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AN EVALUATION OF THE RD-65A AUTOMATIC TRACKING RADIOTHEODOLITE

by

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pattern to trace a circle around the true sonde position), the parabolic receiving antenna is only one metre in diameter as opposed to two metres for the GMD. The weight of the tracking assembly (pedestal) has been considerably reduced from that of the GMD by remoting both the receiver and antenna controls to the main console. The azimuth and elevation units are rotated by synchro motors; however, since no slip rings are employed, azimuth travel is restricted to 270 degrees (a warning buzzer indicates when travel limits are reached). With the system so configured, and with use of solid state components throughout, each system module can readily be handled by two persons.

The receiver employs a straight-forward design, very similar to the GMD, except that there is no provision for automatic frequency control (AFC). The remoteness of the receiver from the antenna necessitates transmission of the 1680 MHz carrier signal over a length of coaxial cable (30 feet) which limits the separation of the two units and results in some signal degradation. The receiver also contains a frequency-to-voltage converter through which the frequency-encoded meteorological information can be displayed on the analog recorder.

The antenna control unit (a separate chassis from the receiver) provides for both manual (hand crank) and automatic tracking modes; the color of the printed angular values (red or black) unambiguously retains a permanent record of the mode in use for any minute of the flight. While the angular displays are purely mechanical analog dials, the antenna control does possess shaft encoders to supply data to the digital printer. Perhaps the most unique feature of the system is an angle-averaging circuit which permits the operator, at his option, to cause the printer to record either the exact minute-by-minute angular values or a one minute averaged value; a code on the print out provides a permanent record of which mode was in use for each minute.

3. System Evaluation

Due to manpower restrictions and to the limited time during which the system was available, we decided to restrict our testing primarily to an evaluation of system accuracy. Furthermore, since many alternative systems already exist for the acquisition of upper air meteorological data, but which have poor or no provision for measuring upper level winds, we were especially interested in the windfinding capability of the RD-65A. To this end, we had available a Beukers Lo-Cate LORAN-C windfinding system which was used as a standard for wind measurements. Although the absolute accuracy of the LORAN-C windfinding system has not been firmly established in the Toronto area, many documented tests conducted in New York State have conclusively demonstrated that the LORAN system is exceptionally accurate being generally better than ± 1 meter per second (mps) for flights taken in daylight hours and within the region of signal ground wave coverage (Toronto lies within this region). This accuracy is probably equal to that of the best windfinding radars available and, in any event, would certainly be as accurate as required for these tests. On all flights therefore, both a standard 1680 MHz and a 403 MHz Lo-Cate sonde were flown from the same balloon train and minute by minute wind values obtained. The Lo-Cate system has a self-contained mini-computer which derives a one-minute average wind for each whole minute from release; the RD-65A data was processed using the USWB time-share computer program for the meteorological data reduction and wind computation of GMD information. This latter program produces a two-minute average wind for each whole minute from release; the averaging interval increases to four minutes above 14 kilometres (km) and the elevation angle is averaged for 3 minutes for angles of 12 degrees or less. Strong wind shears will therefore appear to be more smoothed (or less pronounced) with this program than the results obtained from the LORAN-C system.

Because of the wind-spread use of the GMD-1B as the main source of upper level winds in Canada, and also because of its close similarity to the RD-65A, it is natural to compare these two systems. For this reason, each flight was also tracked with a co-located GMD whose output data were processed by exactly the same program as used for the RD-65A.

The GMD/LORAN-C or RD-65A/LORAN-C comparisons, wind accuracy figures which have averaged over the entire flight are not immediately useful since the error in the computed wind at any particular minute is a function of the elevation angle value as well as the elevation angle error (among other factors); thus, different wind error figures could be obtained for different flights simply due to different elevation angles during the flight (other factors being equal). However, by tracking the same sonde with both the GMD and RD-65A <u>and</u> comparing the accuracies of each against the LORAN-C winds, one can, with a fair degree of confidence, derive the accuracy of the RD-65A relative to the GMD. Further, if the assumption is made that other sources of error are the same for both systems (e.g. height, which is computed from the same data for both systems), one can attribute the difference in wind measurement error to the difference in the elevation angle error (assuming that "limiting angle" conditions have not been approached). If the tracking error in the GMD is known (as it is for our system) the tracking error of the RD-65A elevation angle can be estimated and hence the theoretical wind error for any value of elevation angle may be computed. (An optical theodolite comparison against the RD-65A would, of course, produce the same result.)

Whenever the elevation angle of a tracking radiotheodolite is used as one of the input parameters to compute the upper level winds, it is essential that the "limiting angle" of the system be known. The limiting angle can be defined as the angle above the visible horizon down to which the theodolite can track a target to within its rated accuracy; for angles less than the limiting angle, ground reflections received by the secondary lobes of the antenna pattern cause the elevation angle to deviate from the true value in an erratic and usually unpredictable manner. (The same effect occurs with the azimuth angle when a vertical obstruction is encountered.) For angles equal to or greater than the limiting angle, the radiotheodolite should theoretically track an airborne transmitter to within its rated tracking accuracy. Unfortunately, the limiting angle is not a clearly identifiable value, but rather there is a range (generally about two to five degrees in magnitude) through which the tracking accuracy gradually deteriorates; thus, one can define a lower elevation angle value below which computed wind data will be totally meaningless (this is frequently specified by the manufacturer to be the limiting angle) and an upper value, above which computed wind data will normally be within rated tolerances. Angular data obtained while the theodolite is in between these two limits will result in unpredictable accuracy and winds which may be of little value. One of the objectives of our tests, therefore, was to attempt to define a realistic value for the limiting angle of the RD-65A.

In addition to wind accuracy and limiting angle measurements, two other aspects of the RD-65A were also briefly investigated: (a) the functioning and accuracy of the meteorological data recording circuitry, (b) the general overall suitability of the RD-65A as an operational system, including such items as portability, ease of installation, reliability and maintainability, comprehensiveness of the supplied manual, etc.

4. Evaluation Results

A. Meteorological Data Conversion and Recording System

The ten inch meteorological data chart recorder supplied with the RD-65A was not considered suitable for its intended application. The meteorological data recorder must have a response time of one second or less in order to be compatible with the rate of change of the radiosonde information; the supplied recorder had a rated response time of two seconds and appeared to operate even much slower than that (no actual measurements were taken). This deficiency creates no real problems since there are many suitable alternative recorders available on the commercial market. Of more concern to us was the poor operation exhibited by the frequency-to-voltage converter circuit. It is the function of this circuit to convert the pulse repetition rate of the radiosonde data signal into a dc voltage for display on the previously mentioned analog recorder. The converter circuit failed to meet AES requirements on several points as listed below:

a) A zero output voltage is generated by either setting the receiver INPUT SELECTOR to the zero position or by depressing a button labelled RECORDER ZERO CHECK. Not only did neither of these two methods produce a zero output voltage, they did not even produce the <u>same</u> voltage; in both cases a positive voltage of 0.5% to 1% of full scale voltage resulted.

b) There is no provision to adjust the zero output voltage to correct for the serious offsets noted above. AES requires true zero setability to within ± 0.1% full scale.

c) The zero output voltage continued to drift more than 0.5% over a period of one hour. AES requires a short term (one hour) stability of 0.1% or less.

d) The frequency converter output voltage is overdamped resulting in a marginally acceptable deadband of 0.1%.

e) The Reference Adjust Control (MANUPP, CH. 5) on the receiver is virtually useless. On AES recording equipment this control is a ten-turn potentiometer which adjusts the recorder span over a 20% range; on the RD-65A the Reference Adjust is a single turn potentiometer which adjusts the recorder span over 100% range. The large span and poor resolution exhibited by this control makes it impossible for an operator to accurately adjust the recorder value of the radiosonde reference frequency; without accurate setting, the extracted values of the meteorological data will contain significant errors.

f) No separate input terminal is provided to connect a frequency calibration signal into the frequency-to-voltage converter. Since significant errors in the frequency-to-voltage circuit or in the recorder could exist, it is important in our operations that these errors be measured so that corrections can be applied.

Despite the serious shortcomings of the frequency-to-voltage converter and meteorological data recording system of the RD-65A, this would not pose a problem for AES operations. We have available our own separate converter and recorder system (Leeds and Northrup) which requires only the meteorological data pulse as an input and hence by-passes the entire converter circuitry in question here. Fortunately, the meteorological data pulse is available from a jack on the RD-65A receiver. For the duration of the tests, therefore, a conventional AES frequency converter and recorder were employed to log the meteorological data. The system had sufficient gain to output a usable signal at radiosonde slant ranges of up to 125 km. (This compares to usable ranges of over 200 km for the GMD.)

