



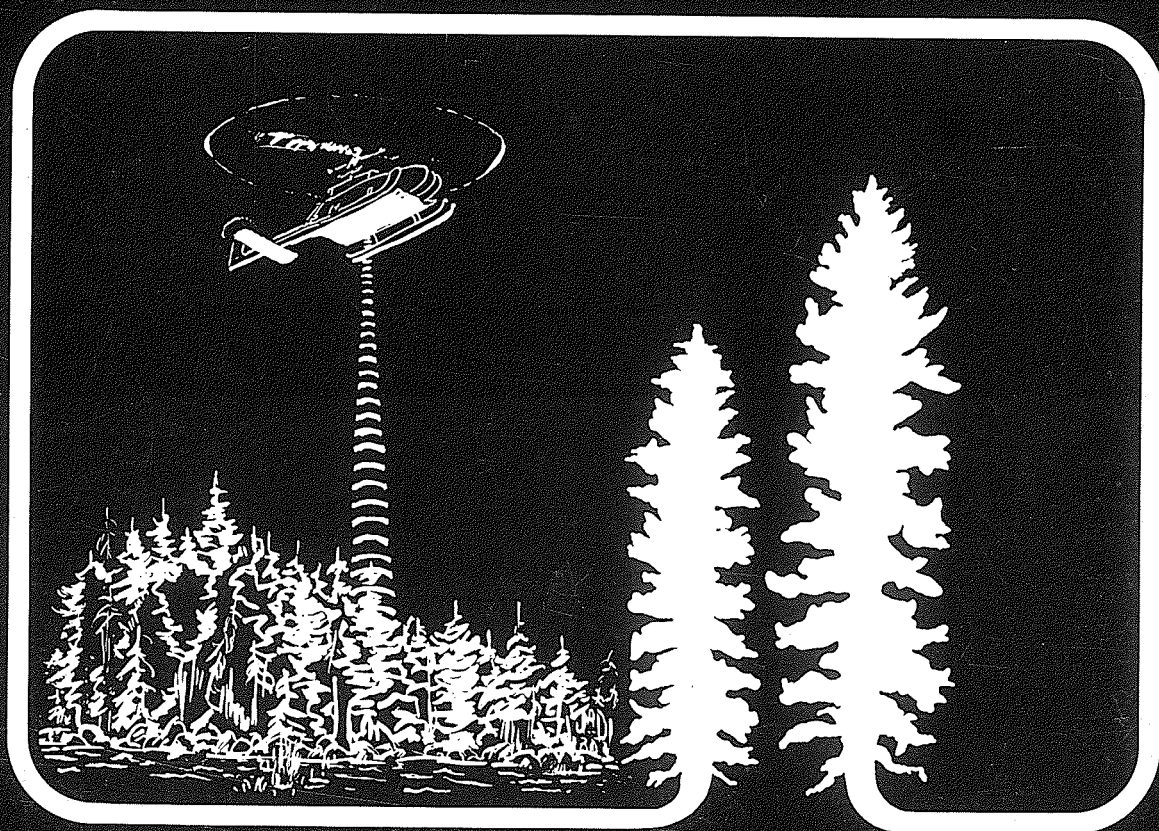
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Description and accuracy evaluation of the Honeywell radar altimeter



C.L. Kirby and R.J. Hall

**DESCRIPTION AND ACCURACY EVALUATION OF THE
HONEYWELL RADAR ALTIMETER**

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ABSTRACT

A Honeywell radar altimeter added to the Northern Forest Research Centre's aerial photo system provides height information for determining scale of low-level aerial photographs. Accuracy of the system was evaluated by comparing test flight results and ground measurements. Error is not dependent on flying height in the operational range of 150-2000 ft (45-600 m); decreasing accuracy occurs at altitudes of 4000 ft (1200 m) and higher. At 500 ft (150 m) the mean percentage error between the altimeter and actual height was -0.2% ($\pm 3.1\%$), and at 1000 ft (300 m) it was -0.4% ($\pm 2.3\%$). Because timber bounce may occur over forested areas, calibration is recommended for each flight. The system has proven useful in forest photo mensuration with applications in estimating timber volumes, forest residues, regeneration stocking, and wood pile volumes in mill yards.

RESUME

Ajouté au système de photographie aérienne du Centre de recherches forestières du Nord, un altimètre radar Honeywell fournit les données sur la hauteur permettant de déterminer l'échelle des photos aériennes à faible altitude. La précision du système a été évaluée par comparaison des résultats des essais de vols avec les mesures prises au sol. L'écart ne dépend pas de la hauteur de vol dans la gamme opérationnelle de 150 à 2000 pi (45-600 m); la précision diminue à des altitudes de 4000 pi (1200 m) et plus. À 500 pi (150 m), l'écart moyen en pourcentage, entre l'altimètre et la hauteur réelle s'établissait à -0,2% ($\pm 3,1\%$) et à 1000 pi (300 m) elle s'établissait à -0,4% ($\pm 2,3\%$). A cause de l'effet "rebondissant" du couvert forestier, il est recommandé d'ajuster le calibre avant chaque vol. Le système s'est avéré utile au mesurage des forêts par photographie avec des applications dans l'estimation des volumes de bois, des déchets forestiers, de la densité de régénération et des volumes de bois empilé dans les cours à bois des usines de transformation.

