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EVALUATION OF A SPERRY LIDAR CEILOMETER

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Final Report

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16. Abstract

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The Sperry Lidar Ceilometer is a compact, single-ended height measuring instrument. No special installation tools are needed. Its digital output is compatible with modern data loggers and processors. The lidar uses a Gallium-Arsenide diode array to produce low power 350w energy pulses at the nonvisible 906 nanometer wave length. This, combined with a 10 inch beam diameter, makes the instrument eyesafe. Maximum ranging error against a target placed horizontally from 300 to 4000 ft was found to be 30 ft. Attempts to range vertically against a hovering helicopter were fruitless. The narrow lidar beam could not be aimed precisely enough to "hit" the helicopter and the RBC was excessively sensitive to helicopter-induced vibration as well as to light modulated by the rotor blades so that no RBC "hits" could be recognized.

Comparison of lidar and 800 ft baseline RBC cloud height measurements produced fairly sharp, clearcut results. The lidar ceilometer tracks the RBC very well. As RBC height changed 300 ft, the lidar changed about 200 ft. The relationship of RBC to lidar height is nearly linear, even using a power equation. Correlation coefficients are very high and the standard error about the regression curves fairly small. Our conclusion is that the RBC tends toward greater cloud height, and/or the lidar tends toward lower cloud height. From our experience, RBC bias could account for about one-third of the RBC-lidar measurement difference.

Access to desiccant fuses and electronics should be improved. An autotype windshield wiper removes water from the lidar cover glass; a more durable method is required. Increasing observation frequency to two per minute would provide more information for aviation uses. Securing the ceilometer above ground level should also be considered. Greater protection of internal circuitry from transient electrical fluctuations is needed.

The Sperry Lidar Ceilometer is a tremendous improvement over the RBC in terms of installation, maintenance, and operation. The lidar shows great promise as a replacement for the Rotating Beam Ceilometer.

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EVALUATION OF A SPERRY LIDAR CEILOMETER

ABSTRACT

We conducted an evaluation of a Sperry Lidar Ceilometer during 1973 at the Sterling Research and Development Center. When possible, evaluations were made relative to the Rotating Beam Ceilometer (RBC).

The Sperry Lidar Ceilometer is a compact, single-ended cloud height measuring instrument. No special installation tools are needed. Its digital output is compatible with modern data loggers and processors. The lidar uses a Gallium-Arsenide diode array to produce low power 350w energy pulses at the nonvisible 906 nanometer wave length. This, combined with a 10 inch beam diameter, makes the instrument eyesafe. Maximum ranging error against a target placed horizontally from 300 to 4000 ft was found to be 30 ft. Attempts to range vertically against a hovering helicopter were fruitless. The narrow lidar beam could not be aimed precisely enough to "hit" the helicopter and the RBC was excessively sensitive to helicopter-induced vibration as well as to light modulated by the rotor blades so that no RBC "hits" could be recognized.

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The Sperry Lidar Ceilometer is a tremendous improvement over the RBC in terms of installation, maintenance, and operation. The lidar shows great promise as a replacement for the Rotating Beam Ceilometer.

1. BACKGROUND

The Federal Aviation Administration (FAA) requested an evaluation of a Sperry Lidar Ceilometer as a possible replacement for the Rotating Beam Ceilometer (RBC). This evaluation was performed pursuant to FAA Engineering Requirement FAA-ER-450-006.

A lidar ceilometer was loaned to the FAA by the Sperry Gyroscope Division of Sperry-Rand Corporation, Great Neck, New York. As agreed by the FAA, Sperry, and the National Weather Service (NWS) in an evaluation plan dated 2/7/73, we have evaluated the lidar relative to the RBC to determine cloud height measuring performance, suitability for automated operation, and the ease with which it may be installed, operated, and maintained.

Cloud height measurements were made with the lidar and an 800 ft baseline RBC from May through October 1973, during a variety of meteorological conditions at the NWS Sterling Research and Development Center, Sterling, Virginia. The conditions and the data were representative of those to be expected at mid-latitude observing sites during the non-winter seasons.

2. SPERRY LIDAR DESCRIPTION

The lidar delivered to us for evaluation is a compact, single-ended cloud height measuring instrument. Its compactness is shown in Figure 1, where the lidar source/detector unit is installed next to an RBC detector. This unit weighs about 43 kg (95 lb) and is 53 x 71 x 41 cm (21 x 28 x 16 in). A separate control/display unit (fig. 2) weighting about 5 kg (10 lbs) measures 23 x 30 x 22 cm (9 x 12 x 9 in). The control/display unit, intended for inside operation, has an alphanumeric display to present the measured cloud base height. On-off and frequency of measurement (1 per minute automatic, 1 per 5 minutes automatic, manual) controls are also in this unit.

The laser light source consists of a stack of 17 Gallium-Arsenide (GaAs) diodes in a fiber coupled array. The laser light is collimated, then transmitted vertically through the atmosphere where it is attenuated, scattered, and reflected. When the light encounters a cloud, a great

Figure 1. The Sperry Lidar Ceilometer installed next to the 800-ft. baseline Rotating Beam Ceilometer detector.

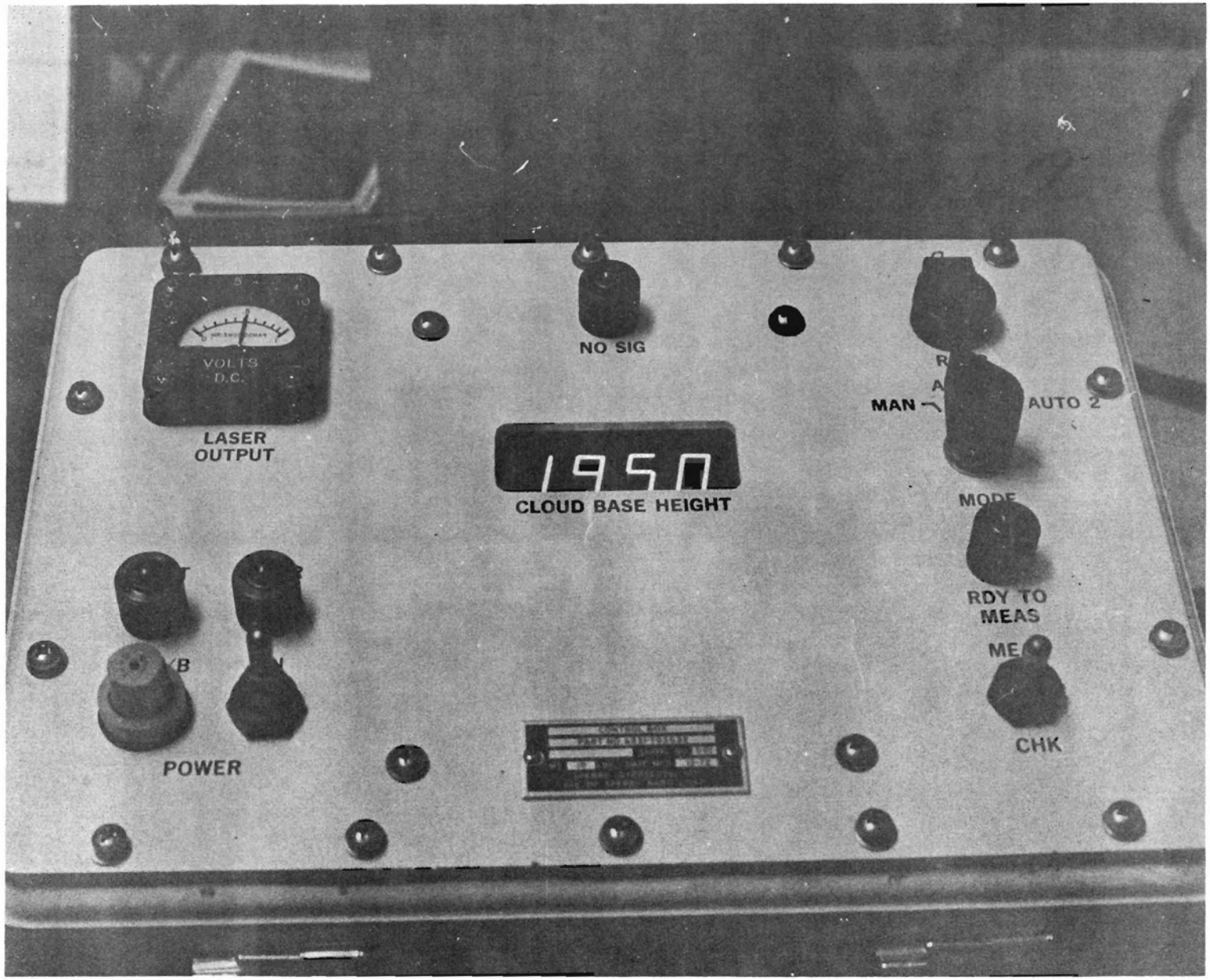


Figure 2. The Sperry lidar display/control unit.

deal more scattering and reflecting takes place, much of it downward into the detector where it is amplified and processed to determine cloud height. Two different fixed gain settings are used by the amplifier, higher gain coming on-line at ranges greater than 2,500 ft.

Both source and detector optics are factory aligned and fixed in position so that field adjustments are unnecessary. Because source and detector are collocated and aimed vertically, leveling is not critical. Height measurement errors due to off-level installation are determined by the function

$$\% \text{ Error} = \frac{1 - \cos \theta L}{\cos \theta L}$$

where θL is the angle off level. A 10 degree angle off level results in a 1.5 percent measurement error.

The GaAs laser source is eye safe. Energy from the 906 nanometer light is readily absorbed by the equeous solution on the eye so that harmful energy does not reach the retina. Corneal damage does not occur because of the combined effects of low peak power (300 to 350 w. Maximum) and low average power contained in the 80 nanosecond energy pulses, as well as a large transmitter beam diameter (25 cm , 10 in).