B. Operational Suitability

Operationally, the RD-65A is quite convenient to use - probably more so than the GMD. Its chief advantage lies in the accessibility of all the controls at the main console rather than being remoted at the pedestal. The penalty one must pay for this convenience is the 30 foot distance limitation between the main console and the remote pedestal; depending upon the application, this may or may not be a problem. The availability of the pulse set control (or SIGNAL GAIN as it is labelled on the RD-65A) proved to be a considerable asset when attempting to adjust the receiver for the best noise-free output signal. Although the lack of any AFC was initially considered to be a serious drawback, no problems were encountered in actual operation. Radiosondes which drifted as much as 4 MHz during a flight required only very infrequent retuning of the receiver.

Targets (i.e. the airborne transmitter) are relatively easy to acquire and the immediate visibility of the recorded angular data is a decided advantage in confirming that the system is operating in the desired mode. The color-coded print out, distinguishing the manual from the auto-track mode of operation, is especially useful during wind computations (calculations cannot be made with data recorded while in the manual mode).

The system can be assembled and installed very quickly and easily but there are two notable drawbacks: (a) there is no apparent method of aligning the pedestal azimuth indicator to the correct bearing other than by physical picking up the entire assembly and rotating it -- a difficult task at best (the remote print out, however, can be set to indicate any value); (b) there is no apparent method of aligning the pedestal azimuth and elevation readings with the remote print out other than by disconnecting the power cable to the pedestal (not an easy task) and then by slewing the console print out to agree with the pedestal values.

The only "operational" problem concerns the supplied manual. This document appears to be a verbatum translation of the Japanese counterpart and, as such, is almost incomprehensible. Because of the exceptionally poor grammatical construction, one can frequently interpret some instructions as the exact opposite of their intent. Even if properly worded, the manual would still be well below AES standards; it is so abbreviated that even the most critical adjustment procedures and maintenance fault-finding analysis have been omitted. As a case in point, the servo feedback amplifiers which control the tracking ability of the antenna must be precisely adjusted otherwise the recorded angular data and hence the computed winds, will be quite meaningless; as received, the elevation servo system was so severely misadjusted that the elevation angle exhibited a dead band of over one degree. Fortunately, the controls (although not labelled) and the required alignment procedure (as determined by an examination of the schematic diagrams) are quite similar to those of the GMD and consequently an experienced GMD operator readily readjusted the RD-65A for optimum operation -- this vital information was not to be found in the manual.

Although no specific tests or studies were conducted, both the maintainability and reliability were judged to be quite good. The all solid state and modular design should result in few failures and minimum down-time. The mechanical portion of the pedestal operated satisfactorily at temperatures as low as -20°C.

C. Windfinding

During the period of these tests the air space over Southern Ontario was almost continuously inhabited by our resident winter jet stream. While these persistent high winds provided us with many opportunities to determine the limiting angle, it soon became apparent that wind-computable flights (i.e. elevation above the limiting angle) were going to be very difficult to obtain. The situation was further aggravated by Air Traffic Control (ATC) regulations which restrict the conditions under which a radiosonde balloon can be launched from our test site. Unfortunately the disappearance of the jet frequently coincided with adverse launch conditions. Nonetheless, by carefully observing the predicted wind patterns, we were able to complete approximately 15 flights which demonstrated the windfinding capabilities and limitations of the RD-65A radiotheodolite.

The flights (or at least the major portion of any particular flight) can be categorized into three rather distinct situations: (a) those flights where the elevation angle decreased from a relatively high value to a point where the computed wind data became totally meaningless. Such flights clearly define a realistic value of the limiting angle; (b) those flights where the elevation angle remained at or just below the limiting angle thereby demonstrating the error involved in using data under these conditions; (c) those flights where the elevation angle clearly remained above the limiting angle and thereby provided data to estimate the wind-finding accuracy of the RD-65A. The records of flights included in this report were selected to best demonstrate the above three conditions. Each graph is a plot of wind speed and elevation angle against time (the flight of March 30 also includes wind direction); GMD winds are plotted on a companion graph. The LORAN-C winds are shown by the solid line while the broken line is the RD-65A or GMD winds. The limiting angle of the GMD is specified as 6^{o} and a labelled vertical line at this value has been included on the GMD wind graphs; from our results the corresponding figure for the RD-65A is 15^{o} and has been so shown on the RD-65A wind plots.

(a) Determination of Limiting Angle

The flights of January 23 and February 18 demonstrate the effect on the accuracy of the winds obtained from the RD-65A when the elevation angle drops to less than 15^{o} above the visible horizon. Below 15^{o} the wind data becomes progressively more erratic until at 12^{o} the winds are almost totally meaningless (this outcome was confirmed simply by observing the elevation angles of the GMD and RD-65A; above 15^{o} the two theodolites displayed almost identical tracking angles while below 15^{o} there was a marked departure of the RD-65A angles from those of the GMD). Based on these observations and on several other flights, we ascertained that the useful limiting angle of the RD-65A is 15^{o}. Notice that on these same two flights the GMD provided good agreement with the LORAN-C winds down to angles of about 7^{o}; at lower angles the winds tend to become somewhat erratic and one should perhaps, reassign a value of 7^{o} as the <u>useful</u> limiting angle of the GMD.

(b) Windfinding Accuracy of the RD-65A

The flights of January 30 and March 30 are good examples of the tracking ability of the RD-65A above the limiting angle. Both the GMD and RD-65A computed winds shown excellent agreement with the LORAN-C derived winds; however, the root mean square (RMS) wind speed error is approximately twice as great for the RD-65A than for the GMD. Knowing that the tracking error for this particular GMD set is 0.04° (RMS) one can then estimate that the RMS tracking error for the RD-65A should be about 0.08° -- a realistic figure in view of the size of the antenna. Unfortunately, favourable winter weather conditions and ATC permission for balloon launch did not combine to permit an optical theodolite comparison which would have provided an additional check on this figure. The second series of graphs for the March 30 sounding demonstrates the errors in the computed wind directions. No RMS calculations were made but a visual inspection indicates that wind direction errors are acceptably small for most applications although they are larger than GMD wind direction errors (as would be expected); the time in the sounding from T = 60 min. to T = 75 min. is a period of "light and variable" winds during which wind direction may have little meaning.

The one minute angle averaging mode did not result in any obvious improvement in the computed wind field either below, at or above the limiting angle. It is conceivable that for angles above 15° other sources of error are significantly larger than that contributed by the elevation angle and hence, any improvement in angular accuracy which can be effected through rapid angle sampling and subsequent averaging would result in large errors regardless of any angle averaging. Although it was not possible to simultaneously obtain both the minute-by-minute and averaged minute angular values for the RD-65A, it is interesting to note that such a comparison was carried out several years ago on GMD data and that the results of that study were essentially the same -- i.e. no obvious improvement in the wind field by using a one minute angular average.

Using any one of several available statistical wind error equations (e.g. WMO, de Jong, 1965) which give Ve = f (h, E, Ee, Ae, dT) where Ve = error in computed wind, h = height, E = elevation angle, Ee = RMS error in elevation angle, Ae = RMS error in azimuth angle, and dT = time averaging interval, one can readily construct a table showing the theoretical wind errors for variations in these parameters. For example, for E = 17° (a reasonably safe value above the limiting angle), Ee = Ae = 0.1°, dT = 2 minutes below 14 km and dT = 4 minutes above 14 km, one would obtain theoretical errors of 3.2 knots at 7 km, 3.9 knots at 17 km (note the effect of using a longer time average at this height) and 5.2 knots at 26 km. Such a flight should produce a net RMS wind error over the total flight of slightly over 4 knots, which is in good agreement with the results actually obtained (4.4 knots and 4.2 knots).

(c) Wind Accuracy Below 15^{o} Elevation

The most questionable outcome of this evaluation is probably the validity of the wind data when the elevation angle is just under 15^{o} (the manufacturer specifies the limiting as 10^{o} using somewhat different terminology). With an elevation angle between 12^{o} and 15^{o} (and occasionally as low as 10^{o}) a crude profile of the true wind field is obtained. Such cases are demonstrated by the flights of February 2 and March 10. During the latter flight, the break-over between accurate tracking and erratic data is quite sharply defined at 15^{o} elevation. However, as long as the elevation remains above 10^{o} some semblance of the true wind field is obtained; averaging the winds over a long time period, say 10 minutes or longer, would probably yield winds which approximate the long period average. Nonetheless, because this angular range (i.e. 10^{o} to 15^{o}) does result in large wind errors (15 knots typical and 60 knots in the extreme), one could not justifiably extend the limiting angle down to 10^{o}.

The flight of February 26 is presented to demonstrate that the RD-65A will not track "through" a vertical obstruction -- a result entirely expected and quite consistent with this type of tracking equipment. In this case the obstruction was a 30 cm wide metal tower placed approximately 4 m in front of the antenna.