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NOTE

The exclusion of certain manufactured products does not imply rejection nor does the mention of other products imply endorsement by the Canadian Forestry Service.

INTRODUCTION

The use of large-scale aerial photographs in forestry has significantly reduced the fieldwork required compared with conventional ground techniques. The accuracy and precision of tree height and volume estimates from large-scale photos have been demonstrated by Kirby and Johnstone (1970); however, a major problem in using large-scale photos has been the accurate determination of photographic scale. Nielsen (1974) reported that conventional methods for estimating scale—such as ground control, radial line triangulation, the use of maps or small-scale photographs, and the indirect method of using conventional altimeters—are often too inaccurate or time consuming. In 1977, the Northern Forest Research Centre (NFRC) obtained a Honeywell radar altimeter system (model AN/APN-194[v]) to provide accurate height information from which to calculate scale of aerial photographs. The system has been adapted for use in helicopters (Jet Ranger—Bell 206B) and fixed-wing aircraft (Piper Aztec—PA-23). Altitude information is given in analog and digital format, and the digital output is displayed on each photograph as the height above ground in feet. Thus it is possible to determine the scale of each photo for photogrammetric and mensurational applications.

Testing was undertaken to determine the accuracy and behavioral characteristics of the altimeter system under actual operating conditions. This report describes the system and presents the results of the evaluation.

DESCRIPTION OF THE HONEYWELL RADAR ALTIMETER SYSTEM AN/APN-194(v)

THEORY OF OPERATION

The Honeywell radar altimeter measures the time delay from the instant a radio frequency signal leaves the transmitter until the moment the ground return signal is detected by the receiver. An analog voltage proportional to the time delay is generated by the altimeter and displayed on the height indicator. For digital output, a time/digital

converter is used to convert the time delay into information in serial binary format. This is then transformed into digital height information by a digital readout unit that records it onto photographic film.

COMPONENTS OF THE SYSTEM

Receiver-transmitter RT-1015/APN-194(v)

The pulse generator in the receiver-transmitter generates pulses of electromagnetic energy at a rate of 10 000 pulses per second. The operating frequency of 4.3 gigahertz (GHz) results in a transmitting wavelength of 2.747 in. (6.977cm). The steady train of pulses drives the transmitter, which converts each pulse into a burst of radio frequency energy (Honeywell 1975).

The function of the receiver-transmitter is to transmit the radio frequency burst, receive the reflected signal, and derive the proper voltage analogs for 0-5000 ft (0-1525 m) radar altitude. The receiver-transmitter consists of four modules: power supply, transmitter, receiver, and range computer. These modules are installed in a compartmentalized chassis (receiver-transmitter) as shown in Fig. 1.

Height Indicator ID 1761/APN-194(v)

The height indicator shows altitudes from 0-5000 ft (0-1525 m) by means of a single pointer against a fixed dial (Fig. 1). The pointer is behind the masked portion of the indicator dial during unreliable operation or for altitudes higher than 5000 ft (1525 m) (U.S. Department of the Navy 1974). Note that the tip of the pointer is not visible in Fig. 1. During unreliable operation, an OFF flag also will be present. A system self-test is possible by actuation of a push-to-test switch on the indicator. Reliable operation is shown in Fig. 2.

Digital Readout Unit

This specially designed unit (Fig. 3) built by Athabasca Research Corporation

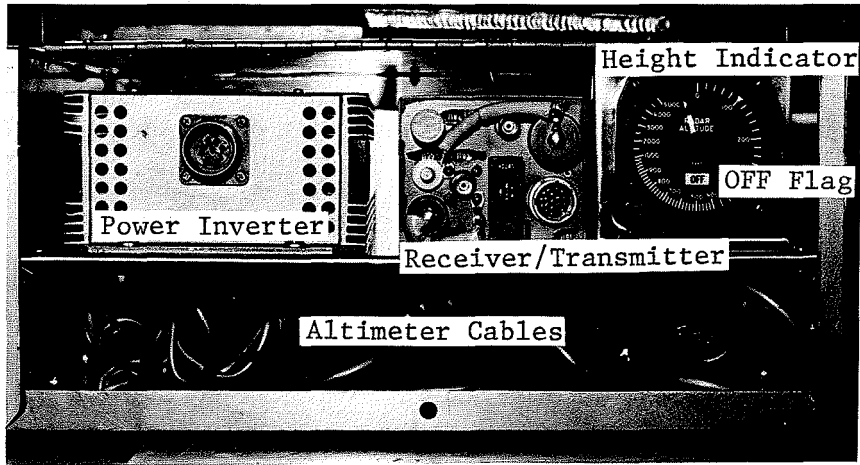


Figure 1. Main control components in a specially constructed housing unit.
 NOTE: The OFF flag is displayed on the height indicator dial.

