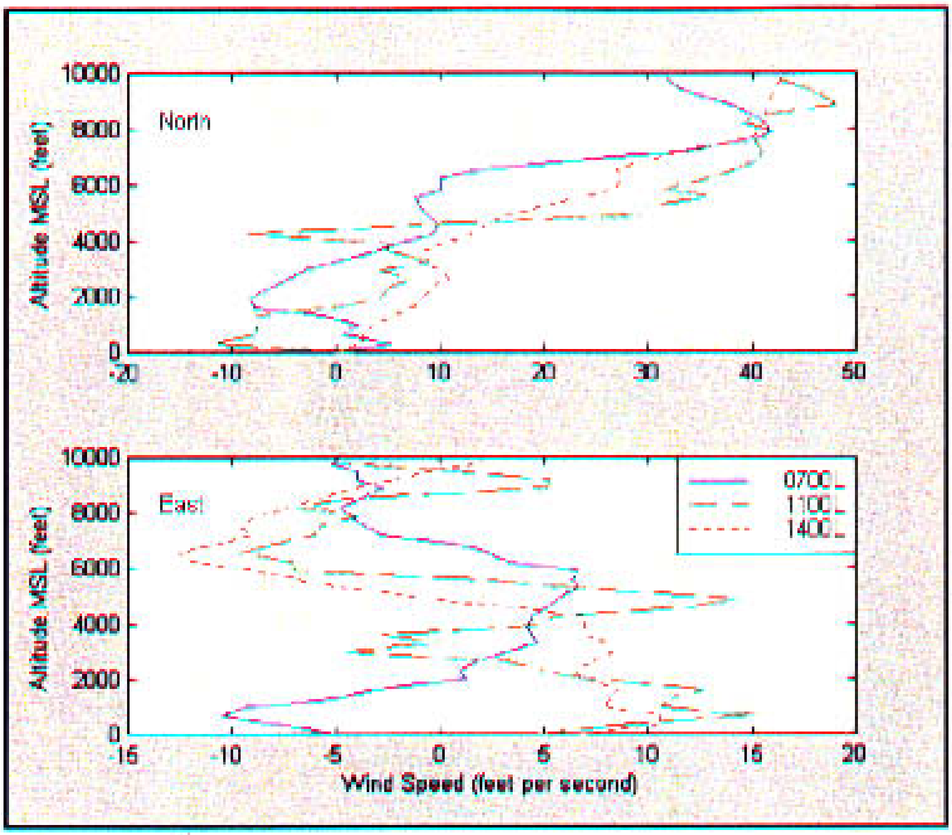

FIGURE 4. Wind Changes Over Time

The measured ground track velocity from the WindPack is taken as the assumed wind. This wind estimate is then fed into a point mass model of the WindPack with the only other force being drag and weight. The simulation then provides an estimate of ground track under that assumed wind condition. The difference between this modeled ground track and the actual measured ground track reflects the errors in the wind estimate. The magnitude of these errors indicates the significance of accounting for momentum changes caused by changes in the wind. Figure 5 presents the results of this validation. Use of the measured ground track velocity as the wind estimate resulted in errors of less than 0.3 feet per second.

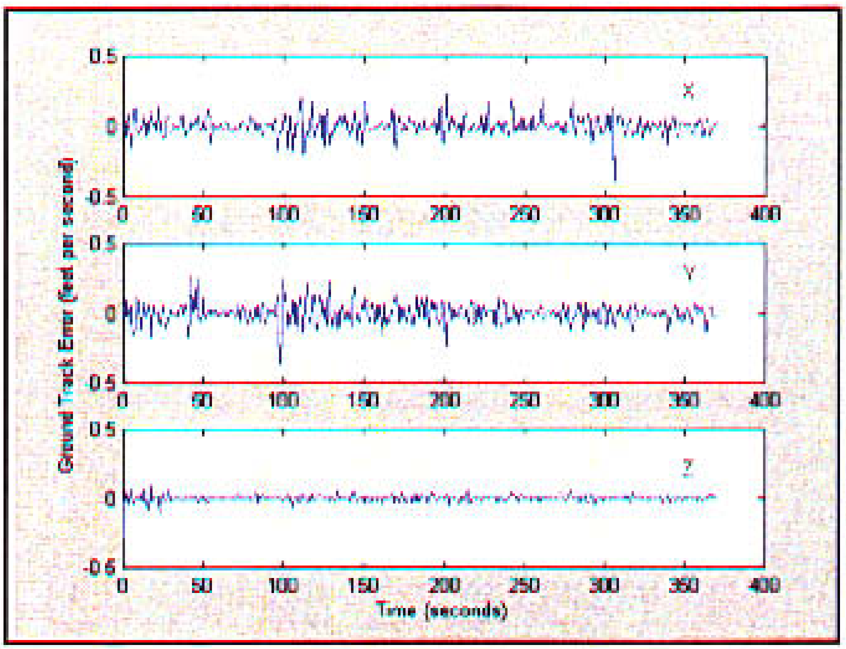

FIGURE 5. Wind Estimation Results

To further assess this technique, the methods for wind estimation utilized with hurricane dropsondes[1] are applied. Hock, et al, derived techniques for correcting ground speed measurements to formulate wind estimates in high shear environments. These techniques are then applied to the measured WindPack data. The derived wind estimate is compared to the measured ground speed.

The data in Figure 6 show that the corrected wind estimate, using the hurricane approach, differs from the measured ground track by less than 0.3 feet per second. More errors are seen close to ground impact where additional shears are present.