5. Summary

This evaluation was primarily undertaken to gain operational experience with the RD-65A and to obtain a rough estimate of its accuracy and limitations. Insufficient data was collected to perform a thorough objective analysis on the windfinding accuracy; an optical theodolite comparison to firmly establish the angular tracking accuracy could not even be attempted during the period of these test. Furthermore the system was not subjected to a full range of environmental conditions ($-20^{o}C$ was the lowest temperature encountered) nor was the system transported from place to place to evaluate its usefulness as a portable instrument. Nonetheless, some general, but rather significant, aspects of the RD-65A did emerge as the results of our tests. These are tabulated below:

a) The frequency-to-voltage converter does not meet AES standards. Replacement of this circuit with a commercially available and inexpensive module would completely solve this problem.

b) The supplied meteorological data recorder should be replaced by a standard 1 or $\frac{1}{2}$ second response recorder.

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c) The limiting angle appears to be 15° above the visible horizon; this figure could perhaps be lowered a few degrees but additional testing would be required for verification.

d) The error in the derived winds is about double that of the GMD; again, additional testing, including extensive comparisons against an optical theodolite would be required to establish a firm figure.

In conclusion then, the RD-65A radiotheodolite may prove to be a very useful tool depending upon the application. If accuracy of the meteorological data is not important (e.g. errors of over $2^{\circ}C$ are acceptable) then the supplied recording system is satisfactory. Wind data although less accurate than the GMD and limited to elevation angles above 15°, may be satisfactory for many applications, especially low-level soundings when the higher elevation angles are most likely to be encountered. The system also has a respectable slant range reception capability of 125 km when tracking a standard 1680 MHz radiosonde; this should permit reception of the meteorological data to above 50 mb under most circumstances. The above described windfinding capabilities of the RD-65A make it almost identical to the Metox or SCR-658, 403 MHz wind tracking system as far as accuracy is concerned; however, the automatic tracking and recording features of the RD-65A offer several obvious advantages.

References

1. de Jong, H. M., 1966: A New Process for the Evaluation of Upper Winds, Journal of Applied Meteorology, 5, 436-449.

2. Environment Canada, Atmospheric Environment Service, 1975: Manual of Upper Air Observations (MANUPP), Toronto.

3. W.M.O. Publication No. 8TP. 3, Guide to Meteorological Instrument & Observing Practices, CH. 12 - Measurement of Upper Wind.

Appendix

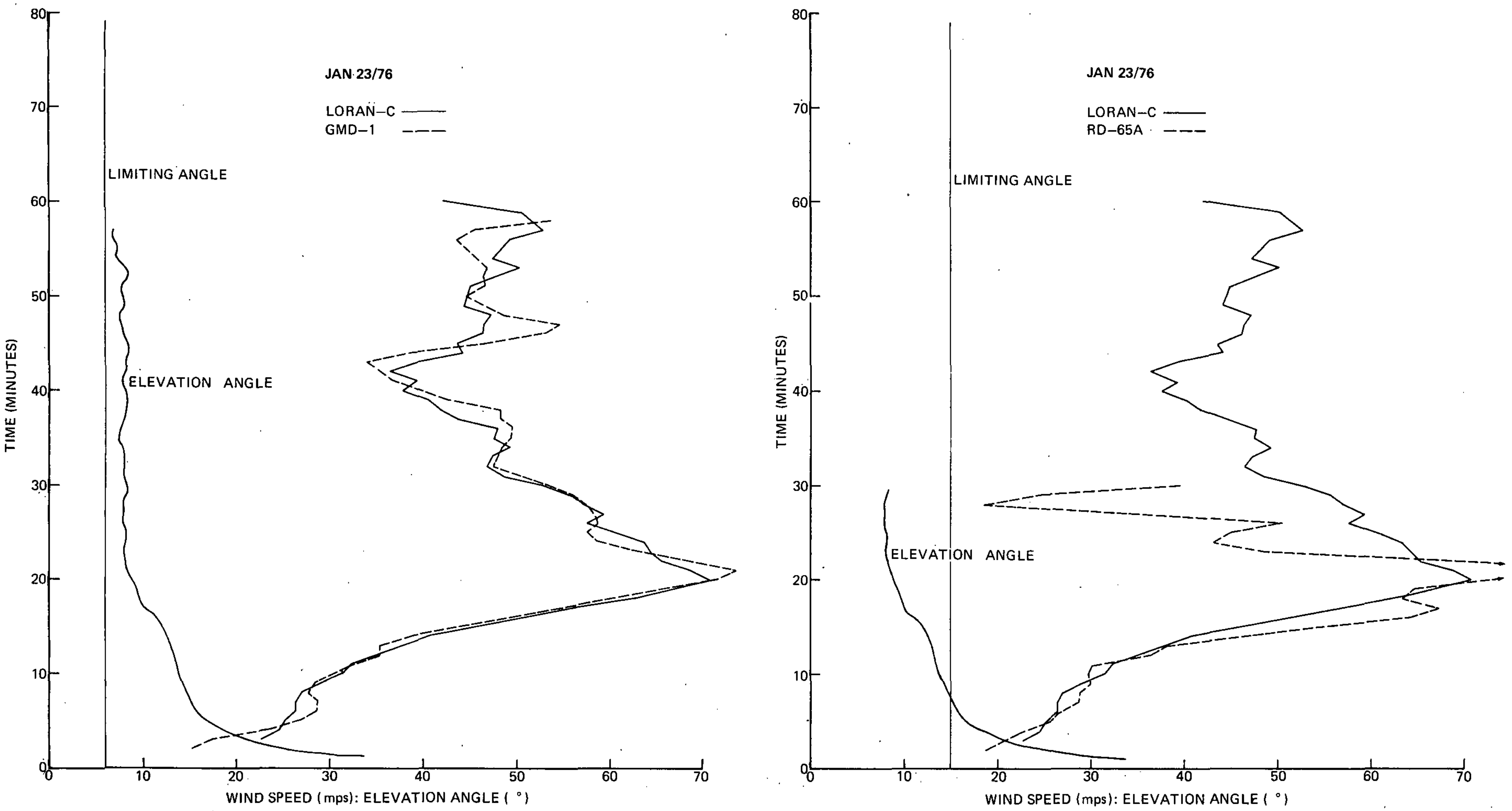
After reviewing a draft manuscript of this report, the United States importer of the RD-65A, Weather Measure Corporation have advised us of the following:

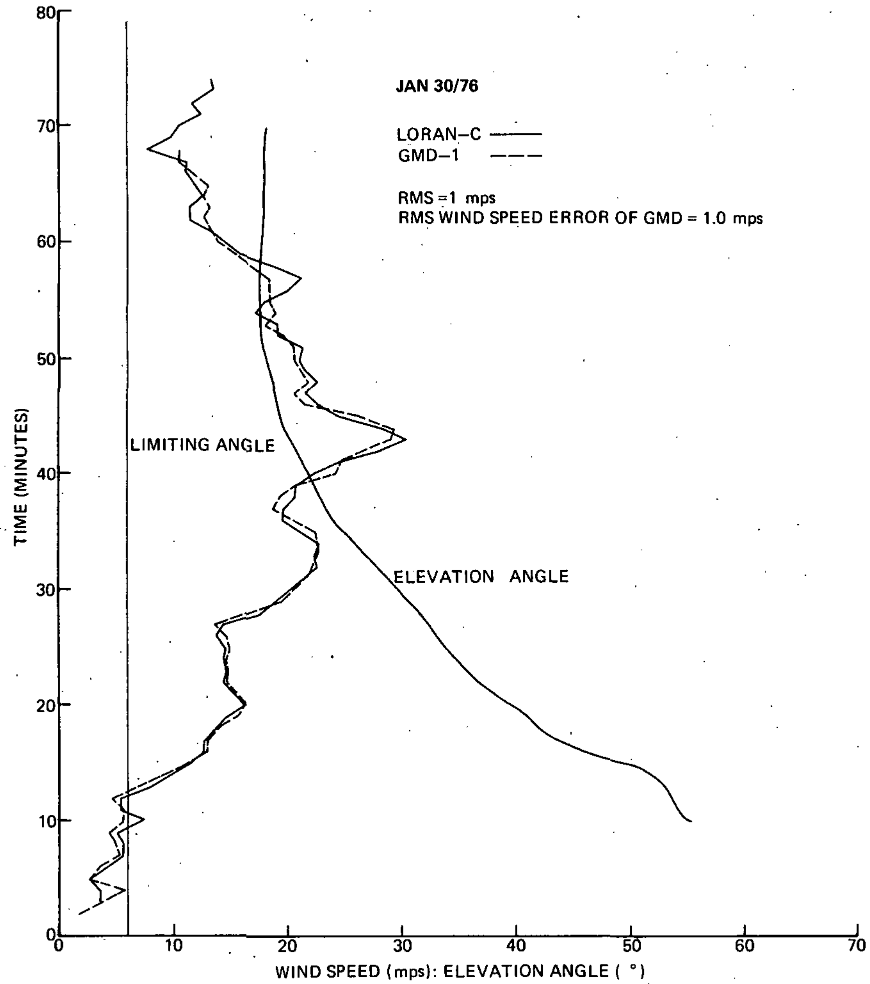
1. A new revised "American" manual is being written.

2. The pedestal can be remoted a considerable distance away from the main console by using an optional antenna preamplifier.