The actual cloud height measurement takes place over 9.8 seconds while the source is producing light pulses. An electrically gated range bin scans from 100 to 5,000 feet in 10-foot increments, looking for cloud reflected and/or back-scattered laser light. About 200 pulses are integrated by the bin in each increment. This integration greatly improves signal/noise so that a preset threshold may be used to trigger the BCD height display. The ceilometer we evaluated displayed only the first cloud layer height which exceeded the threshold. Provision is made, however, for an A-trace recorder or scope if the complete 9.8 second measurement is to be studied.

The control/display unit also incorporates a self-checking function which operates while the lidar is measuring. The source, electronics and display are checked to verify that the lidar is operating properly. The BCD display should read about 2,000 ft to verify proper operation.

A remote-controlled windshield wiper keeps the source/detector cover glasses free of standing water--a necessity as the 906 nanometer light is absorbed by water. A pair of thermostatically controlled IR heaters inhibit frozen precipitation from accumulating on the cover glasses.

Manufacturer specifications of the lidar are listed in Table 1.

TABLE 1

SPERRY LIDAR CEILOMETER TECHNICAL DATA

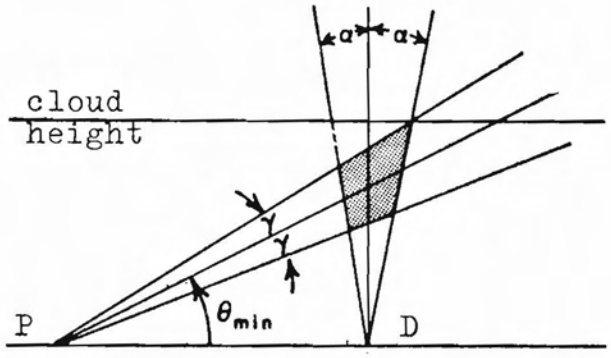
Measuring Range		30 - 1520 m (100 - 5,000 feet)
Measuring Frequency	Automatic	1 per minute or 1 per 5 minutes
	Manual	
Optics		Dall/Kirkham f2.0 1 mrad. divergence 25 cm diameter (10 in)
Laser Source	Material	GaAs Fiber-coupled array
	Wavelength	906 nm ± 10 nm
	Power	300 - 350 watts peak
Environment	Performance	-30°C to +50°C (-22°F to +122°C)
	Storage	-40°C to +60°C (-40°F to +140°F)
Maintenance	Weekly	Clean cover glass
	As needed	Change desiccant
Weight	Transceiver	43 kg (95 lb)
	Control/Display	5 kg (10 lb)
Dimensions	Transceiver	53 x 71 x 41 cm (21 x 28 x 16 in)
	Control/Display	23 x 30 x 23 cm (9 x 12 x 9 in)

3. MEASUREMENT PRINCIPLES

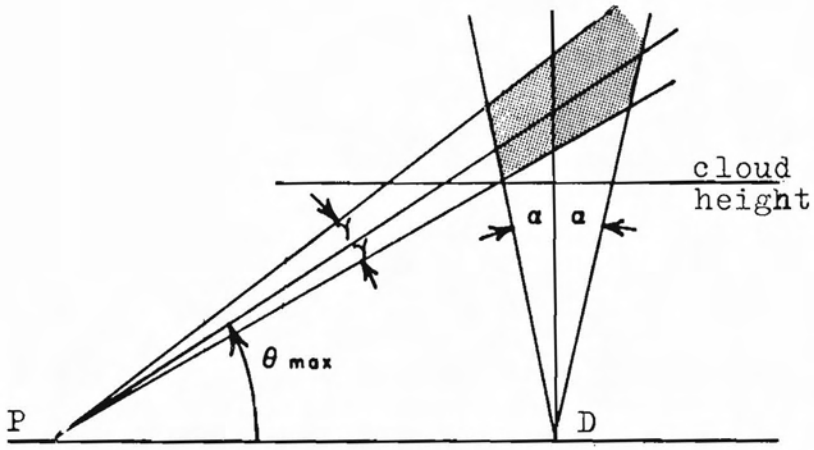
Figure 3 a diagrams the geometry involved in determining the onset of RBC cloud height returns. This lowest detectable elevation angle, θ min , occurs where the upward rotating projector cone (P) intersects with the far edge of the fixed vertical detector cone (D) and the cloud base. Figure 3 b diagrams geometry when maximum cloud return exists. The maximum return occurs when both the projector and the detector cones intersect just above the cloud base, at the elevation angle θ max. This is the traditional, intuitive explanation of how the RBC measures. No account is made of reflected-light attenuation nor secondary scattering. It is possible that in the real world, where such effects occur, the maximum cloud return is at some elevation angle other than θ max. Idealized geometry of figure 3 produces cloud return signals as in figure 4. For simplicity, only one-half of the sinusoidal RBC envelope is drawn.

Figure 5 presents Sperry lidar geometry. Both projector (P) and detector (D) cones are fixed in position to intersect a short distance above the ground. Pulsed light from the projector is scattered downward from within the cone intersection, is received by the detector, and is amplified. Two hundred pulses of 80 nanoseconds duration each are integrated to produce the cloud return form shown in figure 6.a., where amplitude is directly related to the energy received by the detector. Under some conditions, such as when low clouds are present, or the clouds are exceptionally good reflectors, so much energy is received that the lidar amplifier becomes saturated, as in figure 6 b. In these cases, no peak amplitude or signal return is available for cloud height measurement--a condition which also occurs with the RBC. To avoid this problem, a threshold is intuitively selected to indicate cloud height. Returns at or above the selected amplitude are deemed to be cloud returns.

In the absence of any quantified, technical criterion, such as backscatter or extinction coefficients, or optical density, the threshold technique is as rational as is the peak return technique used with the RBC. The peak return technique is, however, more intuitively satisfying. To use this technique with the lidar, amplifier gain must be such that saturation does not occur. This is best accomplished with amplifier gain a function of height rather than with a fixed gain as in the Sperry lidar.

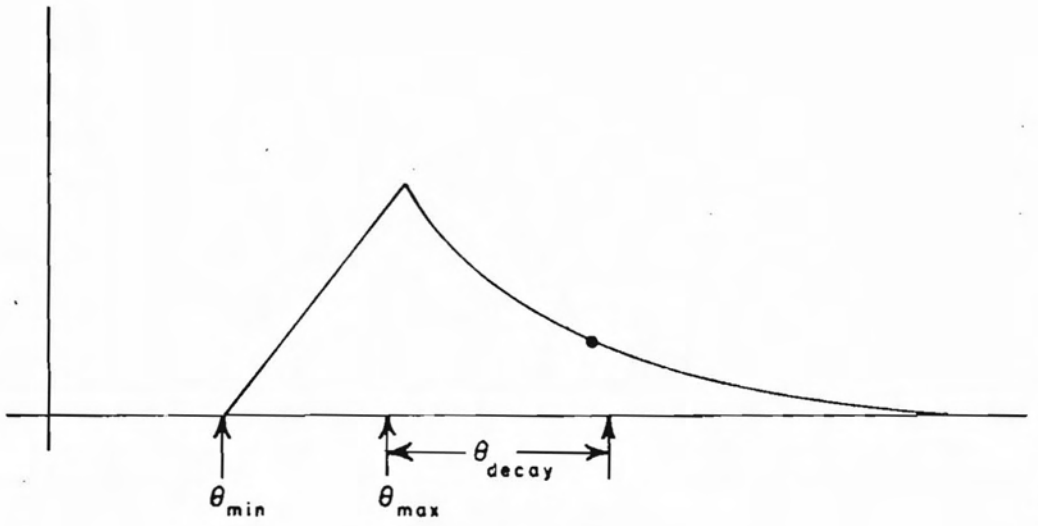


a. GEOMETRY FOR COMPUTING θ_{min}



b. GEOMETRY FOR COMPUTING θ_{max}

Figure 3. Rotating Beam Ceilometer measuring geometry. Detected energy comes from the shaded area.



CEILOMETER RESPONSE CURVE

Figure 4. Rotating Beam Ceilometer idealized response as a function of measuring geometry. Cloud base height is assumed at θ_{max}.

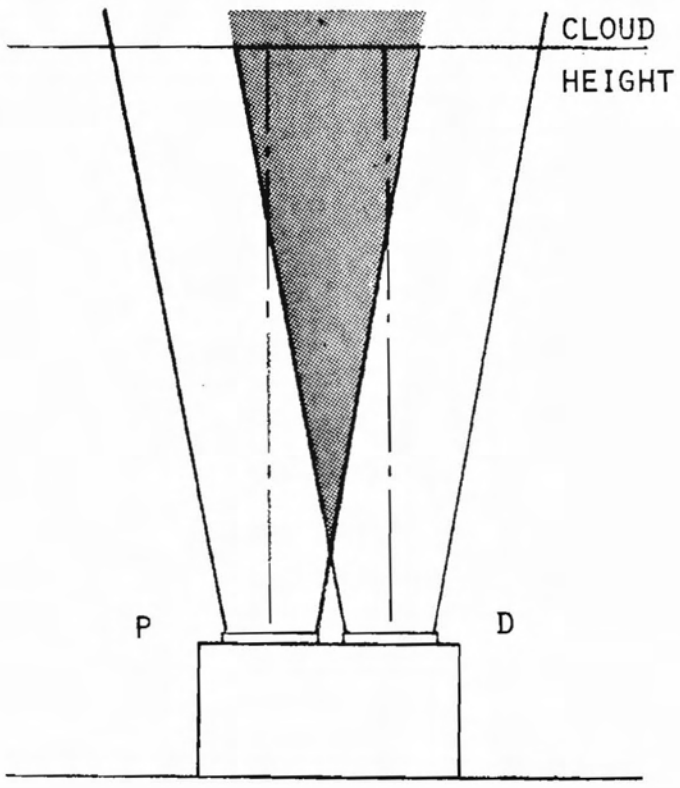


Figure 5. Sperry Lidar Ceilometer measuring geometry. Detected energy is scattered from the shaded area.