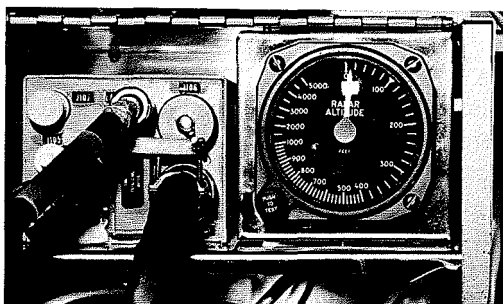


Figure 2. Height indicator showing reliable operation. NOTE: Cables are connected, the tip of the height pointer is visible, and the OFF flag is absent.

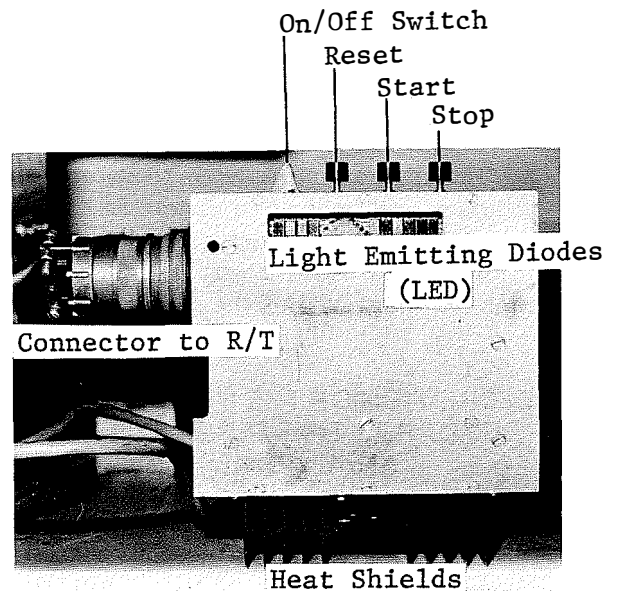


Figure 3. Digital readout unit.

makes use of the serial binary height information. The digital height readout is on light emitting diodes and is displayed through the secondary optics of a 70-mm Vinten aerial camera. Height above ground and time between exposures to 1/100 s are recorded on each film exposure. Fig. 4 shows an aerial photograph with the digital output displayed.

Antennas AS-2595/APN-194(v)

The radar altimeter system uses two identical passive antennas. One antenna acts as a transmitter and the other as a receiver. The actual function of either antenna depends upon where the cables are connected to the receiver-transmitter. The antennas are sealed against moisture and other foreign material and are comprised entirely of stationary parts (Honeywell 1975).

Electromagnetic energy pulses are radiated by the transmit antenna, which contains the energy within an approximately 35° cone-shaped pattern. Ninety percent of the energy is within a 5° cone¹.

Placement of the antennas is critical for system operation; they should be located on a reasonably flat area (on the underside of an aircraft), and there should be no projections extending into a 140° cone about the center of either antenna. The main criterion is to select locations that will provide at least 85 dB of isolation between the antennas. For this to occur there must be a separation of 24-30 in. (61-76 cm), center to center spacing (Honeywell 1975). An interference blanker can be used for those installations that do not obtain the desired antenna isolation. A specially designed housing unit (Fig. 5) was built at NFRC that provides a separation of 30 in. (76 cm).

GENERAL CHARACTERISTICS OF THE SYSTEM

The altimeter system has high altitude resolution (sensitive to 0.5 ft [0.15 m]) and is a short-pulse system that automatically will

define the vertical altitude above ground. Leading-edge tracking, a unique characteristic of the Honeywell pulse technique, provides actual range indications of the nearest object without averaging (Honeywell 1975). This results in altitudinal information that is free of slant range errors even though aircraft attitude changes (up to $\pm 45^\circ$) may shift the antenna pattern intercept area on the terrain. Over other than flat terrain, the altimeter will indicate the distance to the nearest object within the antenna pattern.

Another feature of the system is complete immunity to the Doppler effect (a change in frequency caused by relative motion between observer and source), which otherwise would affect the altitude being recorded (Honeywell 1975). The altimeter system produces accurate height indications over ice and snow-covered surfaces and can be operated in heavy rain or snow.

The standard range for the AN/APN-194(v) is 5000 ft (1525 m); however, this range can be increased to any desired altitude up to 40 000 ft (12 200 m) by using combinations of longer transmitted radio frequency pulses, higher-gain antennas, and a 1-kW transmitter (Honeywell 1975). For other operational and performance characteristics, refer to the Appendix.