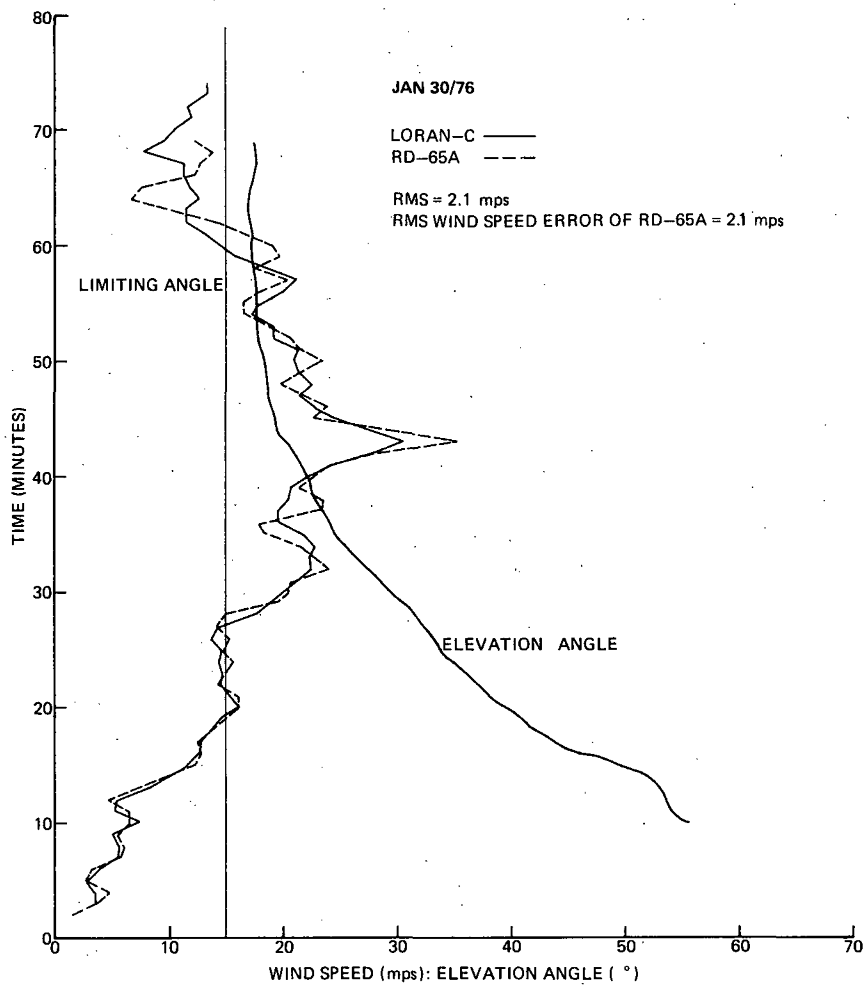
3. It is possible to align the azimuth and elevation angle readout to the pedestal values without removing the inter-connecting cable. The control recorder apparently contains a clutch mechanism which permits disengagement of the receiving synchro from the readout.

4. A newer version of the RD-65A, designated as the RD-65CSA incorporates AFC in the receiver and the pedestal assembly contains slip rings which permit continuous rotation in azimuth.

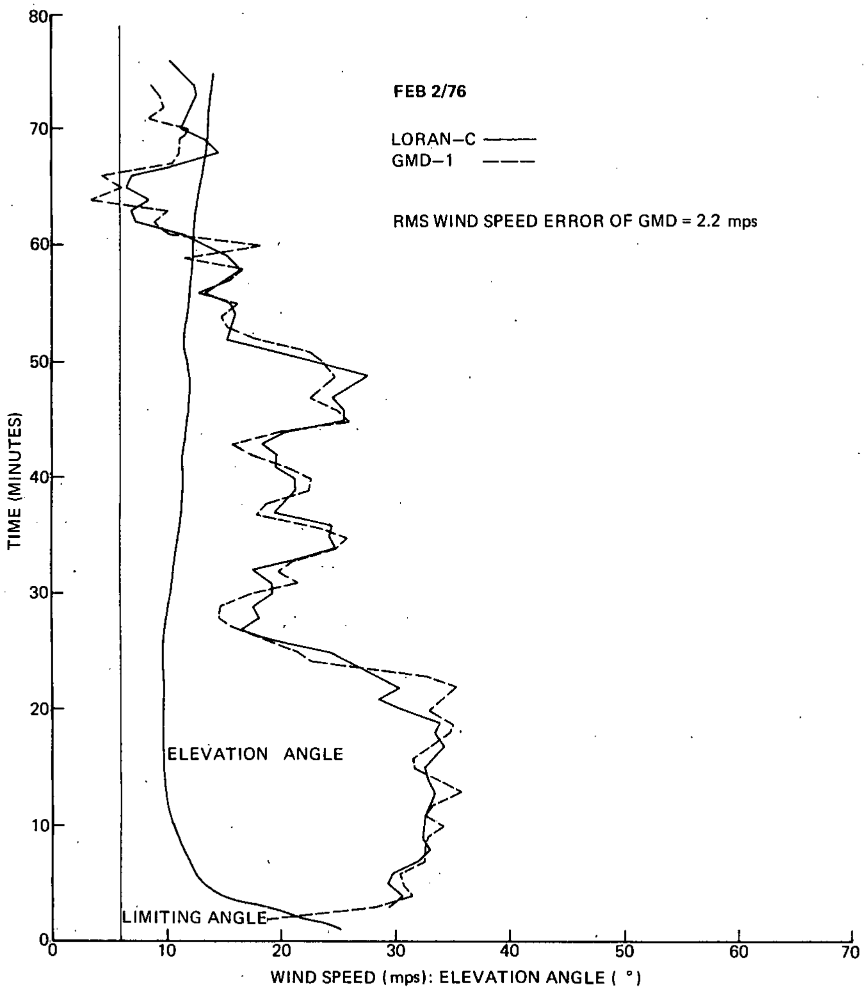

JAN 23/76
LORAN–C
GMD–1
LIMITING ANGLE
ELEVATION ANGLE
TIME (MINUTES)
WIND SPEED (mps): ELEVATION ANGLE (°)
JAN 23/76
LORAN–C
RD–65A
LIMITING ANGLE
ELEVATION ANGLE
TIME (MINUTES)
WIND SPEED (mps): ELEVATION ANGLE (°)