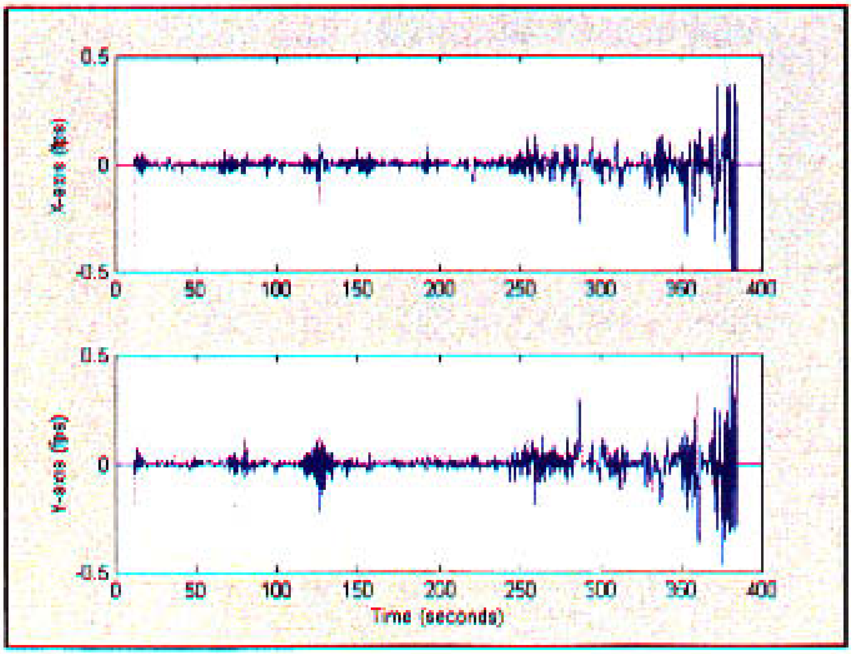

FIGURE 6. Hurricane Wind Estimation Results

The results shown in Figure 5 indicate that the momentum effects can be ignored for wind estimation for the WindPack. Figure 7 illustrates the comparison of the wind estimate to the winds measured by the RAWIN. Recall that the RAWIN balloon was launched only every hour. The closest RAWIN data were used for this comparison.

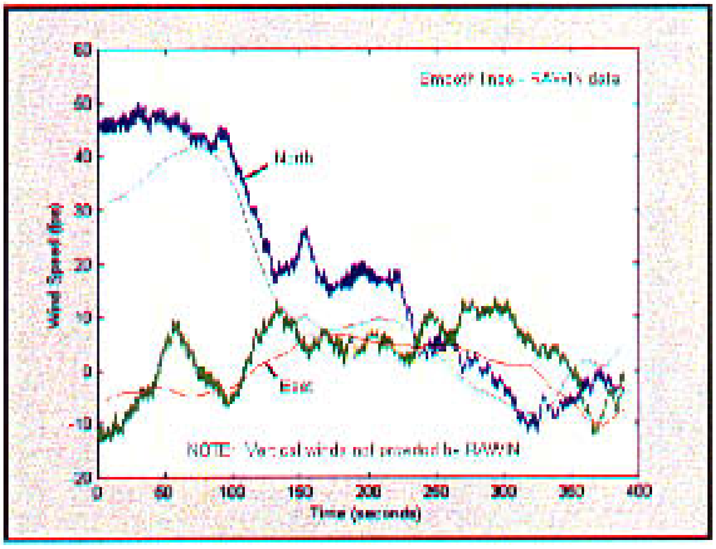

FIGURE 7. Wind Estimation Compared to RAWIN

These results demonstrate this technique will provide significantly better estimates of winds than using the RAWIN system. By adjusting the weight of the calibration system to match the descent rate of the test item, the two parachutes will be subjected to the same (as close as possible) atmospheric conditions. Using the measured GPS ground track velocities is an adequate approximation for wind estimation. Other techniques, such as that presented above, may provide some refinement on the wind estimates, but the difference is likely to be insignificant for most testing. The key to application of this technique is the use of a very stable parachute due to the reductions in apparent mass effects resulting from oscillations.

Flight Test Procedures and Results

The effect of variations in time, location, and rate of descent on the wind data collection methods has been evaluated. The data have been obtained at the sampling rates and in the formats provided in regular operations. Multiple sets of data for each wind estimation method have been obtained for various conditions. Wind estimations were conducted with the RAWIN and the WindPack. Each data collection system is launched or airdropped from a pre-established starting position. Comparison of the two systems included simultaneous launches and airdrops in the same location. The data, time of activation, and position of initial activation have been recorded for each event. For each test the wind estimate is plotted as a function of altitude in a common reference system. The data have been correlated by altitude (using linear interpolation when required) and differenced. The data have been reviewed to assess the magnitude and variation of the difference of the wind estimates. Spatial and time differences of the measurements are considered as a contributor to the difference in the wind estimates.

Wind Characterization Over Time and Distance

To demonstrate the variation of winds over time, RAWIN balloon data were obtained several times throughout a day, from the same location. There are two locations, Tower M and Firing Front, where RAWIN balloons are automatically sent up multiple times throughout the day, usually at 1- to 2-hour intervals. For this study, 2 days were selected when balloon launches had been conducted at least every 2 hours from the same location (9 March 2000 at Tower M and 26 March 2001 at Firing Front). Wind data throughout each of these days was plotted as a function of altitude to demonstrate how much the winds can change over various time durations. The following plots illustrate the trends of wind changes throughout a typical day at Tower M (see Figure 8) and Firing Front (see Figure 9) on the Kofa Range at YPG. These plots show that the wind varies greatly in magnitude and direction at the lower altitudes (<5000 ft) in the same location over a period of time.