POWER REQUIREMENTS

The altimeter system requires 115 V AC (40 voltamps) at 400 Hz, which can be met if the altimeter is hooked up to an aircraft electrical system that can provide the necessary 28 V DC current. A battery pack consisting of two 20 A·h 12 V DC Globe gel/cell[®] batteries in series is used when connection to the aircraft electrical system is not possible. These are vented, spillproof batteries with a gel-type electrolyte. The power inverter converts the DC voltage into the AC voltage required by the altimeter. A fully charged battery pack will provide 2 or more hours of operation.

¹ Personal communication, 1977, Honeywell Ltd.

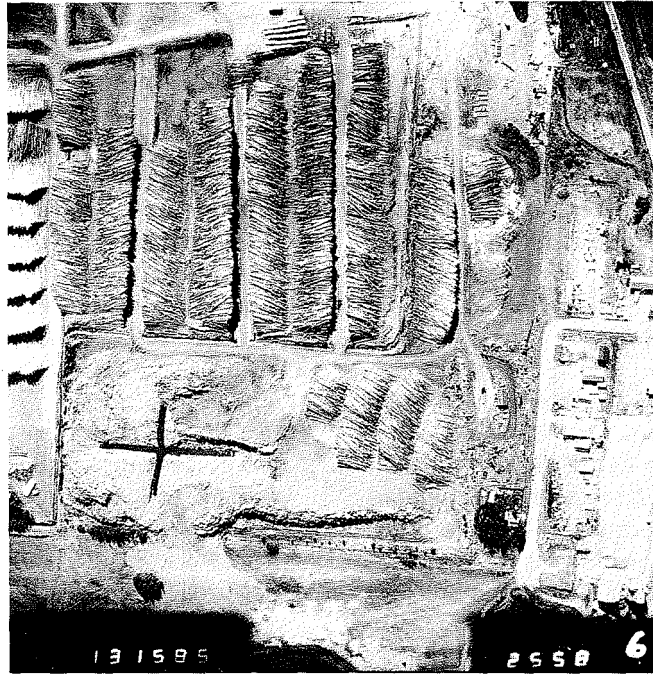


Figure 4. Digital output displayed on an aerial photograph of a mill yard. Lower left corner shows exposure time: 13 min, 15 s, 85/100 s. Lower right corner shows height above ground: 2558 ft (780 m).

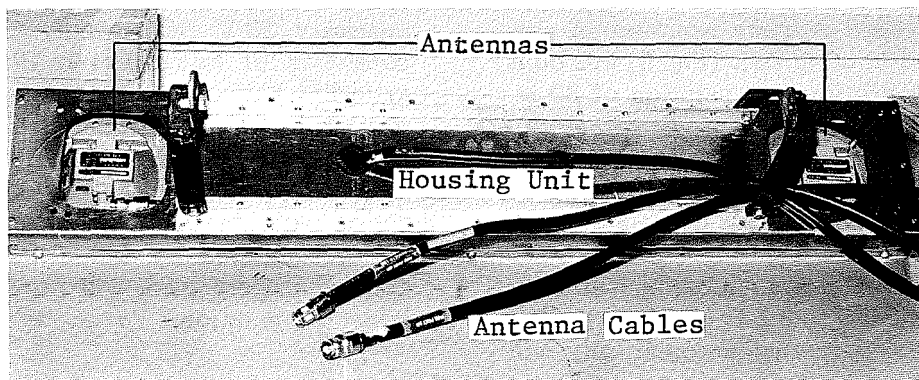


Figure 5. Housing unit for the altimeter antennas.

METHODS

Aerial photographs were obtained at various elevations over five different areas with varying terrain and cover types. The objective in assessment was to verify the radar's indicated height above ground with ground and photo measurements and to indicate whether roughness in terrain, slope, or intervening vegetation (timber bounce) would be major sources of error. The assessment procedure involved calculating sample statistics, performing linear regression analyses, and summarizing observations from the system's use.

Actual flying height for comparison with the radar height (scale check) was determined by selecting two objects that appeared on the aerial photograph, measuring photo and ground distances between the objects, and applying the following formula:

$$H = \frac{GDF}{PD}$$

- H = actual flying height (ft or m)
- F = calibrated focal length of lens (mm)
- GD = ground distance between objects (ft or m)
- PD = photo distance between objects (mm)

The percentage error between indicated radar height and the actual height was calculated as follows:

$$\% \text{ error} = \frac{h-H}{H} 100$$

- h = altitude determined by the altimeter (ft or m)
- H = actual flying height (ft or m)

This procedure was used to evaluate altimeter performance over varying cover types (i.e., bare, timbered, and on sloping ground) and at different altitudes from 150 to 2000 ft (45 to 600 m).