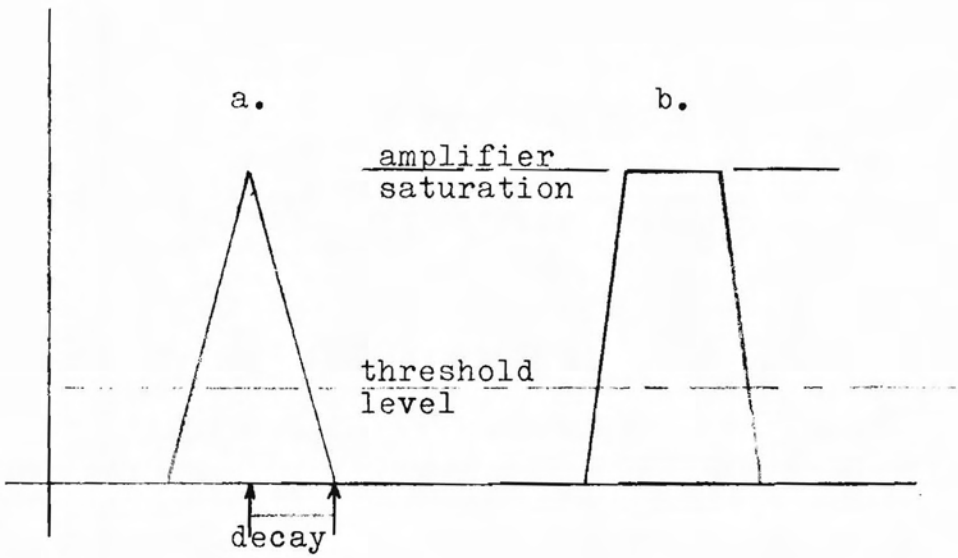


Figure 6. Sperry Lidar Ceilometer idealized response curves. Cloud base height is assumed at the threshold level.

4. BENCH TESTS

Two Sperry engineers delivered the lidar to Sterling on April 16, 1973. The engineers performed electronic and alignment checks to ensure that the ceilometer was working properly. In the process, they discovered that both units required more positive internal grounding connections. They made the appropriate, minor connections and briefed Test and Evaluation Laboratory personnel on the operation, installation, and maintenance of the lidar ceilometer. The Sperry engineers assisted us in setting up the lidar and returned to Great Neck that same day after installation was complete.

We noted no discrepancies with either the physical appearance or the operation of the lidar ceilometer.

5. ACCURACY TESTS

Our first effort was to determine the accuracy of Sperry lidar measured ranges. We placed the lidar on its side, aimed it toward a 4 x 1.5 m (13 x 5 ft) solid target (Figure 7) and ranged against the target at several known distances. The lidar was accurate to -30 ft in all cases. Table 2 presents the fixed target accuracy data as read from the BCD display.

A second accuracy test was conducted after the cloud height data acquisition ended. This second test compared both the RBC and the Sperry lidar against the same solid target--a hovering helicopter. Tests were conducted on October 31, 1973, at the NWS Sterling Research and Development Center with FAA, NWS, and Sperry observers present. As the helicopter hovered above the RBC detector and lidar, observers with theodolites (points B and C, figure 8) determined the true target height. At the same time we analog recorded the RBC and lidar height measurements.

The helicopter, a Fairchild-Hiller FH-1100, was equipped with a hover-site (figure 9) which allowed the pilot to see directly down beneath the aircraft. This device greatly improves the pilot's ability to hover over a target area. The hover-site was not gyro-stabilized,

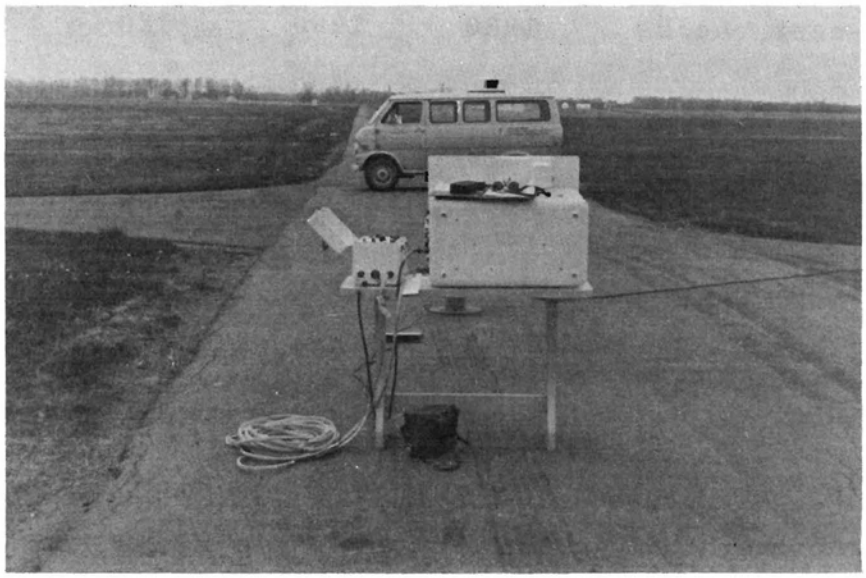


Figure 7. Sperry Lidar Ceilometer and Econoline van target arranged for fixed target accuracy tests.

TABLE 2

SPERRY LIDAR FIXED TARGET RANGING ACCURACY

Measured Distance, Ft	Lidar Ranging Distance, Ft Trial 1	2	3	Measured-Mode, Ft
Pre-test checks	1980	1980	1980	0
260	250	260	260	0
580	560	560	560	20
910	880	880	890	30
1240	1210	1220	1220	20
1580	1550	1550	1550	30
1900	1870	1870	1880	30
2230	2210	2200	2200	30
2560	2530	2530	2530	30
2900	2870	2870	2860	30
3220	3210	3210	3220	10
3550	3520	3520	3520	30
3980	3950	3950	3950	30
Post-test checks	1980	1980	1980	0

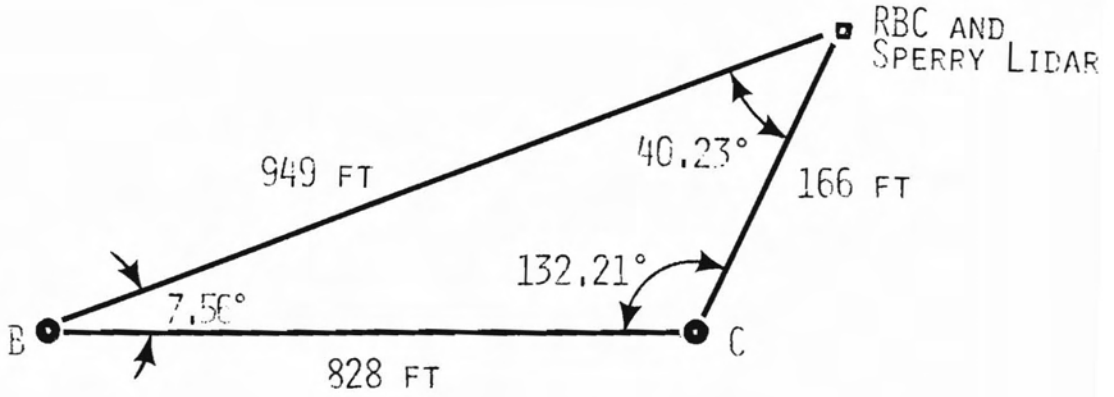


Figure 8. Plan view of the helicopter test site at SR&DC

Figure 9. FH-1100 test target helicopter with hoversite attached to the nose.

however, so that changes in aircraft attitude (pitch or roll) also changed the pilot's surface viewing area. Once off target, the pilot would need other visual guidance to return to the proper location above the ceilometers. For this guidance, we set out on the ground eight 500 ft by 3 ft black vinyl radials at 45 degree angles from the ceilometers. Large, white arrows were painted on the vinyl to indicate target direction. The pilot was quite satisfied with this guidance.

The analog recorder site was radio transceiver-linked to the helicopter and to the two theodolite sites so that simultaneous measurements could be made when the pilot was over the ceilometers.

Only two uncontrolled factors remained to chance. One was weather. Ideal conditions would have been dense 8 - 10 thousand foot overcast skies with steady 10 to 20 knot winds aloft. The test had been postponed one day because of low clouds and gusty winds. October 31 was forecast to be nearly ideal with deteriorating conditions the next day, so we decided to work on the 31st. Cloud cover on the 31st, though not as dense as forecast, did block considerable noise producing sunlight from disturbing the RBC. The winds were a bit less steady than forecast but not gusty enough to cancel the test.

The other uncontrolled factor was ceilometer performance. The RBC produced only noise during the test. The helicopter, while hovering overhead, produced considerable noise in the RBC from rotor downwash. In addition, the rotor itself appeared as a modulated source to the RBC, producing unusual analog patterns as seen in figure 10. The Sperry lidar did not indicate helicopter presence either as a noise source or as a target object. We believe that the narrow (1 mrad.) projector and detector beams could have been slightly off the vertical axis so as to cause the beams to miss the helicopter when overhead. Such a misalignment with the vertical would produce very little ranging error, less than 1/2% at 5 degrees off-axis, but could cause the beam to miss the helicopter.

