

P1.4 COMPARISON OF THREE WIND MEASURING SYSTEMS FOR FLIGHT TEST

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1. ABSTRACT

A preliminary field test of the accuracy of wind velocity measurements obtained using global positioning system–tracked rawinsonde balloons has been performed. Wind comparisons have been conducted using global positioning system (GPS) and radio automatic theodolite sounder (RATS) rawinsondes and a high-precision range instrumentation radar–tracked reflector. Wind velocity differences between the GPS rawinsondes and the radar were significantly less than between the RATS rawinsondes and the radar. These limited test results indicate a root-mean-square wind velocity difference from 4.98 kn (2.56 m/sec) for the radar and RATS to 1.09 kn (0.56 m/sec) for the radar and GPS. Differences are influenced by user reporting requirements, data processing techniques, and the inherent tracking accuracies of the system. This brief field test indicates that the GPS sounding system tracking data are more precise than the RATS system. When high-resolution wind data are needed, use of GPS rawinsonde systems can reduce the burden on range radar operations.

2. INTRODUCTION

Precision radar tracking of a Jimsphere balloon or reflector has been used as a method for high-accuracy wind velocity measurement in support of special aerospace range operations such as the space shuttle program (Wilfong et al. [1997]). Flight test programs expected at the NASA Dryden Flight Research Center (Edwards, California) such as the Future-X (X-40) aircraft and other uninhabited aerial vehicles require rapidly updated, highly accurate atmospheric wind data for “go”/“no go” decisions. Low-altitude wind conditions that impact the final approach and landing are particularly

critical to safety and postflight engineering analyses.

Comparison tests of upper-air wind measurement systems have been conducted by the United States Air Force and NASA Dryden at Edwards Air Force Base (California). Three systems using different tracking techniques were compared: the global positioning system (GPS), the radio automatic theodolite sounder (RATS), and radar. The two rawinsonde packages and the 6-in. (15.24-cm) spherical radar reflector were placed on the same balloon tether line in order to sample the same atmosphere.

Conventional rawinsondes, including the RATS, do not have as much accuracy and resolution as precision tracking radar. However, when radar is used to track a balloon, obtaining radar lock is often difficult, particularly in the presence of ground clutter at low altitudes when the balloon release is at a mission location some distance from the radar. Demonstrating that the GPS rawinsonde system tracking precision is comparable to range radar can allow GPS rawinsondes to support range wind measurement requirements, thereby circumventing the ground clutter problem and freeing the range tracking radar for other missions.

Note that use of trade names or names of manufacturers in this document does not constitute an official endorsement of such products or manufacturers, either expressed or implied, by the National Aeronautics and Space Administration.

3. SYSTEMS DESCRIPTIONS

The RATS system Model IS-4A-1680HS (Vaisala, Inc. [formerly Atmospheric Instrumentation Research, Inc.], Boulder, Colorado) uses ground-based phased arrays to track these sensors. The RATS rawinsonde thermodynamic data (pressure, temperature, and relative humidity) and position angular data are transmitted to a ground receiver every 2 sec (approximately every 30–40 ft [9.14–12.19 m] in

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altitude) during ascent (Atmospheric Instrumentation Research, Inc. [1997]). The RATS-determined winds are calculated from derivatives of position. The calculated winds are smoothed using layer averaging in an elapsed time-based moving window. The averaging interval increases with altitude to reach a maximum value, equivalent to a 4000-ft (1219-m) altitude thickness at an altitude greater than 65,000 ft (19,817 m) (Atmospheric Instrumentation Research, Inc., [1997]).

The W-9000 meteorological processing system (Sippican, Inc. [formerly VIZ, Inc.], Marion, Massachusetts) is a differential GPS-tracked balloon that transmits thermodynamic data (temperature, relative humidity) and GPS position every 1 sec (Sippican, Inc. [2000]). The GPS rawinsonde package derives atmospheric pressure from the measured GPS altitude and the thermodynamic data. Position is determined by real-time code correlating differential computations between GPS sonde signals and those received through the base station. The receiver/processor produces wind vector data by real-time derivatives of position; final wind data represent a 20-sec moving average. Kalman and notch filtering operations are performed on the GPS position data to minimize tracking noise and the effects of the pendulum motion of the sonde that is suspended approximately 100 ft (30.48 m) below the balloon. Vendor literature states the winds are accurate to 1.0 kn (0.5 m/sec) when the system is operated in differential GPS mode (Sippican, Inc. [2000]).