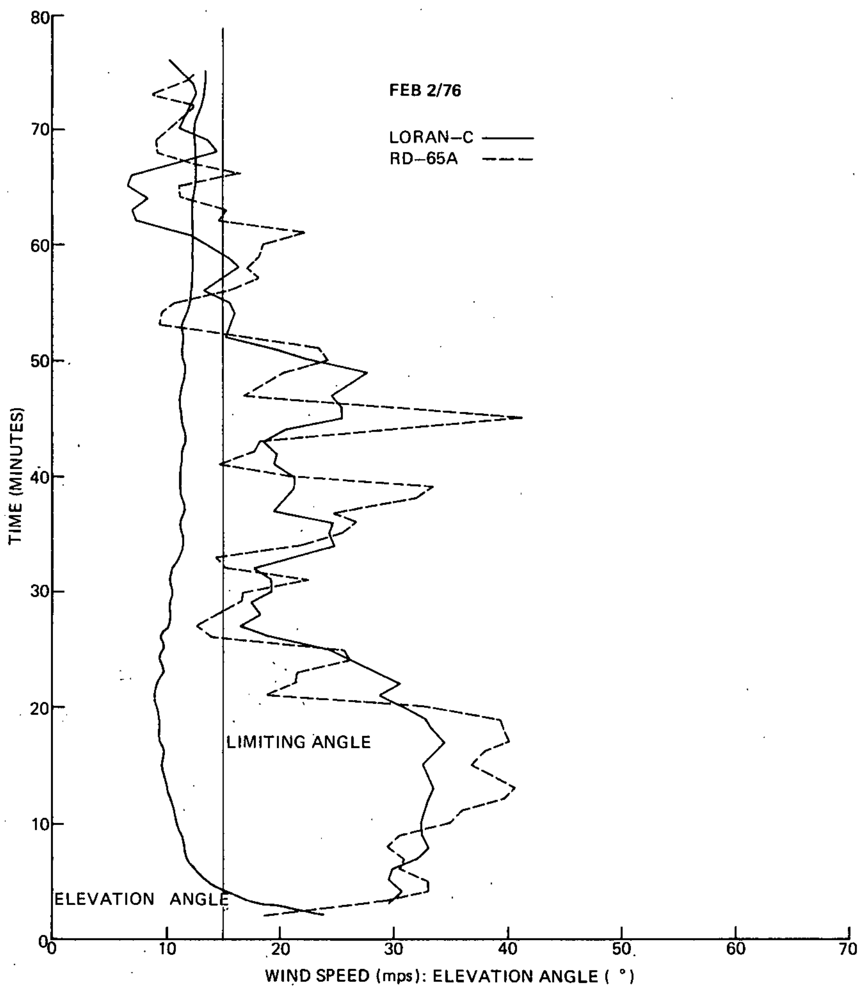


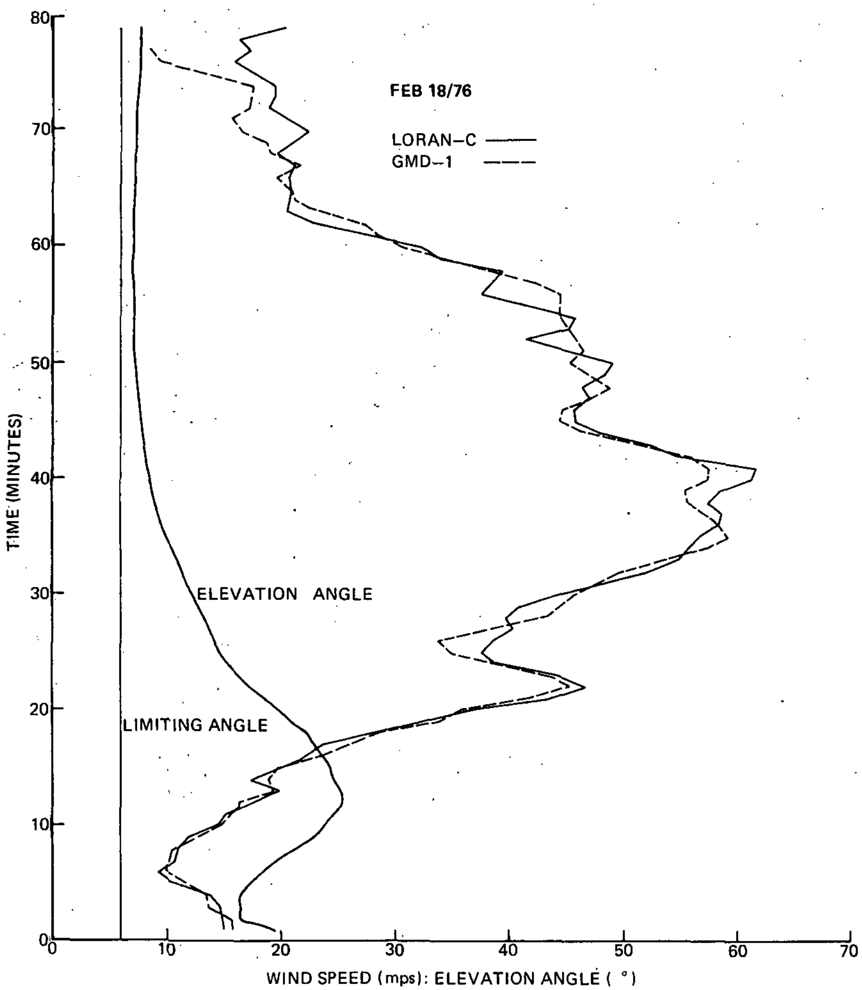
JAN 30/76
LORAN–C
GMD–1
RMS = 1 mps
RMS WIND SPEED ERROR OF GMD = 1.0 mps
LIMITING ANGLE
ELEVATION ANGLE
TIME (MINUTES)
WIND SPEED (mps): ELEVATION ANGLE (°)
0
10
20
30
40
50
60
70
80

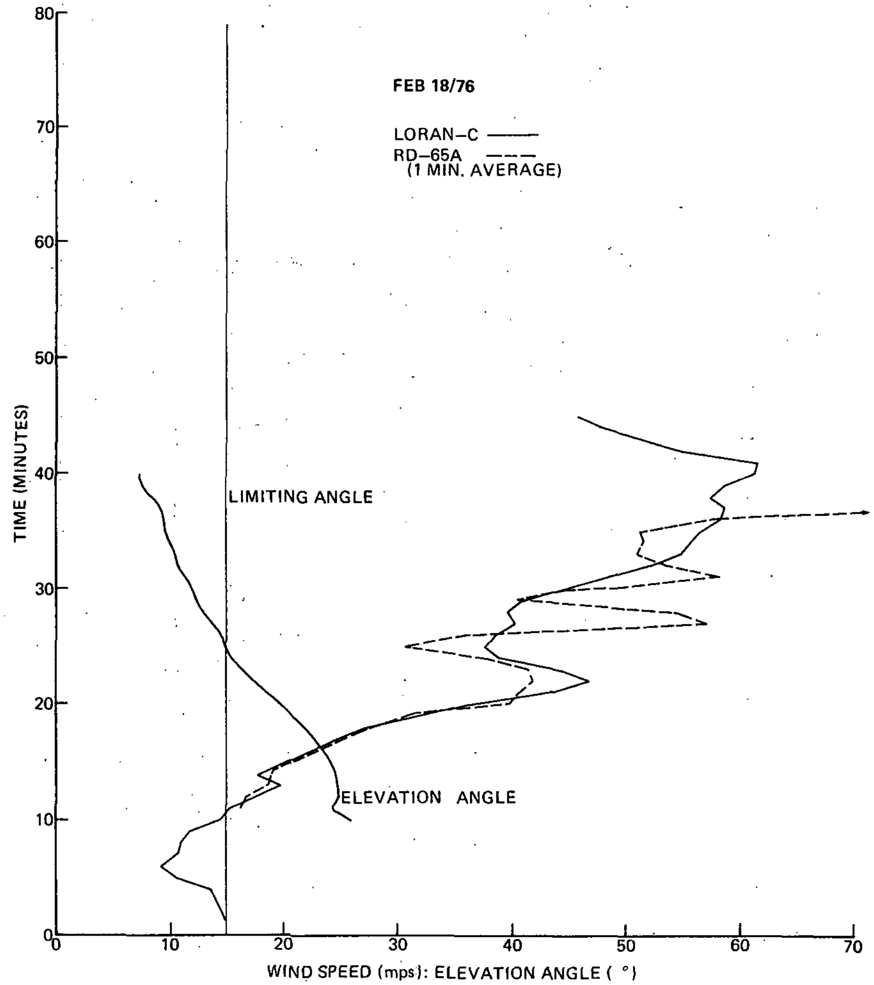


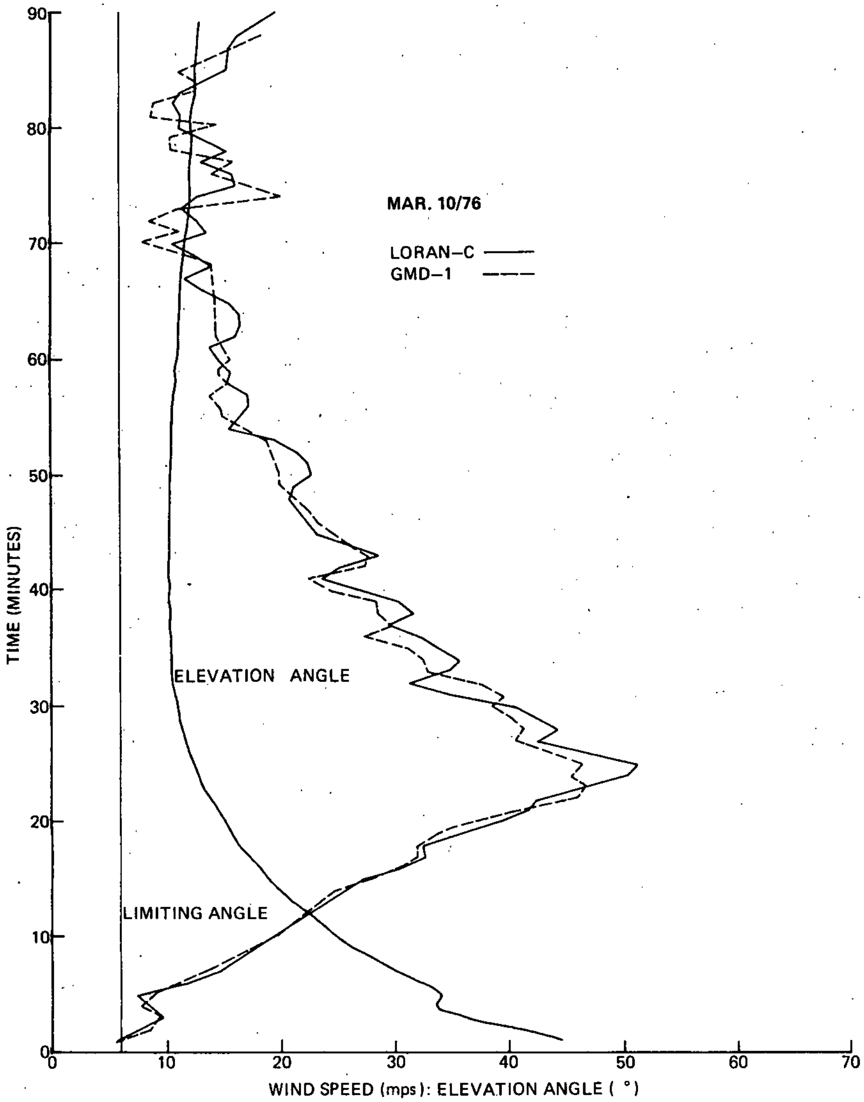
JAN 30/76
LORAN–C
RD–65A
RMS = 2.1 mps
RMS WIND SPEED ERROR OF RD–65A = 2.1 mps
LIMITING ANGLE
ELEVATION ANGLE
TIME (MINUTES)
WIND SPEED (mps): ELEVATION ANGLE (°)
0
10
20
30
40
50
60
70
80