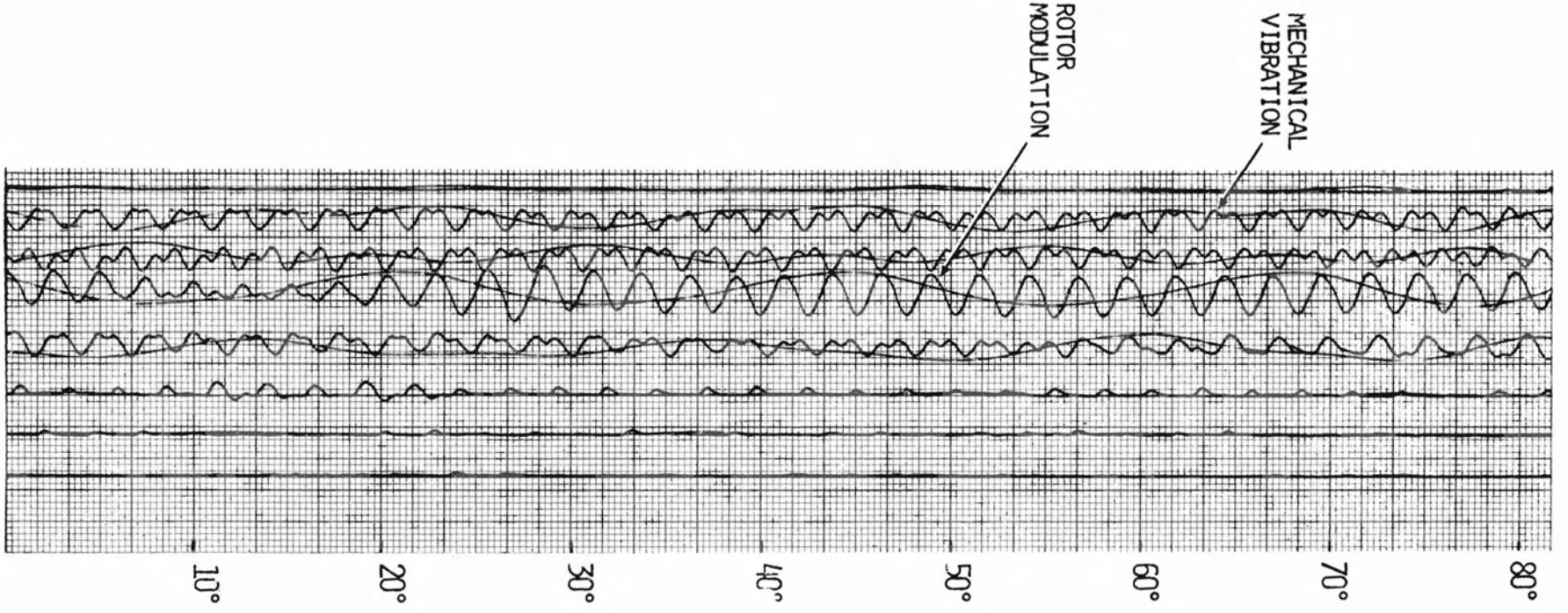


Figure 10. RBC analog record made as the test helicopter passed overhead at 1500 ft above the ceilometer.

We made two trials to test ceilometer ranging. The first trial involved the equipment as described earlier, that is, double theodolites and the pilot using his hover site to position the helicopter above the ceilometers. The helicopter was hovered at 500, 1000, and 1500 feet with identical results--noise on the RBC and no target detected by the lidar.

A second trial was made with the addition of a vertically aligned theodolite next to the RBC detector. The theodolite observer was in radio contact with the helicopter pilot to advise him when the aircraft was overhead. The theodolite and hover-site agreed on the helicopter's position. The helicopter was hovered at 500 ft with noise on the RBC and no ranging indications from the lidar. With this, we concluded the helicopter target test.

We would do a few things differently if we had it to do over. The most annoying problem we encountered during the tests was difficulty in communicating. While the pilot and analog recording site were connected via UHF transceivers on a frequency reserved for research aircraft, the theodolite sites were connected to the recording site via citizen's band transceivers. The background noise from other citizen's band users greatly interfered with test coordination. A better choice, in spite of the cost and preparation time necessary, would have been to rent tranceivers which could operate on a less crowded frequency.

A second change might have been to conduct the tests at night, as was tried by Wanta (1955) at MacArthur Field on Long Island. However, several hours of flying were needed to record just 17 usable RBC observations.

6. CLOUD HEIGHT DATA ANALYSIS AND EVALUATION

6.1 Analysis

We recorded both digital and analog data from the Sperry Lidar Ceilometer, and analog data from the RBC. A recording of both RBC and lidar traces is seen in figure 11. The points of lidar BCD and peak returned energy are identified as is the point of peak RBC returned energy. The lidar

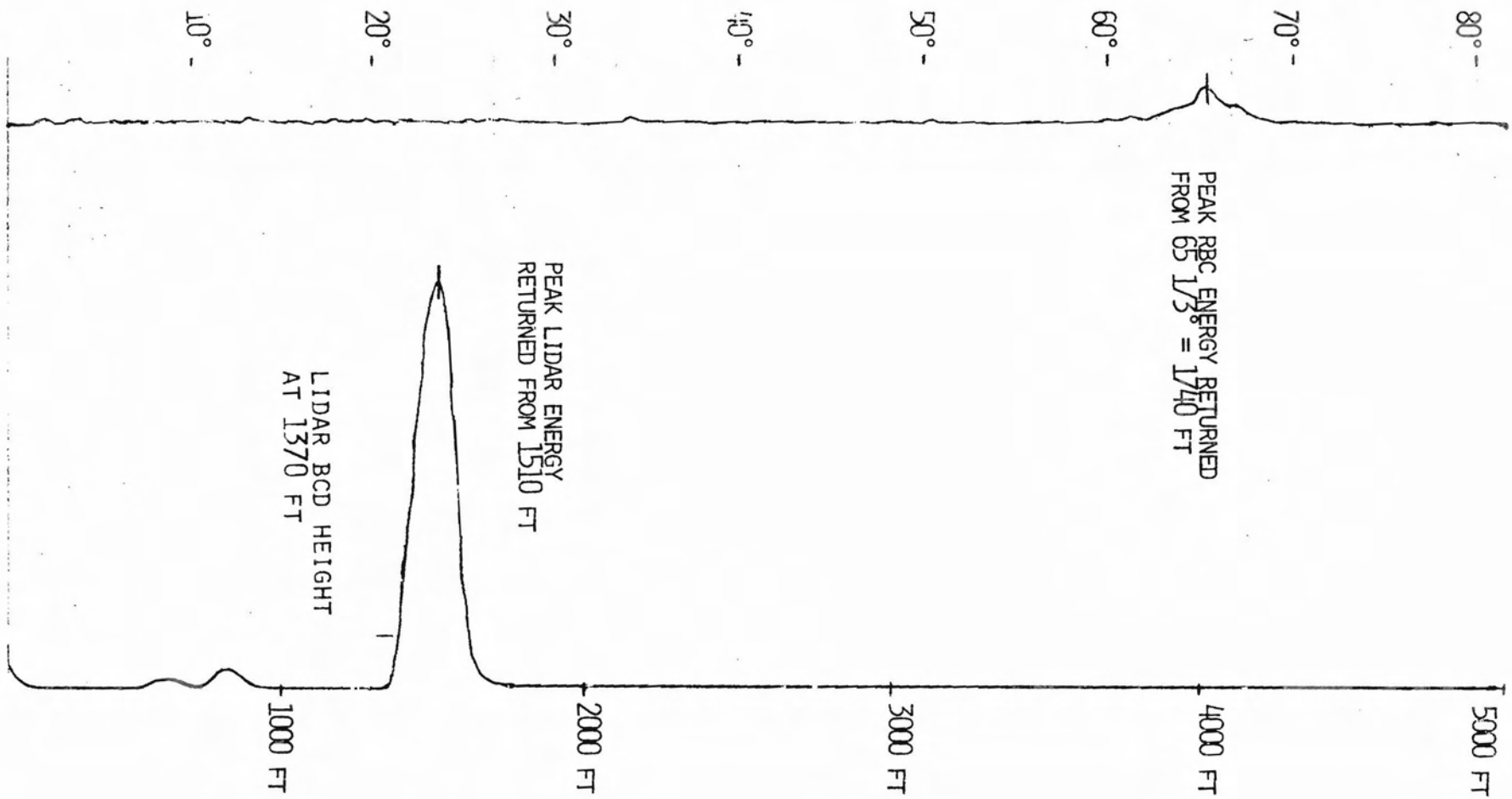


Figure 11. An example of RBC and Sperry Lidar Ceilometer cloud height traces. The RBC scale is linear in degrees of elevation, the lidar scale is linear in feet.

cloud height scale is linear in feet, the RBC in degrees of elevation angle. Note how much easier it is to identify significant points in the lidar trace. Reduction of lidar data is the more simple and direct process.

For analysis purposes, we divided this cloud height data into two sets: lidar BCD output, that is, threshold heights; and peak lidar return heights. In each set, the RBC peak returned energy was considered to correspond to the cloud height. This is an assumption based upon the practical consideration demonstrated in figure 11: the RBC analog trace was more difficult to read as the signal to noise ratio was usually not very great. The energy peak was the most identifiable point on our RBC traces.

The first data set compares the RBC determined cloud height with that output from the lidar BCD indicator (figure 2). Figure 12 is a plot of this data. We were impressed with the narrow spread of lidar heights at any given RBC height. Of some surprise though, is the small sample and relatively wide spread of that data from about 1100 ft to 2100 ft RBC height. Our thought here is that the interval from about 1000 to 2000 ft is a transitional one in which cloud bases are either lifting as a general synoptic pattern departs, or lowers as a pattern approaches. A second process is the lifting of fog into stratus and stratocumulus clouds with the clouds dissipating when they reach between 1000 and 2000 feet. Much of the time then, cloud height would not be long lived in the range of 1000 to 2000 feet.

Following the lead of figure 12, we divided the cloud height into three classes: RBC height less than and equal to 1000 ft , 1000 to 2000 feet, and 2000 to 5000 feet. Correlations, regressions, and standard deviations were computed for these three classes as well as the total data. The two best-fit curves for total RBC and lidar BCD cloud heights are shown in figure 13. Note that the power equation produces a curve nearly identical to the linear curve. Similar results were found when the data was broken into the three classes.