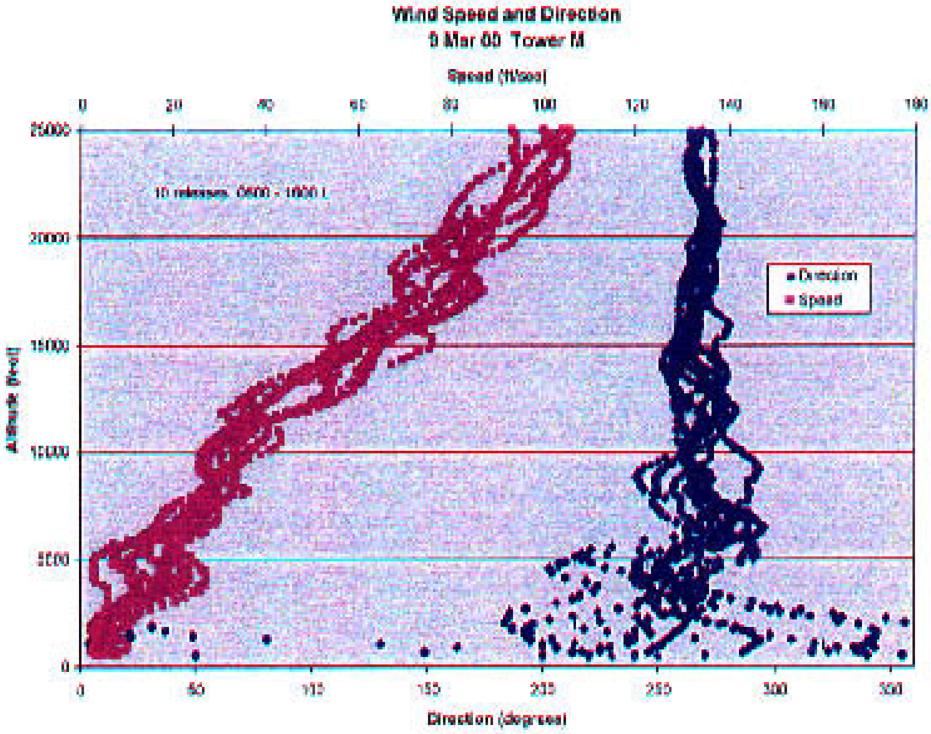

FIGURE 8. Changes in Wind Over 1-Hour Intervals at Tower M

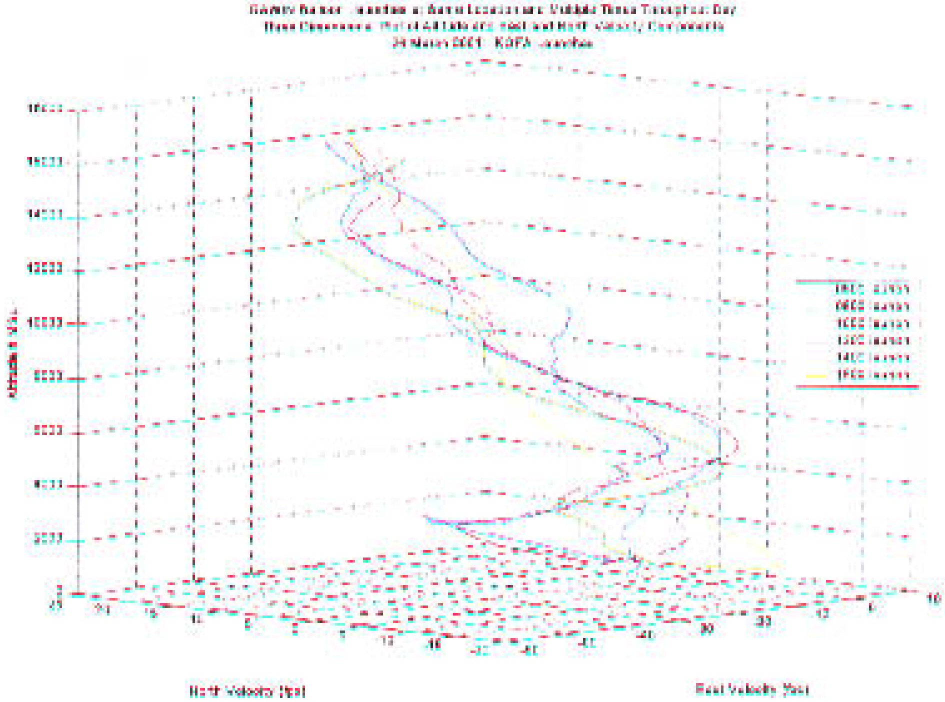

FIGURE 9. Changes in Wind Over 2-Hour Intervals at Firing Front

It then becomes relevant to review wind speed and direction changes at different locations of simultaneous balloon launches. Simultaneous RAWIN launches were performed at multiple sites to analyze the effects of distance separation on wind data collection. For comparisons at 50 kilometers apart, RAWIN balloons were released at the same time from the Firing Front and LaPosa DZ. Firing Front Road is at 430 feet MSL. The balloon release point at La Posa is at 1322 feet MSL, and the terrain near La Posa DZ is up to 3000 feet MSL. The wind profile at each location was plotted as a function of mean sea level altitude for comparison. A plot showing this comparison is shown in Figure 10. For comparisons at 55 kilometers apart, RAWIN balloons were released both at Tower M and at Firing Front. Tower M is at 476 feet MSL. Three simultaneous launches throughout one day at approximately 0900, 1200, and 1500 were correlated. The wind profile at each location was plotted as a function of mean sea level altitude for comparison. Plots showing this comparison are shown in Figures 11 to 13.