The NASA Dryden RIR-716 radar transmits and receives radio frequency pulse signals at a rate of 20 samples/sec (James et al. [1985]). The data stored are the raw time from the local midnight hour, range to the reflector, azimuth from true north, and elevation angle above the horizon. Next, an in-house FORTRAN program called "radar" provides filters to clean the raw data by removing erroneous spikes and corrects for atmospheric refraction (beam bending) (Haering et al. [1995]). Following the refractive corrections, geodetic transforms are applied to convert these data into position coordinates (latitude, longitude, and altitude). When converted, the position coordinates are differentiated with respect to time to determine Earth-relative velocity vectors (positive being north, east, and down) (Haering et al. [1995]).

4. TESTS

Three field tests were conducted, on October 7, November 3, and November 9, 1999. Two tests (the Oct. 7th and Nov. 9th) used only the RATS and GPS; the November 3rd test incorporated the RATS, GPS, and radar. The RATS-GPS configuration consisted of the balloon, parachute, RATS, and GPS tied in a length of approximately 100 ft (30.48 m). The RATS and GPS were separated by 10 ft (3.04 m). The November 3rd configuration consisted of the balloon, parachute, reflector, RATS, and GPS in line; the reflector and RATS were separated by 3 ft (0.91 m) and the RATS and GPS by 10 ft (3.04 m).

Maximum (or balloon-burst) altitude data were desired; however, peak altitudes achieved during these tests ranged from 34 to 50 kft (10.36 to 15.24 m). Premature altitude cutoffs were regularly experienced by the receiver system for the GPS. Evidence obtained suggests a software anomaly in the GPS sounding system was the cause and appears to have been corrected. All thermodynamic and wind data obtained were stored as raw and formatted data. Synoptic upper-air atmospheric data and Edwards AFB surface reports also were collected and stored for reference purposes.

Test days were selected at random based on NASA and Air Force range schedules and not on meteorological conditions. Because the raw output data from each system are stored in different time base and altitude intervals, running each file through a software code to height-synchronize each output parameter into 100-ft (30.48-m) increments became mandatory.

5. RESULTS

The primary comparison data were obtained during the November 3rd test, when all three systems were flown together. Figures 1 and 2 show the observed wind speed and direction as a function of altitude for the November 3rd sondes. The winds were generally light to an altitude of 18,000 ft (5487.8 m). In particular, the winds were extremely light at altitudes between 16,000 and 18,000 ft (4878.0–5487.8 m). These light conditions tend to increase the variability in direction and limit the ability of the measurement system to accurately determine direction. All three systems show general agreement in velocity and direction.

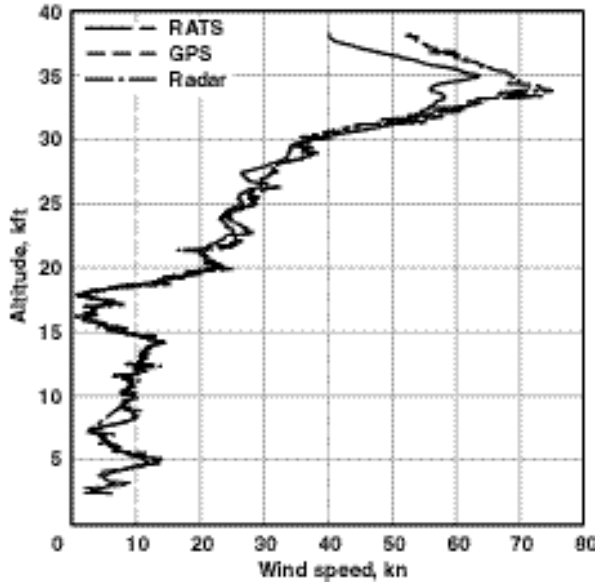


Figure 1. November 3rd RATS, GPS, and radar wind speed profile.