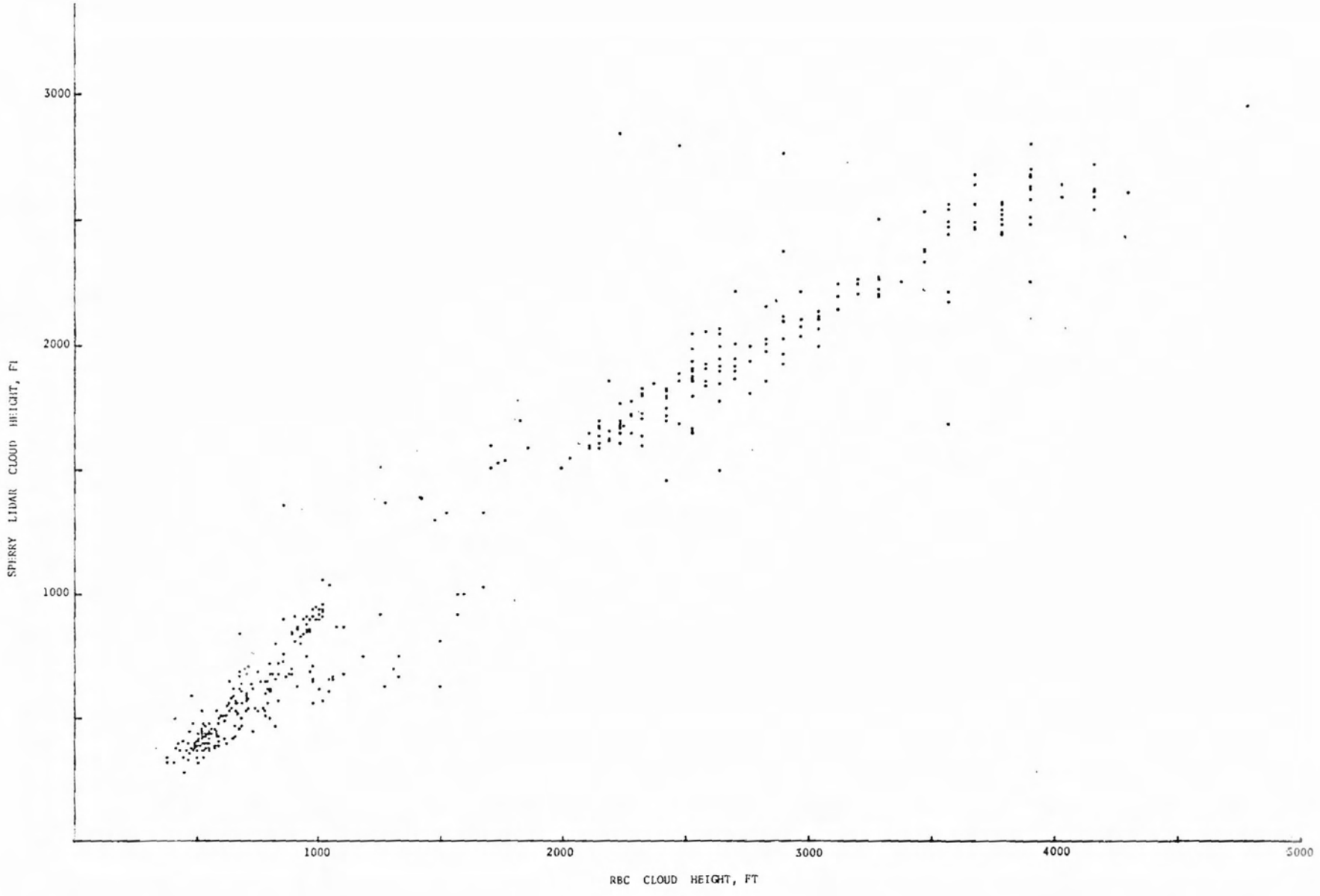


Figure 12. RBC cloud height versus Sperry Lidar BCD cloud height.

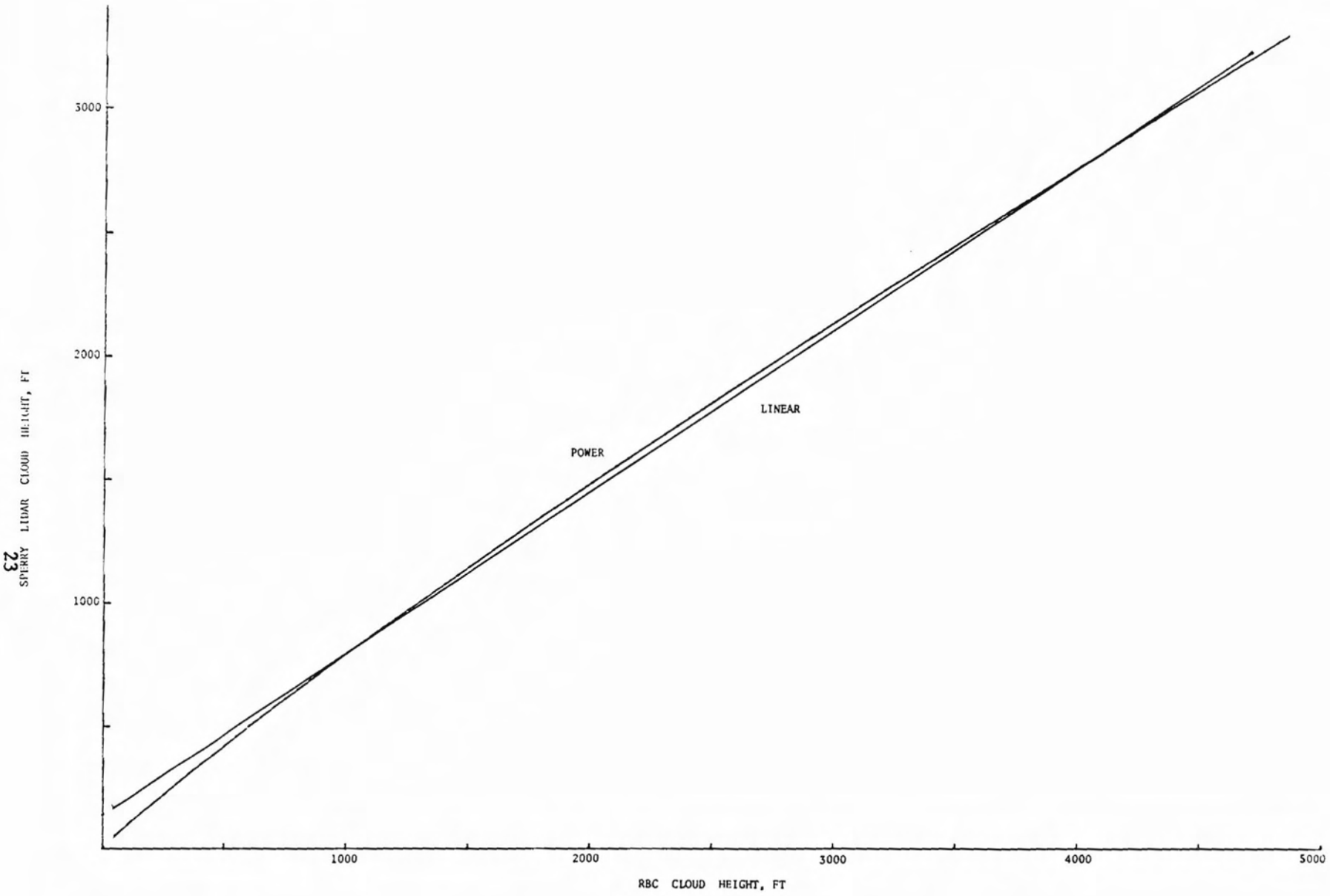


Figure 13. Best-fit regression curves of RBC versus Sperry lidar BCD cloud height

TABLE 3

STATISTICAL SUMMARY I

RBC vs Sperry Lidar BCD Cloud Heights

		Correlations		Standard Errors		Standard Deviations		RBC
	n	Power	Linear	Power	Linear	RBC	Lidar	Range
RBC $\leq$ 1000 ft	160	0.83	0.80	82 ft	88 ft	132 ft	147 ft	474 - 1000 ft
1000 ft $\leq$ RBC $\leq$ 2000 ft	74	0.61	0.69	206 ft	188 ft	272 ft	260 ft	1012 - 1947 ft
2000 ft $\leq$ RBC $\leq$ 5000 ft	183	0.89	0.88	165 ft	168 ft	622 ft	360 ft	2084 - 4868 ft
TOTAL DATA	417	0.98	0.98	154 ft	162 ft	1153 ft	774 ft	474 - 4868 ft

TOTAL DATA REGRESSION EQUATIONS: Power--------Lidar Height = 1.776 (RBC Height)$^{0.888}$

Linear-------Lidar Height = 0.657 (RBC Height) + 174 ft

Table 3 summarizes our computations. Sample size (n), correlations, standard errors about the regression curves, standard deviations about the means and the ranges of RBC heights analyzed are presented. The two best-fit regression equations for total data are shown below the table. These two curves are drawn in figure 13.

In the second set of data for cloud height analysis, the peak amplitude of the lidar returned energy trace was taken as the cloud height. We performed the same analyses as with the BCD data. Figure 14 is a plot of these RBC peak versus lidar peak returned energy cloud heights. This figure is nearly identical to figure 12 except that there are more data in the 1000 to 2000 feet RBC range. As earlier, cloud heights are much more spread out in this range.

Table 4 summarizes computations based upon these data. The statistics in table 4 are approximately the same as those in table 2, indicating that both the lidar BCD and lidar peak returned energy produce the same relationship with RBC determined cloud heights. The regression equations, particularly that for linear analysis, present approximately the same curve slopes (0.657 for BCD data, 0.671 for peak data) but a higher y-intercept (302 ft for peak, 174 for BCD). The regression curves, drawn in figure 15, are very similar to those in figure 13. The figure 15 curves are displaced slightly above those in figure 13 while the slopes remain almost identical, as does the near linearity of the power curve.