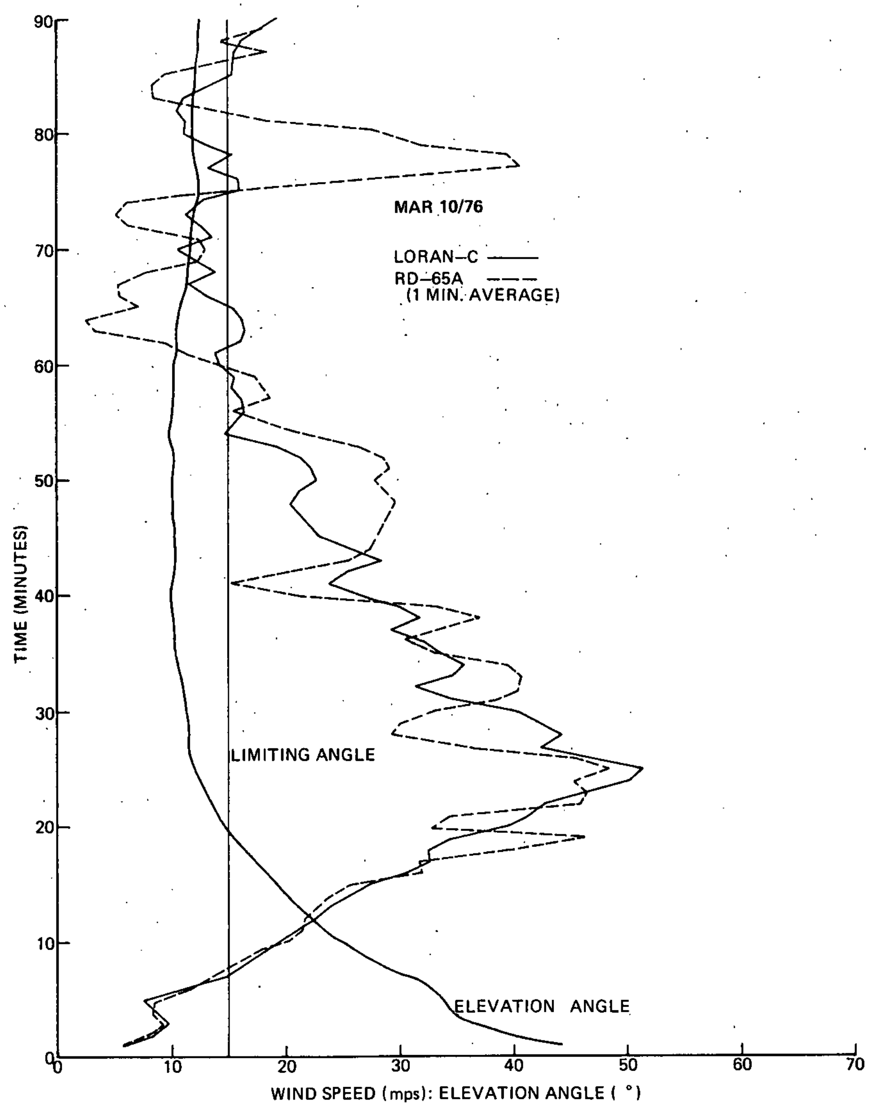

FEB 2/76
LORAN–C
GMD–1
RMS WIND SPEED ERROR OF GMD = 2.2 mps
ELEVATION ANGLE
LIMITING ANGLE
TIME (MINUTES)
WIND SPEED (mps): ELEVATION ANGLE (°)
0
10
20
30
40
50
60
70
80

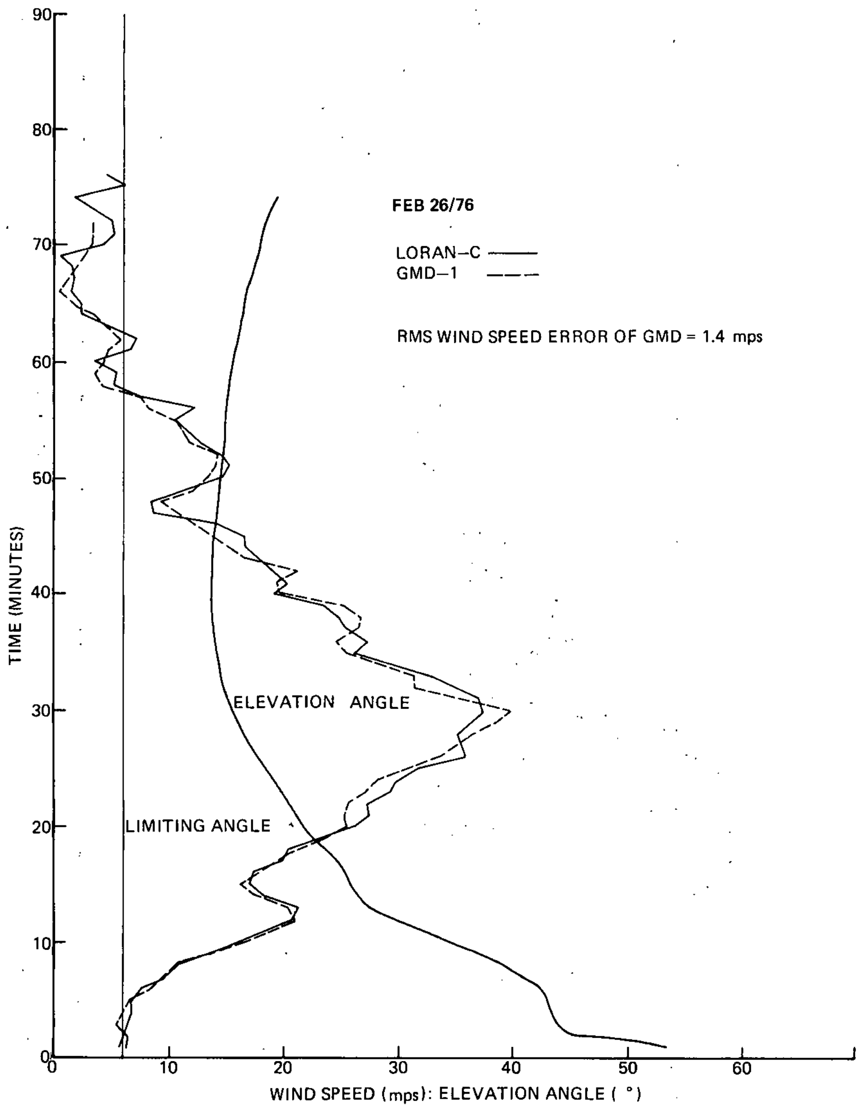

FEB 2/76
LORAN–C
RD–65A
LIMITING ANGLE
ELEVATION ANGLE
TIME (MINUTES)
WIND SPEED (mps): ELEVATION ANGLE (°)
0
10
20
30
40
50
60
70
80