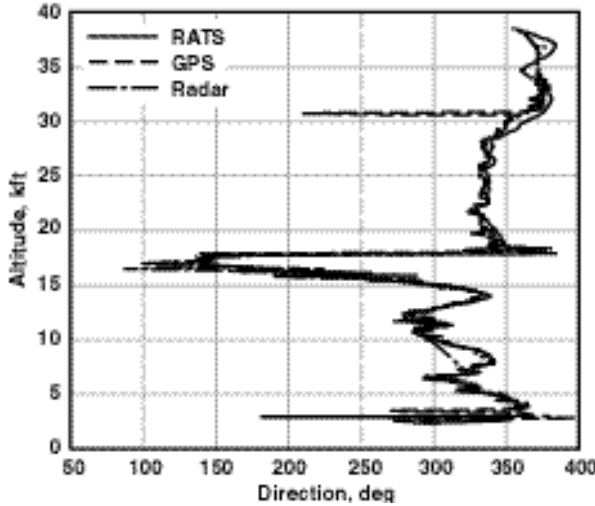


Figure 2. November 3rd RATS, GPS, and radar wind direction profile.

Figures 3 and 4 show differences in the wind velocity and direction, respectively, for the radar and GPS and the radar and RATS. Missing data and large differences in wind velocity and direction were caused by light winds and the loss in radar tracking of the reflector. During the November 3rd ascent, the radar lost precise track of the reflector several times, including one time from an altitude of 2,372 ft to 5,000 ft (723–1524 m) (not shown) and another from an altitude of 7,200 to 10,000 ft (2195.0–3048.7 m). In contrast, both rawinsonde systems continuously maintained track from near

ground level during all three flights. Wind shifts at these low altitudes can be significant to aircraft landing-approach flightpath fidelity, flight control, and postflight engineering evaluations.

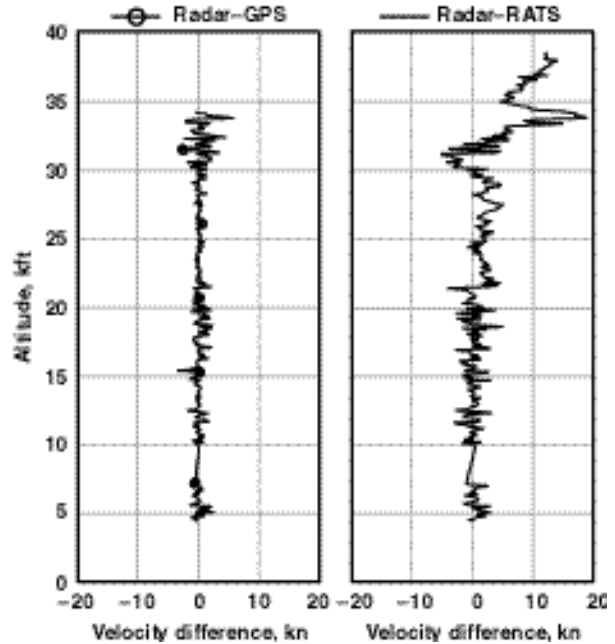


Figure 3. November 3rd wind velocity differences.

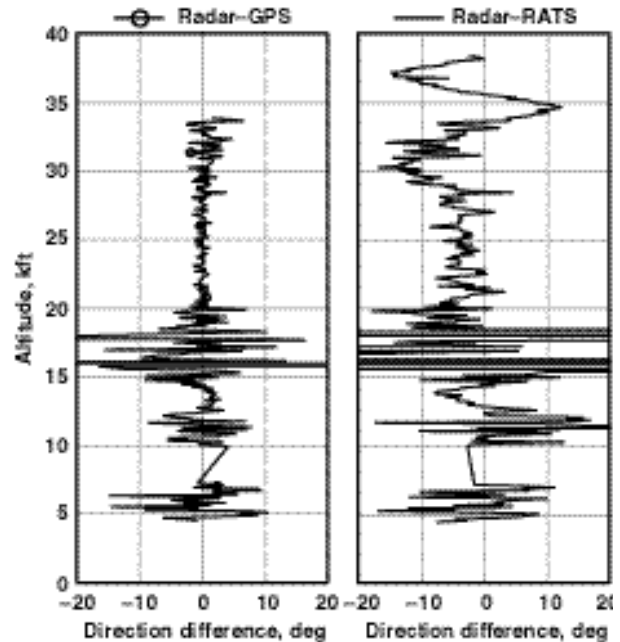


Figure 4. November 3rd wind direction differences.

To reduce noise and sonde pendulum motion, an infinite impulse-response filter was used on the radar position and velocity data. The respective cutoff frequencies for the second-order low-pass (Butterworth) filter were 0.05 Hz for position and 0.05 Hz for velocity. After filtering, the calculated resultant root-mean-square differences for the radar and GPS are 1.09 kn (0.56 m/sec) in velocity (table 1) and 7.23° in direction (table 2). Similarly, the root-mean-square differences for the radar and RATS are 4.98 (2.5 m/sec) in velocity and 13.65° in direction. Comparison statistics for all flights, including mean difference, standard deviation, root mean square, and mean absolute difference, are presented.