6. 2 Evaluation

Statistical analyses of RBC and Sperry Lidar Ceilometer cloud heights produced high correlations and low standard errors (or variations) about lines of regression. High correlations suggest that when the RBC measured cloud height increases (decreases) the lidar height can also be counted on to increase (decrease). That is, the lidar and RBC track one another quite well in a dynamic cloud field. Low standard errors indicate that the difference between RBC and lidar determined cloud height at any one time is likely to be of the same magnitude of performance as is required of human observers by Federal Meteorological Handbook No. 1 (1970), plus or minus 50 feet given that cloud bases are less than 5000 feet.

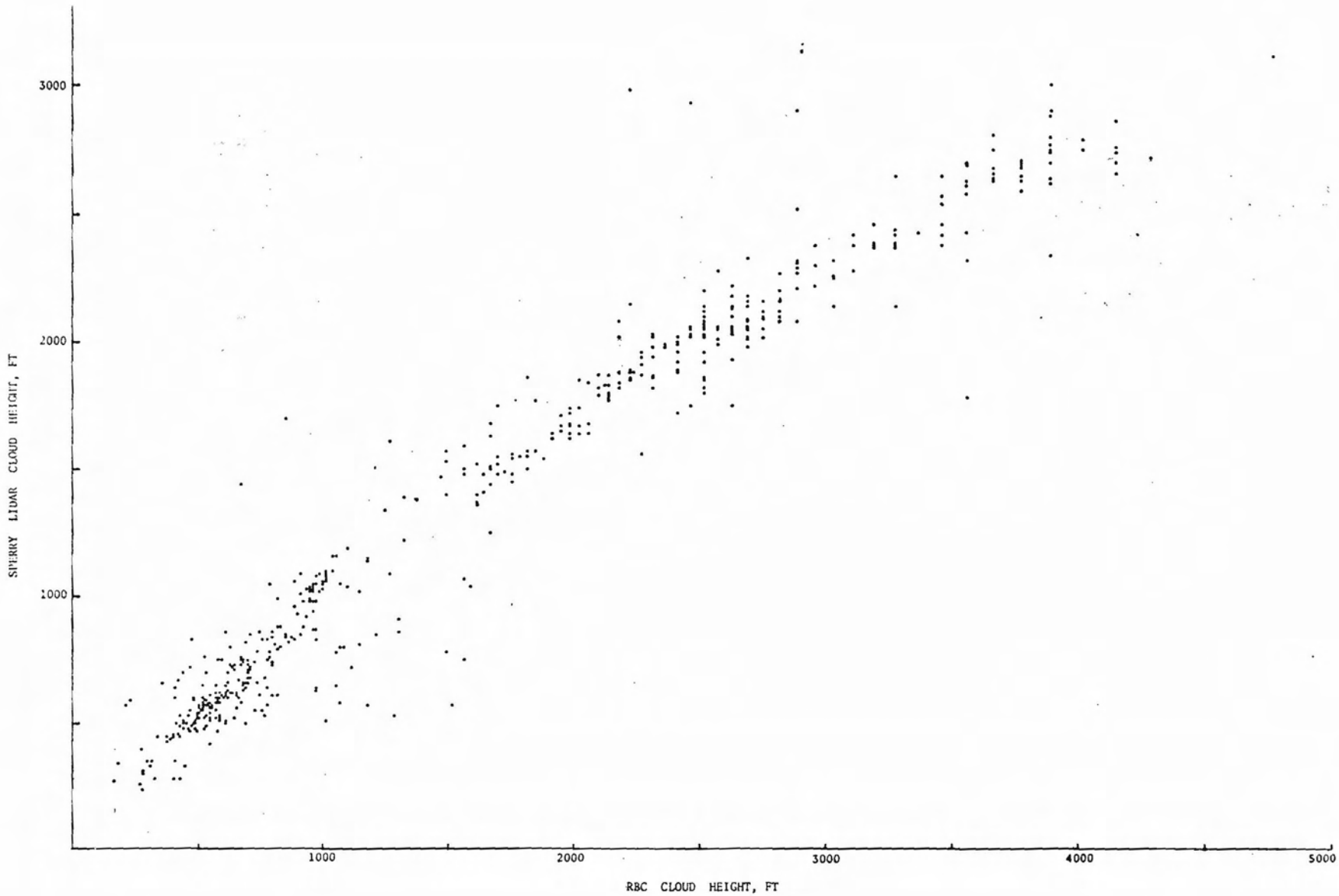


Figure 14. RBC cloud height versus Sperry lidar peak returned energy cloud height.

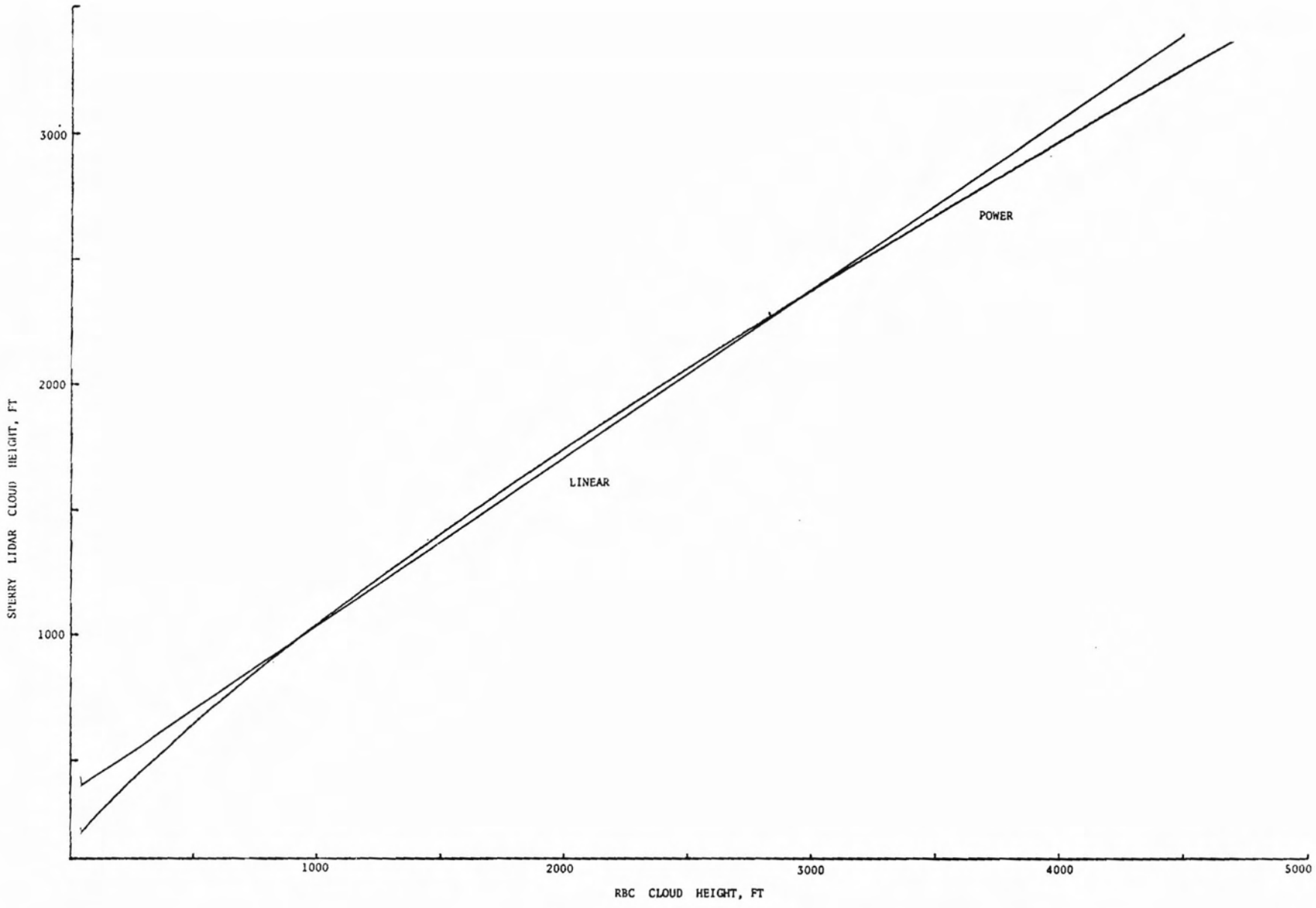


Figure 15. Best-fit regression curves of RBC versus Sperry lidar peak returned energy cloud height.

TABLE 4

STATISTICAL SUMMARY II

RBC vs Sperry Lidar Peak Return Cloud Heights

		Correlations		Standard Errors		Standard Deviations		RBC
	n	Power	Linear	Power	Linear	RBC	Lidar	Range
RBC $\leq$1000 ft	204	0.76	0.72	115 ft	122 ft	131 ft	137 ft	455 - 920 ft
1000 ft $\leq$RBC $\leq$2000 ft	116	0.69	0.76	257 ft	228 ft	343 ft	291 ft	1012 - 1980 ft
2000 ft $\leq$ RBC $\leq$5000 ft	224	0.90	0.90	154 ft	157 ft	621 ft	361 ft	2014 - 4868 ft
TOTAL DATA	544	0.97	0.97	173 ft	164 ft	1104 ft	761 ft	455 - 4868 ft

TOTAL DATA REGRESSION EQUATIONS: Power--------Lidar Height = 4.009 (RBC Height)$^{0.795}$

Linear-------Lidar Height = 0.671 (RBC Height) + 302 ft

The slope of the linear regressions (which are nearly identical with the power regressions) indicate that the RBC/lidar height measurements are not 1:1. Overall, one unit change in RBC height is accompanied by but two-thirds of a unit change in lidar determined height. In other words, one or both of the ceilometers is biased: the lidar tends toward lower cloud heights and/or the RBC tends toward greater cloud heights.