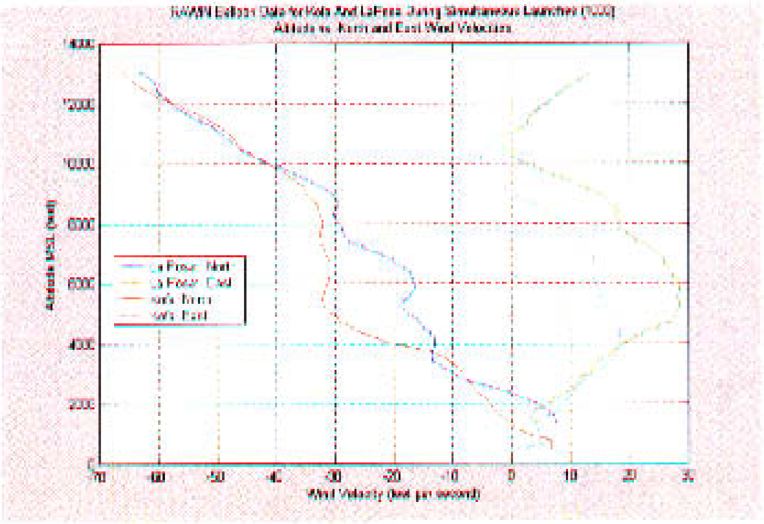

FIGURE 10. Wind Variations for Simultaneous RAWIN Launches Conducted at La Posa and Firing Front

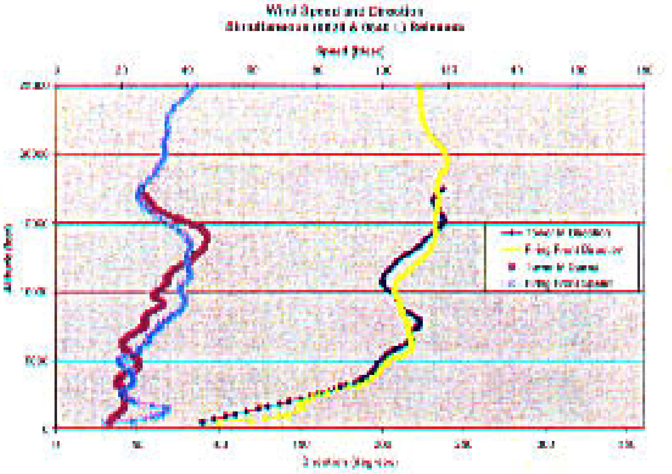

FIGURE 11. Wind Variations for Simultaneous Launches Conducted at Tower M and Firing Front (~0900)

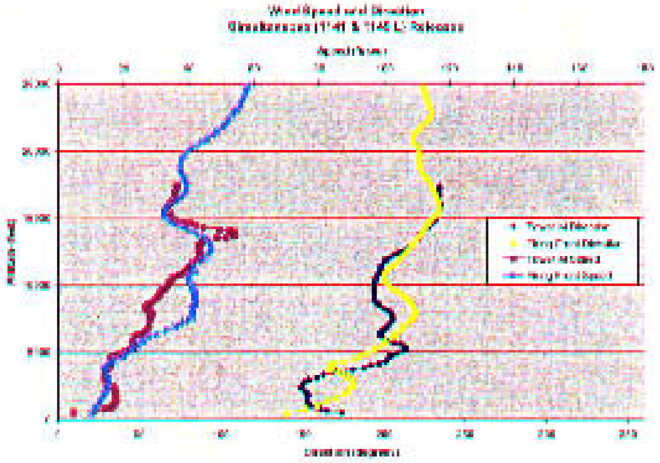

FIGURE 12. Wind Variations for Simultaneous Launches Conducted at Tower M and Firing Front (~1200)

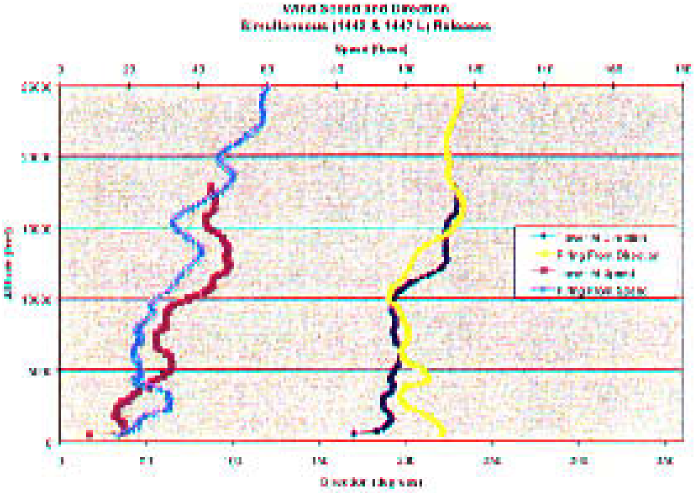

FIGURE 13. Wind Variations for Simultaneous Launches Conducted at Tower M and Firing Front (~1500)

The preceding plots demonstrate several trends. When comparing the Firing Front to the LaPosa launches, the terrain in between the two locations remains the primary consideration. With a mountain range of about 2000 feet on the southern side of La Posa DZ, it appears the winds become consistent with each other at about 10,000 feet MSL. Close to the ground, they differ greatly (up to approximately 15 fps difference in magnitude).