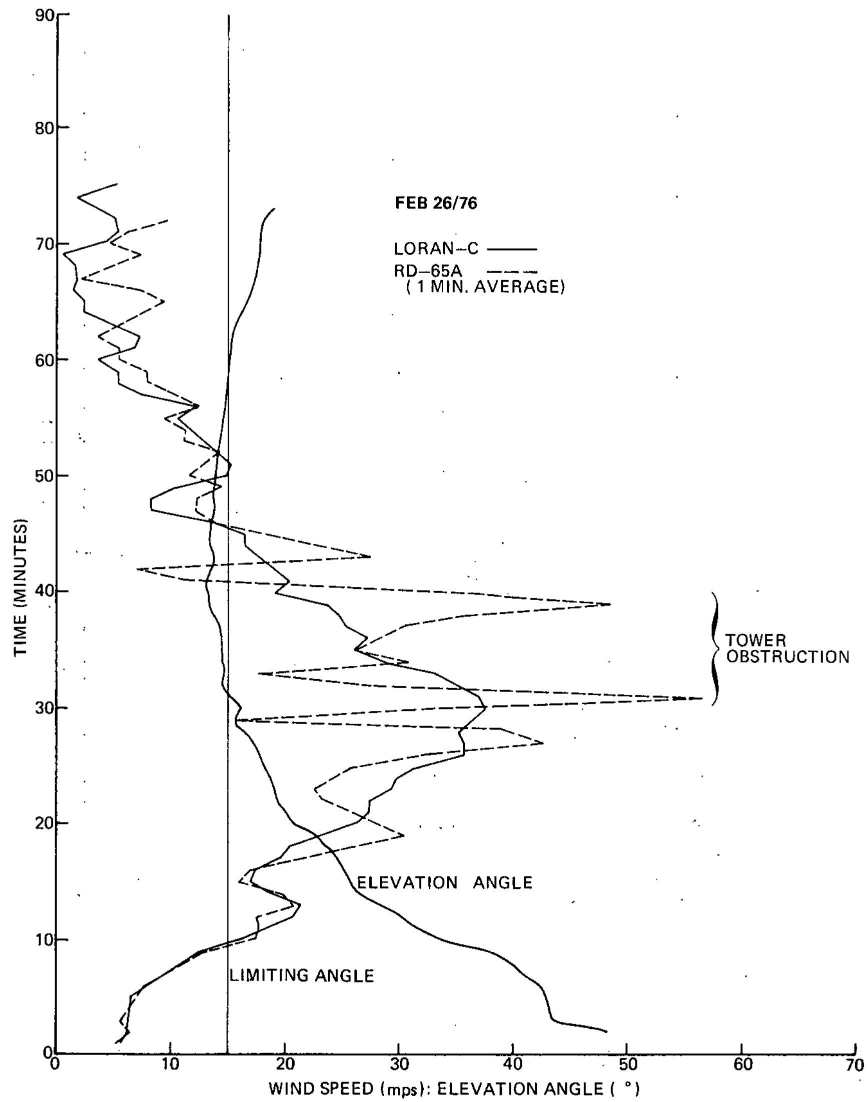

FEB 18/76
LORAN–C
GMD–1
ELEVATION ANGLE
LIMITING ANGLE
TIME (MINUTES)
WIND SPEED (mps): ELEVATION ANGLE (°)
0
10
20
30
40
50
60
70
80

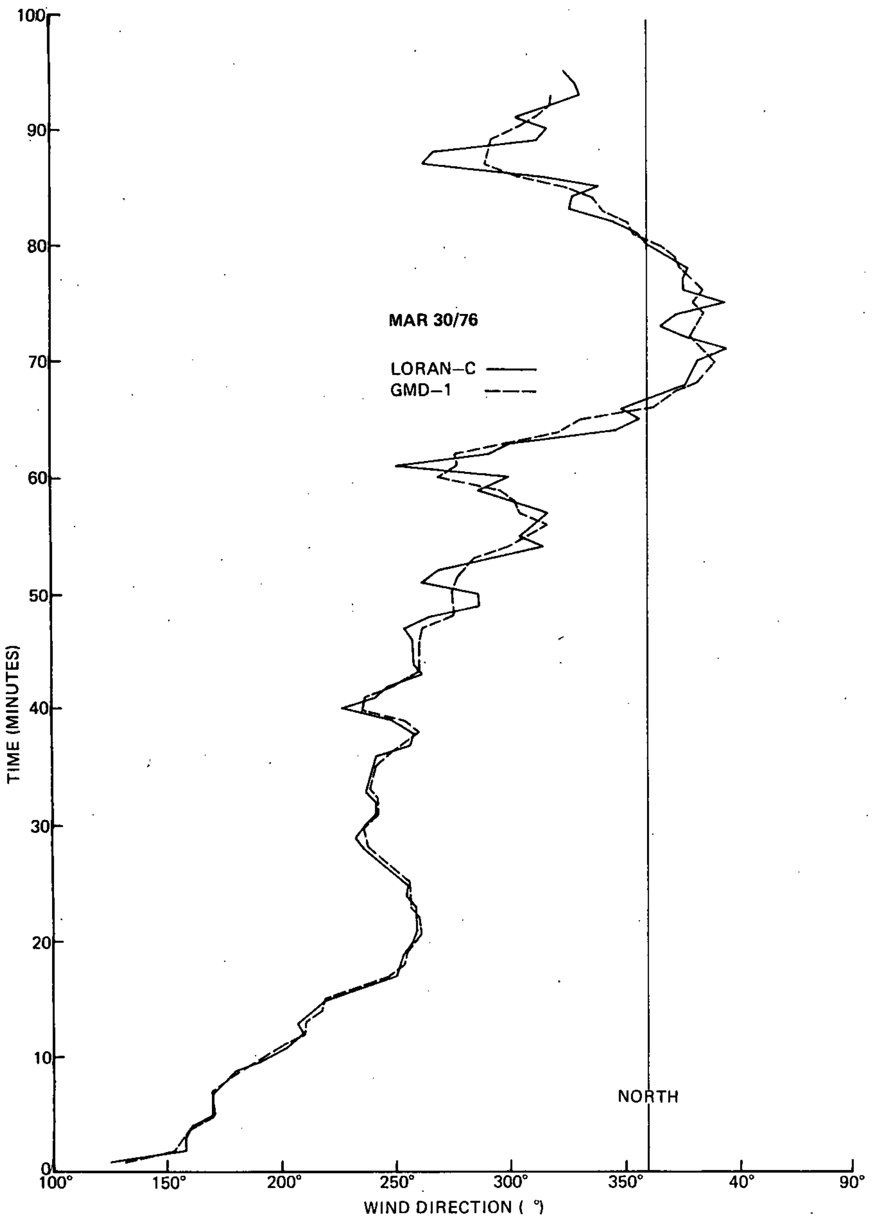

FEB 18/76
LORAN–C
RD–65A
(1 MIN. AVERAGE)
LIMITING ANGLE
ELEVATION ANGLE
TIME (MINUTES)
WIND SPEED (mps): ELEVATION ANGLE (°)
0
10
20
30
40
50
60
70
80

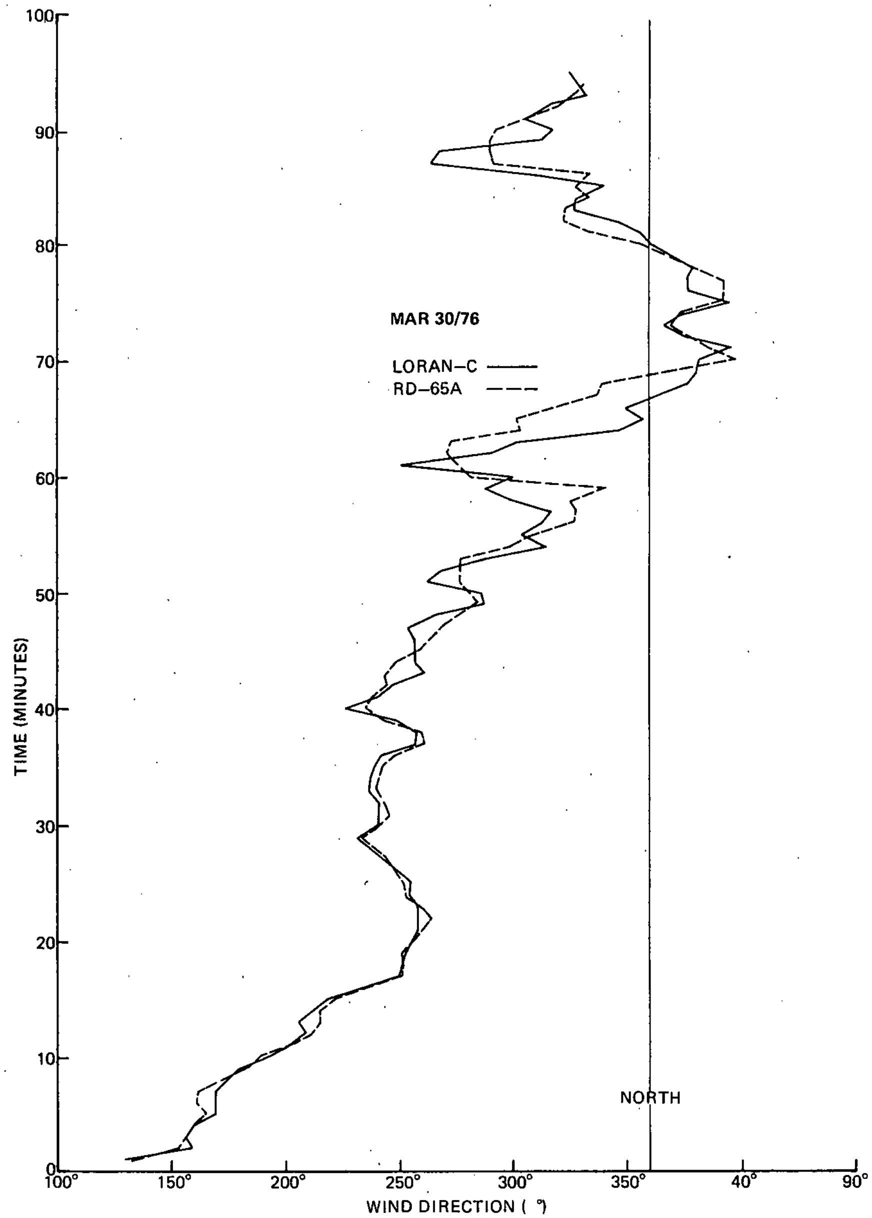

MAR. 10/76
LORAN–C
GMD–1
ELEVATION ANGLE
LIMITING ANGLE
TIME (MINUTES)
WIND SPEED (mps): ELEVATION ANGLE (°)