We have no definitive method for determining which of the ceilometers is the more correct. Several factors would be involved in setting the issue. Among the factors which would need investigation is the question of interaction between transmitted energy and reflecting particles having wide diversities of optical characteristics, as well as such mundane matters as detector sensitivity, light intensity versus cloud penetration, and overall instrument accuracy. So far, only ranging devices such as the French Pulsed Light Ceilometer (Staff, 1971) and the Sperry Lidar Ceilometer have been successfully ranged against fixed targets at known distances. Both of these modern ceilometers were found to be quite accurate against solid targets. This of course only suggests similar performance when ranged against clouds.

Based upon our experience, the RBC could have been as much as 1° off in elevation. This would account for up to 700 ft of the RBC--lidar difference at 5000 ft height, leaving another 1000 ft of difference unexplained. It is unlikely that the lidar was overly sensitive to changes in aerosol within the transition zone from clear air to cloud. Lidar performance during haze and fog conditions was good with only slight indications of excess sensitivity recorded on the analog charts. We are therefore unable to satisfactorily account for all of the RBC-lidar cloud height measurement differences.

Other data stratifications, namely rain versus no rain, day versus night, fog versus no fog, and low versus high visibility, failed to yield differences in cloud height performance. The only conditions in which lidar performance differed from that of the RBC was when dense fog was present to the extent that the RBC was unable to measure a definite cloud base height. Under dense fog conditions, the lidar was frequently able to determine cloud height when the RBC could not. We were not able to successfully relate these conditions to visibility or to transmittance. The lidar was never sensitive to solar noise. The RBC was frequently unable to measure cloud height during daytimes when scattered or broken clouds were present.

Two options are available for lidar cloud height determination: (1) select the greatest amplitude lidar return to be the cloud base. This is the method used for RBC cloud height determination. If this is the option taken, lidar amplifier gain should be an inverse function of range, that is, 1/r in order to avoid amplifier saturation; (2) select a convenient threshold value in the range of about 0.5 to 1.0 VDC of lidar return to be the cloud base. This is how it's done in the Sperry Lidar Ceilometer BCD height indicator. Either a fixed amplifier gain or 1/r gain will work with this option.

7. LIDAR CEILOMETER CHARACTERISTICS

7.1 Some pleasing Characteristics

Several characteristics of Sperry Lidar Ceilometer performance are easily evaluated.

(a) Noise rejection. The ceilometer is totally blind to solar noise and mechanical vibration, two persistent sources of noise to the RBC. Figure 10 shows RBC vibration noise.

(b) Digital outputs. The lidar analog output is quite straightforward and unambiguous. The lidar output can be digitized with very little logic. This makes for inexpensive, easy to install remote digital displays. The problem of analog recording, similar to the problems we face with RBC recorders, exists however. We used an X-Y recorder in this evaluation, but available X-Y recorders are fairly expensive and require replaceable pens which last but a few hours. In addition, several operating controls are needed. At present, lidar analog recording is only slightly improved over RBC recording. Tape cassette recording for legal records is a simple matter however.

(c) Installation. The Sperry Lidar Ceilometer is easy to install. Two men can carry the 43 kg (95 lb) transceiver nearly anywhere. A simple bubble level is adequate for leveling the ceilometer. This is in contrast to the

precision levels and hoists needed for setting up the two 700 lb RBC units. In addition, the RBC requires very large concrete pads while a simple wooden pallet anchored to the ground will do for the lidar. This is covered more fully in Section 7.2.

(d) Operation. The lidar ceilometer is also easier to operate than the RBC. The lidar uses only a power on/off and a measure switch, whereas the RBC has two power switches and four associated recorder controls which must be coordinated to produce legible cloud height traces.

(e) Optical mounts. Both source and receiver optics are mounted on a common solid plate. The plate is machined so that optical surfaces, including the source and detector cell, are aligned relative to one another. No adjustments need be made while the lidar is at a field operating site.

(f) Indicator lamps. Indicator lamps showing whether or not power and signal cables are operative at the transceiver are helpful diagnostic devices. In addition to assisting in maintenance, the lamps also encourage user confidence in the operating status of the ceilometer.

(g) Calibration cloud. The Sperry Lidar Ceilometer uses a light pipe to transmit a few time-selected pulses of light directly to the detector cell. The output of the ceilometer is thus a controlled check that the GaAs array is lasing, that the detector is sensitive enough to see the light and that cloud height measuring circuitry is operating properly. This feature was quite successful in building and maintaining our confidence that the lidar was operating properly. This feature is also a helpful diagnostic tool when malfunction is suspected.

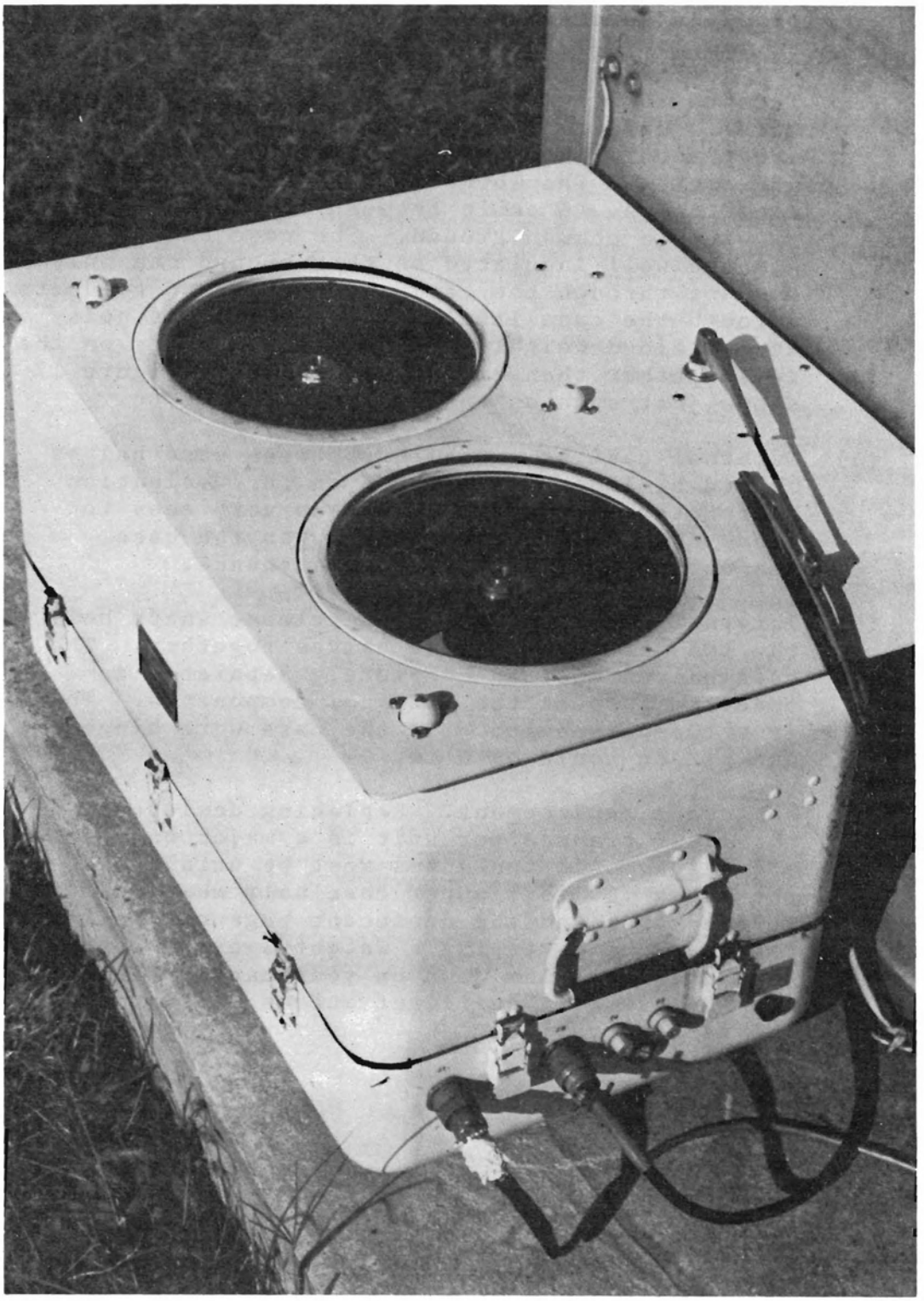
(h) Resolution. The Sperry lidar is able to resolve cloud height information to within about 10 meters (30 ft). This is well within the resolution suggested to have practical usefulness (15 meters, or about 50 ft) by the World Meteorological Organization's Commission for Aeronautical Meteorology (1972).

7.2 Some Areas for Improvement and Advancement

We observed several deficiencies in the lidar ceilometer. Only the first two deficiencies are serious enough to compromise use of the ceilometer at field observing stations.

(a) Cover glass wiper. The lidar cover glass surfaces must be kept water free as water is an excellent attenuator of light at the 906nm GaAs wavelength. The windshield wiper (figure 16) on our ceilometer, simple as it was to construct and operate, was inadequate for continuous operation. The original wiper loosened and ceased to wipe the glass after less than an hour's use. Replacement with a stainless steel drive shaft allowed one to two hours of operation before the wiper blade had to be retightened to the shaft. The windshield wiper is not an acceptable method for cover glass cleaning. Because water must be removed from the glass, a reliable method of removal must be developed if the 906 nm GaAs source is to be used for continuous cloud-height measurements.