RESULTS

Descriptions and results obtained for the five test areas and measurements taken at these locations are as follows:

Edmonton, Alberta—Northern Forest Research Centre—1977

The first flight after acquiring the altimeter system was in August 1977. The purpose was to determine if the system was functioning properly and to conduct accuracy tests on the resultant photography by performing scale checks. There was easy access for ground measurements because the photos were taken over the NFRC grounds. The measured distances were over flat ground on sidewalks and roads. The results of the scale checks are shown in Table 1.

Whitecourt, Alberta—Judy Creek—1978

Aerial photos were taken over rolling terrain with forest and forest to clear-cut transitions in the Judy Creek area during January 1978. Two altitudes were evaluated, and the results are shown in Table 1.

Hinton, Alberta—1978

Photography obtained in May 1978 of clear-cut areas on flat to sloping terrain (up to 20%) provided the opportunity to test the altimeter's accuracy at different altitudes flown up to 1200 m. As Table 1 shows, the altimeter performed well but with less accuracy at the 1200-m altitude.

Whitehorse, Yukon—1978

A project in August 1978 with the Department of Indian and Northern Affairs (Yukon Lands and Forest Service) to obtain large-scale aerial photographs for forest sampling provided another opportunity to test

Table 1. Summary of scale checks, 1977 and 1978

Height above ground ft (m)	No. of observations	Mean altimeter error % of actual height	Standard deviation (%)
Edmonton¹			
150-350 (45-107)	13	-2.2	±2.1
500-600 (150-180)	3	+0.6	±0.8
Whitecourt¹			
500-600 (150-180)	6	-1.6	±4.1
1700-2000 (500-600)	11	-0.8	±1.5
860 (262)	1	+1.8	
Hinton²			
150-350 (45-107)	22	-0.8	±2.5
500-600 (150-180)	14	+0.2	±2.9
1700-2000 (500-600)	5	+0.5	±1.7
4000 (1200)	4	-8.3	±2.0
Whitehorse¹			
1000-1300 (300-400)	<u>25</u>	-0.5	±2.3
	104		

¹ Power source for the altimeter system: 1 battery pack.

² Power source for the altimeter system and aerial cameras: 1 battery pack.

the radar altimeter. Scale checks were performed over relatively flat terrain on a variety of areas including forested land, cleared land, and the airport runway. Table 1 shows the results.

The height verification data from these four test areas (Edmonton, Whitecourt, Hinton, and Whitehorse) were grouped to determine the altimeter accuracy at various height classes. The mean and standard deviation of the percentage error between the altimeter and actual height values were calculated. For the operational range of 150-2000 ft (45-600 m) the altimeter performs within the manufacturer's accuracy standard of $\pm(3 \text{ ft [1 m] plus } 4\%)$ of the actual altitude (Table 2). The results also show that one can expect lower altimeter accuracies at higher altitudes (i.e., 4000+ ft or 1200+ m).

Simple linear regressions were fitted to indicate how well the altimeter determines

actual altitude above ground. Regressions for the 150-850 ft (45-250 m) and 850-2000 ft (250-600 m) height ranges are shown in Figs. 6 and 7, respectively. Both regressions show high coefficients of determination (r^2) values of 0.996 and 0.994, respectively.

The altitudinal range of 150-850 ft (45-250 m) had a mean altimeter-actual height difference of -2.0 ft (-0.6 m) with a standard error ($s_{y \cdot x}$) of $\pm 11.1 \text{ ft } (\pm 3.4 \text{ m})$ ($\pm 2.3\%$ at mean altitude for the given range). The higher altitudinal range of 850-2000 ft (250-600 m) showed a mean altimeter-actual height difference of -7.2 ft (-2.2 m) and $s_{y \cdot x} \pm 28.2 \text{ ft } (\pm 8.6 \text{ m})$ ($\pm 2.0\%$ at mean altitude for the given range). In terms of tree height determination at the 850-2000 ft (250-600 m) range, therefore, heights should be within $\pm 2\%$ without calibration. For example, for a 65-ft (20-m) tree there would be an error of $\pm 1.3 \text{ ft } (\pm 0.4 \text{ m})$ attributable to the variation in height by the altimeter.

Table 2. Combined results, 1977 and 1978

Height above ground ft (m)	No. of observations	Mean altimeter error % of actual height	Standard deviation (%)
150-350 (45-107)	35	-1.3	±2.5
500-600 (150-180)	23	-0.2	±3.1
800-1300 (250-400)	26	-0.4	±2.3
1700-2000 (500-600)	16	-0.4	±1.6
4000 (1200)	<u>4</u>	-8.3	±2.0
	104		

Film roll examinations of the digital height display showed that occasionally there were misaveraged height values in a string of consecutive frames. The manufacturer indicated that electrical interference from the aircraft appeared to be the cause of the misaveraging and could be corrected by a filtering device. It was also determined that misaveraging occurred more frequently when only one battery pack (instead of two) was used for the cameras and the altimeter (Table 3). It is suggested, therefore, that the altimeter should run off its own battery pack.