When comparing the Firing Front to the Tower M launches, it is noticeable that later in the day the winds closer to the ground also vary to the same degree. It is also observed from these plots that the winds become more consistent in speed and direction at about a 10,000-foot altitude.

Computed Air Release Point (CARP) Comparison

Wind estimates are used in calculating release points as well as for post-processing airdrop data. In order to determine the effect of using late winds or winds a great distance from the DZ, the release points have been calculated for the various wind profiles that were used in this wind study.

The following profiles were compared: two sites at 50 km (31 miles) separation, two sites at 55 km (34 miles) separation, and one site with multiple RAWIN releases throughout the day. The descent rate of the airdrop test item, as well as the airdrop altitude, is a variable used in the release point calculations. For all of the following release point calculations, a descent rate of 28 feet/sec was used. The airdrop altitude used in the calculations is stated for each profile and is at least 10,000 feet MSL The altitude stated for each profile is the altitude at which the airdrop test item is considered under canopy and falling at 28 feet per second rate of descent. For comparison purposes, forward throw, as well as altitude loss during opening, was not considered in calculating the release point.

For the two sites at 50-kilometer separation, the wind estimates from the La Posa and Firing Front launches were used. If a drop were conducted at La Posa DZ, calculating wind estimates from data obtained at La Posa versus Firing Front would result in a difference of release point of approximately 800 meters at an altitude of 10,000 feet MSL.

For the two sites at a 55-kilometer separation, the wind estimates from Tower M and Firing Front were used. Determining a CARP from wind data up to 17,500 feet MSL obtained at Tower M versus Firing Front for this case, results in a difference in release points that increases in the afternoon launches. At 0900 local time, the difference in offset would be 1300 meters, at 1200 local time the difference in offset would be 3500 meters, and at 1500 local time the difference in offset would be 3000 meters.

For determining the effect of using old winds, the winds at Firing Front at 0500, 0800, 1000, 1200, 1300, and 1600 were used. Release points were calculated from the wind estimates at each time at an altitude of 10,000 and 18,000 feet MSL. Table 1 depicts the difference in release points for all time intervals.

TABLE 1. Difference in Release Points Calculated from Multiple RAWIN Balloon Launches

Altitude	Launch	Difference in Release Pt (meters)				
ft MSL	Time	0500L	0800L	1000L	1200L	1300L
10,000	0800L	733	0			
10,000	1000L	808	76	0		
10,000	1200L	816	303	295	0	
10,000	1300L	1386	686	614	597	0
10,000	1600L	1556	829	757	905	467
18,000	0800L	1092	0			
18,000	1000L	1133	432	0		
18,000	1200L	946	435	188	0	
18,000	1300L	1734	887	607	790	0
18,000	1600L	2684	1735	1551	1738	954

As would be expected, the table shows that the change in winds vary at different times of the day. As the altitude increases from 10,000 feet MSL to 18,000 feet MSL, the difference in release point increases greatly. It is also noted the greater delays in time of wind data collection causes immense differences in the CARP

Precision of WindPack

A flight test was conducted on 6 February 2001 to review how winds vary across the DZ during simultaneous airdrops of several WindPacks and includes comparison to RAWIN data collection within 15 minutes of the airdrop in the same vicinity. For the wind comparisons at different locations in a DZ, four WindPacks were weighted to 68 pounds to achieve a 28 feet per second rate of descent and a 9.83-foot tri-lobe parachute was used. The airdrop test occurred at Sidewinder DZ from a UH-1 Helicopter. A WindPack was dropped from a helicopter at the leading edge of the DZ at an altitude of 10,000 feet MSL, and then the other three WindPacks were dropped at 5-second intervals as the helicopter flew across the DZ at about 70 Knots Indicated Air Speed. With the 5-second interval between each drop, the WindPacks were about 200 meters apart (600 meter spread).

Figures 14 through 16 are from the airdrops comparing the four consecutive WindPacks across Sidewinder DZ to each other and to the simultaneous RAWIN launch in same location of the drop.