(b) Transient protection. On June 21, 1973, the lidar ceilometer suffered considerable damage as the result of a nearby lightning strike. During a thunderstorm, cloud to ground lightning struck an abandoned instrument pad about 1500 feet from the lidar. The resulting transient surged through abandoned underground cabling which passed near buried lidar signal cables. The gradient was strong enough near the lidar cables to induce a catastrophic surge back through the lidar output circuitry. Several



integrated circuits were destroyed. Many were extended beyond their limits and failed during the next 20 hours of operation. Even though such an occurrence is unusual, improved transient protection is needed to insure normal reliability of the ceilometer.

(c) Transceiver case insulation. The transceiver unit is constructed in two half-sections. The upper section holds the laser source, detector and optics. The lower half holds most of the electronics. A cable between the two halves provides a common ground. The case halves must be well-insulated so that ground can only conduct through the cable. When ground conducts through the case itself, lidar output is noisy at low cloud heights and BCD output holds on the noise rather than true cloud height. Figure 17 shows just such an analog trace.

(d) Internal cabling. Cabling between case halves should be longer than those on our evaluation ceilometer. It would have been very easy to break the cables by stretching as the case was opened during routine maintenance.

(e) Internal access. Ten quick-release snaps hold the two transceiver case halves together. The case halves must be completely separated in order to inspect the internal components. This is a two-person job. If the case were hinged, one person could open it.

(f) Desiccant replacement. Replacing desiccant in the lidar transceiver unit is a major one-person operation. All ten snaps must be unfastened, the 27 kg (60 lb) upper case half must be propped open and the desiccant bags carefully replaced while keeping a watchful eye that the case does not slam down on your hand. Hinged case halves or a desiccant access panel would solve this problem.

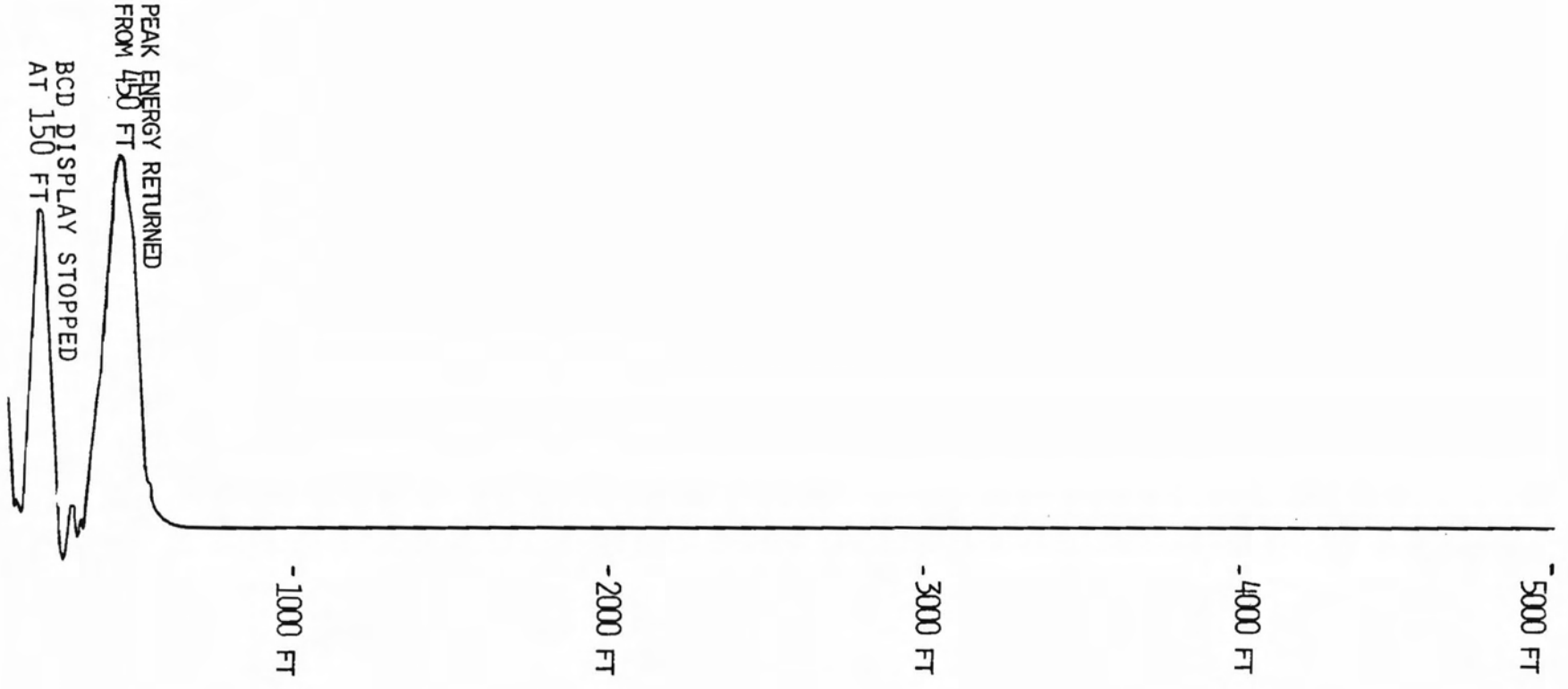


Figure 17. Noise near the bottom of this lidar analog record was the result of poor insulation between the case halves. The BCD output displayed the noise as a cloud base 150 ft above ground.

(g) Fuse replacement. Lidar ceilometer protection fuses are enclosed within the transceiver case. The case must be completely opened to inspect and/or replace the fuses. External access is needed.

(h) Field test set. A field control/test set would be helpful to the technician as he checks out the transceiver. The control/test set should have the same functions and output as the control unit. In addition, a small analog recorder should be included so that ceilometer sensitivity can be evaluated in the field. One technician should be able to perform and check any maintenance on the lidar at the lidar site.

(i) Mounting base. The lidar ceilometer needs an elevated metal base to position the unit a few feet above the ground. A base about three feet high would seem adequate at most installations. This would allow the technician a more comfortable position from which to work on the lidar (than if the unit were placed directly on the ground) and would place the ceilometer above the height of most tall grass which could block the light and most snow accumulations which could completely cover the laser optics. At some remote, unattended locations, a taller mounting base might be needed.

(j) Indicator lamps. Brighter indicator lamps are needed in the control/display unit. The lamps are barely visible in normal room lighting.

(k) Observation Frequency. The World Meteorological Organization's Commission for Aeronautical Meteorology has stated its feeling that observation frequency should be at one per minute (1972). Previous work has shown that cloud height observations made at two per minute provide nearly the same information as observations at ten per minute (Staff, 1971). Based upon the Commission's thought and our investigations, an observation frequency of two per minute seems to be the minimum practical rate. This would be an excellent minimum design goal for future lidar ceilometers.

8. INSTALLATION

The Sperry lidar is very easy to install. It is lightweight so that no hoists or cranes are needed as they are for RBC installation. Precision cloud height measurement is nearly independent of precision leveling; only a simple bubble level is needed. The unit is small so that a large plot of cleared ground is not required.

Both the RBC and lidar require 110 VAC line power. The lidar, like the RBC, needs some form of output signal transmission. The RBC traditionally uses two pairs of #22 buried telephone-type signal cables, although radio telemetry could be used instead. The Sperry lidar also uses buried telephone-type cables, although 10 pairs of #18 to #14 AWG are required. The lidar could use telemetry. We sent the lidar output over about two thousand feet of buried cable with no signal level nor noise problems. Longer cable lengths could have been used.

9. AUTOMATION POTENTIAL

The Sperry Lidar Ceilometer is easily adaptable to automated observations. The GaAs laser source and integrated circuitry should have long-lifetimes and should be able to operate on a six-month maintenance cycle, perhaps even a twelve-month cycle. As noted earlier, improved transient protection and cover glass cleaning is required for operational use.

The lidar digital output is directly compatible with transistor logic level data loggers and processors such as the AMOS III-70.

Signal to noise ratios are very high. Sperry states that about 200 pulses are integrated to form each cloud return signal pattern. Since the cloud return signal is fairly consistent, and noise is assumed to be random, it is unlikely that any noise source would affect lidar cloud height determination.

10. SUMMARY

The Sperry Lidar Ceilometer is much smaller and lighter than the RBC. No special tools or vehicles are required for its installation. Routine maintenance of the lidar consists of cover glass cleaning and desiccant replacement. A calibration feature checks ceilometer performance and unless the calibration analog recording indicates low gain or a noisy signal, no other maintenance need be performed. Regular RBC electronic checks are required to insure the RBC is operating. RBC cloud height measureing performance is not a valid indicator of how well the ceilometer is operating. Lidar ceilometer digital output is directly compatible with transistor logic level data loggers and processors such as the AMOS III-70. The RBC 120 hz analog has not yet been digitized successfully.

Sperry lidar circuitry needs improved electrical transient protection as well as a more effective method for removing water from the projector and detector cover glasses. The add-on windshield wiper is not designed for continuous operation. Improved access to desiccant bags, electronics and fuses are needed to improve serviceability. A test set for field maintenance would also be helpful. The lidar ceilometer should have provision for installation a few feet above ground level so that tall weeds and snow will not interfere with the laser energy. An observation rate increase to two per minute would make the ceilometer more useful for aviation operations.

The lidar ceilometer proved to be quite accurate when ranged horizontally against solid targets at known distances. It was always within 30 ft of the known range. The RBC is not designed to be placed on its side for solid target triangulation measurements.

Lidar measured cloud heights tracked RBC cloud heights very well. The lidar nearly always indicated lower heights than the RBC. As RBC height increased, the RBC minus lidar height deficit increased nearly linearly. A three foot RBC height increase was accompanied by a two foot lidar height increase. Correlations were excellent, better than 0.95, and variations were small, about 170 ft. We have no explanation for this consistent pattern of RBC cloud height over-estimation and/or lidar cloud height under-estimation.

The Sperry Lidar Ceilometer is a tremendous improvement over the RBC in terms of installation, maintenance and operation. The lidar shows great promise as a replacement for the Rotating Beam Ceilometer.

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