Fort Smith, Northwest Territories, and Whitecourt, Alberta—1979

A study was conducted in 1979 to determine if timber bounce was a problem. Height verification data was obtained at Fort Smith and Whitecourt in open and timbered areas. Measurements under timbered stands were taken only at Whitecourt in average stocked stands of lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) that were 80 ft (24 m) high. Open measurements were taken from clear-cuts, an airport runway, and an open timbered area (low crown closure). Photography was obtained in the 850-1300 ft (250-400 m) above ground range. As the results in Table 4 show, there was a difference in the mean altimeter error between open and timbered areas.

A two-sample unpaired *t*-test for the accuracy of height above ground showed that

the open and timbered areas were significantly different at the 95% probability level. These results suggest that timber bounce is a negative factor in altimeter performance.

CONCLUSIONS AND RECOMMENDATIONS

One of the main problems in using large-scale aerial photographs has been the accurate determination of photographic scale. The altimeter system described in this report solves the problem by providing digital flying height-to-ground information that is printed on each aerial photograph. The radar altimeter has been dependable in operating without repair, maintenance, or adjustments in its 3 years of operation. The altimeter system was purchased for \$8,000 in 1977.

Comparing average results for data to 1978 (Table 2) and 1979 (Table 4) for the 850-1300 ft (250-400 m) altitude range, one can see that the mean errors are similar, which indicates that altimeter performance has not changed substantially during its first 3 years.

Accurate measurements were recorded for slopes up to 20%, but steep slopes and densely timbered areas will cause lower altimeter accuracies in height determination. The altimeter is sufficiently accurate in open areas for such mensurational applications as the estimation of forest residues (Kirby and Hall 1979), regeneration stocking, and wood pile volumes in mill yards. Calibration may be