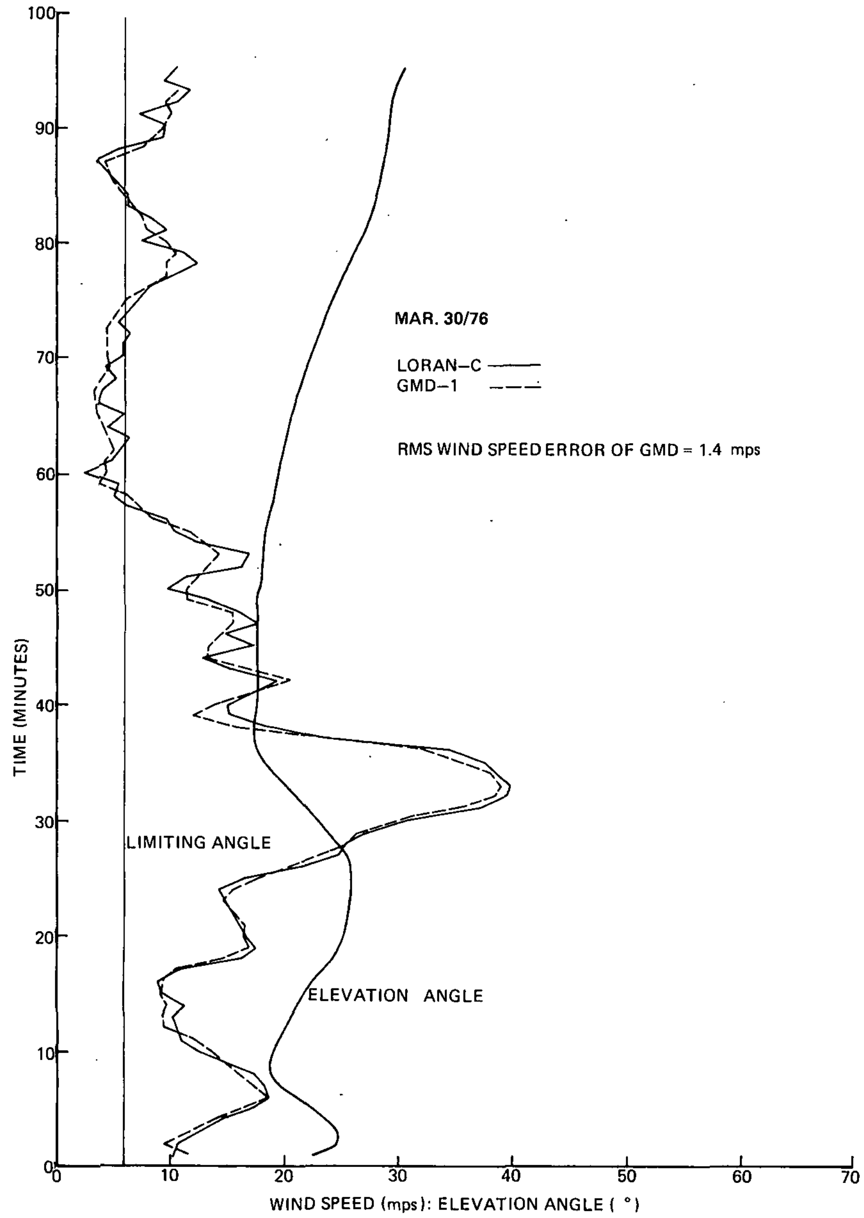

MAR 10/76
LORAN–C
RD–65A
(1 MIN. AVERAGE)
LIMITING ANGLE
ELEVATION ANGLE
TIME (MINUTES)
WIND SPEED (mps): ELEVATION ANGLE (°)

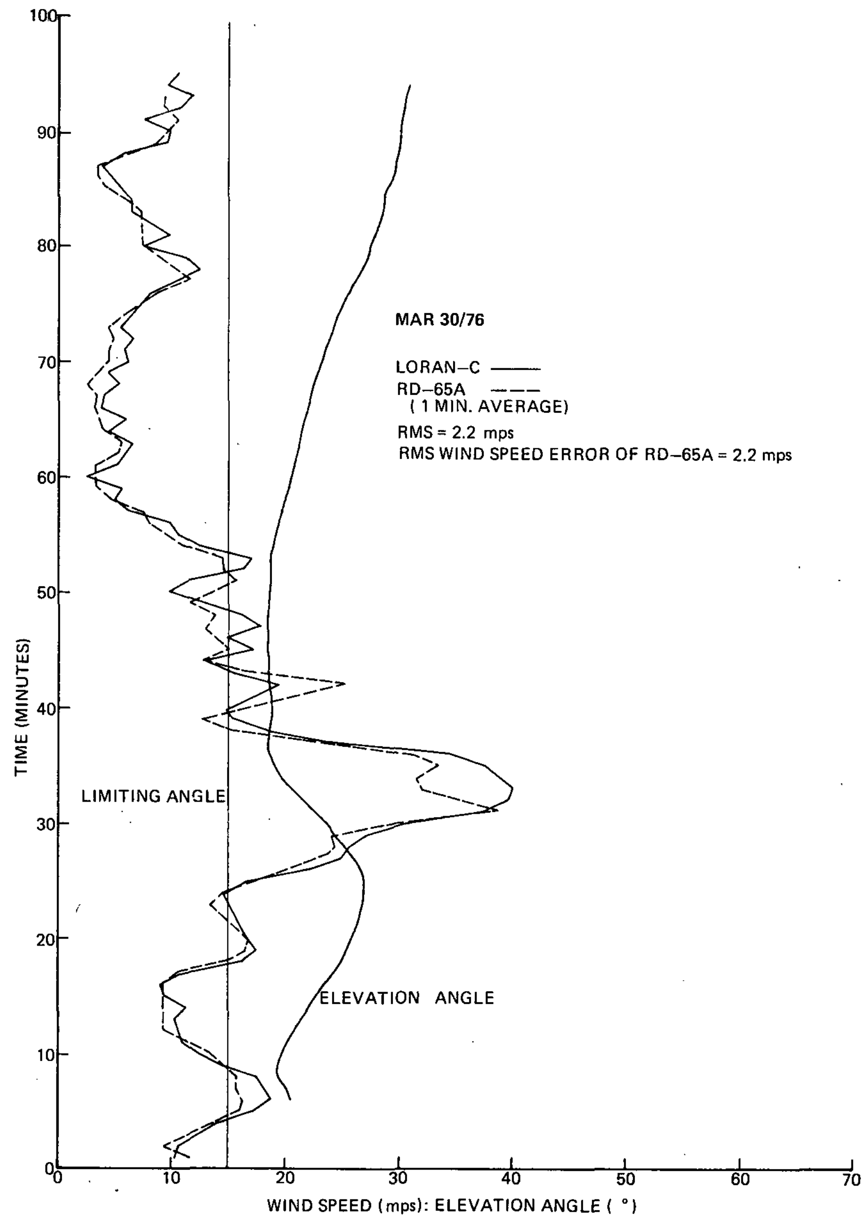

FEB 26/76
LORAN–C
GMD–1
RMS WIND SPEED ERROR OF GMD = 1.4 mps
ELEVATION ANGLE
LIMITING ANGLE
TIME (MINUTES)
WIND SPEED (mps): ELEVATION ANGLE (°)
0
10
20
30
40
50
60
70
80
90


FEB 26/76
LORAN–C
RD–65A
(1 MIN. AVERAGE)
TOWER OBSTRUCTION
ELEVATION ANGLE
LIMITING ANGLE
TIME (MINUTES)
WIND SPEED (mps): ELEVATION ANGLE (°)
0
10
20
30
40
50
60
70
80
90


MAR 30/76
LORAN–C
GMD–1
NORTH
TIME (MINUTES)
WIND DIRECTION (°)


MAR 30/76
LORAN–C
RD–65A
NORTH
TIME (MINUTES)
WIND DIRECTION (°)


MAR. 30/76
LORAN–C
GMD–1
RMS WIND SPEED ERROR OF GMD = 1.4 mps
LIMITING ANGLE
ELEVATION ANGLE
TIME (MINUTES)
WIND SPEED (mps): ELEVATION ANGLE (°)


MAR 30/76
LORAN–C
RD–65A
(1 MIN. AVERAGE)
RMS = 2.2 mps
RMS WIND SPEED ERROR OF RD–65A = 2.2 mps
LIMITING ANGLE
ELEVATION ANGLE
TIME (MINUTES)
WIND SPEED (mps): ELEVATION ANGLE (°)

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CANADA

Environment - Atmospheric Environment Service
4905 Dufferin Street, Downsview, Ontario

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11 pps. 16 figs. 3 refs. 1 appendix

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