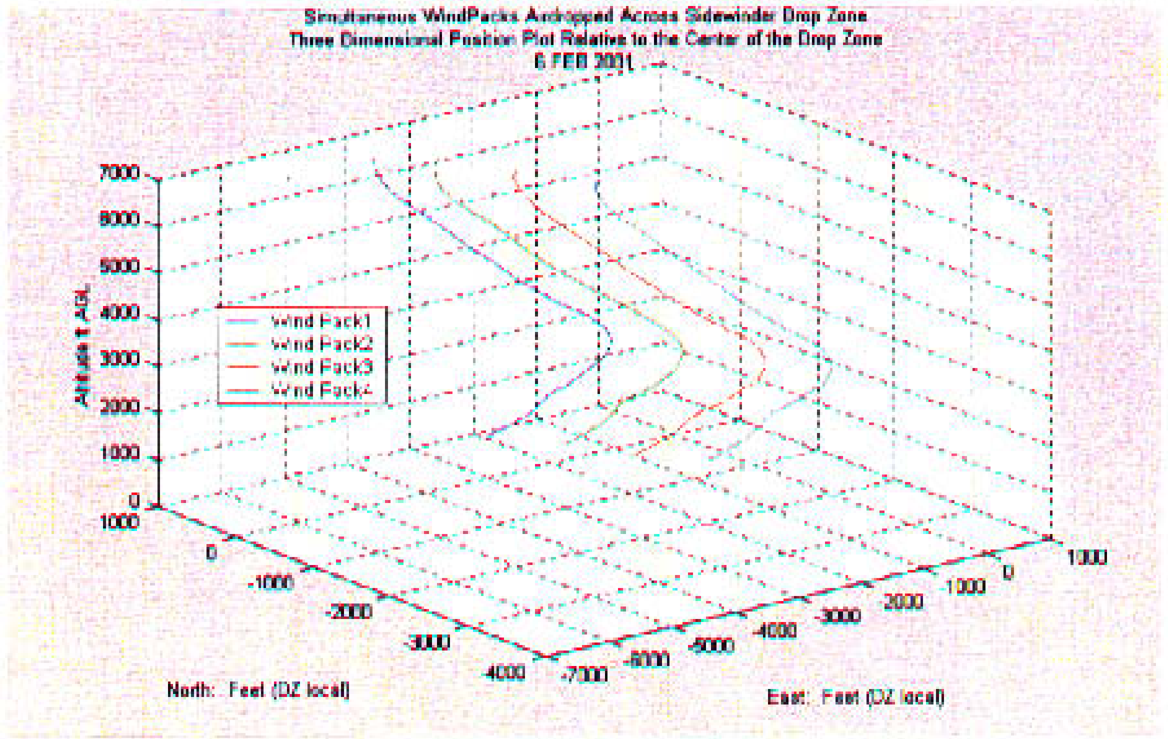

FIGURE 14. Trajectories of Simultaneous WindPacks Airdropped Across the DZ

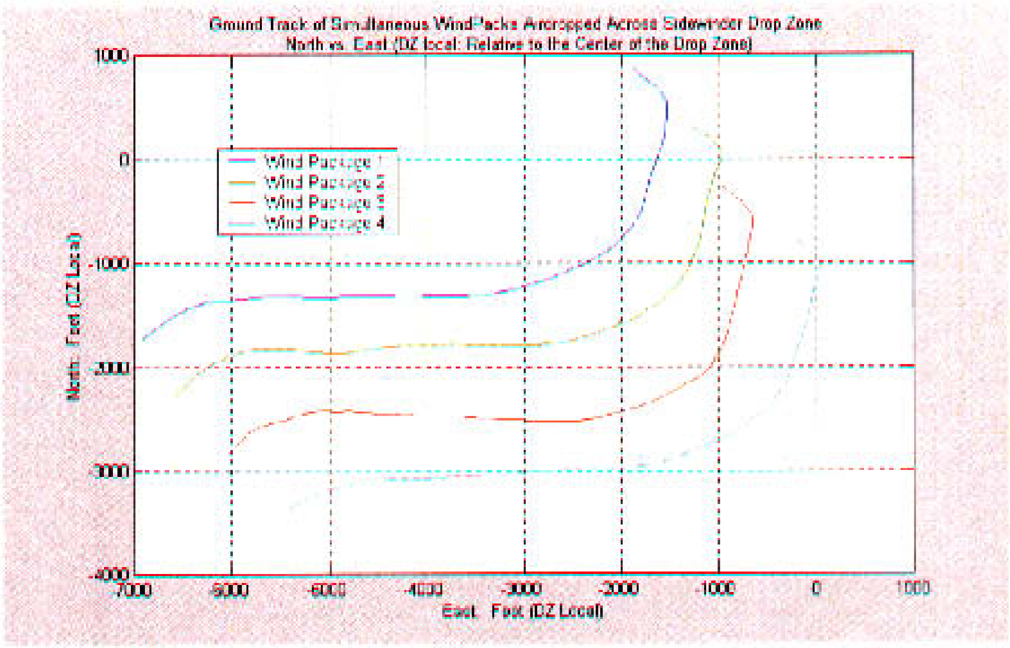

FIGURE 15. Ground Track of Simultaneous WindPacks Airdropped Across the DZ

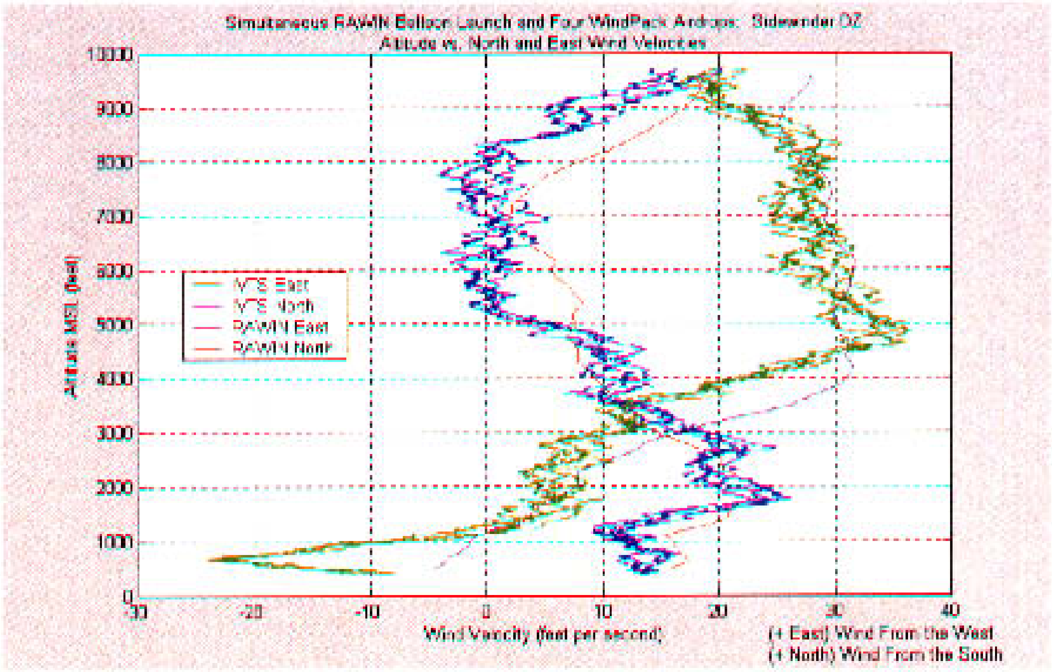

FIGURE 16. Comparison of RAWIN and WindPack North and East Wind Velocity Components