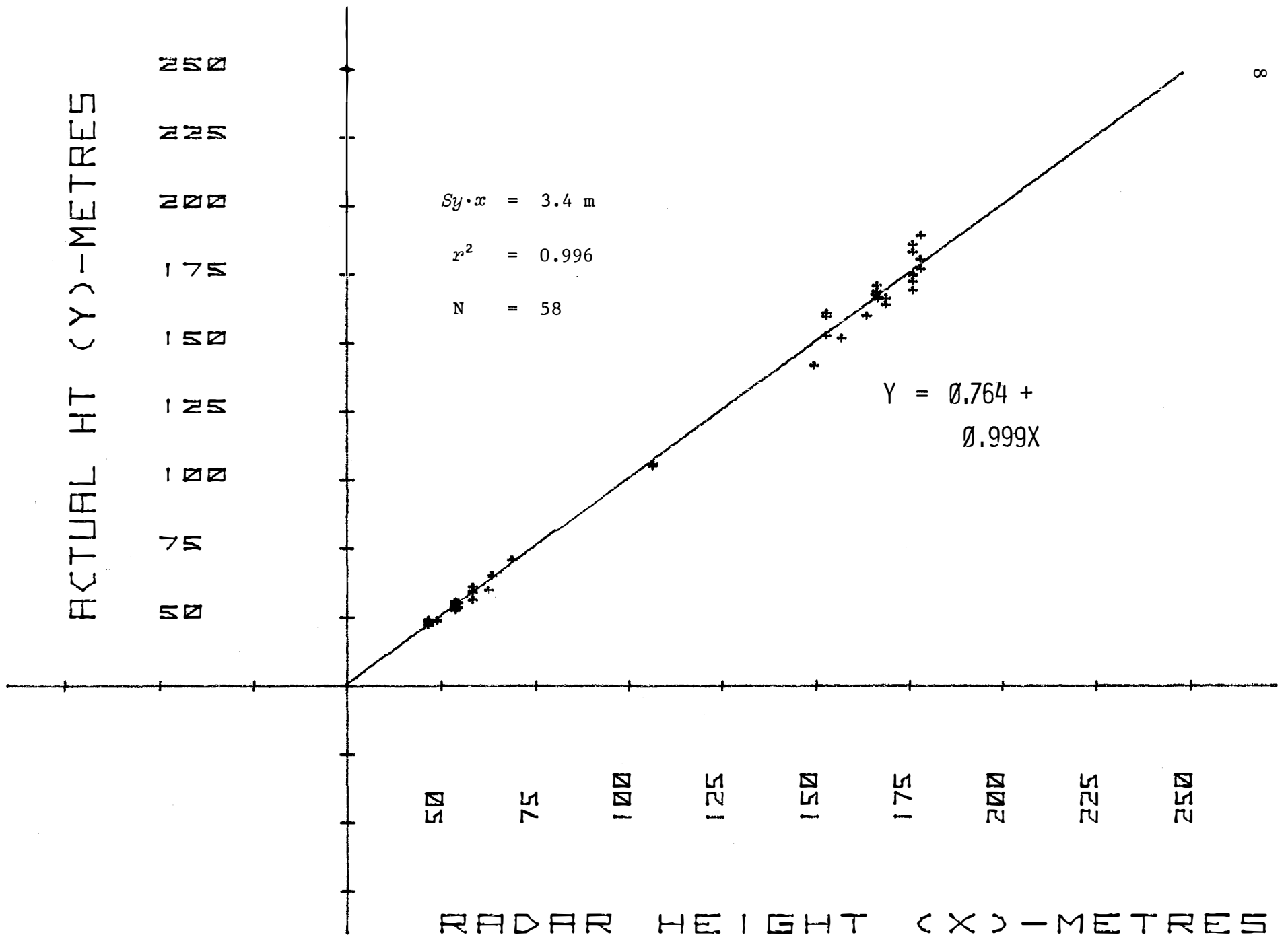


Figure 6. Linear regression of actual height versus altimeter height for altitude above ground range for 150-850 ft (45-250 m).

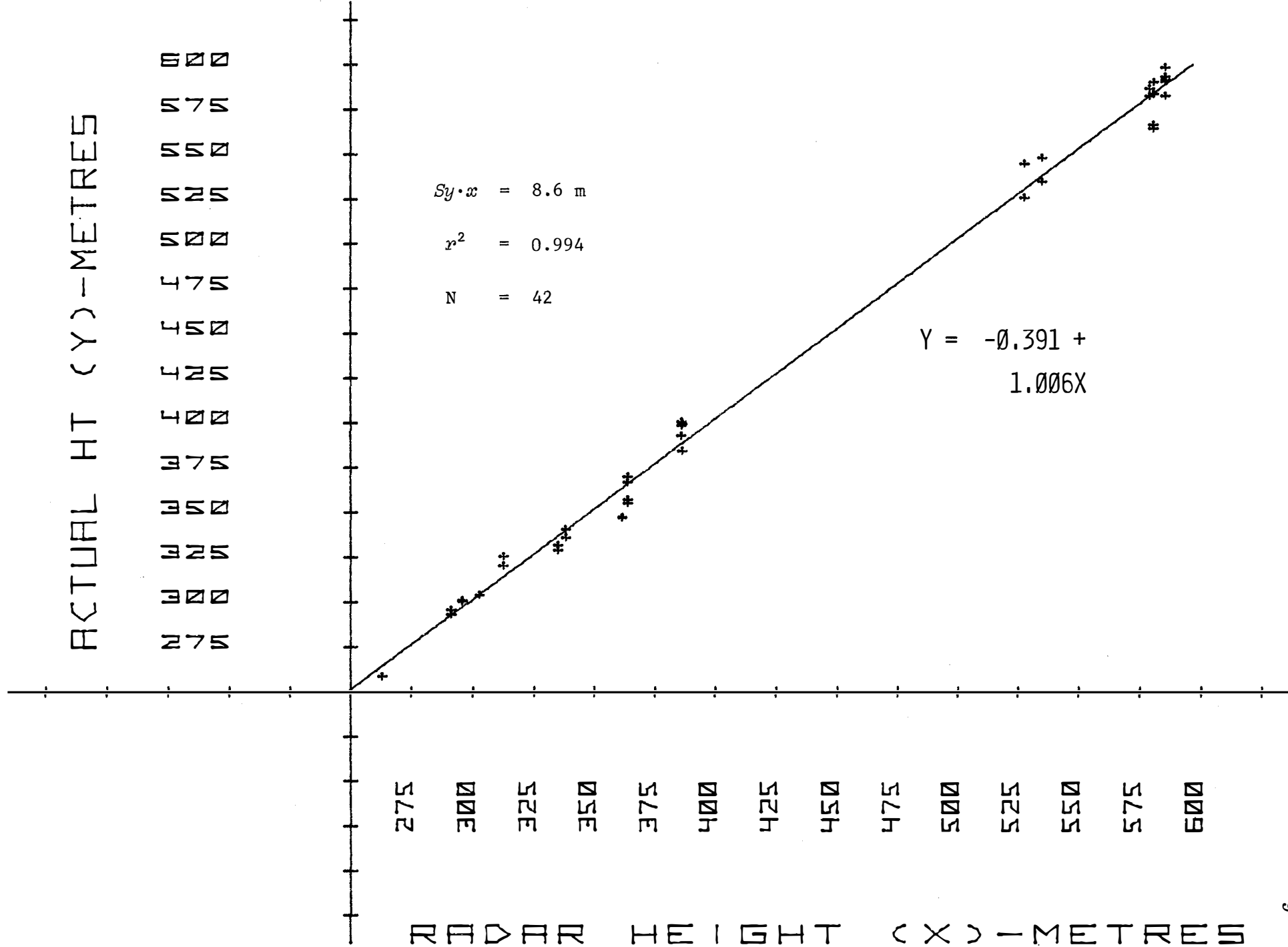


Figure 7. Linear regression of actual height versus altimeter height for altitude above ground range for 850-2000 ft (250-600 m).