Figure 5 shows the residual reflector pendulum motion imbedded in the radar wind velocity data plotted with the GPS-tracked winds. After filtering and smoothing the data, the residual pendulum motion of the radar track at times appears greater than the GPS residual motion by as much as 0.5 kn (0.25 m/sec). If identically equivalent filtering had been used for pendulum motion removal, the root-mean-square velocity differences between the radar and GPS likely would be less

than 1.0 kn (0.51 m/sec). The velocity and direction differences for the RATS and GPS on October 7th and November 9th are similar to those experienced on November 3rd.

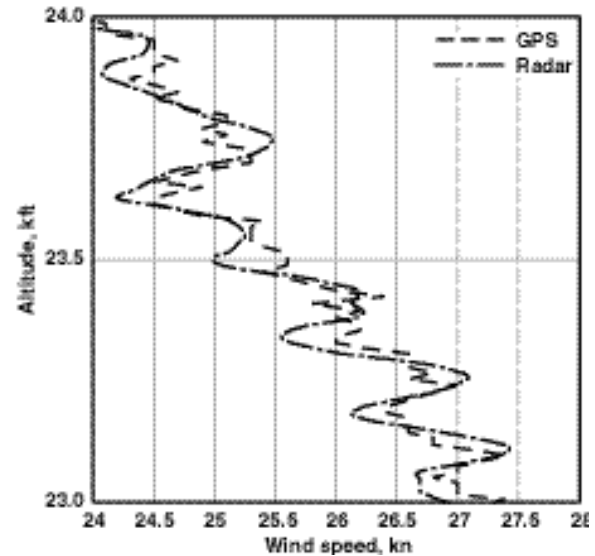


Figure 5. Pendulum motion of radar and GPS.

Table 1. Balloon test velocity data.

Test date	Comparison	Mean difference, kn	Standard deviation, kn	Root mean square, kn	Mean absolute difference, kn
October 7, 1999	RATS–GPS	–2.00	3.86	4.35	3.36
November 3, 1999	RATS–GPS	–0.88	2.47	2.63	1.63
November 3, 1999	Radar–GPS	0.18	1.07	1.09	0.71
November 3, 1999	Radar–RATS	2.53	4.32	4.98	3.24
November 9, 1999	RATS–GPS	–1.15	2.48	2.26	2.73

Table 2. Balloon test direction data.

Test date	Comparison	Mean difference, deg	Standard deviation, deg	Root mean square, deg	Mean absolute difference, deg
October 7, 1999	RATS–GPS	3.63	8.28	9.07	6.99
November 3, 1999	RATS–GPS	3.85	12.43	12.99	7.91
November 3, 1999	Radar–GPS	0.36	7.21	7.23	2.91
November 3, 1999	Radar–RATS	3.37	13.23	13.65	8.50
November 9, 1999	RATS–GPS	3.64	10.28	10.91	8.15

The wind data from the RATS are displayed on the system monitor in near-real time. The GPS wind data are displayed on the system monitor at 60-sec intervals, but intermediate processing is available. Complete postflight reduction of data is available from both systems within 15 min of reaching termination altitude. Although rawinsonde systems normally are used to provide the pressure, temperature, and humidity, the integration of the GPS for winds has improved the wind accuracy to approximately 1 kn. With this improvement, GPS rawinsondes could provide sufficient wind measurements without requiring the use of additional range radar facilities.

6. CONCLUSION

Limited tests have shown that the use of global positioning system (GPS) rawinsondes has the potential to provide researchers and planners increased wind measurement accuracy and resolution over conventional rawinsonde tracking systems. One test involving all three methods investigated shows that the wind velocity root mean square of the radar and GPS was within 1.09 kn (0.56 m/sec), yet the wind velocity root mean square of the radar and radio automatic theodolite sounder (RATS) comparison was more than quadruple that at 4.98 kn (2.56 m/sec). Similarly, root-mean-square direction differences were 7.23° for the radar and GPS and 13.99° for the radar and RATS. These test results indicate

that the GPS sonde system provides cost-effective, fast-response, wind data profiles with accuracy comparable to the radar-tracked reflectors.

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