There are a number of observations that can be made from the previous plots. The WindPack data are relatively consistent with each other across the DZ, which contributes to the argument that they are precisely collecting wind data. The WindPack is shown as an exceptionally precise wind measurement tool. It is also realized that the wind variation over a DZ (~600 meter spread) is minimal. However, there are great differences between the WindPack and RAWIN wind data. The wind velocities vary up to 10 feet per second in magnitude. This could be due to the difference in sample rates and accuracies of the two systems.

High and Low Velocity WindPack Comparison

On 8 February 2001 the WindPack system was dropped at two different descent rates, in order to see how a change in descent rate (and therefore a change in data sample rate) would affect the wind data. Two WindPacks were weighted to 68 pounds and a 9.83-foot tri-lobe parachute was used, in order to have a rate of descent of 28 feet per second. Another two WindPacks were weighted to 35 pounds and a 2.75-foot tri-lobe was used, in order to have a rate of descent of 78 feet per second. The airdrop test occurred at Sidewinder DZ from a UH-1 Helicopter. The first 68-pound WindPack was dropped at the leading edge of Sidewinder DZ. The second 68-pound WindPack was dropped about 20 seconds later, which was approximately 800 meters from the first WindPack release point. The UH-1 did an additional pass across Sidewinder DZ, dropping the two 35-pound WindPacks at the different release points. Dropping a high and a low velocity WindPack at the same time from the same release point would have been an ideal situation. However, due to different times of flight of the WindPacks, separate release points had to be used. The wind estimates obtained from the WindPacks were plotted as a function of altitude to assess the difference in data obtained from a Windpack dropped at a low rate of descent (28 fps) to the data from a WindPack dropped at a high rate of descent (78 fps). Note that on the high velocity WindPack the larger Tri-lobe Parachute is deployed at about 3000 feet MSL to slow down the rate of descent of the package. These data are illustrated in Figure 17.

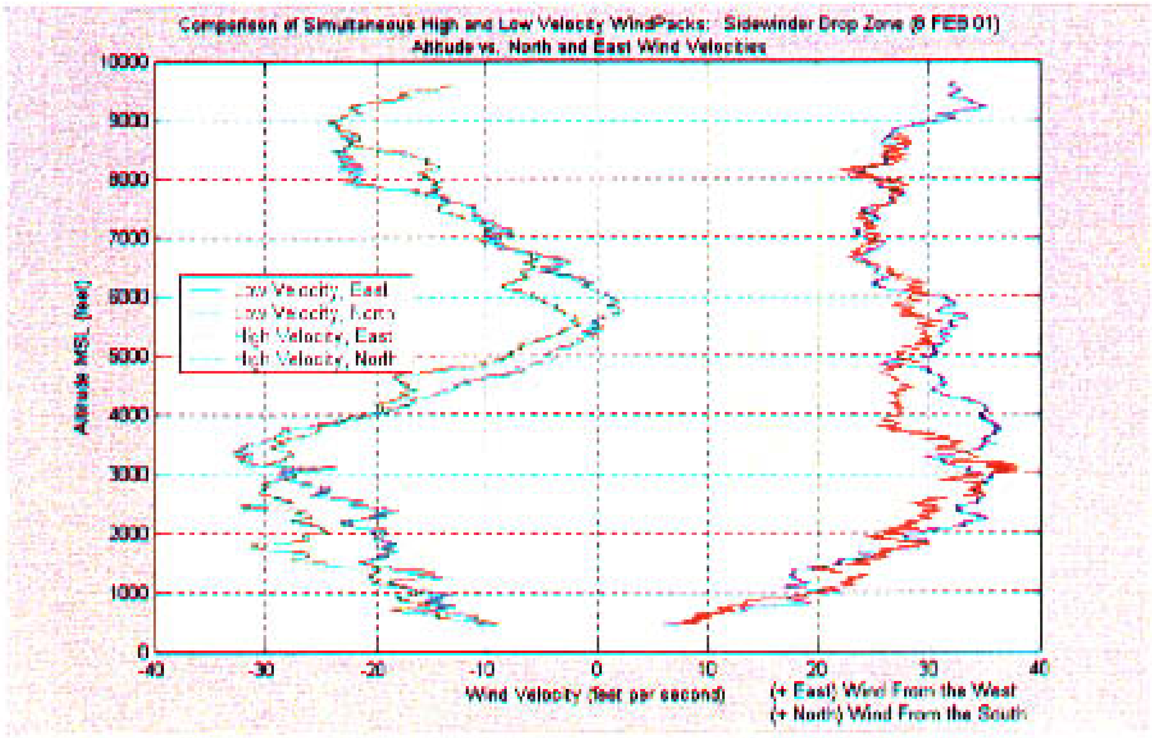

FIGURE 17. Comparison of High and Low Velocity WindPacks

When attempting to evaluate the effects of rate of descent on the wind measurements performed by the WindPack, it is realized that there are differences in the data for simultaneous airdrops. It is unknown if these discrepancies are actual changes in wind or a resultant loss of accuracy of the WindPack when weighted to a higher vertical velocity. It can be noted that there are apparent oscillations in the higher rate of descent. These oscillations look as though they are higher in frequency, but roughly the same magnitude of the lower velocity WindPack. The oscillations appear to be the same after the high velocity load was decelerated at about 3000 feet MSL. Differences in the wind velocities at the lower altitudes (when the WindPacks are closer in rate of rate of descent to each other) can be contributed to changes in release points and time separations.