Table 3. Misaveraging of height values

Location	% of aerial frames misaveraged		Total no. aerial frames
	1 battery pack to run altimeter and aerial cameras	1 battery pack to run altimeter only	
Edmonton		12.6	440
Whitecourt		10.5	95
Hinton	18.5		581
Whitehorse	—	11.5	1710
\bar{x}	18.5	11.5	

Table 4. Summary of scale checks in 1979

Study area	No. of observations	Mean altimeter error % of actual height	Standard deviation (%)
Open area ¹			
Fort Smith	21	-0.29	±1.33
Whitecourt	33	1.13	±1.52
Timbered area ¹			
Whitecourt	30	-3.59	±2.09
Combined	84	-0.91	±2.68

¹ Power source for the altimeter system: 1 battery pack.

required in open areas with sloping terrain. In forested areas, calibration of the altimeter is recommended for better measurements of tree heights and better estimation of tree diameters and volumes.

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REFERENCES

- Honeywell Ltd. 1975. Pulse radar altimeter systems—AN/APN-194(v). Honeywell Government and Aeronautical Products Division. Minneapolis, Minnesota. 7 pp. (In Canada: Honeywell Ltd., 740 Ellesmere Road, Scarborough, Ont.)

- Kirby, C.L. and R.J. Hall. 1979. The estimation of logging residues using large-scale aerial photographs. Pages 57-62 *in* Proceedings of the International Fire Management Workshop, Edmonton, Alberta. Environ. Can., Can. For. Serv., North. For. Res. Cent. Edmonton, Alberta. Inf. Rep. NOR-X-215.
- Kirby, C.L. and W.D. Johnstone. 1970. Estimation of lodgepole pine diameter, basal area, and stand volume from measurements on large-scale aerial photographs. Can. Dep. Fish. For., Can. For. Serv., For. Res. Lab. Edmonton, Alberta. Inf. Rep. A-X-37. 22 pp.
- Nielsen, U. 1974. Description and performance of the forestry radar altimeter. Can. Dep. Environ., Can. For. Serv., For. Manage. Inst. Ottawa, Ontario. Inf. Rep. FMR-X-59. 17 pp.
- U.S. Department of the Navy, Naval Air Systems Command. 1974. Military specification—altimeter set, electronic AN/APN-194(v). 54 pp.

APPENDIX

OPERATIONAL AND PERFORMANCE CHARACTERISTICS OF THE AN/APN-194(v)

(Source: Honeywell Ltd. 1975)

Operational Characteristics

Operating frequency: 4.3 GHz

Transmitting wavelength: 2.747 in. (6.977 cm)

Pulse repetition rate: 8.5 kHz

Pulse width: $\begin{matrix} 22 + 7 \\ 22 - 2 \end{matrix}$) or 90 ± 30 ns

Radiated power: 100 W peak

Outputs: Range analog: 0 to 5000 ft (0 to 1500 m)

(1) Linear: 0 to 25 V

(2) Two linear segments

0 to 400 ft (0 to 122 m): +1.0 V to +9.0 V

400 to 5000 ft (122 to 1525 m): +9.0 to +21.006 V

Range digital: 0 to 5000 ft (0 to 1525 m) for receiver-transmitter RT-1015/APN-194(v) only

Range analog: 0 to ± 500 ft/s (0 to ± 152 m/s); 0 to ± 5 VPower requirements: 115 V AC, 400 Hz; receiver-transmitter—40 voltamps (VA); and indicator—
5 VA
28 V DC, 40 W

Minimum transmit antenna gain required: 8 dB

Performance Characteristics

Altitude range: 0 to 5000 ft (0 to 1500 m)

Range accuracy (static): $\pm(3$ ft [1 m] + 4% of actual altitude)Rate accuracy: $\pm(5$ ft/s [1.5 m/s] + 6% of actual rate)

Digital range: Serial, 20-bit word, 1 ft Least Significant Bit (LSB)

Track rate capability: ± 2000 ft/s (± 610 m/s)

System sensitivity: 0.80 dBm (1 dBm = 1 mW into 600 ohm load)

Search rate: 15 000 ft/s (4573 m/s) minimum

Maneuverability: Pitch $\pm 45^\circ$
Roll $\pm 45^\circ$

Self-test: Manual with 100-ft readout

Temperature range: -62°C to $+125^{\circ}\text{C}$

Receiver-transmitter reliability (predicted): Approximately 4500 hours mature Mean Time Between Failure (MTBF)

Total operating life (predicted): Approximately 10 000 hours (with reasonable servicing and replacement of parts)

Physical Characteristics

Weight: Receiver-transmitter: 2.0 kg
Indicator (each): 0.7 kg
Antenna (each): 0.3 kg