Post-Processing Applicability

Finally, a WindPack was airdropped simultaneously with a WindPack instrumented payload weighted at the same rate of descent in order to correct the trajectory of the payload for winds. The example includes an airdrop of a G-12 parachute on a 2200-pound A22 container and a simultaneous WindPack drop. The horizontal wind components were effectively "subtracted" out of the payload GPS data to compute the wind speed relative to the air mass. This test was conducted to demonstrate the effectiveness of the post-processing advantages of the WindPack instrumentation. This is shown in Figure 18. Figure 18 shows a nominal zero airspeed in the North and East components with periodic variations induced by accelerations. Only with a valid wind estimate, could the true airspeed be determined.

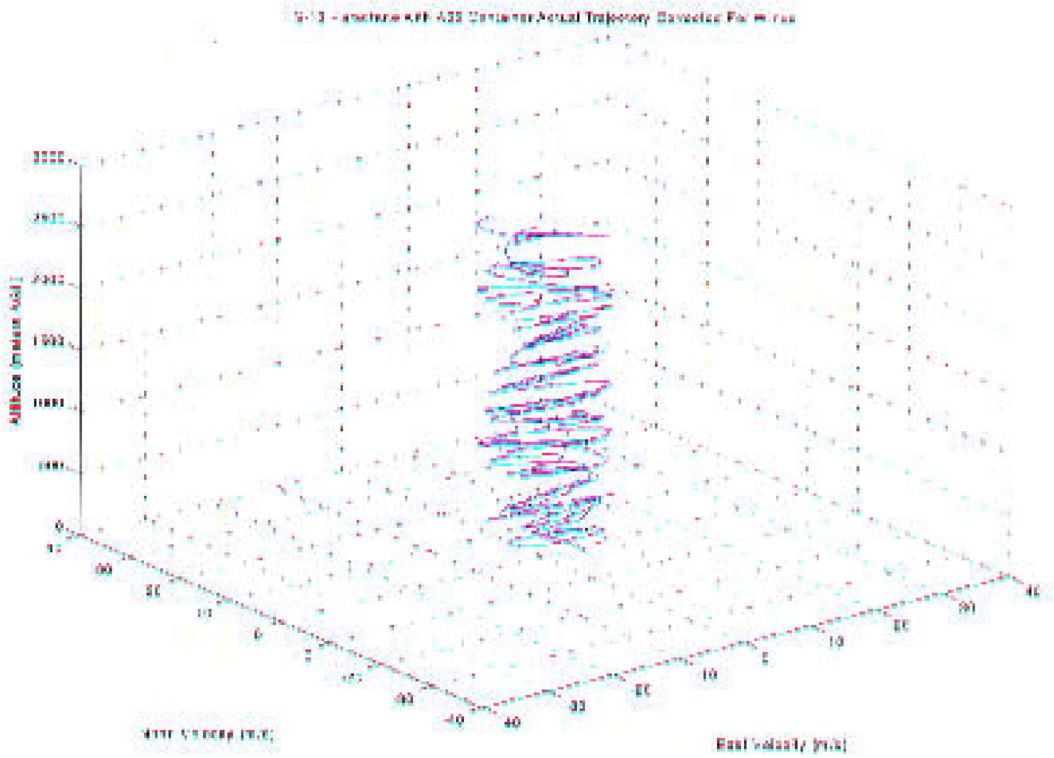

FIGURE 18. Illustration of WindPack Post-Processing Applied to Airdrop Payloads

Conclusions

This study shows the ability to obtain a more precise wind estimate using the YPG WindPack over that of Rawinsonde data. In addition, wind variations over time and distance were assessed. Sources of error or differences in wind data could have come from slight variations in location and time of the launches and airdrops that would have affected the correlations made. Analysis of vertical velocities was not conducted. When there are apparent variations in vertical velocity, it may be due to thermals present, which could cause localized perturbations to winds. Further testing should be conducted to evaluate the vertical velocities and how thermals can affect them.

Another area that requires additional validation would include that of the comparison of high and low velocity WindPacks. Testing should be done to attribute causes to the difference in wind profiles of high and low velocity WindPacks, and determine if there is a loss of accuracy at the higher rate of descent.

It can be stated that to have a wind estimate close to the proximity and time of the airdrop is the most ideal case. However, using delayed winds or winds in the near vicinity to calculate the CARP would not drastically hinder airdrop operations. Using the WindPack data to calculate the CARP is more accurate, but these data have a greater necessity when post-processing airdrop-related position data is a requirement. The airdrop developmental testing environment will greatly benefit from this capability.

References

1. Hock, T.F. and J.L. Franklin, 1999: "The NCAR GPS Dropwindsonde", Bulletin American Meteorological Society, Vol. 80, Number 3, 407-420.
2. Dellicker, S., "Low Cost Parachute Navigation Guidance and Control," MS thesis, Naval Postgraduate School, September 1999.
3. Dellicker, S., "Low Cost Parachute Navigation Guidance and Control," AIAA-99-1706, 1999
4. Porter, W., "AGAS, Wind Characterization," presentation, May 2000.
5. Bybee, J., "Wind Study", email, 28 April 2001.
6. Weingarton, D., "RAWIN Balloon", email, 8 March 2001.